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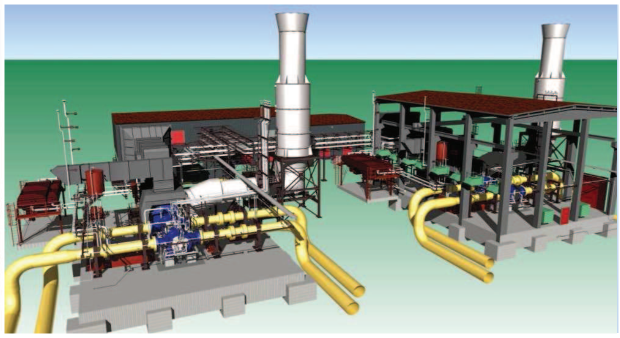

IGU Working Committee 3 Transmission

New Transmission Projects, Public Acceptance and New Technologies

Peter Tóth / Alessandro Moretti

June 2015

WGC PARIS 2015
WORLD GAS CONFERENCE

IGU
INTERNATIONAL GAS UNION
UNION INTERNATIONALE DU GAZ

2012-2015 Triennium Work Report
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New Transmission Projects, Public Acceptance and New Technologies

Study Group 3.1 and Study Group 3.3

Executive Summary:

All new gas transportation projects are both complex and unique due to their specific characteristics. Sometimes, new projects involve construction of high pressure gas transmission infrastructure over particularly long distances, in difficult terrain or through densely populated areas. Some projects encompass all of these challenges. The purpose of the Study Group 3.1 was to gather information on new gas transportation projects (pipelines and compressor stations); to analyse the solution used in each case and propose the best practices that can be applied by the gas industry in the future.

With respect to high importance of the gas industry, it is crucial to obtain the best public acceptance of gas transmission technology and technical construction. That is why the Study Group 3.3 analysed the development of the transmission infrastructure from the two key perspectives: firstly, the requirements surrounding the new gas transmission projects during the planning, permitting, construction and operational phase and, secondly, the new gas industry technologies and measures used to transport of the natural gas in a safe, reliable and efficient way.

Produced by:
International Gas Union

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Meetings

Meeting	*Date*	*Place*	*Issues*
1	*October 24–26, 2012*	*Mar del Plata, Argentina*	*Kick-off / Interesting subjects*
2	*March 25 – 27, 2013*	*Bratislava, Slovakia*	*Optimized subjects and workflow*
3	*October 01–03, 2013*	*Houston, USA*	*Subjects owners / Questionnaires*
4	*March 10 - 13, 2014*	*Torino, Italy*	*First draft report / Evaluation of the questionnaires*
5	*October 06–09, 2014*	*Prague, Czech Republic*	*Second draft report / Conclusions and recommendations*
6	*March 17 – 19, 2015*	*Oran, Algeria*	*Final report / WGC Paris*

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Chap. 1 Introduction

As the need for a clean, efficient energy continues to grow, gas has a vital role to play in meeting the world's expanding energy requirements. On the other hand, the natural gas sources have been identified mainly in remote regions, far from consumers and in some cases far out to sea. Therefore the natural gas transportation systems are of vital importance and the pipelines used for gas transmission usually cross the country borders and entire continents.

In order to cover the expanding energy requirements, new systems need to be designed to transport large quantities of gas economically and in an environmentally friendly way. In addition, existing systems need to be upgraded to avoid accidents and optimized in order to be competitive with the new systems, which usually utilize the best available technology on the market.

The gas transmission pipelines and the associated above-ground installations (compressor stations, interconnections, valve stations, etc) interact locally with human activities during planning, permitting, construction and operational phase of new gas transmission projects. Therefore, the landowners, farmers, residents, associations and other groups may have concerns about them.

On the other hand, the pipeline projects contribute to the socio-economic advancement of their host regions or countries through the payment of tariffs, fees and taxes, employment and through economic opportunities associated with the procurement of goods and services.

The general notion of public gathers a wide range of actors who organize and plan their actions in very different ways, depending on the local context. Obviously laws, regulations, habits and also customs and history may influence the public behaviour, as well as contextual factors.

The future position of natural gas in the eyes of the public significantly depends on how reliable and secure supplies will be from its sources to consumers.

Key points in the area of gas transmission infrastructures:

- Reporting of strategic transmission infrastructure projects;
- Studying of improvements concerning the compression processes, turbo machinery, performance optimization and emissions;
- Assessing the feasibility of construction of new pipelines across the densely populated areas;
- Dealing with the problems concerning technology acceptance and technical construction.

Key points in the area of public acceptance:

- Identification of the key public actors / stakeholders;
- Planning of stakeholders management;
- Management and control of stakeholder engagement;
- Effective communication with the public;
- Mitigation during and after technology construction.

Key points in the area of technologies applied in the gas transmission systems:

- Reporting of measures taken by the companies in order to reduce their environmental footprints;
- Discussions about new pipe materials;
- Analyses concerning alternative utilization of the pipelines for CO2 transportation.

Analysis of the above mentioned points was conducted, based on discussions among the members of Study Group 3.1 (SG3.1) and Study Group 3.3 (SG3.3), who met at six-monthly intervals, and the analysis of data received in response to a global survey that was issued in 2013 to WOC3 members. This allowed for detailed discussion and knowledge sharing during the meetings, as well as a more global view at chosen solutions and recommendation. The case studies received from four member companies have been provided to look at specific issues and projects in more detail. Gathering feedback from members on their experiences and successful projects was one of the main benefits for whole working committee.

The Study Groups Leaders would like to thank all the members of SG3.1 and SG3.3 for their input and sharing of knowledge and best practices related to new gas transmission infrastructure projects to the benefit of all IGU members.

Chap. 2 Strategic Transmission Infrastructure projects

Every new natural gas transport project is complex and unique because of special characteristics. In some cases, the new project involves laying high pressure gas pipelines along very long distances, across difficult land, densely populated areas and across several countries. Some projects have a combination of these special characteristics.

The purpose of this Chapter is to report about strategic transmission infrastructure projects from all over the world.

For this information on new pipeline projects related to natural gas transport have been gathered by a questionnaire prepared by Study Group 3.1 in order to get detailed information about the pipelines and the related compressor stations.

Thus the Chapter intends:

- to continue with information collecting started in the last triennium (2009-2012) and updating of projects;
- to add more detailed information regarding compressor stations;
- to connect the information related to the pipeline part to the information regarding compressor stations of the particular solutions.

Knowing that worldwide huge pipeline project are planned and are already in the construction phase and the scope of this report is limited, SG 3.1 had to focus of some important projects where adequate information has been made available. Study Group 3.1 with, from global perspective, a small amount of people/companies had to be very selective in the numbers of topics and the amount of information that could be handled, and thus we are only talking about topics/information the members of the group had direct access to. Nevertheless where deemed necessary and for the sake of completeness some findings have been added based on public available information.

Following this approach SG 3.1 tried to identify main corridors transporting natural gas via different countries and long distances from the gas source to the dedicated areas for gas consumption.

The analysis of new strategic transmission infrastructure projects chosen by SG 3.1 follows the following approach:

- overview of main gas supply corridors on the different continents or countries;
- describing existing or new pipelines;
- introducing possible pipeline projects;
- most important pipelines on the route, e.g. .new elements or expansion.

In the Appendices 1 to 14 you will find a description of projects selected by the IGU Study Group 3.1. To elaborate the projects a template has been issued. This table has been completed by members of the Study Group or people involved in the projects. The projects were selected taking into account that the Study Group aimed at projects in different stages of their lifetime and a geographical spread.

Based on information in the templates but also on a variety of discussions, e-mails and telephone calls the Study Group compared the main issues that occurred in the execution of the projects.

The Table below summarizes natural gas infrastructure projects investigated by the study group. Detailed information is available in the project templates in the Annex 1 of this report.

Table 2.1 Project Characteristics of selected natural gas pipeline projects
(for further information see Annex 1)

No	Name	Countries	Project Phase	CAPEX	Type of Project
Bi-directional Interconnectors					
1	Poland-Czech Republic Interconnection within the North-South Corridor (STORK II)	Czech Republic – Poland	ESIA completed	-	Onshore, 107 km, 40″, 73.5 barg
2	Bidirectional Austrian Czech Interconnection (BACI)	Czech Republic – Austria	Planning	-	Onshore, ca. 58 km, 32″, 73.5 barg
3	Connection to Oberkappel	Czech Republic – Austria	Planning	-	Onshore, ca. 110 km, 32″, 73.5 barg
4	SK-HU Interconnector DN800	Slovakia – Hungary	Pre-Construction	192 m€	Onshore, 111 km, 32″, 75 barg
Domestic Pipelines					
5	GAZELLE	Czech Republic	Operation since 2011	500 m$	Onshore, 160 km, 56″, 84 barg
6	Capacity Expansion Ellund-Egtved (Froeslev – Egtved II)	Denmark	Operation since 2013	98 m€	Onshore, 94 km, 30``, 80 barg
7	Moravia	Czech Republic	Planning	-	Onshore, 155 km, 36″ to 48″83.5 barg
8	Eridan	France	Pre-construction	820 m$	Onshore, 220 km, 48″, 80 barg

Cross-Border Pipelines (Feeder)					
9	Nord Stream	From Russia to Germany via Baltic Sea	Operation	7,400 m€	Offshore, 1,224 km, 2 x 48'', up to 220 barg
10	New gas pipeline across the Black Sea towards Turkey (*no project template available*)	From Russia Black Sea to Greek-Turkish border, transit country Russia	Planning	n/a	Offshore: ca. 910 km, 32'', up to 300 barg Onshore ca. 180 km, up to 100 barg
11	Trans Adriatic Pipeline	Transit countries Greece, Albania, Italy via Mediterranean Sea	Planning	-	Offshore: 105 km, 36'', 145 barg Onshore: 766 km, 48'', 95barg
12	Eastring	From Turkey to Austria, transit countries Bulgaria, Romania, Hungary/Ukraine, Slovakia	Planning	1,630 m€	Onshore 1,015 km, 56", 100 barg
Regional supply networks					
13	Eastern Transmission Pipeline	China (Hong Kong)	Operation	0.4 m $HK	Onshore, 23 km, 24'' and 30'', 35 barg
14	Relocation of the existing 300 mm gas transmission pipeline to allow the construction of a new railway bridge	Australia	Operation	-	Onshore, 0.6 km, 12'', 28 barg

2.1 Overview of main gas supply corridors

In the following sub-sections the main projects on the continents are described depending on the information which has been made available by the WOC 3 members.

For the sake of completeness or where deemed necessary some findings have been completed based on public available information about the different projects.

In general this overview does not warrant or guarantee the completeness and correctness of the information contained herein.

2.1.1 Africa

2.1.1.1 Main gas corridors

In Africa gas transmission pipelines can be found in the North mainly dedicated for domestic consumption and/or for gas exports to Europe.

Figure 2.1 Gas (red) and oil (green) pipelines in Africa as of 2012
(source: http://www.theodora.com/pipelines/africa_pipelines_map.jpg)

In the following a detailed description is focusing on natural gas pipeline projects in Algeria, one the most important natural gas exporter from Africa to Europe.

2.1.1.2 Detailed description of the selected projects – Algeria

Figure 2.2 shows the plans for the extension of the Algerian gas network. Some projects are already under construction and planned to be in operation in 2016.

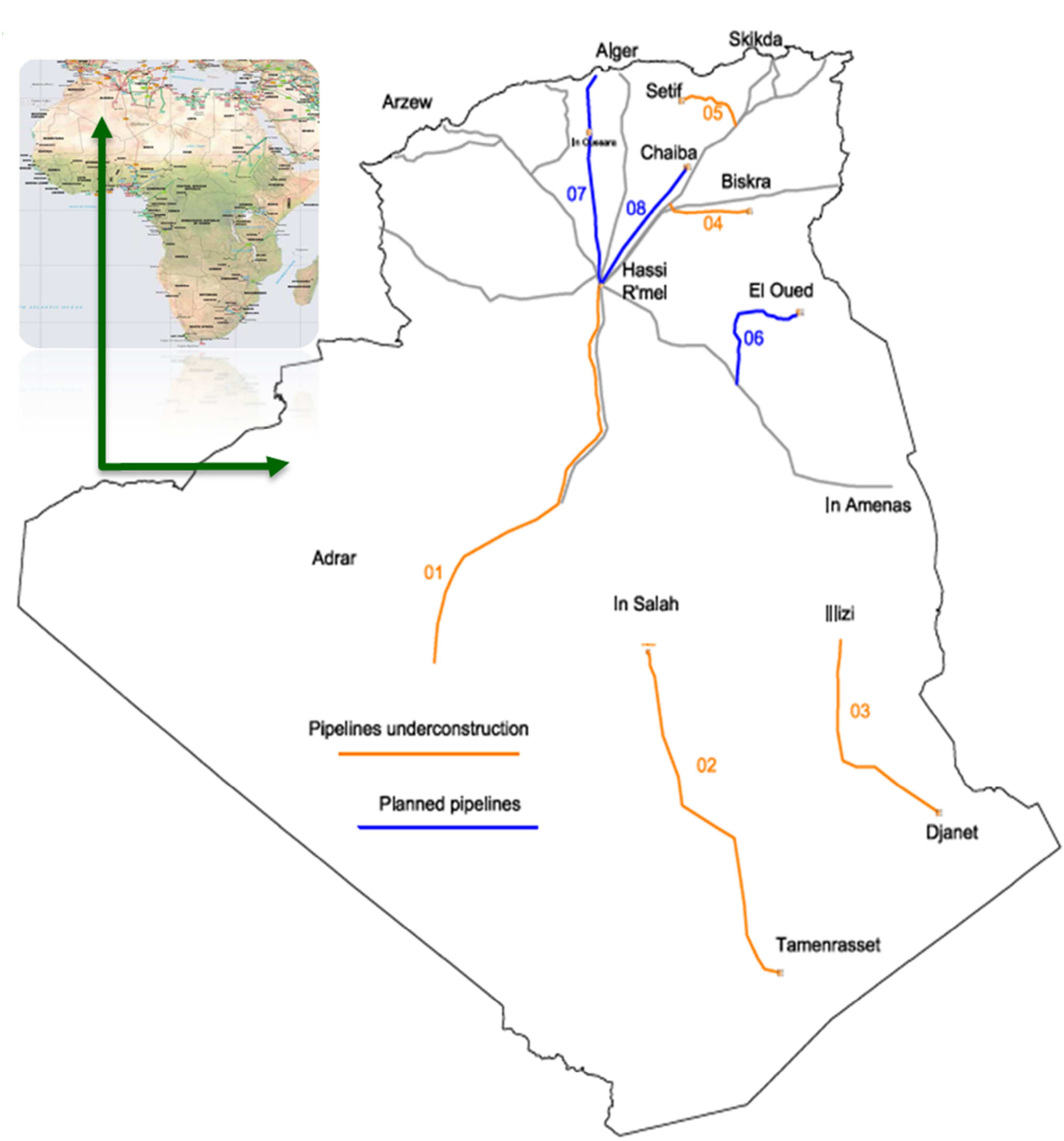


Figure 2.2 Gas pipelines under construction and Planned in Algeria
(source: GRTG)

The following table list pipelines (numbering referring to Figure 2.2) planned to be in operation by 2016.

N°	Pipeline name	Length /km	Diameter
01	Adrar – Hassi R'mel	750	48"
02	In Salah- Tamenrasset	530	16"
03	Illizi Djanet	380	10"
04	PP Biskra	120	28"
05	PP SETIF	120	28"
06	PP El Oued	220	28"
07	Hassi R'mel – In Ouassara - Alger	400	48"
08	Hassi R'mel - Chaiba	250	48"

Table 2.2 Pipelines in Algeria planned to be in operation by 2016

N°	Purpose
01	To transport Natural gas from Adrar gas fields to Hassi R'mel as the terminal Dispatcher of Algerian gas.
02& 03	To transport natural gas from In Salah gas fields to Tamenrasset as energy for domestic consumption
04,05 & 06	To transport natural gas to new power plant of Biskra , Setif and El Oued
07&08	To reinforce the national network for operating power plants.

Table 2.3 Description of the Pipelines in Algeria

2.1.2 Europe

The European gas market can be seen as almost saturated and the natural gas consumption in the European Union (EU) tends to decline in the future. Thus the EU market only offers in competition still limited capacity for additional natural gas volumes. In addition the expansion of the European natural gas network has almost finished, nevertheless some more or less smaller activities for improving the national and cross-border networks are still going on. Here currently activities cover the implementation of interconnectors and the revamp of existing pipeline systems for cross-border physical reverse flow for an optimization of gas streams are in the focus of the competent national transmission system operators (TSO) – see Table 2.1 Project Characteristics of selected natural gas pipeline projects. As the European natural gas network is subject to ageing in near future the TSOs have to focus more on rehabilitation and maintenance measures than on new-build projects.

The overall length of the European high-pressure pipeline network sums up at ca. 247,136 km (ENTSOG 2013 data, figure does not included Unified Gas Supply System of the Russian Federation – see Section 2.1.4).

2.1.2.1 Main gas corridors

The EU only receives a small part of its natural gas imports from remote areas as liquefied natural gas (LNG) by tanker. Due to lower cost and greater capacity, the largest part is imported into the EU, above all, by pipeline from the neighbourhood through three large import corridors at the moment:

- Norway (1st or Northern Gas Corridor)
- Russia (2nd or Eastern Gas Corridor)
- North Africa (3rd or Western Gas Corridor).

Furthermore a 4th one will be established in the near future (final investment decision was taken December 2013):

- South-East Europe (4th or Southern Gas Corridor)

Concerning the Eastern Gas Corridor (Russia) transportation of Russian natural gas to Europe proceeds through several trunklines:

- The "Brotherhood" pipeline (Urengoy-Pomary-Uzhgorod) is the largest gas transportation route. It can carry over 100 bcm gas per year, transiting Ukraine and running to Slovakia via Uzhgorod. In Slovakia, the pipeline is split:
    - Its first branch goes to Czech Republic. Russian gas transported through the Czech Republic flows in the direction of Waidhaus and Hora Svaté Kateřiny, as well as from the Yamal-Europe gas pipeline, with Olbernhau and Brandov as entry points.
    - Its second branch goes to Austria. This country plays an important role in the delivery of Russian natural gas to Italy, Hungary, Slovenia and Croatia.
    - Its third branch (construction was finished in 2014) goes to Hungary in the direction of Balassagyarmat.
- The Yamal-Europe pipeline runs across Russia, Belarus and Poland reaching Germany. Its length is beyond 2000 km, 14 compressor stations are operational along it. Yamal – Europe full capacity – 33 bcm per annum.
- The gas transportation route through Romania carries Russian gas to this country, transiting Ukraine and Moldova, and runs further to the Balkan countries and Turkey.

- The Blue Stream is intended for direct gas deliveries to Turkey, bypassing transit countries. The 1,213-km-long gas pipeline consists of overland and offshore sections. The offshore section of Blue Stream is unique in its design and construction, the subsea pipe being 393 km long.
- The Nord Stream offshore pipeline laid on the bottom of the Baltic sea with capacity of 55 bcm per year allows direct gas transportation for clients in Western Europe, primarily in Germany, bypassing transit states.
- Aiming at improving flexibility and reliability of supplies, the Gazprom Group diversifies the gas delivery routes, being actively involved in the development of new gas pipeline across the Black Sea towards Turkey. This offshore gas trunkline is planned to directly connect the Russian UGTS to the end consumers in Southern Europe (see the project description in section 2.1.2.2.3).

An overview of these important European gas corridors is given in Figure 2.3.

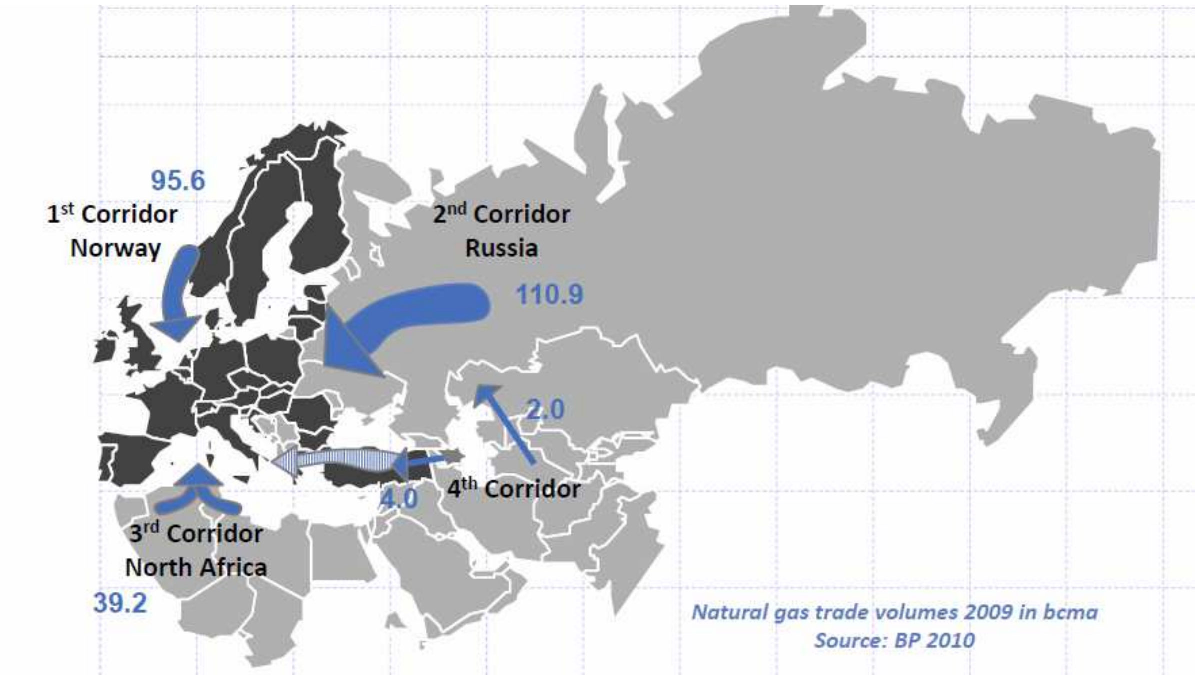


Figure 2.3 Important gas corridors to Western Europe

2.1.2.2 Detailed description of the selected projects

In the following SG 3.1 focuses on the Southern corridor and it most outstanding projects. Here following new pipeline routes will be described in more detail:

- Southern Gas Corridor;
- New gas pipeline across the Black Sea towards Turkey for diversification of gas export routes to Europe;
- Trans Adriatic Pipeline (TAP) as part of the Southern Gas Corridor serving the diversification of gas sources for Europe;
- Eastring.

Projects templates for the last two projects are available as well in the Annex 1.

2.1.2.2.1 Southern Gas Corridor

The **Southern Gas Corridor** is an initiative of the European Commission for gas supply from Caspian and Middle Eastern regions to Europe. The Southern Gas Corridor project is set to come online by 2018/2019. The main motivation for establishing the Southern Corridor is (*source: https://dgap.org/en/think-tank/publications/further-publications/southern-gas-corridor-and-south-caucasus*):

- Firstly, setting up such a Southern Gas Corridor has the advantage that the EU will be able to diversify its supply sources. Thus, potential damage caused by technical failure or by politically motivated interruption from one supply source may be reduced and competition improved. This aspect is important to the entire EU but especially relevant for the states of South East Europe, as they are currently receiving a large part of their natural gas from a single supplier (Russia) and via a single transit route (Ukraine). Furthermore, natural gas plays an important role in the energy mix of these countries.
- Secondly, the EU does not have direct access to the natural gas reserves of the Caspian Region and the Middle East at the moment. Imports from these regions are a good option as they represent nearly 50% of the worldwide natural gas reserves, have free export potential, and are situated in immediate vicinity and within pipeline distance to the EU.

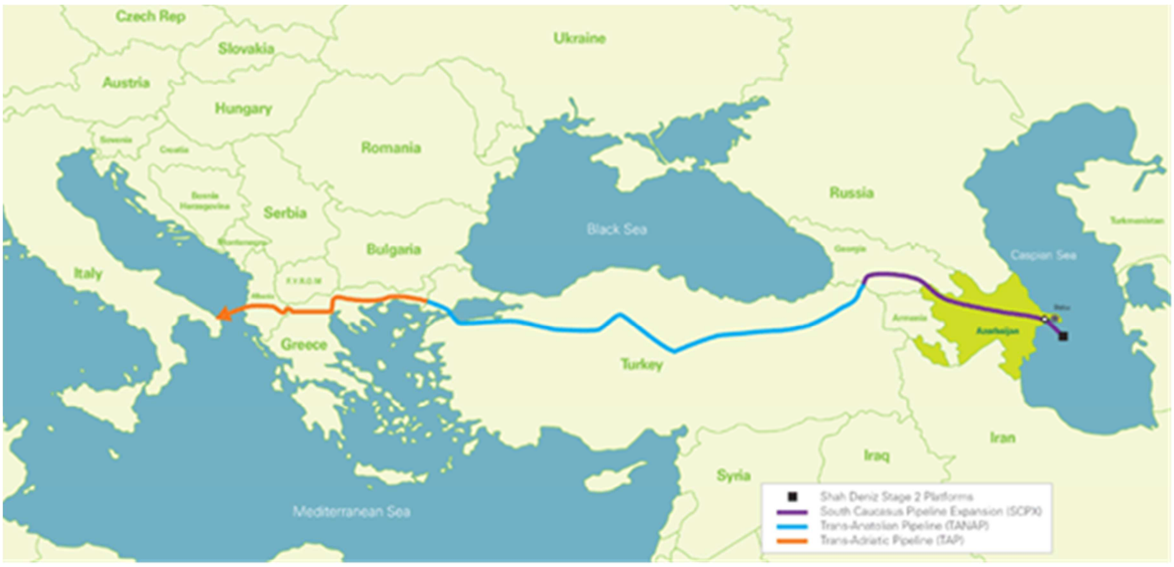


Figure 2.4 Route of the Southern Gas Corridor from Azerbaijan to Italy

(source:http://www.bp.com/en/global/corporate/press/press-releases/shah-deniz-final-investment-decision-paves-way.html)

On 17 December 2013 the Shah Deniz consortium announced the final investment decision (FID) for the Stage 2 development of the Shah Deniz gas field in the Caspian Sea, offshore Azerbaijan. This decision triggers plans to expand the South Caucasus Pipeline through Azerbaijan and Georgia, to construct the Trans Anatolian Gas Pipeline

(TANAP) across Turkey and to construct the Trans Adriatic Pipeline (TAP) across Greece, Albania and into Italy. Together these projects, as well as gas transmission infrastructure to Bulgaria, will create a new Southern Gas Corridor to Europe.

The Shah Deniz project entails several elements: offshore it includes drilling and completion of 26 subsea wells and construction of two bridge-linked platforms; onshore there will be new processing and compression facilities at Sangachal. The total cost of the Shah Deniz Stage 2 and South Caucasus Pipeline (SCP) expansion projects will be around $28bn. Together with the investments into the Trans Anatolian Gas Pipeline (TANAP) and Trans Adriatic Pipeline (TAP) this amount will sum up to nearly $50 bn.

16 billion cubic metres per year (bcma) of gas produced from the giant Shah Deniz field will be carried some 3,500 kilometres to provide energy for millions of consumers in Georgia, Turkey, Greece, Bulgaria and Italy. First gas is targeted for late 2018, with sales to Georgia and Turkey; first deliveries to Europe will follow approximately a year later.

2.1.2.2.2 Trans Adriatic Pipeline (TAP)

The Trans Adriatic Pipeline (the pipeline) will transport gas via Greece and Albania and across the Adriatic Sea to Italy. It is the last part of the 4th or Southern Gas Corridor. The project is aimed at enhancing supply security as well as the diversification of gas supplies for the European markets. TAP will open a new southern gas corridor to Europe and a market outlet for natural gas from the Caspian Sea region and is initially designed to transport 10 bcm/a, with the possibility for later expansion in transmission capacity to 20 bcm/a as more gas becomes available.

Figure 2.5 Route of the Trans Adriatic Pipeline (TAP)
(*source: https://www.trans-adriatic-pipeline.com/tap-project/route/*)

The pipeline will begin at the Greek / Turkish border near Kipoi in Greece, where it will tie in with TANAP's gas transmission system. TAP will be routed through northern Greece and enter Albania east of Korca. It will continue through Albania and reach the Adriatic coastline near the city of Fier. At this point, the pipeline will cross the Adriatic Sea and terminate at the pipeline receiving terminal (PRT) close to Lecce in Italy where the gas will be tied in into the Snam Rete Gas (SRG) network. The total length of the TAP System will be approximately 871 km including the offshore pipeline section of 105 km.

For Phase 1 of the project (10 bcm/a), compressors are located in two places, namely at the head compressor station near Kipoi (GCS00), approx. 3 km from the Turkish / Greek border, and at Fier, close to the Albanian coast (ACS03). At this compressor station, the pressure will be boosted prior to entering the offshore pipeline. A pipeline receiving terminal (PRT) will be located near Lecce, Italy. In Phase 1, the station ACS02 at Bilisht in Albania near the Greek / Albanian border will serve as a metering and pigging station only.

For the final expansion to 20 BCMY, it is necessary to upgrade the ACS02 station on the Albanian border and to install an additional compressor station GCS01 close to Serres in Greece.

In compliance with the requirements of the Security of Supply Regulation, physical reverse flow has been implemented in TAP’s design. Thus, in planned or emergency situations, the transmission of gas from Italy to Albania and Greece will be feasible.

2.1.2.2.3 <u>New gas pipeline across the Black Sea towards Turkey</u>

In February 2015 Turkey and Russia agreed on the route for the planned new gas pipeline across the Black Sea towards Turkey which is intended to replace the South Stream project which has been officially put on hold end of 2014. On December 1, 2014 Gazprom and Turkish company Botas Petroleum Pipeline Corporation signed the Memorandum of Understanding on constructing of a new offshore gas pipeline from Russia to Turkey across the Black Sea. The new gas pipeline across the Black Sea towards Turkey aimed to carry Russian gas from southern Russia to EU consumers.

Figure 2.6 Route of planned new gas pipeline across the Black Sea towards Turkey

(source: http://www.gazprom.com/f/posts/64/656707/map_tur_potok_eng.jpg)

Under this new project, the offshore pipeline with a total length of ca. 910 kilometers starts at the Russian Black Sea coast near Anapa in the Krasnodar Territory and will end on Turkish territory. 660 kilometers of the pipeline's route will be laid within the old corridor of South Stream and 250 kilometers – within a new corridor towards the European part of Turkey. Onshore this pipeline would go ca. 180 km through Turkey's Luleburgaz region to the town of Ipsala near the Turkey-Greece border.

The total capacity of this project will be 63 billion cubic meters of gas. About 50 billion cubic meters will be delivered to the Ipsala gas hub for further export.

The tentative date for the completion of the first offshore line is December 2016. One string is able to carry 15.75 bcm of gas. In total 4 lines summing up to a total capacity of 63 bcm/a are planned to be laid through the black sea.

2.1.2.2.4 Eastring

Eastring is a project of a new transmission pipeline, connecting existing interconnection point (IP) Veľké Kapušany, at the border between Slovakia and Ukraine, with existing interconnection point Malkoclar, at the border between Bulgaria and Turkey (Figure 2.7).

The main purpose of this project is to carry natural gas from:

- Western Europe to the Balkan countries, enabling those countries to diversify their natural gas sources;
- alternative gas sources, including but not limited to Russia, AGRI, TANAP, Caspian, Iran, Iraq, Egypt, Israel and Cyprus to Central, South and Western Europe.

Figure 2.7 Route of the Eastring project

By establishing Eastring, this project would safeguard supply if Eastern Gas Corridor flows are disrupted and therefore it will increase gas supply security in the broader Central-South-East European region, allow access to alternative natural gas sources for Central, Western and Southern Europe and also create a platform for a competitive and liquid internal gas market, while enabling the entry of new market players.

Summary of the technical details:

- Commissioning: 2018 EoY
- Capacity: 20 bcm/y (first stage and second stage) up to 40 bcm/y (final stage)
- Mode: bi-directional flow
- Length: 832 - 1,015 km
- Diameter: DN1400
- Estimated CAPEX: EUR 1,370 – 1,630 mil.

Projects mission lies in finding a solution which shall:

- lift the current non-existence of physical gas supply alternative for the Romania, Moldova and Balkan countries (primarily Bulgaria). Moreover, it lies not only the provision of an alternative gas route but also alternative gas sources, cross border liquidity and attractive transmission fees;
- not be linked to any particular gas supplier and open to all gas sources without limitation;
- be compliant with the EU law and its spirit, increase the cross-border interconnectivity and liquidity and represent an important step towards the single EU gas market;
- facilitate future access to new gas sources (gas source diversification) without limitation to one supplier only;
- represent the most economic and time efficient solution by utilization the robust and reliable existing infrastructure.

The project is planned to be implemented by the Slovak TSO Eustream and other relevant TSOs (mainly from Hungary, Romania, Bulgaria and Western Europe). Project connects gas transmission system in Slovakia with UA/RO/BG transit pipelines in following basic routing options:

- Slovakia (Veľké Kapušany) to Romania:
  - via Ukraine, using existing infrastructure, or
  - via Hungary, using new pipeline.
- Romania
  - Option A – new pipeline, which passes production and storage area of Transylvania and continues to existing IP Isaccea and then further to BG/TR border utilizing existing UA-RO-BG transit assets;
  - Option B – new pipeline, which passes both areas of production and storage (Transylvania and in the vicinity of Bucharest), and continues to BG/TR interconnection point Malkoclar.

In case of the shorter variant (see Figure 2.8), the proposed 832 km Eastring project is planned to go via Slovak transmission system towards Ukrainian or Hungarian transmission system and afterward to Romania (connecting IPs of Mediesu Aurit and Isaccea). Pipeline length, in case of longer routing variant, connecting Veľké Kapušany with Malkoclar, is 1,015 km. Expected project costs vary from EUR 1,370 – 1,630 mil. depending on chosen routing option and stage of the project.

In both cases, this project will offer an alternative connection to Southern Gas Corridor, while compliant with the EU energy policy. The initial yearly capacity of Eastring project is 20bcm and the target capacity is 40bcm per year.

Commissioning of the Eastring project is expected on EoY 2018. The most important benefits and advantages of the Eastring project can be summarized by the following:

- diversification of natural gas sources for the region of the South East Europe, which are currently fully dependent on one gas source only - opportunity for gas from European hubs (Baumgarten, NCG, Gaspool, TTF) and potential future gas hubs;
- Eastring increases the cross-border interconnectivity and liquidity – Eastring connects the German and Turkish market and thus creates a major European bidirectional conjunction with great transit potential. Turkey will become a key transit country for all suppliers using Southern Gas Corridor (Russia, Azerbaijan and others with Caspian gas);
- possibility to connect to other contemplated projects (TAP, Nabucco, AGRI, potential Romanian exploration project in the Black Sea);
- most economic and time efficient project to construct in the concerned region, which is compliant with EU law and its Third energy package.

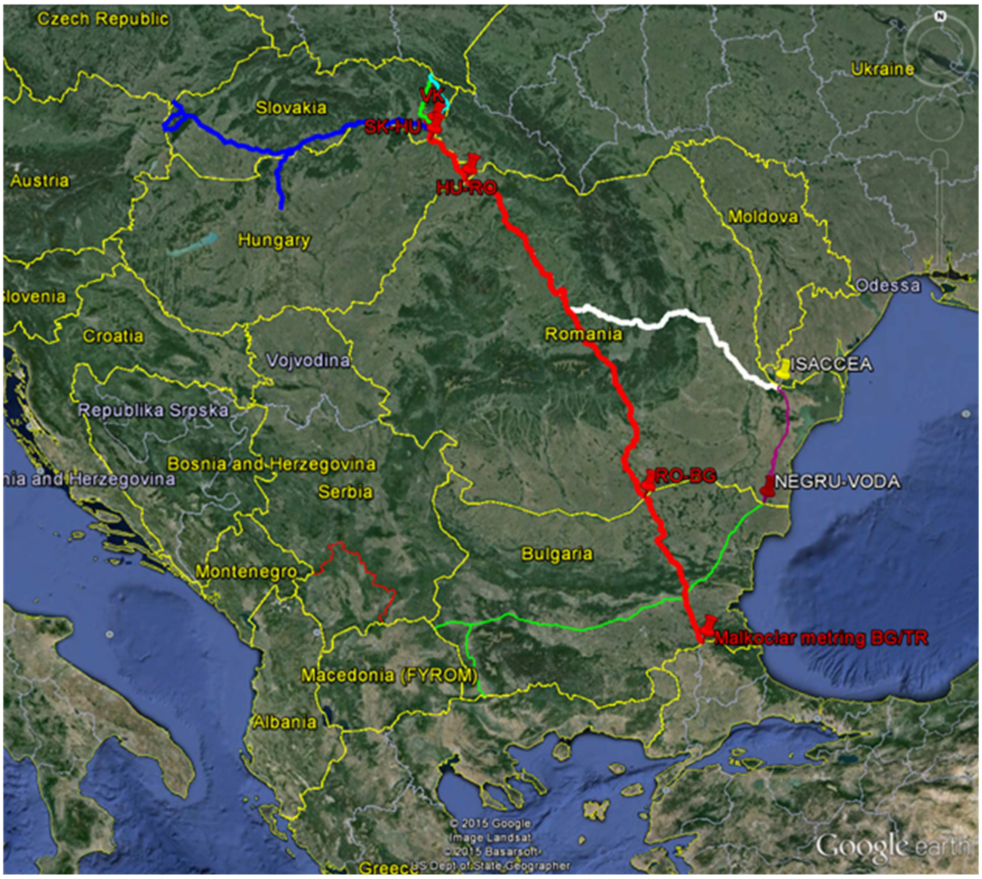


Figure 2.8 Detailed route of the Eastring project

2.1.3 Middle East

2.1.3.1 Main gas corridors

The Middle Eastern Countries possess about 40% of proven natural gas reserves, thereof Iran and Qatar approximately 15% each.

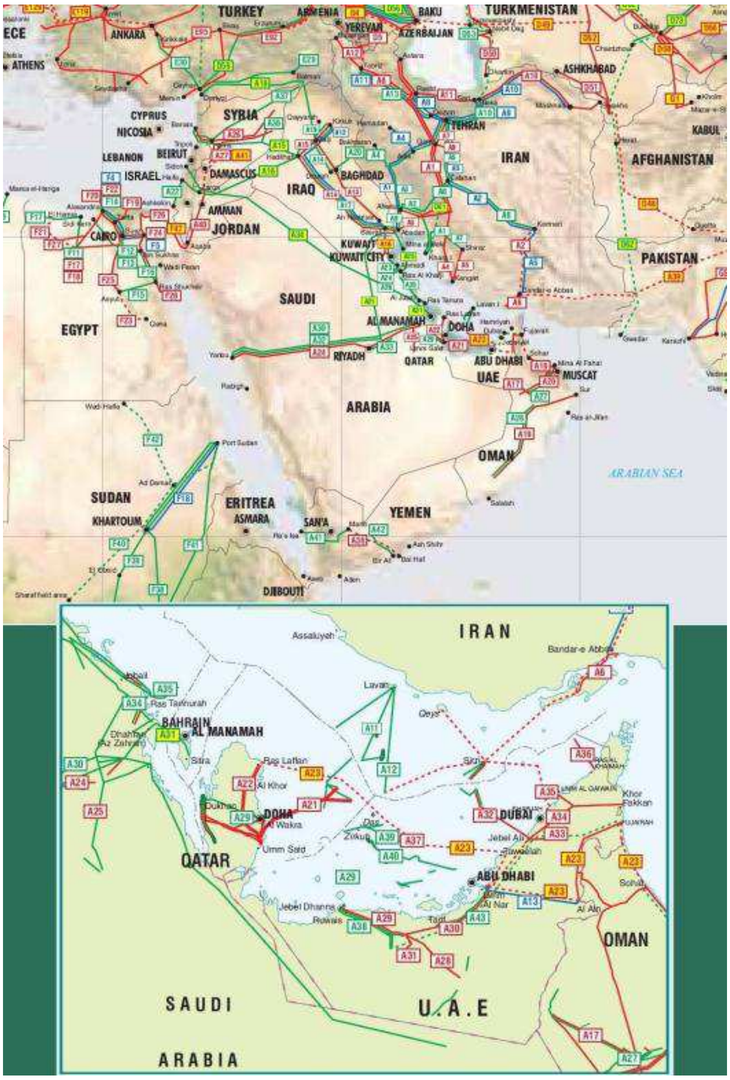


Figure 2.9 Gas (red) and oil (green) pipelines in the Middle East as of 2008

(source: http://www.theodora.com/pipelines/middle_east_pipelines_map.jpg)

Multiple high-pressure gas pipelines transporting the natural gas dedicated for export purposes either to cross-border trunk pipelines or to LNG liquefaction facilities. Only in exceptional cases the national onshore or offshore gas pipeline systems are connected to those of the neighbouring countries (Figure 2.9).

2.1.3.2 Detailed description of the selected projects – Trans Anatolian Pipeline (TANAP)

Trans Anatolia Natural Gas Pipeline (TANAP) Project is the central part of the Southern or 4th Gas Corridor and intends for the transportation of the natural gas to be produced in Shah Deniz 2 field and other fields of Azerbaijan (and other possible neighboring countries) through Turkey to Europe. The TANAP project is planned to begin from Georgia-Turkey border and go through the provincial borders of Ardahan, Kars, Erzurum, Bayburt, Gümüşhane, Erzincan, Sivas, Yozgat, Kırıkkale, Ankara, Eskişehir, Bilecik, Kütahya, Bursa, Balıkesir, Çanakkale, Tekirdağ, Edirne, respectively.

The TANAP pipeline length of within the borders of Turkey is about 1,900 km on the section up to Türkgözü/Malkoçlar-Bulgaria border, with a Greece connection of about 67 km. TANAP includes an outside pipe diameter of 56 inches, across land and two 36 inch outside diameter are planned for the marine crossing through the Sea of Marmara.

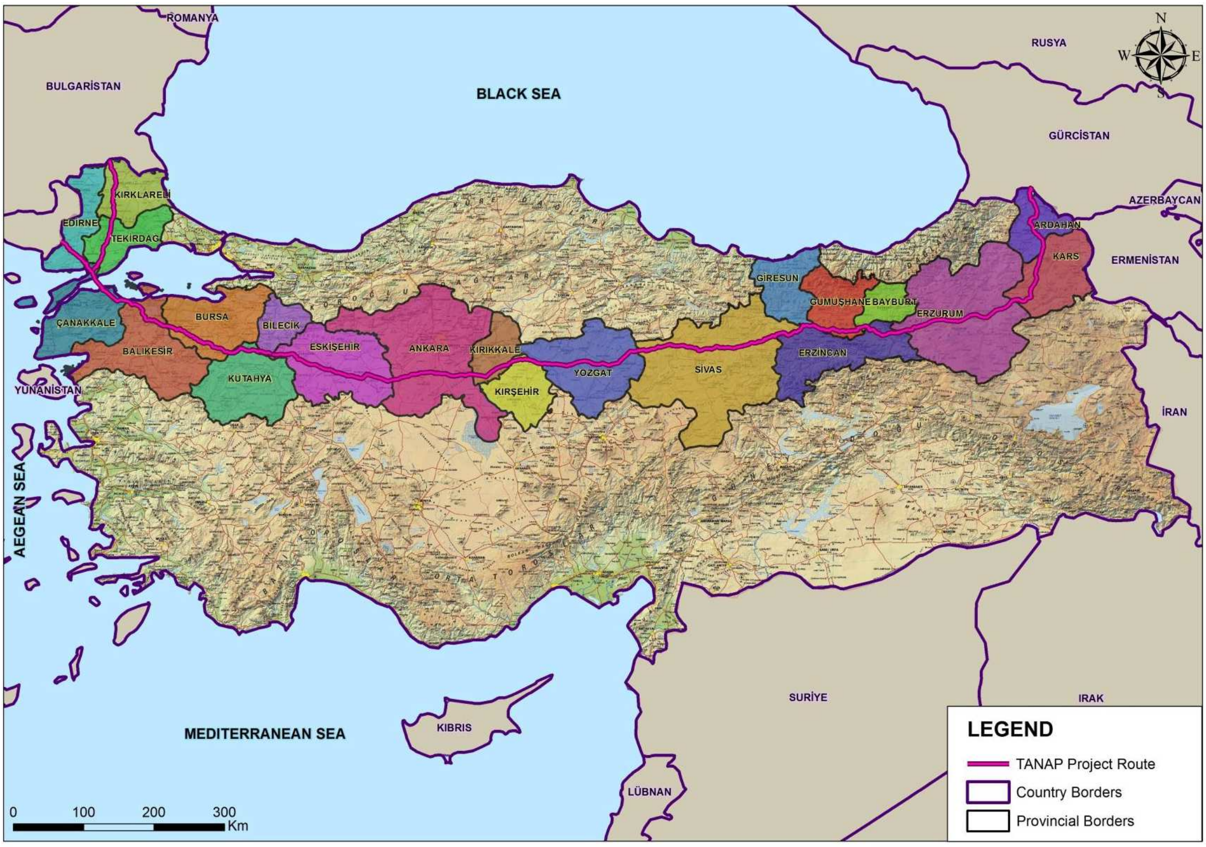


Figure 2.10 Route of the Trans Anatolian Pipeline (TANAP)
(source: http://www.tanap.com/en/wp-content/uploads/2013/03/TANAP_EIA_Application_File-1.pdf)

2.1.4 Eurasia - the Russian Unified Gas Supply System

The Russian Unified Gas Supply System (UGSS) is the world's largest gas transmission system and represents a unique engineering complex encompassing gas production, processing, transmission, storage and distribution facilities. It assures continuous gas supply from the wellhead to the ultimate consumer.

Gas produced in Russia and imported from Central Asia and Azerbaijan are delivered to customers through system of integrated pipelines. This system is about 168,000 km long. 222 compressor stations are used for gas transmission. The UGSS of Russia is owned by Gazprom.

Figure 2.11 Russian Unified Gas Supply System (UGSS)
(source: Gazprom)

The System is almost fully loaded. For instance, in 2012 a total of 666.2 bcm was pumped into the Unified Gas Supply System, taking account of natural gas supplied by Gazprom, independent and Central Asian producers. In the 1970s and 1980s, when the gas transmission system was built, Gazprom provided it with a substantial reliability margin.

Useful life of gas trunkline	**Length,** 1000 **km**
up to 10 years	22.2
from 11 to 20 years	20.4
from 21 to 30 years	61.7
over 31 years	64.0
Total	**168.3**

Figure 2.12 Gazprom Group's gas trunklines in Russia in terms of useful life, 2012
(source: Gazprom)

As vacant capacities are available, Gazprom allows access to its gas pipelines to independent companies possessing the infrastructure for gas supply and extraction, acting under agreements with customers and meeting the technical standards for the gas quality.

	For the year ended December 31,								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total amount received into the gas transportation system									
Amount received into the system, including	646,9	660,9	654,8	669,2	552,4	614,1	630,9	613,7	621,0
Central Asian gas	54,6	57,0	59,9	61,4	35,7	35,3	31,8	31,7	29,3
Azerbaijanian gas	–	–	–	–	–	0,8	1,5	1,6	1,4
Gas withdrawn from UGSFs in Russia	42,8	48,2	41,7	36,1	30,0	40,8	47,1	44,3	32,7
Decrease in the amount of gas within the gas transportation system	10,0	8,7	10,2	9,0	7,3	6,3	5,2	8,2	5,7
Total	**699,7**	**717,8**	**706,7**	**714,3**	**589,7**	**661,2**	**683,2**	**666,2**	**659,4**
Total distribution from the gas transportation system									
Supply inside Russia, including	339,8	352,0	356,4	352,8	335,6	354,9	365,6	362,3	354,6
Central Asian gas	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,0
Supply outside Russia, including	251,2	254,7	247,3	251,1	195,6	209,3	217,7	209,3	220,2
Central Asian gas	54,5	56,8	59,7	61,3	35,6	35,2	31,8	31,6	29,3
Azerbaijanian gas	–	–	–	–	–	0,8	1,5	1,6	1,4
Gas pumped into UGSFs in Russia	46,3	50,3	43,0	51,6	15,7	47,7	48,2	44,1	38,4
Technical needs of the gas transportation system and UGSFs	51,7	52,0	49,5	49,6	36,3	43,6	45,8	40,9	40,6
Increase in the amount of gas within the gas transportation system	10,7	8,8	10,5	9,2	6,5	5,7	5,9	9,6	5,6
Total	**699,7**	**717,8**	**706,7**	**714,3**	**589,7**	**661,2**	**683,2**	**666,2**	**659,4**

Figure 2.13 Gas received into and distributed from Gazprom's GTS in Russia, bcm (source: Gazprom)

Gazprom satisfies all the requests by independent gas producers seeking access to the Unified Gas Supply System (UGSS), unless it cannot be granted for purely technical reasons. The main reason is the limited capacity of the gas transmission system. The interaction between Gazprom and other gas market players is fully in line with the Federal Law on Gas Supply in the Russian Federation, which sets the terms and conditions for granting access to free transmission capacity of the UGSS as well as entitles Gazprom to conclude supply contracts or reasonably deny access.

The tariff on gas transmission via the Gazprom trunklines for independent producers is rated by the Russian Federal Tariff Service (FTS). Before August 1, 2006 a single tariff was fixed for the transmission of 1,000 cubic meters of gas per 100 km.

A new procedure for differentiated pricing has been valid since August 1, 2006 and provides the two-component rate: first – a charge for transmission of 1,000 cubic meters of gas per 100 km; and second – a charge for using gas trunklines (in RUB per 1,000 cubic meters), which is determined based on gas entry and exit points within the gas transmission system.

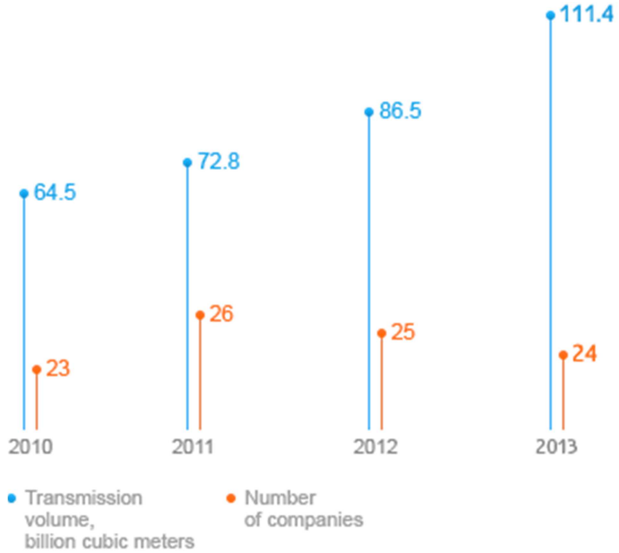


Figure 2.14 Highlights of independent gas producers access to the gas transmission system
(source: Gazprom)

The Unified Gas Supply System is able to secure uninterrupted gas supplies due to centralized control, considerable branching and parallel transmission routes.

All transmission processes are under twenty-four-hour control of the Central Operations and Dispatch Department of Gazprom. The Unified System has performed seamlessly, providing continuous supply of gas to Russian and foreign customers.

Figure 2.15 In Central Operations and Dispatch Department room
(source: Gazprom)

Every year Gazprom allocates investments (23.6 bln rub in 2012) for upgrading the gas transmission system. As a result of repair and technical condition improvement, the number of gas pipeline breakdowns in 2012 was reduced twice comparing to 2002 (16 versus 32 breakdowns). Fewer breakdowns head directly from the use of progressive gas transmission system inspection techniques and scheduled preventive maintenance operations, which enable efficient detection of worn out sections and obsolete equipment.

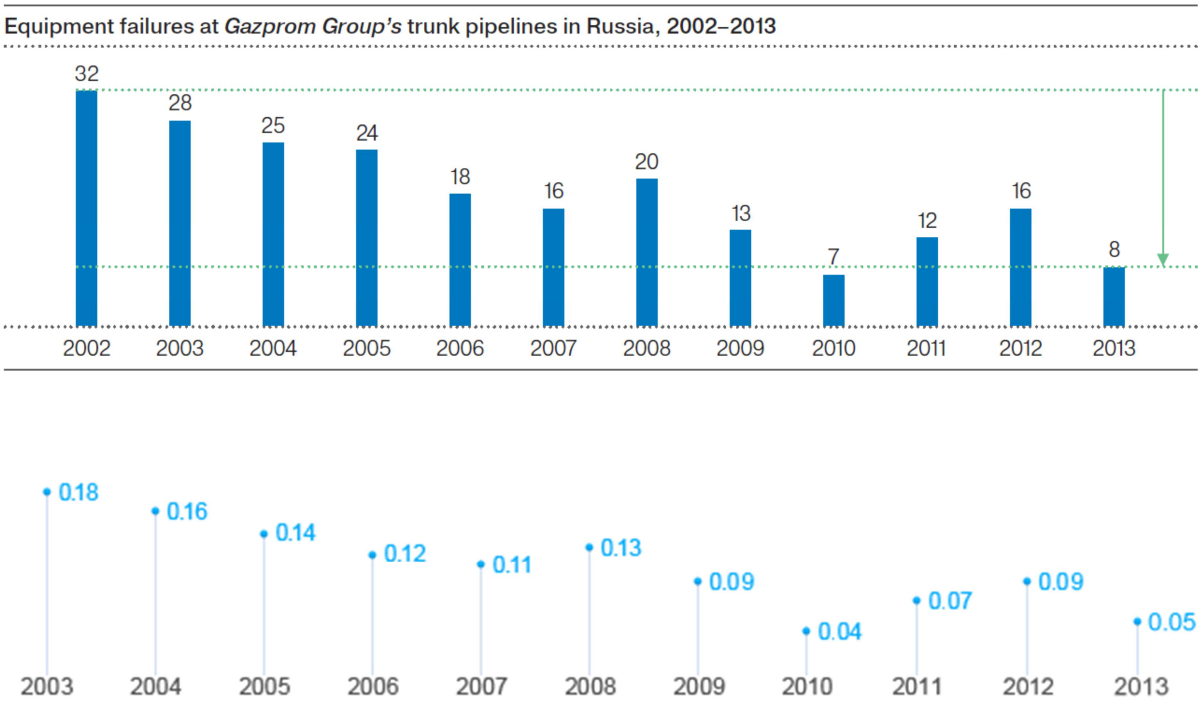


Figure 2.16 Number of GTS failures (total amount and per 1,000 kilometers) (source: Gazprom)

Stable operation of the gas transmission system is secured by cutting-edge inspection methods as well as preventive maintenance and repair operations. It is objectively proved by the reduction of technical failures on gas pipelines.

In order to improve the reliability of gas supply, the technical and environmental safety of transmission as well as the efficient distribution of gas flows, Gazprom annually performs the overhaul as well as preventive maintenance operations on the GTS.

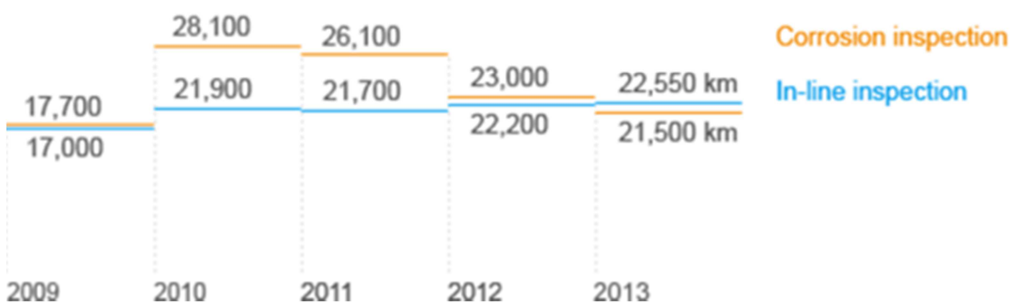


Figure 2.17 Inspection of Gazprom's GTS pipelines in Russia (source: Gazprom)

The key tasks to be met until 2015 during the line pipe overhaul are as follows:

- maintaining the desired throughput of line pipes by considerably reducing the total length of gas pipeline sections operating under a pressure lower than the nominal one;

- determining and forecasting the technical condition of gas pipelines over a long term.

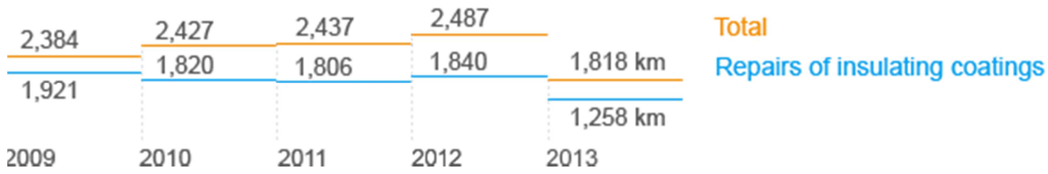


Figure 2.18 Overhaul of gas trunklines in Russia

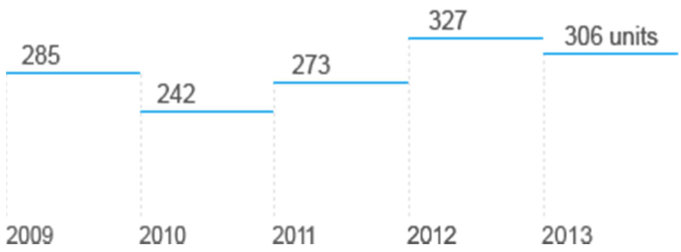


Figure 2.19 Capital repairs of gas distribution stations in Russia (source: Gazprom)

Gazprom consistently implements comprehensive reconstruction and upgrade programs for gas transmission facilities. The program adopted for 2011–2015 will enable to:

- reduce energy consumption and improve energy efficiency by using cutting-edge gas compressor equipment;
- mitigate emissions of nitrogen and carbon oxides by upgrading combustion chambers of operated units and using low-emission gas-turbine units for the re-equipment of compressor workshops;
- decrease process losses in gas transmission through the construction, reconstruction and upgrade of metering nodes in transmission facilities.

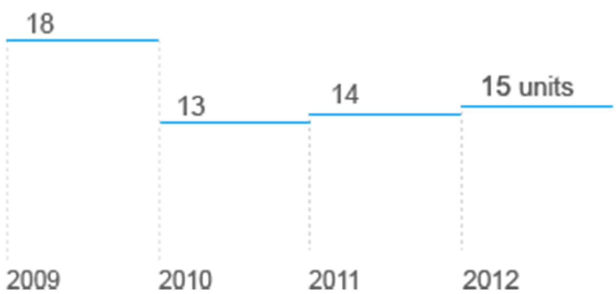
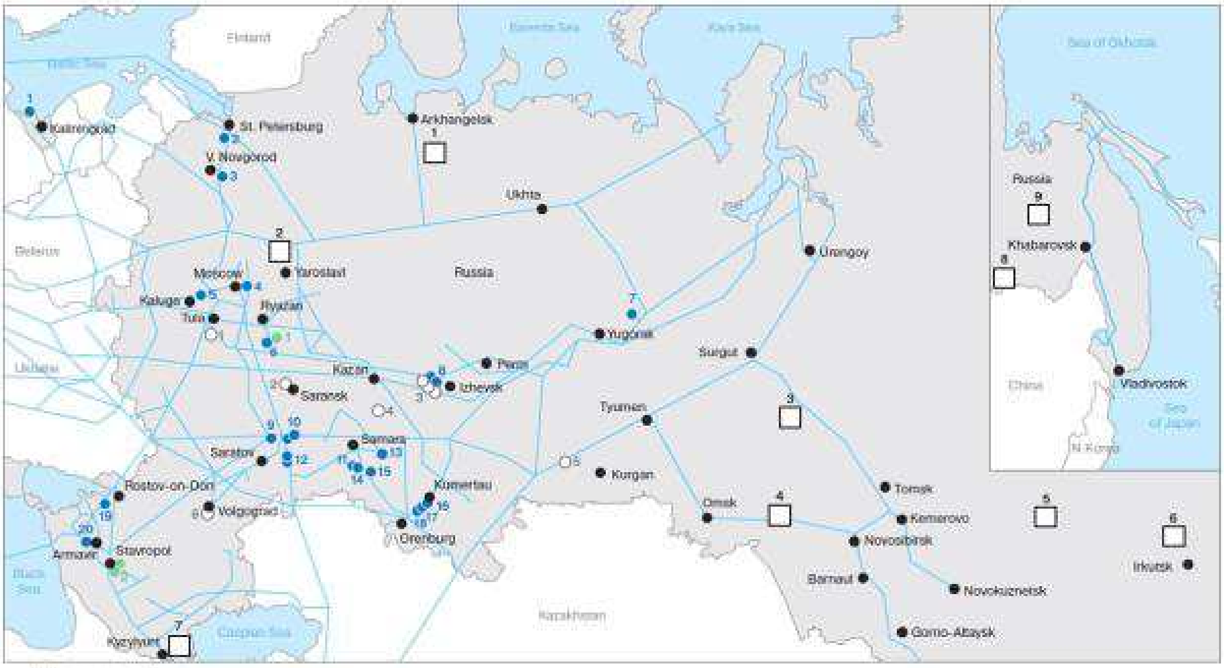


Figure 2.20 Replacement and upgrade of gas compressor units in Russia (source: Gazprom)

The key objectives set for gas transmission and underground storage facility reconstruction until 2015 are as follows:

- debottlenecking the gas transmission system with due consideration given to its loading at present and in future;
- retaining the technologically possible throughput of the GTS by comprehensively reconstructing primary and auxiliary equipment at compressor stations and line pipes;
- further improving the reliability of gas supply to consumers by retrofitting gas branches and gas distribution stations;
- assuring energy efficiency (energy conservation) during the GTS operation including through the use of gas compressor units with higher efficiency;
- further building up the UGS facility potential.



— Major gas pipelines

● Operating UGSFs, active capacity less, than 5 bcm	● Operating UGSFs, active capacity more, than 5 bcm	○ UGSFs under construction and projected UGSFs	□ Exploration areas for UGSFs
1 Kaliningradskoe	1 Kasimovskoe	1 Novomoskovskoe	1 Arkhangelskaya
2 Gatchinskoye	2 Severo-Stavropolskoye	2 Bednodemianovskoe	2 Skalinskaya
3 Nevskoye		3 Udmurtskiy reserving complex	3 Tiginskaya
4 Stchyolkovskoye		4 Arbuzovskoe	4 Kolmakovskaya
5 Kaluzhskoye		5 Shatrovskoe	5 Achinskaya
6 Uvyazovskoye		6 Volgogradskoe	6 Angarskaya
7 Punginskoye			7 Area in Dagestan
8 Karashurskoye			8 Blagoveshchenskaya
9 Pestchano-Umetskoye			9 Adnikanskaya
10 Elshano-Kurdyumskoye			
11 Dmitrievskoye			
12 Stepnovskoye			
13 Amanakskoye			
14 Mikhailovskoye			
15 Kiryushkinskoye			
16 Kantchurinskoye			
17 Musinskoye			
18 Sovhoznoye			
19 Kuschevskoye			
20 Krasnodarskoye			

Figure 2.21 Gazprom's operational and prospective UGS facilities in Russia (source: Gazprom)

Underground gas storage facilities are an integral part of the Unified Gas Supply System and are situated in the key gas consumption regions. UGS facilities help smooth out seasonal fluctuations of gas demand, reduce peak loads in the Unified Gas Supply System and provide better flexibility and reliability of gas supply. UGS facilities are situated in the main gas consuming regions.

During the heating season the network of UGS facilities supplies about 20% of gas to Russian consumers and for export, and in cold snaps this amount may come up to 40 per cent. Thus, in the 2012–2013 withdrawal season during the peak period of withdrawal from Russian UGS facilities this amount equaled 38.3% of total gas consumption in Russia.

With a view to supply gas to the domestic market and fulfill its export obligations, for gas supplies from new production regions, debottlenecks the existing gas transmission corridors and diversifies gas transmission routes Gazprom carries out different projects for building gas transmission capacities.

2.1.4.1 Priority Gazprom's projects

Gas transportation projects

Gazprom Group's major gas transportation projects

Name	Project parameters			Implementation period
	Length	Number of CS / total capacity of CS	Annual capacity	
Gryazovets – Vyborg (expansion)	216 km	– /25 MW	9.4 bcm	2014–2017
Expansion of UGSS for providing the South Stream gas pipeline with gas	2,506 km	10 CS/ 1,516 MW	Up to 63 bcm	2014–2017
New gas pipeline across the Black Sea towards Turkey				
Offshore section	c. 910 km		Up to 63 bcm	first line 2016
Onshore section	180 km			
Murmansk – Volkhov	1,365 km	Up to 10 CS /1,225 MW	Up to 46 bcm (depending upon the production rate at the Shtokmanovskoye field)	
Bovanenkovo – Ukhta				
first line	1,205 km	9 CS / 1,108 MW	60 bcm	2014
second line	1,195 km	9 CS / 1,108 MW	60 bcm	2014–2019
Ukhta – Torzhok				
first line	1,371 km	8 CS / 805 MW	45 bcm	2017
second line	972 km	7 CS / 625 MW	45 bcm	2014–2017
Sakhalin – Khabarovsk – Vladivostok	The project is subject to adjustment based on the adjusted balance of gas			
Power of Siberia	3,056 km, including 2,177 km to Blagoveshchensk	9 CS/1,330 MW, including 8 CS/1,298 MW to Blagoveshchensk	Up to 61 bcm	2018

Table 2.4 Gazprom Group's major gas transportation projects

(source: Gazprom in Figures 2009-2013. Factbook, www.gazprom.ru)

Figure 2.22 Priority Gazprom's projects

- **Bovanenkovo – Ukhta and Ukhta – Torzhok**. A unique next generation gas transportation system, unprecedented in Russia, is being built to transport Yamal gas to Central Russia. The first stage of the Bovanenkovo – Ukhta pipeline and the first line of the Ukhta – Torzhok pipeline with the total length of 2,600 km were commissioned in 2012.
- **Gryazovets – Vyborg.** The gas pipeline is intended for feeding gas into Nord Stream as well as supplying additional gas volumes to consumers in Northwestern Russia.
- **Southern Corridor**. Enabling to supply additional volumes of natural gas to Russia's central and southern regions, the Southern Corridor gas pipeline system will develop industries and utilities, intensify gasification and ensure uninterrupted gas supplies into the new gas pipeline across the Black Sea towards Turkey. Total length of the gas transmission system will account for 2,506.2 kilometers. The project requires that 10 compressor stations are constructed with total capacity of 1,516 MW. The annual throughput of the Southern Corridor gas pipeline system will amount 63 billion cubic meters. The project period is from 2010 to 2017.
- **Sakhalin – Khabarovsk – Vladivostok**. The gas transmission system is a priority of the Eastern Gas Program. Its total length is above 1,800 kilometers. In September 2011 the first 1,350 kilometer segment was put onstream and gas supplies were launched to the Primorye Territory. The system commissioning gave start to massive gasification of the Far Eastern regions and created conditions for gas supplies to Asia-Pacific countries. The Sakhalin offshore fields including those within the Sakhalin III project will be the main resource base for the GTS development. As the principal source of natural gas for the Sakhalin – Khabarovsk – Vladivostok gas transportation system, Sakhalin III will support gas supplies to the Russian Far East regions and enable the implementation of Vladivostok-LNG project.
- **The Murmansk – Volkhov.** gas pipeline will ensure gas supplies from the Shtokman field to consumers in Northwestern Russia and gas exports via Nord Stream. In particular, the gas pipeline construction will allow implementing the socially significant gasification program in the Murmansk Oblast and Karelia, thus boosting industrial development of the region.

  Current status. Initial data acquisition has been carried out. The engineering survey is underway and the project documentation is being prepared.
- **Nord Stream.** The gas pipeline crosses the Baltic Sea and directly links the Russian and European gas transmission systems. The length of Nord Stream is 1,224 kilometers. In November 2011 the first string of the gas pipeline was brought onstream. In April 2012 the second string was laid ahead of schedule. In late May full load tests (75 billion cubic meters of gas a day, which correlates with the design capacity of 27.5 billion cubic meters a year) of Nord Stream's first

string were completed. The annual gas throughput of Nord Stream is 55 billion cubic meters after its two strings reach their design capacity.

- **The Power of Siberia** will become a unified gas transmission system (GTS) for the Irkutsk and Yakutia gas production centers and convey gas from these centers to Vladivostok via Khabarovsk.

  The Yakutia – Khabarovsk – Vladivostok gas trunkline will be constructed at the first stage, and at the second stage the Irkutsk center will be connected to the Yakutia center by the gas pipeline.

  The GTS route will run in parallel with the Eastern Siberia – Pacific Ocean operational oil pipeline, thus enabling to streamline the infrastructure and power supply costs. The GTS route will pass, inter alia, through swampy, mountainous and seismically hazardous areas.

- **Altai project.** Gazprom diversifies its exports by entering the Chinese market. The relevant obligations on gas supply to China will not affect the contracts that have already been concluded with other purchasers of Russian gas. Gazprom possesses sufficient gas resources and production capabilities to meet these obligations. For the supply of 30 billion cubic meters a year the new Altai pipeline system is planned for construction within the existing transmission corridor from Western Siberia to Novosibirsk with follow-up extension to the Russian-Chinese border. The 2,600-kilometer gas pipeline will be constructed with the use of 1,420-millimeter pipes as well as modern and powerful compressor stations ensuring high efficiency and reliability of export supplies.

- **New gas pipeline across the Black Sea towards Turkey:** see Section 2.1.2.2.3

2.1.5 Asia

Due to the fact that Asia is the largest continent and thus multiple natural gas pipeline corridors have been established, SG 3.1 decided to focus mainly on China (see Section 2.1.5.1) and the Asian part of Russia (Gazprom's Eastern Projects – see Section 2.1.5.4) in the following.

2.1.5.1 Main gas corridors – China

In 2015, Natural gas demand in China is estimated to increase by 100 bcm from 2013. Petro China, the biggest oil and gas producer in China, is constructing yearly more than 4,000km of natural gas pipelines that mainly transmit natural gas from Central Asia to the eastern coast of China ant its cost is about US$ 10 billion (JOGMEC report, Natural Gas Pipeline in China, 2013).

By the end of 2010, the total length of China's domestic natural gas pipelines have reached 40,000 km. The first natural gas pipeline to bring Turkmen gas to China came online end-2009; this pipeline is estimated to reach a capacity of 30 bcm by June 2012.

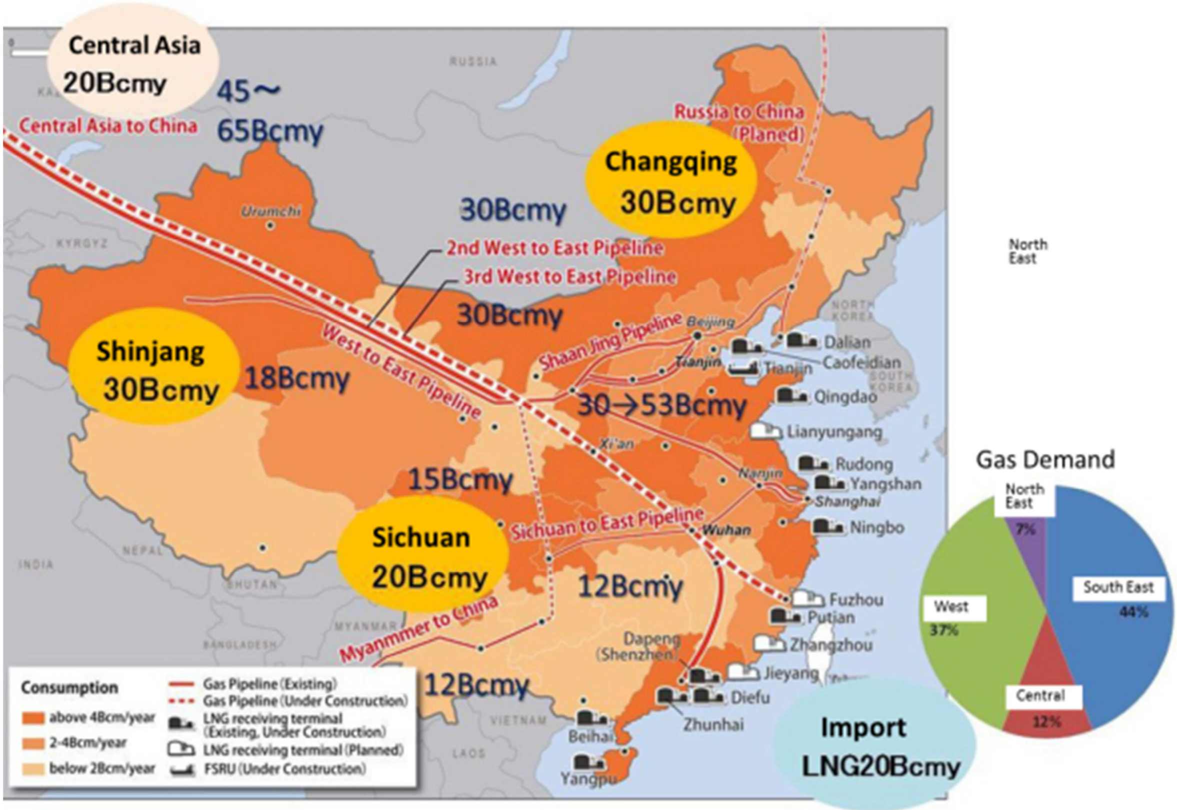


Figure 2.23 Major Natural Gas Transportation Pipelines and Capacity in China
(source: JOGMEC report, JOGMEC report, Natural Gas Pipeline in China, 2013)

In 2010, the east section of the Second phase of West-East Gas Pipeline (see following section for details), the Sichuan-East China Gas Pipeline, the Shibuya Cullinan double Pipeline, the Jiangdu-Rudong Pipeline and the Shaanxi-Beijing Gas Pipeline III have been put into operation. In addition, the construction of the China-Myanmar Gas Pipeline has officially been started. This pipeline will have a capacity of 12 bcm.

	2010	**2012**	**2015**
Natural gas demand	100 bcm	140 bcm	240 bcm
Total length and capacity of natural gas pipeline	40,000 km 100 bcm	50,000 km 130 bcm	84,000 km 250 bcm
Total capacity of LNG receiving terminals	12,400,000 t (17 bcm)	23,000,000 t (32 bcm)	62,400,000 t (85 bcm)
Total capacity of underground storage(working gas volume)	2 bcm	2 bcm	25.7 bcm

Figure 2.24 Major Natural Gas Infrastructure and its Capacity in China
(source: JOGMEC report, JOGMEC report, Natural Gas Pipeline in China, 2013)

As China has formed national and regional gas pipeline networks, the total capacity of the main pipeline network has exceeded 100 bcm a year. Regional gas pipeline networks have been formed in the southwest, the Bohai Rim, Yangtze River Delta, the central South, and the northwest *(source: IEA report, People´s Republic of China, 2012)*.

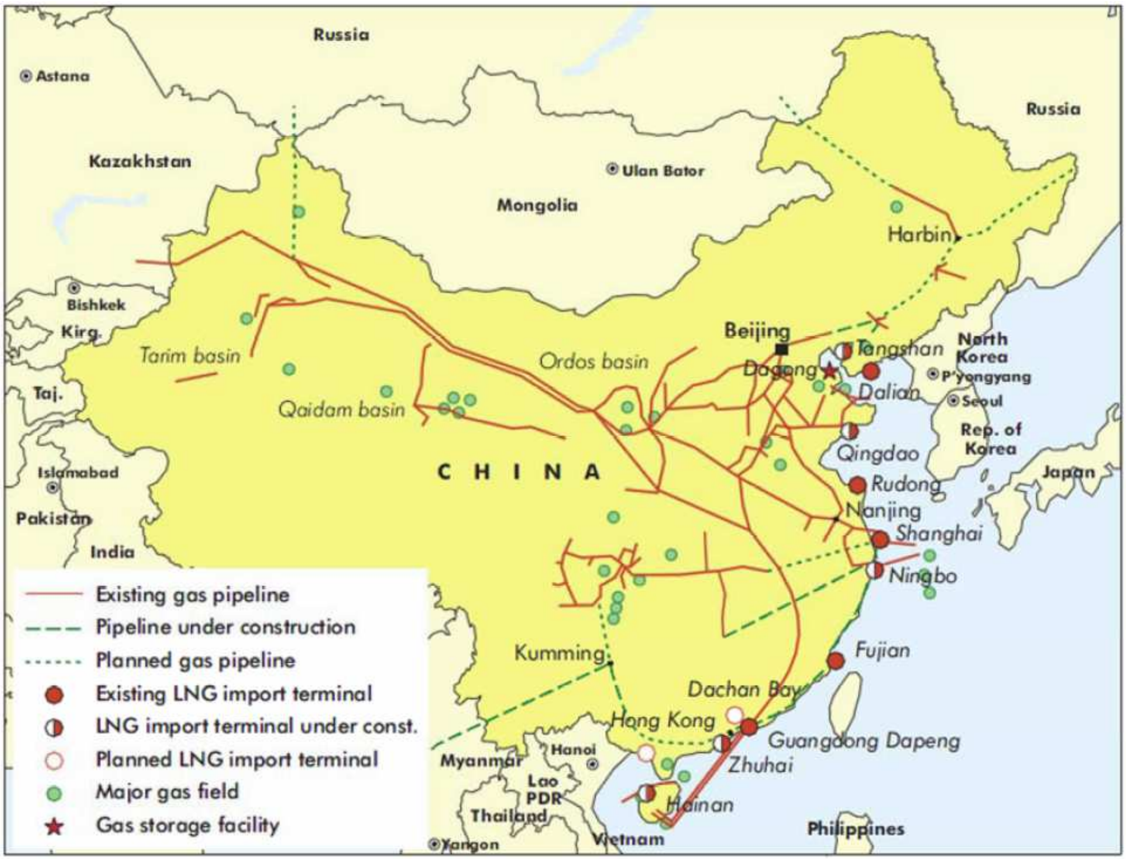


Figure 2.25 Major Natural Gas Transportation Corridors in the People´s Republic of China
(source: IEA report, People´s Republic of China, 2012
http://www.iea.org/publications/freepublications/publication/China_2012.pdf)

China is expanding not only its pipeline capacity but also its LNG regasification capacity. The country started importing LNG in 2006 and has now five LNG terminals in operation. Six LNG terminals are reported to be under construction/expansion, which would increase China's total LNG regasification capacity from around 29 bcm to over 50 bcm in a few years. (source: IEA report, People´s Republic of China, 2012).

2.1.5.2 Detailed description of the selected projects – China

2.1.5.2.1 <u>2nd West-East Gas Pipeline</u>

The 8.704 km long Second West-East Gas Pipeline is made of high strength steel L555MB or X80 steel in 48'' and has been built between 2008 and 2012. It imports natural Gas from Turkmenistan to China down to the region of Hong Kong (see Figure). For the 4,978 km long main pipeline 48'' steel pipe with a MAOP 120 bar have been used. The project is divided into western and eastern segments, with Zhongwei in Ningxia Hui Autonomous Region as the midpoint.

The average distance of the compressor stations on the main line is ca. 230 km. Hence the maximum capacity is around 30 bcm/a, whereas the compression ratio is between 1,5 and 1,6 (*source:*

http://www.cnpc.com.cn/en/aboutcnpc/technologyinnovation/RandDProgress/2008/Key_technological_breakthrough_supports_construction_of_Second_West_East_Gas_Pipeline.htm).

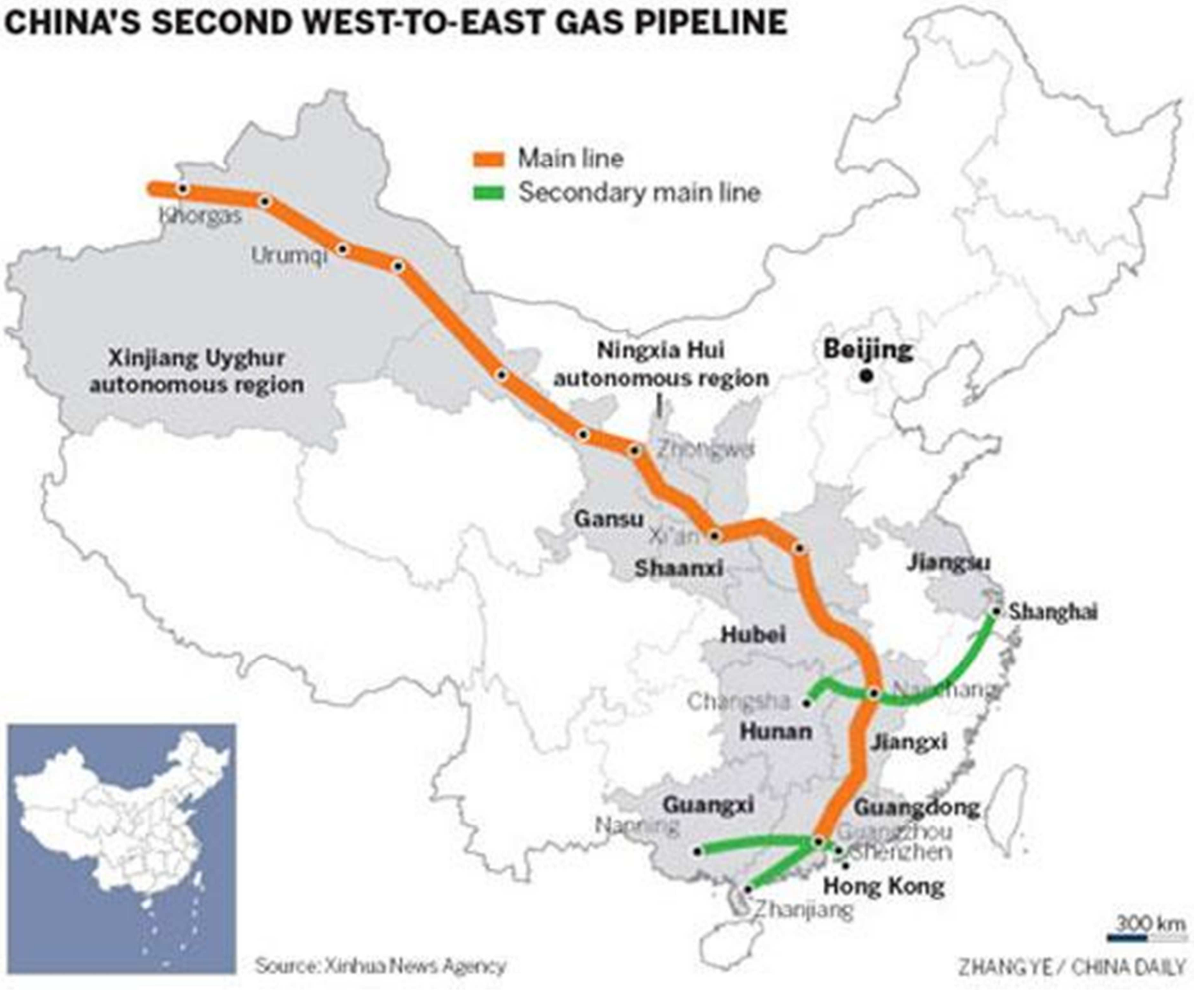


Figure 2.26 Route of the Second West-East Gas pipeline in China
(source: China Daily, http://www.china.org.cn/business/2011-11/25/content_24002229.htm)

2.1.5.2.2 3rd China West-East Gas Pipeline

The construction of the third pipeline started in October 2012 and it will be completed by 2015. The third pipeline will run from Horgos in western Xinjiang to Fuzhou in Fujian. It will cross Xinjiang, Gansu, Ningxia, Shaanxi, Henan, Hubei, Hunan, Jiangxi, Fujian, and Guangdong provinces.

The total length of the third pipeline is 7,378 kilometres (4,584 mi), including 5,220-kilometre (3,240 mi) trunklines and eight branches. In addition, the project includes three gas storages and a LNG plant. The pipeline will have a capacity of 30 billion cubic metres (1.1 trillion cubic feet) of natural gas per year with operating pressure of 10–12 megapascals (1,500–1,700 psi). The pipeline will be supplied from Central Asia–China gas pipeline's Line C supplemented by supplies from the Tarim basin and coalbed methane in Xinjiang. Compressors for the pipeline are supplied by Rolls-Royce.

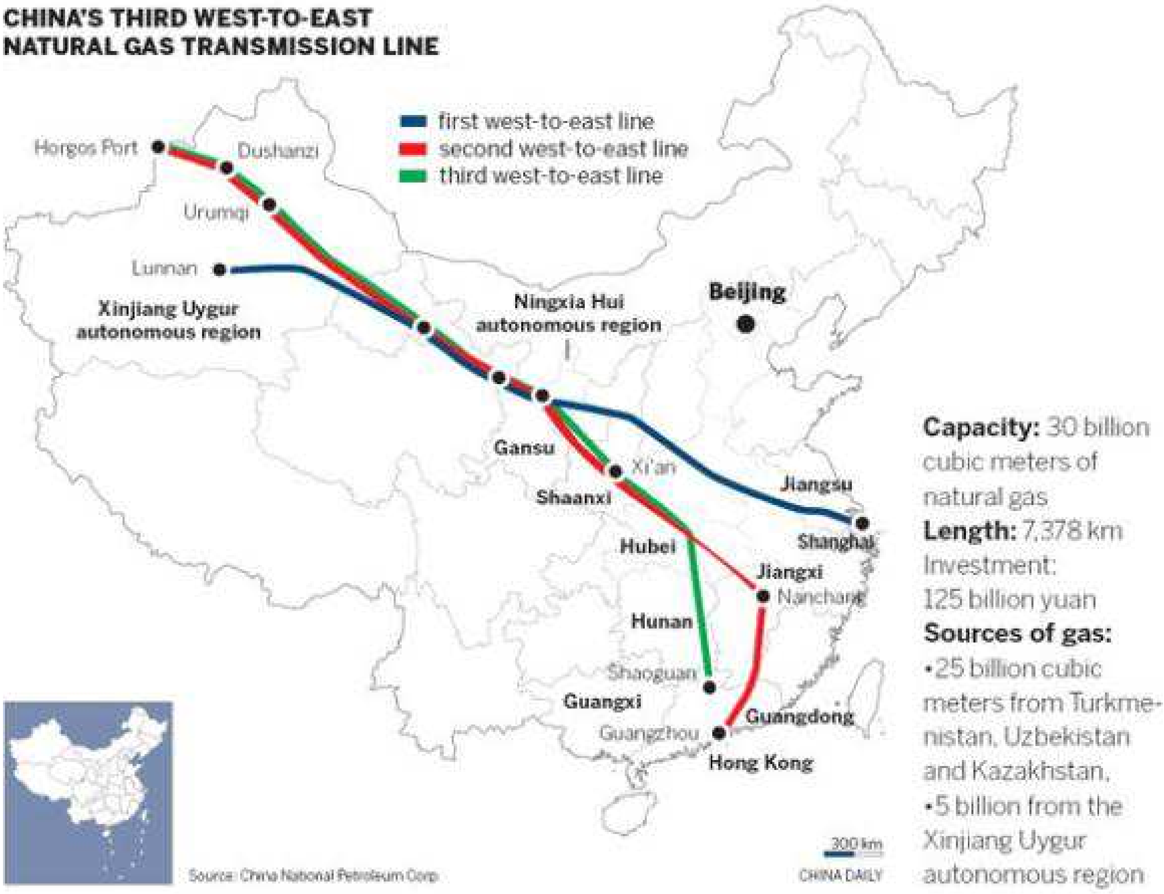


Figure 2.27 Route of the Second West-East Gas pipeline in China

(source: China Daily, http://www.chinadaily.com.cn/bizchina/img/attachement/jpg/site1/20121017/0023ae606c3e11e844f401.jpg)

2.1.5.2.3 <u>4th and 5th China West-East Gas Pipeline</u>

The fourth China West-East Gas Pipeline will transport natural gas from the Tarim Basin or Sichuan to East China. Its lengths will be 5,000 km with a capacity of 4-30 bcm/a. The construction of 4th pipeline has been started in June 2013 by Petro China, and it will become online in 2015.

The 5th string is planned to be 2,900 km long with an annual capacity of 16 bcm/a. Gas source is Georgia. This project is already proposed.

2.1.5.2.4 <u>Myanmar-China Gas Pipeline (Chinese section)</u>

Myanmar-China Pipeline (1,727 km long, 12 bcm/a capacity) that transports natural gas from Burma to China is constructed by Petro China and came into online in June

2013.Chinese section starts at Ruili, the border of Burma, and ends at Kunming. China can import one-fourth of the demand of their imported natural gas by utilizing this pipeline.

Figure 2.28 Route of Myanmar-China gas pipeline
(source: http://jbpress.ismedia.jp/articles/-/37064)

2.1.5.2.5 4th Shaanxi-Beijing Pipeline

Petro China is constructing 4th Shaanxi-Beijing Pipeline (1,036 km long, 23 bcm/a capacity, under construction) that connects Shaanxi and Beijing. This pipeline is estimated to start operation in 2015.

2.1.5.2.6 Central Asia–China gas pipeline

The Central Asia–China gas pipeline, also known also as Turkmenistan–China gas pipeline, is planned to be 1,833 km long and should have a capacity of 40 bcm/a via 2 strings. The costs are expected to be at approximately € 7.3 bn. Status: under construction, gas source: Turkmenistan.

Figure 2.29 Central Asia–China gas pipeline
(source: http://en.wikipedia.org/wiki/File:CentralAsiaChinapipeline.png)

2.1.5.2.7 Eastern Transmission Pipeline (ETP)

(see Project template for detailed information in the Annex 1)

For gas distribution it is important to expand and further secure also the gas supply to the customers, especially in Hong Kong which is subject to an escalating growth. For this purpose in the eastern New Territories a 23 km, 30'' diameter Eastern Transmission Pipeline (ETP) has been constructed until end of 2006 from Ma On Shan to Tseng Lan Shue via Sai Sha Road, Tai Mong Tsai Road, Hiram's Highway, and Clear Water Bay Road and including construction of Sai O Offtake & Pigging Station and to Tseng Lan Shue Offtake & Pigging Station (see Figure). The design of this pipeline section is 35 barg. Its capacity is 6.4 bcm/a.

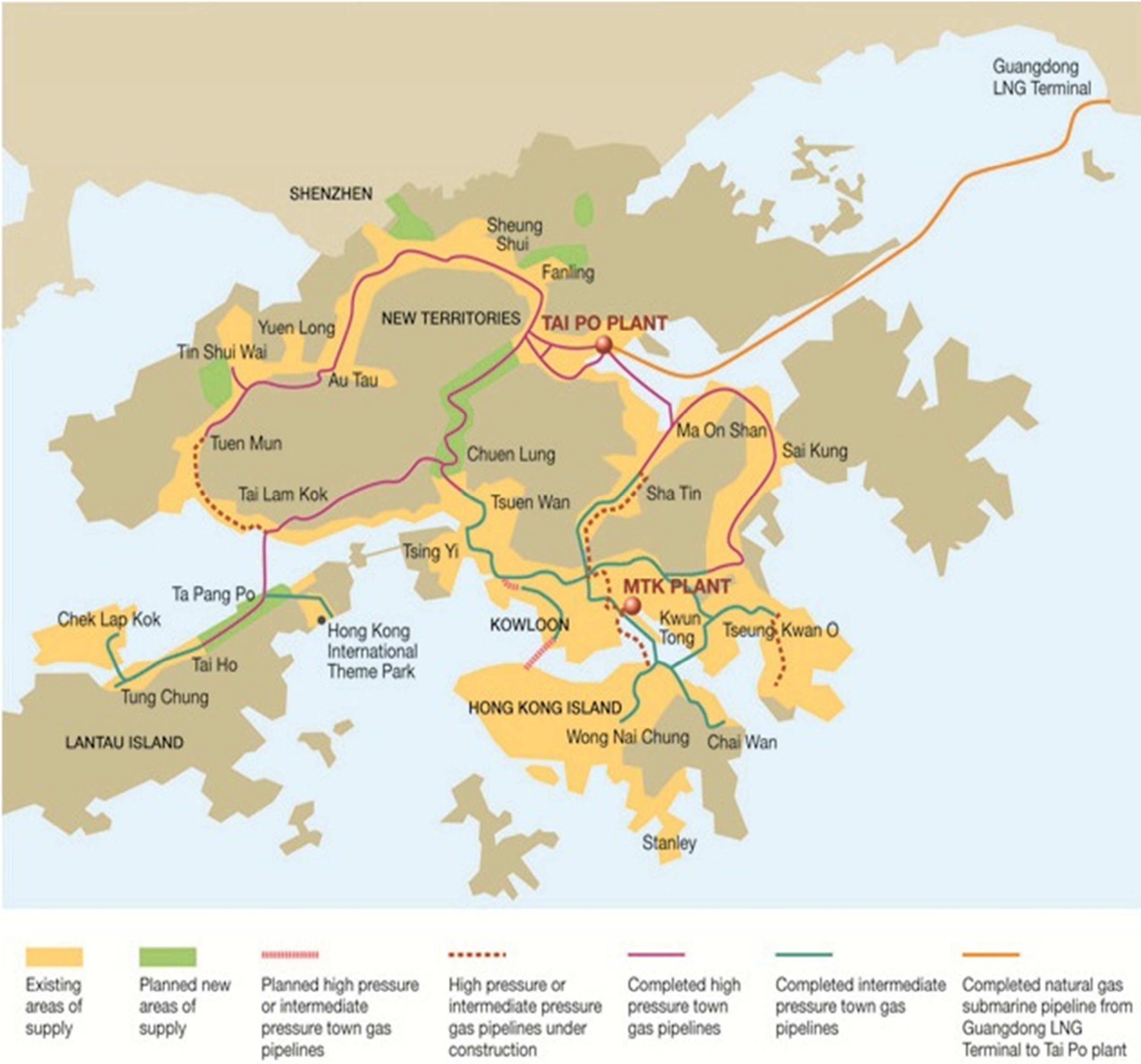


Figure 2.30 Towngas distribution gas network in Hong Kong comprising 3,500 km of natural gas pipelines

(source: http://www.towngas.com/Eng/Corp/AbtTG/HKBus/Netwk.aspx)

2.1.5.3 Thailand

The present transmission pipeline system in Thailand stretches over a distance of 3,715 kilometers including a 1,474 kilometers onshore and 2,241 kilometers subsea pipelines. This gas pipeline system connects with various gas pipelines in the Gulf of Thailand, the pipeline grid from Yadana, Yetagun and recently Zawtika, Myanmar at the Thai-Myanmar border with power plants, the Gas Separation Plants and industrial users. The system also contains Dew Point Control Unit and the Common Header which control the quality of gas from different sources in the Gulf of Thailand to ensure common and uniformed heat and quality.

Figure 2.31 Gas transmission system in Thailand

2.1.5.3.1 Zawtika Project

In 2014, Zawtika gas field in Myanmar started exporting the gas. The $2bn project initially started delivering natural gas for domestic purpose in Myanmar in March 2014 at a rate of approximately 60 million standard cubic feet per day (MMscf/d). In August 2014, it started exporting natural gas to Thailand at a rate of 240MMscf/d. Nearly 80% of the produced natural gas will be exported to Thailand through a 28in diameter, 300km long pipeline. About 230km of the pipeline will be laid offshore, while the remaining 70km will be onshore.

2.1.5.4 Russia - Eastern Gas Program

Eastern Siberia and the Far East cover nearly 60% of the Russian Federation. According to the official estimate, the initial aggregate gas resources of Eastern Russia account for 52.4 trillion cubic meters onshore and 14.9 trillion cubic meters offshore. (At the same time, the regional gas potential has been poorly explored standing at 7.3% for the onshore area and 6% for the continental shelf.) (source: Gazprom)

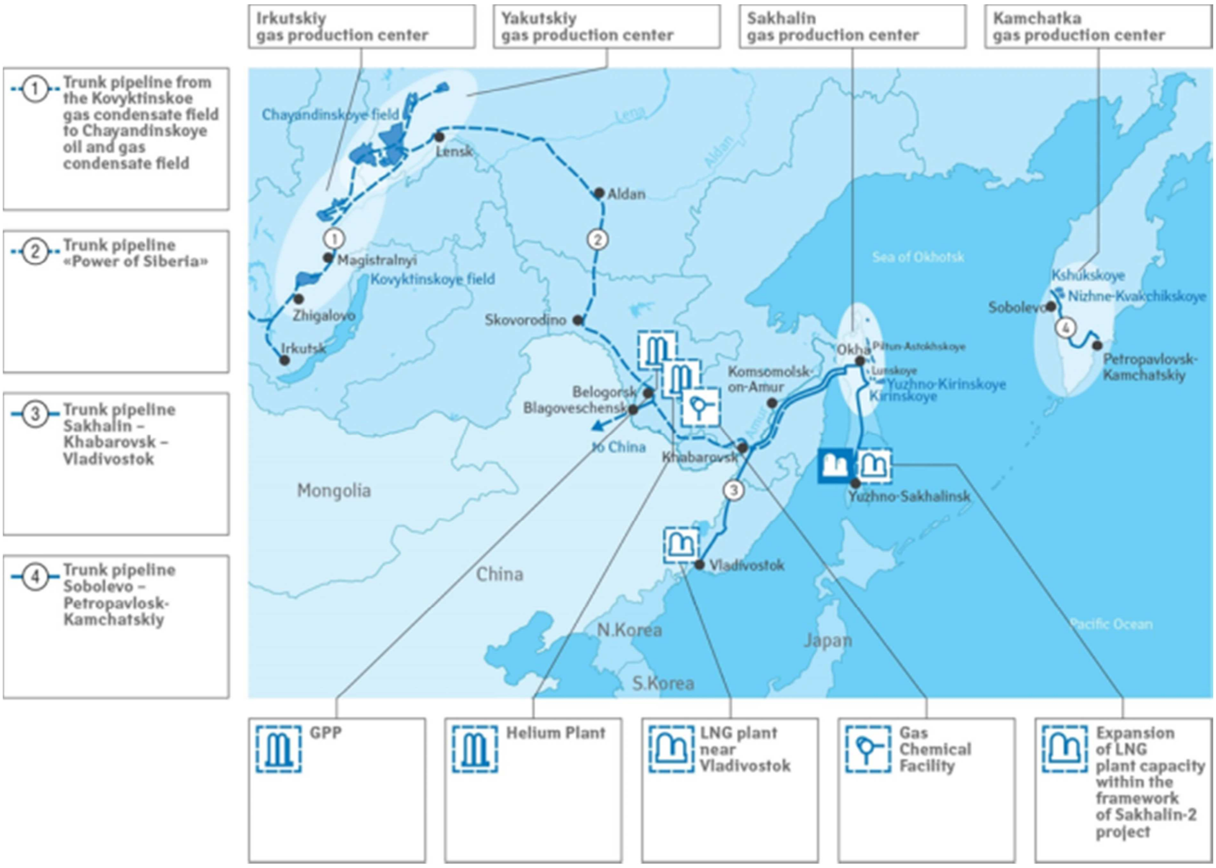


Figure 2.32 Gazprom's Eastern projects
(source: Gazprom)

New gas production centers have already been set up in Eastern Russia, namely the Sakhalin Region and the Kamchatka Territory, a gas production center is being shaped in the Republic of Sakha (Yakutia). The Irkutsk Region and the Krasnoyarsk Territory are next in turn.

A top priority for Gazprom in the east as well as a basic principle of the Eastern Gas Program is supplying Russian consumers with natural gas.

The gas pipelines currently under development form a part of the Russian Unified gas Supply system (UGSS, refer to Section 2.1.4).

Main Gazprom's eastern projects are *(*Figure 2.32*)* (source: Gazprom):

- Chayandinskoye and Kovyktinskoye fileds. The basic fields for the creation of the Yakutia and Irkutsk gas production centers.
- Sakhalin II and III projects. The basic fields for Sakhalin Region. Russia's first LNG plant was built as a part of the Sakhalin II project. (Russian LNG exports began in 2009.)
- Sakhalin – Khabarovsk – Vladivostok gas transmission system is intended for the development of gas supply to the Khabarovsk Territory and the Sakhalin Region as well as the start of gas supply to the Primorye Territory.
- Power of Siberia gas transmission system will become a unified gas transmission system for the Irkutsk and Yakutia gas production centers and transfer gas from these centers to Vladivostok via Khabarovsk.
- Vladivostok-LNG project implies the construction of an LNG plant in the Primorye Territory.
- Gas processing complex in Belogorsk will process the multi-component gas with a considerable amount of helium fed from the Chayandinskoye field.

2.1.6 Australia

2.1.6.1 Main gas corridors

The present transmission pipelines networks, consisting of around 15 300km of high pressure pipelines is shown on Map 1. The construction started since the late 1960s when Australia's oil and gas industries were being developed.

The pipelines networks cross extensive parts of Australia with three distinct interconnecting networks (Figure 2.33):

- Eastern Australia incorporating South Australia, New South Wales, the Australian Capital Territory, Queensland and Victoria
- The central network incorporating the Northern Territory and
- The western network incorporating Western Australia.

These pipeline networks are not presently linked. New pipelines and extensions to existing pipelines have been built in the past including the important linkage connecting New South Wales and Victoria via the Wagga Wagga to Wodonga pipeline. The Australian Gas Association maintains that at present, new pipeline proposals totalling some 11 000 km in length are at various stages of consideration (source: http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp9899/99rp05#GAS).

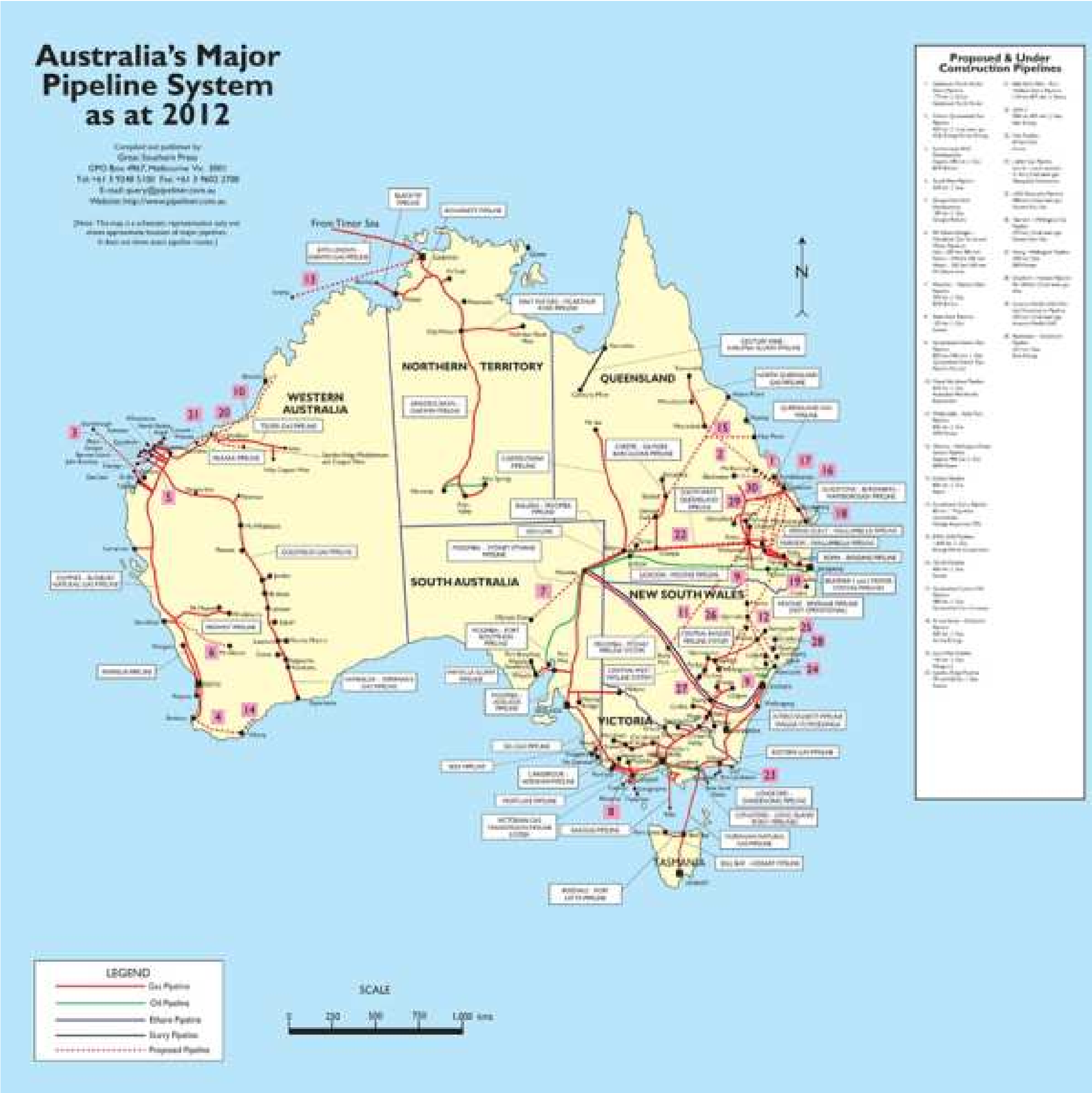


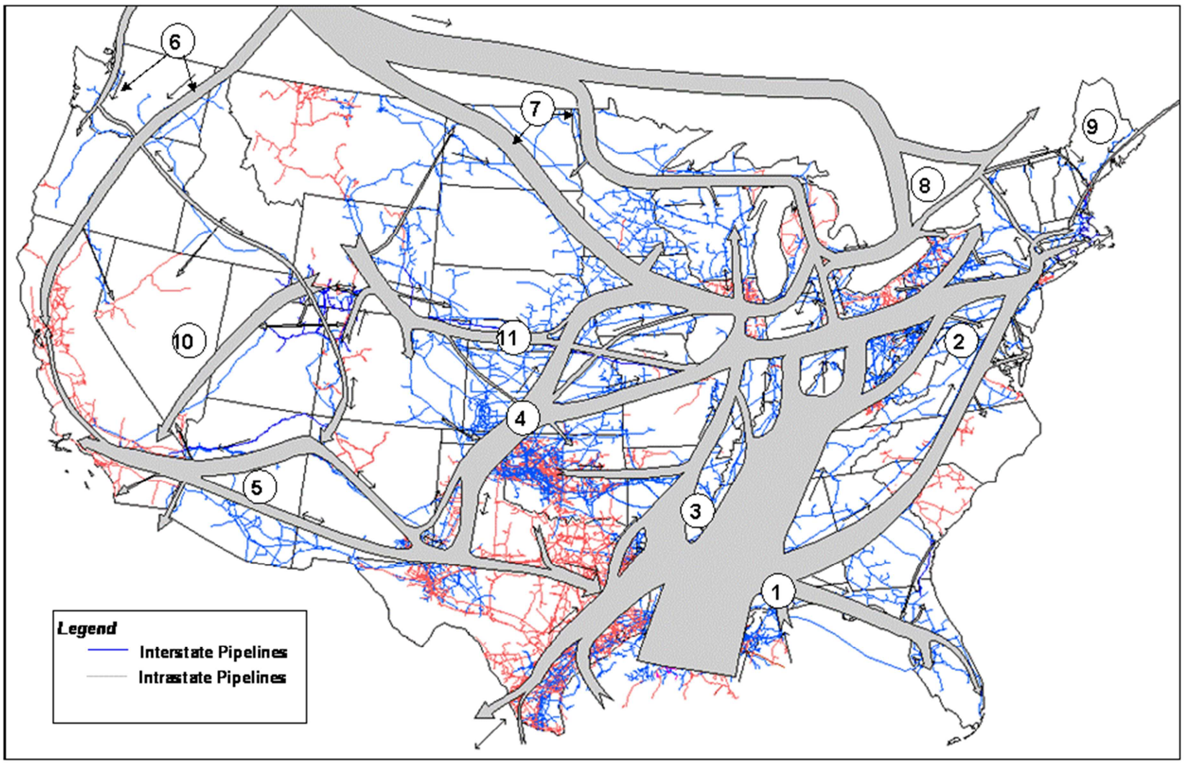
Figure 2.33 Australia's Pipeline system as of 2012 – natural gas pipelines are marked in red colour
(source: http://pipelinesinternational.com/shop/pipeline_map_of_australia/078816/)

2.1.7 North America

2.1.7.1 Main gas corridors

The national natural gas delivery network is intricate and expansive, but most of the major transportation routes can be broadly categorized into 11 distinct corridors or flow patterns (Figure 2.34):

- 5 major routes extend from the producing areas of the Southwest (e.g. Gulf of Mexico)
- 4 routes enter the United States from Canada
- 2 originate in the Rocky Mountain area.



Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division, GasTran Gas Transportation Information System.

The EIA has determined that the informational map displays here do not raise security concerns, based on the application of the Federal Geographic Data Committee's *Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns*.

Figure 2.34 Major Natural Gas Transportation Corridors in the USA

(source: http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/transcorr.html)

A summary of the major corridors and links to details about each corridor are given in the following based on EIA information (source: http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/transcorr.html)

Corridors from the Southwest Region

More than 20 of the major interstate pipelines originate in the Southwest Region. Some extend to the Southeast through Louisiana and Arkansas, others to the Central and Midwestern States through Texas, Oklahoma, and Arkansas, and to the Western States through New Mexico. This area of the country exports about 45% (6.1 trillion cubic feet in 2007) of its production, which is 47% of the total natural gas consumed elsewhere in the lower 48 States.

Pipelines exiting the region have the capacity to accommodate as much as 45.2 Bcf per day: 62% to the Southeast Region, 20% to the Central Region, 13% to the Western Region, and the rest to Mexico. Much of the pipeline capacity directed toward the Southeast traverses the region en route to Midwestern and Northeastern markets. To a lesser degree, this is also true for the pipeline capacity exiting to the midsection of the country, much of which is ultimately destined for the Midwestern States.

1. Southwest-Southeast: from the area of East Texas, Louisiana, and the Gulf of Mexico, to the Southeastern States.
2. Southwest-Northeast: from the area of East Texas, Louisiana, and the Gulf of Mexico, to the U.S. Northeast (via the Southeast Region).
3. Southwest-Midwest: from the area of East Texas, Louisiana, Gulf of Mexico, and Arkansas to the Midwest.
4. Southwest Panhandle-Midwest: from the area of southwestern Texas, the Texas and Oklahoma panhandles, western Arkansas, and southwestern Kansas to the Midwest.
5. Southwest-Western: from the area of southwestern Texas (Permian Basin) and northern New Mexico (San Juan Basin) to the Western States, primarily California.

Corridors from Canada

6. Canada-Western: from the area of Western Canada to Western markets in the United States, principally California, Oregon, and Washington State.
7. Canada-Midwest: from the area of Western Canada to Midwestern markets in the United States.
8. Canada-Northeast: from the area of Western Canada to Northeastern markets in the United States.
9. Eastern Offshore Canada-Northeast: from the area of offshore eastern Canada (Sable Island) to New England markets in the United States.

Corridors from the Rocky Mountain Area

In the Central Region, only two major interstate pipelines originating within the region provides transportation services directly to another region, Kern River Transmission Company and the Rockies Express Pipeline Company. All the others operate primarily within the Central Region itself or originate in other regions. Shippers using these interregional lines to move supplies outside the region take advantage of the interconnections these lines have with the interstate pipelines traversing the region, principally those coming out of the Southwest Region.

10. Rocky Mountains-Western: from the Rocky Mountain area of Utah, Colorado, and Wyoming to the Western States, primarily Nevada and California with support for markets in Oregon and Washington.
11. Rocky Mountains-Midwest: from the Rocky Mountain area to the Midwest, including markets in Iowa, Missouri, and eastern Kansas.

2.1.8 South America

2.1.8.1 Main gas corridors

In South America gas transmission pipelines can be found in the North and South mainly dedicated for domestic consumption and/or for gas exports in the neighbouring countries.

Figure 2.35 Gas (red) and oil (green) pipelines in South America as of 2008

(source:http://www.theodora.com/pipelines/central_america_south_america_caribbean_pipelines_map.jpg)

2.1.8.2 Brazil

Currently, the total length of transmission pipelines in Brazil is 9244 km, with 8582.8 kilometers of integrated network. Despite this extension representing an increase of 310% compared to existing pipelines in June 1999 (2.317 km), the infrastructure of gas pipelines in Brazil is still modest compared to other countries, as shown in Figure 2.36.

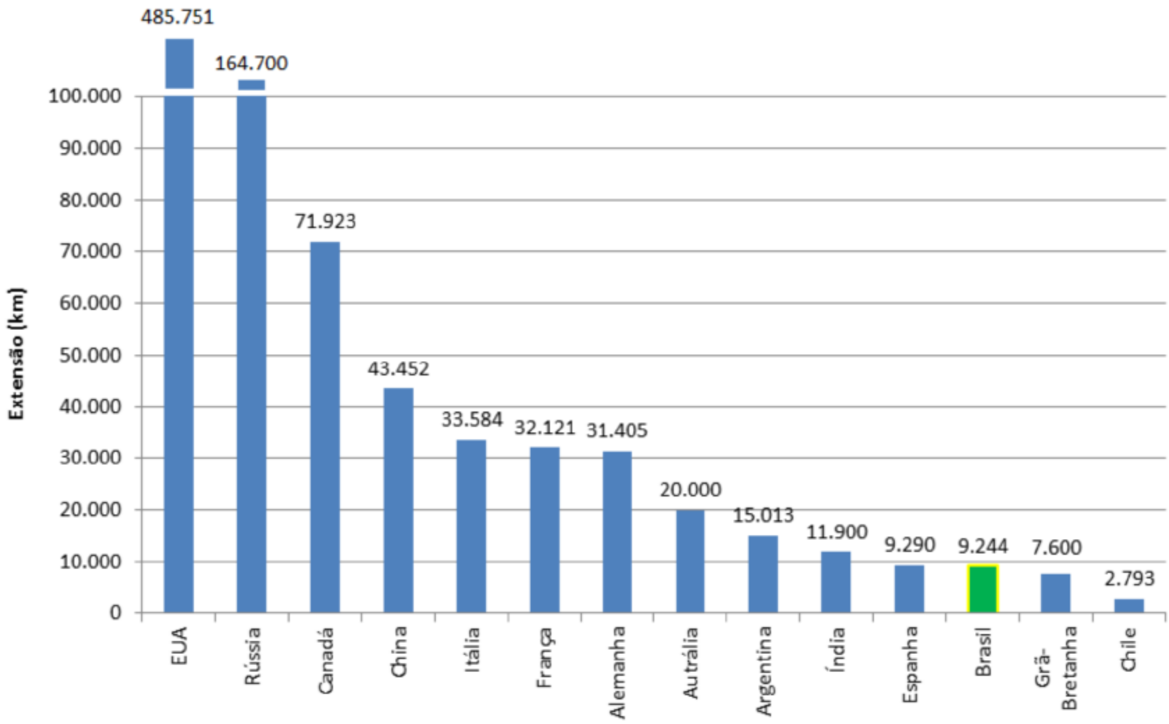


Figure 2.36 Pipeline transport infrastructure in selected countries

Sources: BTS (2012) for the U.S. (reference 2009); Gazprom (2012) to Russia (reference 2011); CEPA (2012) for Canada (reference 2011); EIA (2012a), to China (reference 2011); GRTgaz (2012), to France (reference 2011); AER (2012), in Australia (Reference 2012); Enargas (2012) for Argentina (reference 2010); GAIL (2012), to India (reference 2012); MME (2012) for Brazil (reference 2012); ENAGAS (2012) for Spain (reference 2012); National Grid (2012) for England (reference 2012); Energy Delta Institute (2012a, 2012b, 2012c) to other countries (reference 2011).

In order to change this scenario, the Brazilian government proposed a new regulatory framework for the industry natural gas, aiming mainly to the expansion of the gas pipeline network and a more competitive structure for this industry. The perspective of a growth in natural gas production, due to the pre-salt exploration and the expectation of gas discoveries in onshore basins place the possibility of an expansion in gas pipeline network.

Published on March 4, 2009, Law Nº. 11.909/2009 ("The Gas Act"), regulated by Decree Nº 7.382, of December 2, 2010, contains the groundwork for the expansion of the Brazilian natural gas market. That legal framework was the result of discussions among several players in the sector and the Executive and Legislative powers, and treats the specifics of the natural gas industry. Furthermore, strengthened the role of the Ministry of Mines and Energy as the grantor and formulator of public policies for the natural gas sector, assigning it the responsibility for drafting the Ten-Year Plan for Expansion of Gas Pipelines (PEMAT).

The PEMAT, to be preferably published on an annual basis, will be based on studies conducted by Energy Research Company (EPE). Such studies should include, as Decree Nº 7.382/2010 (art. 6, § 2), among other elements, proposals of routes, compression systems to be installed; delivery points location, as well as estimates of investments in pipelines.

Within this context, the MME requests to EPE to undertake studies on the needs of construction of new gas pipelines or expansions for the existing ones as well. These studies will identify the eligible alternatives under technical, economic and environmental aspects.

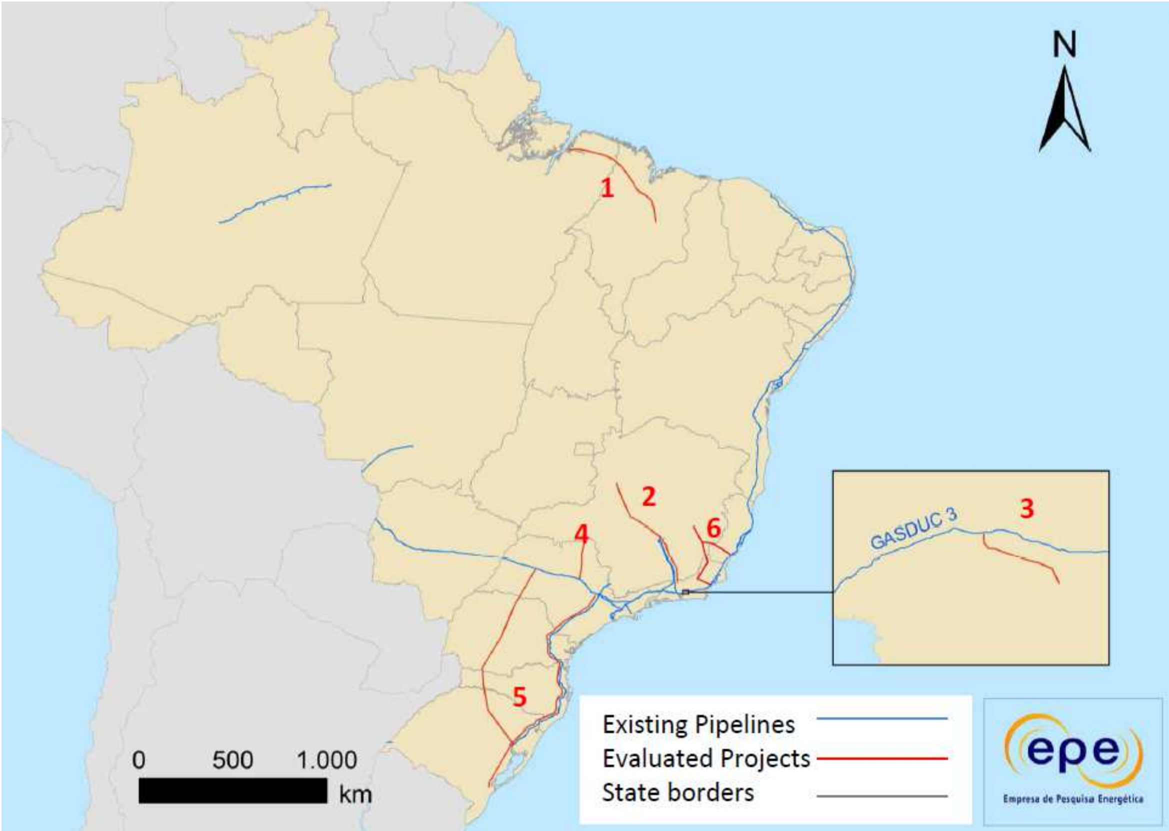


Figure 2.37 Alternatives studied

In this first issue, some proposals were studied in more detail (Figure 2.37):

1. Parnaíba Basin/MA-PI – Barcarena/PA (not connected to main network);
2. São Francisco Basin/MG or Southwest Integrated Network/MG (connected to main network);
3. COMPERJ, Itaboraí/RJ – Southwest Integrated Network/RJ (connected to main network);
4. GASBOL – Triângulo Mineiro/MG (connected to main network);
5. GASBOL or Southwest Integrated Network– South Region (connected to main network);
6. Southwest Integrated Network/ ES or RJ – Vale do Aço/MG (connected to main network).

Among the alternatives evaluated for PEMAT 2022, the pipeline Itaboraí / RJ - Guapimirim / RJ (Figure 2.38) is which proved to be eligible for proposal by the MME, seeking referral to the Public Call to be held by ANP (National Petroleum Agency) considering the constraints of underlying demand and potential supply studies.

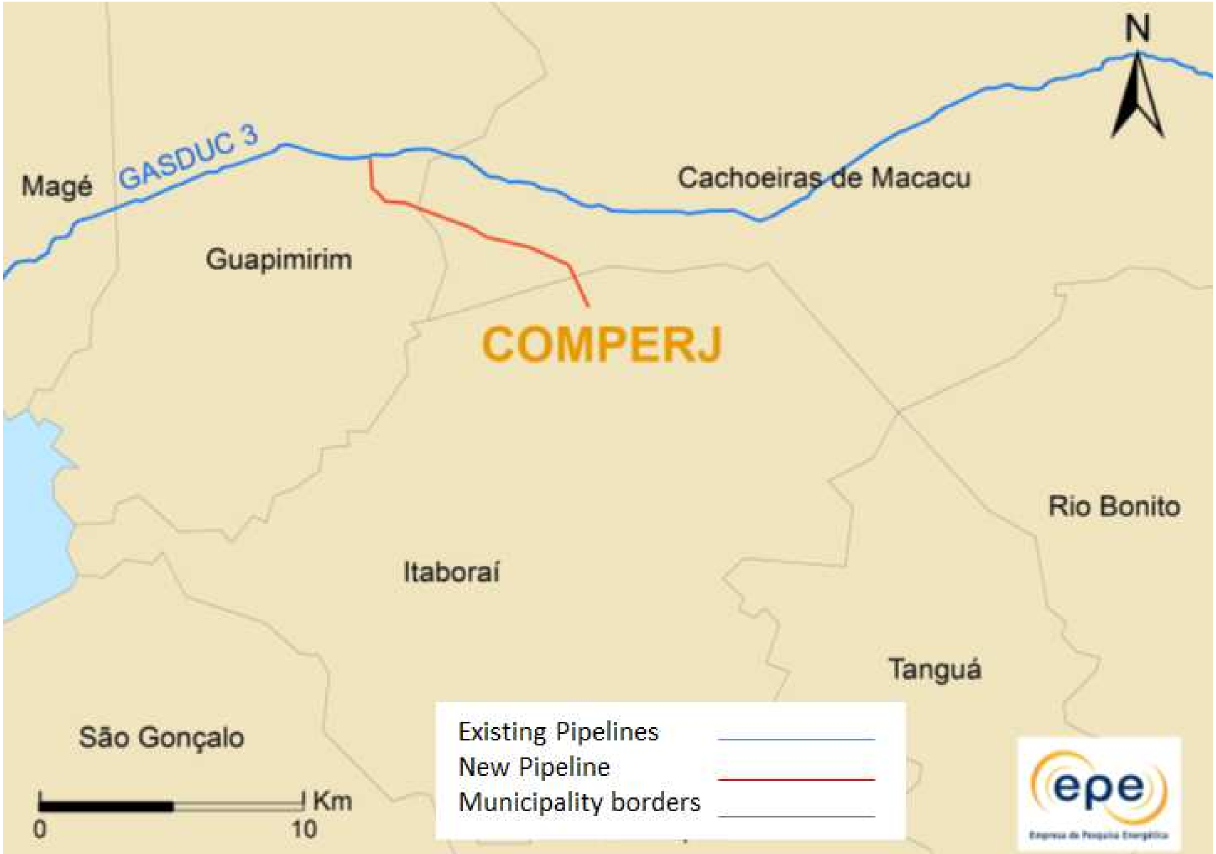


Figure 2.38 COMPERJ, Itaboraí/RJ – Southwest Integrated Network/RJ – Preliminar Proposed Route

EPE concluded that the pipeline to be proposed has the following characteristics: 11 km long, 24-inch diameter, operating pressure of 100 kgf/cm^2 (Min. 60 Kgf/cm$^{2;}$ Max. 100 Kgf/cm^2) and maximum flow of natural gas to 17 million m3/day.

The value of total investment (CAPEX) to be adopted by ANP, after the proposition of the duct by the MME, aimed at defining the maximum rate for Public Call is R$ 112.32 million (aprox. US$ 50,4 millions) and the operating costs (OPEX) amount to R$ 4.49million (US$ 2,0 millions) per year.

Studies indicate Corridor 2, with 11 km in length, as the most promising among corridors studied. Although more extensive, has two positive aspects in relation to the Corridor 1. They are:

a) its connection to the existing pipeline (GASDUC 3) through an existing delivery station;

b) the possibility of the deployment in an existing right-of-way.

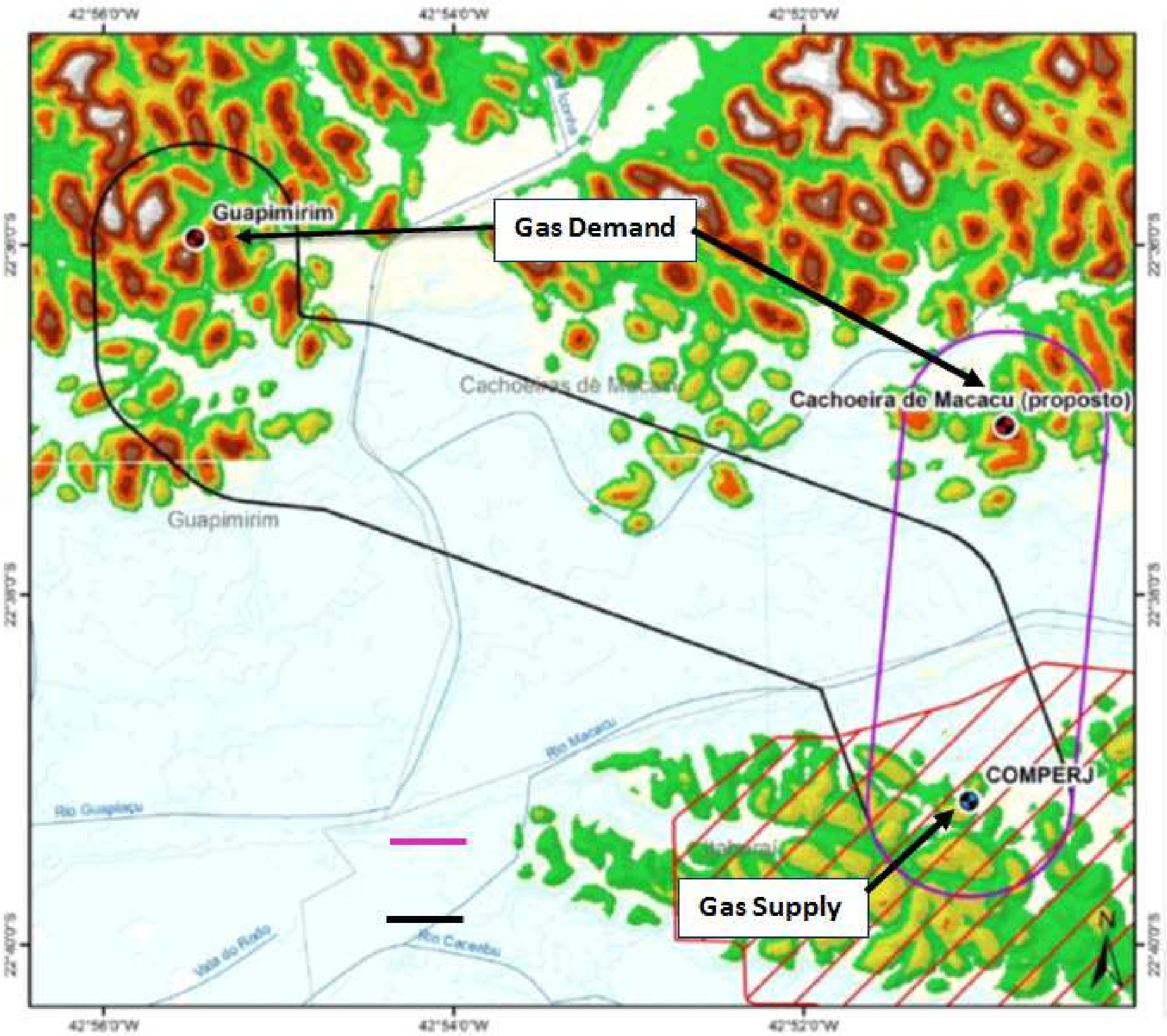


Figure 2.39 Elevation Map

Thus, this alternative would be less spending on equipment and land expropriations. Moreover, would require vegetation removal in smaller areas and less impacts to the physical, biotic and socio-economic environment. The lack or minimization of those impacts can serve as a facilitator aspect, especially in the context of licensing for the enterprise deploying.

2.1.8.3 Detailed description of the selected projects

In the last IGU Triennium 2009-2012 WOC 3, SG 3.1 reported in its final report "NEW GAS TRANSMISSION INFRASTRUCTURES" about two South American natural gas pipeline project:

- Urucu – Manaus in Brasil (see also Appendix 6 of the SG 3.1 final report 2009-2012) and
- Tierra del Fuego in Argentina (see also Appendix 9 of the SG 3.1 final report 2009-2012)

Therefore SG 3.1 decided not to include these outstanding projects again in this report.

2.2 Conclusions and Recommendations

Based on the information gathered via the questionnaires and on experience transfer SG members had during engaged discussions in their meetings in this Triennium common challenges, solutions and recommendations for transmission pipeline systems can be summarized as follows:

- **Permitting**
  ESIA – environmental and social impact assessment issues are increasing; principles issued by project financing institutions such as World Bank, EBRD, EIB, etc. increase efforts for development and execution phase; stakeholder engagement as early as possible; project affected people by land easement and acquisition; fair compensation and treatment of land owners ("keep your promise"); local content to be considered for procurement of services and goods to get local support for project implementation; ensure local people to benefit from project during operations as well.
- **Political support (especially for cross-border pipelines)**
  High level political support by government, affected transit countries and other organizations will ease project implementation; governmental agreements will warrant investors certain security for their investment, e.g. in terms of taxation, expropriation rights for right of way purposes, etc.; geopolitical conditions may accelerate or stop a project.
- **Financing / Partnering**
  Large pipeline projects connected to billion dollar investments need a long time from the first concept to first gas (sometimes 10 years or more), connected with high project development costs, which could lead together with the upfront financing fees up to an amount of 30% of the total project costs; the huge investments are most often facilitated by project companies founded for this purpose whereas more and more the gas producers upstream taking over the role of the so-called midstreamers as shareholders. Long-term gas supply contracts and a guaranteed high capacity utilization are the backbone for these kinds of investments; the return on investment has to meet the requirements of the investors when considering the project and country risks. Hence for pipeline systems transiting European countries a regulation or TPA exemption (TPA – thirst party access) becomes of vital importance.

Chap. 3 Improvements of the compression process, turbo machineries, performance optimization, emissions

3.1 Introduction

A Strategic Framework has been established for this triennium, outlining the themes which will form the 2012-2015 technical programme. To support the theme "Growing together towards a friendly planet" and reinforce the IGU's role in the gas industry, the strategic themes are also guidelines to sustain future global growth of gas.

Improvements of the compression process, turbo machineries, performance optimization, and emissions are linked to:

- obtain official recognition for natural gas as a destination fuel for sustainable development;
- improve the availability of natural gas;
- promote an appropriate mix of gas and renewables and electricity.

The IGU/WOC3 issued a questionnaire on the subject and distributed it to all IGU/WOC3 members in autumn 2013. The focus of the research including the data collection and their analysis was on the following topics:

- to evaluate the current level of both the compressor and drive efficiency of machines installed during last years;
- to gather the information regarding emission limits (NOx and CO) in line with the legislation requirements for involved countries;
- to assess the total power distribution of the compressor station to the particular units power in order to cover the whole operational range of CS including the backup philosophy;
- availability of electric power and flexibility with regard to operation under Smart Grid conditions/restrictions;
- to compare electric drive vs. gas turbine drive (pros and cons).

Responses were received from different countries, covering 22 compressor stations and 99 compressor units installations with total power 1146 MW. The charts included in this chapter are the results of the provided data and at this point we would like to thank all member companies who participated in this survey.

The integrated results of the received data are connected with the information about the installations of the compressor stations and the case studies from four member companies provide technical details about the latest development in this area.

3.2 Gas turbine drive

3.2.1 Turbo package

The term Turbo package means any blade-type machines able to convert gas kinetic energy to mechanical work or to convert mechanical work to gas kinetic energy. The devices converting mechanical work to gas kinetic energy are called compressors. The term gas turbine is used for a device able to convert gas kinetic energy to mechanical work.

In general the turbo packages used for gas transmission by pipeline systems consist of a gas generator, gas turbine and a centrifugal compressor.

A gas generator is usually an aeroderivative engine of an aircraft jet engine modified for heavy-duty use. A jet engine is normally used as a driving unit in aviation. This type of a drive uses the kinetic energy of combustion gases produced by an engine, which pushes the generator and the whole aircraft forward according to the Newton's Law.

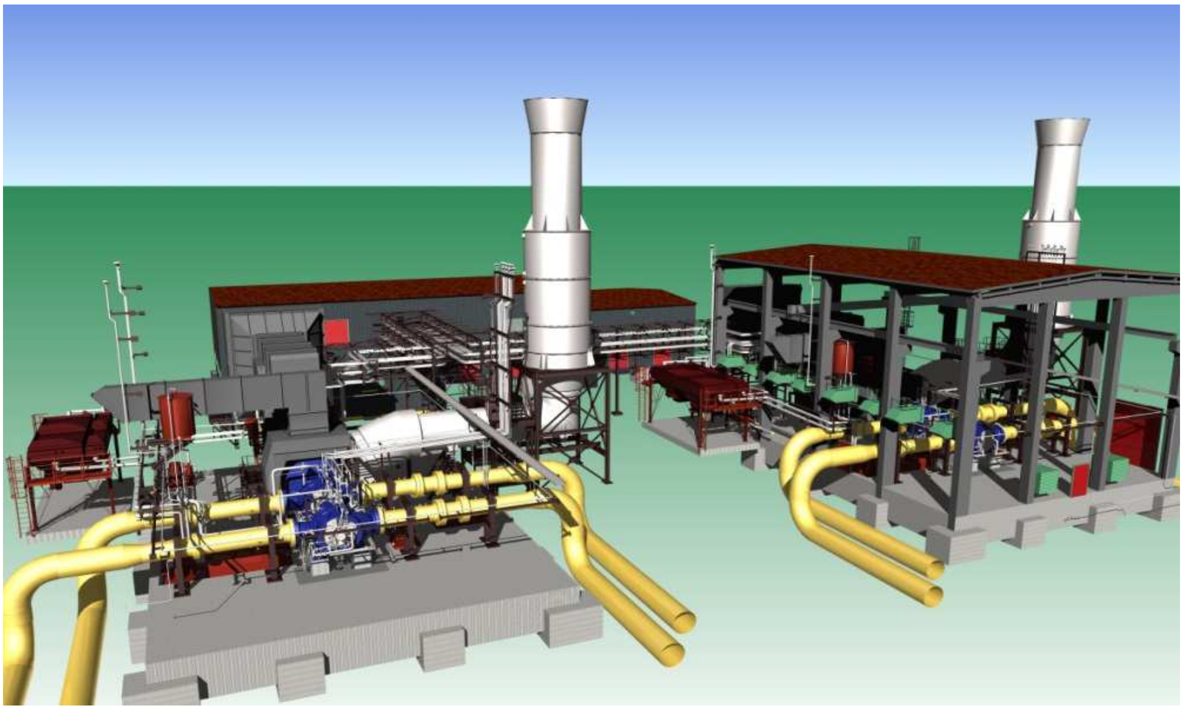


Figure 3.1 Model of the turbo packages at compressor station Veľké Zlievce, Eustream, Slovakia

Jet engines modified for heavy applications are designated by the term "gas generator", the purpose of which is to produce a big amount of exhaust gases with a lot of energy. Processing and conversion of energy contained in combustion gases produced by a gas generator is provided by a heavy-duty power turbine.

In a power turbine, usually mechanically connected to a gas generator, expansion of exhaust gasses, the kinetic energy of which is transferred to the shaft of the gas turbine through the blades and vanes occurs. Mechanical work produced on the shaft of the turbine is the output. That may be subsequently used by an electric generator for electric power production, however, in gas applications the gas turbine is connected to a radial centrifugal compressor by a coupling device. The compressor delivers mechanical work produced by a gas turbine to process gas (transported by gas transmission system), which results in the increase in gas pressure in the pipeline downstream of the compressor. The pressure increase then provides moving of gas in the pipeline to the part with lower pressure, which is the basic principle of pipeline transmission network operation.

A lot of the components of the aircraft engine were modified and adopted to the needs of heavy-duty applications in development of a heavy-duty gas generator.

The latest installation of the compressor station (as of 2014, see Figure 3.1) is used for a detailed description of the Turbo package. In this case the Turbo Package, from the manufacturer Rolls-Royce, consists of a gas generator RB 211 24 GT DLE, power turbine RT 61 and two centrifugal compressors RF BB 36. This Turbo package is able to achieve power up to 33 MW with thermal efficiency of the equipment up to 41 % and consists of the following basic technologic units:

- gas generator RB 211 24 GT DLE
- centrifugal gas compressor RF 2/1 BB – 36 connected in tandem
- power turbine RT 61
- synthetic oil system
- mineral oil system
- hydraulic starter system
- inlet duct of the Turbo package and anti-icing system
- gas generator enclosure ventilation system
- exhaust duct of the Turbo package
- dry gas seal system
- fuel gas system
- firefighting and gas detection system
- diagnostic system of the Turbo package
- control system of the Turbo Package

Gas generator RB 211 24 GT DLE is a gas turbine with an open circle derived from the aircraft engine RB 211. The concept of the above mentioned gas generator operating with a high compression ratio of air compression up to 21:1 consists of a seven-stage middle-pressure axial compressor and a six-stage high-pressure axial compressor. Each spool is driven by a separate single-stage turbine connected mechanically to a corresponding compressor by coaxial shafts. The two spools are mechanically independent from each other and they rotate with different speed. The generator consists of five basic modules, which may be dismounted as separate groups and of the module 06, which consists of combustion system devices, a starting device, cables, auxiliaries and accessories, which are not included in the previous five modules. Module 05 is a module of a middle-pressure turbine. Module 04 is a module of a high-pressure system. Module 03 is an intermediate casing module. Module 02 is a module of a middle-pressure compressor, which consists of two parts of a horizontally split rotor. Module 01 is the inlet module. Variable inlet guide vanes are adjustable depending on the temperature of the inlet air and on the speed of the axial compressor (VIGV). In the fourth module there are nine individual combustion chambers with split DLE combustions intended to achieve low emissions.

The gas turbine utilizes hot gas energy delivered by the gas generator RB 211 24 GT DLE to drive the compressor, to which it is connected by a coupling device with measurement of power and torque. The following are the main parts of the power turbine: a three-stage rotor and a stator. The rotor consists of three disks with blades and a shaft imbedded in two radial bearings and one two-sided thrust bearing. The stator is a welded box made of heat-resistant steel, which contains the gas generator connecting flange, turbine stator vanes, guide rings and exhaust diffuser.

Radial centrifugal compressor RF BB 36 is a single-casing single-stage compressor driven by a power turbine through a coupling device. The centrifugal compressor may be operated in tandem connection through a process gas distribution system, i.e. it can be operated both in serial and parallel connection. The main parts of the compressor are casing inlet volute, rotor with rotating wheels, one both-sided thrust bearing and two radial bearings, labyrinth seals, dry gas seal, mineral oil pump and variable inlet guide vanes.

3.2.2 Efficiency of the gas turbines

Efficiency is one of the important parameters of a Turbo package and defines the rate of the ability of the machine to transform the delivered energy in fuel to mechanical work.

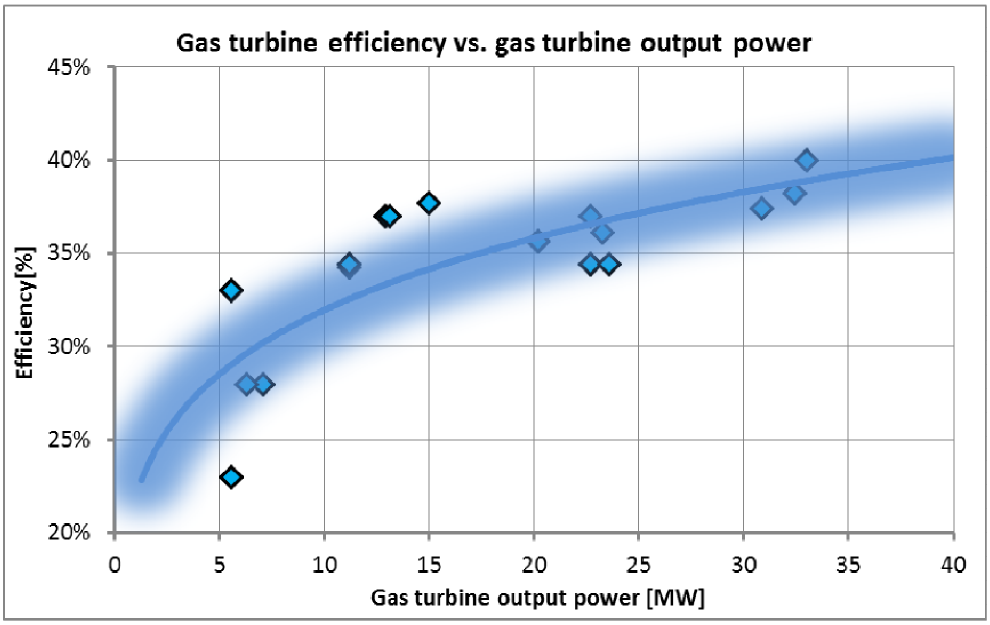


Figure 3.2 Dependence of the gas turbine efficiency on the design output power

Monitoring of the "whole" efficiency, which assessed the efficiency of the entire machine, is used for energy assessment of thermal machines. It is calculated from the ratio of the values of the energy entering the device in form of fuel and mechanical work continuously taken from the shaft of the power turbine.

The dependency of the gas turbine efficiency on the gas turbine output power is shown in Figure 3.2. Efficiency of the gas turbine increases at higher design output power. The results are based on the data collected within the questionnaire about compressor stations.

The operational range connected with the limited area of operation where emission limits are guaranteed is another very important parameter of the gas turbine. This area is usually bounded by maximum and minimum load of gas turbine. The minimum load (Figure 3.3) is one of the main factors which determine the flexibility of the whole Turbo package (see also Chapter 3.6.1).

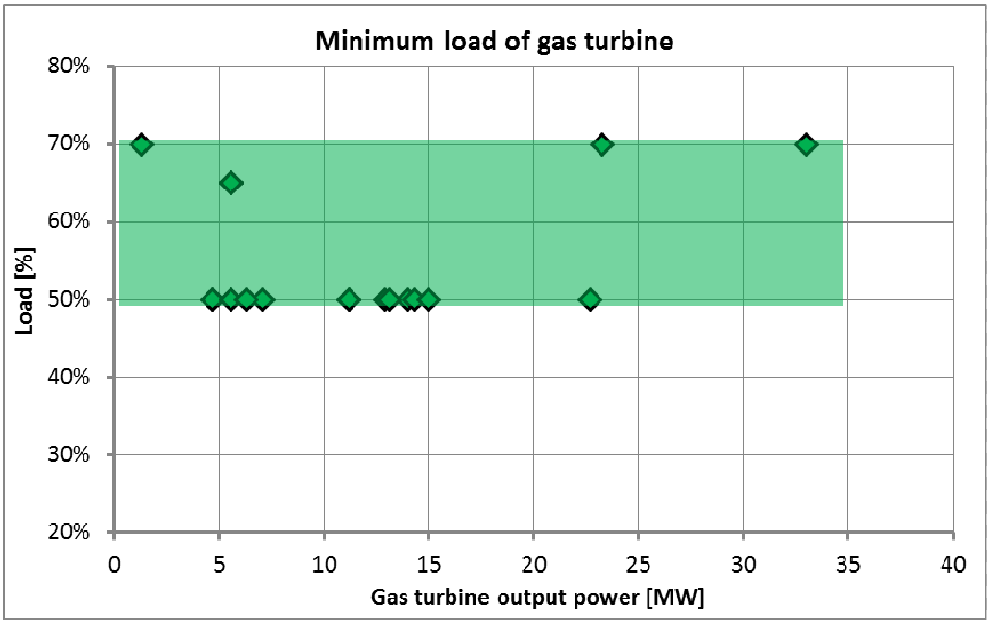


Figure 3.3 Minimum load of the gas turbine vs. design output power

3.2.3 Legislation requirements applied to emission limits

All major international environmental authorities (European Commission, local environmental ministries) are introducing increasingly stringent limits to the amount of pollutants emitted by industry. Gas turbines are an important contributor to pollutants such as NOx, SOx, CO, UHC, and as such, they are subject to regulatory restrictions applicable to new installations and, in many cases, also to units already installed and running for a long time.

The basic principle, which tends to be adopted for new unit applications, is compliance with the Best Available Technology (BAT), while for older, previously installed units, the regulations tend to be more tolerant. The increasing demand for power and the consequent introduction of new equipment, even complying with BAT, implies an increase of emissions which counts against the overall tons of pollutant reduction targets set by localities and countries in compliance with international directives.

There is a detailed overview of the legislation requirements of member companies which participated in our survey in the figures below (Figure 3.4). The objectives of the survey were as follows:

- Specify please name and year of validity of the legislation concerning emission limits for new compressor units used for gas transmission (Figure 3.5).
- Specify please current applicable values of emission limit for both nitrogen oxides (NOx) and carbon monoxide (CO) production. If the limit value depends on thermal power, specify please values for the relevant range of thermal power (Figure 3.6).
- If change of emission limits is expected in the coming years (Figure 3.5), specify please new or assumed values of emission limits both for NOx and CO. If the limit value depends on thermal power specify please values for the relevant range of thermal power (Figure 3.7).

The abbreviations NO and N/A mean the following in the figures below:

- NO = change is not expected (Figure 3.5), emission limits do not depend on thermal power, there are no emission limits for NOx or CO;
- N/A = not available.

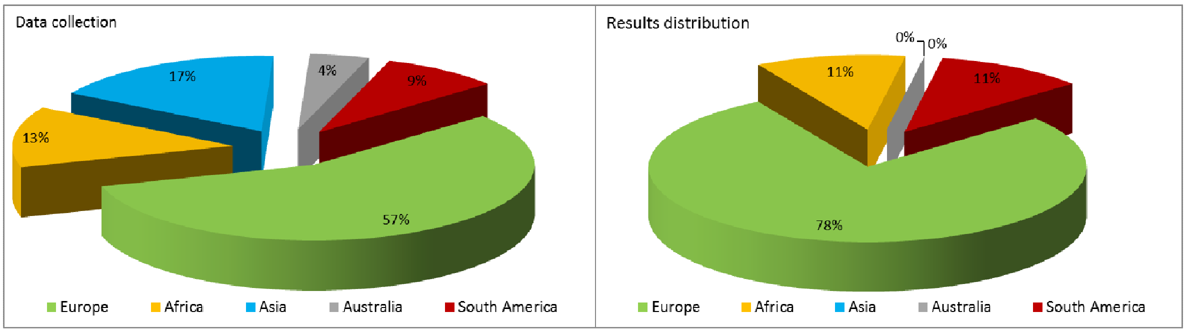


Figure 3.4 Data collection and the results distribution

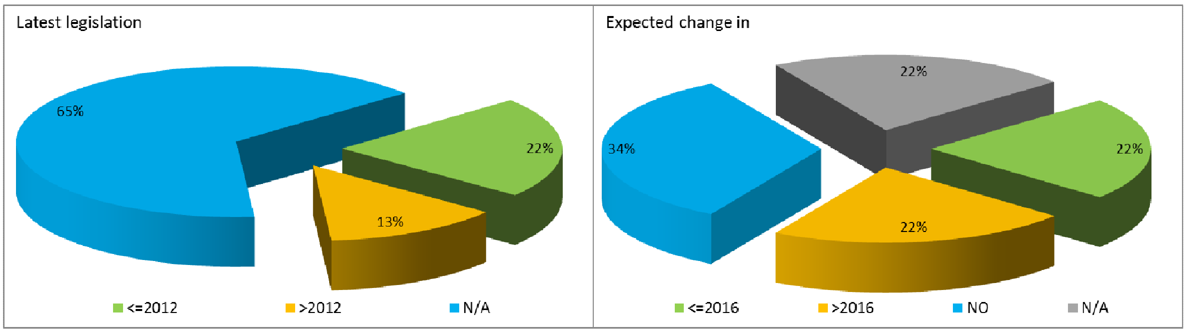


Figure 3.5 Latest legislation and the expected changes

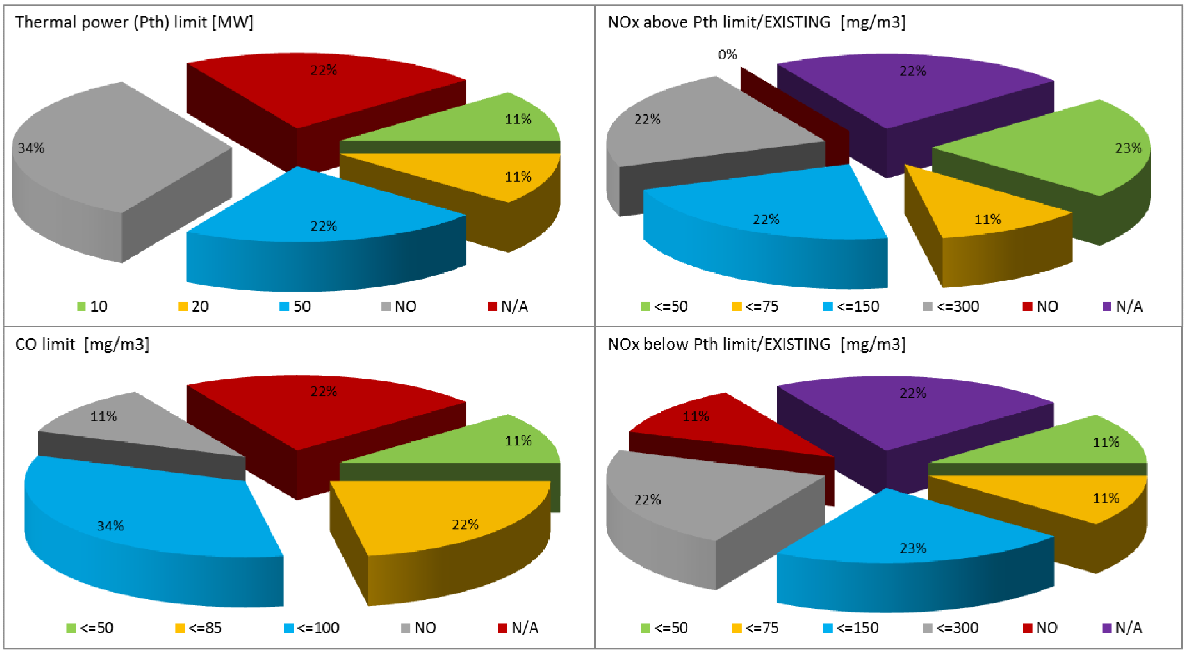


Figure 3.6 Actual thermal power limit and emission limits for EXISTING sources

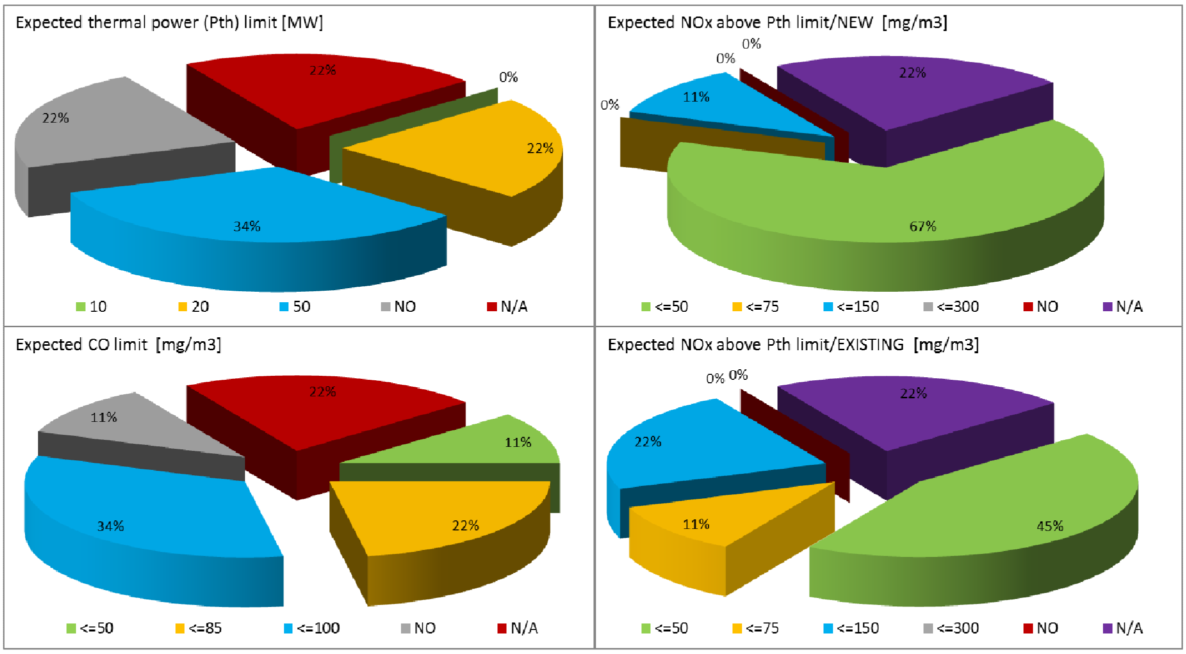


Figure 3.7 Expected thermal power limit and emission limits for NEW sources

As it is shown in Figure 3.8, several installations of compressor stations could be affected by the new legislation of emission limits (TSAC). It will be necessary to implement technical measures in order to adapt the existing installations to stricter emission limits, see also Chapter 3.5. The abbreviations in Figure 3.8 mean the following:

- TDLE = gas turbine drive, Dry Low Emission system;
- TSAC = gas turbine drive, Single Annular Combustor;
- E = electric drive;
- TEX = turbo expander drive.

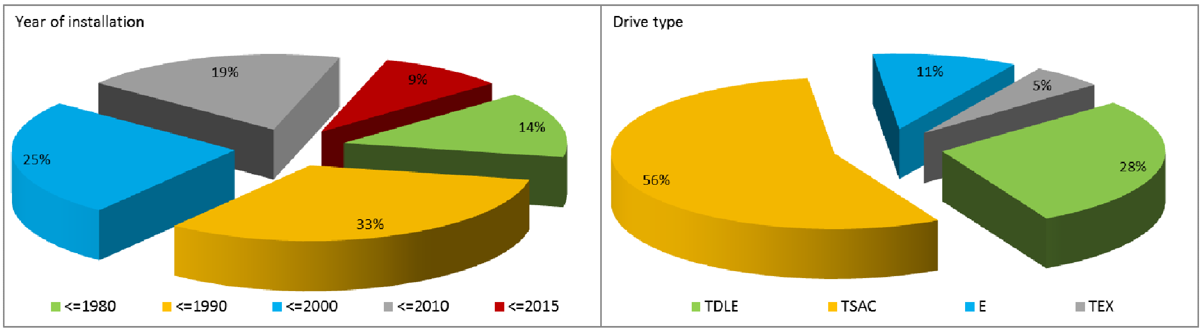


Figure 3.8 Year of installation of compressor unit and the drive type

3.3 Electric drive

3.3.1 Electric package

A separate group of mechanical energy generators, electric drives, forms an alternative to the described method of driving the gas centrifugal compressor. The Electric packages installed within the transmission networks in general they consist of two basic units, an electric motor and a radial centrifugal compressor. The two units are connected through a toothed gear coupling and a torque rod and they are located in an acoustic casing.

The standard Electric package unit consists of three basic parts:

1.) Main package
- Variable frequency drive
- Electric motor
- Compressor

2.) Accessories of the Electric package:
- Low-pressure pump box
- High-pressure pump box
- Oil and anti-freeze substance - water mixture cooler
- Piping network

3.) Systems of the Electric package:
- Lubrication and sealing oil system
- Transformer oil system
- Anti-freeze substance - water mixture system
- Control system

Medium voltage variable frequency drives (VFDs) are typically rated between 2.3 and 13.8 kV, and deliver power ranging from 150 kW to 120 MW at motor speeds from 10 to 15.000 rpm. Primary function of VFD in industry is to provide smooth control along with energy savings. The variable speed motor drive system is more efficient than all other flow control methods including valves, turbines, hydraulic transmissions, dampers, etc. Adjustable speed motor-drive systems are more reliable than traditional mechanical approaches such as using valves, gears, louvers or turbines to control speed and flow. Unlike mechanical control system they don't have any moving parts hence they are highly reliable.

Variable frequency drives provide the following advantages:

- energy savings;
- low motor starting current;
- reduction of thermal and mechanical;
- stresses on motors and belts during starts;
- simple installation;
- high power factor;
- lower kVA.

Understanding the basic principles behind VFD operation requires understanding the three basic sections of the VFD: the rectifier, DC bus, and inverter.

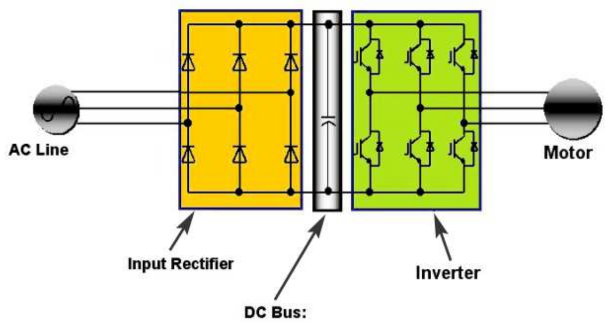


Figure 3.9 Basic sections of the VFD

The rectifier in a VFD is used to convert incoming AC power into direct current (DC) power. A VFD may have multiple rectifier sections, with 6 recti-fiers per section, enabling a VFD to be "12 pulse," and more. The benefit of "multi-pulse" VFDs is from the harmonic distortion point of view. After the power flows through the rectifiers it is stored on a DC bus. The final section of the VFD is referred to as an "inverter." The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common choice in modern VFDs. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. By varying the voltage and the frequency, it is possible to vary the speed of the connected three-phase motor continuously and virtually without losses. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.

As an example you can see on Figure 3.10 a standard drive with five typical separate components: harmonic filter, power factor correction components, transformer, power converter and motor output filter.

Most modern VFD use an integrated design drive, which have only three components: the drive, an isolation transformer and a power converter. The simplicity of an integrated design results in a more straightforward system with fewer components, thereby increasing reliability and reducing downtime.

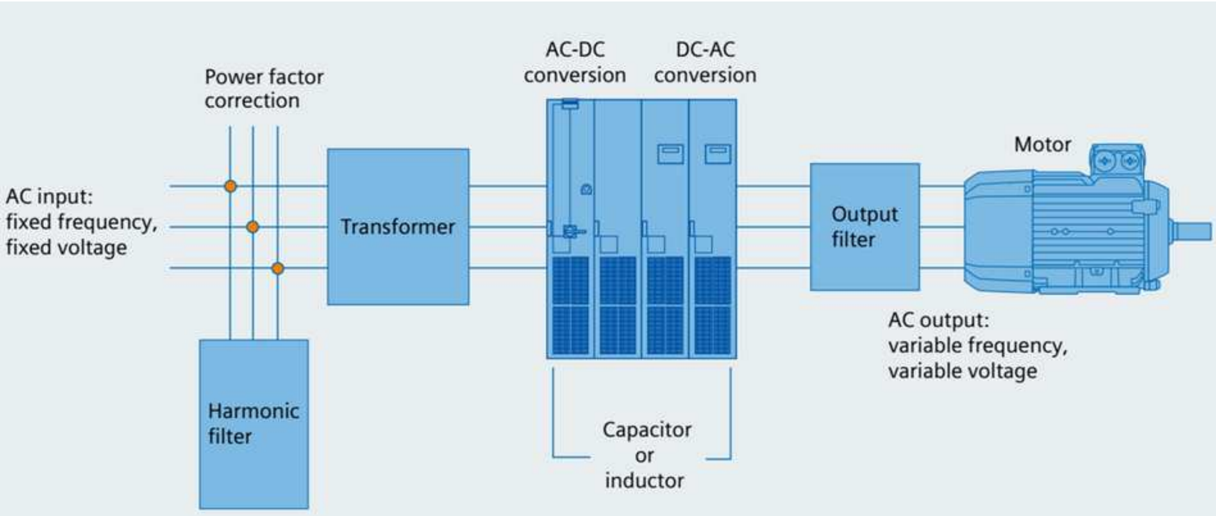


Figure 3.10 Typically required components in a medium voltage VFD installation

3.3.2 Efficiency of the electric drives

Efficiency of the electric drive is almost constant in the entire operating speed range of the unit and its dependence on the electric drive design output power is shown in Figure 3.11. In comparison with the high efficiency of the electric drive the thermal effectiveness with regards to electric power production is at the level of about 44 % (see Figure 3.12). The thermal effectiveness of the latest Turbo Packages reach the value 41% in ideal conditions, see Figure 3.2. In such a comparison the fact that the losses, which cause lower efficiency of the Turbo Package in comparison with the Electric Package, occur in case of electric power in a comparable amount in the process of production of electric power and thus they have already been included in the price of electric power.

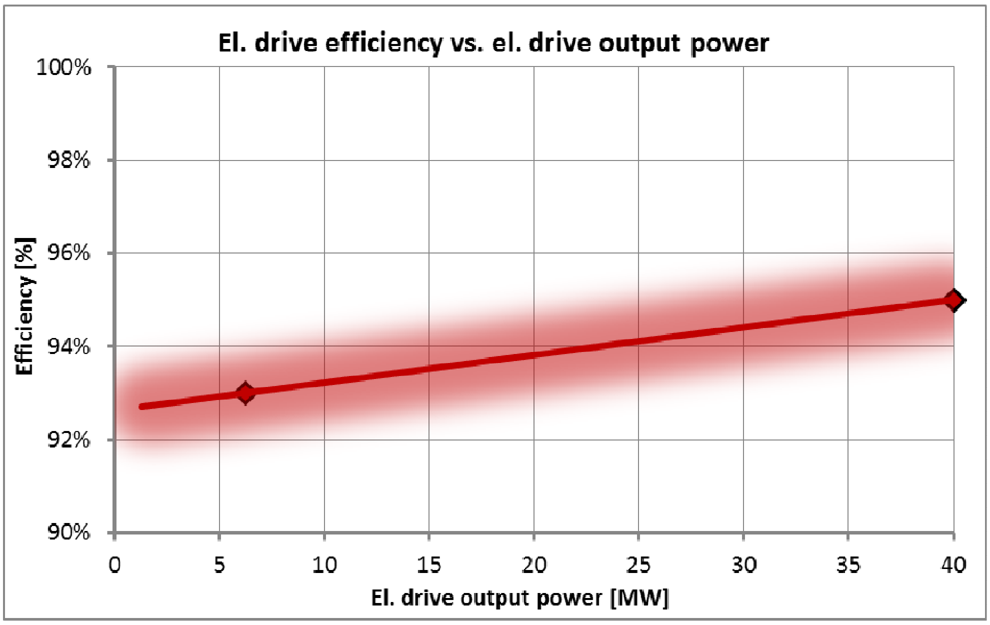


Figure 3.11 Dependence of the el. drive efficiency on the output power

The fees for produced emissions are a similar case. In case of Electric Packages this factor has also already been included in the price of electric power. A necessity to plan the operation in order to buy electric power could be the main disadvantage of Electric Packages. On the other hand, the operation of the Electric package under Smart Grid conditions may increase the flexibility in this respect.

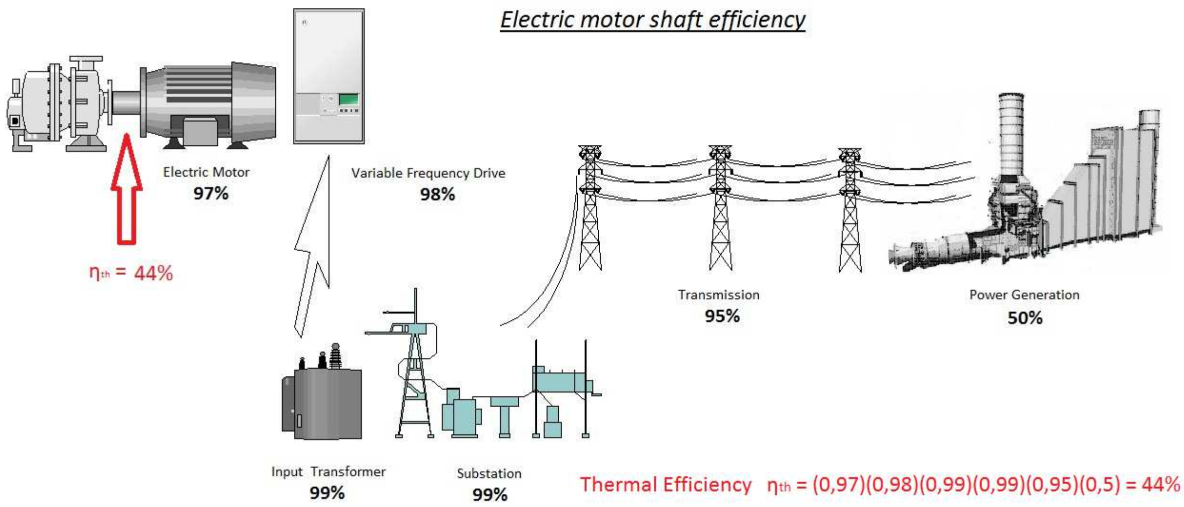


Figure 3.12 Thermal effectiveness of the electric drive

3.3.3 Flexibility with regard to operation, Smart Grid conditions and the comparison of the Electric package vs. Turbo package

In the perspective of appropriate mix of gas and renewables and electricity is needed to analyse how the energy consumption in the gas industry is and can become a part in the necessary balance between electricity production and consumption. Electric power must be used when produced. Only very limited electric storage is available, variable or interruptible electric loads are required to balance the production. Variable load is the basic requirement in a Smart Grid. Smart Grid is an electric power term, it is so to say the electric contribution to the universal Smart Energy system which is capable of varying the loads and also shift energy carrier between for example natural gas and electricity. Gas compression is a prerequisite for large scale gas usage. Conventional gas storage and line-pack facilitates the dynamic load balance when utilised in a Smart Energy system.

Forecasts on power production / load are reliable. However, variable loads are required and gas industry could be an important partner when it comes to harvesting the potential sustainable electric power generation.

The main points connected with this Chapter were the following:

- availability of electric power at the relevant locations;
- environmental issues;

- operation of an electric drive in under Smart Energy/Grid system;
- compressor size for electric drives;
- costs comparison.

the abbreviations DOC and N/A mean the following in the figures below:

- DOC=depends on a case
- N/A= not applicable

3.3.3.1 Availability of electric power at the relevant locations

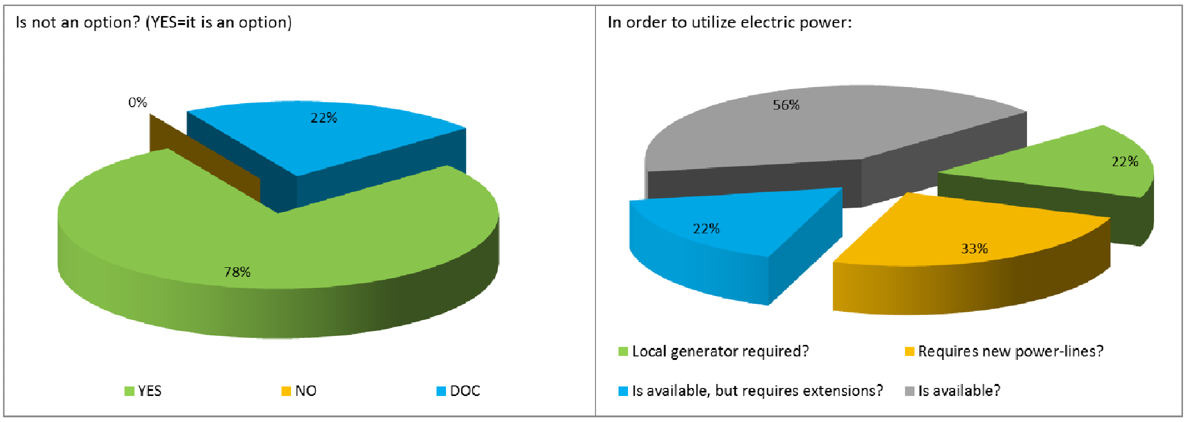


Figure 3.13 Availability of electric power

Electric power is available at 78% of the relevant locations. It is directly possible to use the electric power at 56% of these locations. New power-lines are required at 33%, extensions of the power system are required at 22% and a local generator is required at another 22%.

3.3.3.1 Environmental issues

The majority, 67% answered that neighbour concerns does not influence the decisions regarding compressor drive. The remaining 33% answered that neighbour concerns does influence the decisions.

67% answered that there are no restrictions imposed at specific locations where climate, altitude, off-shore and sub-sea where mentioned as possible obstacles. 22% does have restrictions and 11% answered that this is not applicable.

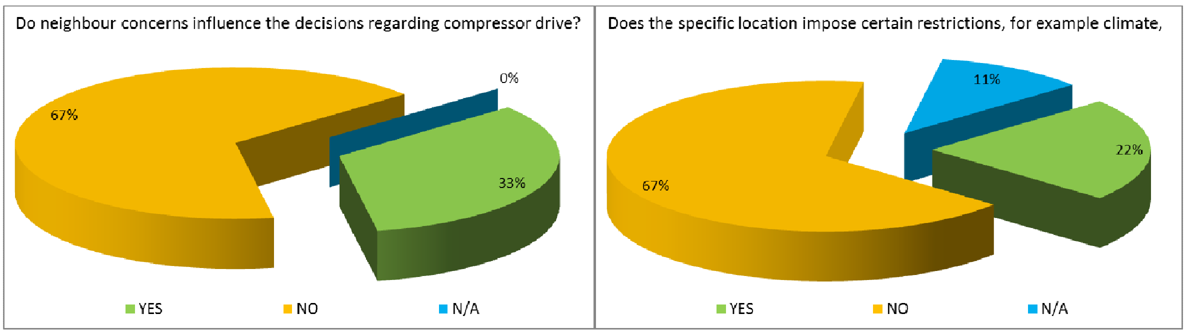


Figure 3.14 Neighbour concerns and the impact of specific location

3.3.3.1 Smart Energy / Smart Grid systems

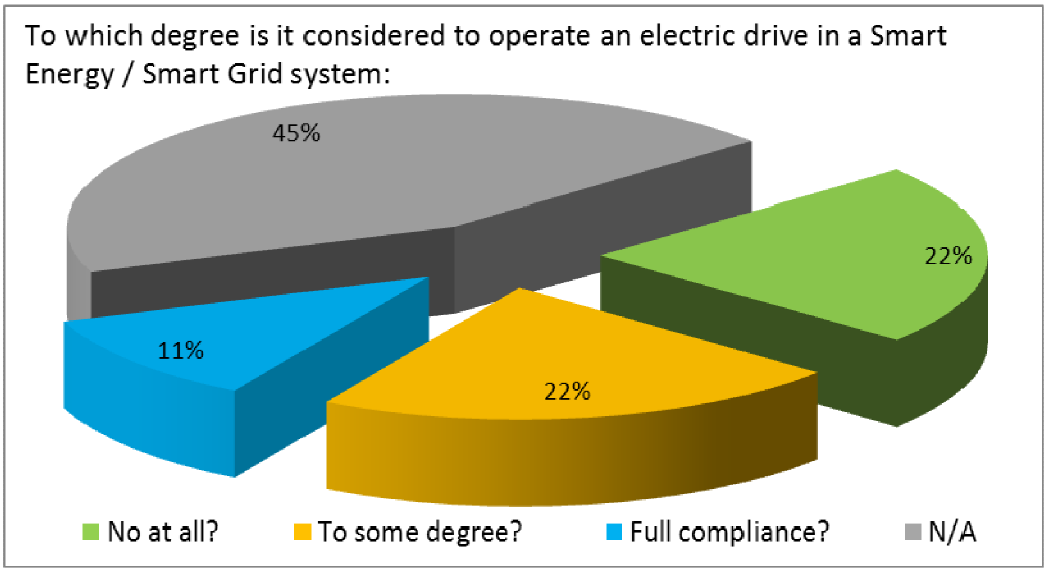


Figure 3.15 Operation in Smart Energy/Grid system

45% answers that operating an electric drive in a Smart Energy / Smart Grid system is not applicable, 22% answers that it is not at all considered, another 22% is considering it to some degree and 11% is aiming at full compliance with a Smart Energy / Smart Grid system.

Half of the 22% who to some degree considers to operate an electric drive in a Smart Energy / Smart Grid system is answering that they are specifically considering short time electric load changes for power grid stabilisation and the other half is considering electric load with focus on Gas storage planning and/or line pack planning.

The brief conclusion is that there is a growing comprehension of the possibilities when designing energy requiring installations and a mix of available energy carriers is taken into consideration. It seems that more attention on Smart Grid requirements is developed in regions where large or relatively large parts of the electric power are based on wind turbines. The same attention is probably maturing in the regions where photo voltaic based electric power is increasing.

3.3.3.2 Compressor size

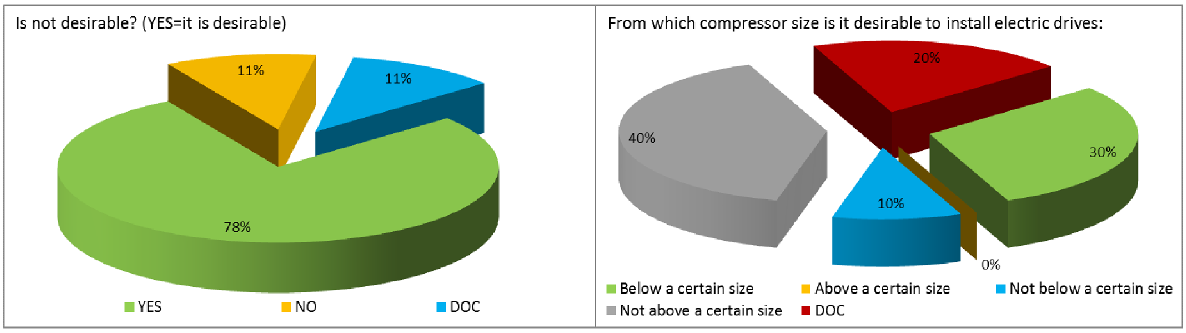


Figure 3.16 Compressor size of electrically driven units

The compressor size is a significant factor for electric drives. 78% answered yes to this question and there is for 70% a compressor size below certain size. For 10% compressor not below a certain size applies. For 20% the decision depends on the case; this has not been detailed further. The compressor size of approximately 20-25MW was mentioned in the responses.

3.3.4 Comparison of the electric drive vs. gas turbine drive

33% answered that an electric drive is less expensive with regard to purchase and 45% answered the opposite. Two equally large groups 11% each are using gas turbines or electric drives only and does hence not have a reference for comparison.

The question concerning installation cost returned the exact same pattern 33% less expensive, 45% more expensive and the 2 x 11% does not have a reference for comparison.

45% answers that operation of an electric drive is less expensive and 22% answered the opposite. 11% answers that it depends on the case and the 2 x 11% does not have reference for comparison.

All answers (78%), except for the 2 x 11% who does not have a reference for comparison was yes, an electric drive is less expensive with regard to maintenance.

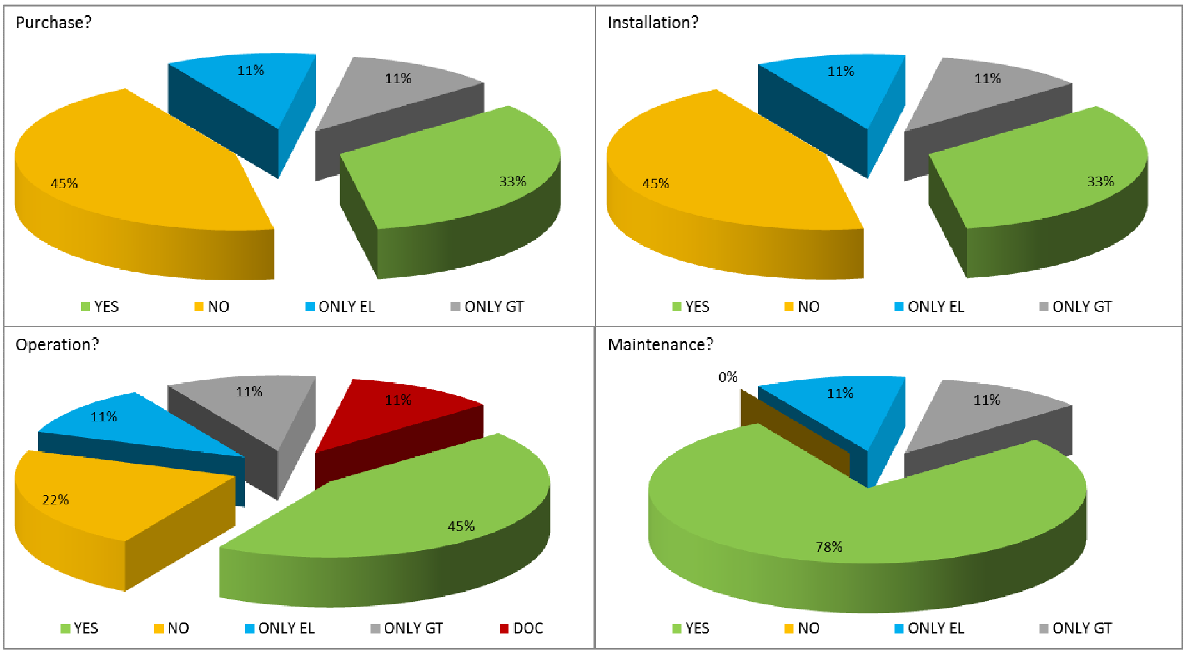


Figure 3.17 Costs comparison of the electric drive vs. gas turbine drive

The comparison of cost for purchase, installation and operation of electric drive versus gas turbine drive seems to reflect a general impression/experience that maintenance (78%) and operation (45%) of an electric drive is less expensive, but purchasing and installing an electric drive is more expensive (45%). It is however not clear if these 45% are including additional costs as power lines or transformer stations, as 33% answers that an electric drive is less expensive to purchase.

The Table below provides a summary of advantages and disadvantages of both alternatives of a compressor drive.

Parameter	Electric package	Turbo package
Thermal effectiveness	around 44%*	up to 41%*
Dependence of effectiveness on air temperature	None	High
Reliability	High	Medium
Operation availability	High	High
Emissions	None, but included in the price for el. power	Emission fees
Speed operating range	Big	Limited
Speed regulation dynamics	Very high	Medium
Torque regulation dynamics	High	High
Rated parameters onset time	A few seconds; quick onset	A few minutes (10 – 15 min)
Maintenance costs	Low	Medium
Noise level	Low	Medium
Impact on power supply network	Minimum	None
Operating point of the compressor is limited by technology limits and drive conditions	No limitations by drive conditions	Slight limitations by drive conditions
Availability of technology	Subject to purchase of el. power. High prices in case of unplanned operation.	Immediate

Table 3.1 Electric package vs. gas turbine package

(*informative values)

3.4 Increasing of the operational flexibility of the compressor units

Purpose and target of the project which was implemented in the transmission system operated by Eustream is to increase the natural gas transmission effectiveness by installing two new turbo-sets equipped by tandem compressors with compression ratio 1.08 – 1.50. The turbo-sets meet emission limits NOx 75 mg/m3 and CO 100 mg/m3 at power output extent of 70% at least up to 100% of the nominal power output in a dry way. The tandem design of each turbo-sets must enable operation of its compressor part in serial and parallel operational mode as well by means of interconnection of its hydraulic distribution pipelines. Major characteristics of the project is described in Chapter 3.2.1

Each turbo-set includes gas generator, power turbine, driving two compressors arranged in tandem and connected with shaft. Each of the four compressors have been supplied with Variable Inlet Guide Vanes (VIGV) on the intake to allow the compressors to operate at lowers flows without approaching the surge profiles of the compressors. The project is strongly focusing the expected operation of transmission system of Eustream into the future where high flexibility of efficient operation is required.

The two compressors on one shaft can by operated in both serial (high pressure ratio and low flow rate) and parallel (low pressure ratio and high flow rate) mode:

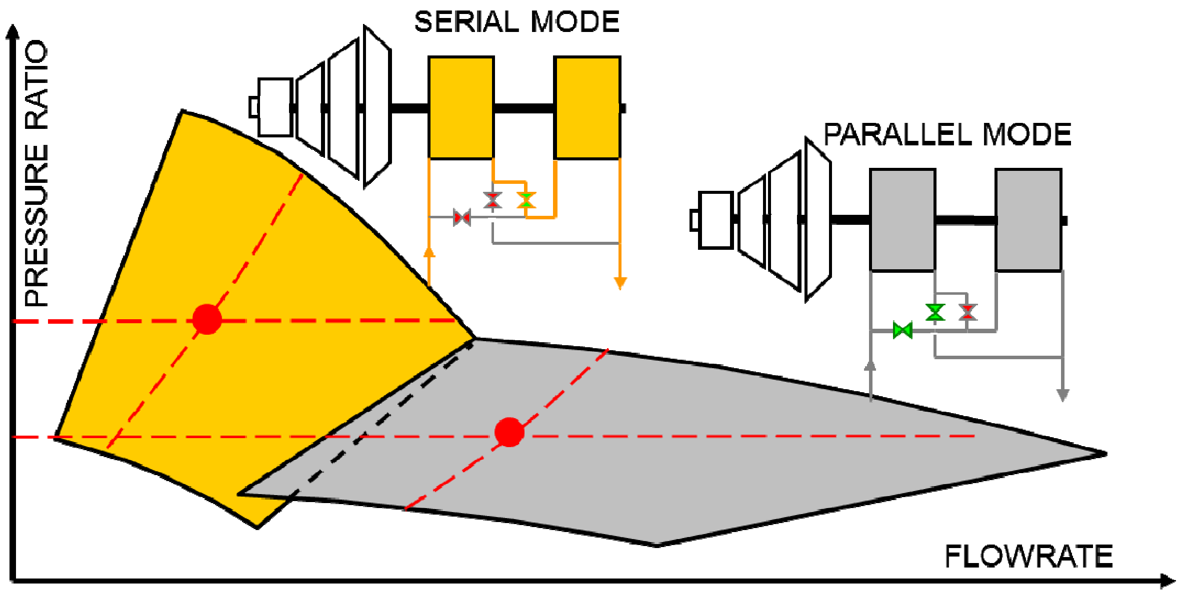


Figure 3.18 Scheme of the tandem compressor arrangement

The VIGV control system for the compressors is positioned automatically by the unit controls system. There are two modes of the VIGV operation:

- Operator-Assisted
- Automatic.

There are two VIGV positions:

- Radial for normal and higher flow operations
- Pre-Swirl for lower flow operation only

In Automatic mode, the control system will determine the operating point location relative to the surge limit of the compressor and will select between the Radial and Pre-Swirl VIGV positions. VIGV system will operate without intervention from operator. Both compressors will operate in either Pre-Swirl or Radial. Both compressors VIGV systems will operate without intervention from operator. The VIGVs will minimize the compressors from operation with recycle. At low flow operations the VIGVs will move to the Pre-Swirl position which in turn, moves each compressor’s surge limit to the left and towards lower flow.

This possibility increases the flexibility of the unit performance, because this switching moves the whole performance map from right to left.

Taking into account the operational modes:

- Serial + VIGV Radial
- Serial + VIGV Pre-swirl
- Parallel + VIGV Radial
- Parallel + VIGV Pre-swirl

it is possible to cover the whole operational area of the compressor station with high flexibility of efficient operation. The whole concept of operation including the optimization of the performance maps was developed by internal specialists of Eustream.

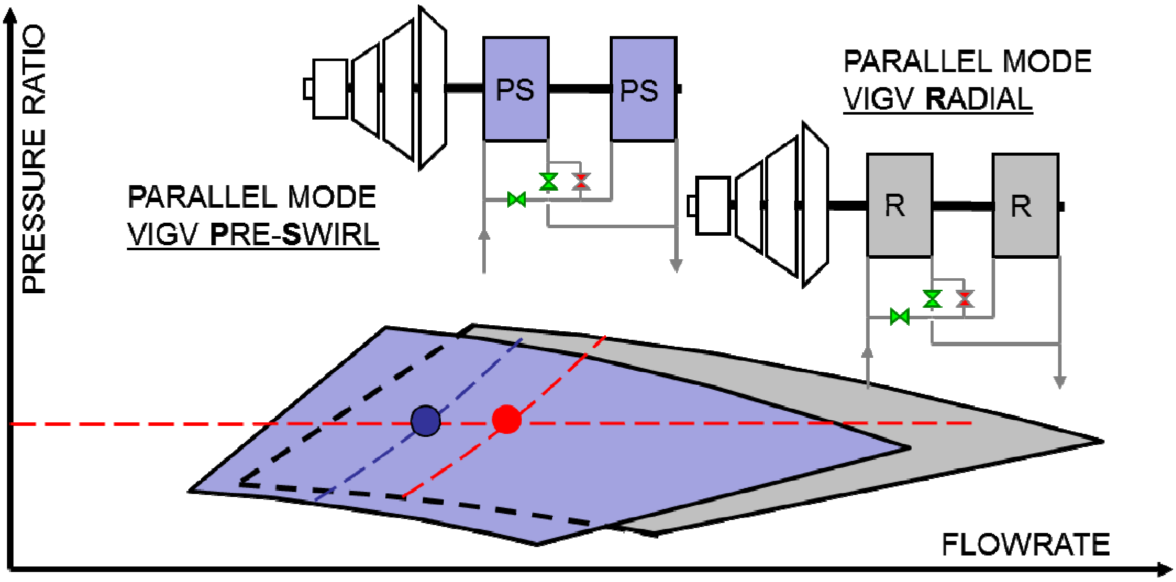


Figure 3.19 Influence of the VIGV on the performance map flexibility

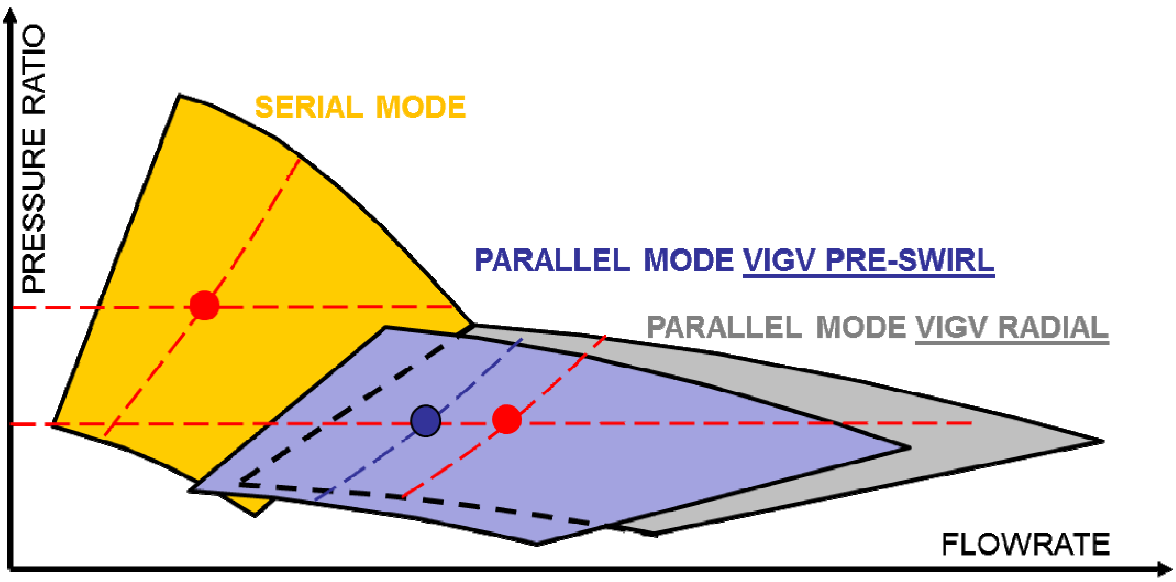


Figure 3.20 Increasing of the compressor performance map flexibility

3.5 Gas turbine emissions decreasing

(see Annex 2 and Annex 3 for detailed information)

NOx is the main pollutant species produced by gas turbines, and its reduction is the primary objective of the emission reduction technologies developed. In addition to the technologies developed to reduce emissions at the engine level, in particular within the engine combustion system, there are technologies which implement pollutant abatement at the engine exhaust system (Selective Catalyst Reduction Systems).

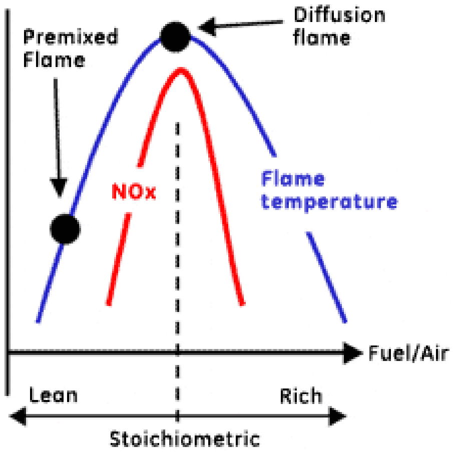


Figure 3.21 NO_x production rate

On the Figure 3.22 are shown the technologies which are applied for emission decreasing at gas transmission systems:

- DLE – dry low emissions;
- DLN – dry low NOx;
- ELE – electric drive is utilized;
- N/A – information was not provided.

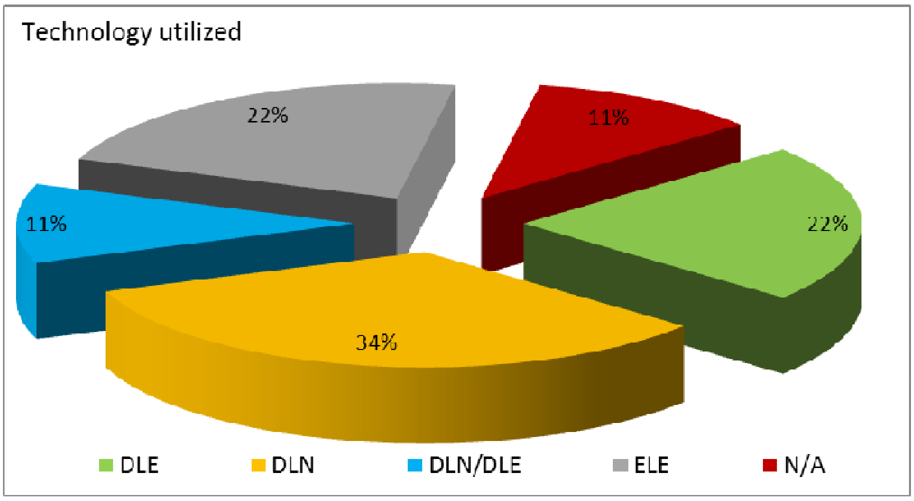


Figure 3.22 Technologies utilized to reduce emissions

The experience of the Eustream company (Slovakia) with the modification of four LM2500 based gas turbines from Single Annular Combustor (SAC) to Dry Low emission (DLE) system is described in this Chapter. In connection with that also the main overview of the

DLE system of LM2500 base model from the manufacturer GE Oil & Gas is included in the paragraphs below (see Annex 2, http://site.ge-energy.com/businesses/ge_oilandgas/en/techinsights/pdf/retrofittability-dln-dle-systems.pdf for the details).

3.5.1 Gas Turbine Combustion systems

The gas turbine combustor is the device that provides thermal energy to the engine thermodynamic cycle by a combustion reaction. The combustion in a gas turbine is a continuous process and needs to be maintained stable over a wide range of operating conditions, e.g., air fuel ratio, pressure, reactant temperature and reactant composition. The fuel is burned with a large amount of excess air to keep the turbine inlet temperature at an appropriate level.

Gas turbine combustion systems can be of two types:

- Diffusion
- Premixed

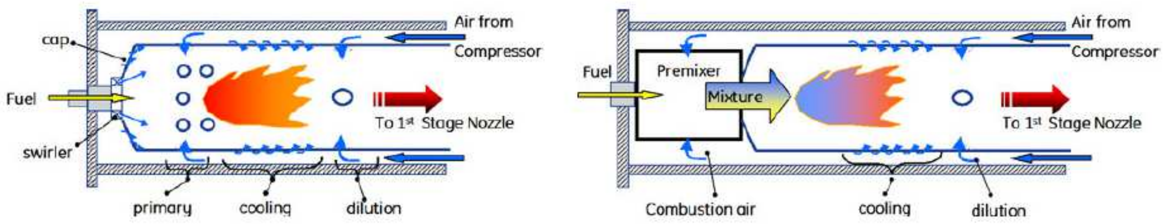


Figure 3.23 Diffusion combustor (left side) and premixed combustor (right side)

In diffusion combustors fuel and air are injected separately into the reaction zone, the reactants combine by a diffusion process and as a result, the flame speed is limited by the rate of diffusion. These combustors were the standard until about 30 years ago. The geometry is relatively simple and can be regulated very easily, thanks to the capability of diffusion flames to sustain stable combustion over a wide range of fuel/air ratios.

The main drawback of diffusion combustors is the difficulty in controlling NOx emissions. As shown in Figure 3.23, the primary parameter affecting NOx formation is the reaction temperature, which is strongly dependent on the fuel/air ratio. In these combustors, due to the diffusion process, the reaction stabilizes in stoichiometric regions where the temperature and consequently, NOx formation, are high (Figure 3.21).

In this system, NOx reduction is possible by injecting steam or water. The injected diluent provides a heat sink that reduces the combustion zone temperature. As the combustion zone temperature decreases, NOx production decreases exponentially. The main drawback of these traditional systems is that they require large quantities of water that often are not available, especially in oil and gas applications.

To overcome this limitation of diffusion combustion systems, DLN systems with premixed combustion were introduced for gas turbines (Figure 3.23).

In DLN systems, the fuel and the air necessary for combustion are mixed together prior to being injected into the reaction zone (Figure 3.23). Thus, the fuel/air ratio at which combustion occurs can be controlled and the flame temperature reduced by lean combustion to achieve a very low level of NOx production.

To obtain low NOx without blowout and high CO, the fuel/air ratio must be maintained within a relatively narrow range. Since from ignition to full load, the overall fuel/air ratio of a gas turbine varies much beyond the optimal range of a premixed flame, the implementation of special control and operating mode strategies is necessary. In the following, the possible strategies and associated combustor configurations are described:

- Hybrid chamber - this chamber is able to operate in both diffusion and premix modes. Transient states accompanying ignition and startup occur in the diffusion mode. Starting from a sufficiently high load value, when the fuel/air ratio is able to sustain a stable premixed flame, the combustor switches to the premix mode.
- Variable geometry - this chamber is equipped with a device, which varies the distribution of air within the chamber in relation to the load to control the fuel/air ratio in the combustion zone. This method handles partial load operation without any problems and has, in principle, no contra-indications. Its application is quite simple for turbines equipped with a single can combustion chamber but is mechanically more complicated for multi-can and annular combustion systems.
- Multiple burners - the load is divided among a number of burners, each of which can operate independently of the others. At partial load, some of the burners are extinguished. One advantage of this system, which operates only on the fuel, is the absence of moving parts.

3.5.2 DLE Combustion systems

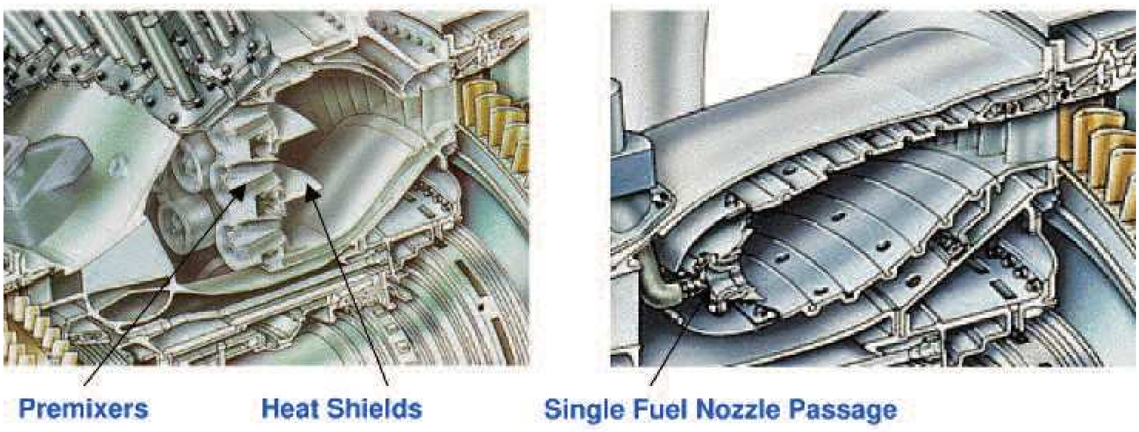


Figure 3.24 DLE (Triple Annular Combustor) vs. Single Annular Combustor (SAC)

The original LM2500 gas turbines operated with a standard annular combustor that utilized a single compressor diffuser passage and a single row of 30 fuel nozzles, and NOx emissions abatement was accomplished with water or steam injection to suppress the firing temperature and reduce the formation of NOx. In 1995, a Dry Low Emissions (DLE) combustion technology was introduced to achieve 25 ppm NOx emissions without water or steam injection. The DLE combustor uses 30 premixers comprised of 75 staged injectors and a 4-passage compressor diffuser.

The LM2500 DLE gas turbine can achieve 25 ppm NOx and 25 ppm CO from 75% to 100% load. The SAC and DLE Combustors are compared in figure Figure 3.24.

3.5.3 Retrofit

All the gas turbines produced by GE Oil & Gas are retrofitable with an emission reduction system. For the engine models still in production, the emission targets are the same as the new units, but older machines can. In most cases, also be retrofitted with a Dry Low Emission combustor. As for new unit applications, it is necessary to analyze the fuel gas composition to verify that the DLE combustion parameters are satisfied.

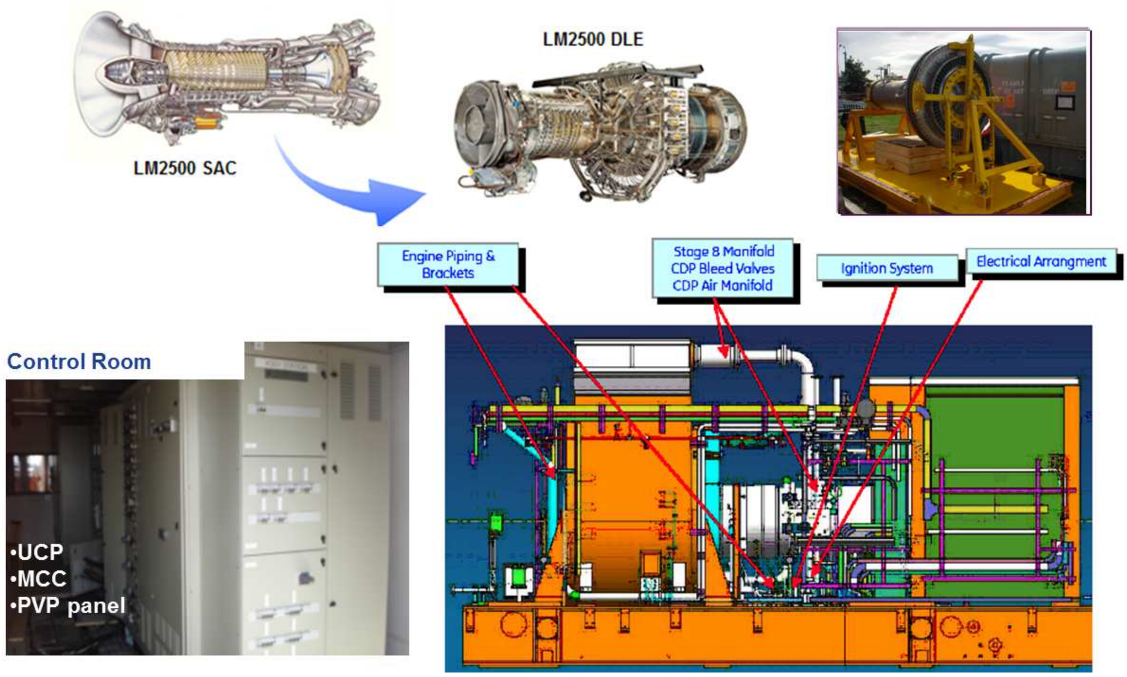


Figure 3.25 Main scheme of the modification

The items involved in the gas turbine package modification depend on a number of factors, the main ones being the following:

- New gas generator
- Power Turbine refurbishment
- Enclosure / ventilation configuration
- New fuel valves, piping & instrumentation
- New Unit Control System Mark Vie&MCC
- New bleed line and valve
- Gas chromatograph
- Minor Package Modifications

In the project at Eustream company the contractor was responsible for the design, coordination and management of subcontractors in full extent of the deliveries for all four turbo packages. The scope of services contained, among other, the following:

- Design and engineering
- Documentation elaboration
- Obtaining of building permit and change the Integrated Preventive and Pollution Control)
- Certification
- Preparation of reports
- Inspections and tests at the factory
- Packing and transport
- Establishment of SITE, installation and assembly
- Testing at SITE, COMMISSIONING and startup

The scope of the delivery was realized on four units at the following compressor stations:

- CS01 Veľké Kapušany: 1 unit
- CS03 Veľké Zlievce: 2 units
- CS04 Ivanka pri Nitre: 1 unit

The designed lifetime of the TURBO-SET after modification should be minimally 20 years, or minimally 170 thousand running hours under the specified maintenance cycle.

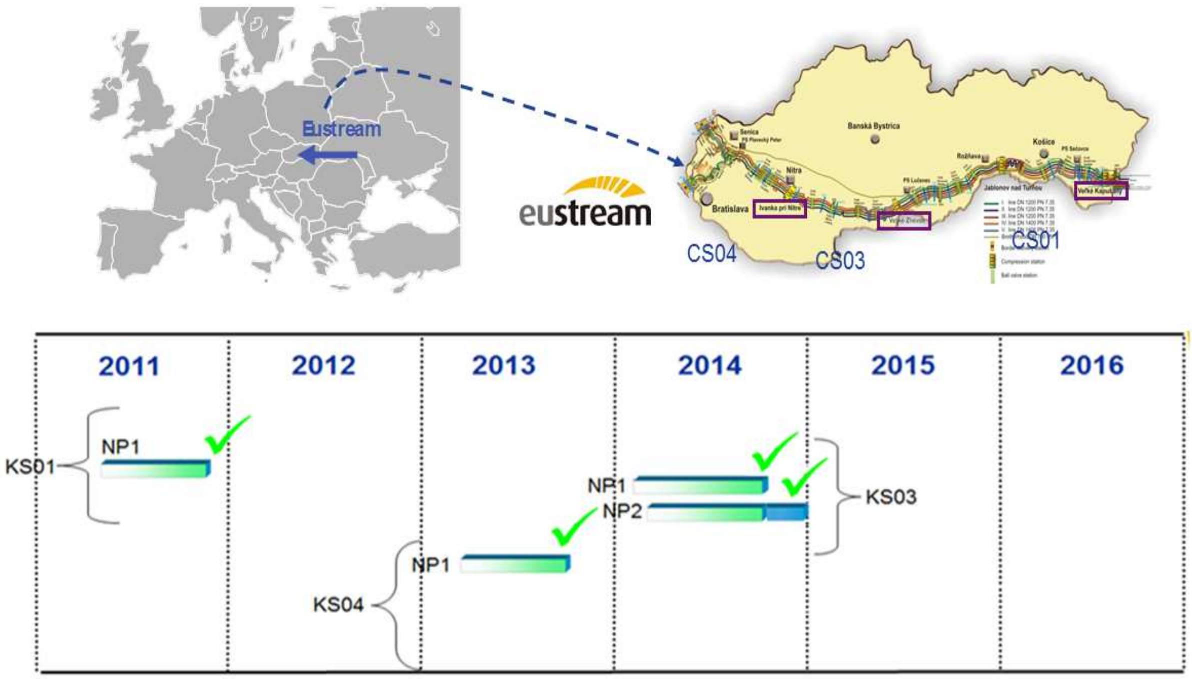


Figure 3.26 Time schedule of the modifications

There is a time schedule of the modification in Figure 3.26 and there is comparison of the planned schedule and the real progress on site for particular units in Figure 3.27, Figure 3.28, Figure 3.29 and Figure 3.30.

The acceptance tests were completed successfully, guaranteed parameters were met and the project was finished in line with the schedule. As it is shown in Figure 3.30 the last modification was finished 3 months ahead of the schedule as a result of the highly efficient optimization of the construction works on site.

Figure 3.27 Time schedule vs. real progress at CS01

Figure 3.28 Time schedule vs. real progress at CS04

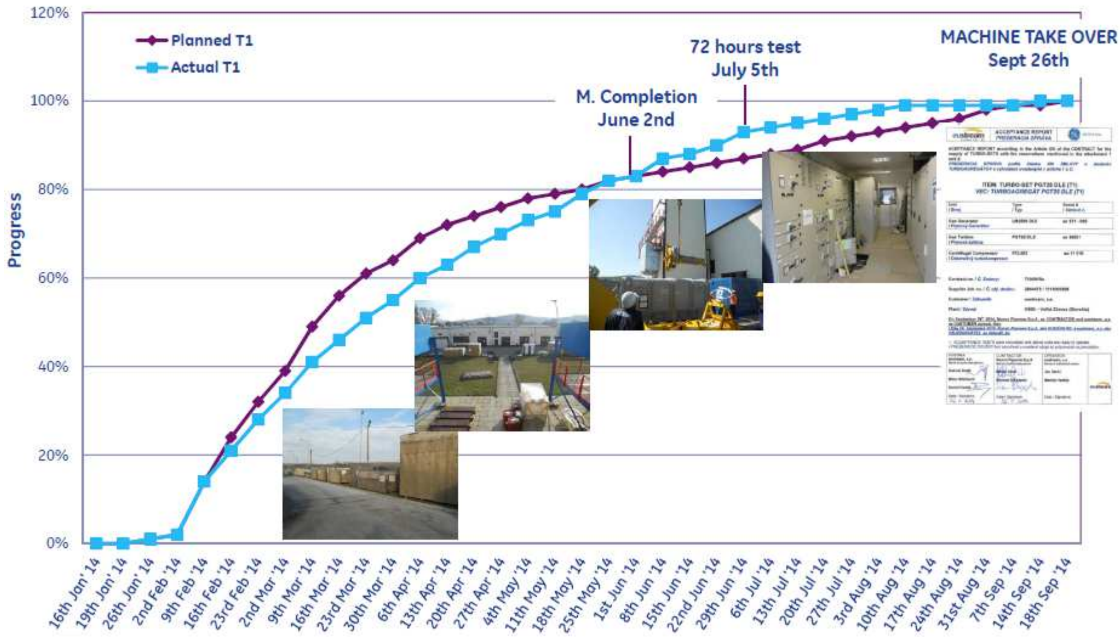


Figure 3.29 Time schedule vs. real progress at CS03, unit No.1

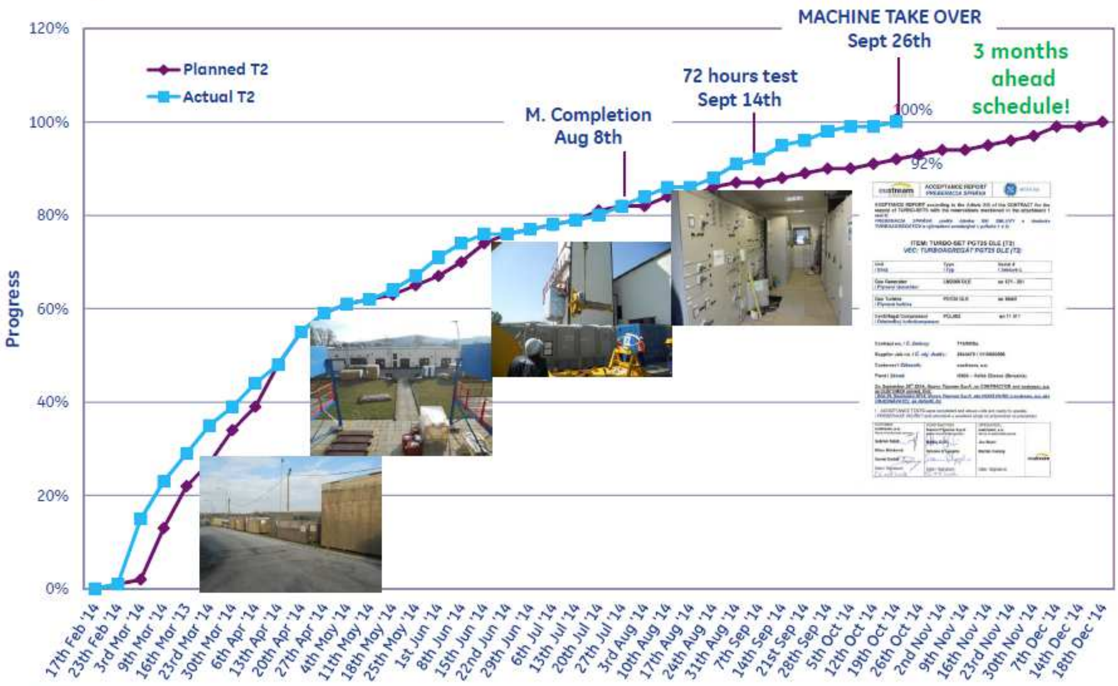


Figure 3.30 Time schedule vs. real progress at CS03, unit No.2

3.6 Gas compressors performance optimization

3.6.1 Distribution of the total power to the particular units in the compressor stations and the backup philosophy

The key requirement of the compressor station is to cover the whole expected operational range of the transmission system on the continuous base. This requirement also puts emphasis on the parallel cooperation of compressor units in the compressor station in connection with the usable operational range. When compared with the full compressor map, e.g. the dry low emission system (DLE) has a limited effective area of operation. This area is usually guaranteed at the loads higher than 70% - it depends on the technology and manufacturer. This issue leads to narrowing the operational area of the compressor unit as shown in the Figure 3.31.

The minimum power in connection with DLE system adds a new restriction in the compressor performance map and the usable area of compressor is determined by the following lines:

- A - Maximum power at ambient temperature
- B - Minimum power based on DLE technology
- C - Surge line
- D - Choke line
- E - Maximum compressor speed
- F - Minimum compressor speed

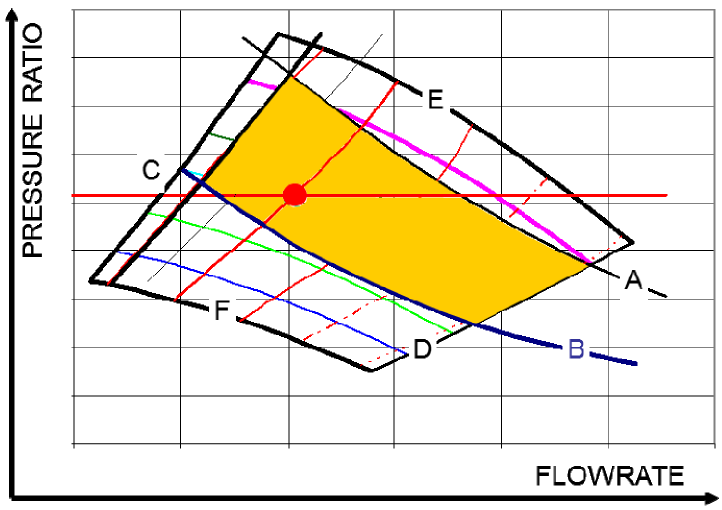


Figure 3.31 Real usable operational range of compressor unit

The net usable area of a compressor has to be included into overall optimization process. The parallel cooperation of the compressor units in the compressor stations should be optimized to cover all expected operational regimes without any empty space – see Figure 3.32. Any empty space represents an area where the compressor station is not able to cover the system requirements on the continuous basis.

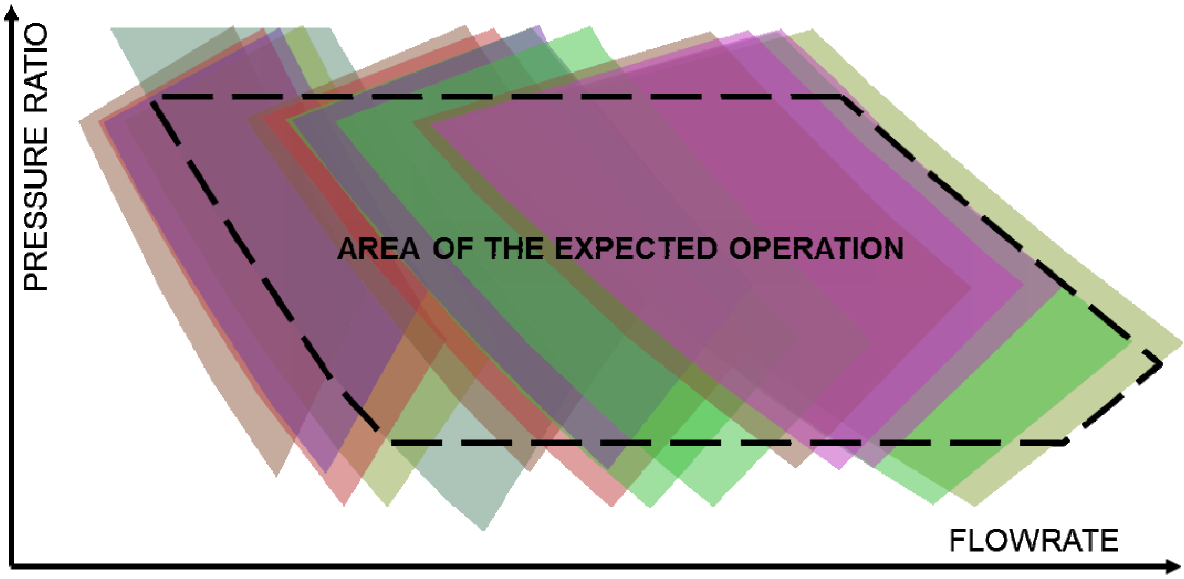


Figure 3.32 Parallel cooperation of compressor units in compressor station

The backup philosophy is a very important factor, which affects the total configuration of the compressor station. Different compressor station installations have been analysed within the working group and the result is provided in Figure 3.33. The most compressor station installations (47%) use the backup method 2+1B (one backup machine for 2 machines in operation) and the least applications (12%) are with the N+1B backup (only one backup machine for all machines in operation). The backup system 1+1B is used in 23% cases and the method 3+1B is applied in 18% of the compressor station installations.

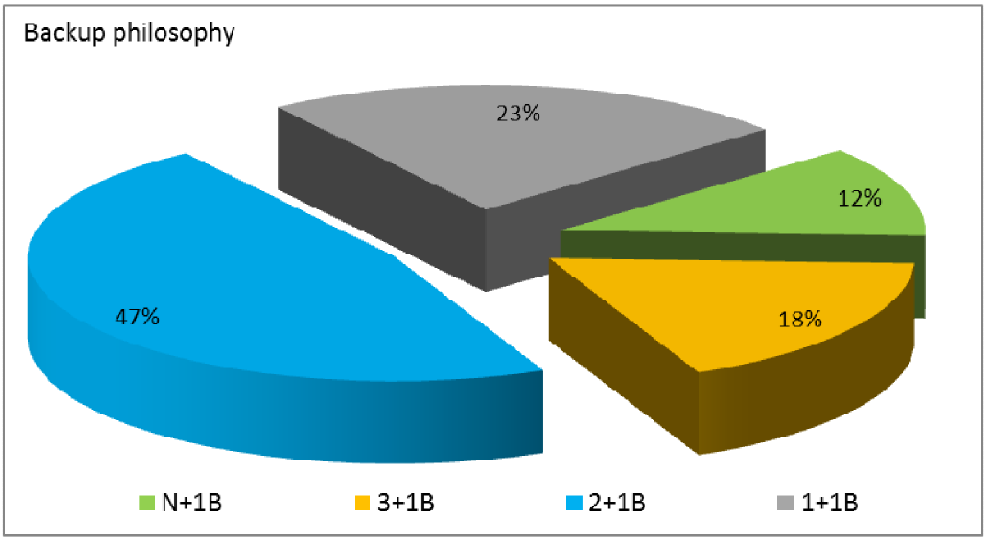


Figure 3.33 Backup philosophy of compressor stations

3.6.2 Efficiency of the gas compressors and the efficiency of the package

In terms of efficiency of the installed compressors we can say that the average efficiency of the analyzed installations is 81.6%. If we consider the installation year of the assessed compressors (Figure 3.8), this result is really positive.

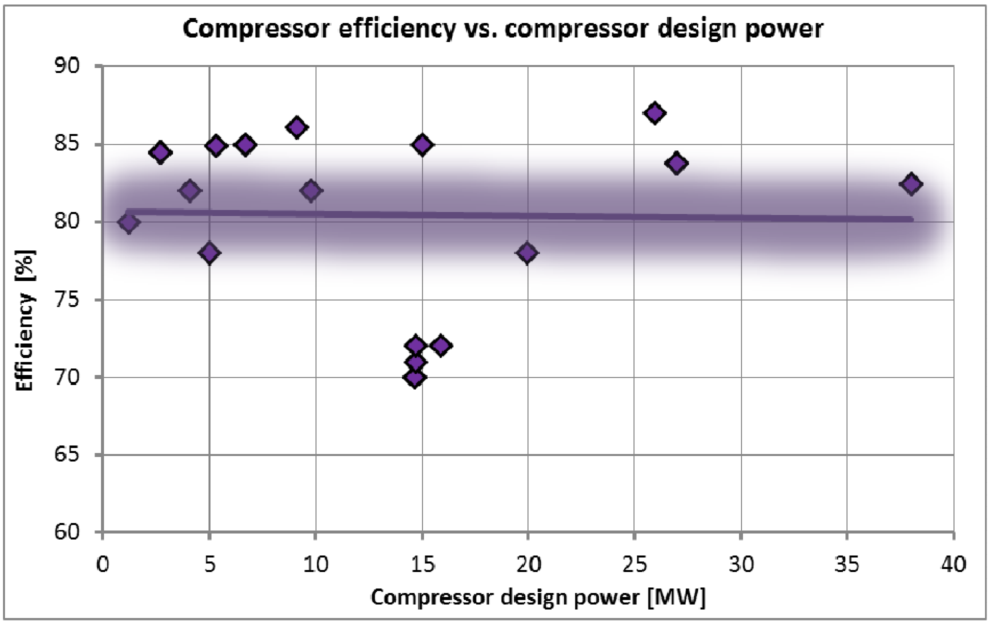


Figure 3.34 Dependence of the compressor efficiency on the design power

As Figure 3.34 shows the efficiency of the compressors is constant in fact and it is almost independent of the installed power of the compressor. If we compare this result with the course of the gas turbine efficiency (Figure 3.2) we can see that the total efficiency of the compressor unit plus the gas turbine depends on the size of the installed power of the gas turbine (Figure 3.35, the lower blue curve).

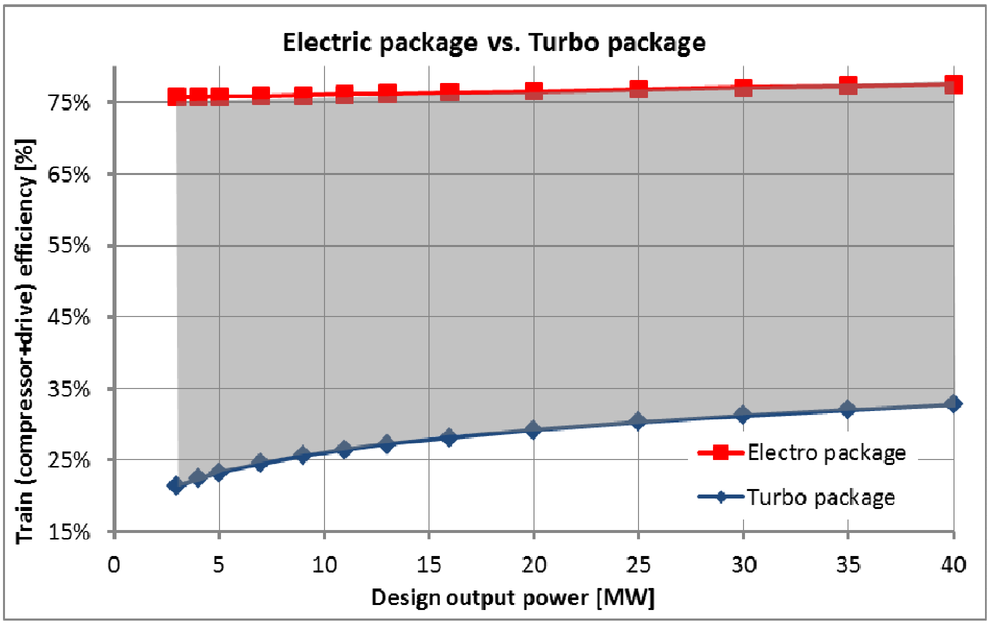


Figure 3.35 Comparison of the installation efficiency

In case of the electric-motor drive the course of the efficiency is roughly constant (Figure 3.11) and the total efficiency of the compressor unit plus the electric drive is little dependent on the value of the installed power of the compressor and of the electric motor (Figure 3.35, the upper red curve).

Comparison of efficiency of both drives (Figure 3.35) shows significantly higher efficiency of the electric drive from the point of view of the installation and the difference is more significant with lower power.

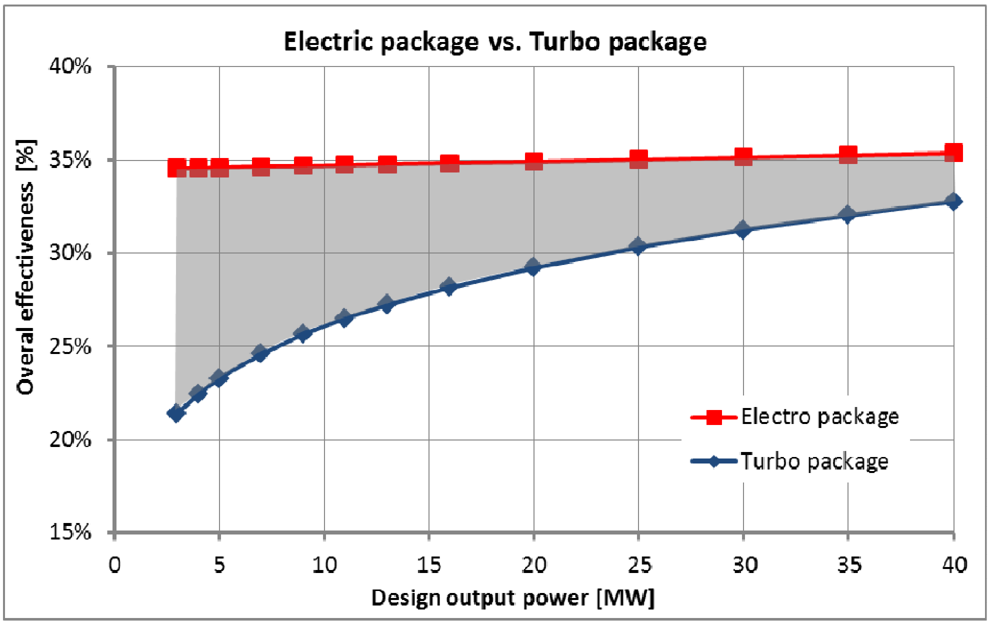


Figure 3.36 Comparison of the overall effectiveness

If we compare thermal efficiency of both alternatives of a compressor drive (Figure 3.36) having taken the total efficiency of electric power generation into consideration (Figure 3.12), the differences in efficiency are smaller. Despite that the difference is still significant especially with lower power and the electric drive benefits from high efficiency of electric power generation in power plants with high installed power. In order to decide on the economic convenience of either alternative it is always important to take the current price of particular commodities into consideration (el. power, gas, CO_2) and the supporting documents may be used as a technical input for preparation of a complex analysis in this area.

3.6.3 Main design factors of analyzed installations

One of the main goals of the performed analysis was to identify the main parameters which could be used in optimization of the design of the machines in newly installed compressor stations.

We focused on the following parameters in the analysis:

- compression ratio;
- compressor power;
- compressor power vs. compressor drive power.

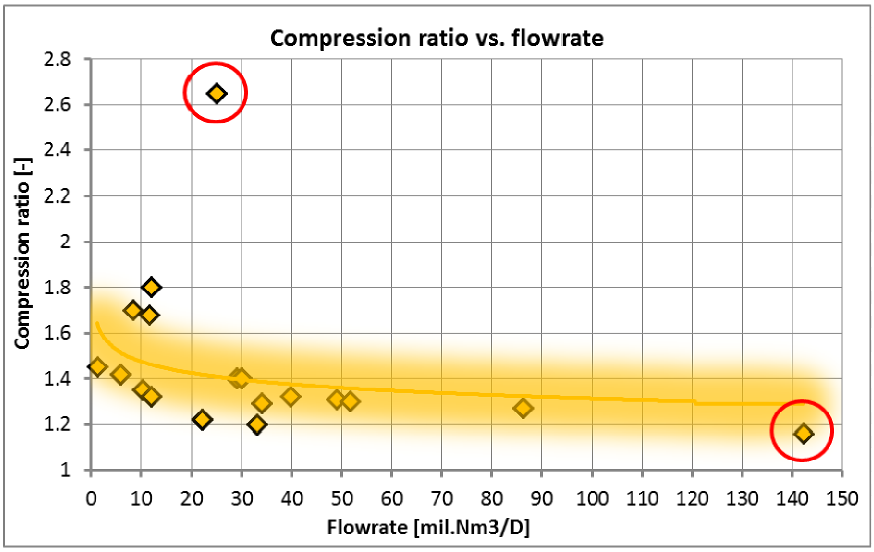


Figure 3.37 Dependence of the compression ratio on the flowrate

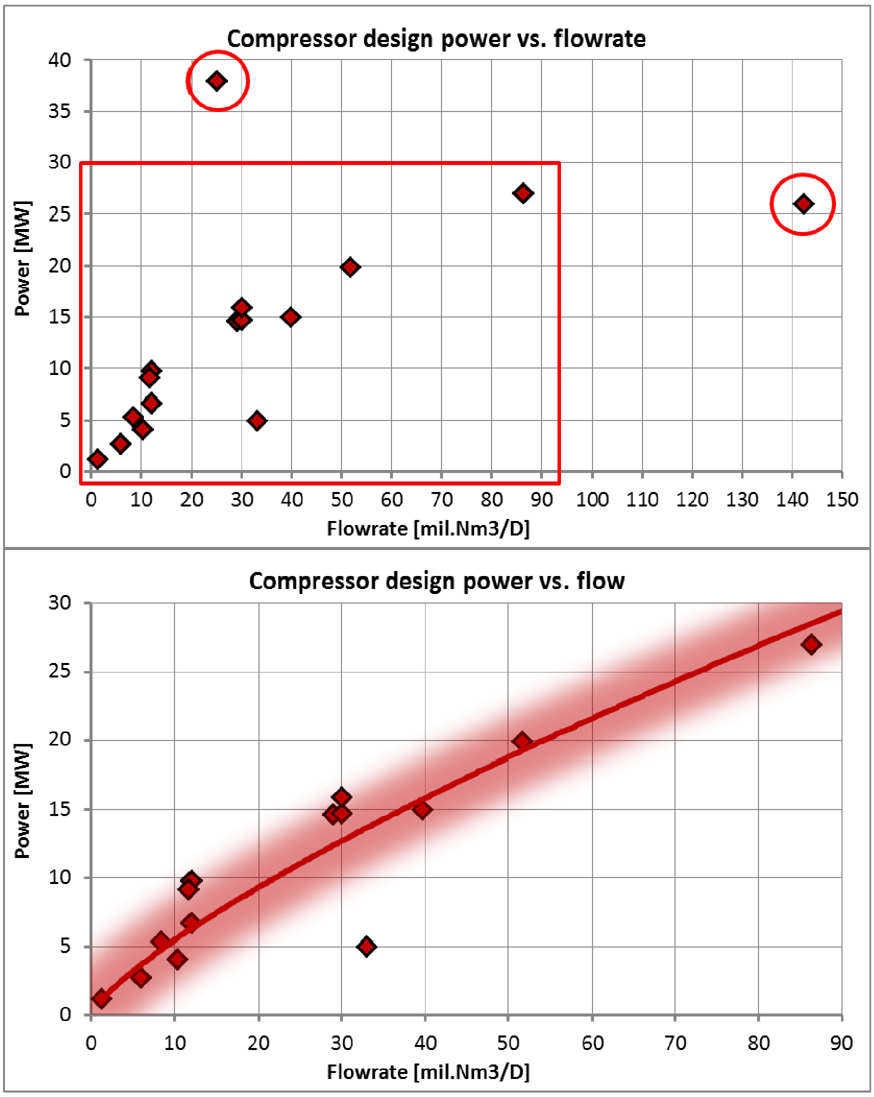


Figure 3.38 Dependence of the compressor design power on the flowrate

If we look at the dependence of the compression ratio on the compressor flow rate in particular installations (Figure 3.37), we can see higher compression ratios with lower flow rates and the compression ratio decreases with increasing flow rate gradually.

The dependence of the compressor design power on the compressor flow rate for particular installations is shown in Figure 3.38. The two installations significantly out of the plotted curve (in a red circle) represent special applications of compressor machines. If we compare Figure 3.37 and Figure 3.38, we can see that the former is marked by a high compression ratio (2.65) with quite a low flow rate and the latter by an extremely low compression ratio (1.16) with a high flow rate.

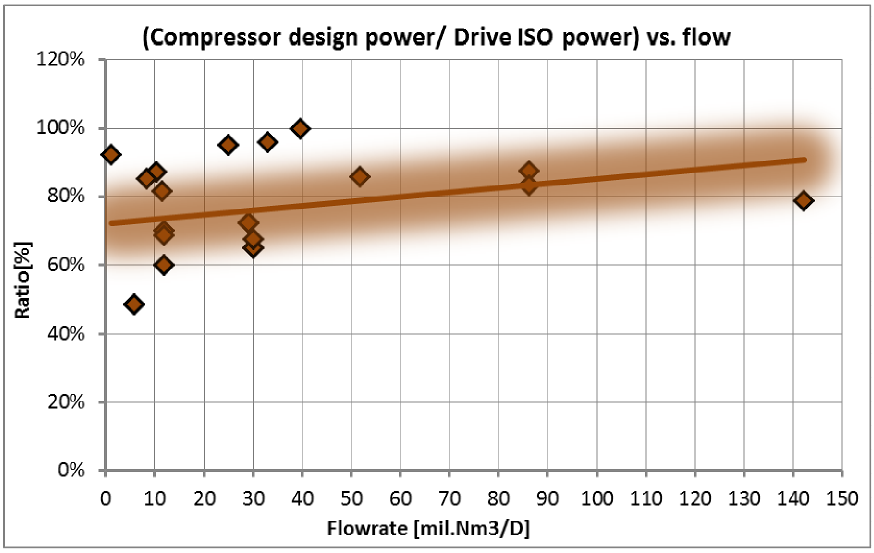


Figure 3.39 Dependence of the compressor/drive ISO power ratio on the flowrate

The ratio of the compressor design (required) power and the compressor drive ISO power stated at a reference ambient temperature 15°C is also very interesting information (Figure 3.39). The above mentioned ratio is affected by several factors and the temperature of air at the installation point is one of them. If there are significant differences in the ambient temperature during operation of the compressor which uses a gas turbine as a drive (e.g. summer/winter), then the worst conditions as usually used to set maximum technical capacity of the transit system (to be on the safe side). In case of the temperature of air that means especially higher temperatures (e.g. in hot summer days), when the gas turbine achieves significantly lower power. That should be taken into consideration already in the design, and the ISO gas turbine power (i.e. with reference temperature 15°C) should be designed so that it can achieve the power which should be delivered to the compressor also in high temperature of air (e.g. 30°C). Of course that leads to higher required power in ISO reference conditions.

Chap. 4 Optimization of the gas transmission systems performance

The basic elements for optimization and development of the transmission systems from a long-term perspective are in general the hydraulic simulations, which are used to obtain a broad spectrum analysis of the transmission system performance. An essential requirement for coping with this complex issue is to have a precise mathematical model that captures the physical essence of the flow of the transmitted medium – natural gas.

At the present time, several commercial programs intended for making gas calculations apply various physical models for flow and different methods for their mathematical solution. The most accurate model is the complete four-equation model of nonisothermic gas flow – equation of continuity, momentum, energy and state. For numerically resolving these mutually interlinked equations, the outcome of which shows the course of the four basic values of pressure, temperature, density and gas flow velocity.

In addition to the geometrical values of the pipeline (length, diameter), consideration is also given to the influence of elevation, roughness of pipeline (impact on pressure drop) and the state equation for real gas on precisely said determined four basic values. The module of thermal dynamics also calculates the transfer of heat between the pipeline and its surroundings and the Joule-Thomson effect. Calculation of the parameters of compressor stations is based on detailed compressor model and includes a detailed graphic illustration of compressor performance curves with all related restrictions. Multi-compressor operation of a station in any serial or parallel mode is simulated with real distribution of load on individual machines. The model also includes the influence of ambient temperatures on the available maximum output power of the compressor.

The accuracy of the results of the calculation in the case of transmission systems over large distances is to a large extent influenced by the accuracy of the geometric parameters given for the pipelines. Unchanging pipeline parameters like elevation, length, or inner diameter can be relatively accurately identified, for example, by using data from internal inspection of pipelines. On the other hand, data like pipeline roughness and the parameters of the surroundings in which the pipeline is placed (heat transfer coefficient HTC and soil temperature) cannot be clearly identified. In the case of pipe roughness it is possible to tune the network model for the conditions of real operation and so take consideration of its integral value for the respective sections of the pipeline network. Where the properties of the pipe surroundings are concerned, detailed mapping of this along the whole length of the gas pipeline is possible, but highly demanding and the optimum level of detail is still questionable.

The aim of this chapter, following on from already published contributions on this issue, is to point by practical example to the specifics of the hydraulic simulations and optimization of the gas transmission systems performance.

4.1 Hydraulics simulations of the gas transmission as a reliable tool for the performance optimization

One of the areas for verifying the accuracy of simulating nonstationary nonisothermic gas flow is also the time change of the thermal and pressure profile of the flowing gas at start-up or shut-down of the compressor station. In this way the sudden change of the pressure and temperature causes the dynamic response of the system. Subsequently, in selected points of the system the calculated gas temperature and pressure from simulation could by compared with the measured values. For this purpose, it is advantageous if the pressure and temperatures sensors are installed along the transmission pipeline route at ball valve stations (approx. every 25 km) on all lines. In order to calculate correctly the transfer of heat from the gas to the surroundings it is necessary at some points to install also sensors of not influenced soil temperature.

In this part we concentrate on the start-up of the station, when the fairly stationary operation of the system is subjected to a change such as the pressure and also temperature of the gas as a consequence of gas compression in getting the station up to the required set-point. The detailed description of the analyzed system is in the Chapter 4.4. Considering the fact that the control system provides dynamic data from temperature and pressure measurement along the whole length of the examined section of pipeline, these values were used for direct comparison with the values from hydraulic simulation.

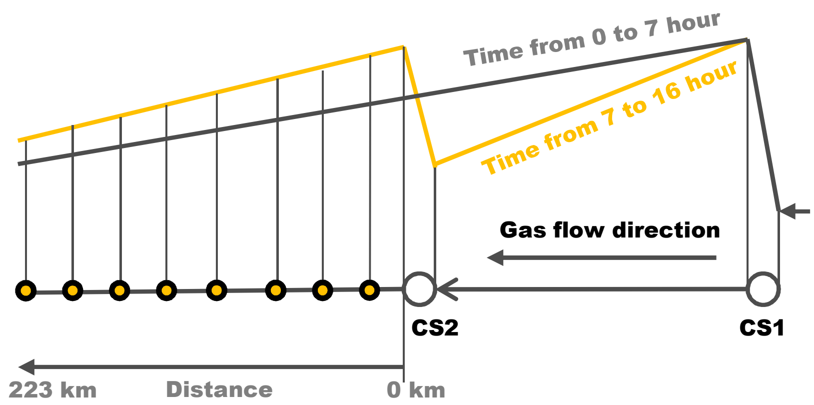


Figure 4.1 Scheme of model situation with start-up of compressor station for pressure and temperature profile

Simulation of the real transmission of gas in this case was performed in connection with a change to the transmission mode with a growth of 20 mil.Nm3/day, which required substantial changes to be made to the transmission system configuration. The first part of the simulation from the starting time through the first seven hours represents operation of the system prior to the change, which was made at 07:00 by start-up of the compressor station CS2. In the simulation the compressor station CS2 was controlled with a set-point for output pressure according to the real situation on the given day. The rest of the simulation from 07:00 till 16:00 represents the dynamic response of the system to the executed change. We can see a simplified scheme of the model situation in Figure 4.1.

The aim of the calculations was to compare the measures and the calculated pressure and temperature profiles in individual time intervals. Furthermore, the development of selected parameters at individual nodes of the system at various distances from the started compressor station CS2 was also subsequently monitored. Comparison of the results gained from simulations with the results measured was done by elaborating them into a single graph concurrently to make interpretation as simple as possible. The same color represents the same point of the system, while the results from simulation are shown by an unbroken line and the results from measurement are shown by a broken line.

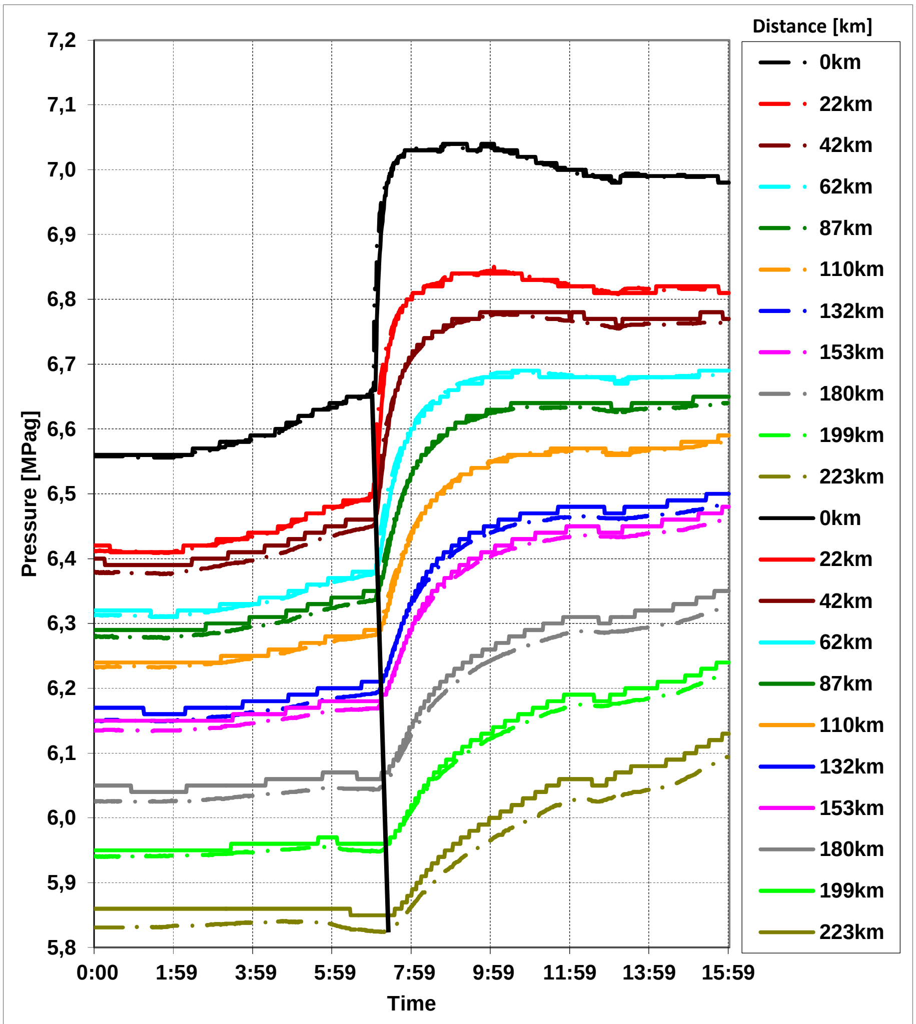


Figure 4.2 Development of pressure in dependence on distance from point of change

Figure 4.2 shows the development of pressure at individual monitored points of the system while giving the distance of the respective point from the point of initial change, i.e. compressor station CS2. Start-up of the compressor station manifested immediately in a sharp growth in exit pressure after the compressor station, which was followed by a gradually spreading growth in pressure in the pipeline network after the compressor station. As the distance from the compressor station increased, the respective tendency of growth in pressure from simulation decreased substantially in line with the real data from metering. As can be seen from the comparison of measured and calculated developments over time at the examined points of the system, there is a difference in the level of accuracy of metering equipment also for the greatest distance of 223km from the compressor station CS2.

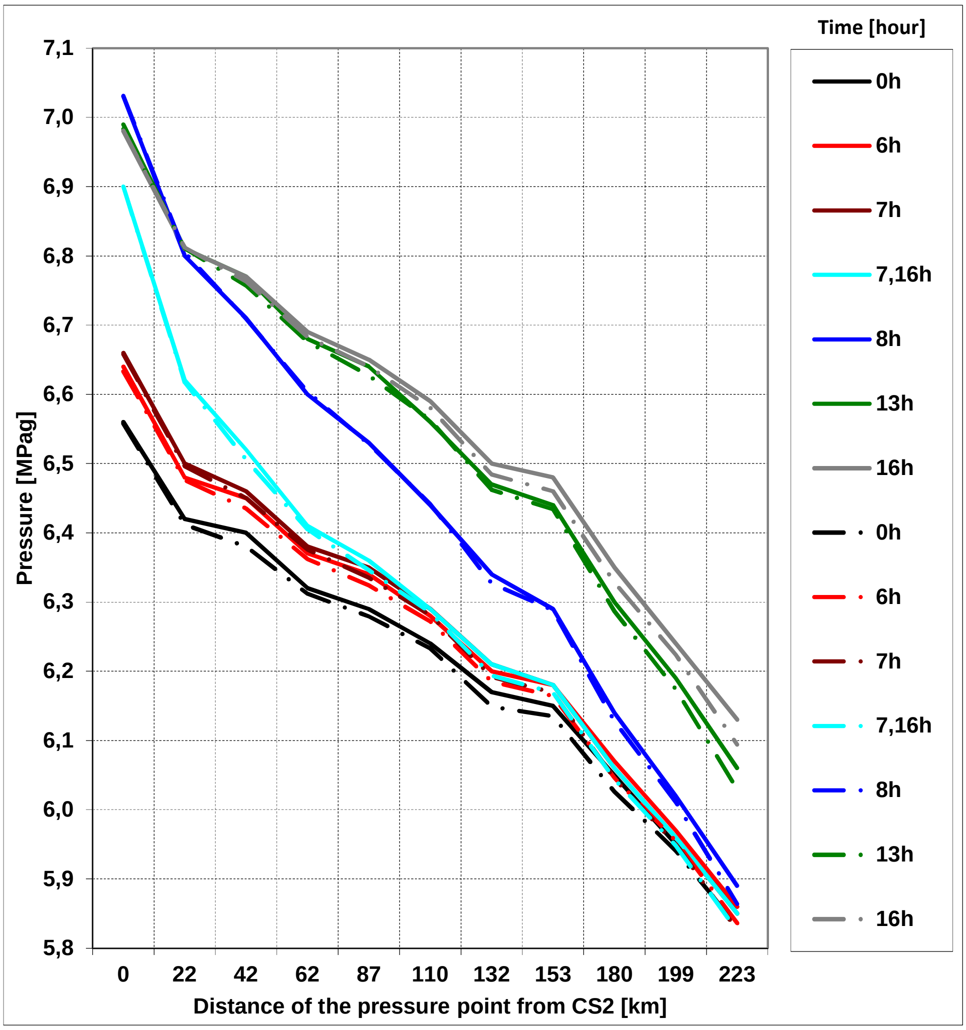


Figure 4.3 Profile of pressure development over time

If we look at the comparison of the profile of pressure development in the pipeline network, we can see even during the largest gradient of changes a good compliance between measured and calculated values, which capture the distinctly dynamic nature of changes in the pipeline part of the system caused by the start-up of a compressor station. From the illustration we can also see that at 7,16 hrs of the simulation the pressure on exit from the compressor station is already on the level of 6.9 MPag, whereby the pressure at the maximum monitored distance from CS2 (223 km) is still without significant change. A more marked change in pressure in this point only comes after 8 hrs of the simulation, when for comparison the pressure on exit from CS2 is 7

MPag. A certain stabilising of the pressure profile after start-up of the compressor station comes after 13 hrs of the simulation.

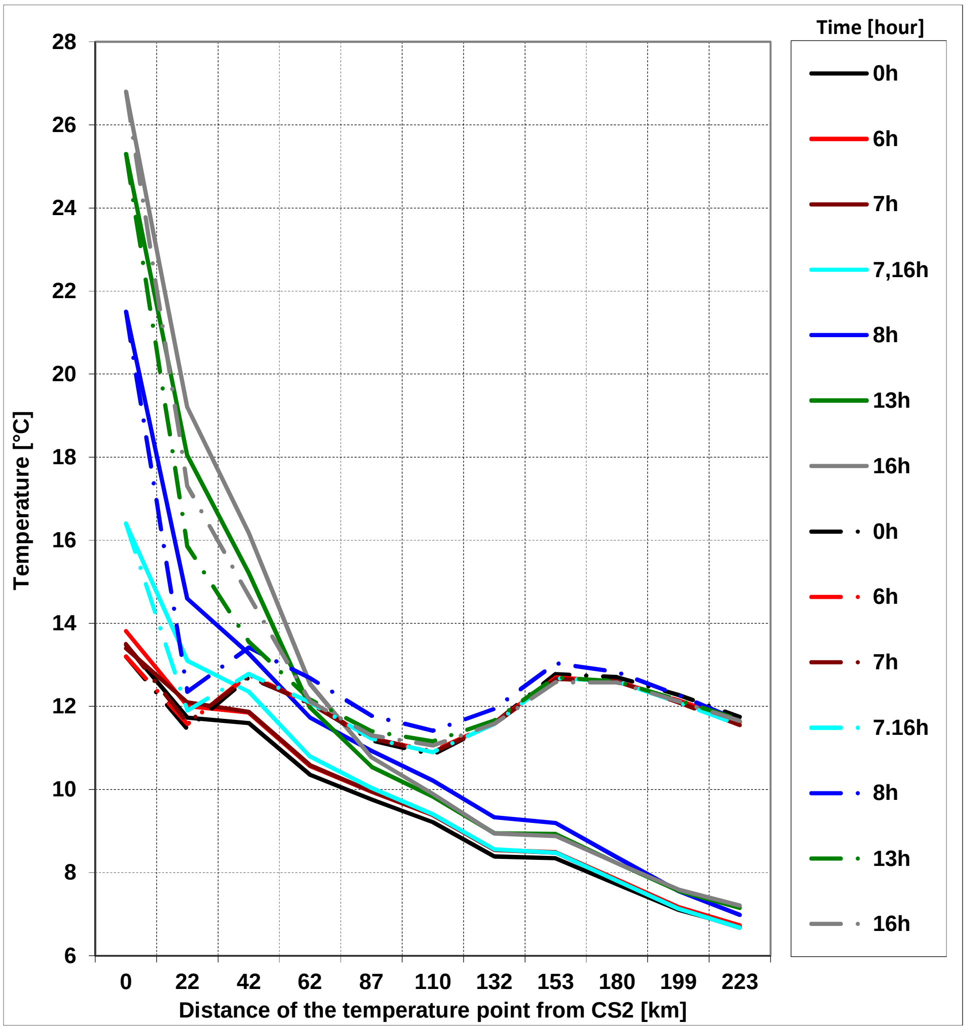


Figure 4.4 Profile of temperature development over time

A very interesting example of how to interpret the results of simulation can be seen in Figure 4.4, showing development of the temperature profile along the transmission system. The first interesting piece of information for the times 0h, 6h and 7h (before the start-up of CS2) is the drop in gas temperature between the distances 0 and 22km and the slight increase in temperature between the 22km and 42 km points in the case of measured data. On this section the pipeline passes through rocky terrain with changing elevations of up to 300m. In the simulation we can also see a significant drop between 0 and 22km, but the subsequent temperature then only slightly falls between 22 and 42km. The difference between the measured and the calculated values in the case of significant dynamic changes is approx. 2°C. Considering the fact that the simulation was performed for a constant heat-transfer coefficient and also a constant value of not affected soil temperature along the whole section, this represents a good result.

As is shown in the Figure 4.4, there is compliance between the measured and the calculated values of temperatures between 0-110 km, but in the range of 110km-153km there is a growth in this deviation to 5°C. The figure also reveals that at a distance of between 110km to 153km in reality the flowing gas heats up and it is clear that this heating up can only be as a result of the transfer of heat from the surroundings of the pipeline to the flowing gas. Because at a distance of 110km from CS2 the compressor station CS3 is located, an analysis was then made of the operation of the transmission system in the period before the examined day. The result was that three days before the examined status compressor station CS3, which had long been operating, was shut down. For this reason, the heat accumulated in the soil behind CS3 heats up the flowing gas in real conditions. This is clearly the cause of the difference in values compared to the real status, as the simulation was carried out with a constant value of not influenced soil temperatures along the whole section without considering the heat accumulated after CS3 before the simulation itself.

As can be seen from the attained results, even despite certain differences in gas temperature caused by not accounting for heat accumulation from the pipeline environment in the initial conditions of the simulation, there is compliance between measured and calculated values in the case of pressure to the scope of accuracy of metering devices. It should be noted that this example also points indirectly to the fact that for making the model of the pipeline network more exact it will, with great likelihood, not be necessary to have more detailed mapping of soil properties along the pipeline route, which would also be extremely demanding in terms of work. Furthermore, even with detailed mapping of soil properties it would be very difficult to estimate the respective accumulation of heat, which could be dominant parameter, from the perspective of the impact on accuracy of the temperature calculation.

4.2 Optimum distance between compressor stations

For the transport of natural gas (but also liquids) via pipelines over long distances there is a need to build up a pressure difference between starting and target point. In addition pressure losses occurring with increasing distance in the pipeline have to be compensated. Pressure losses emerge in the gas flow caused by both internal friction between the gas molecules themselves and external friction of the fluid stream along the inner pipe walls.

The necessary pressure increase (compression of the fluid) up to the required pressure level needed for gas transport is achieved at the starting point of the pipeline system using a head compressor. Additional compression facilities are integrated into the pipeline system by so-called intermediate compressor stations (Figure 4.5). The distance of the compressor stations depends among others on pipe diameter, operating pressure and length of the pipeline.

Intermediate compressor stations often equipped with gas turbine driven compressors (turbo compressors). Depending on the gas volume flow one or more compressor units can be operated in parallel.

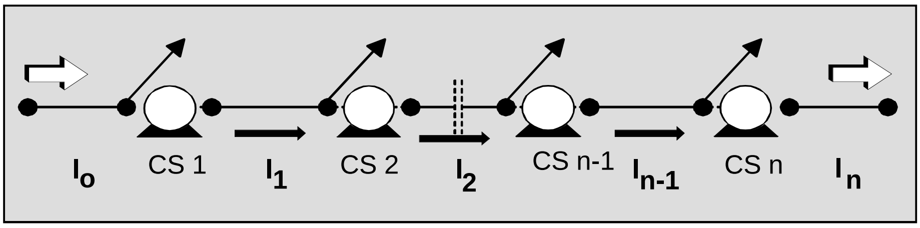


Figure 4.5 General arrangement of compressor stations (CS) between the pipeline sections (l) based on Fasold
(source: Gas Transmission Engineering and the Integrated European Gas Transmission System. Oil Gas European Magazine 4/1999, pp. 23-27.)

Optimisation calculations for large gas transmission systems have shown that in Western Europe a compression ratio between 1.3 and 1.6 correlates with the economic optimum. For a 56'' (DN1400) or 48'' (DN1200), 100 bar system with a capacity of ca. 30 bcm/a or 20 bcm/a (load factor assumed as 0.9) this corresponds to an average compressor stations distance of ca. 250 km. Countries or projects where fuel gas costs are charged rather at production costs ("lowest value principle") and in addition if possible including any tax reliefs than at market prices, shorter distances for compressor stations (e.g. 125 km) could be economically viable. Considering a corresponding system design due to the higher operating volume this leads to an increased capacity of the pipeline up to 48 bcm/a for a 56'' pipeline. Taking into account the long life time of the pipeline system this approach results in lower specific transportation costs or a higher NPV despite the fact that the CAPEX are higher because more compressor stations are needed.

4.3 Influence of the surrounding on the transmission system capacity

Determination of real maximum technical capacity of the transmission systems is a challenge and a hard task for all TSO. Difficulty of the task rises proportionally with complexity of the transmission network and number of entry, exit and entry-exit points.

A significant impact entering as a boundary condition of the task of solution of maximum technical capacity is a summary of the impacts of the surrounding on the transmission system. Also due to that it is necessary do deal not only with tuning of the transmission network model for calculation of the capacity regarding the compressor stations (a number and type of installed compressors and drives, features of the compressors and drives, pressure losses at the entry and exit of the compressor station, impact of cooling of gas at the exit from the compressors...) and a line section (length and diameters of pipes, setting of HTC and roughness of pipes...), but also setting and implementation of boundary conditions describing the impact of the surrounding on the system and its technical capacity.

Within this chapter we will analyze the technical capacity of a simple model transmission network to point out the impact of the changes of both air and soil temperature which the system is situated in.

Three variants of simple virtual transmission systems (V1, V2, V3) shown in Figure 4.6, Figure 4.7 and Figure 4.8 have been used to analyze the impact of the surrounding on maximum technical capacity of the transmission system.

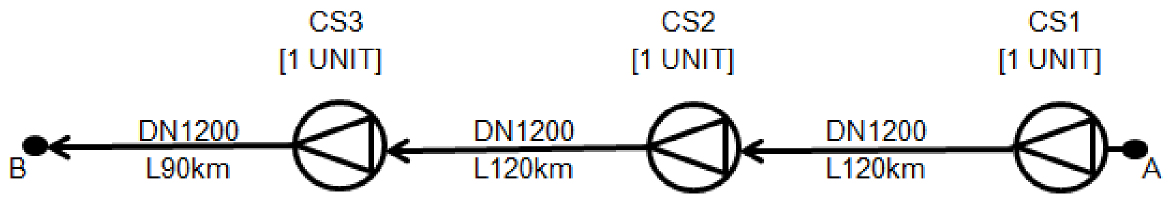


Figure 4.6 Transmission system V1

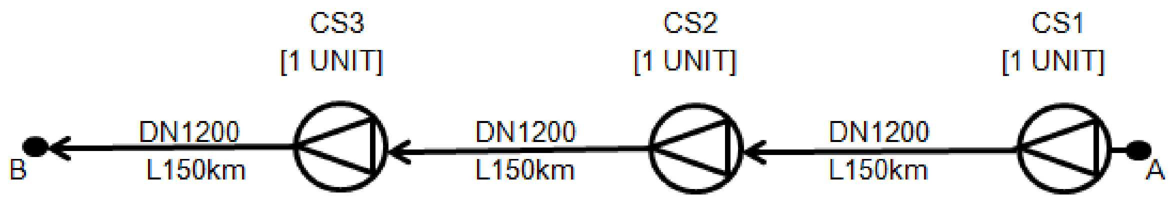


Figure 4.7 Transmission system V2

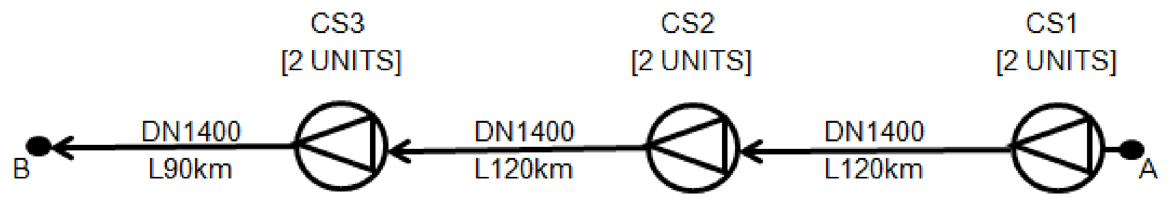


Figure 4.8 Transmission system V3

Each system consists of three compressor stations, one pipeline and has one entry and one exit point. Total length of pipes in the V1 system (Figure 4.6) is 330 km with diameter DN1200. The V2 system (Figure 4.7) consists of the DN1200 line with total length of 450 km. There is one compressor driven by a gas turbine operated at each of three compressor stations of the V1 and V2 system. The V3 system (Figure 4.8) consists of a DN1400 line with total length of 330 km and there are two compressors driven by a gas turbine operated at each of three compressor stations. The same compressor and drive type line is used in all variants, i.e. the features of the compressors and drives are the same in all variants and at all compressor stations and they are driven to maximum performance. Gas at the exit from the compressor station is cooled down to temperature 42°C. The pipes are buried in the ground and their axis is located 1.5 m under the surface.

The same boundary conditions and composition of gas (corresponding with the gas supplied from Russia) are set in all variants. The pressure boundary condition 4.9 MPag and temperature 23°C is set in the entry point of the system. The pressure boundary condition 4.9 MPag has been met in the exit point.

Setting of the system parameters was identical for all calculation scenarios of the variants V1, V2 and V3 and the calculations were performed with Heat Dynamics (HD) utilizing the Heat transfer coefficient (HTC). Just for comparison in some scenarios the HD was disabled (marked by HD off = constant gas temperature 10°C). Setting of roughness was the same for all system variants.

4.3.1 Air Temperature

The air temperature affects power of the gas turbine (Figure 4.9) and the lower (higher) the air temperature, the higher (lower) the maximum power of a gas turbine supplied to the compressor. Higher (lower) power results in higher (lower) output pressure of compressor station and taking into account the constant inlet pressure at next compressor station the transported capacity increases (decreases).

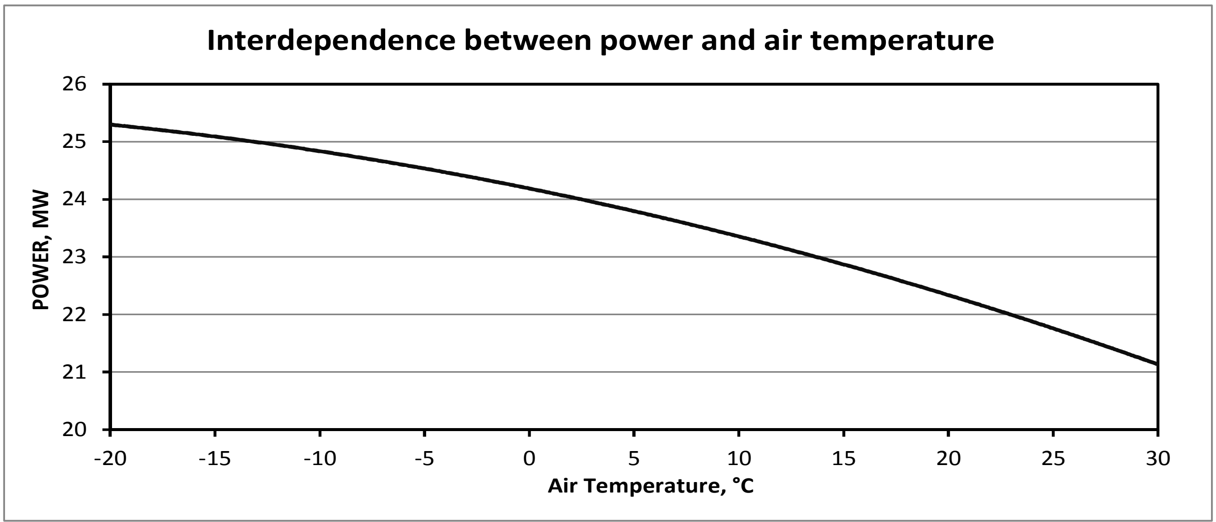


Figure 4.9 Interdependence between output ower of gas turbine and the air temperature

This effect is connected with change of the transmission capacity not only of a particular gas compressor but also of the entire transmission system. Figure 4.10 shows the example of pressure profiles along the transmissions system, illustrating the impact of the air temperature on the power of a gas turbine and the transmission capacity of a gas compressor and the system. The impact may be observed as a difference in the course of pressure profiles. With low air temperature (-20°C) maximum exit pressure of compressor station (CS) at the level of 7.5 MPag was achieved and with high temperature (35°C) the reached CS exit pressure was only at the level of approx. 7.1 MPag.

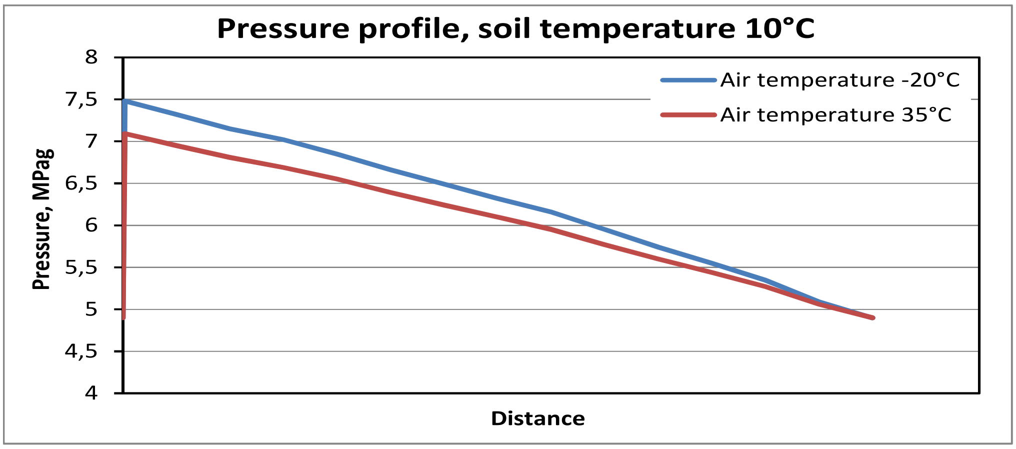


Figure 4.10 Gas pressure profile for different air temperatures

4.3.2 Soil temperature

Regarding the soil temperature, it influences temperature of the gas transported in the pipeline. At lower soil temperature the gas temperature in the pipe decreases faster. This effect results in smaller pressure losses of the system and causes higher input pressures with lower gas temperature at the compressor stations with a potential for higher capacity. On the contrary, the higher the soil temperature, the slighter decrease of gas temperature, which results in bigger pressure losses and subsequently lower input pressures with higher gas temperature at the downstream compressor stations, which decreases the total capacity of the system. Comparison of pressure and temperature profile with the same capacity for different soil temperatures and the variant when the heat dynamics is off is shown in Figure 4.11 and Figure 4.12.

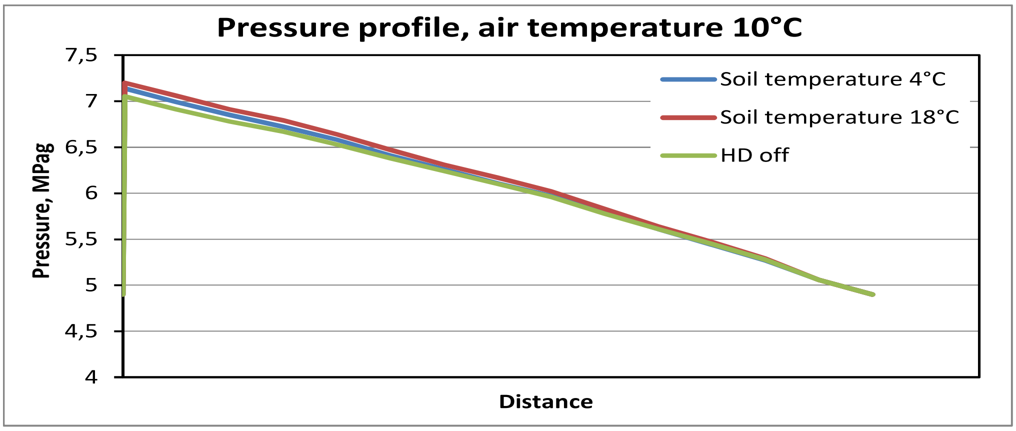


Figure 4.11 Gas pressure profile for different soil temperatures

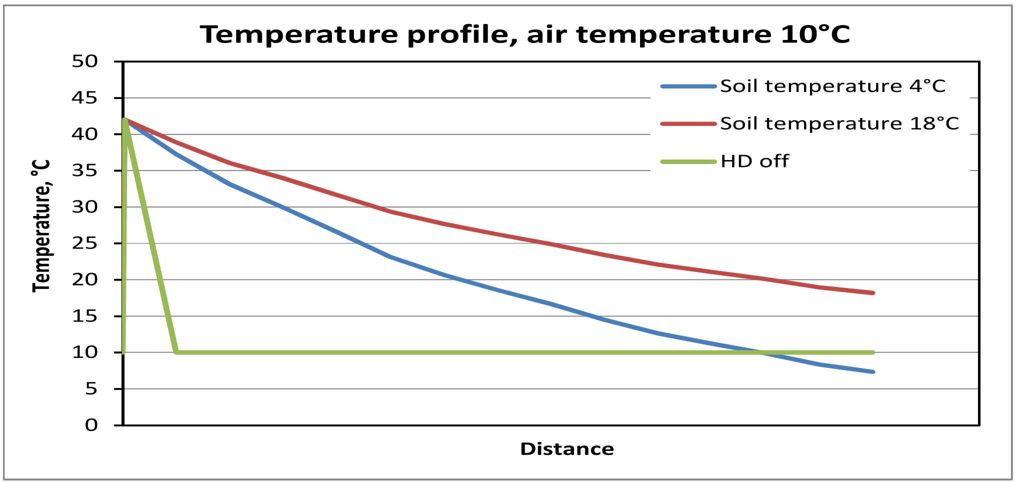


Figure 4.12 Gas temperature profile for different soil temperatures

4.3.3 Results of calculations

The following scenarios of capacity calculation have been analysed according to the above mentioned principles:

- air temperature [°C]: -20, -10, 0, 10, 20, 30, 35;
- soil temperature with a HD simple on [°C]: 4, 10, 18;
- soil temperature with a HD off = constant gas temperature 10°C.

The scenarios were recalculated in all three above mentioned variants of simple transmission systems (V1, V2, and V3). The results were processed into the charts below, where the absolute values of differences in capacity as well as difference in percentage between particular scenarios are compared.

The results show that the capacity of the system increases with the decreasing air temperature. The difference in absolute values varies is the biggest in the V3 variant, however, the percentage difference between individual variants and within the variants between soil temperatures is almost the same. Particularly we can see that it is about 9% between the air temperatures 35°C and -20°C, which is quite a high value if we convert it into a numerical capacity.

If we compare the capacities in soil temperature, we can also see that they rise with the decreasing soil temperature. Although it is not as significant in this case as with the air temperature.

In general we can see that in comparison of the capacity with the air temperature 35°C and soil temperature 18°C with the capacity with the air temperature -20°C and HD off, we get more than 15 %, which can mean an extremely big difference in quantification.

The results were achieved under the same conditions for all virtual transmission systems. They were not limited by maximum operating pressure or compression ratio at the compressor station or by any other parameters which could affect the resulting capacities. Therefore we can state that the results are standard and based on them also suitable setting of soil temperature and air temperature and the use of HD should be considered when determining maximum capacities of different transmission systems.

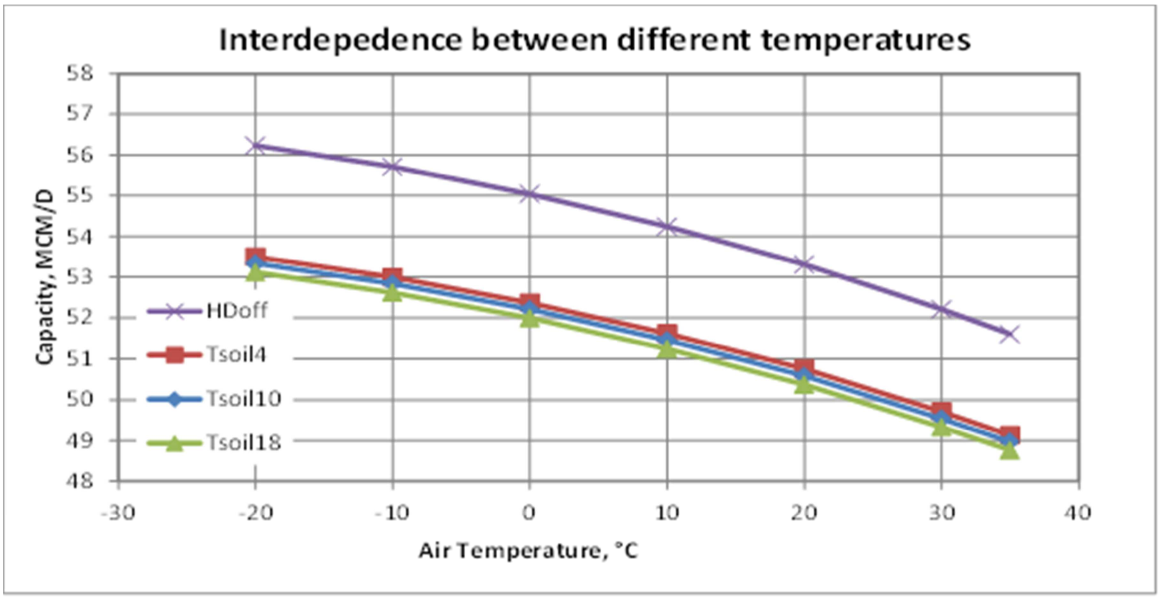


Figure 4.13 Comparison of capacity with different temperature for system V1

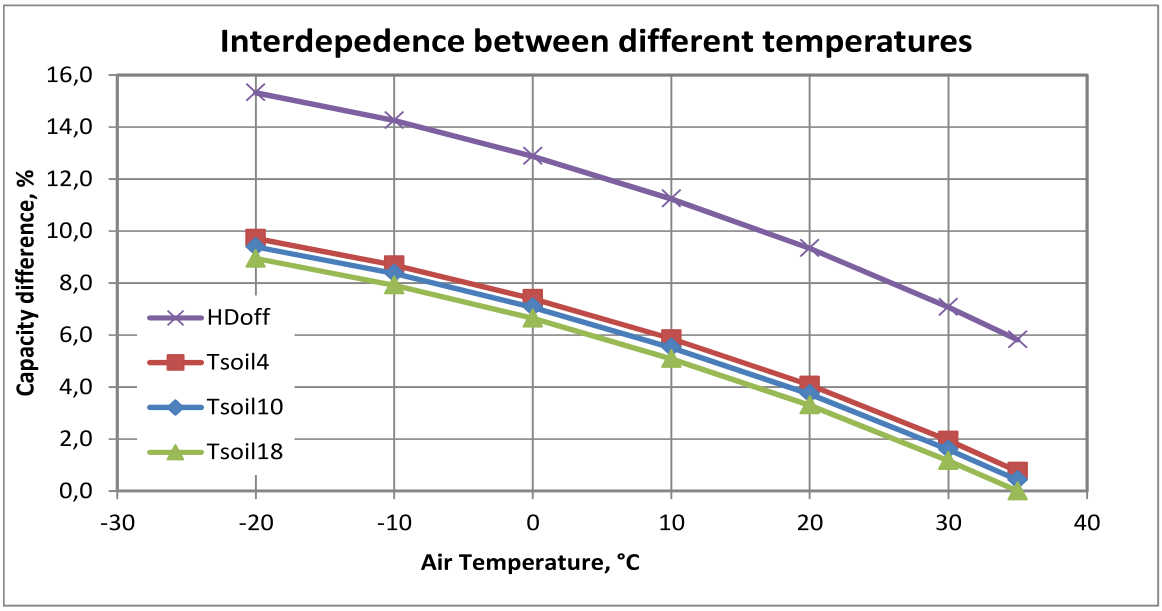


Figure 4.14 Comparison of capacity with different temperatures for system V1, differences in percentage

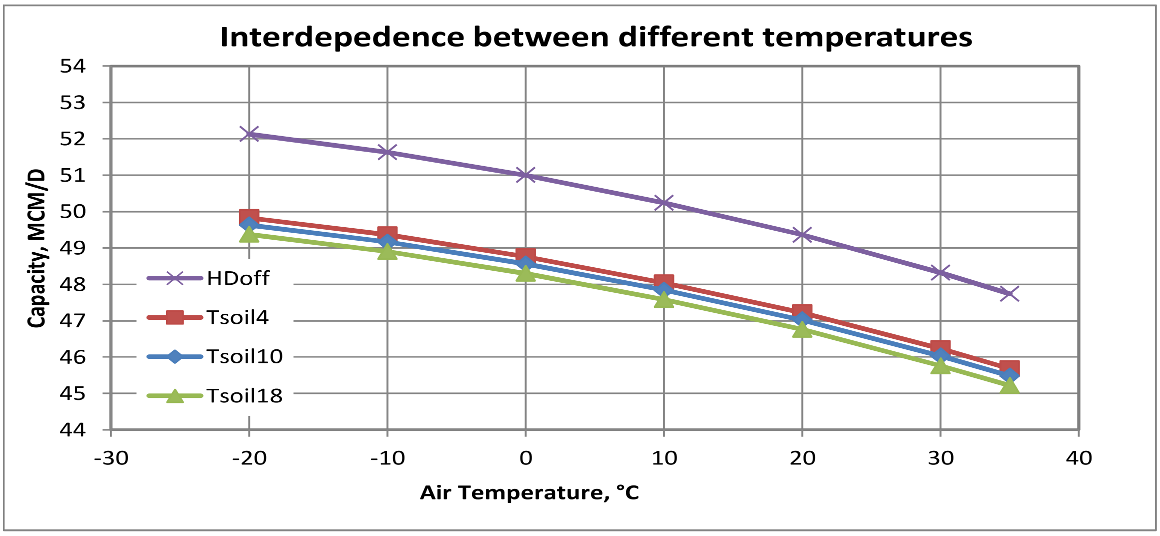


Figure 4.15 Comparison of capacity with different temperature for system V2

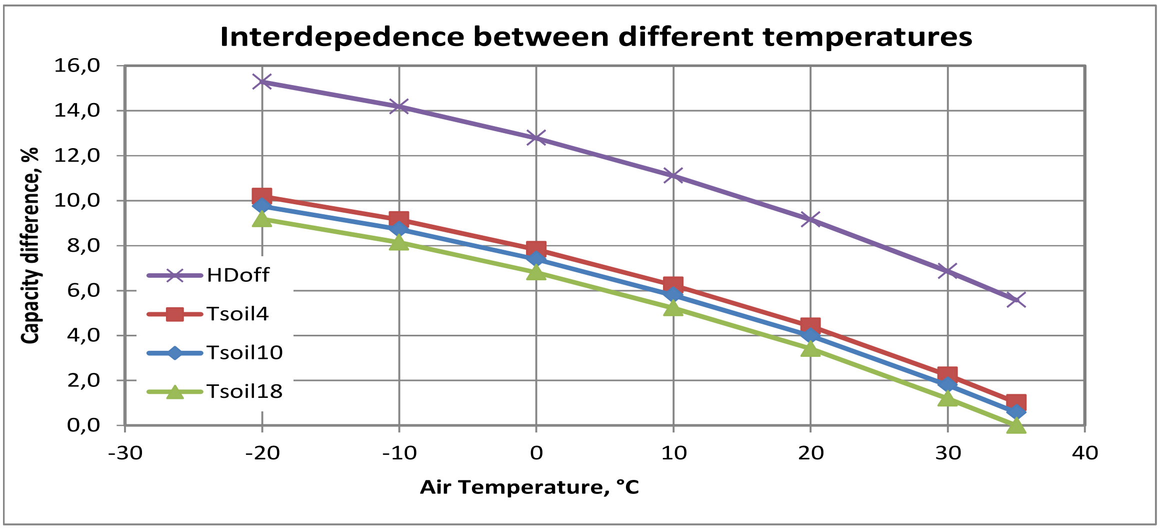


Figure 4.16 Comparison of capacity with different temperatures for system V2, differences in percentage

For instance for the conditions of the transmission systems presented above, in order to get the transmission guarantee of worst case, HD on, soil temperature 18°C and air temperature 35°C should be used. However, such a condition is rare during the year and capacity possibilities would be limited by that significantly.

Thus also regarding the results, as the soil temperature has a less significant impact based on the results and also as the air temperature varies during 24 hours, e.g. HD on, soil temperature 15 °C and air temperature 30 would be stated. That would correspondent to average summer temperatures.

On the other hand HD on, soil temperature 10 °C and air temperature 10 °C could be stated for a winter season. Although such a range would limit coverage of transmission of worst case, however, from the long-term point of view it could be acceptable.

We recommend divide the period into "summer" and "winter" so that the use of the scenarios "summer" and "winter" could be defined based on real multiyear data from soil temperature and air temperature charts.

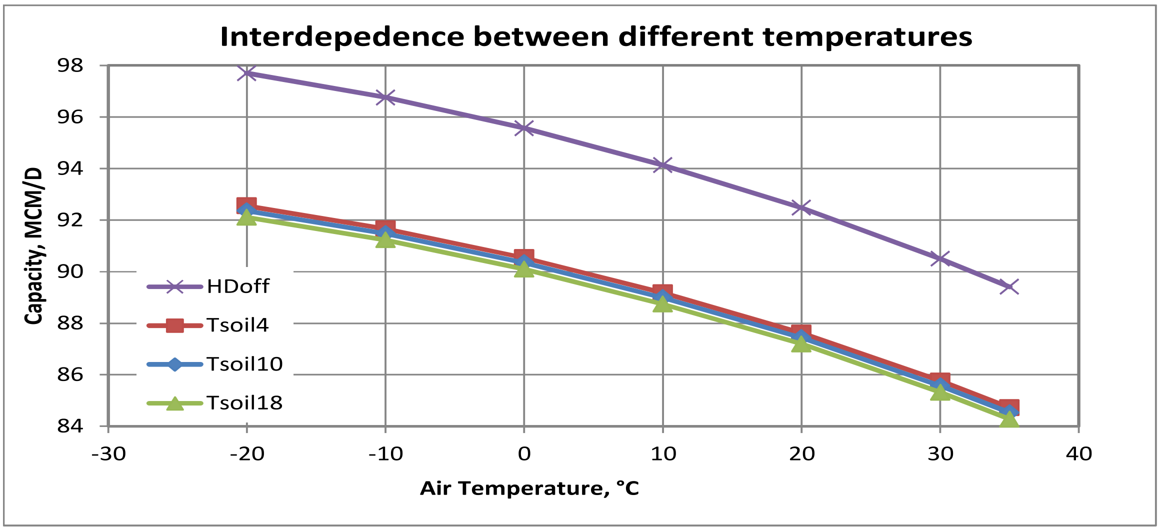


Figure 4.17 Comparison of capacity with different temperature for system V3

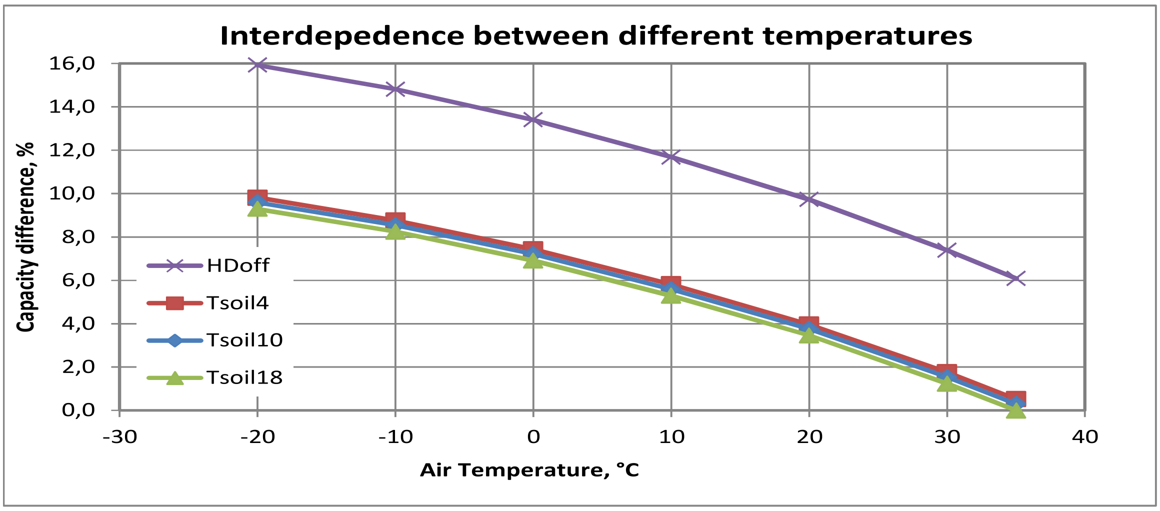


Figure 4.18 Comparison of capacity with different temperatures for system V3, differences in percentage

When modelling a network and subsequent calculation of the transmission system capacity it is important to set soil and air temperature correctly to get them as close to reality as possible, to determine the maximum capacity of transmission system as accurately as possible.

Of course, actualisation of available capacities on daily basis for actual conditions is the most accurate principle.

4.4 Optimization of the required compressor fleet

The configuration of the transmission system is adjusted optimally with regard to design transmission capacity. However, the required transmission capacity is developing and changing in relation to continuous changes to transmission contracts. The required capacity and resulting real flow-rates of existing transmission systems are in general influenced by new parallel pipeline systems. In order to be competitive to new parallel gas transmission routes (as a result of the competitive environment), which are using the latest solutions, the optimization of existing routes is essential. At this point the main principles and results of the optimization of the Slovak transmission system operated by Eustream are described.

Eustream operates a high-pressure gas transmission system that is interconnected with major European trunk lines in Ukraine, the Czech Republic and Austria. The Slovak transmission system consists of four to five parallel pipelines, mostly 1200/1400mm in diameter with an operating pressure of 73 bars. The pressure differential needed for design capacity (almost 293 million cubic meters per day) was in the past ensured by four large compressor stations with an aggregate power of more than 1000 MW.

In order to address the impact of new parallel pipeline systems in Europe and to adapt the system for the new conditions (gas flow volatility) the overall optimization of the compressor fleet was launched already in 2005. The required target technical capacity of the transmission system in medium-term was set to 220 million cubic meters per day (https://tis.eustream.sk/TIS/#/?nav=bd.ltc.vk).

For reaching the maximal required transmission capacity the existing compressor units have sufficient power, even when it will be needed to carry out certain technological adjustments for reaching harmony with new emission limits which will come into force in 2016.

Before the optimization the compressor fleet consisted of the following general types of the compressor units technology:

- technology with dry low emissions system [DLE] inline with new emission limits;
- SAC technology with possibility of modifying to DLE [MDLE];
- technology with ellectrically driven compressor units [ES];
- obsolete technology with output power 6MW [6MW units].

Nearly 50% of the installed power was generated by 6MW units (Figure 4.19) with a consequence, that pipeline yards of compressors stations are very complex with a large number of installed fittings. This increases the risk of natural gas leakage. The technology of 6MW units is comparatively obsolete, even though it is reliable, it contains some technologies, for example expansion starting system, which, due to operational reasons, ventilates remarkable amount of natural gas to atmosphere. Therefore the efforts of Eustream to reduce methane emissions are focused mainly on this technology.

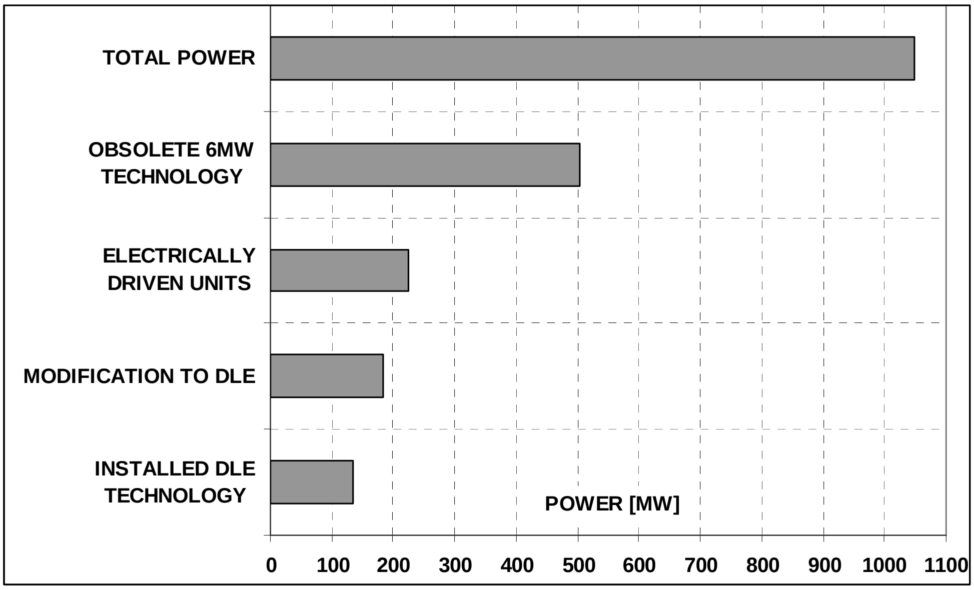


Figure 4.19 The total power distribution before optimization

Regarding the new legislation, the technology MDLE will fail to comply with the new emission limits proposed by the European Commission as of 2016. Concerning the 6MW units technology, these units will most probably not comply with the new emission limits proposed by the legislation of the Slovak Republic. The total power influenced by the new emission limits was nearly 700 MW – see Figure 4.19.

Regarding the MDLE units, the project of replacement of gas generators with standard system of fuel consumption by DLE with low values of produced emissions was launched in 2010 (for detail see Chapter 3.5). The final number of modifications will depend on the development regarding the required capacity in the future.

The 6MW units required to cover the target technical capacity have to be adapted to reach the new emission limits. This automatically raises the question, weather it is reasonable to invest in the obsolete 6MW technology. The alternative would be to shut down these units and install new big units with higher operational flexibility and lower emissions. This alternative has been thoroughly analyzed and has proved to be viable.

On the other hand the replacement of the 6MW units by the new units with the same output power of 6MW was proven as ineffective because of high investment per one megawatt of output power. The main recommendation of the optimization was to replace the required 6MW technology by new units with the output power of 23 – 33 MW. In this case it is necessary to put emphasis on the optimization of the power distribution in the compressor station which was described in Chapter 3.6.1.

Based on the experience with the operation of the transmission system and taking into account the hydraulic analyses including the new restrictions, the reduction of the installed power at compressor stations is possible in the first phase under the conditions of target transmission capacity decreasing from 300 to 220 million cubic meters per day.

The second phase of the power reduction is based on optimization of the compressor stations operation. The main messages of the second phase are as follows:

- During the gas transmission in the pipeline network, energy supplied to gas in the form of compression work is fully used for overcoming pressure losses due to hydraulic resistances. From this point of view, especially the length losses in pipelines between the compressor stations are significant. The length losses depend on the flowrate (higher flowrate = higher losses) and the pressure (higher pressure = lower losses).

- The total power reduction is mainly determined by the required target capacity and level of the optimization. The rough principle of optimization is to add as much compression work as possible at the beginning of the system (CS1) in order to increase pressure up to the maximum operational pressure of pipelines [MAOP] (Figure 4.20, yellow color). The high level of pressure at the beginning of the system reduces the pressure losses and resulting required power downstream – at the other compressor stations (Figure 4.20, yellow color vs. grey color).

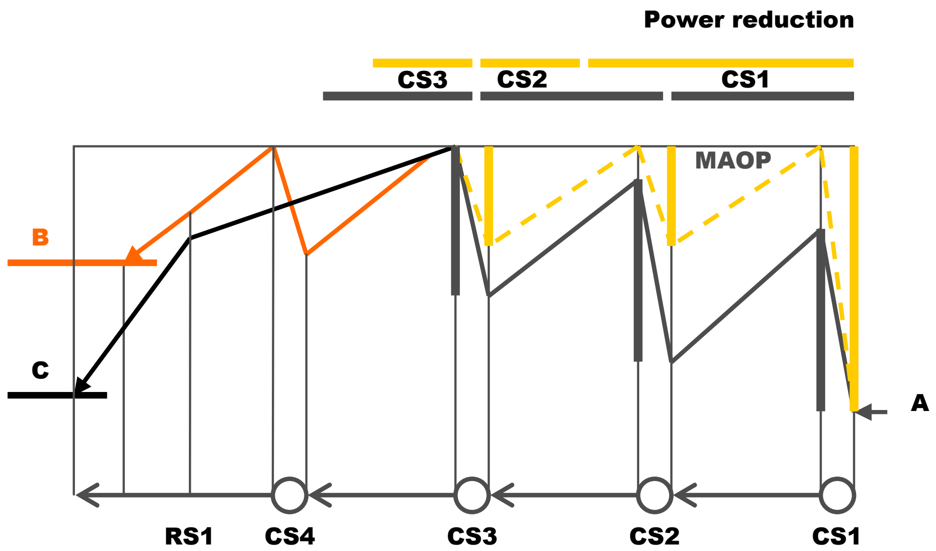


Figure 4.20 Main principle of second phase optimization

In order to enable high pressure at the outlet of the CS1 the high pressure ratio at this compressor station is necessary. The maximum pressure ratio before optimization was 1.39 and in order to reach the MAOP the pressure ratio higher than 1.5 is required.

In addition, before optimizing at low pressure ratios of CS01 the inlet pressure fluctuations had significant impact on the system operation. Due to that only in case of the high pressure ratio (1.5 = optimum after optimization) in the whole operational range of the CS1 the proposed power reduction was recommended at the other compressor station (Figure 4.20 and Figure 4.21). The highest level of the power reduction is at the compressor station CS2.

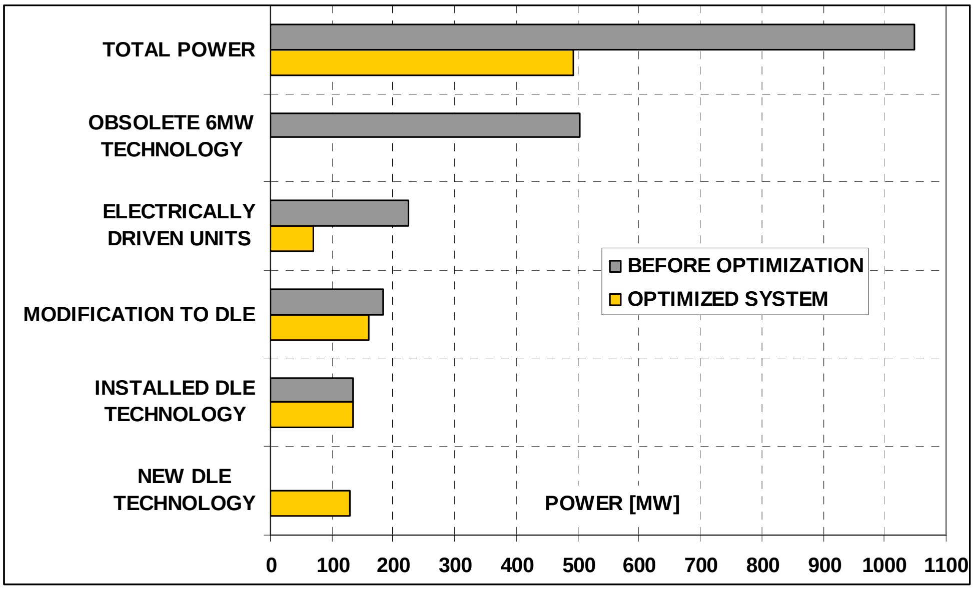


Figure 4.21 Expected power decreasing after optimization

The project of the pressure ratio increasing at CS1 represents the first measure and it was a starting point of all the following projects. The new design of the transmission system after optimization (Figure 4.21) will provide enough compressor power including backup in order to secure the required transmission capacity. In addition, the high pressure ratio of CS1 reduces the influence of the inlet pressure fluctuation on the whole transmission system operation. It results in a stable system operation behind CS1 without dynamic changes and thus increases safety, reliability and flexibility of gas transmission.

As it is shown in Figure 4.20, as a result of the CS1 pressure ratio increase the pressure ratio of the downstream compressor stations decreases. This also puts emphasis on the operational range of the compressor units at the downstream compressor stations in connection with the DLE system. In order to meet the new requirements the new units with tandem compressors (see detailed description in Chapter 3.4) were installed at the station CS3.

The project of new units at CS3 is strongly focusing the expected operation of the transmission system in the future and the aim of this project is:

- to replace obsolete 6MW units with high emissions by new fully automated turbo-compressor units with low emissions;
- to broaden the CS3 operational range in both low as well as high compression ratio area;
- to substitute the 6MW units operation at low pressure ratio;
- to be in compliance with existing big compressor units with high pressure ratio.

Chap. 5 Public Acceptance of Technology and Technical Constructions

For the last decade, the interest for information sessions organised by pipeline operators and risk analysis realised in the frame of projects to the address of stakeholders has increased.

Very attentive examination of the projects by all the authorities but also by the population has been recorded.

The gas transmission pipes and the associated above-ground installations (compressor stations, interconnections, valve stations etc) interact locally with human activities. Therefore, landowners, farmers, residents, associations and other groups may have concerns about them.

The use of new technologies for design, construction and operation may increase the need for information of the public.

The development of the internet and other media facilitates the circulation of information.

Finally, in the territories crossed by a new gas project, aside the gas companies (developers) and the official institutions (ministries, local and national authorities, specialized services, agencies etc) the different parts of the "public" behave more and more as real actors.

5.1 Who are the key public actors?

The general notion of public gathers a wide range of actors who organize and plan their actions in very different ways depending on the local context. Obviously laws, regulations, habits and also customs and history may influence the public behavior as well as contextual factors.

Usually, the main following categories of actors are distinguished:

5.1.1 The landowners

The landowners are directly involved in the infrastructure because the infrastructures are laid/built in their parcels of land either through a right of way agreement concluded with the company or an authority (in the case of a gas pipe for example), through a land acquisition agreement (in case of the construction of a compressor station or a valve station for example) or through another permitting or legal process (general interest process, public utility, other). A landowner is rarely favourable to a new infrastructure settled in his private parcel which is related by the well-known acronym "NIMBY" (Not In My Back Yard).

5.1.2 The farmers

The farmers operate the soil within the frame of their professional activity. As such, they are mainly involved in the construction phase.

As the construction phase brings damages to the cultures all over the working site, the farmers pay a particular attention to the compensation but also to the quality of reinstatement after construction.

5.1.3 The residents

As they live near the future infrastructure, the residents are both concerned by the construction work and the operation phase.

Usually, local residents feel even concerned very early in the project by the choice of the route or by the choice of site's location. They also pay attention to the communication process all along the project.

5.1.4 The groups

Different types of groups may be met during a project of gas infrastructure. Drawing a precise cartography of this group is not easy; however the main characteristics of these groups may be suggested

- *Campaigners:*

* pressure groups : possibly already established groups that agree to a certain course of concerted action (to write letters to local authorities or local representatives etc) . The status of these groups may be sometimes recognized by the authorities in certain countries.

* action groups (local) : possibly new groups or local communities that form around a particular issue as local species protection group , NIMBY associations etc. These groups may act in a proactive way with campaigning including public meetings, distribution of leaflets etc. The status of these groups are not always recognized by the authorities particularly if they are formed late in the project.

- *Protestors:*

Groups that protest against the project. These groups may plan actions at a local or regional level on the legal stage (actions against planning of permitting, etc) .

5.1.5 Other actors

Other actors may have a role (politicians, others) in relation with the other actors. However it is not easy to characterise them because their role depends mainly on the authorities that grant the necessary permits and licences for the infrastructure.

5.2 Main impacts of gas transmission infrastructure

Compared to other gas infrastructures (LNG terminal, production plant) the transmission gas infrastructure can be considered as underground linear structures with localized above-ground installations. Furthermore, it seems important to distinguish impacts of the linear part (gas pipe) and the impacts of the above-ground installation (compressor station, interconnection ...).

Another usual distinction is done between temporary and permanent impacts.

5.2.1 Construction phase

5.2.1.1 Gas pipe main impacts – suggestion for classification

Gas pipe main impacts on	Temporary due to construction phase	Permanent due to construction phase
Ground, soil, air geology	Geology : Possible accidental pollution	Possible in landslide or unstable areas
Topography	Profile modifications due to construction work	Negligible
Hydrogeology	Possible accidental pollution Local pumping effects	Negligible (specific measures in drinking water pickling areas) Negligible disturbance of underground water circulation
Hydrology (rivers)	Possible accidental pollution Local increase of turbidity, impact on fish , increase of water temperature, impact on water quality, Water withdrawal, water pollution when discharge, (hydrostatic tests)	Usually negligible
Hydrology (floodplain)	Possible accidental pollution, possible material divagation during flood	Usually negligible
Nature (rivers)	Possible accidental pollution	Possible modification of wildlife due to disappearance of the riparian

	Possible local destruction of riparian and spawning areas, possible destruction of aquatic fauna	
Nature (other areas)	Flora : possible various impacts depending on the flora variety Fauna : possible disturbance due to construction work , possible destruction of non mobile species, habitat loss for certain species	Modification of eco system due to the construction phase and the narrow non sylvandi - band in forests Possible tree instability Creation of possible corridors for fauna Ground preservation /construction
Nature (landscape)	Visual impact due to the Right Of Way (ROW) and the general working activity	Milestones and signalization devices Non sylvandi band in forests and at hedge crossing Visual impact in slopes and at rivers crossings
Human environment	Noise (bus, pipelayers, etc.) Possible air pollution (exhaust) Dust , possible soil pollution (liquid) Welding fumes Increase of the traffic on roads/tracks near the working site Traffic disturbance at road crossings	Narrow non sylvandi band in forest areas (possibly increased in case of parallel pipes) Possible modification of urbanism documentation and rules due to the pipe (public utility easement or other easement)
Human activities	Economy :possible creation of local jobs Agriculture : impacts on the cultures , modification of agricultural yields during the first 3 / 4 years , land occupation, Forestry : land occupation, possible disturbance Industry :possible	Urban development Possible limitation of construction near the infrastructure (commercial centre, public sites, public buildings …) , necessity of having a preliminary agreement before building , others Agriculture : possible decrease of agricultural

	effects on careers activities, restaurants, hotels occupancy Tourism and leisure : Tracks occupation, possible impact on fishing activities and walk , hunting , golfing, etc	surfaces (when re forestation)
Culture	Archaeology : possible destruction on old remains Monuments and other sites:	Negligible if previous measures are taken according to the regulation
Infrastructures	Roads highways : land occupation, possible traffic disturbance, possible surface modification Railways : Possible traffic disturbance , possible accidental soil subsidence Airlines : Possible punctual impact Underground and above-ground networks Possible deviation or reinforcement during construction phase Wind wheels : possible constraint (to integrate during engineering) Installation with technology risk : possible constraint (to integrate during engineering)	Negligible except in case of radio easement Or in other cases depending on the national regulation

Table 5.1 Gas pipe main impacts – construction phase

5.2.1.2 Main impacts of a gas above-ground installation - suggestion for classification

Gas above-ground installation impacts on	Temporary impacts due to construction phase	Permanent impacts due to construction phase
Sol, air geology	Geology :Possible accidental pollution	Negligible if the choice of land has avoided landslide or unstable areas
Topography	Profile modifications due to construction work	Possible permanent modification (example construction in slope)
Hydrogeology	Possible accidental pollution Local pumping effects	Possible local disturbance of underground water circulation Modification of rainwater circulation
Hydrology (rivers)	Water withdrawal, water pollution when discharge, (hydrostatic tests)	Negligible because rivers crossing are generally avoided
Hydrology (floodplain)	Possible accidental pollution, possible material divagation during flood nearby the site work	Negligible because floodplains are generally avoided
Nature (other areas)	Flora : possible various impacts depending on the flora variety Fauna : possible disturbance due to construction work , possible destruction of non mobile species, habitat loss for certain species	Possible modification of eco system due to the construction phase Impacts on habitat for fauna and modification of uses of soils Could break some "corridor"
Nature (landscape)	Visual impact due the general working activity	Visual or various impacts due to above-ground installation (piping, support, buildings, fences, roads, lightning matte, security device, etc)
Human environment	Noise (bus, pipelayers, etc.) Possible local air	Possible modification of urbanism documentation and rules

	pollution (exhaust) Dust , possible soils pollution (liquid) Welding fumes Increase of the traffic on roads/tracks near the working site	Possible limitation of construction near the infrastructure (commercial centre, public sites, public buildings …) , necessity of having a preliminary agreement before building , others
Human activities	Economy :possible creation of local jobs, restaurants et hotels occupancy Agriculture : impacts on the cultures , land occupation, Forestry : land occupation, possible disturbance near the site Tourism and leisure : Negligible if the choice of location has avoided touristic areas	Suppression of agricultural activity /forestry on the site
Culture	Archaeology : possible destruction on old remains Monuments and other sites:	Negligible if previous measures are taken according to the regulation Visual impact
Infrastructures	Roads highways and railways : Negligible Underground and above-ground networks Possible deviation or reinforcement during construction phase Wind wheels : possible constraint (to integrate during basic engineering) Installation with technology risk : possible constraint (to integrate during engineering)	Negligible except in case of radio easement Airlines : negligible because the choice of site is done to avoid this kind of impact Others : negligible because the choice of site is done to avoid this kind of impact Noise (compressor stations)

Table 5.2 Main impacts of a gas above-ground installation – construction phase

Temporary impacts on health and safety are mainly due to construction work , they are linked to noise production, exhaust gas emission and possibly water /soil pollution by oil or other liquids.

If the regulation or national rules limit the noise acceptable level emission, the contractors have to comply with these impositions. Other measures as adaptation of hourly work schedule may be considered. If the construction work is located near buildings some measures are usually taken to avoid dust as much as possible . As far as soil pollution is concerned , if necessary, measures can be taken to minimize the risk of pollution (night parking of construction machinery on dedicated zones) and decontamination procedures may be written to cope with a potential pollution on site.

5.2.2 Operation

5.2.2.1 Gas pipe main impacts – suggestion for classification

Gas pipe main impacts on	Temporary due to operation phase	Permanent due to operation phase (*)
Sol, air geology	Climate, air : Gas emission during maintenance	- climate change -ozone
Topography		
Hydrogeology		
Hydrology (rivers)	Negligible except punctually during survey	
Hydrology (floodplain)		
Nature (rivers)	Possible punctual impact during survey	
Nature (other areas)		
Nature (landscape)	Negligible except for maintenance of the ROW	
Human environment		
Human activities	Possible punctual impact in forest areas or during maintenance acts Possible impacts on other activities (careers,…)	

Infrastructures	Airlines : possible noise and gas emission during maintenance Possible punctual impact during maintenance	

(*) not include accidental event

Table 5.3 Gas pipe main impacts – operation

5.2.2.2 Gas above-ground installation – suggestion for classification

Gas above-ground installation main impacts on	Temporary due to operation phase	Permanent due to operation phase (*)
Sol, air geology	Possible accidental pollution during maintenance (pig inspection) Gas emission (actuators, flow valves, heat exchanger, other process) , possible NOx emission (exhaust from gas turbine), Possible accidental pollution (glycol, methanol, used water other effluents), Noise	Gas emission (actuators, flow valves, heat exchanger, other process and vessels) , possible NOx emission (exhaust from gas turbine), Possible accidental pollution (glycol, methanol, used water other effluents), Noise
Topography		
Hydrogeology		
Hydrology (rivers)		
Hydrology (floodplain)		
Nature (other areas)	Flora : possible punctual impact during maintenance (weed killing etc)	Possible disturbance of wildlife (noise , emissions , traffic…)
Nature (landscape)		
Human environment	Gas emission (actuators, flow valves, heat exchanger, other process) , possible NOx emission (exhaust from gas turbine), Possible accidental	Gas emission (actuators, flow valves, heat exchanger, other process) , possible NOx emission (exhaust from gas turbine), Possible accidental

	pollution (glycol, methanol, used water other effluents), Noise	pollution (glycol, methanol, used water other effluents), Noise Safety impact due to gas (third party aggression on pipe, consequence of other hazardous phenomena) ATEX risk Safety due to utility (electricity, storage / use of flammable liquid)
Human activities	Economy : possible increase of delivery services	Economy :possible increase of local jobs or delivery services Local tax (depend on regulation)
Culture		
Infrastructures		Possible traffic increase

(*) not include accidental event

Table 5.4 Gas above-ground installation - operation

Temporary impacts on health and safety are mainly linked to gas emission. Other parts of this document report on this topic.

5.2.3 Reduction of the environmental impacts

Mitigation measures taken by the operators to reduce the environmental impacts are very various.

This part of the chapter has no other ambition than showing examples of mitigation measures taken in recent gas pipe projects.

5.2.3.1 Local reduction in track width

When necessary, the track has to be kept as narrow as possible, on the one hand to limit direct destruction when opening up the track and on the other hand to minimize the indirect effects linked to compacting of the ground by the plant. This measure may be taken in some sensitive areas or in forests.

Figure 5.1 Local reduction in track width

5.2.3.2 Sorting the types of soil excavated during trench digging

When digging trenches, the topsoil is to be separated from the underlying strata. The strata are to be backfilled in their original order. The seeds and plant multiplication organs are thus put back at the same depth as prior to the work. Furthermore, all excess soil is to be removed to avoid ground subsidence in sensitive areas (especially wetlands).

Figure 5.2 Sorting the types of soil excavated during trench digging

5.2.3.3 Spraying water on the tracks in dry weather

The areas particularly sensitive to dust emission and containing plants of particular interest during the work phase are sprayed with water if significant dust emission levels are noted. This measure can only be implemented for limited areas in compliance with the legislation in force concerning the orders restricting use of water in the event of drought.

5.2.3.4 Replanting hedges lined with trees, shrubs and bushes

Freshly planted hedge cannot rival a hedge that is several decades old in terms of ecological or agronomic efficiency, but it does ensure the lasting nature of the network.

This measure consolidates the functionality of tree alignments as preferential axes of movement for some species and nesting areas for birds.

Usually, if isolated trees or trees forming part of a network of hedges are to be felled, a prior visit is also made by a specialist to implement the same conservation measures where necessary.

5.2.3.5 Replanting trees outside the non sylvandi strip

This measure is aimed at replanting high trees outside the non sylvandi strip, taking care to plant the same species as those that were present prior to felling.

Figure 5.3 Replanting trees outside the non sylvandi strip

5.2.3.6 Restoration of the environment: river beds

The river beds are reconstituted, as closely as possible to the initial situation: the strata are put back in place in their order of excavation. Care is taken to comply with the initial particle size. In particular, clays must be put back on the underlying rock in karstic rivers to avoid water seepage into the underlying strata, which could lead to the river drying up in summer. After reconstitution of the minor bed, the environment should return to its initial situation and enable recolonization by the species present.

In the event that the layout goes through a confirmed spawning bed, particular care must be taken concerning reconstitution of the minor bed exactly as it stands, especially concerning factors favourable to spawning (rocks, sand or gravel banks).

The longitudinal and cross-sectional profiles are checked when restoring the site after the work. Gravel and pebbles may be placed on the beds of the rivers and streams to recreate the particle sizes in the crossing area.

Figure 5.4 Restoration of the environment -river beds

5.2.3.7 Implementation of a particle filtration system

The system implemented is different for small rivers or streams and large rivers:

For small rivers or streams: a culvert is laid to channel the rivers or streams during the work Cofferdams are put up at each end of the culvert to ensure that all the water flows through the culvert. The work to dig the trench and lay the piping is then carried out between the two cofferdams and under the culvert. The cofferdams and culvert are then removed.

For medium-sized and large rivers: a filter is installed to prevent particles from being carried downstream from the work area. This keeps the water clearer, and hence reduces the negative impact on the river fauna.

Various possibilities can be envisaged for these filters:

- Either they are made of fine-mesh geo-textiles that are installed upstream and downstream from the trench dug, to isolate the work area and limit the quantities of suspended matter in the river. The filtering textiles must remain in place for a while to enable the sediments to settle in the work area.
- Or the filters are straw filters, made with bales of straw.

Other solutions are also being examined (such as puzzolana filters for example); the most efficient technique will be adopted.

Figure 5.5 Implementation of a particle filtration system

5.2.3.8 Laying clay plugs

After a hydro-geological assessment, clay plugs are laid around the pipeline in predefined wet areas, to reduce the risk of drainage caused by the pipeline, and which would constitute a threat for the long-term stability of the areas.

5.2.3.9 Restoration of the environment: banks

For all the rivers or streams, the soil excavated from the banks are put back in place on the pipeline. It is covered by a biodegradable coconut matting 'geo-textile' anchored in the ground, and used to hold the loose soil in place.

Bundles of helophytes (depending on the vegetation present locally) are placed at the foot of the banks to limit erosion for highly friable banks.

The existing riparian woodlands are reconstitute outside the non sylvandi strip by replanting the species initially present (black alder, common ash, white willow) (plant engineering techniques).

Figure 5.6 Restoration of the environment – banks

Other measures can be taken according to the specificity of the environment.

Examples of specific measure	
Protection of amphibians (yellow-bellied toads) by installing protective sheeting near ponds	Protective fishing with fishing federations
Crushing clods to avoid nesting	Use of pebbles to reconstitute river and stream beds
Plugging holes in some trees to avoid nesting of chiroptera	Special treatment of drilling mud
Choice of work period	Setting up a pollution clean-up team (dealing with oil leaks, etc.)
Preservation of trees on tracks	Moving species of particular interest
Replanting hedges with regional natural parks	Installation of a device preventing birds living in river banks from nesting

Channelling rainwater by digging a ditch alongside the track	Reducing the period during which the trench stays open
Use of healing balm on young trees	Creation of ponds for amphibians
Botanical diagnosis before opening up a track	Putting up mobile barriers on each side of the work site
Ecological monitoring following work	Conservative fishing
Protection from boars by putting up specific gates and fences	Use of suitable plant for wetlands
Filtration of waste and drawdown water via a settling basin (initial plug) and bales of straw or other sediment traps	Adjustment of the locations for the isolating valve installations / taking the ecological and landscape aspects into account
Limitation of the pumping and disposal flow rates during hydrostatic tests	Placing felled trunks of suitable trees vertically close to the site

Table 5.5 Examples of specific measures

Some measures may be taken according to specificity of human activities.

Figure 5.7 Reinstatement of touristic area near a pipe

Figure 5.8 Compressor station in the landscape

Figure 5.9 Compressor station in the landscape

5.2.4 Public perception by the different stakeholders

A large consultation of the gas transmission companies, based on questionnaires have been launched by WOC 3 of the IGU. Key issues can be identified.

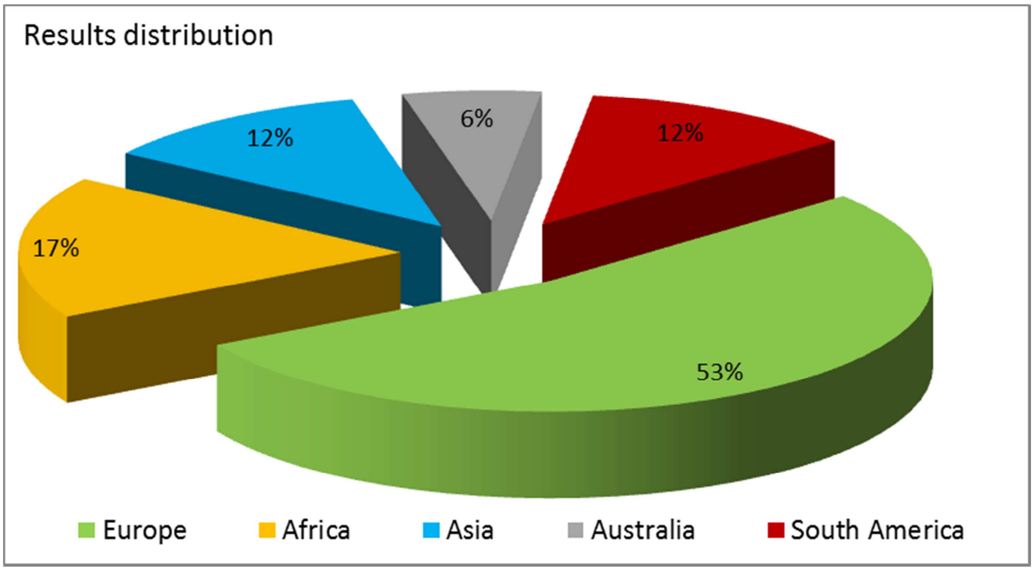


Figure 5.10 Results distribution

5.2.4.1 Communication process

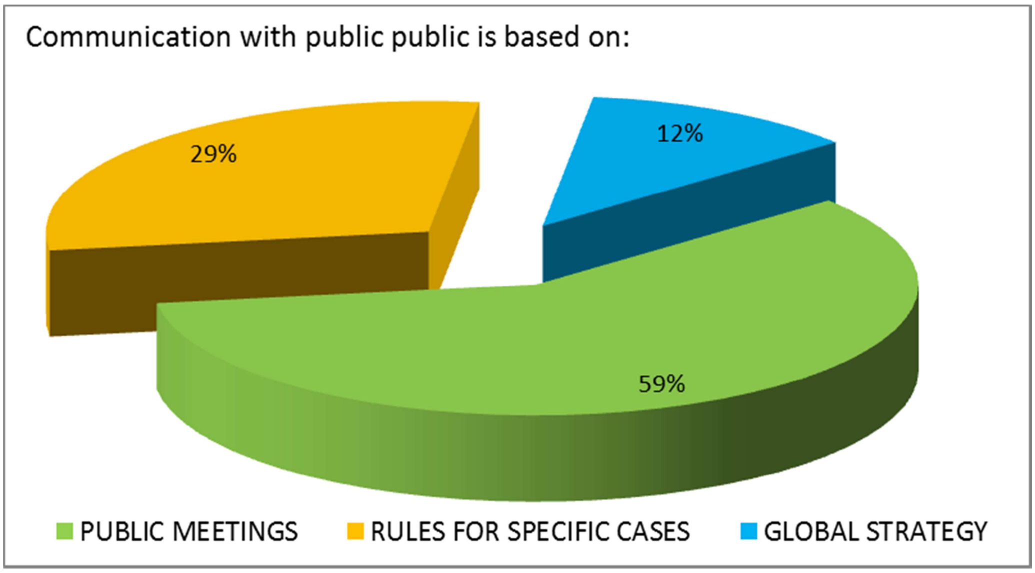


Figure 5.11 Communication with public

Some good practices have been recorded in the companies as

- making early contact with the public ,
- attending meetings where people can be informed of the project key milestones,
- organizing information forums for authorities and local residents ,
- publishing newsletters

- giving regular information through specific website

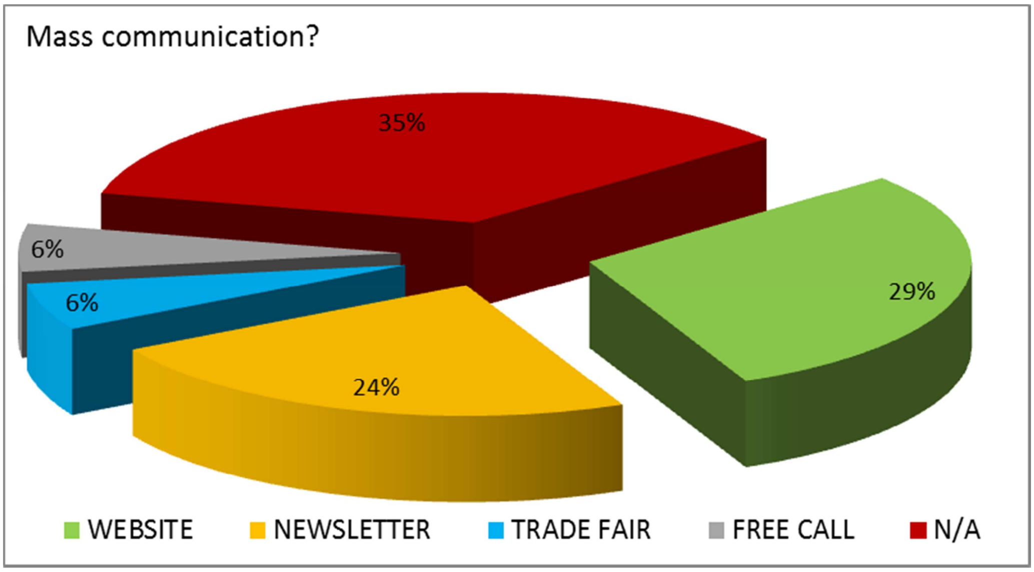


Figure 5.12 Mass communication

Editing regular newsletter of a project contributes to maintain a contact and the thread of information with the public. Similarly, scheduling common actions with local authorities and other stakeholders may have a training effect (DOC=depends on case).

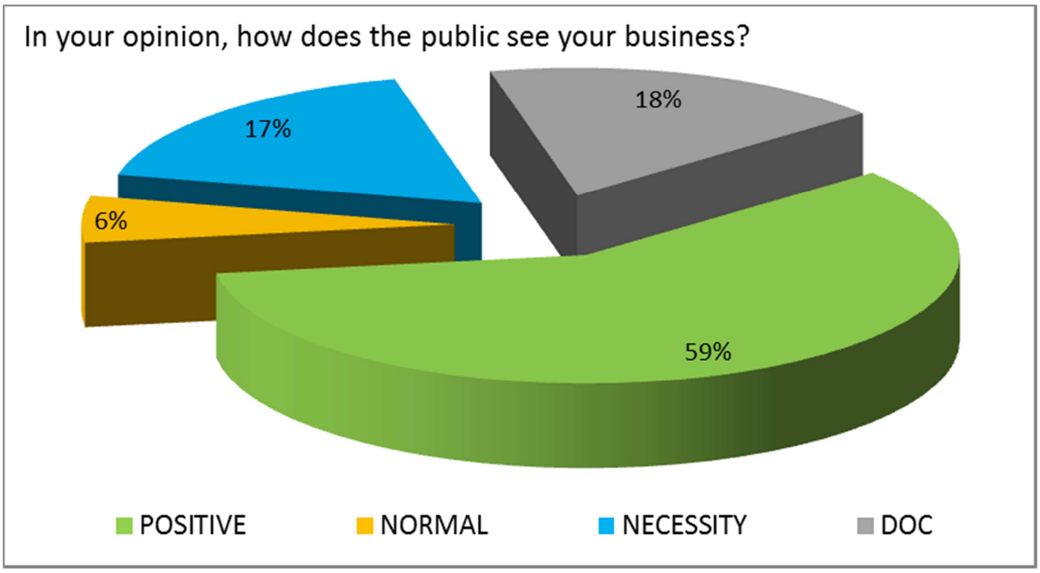


Figure 5.13 Signification of DOC

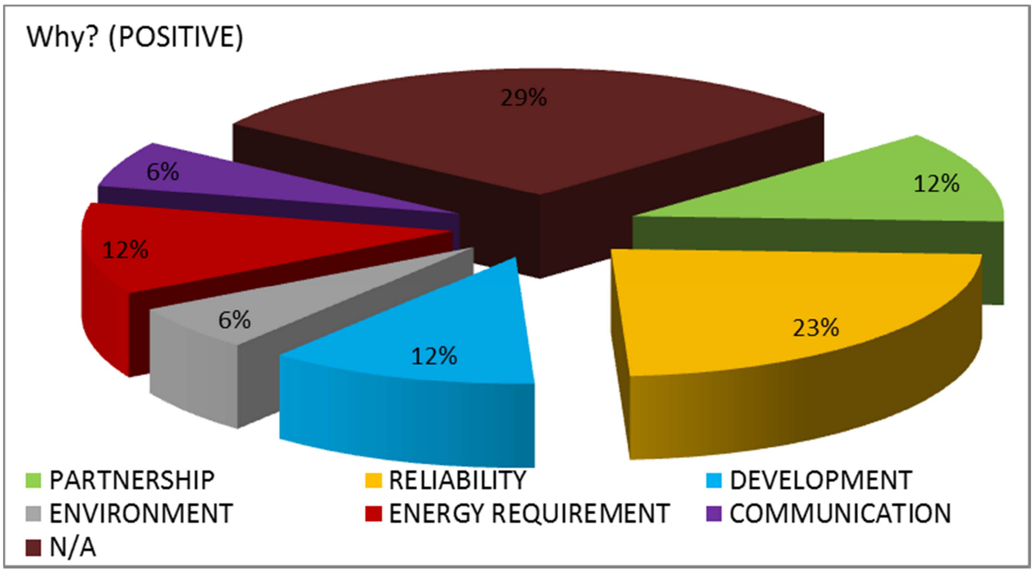


Figure 5.14 Positive perception

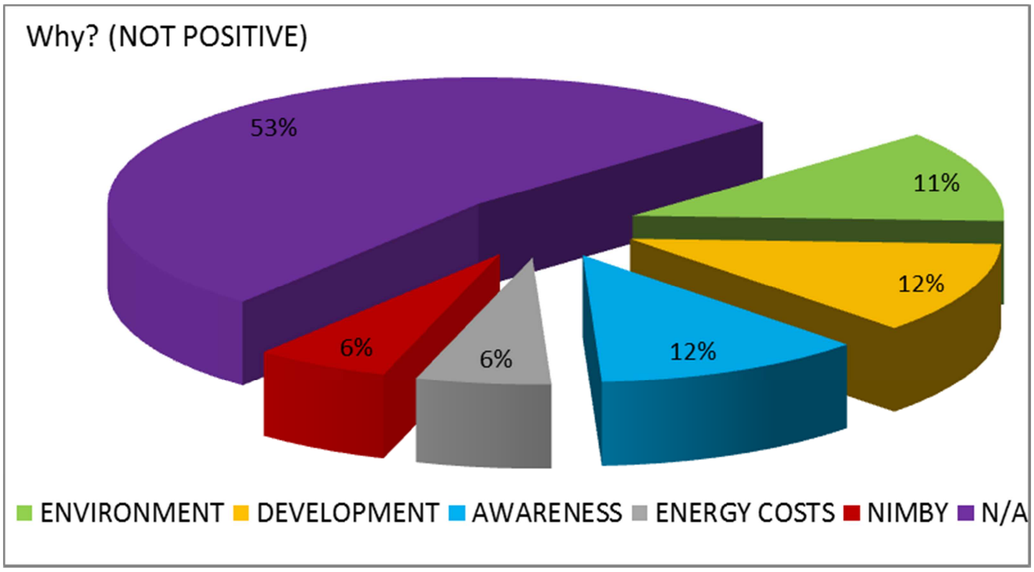


Figure 5.15 Not positive perception

Table 5.7 In your opinion, how does the public see your business?	
A) As a necessity for the public at large. C) Mainly positive H) We generally have a fine communication and understanding with the public. We have high standards for informing the public that can be affected by our activities both directly and through the newspapers etc. I) The company, due to his young age, is little known to the general public. This lack of awareness makes it more the issue of communication in connection with the construction of a new book as	Europe

we speak to an audience that does not know our business and our expertise. This means that the way an individual perceives the activity of our company is related to how to place the project in the vicinity of his home. It is hoped that people perceive our company as a concerned corporate environmental, agricultural activity and eager to promote economic activity in the territories. J) As reliable and prudent. S) Positive evaluation is prevailing; we are considered as reliable, stable partner. T) Gas transmission business well known and appreciated (e.g. traditionally as a good employer and business partner) in regions of operation. W) In our opinion the public, especially where we have a long and well established operational experience, considers our company reliable, safe and environmentally sustainable.	
F) As a noisy activity. L) Very courageous and noble job. In certain cases they see it as an aggression. N) Not usually happy - complains about the bills.	Nord Africa
G) Safe, reliable, and responsible to public. O) Urban area: Customer needs gas to have comfortable life. Most people need gas. Suburban area: Residential people know importance of gas supply, but they don't want pipelines in their front of their house.	Asia
D) The perception is very variable, since places where they see us as a way to improve the development, to places where they see us as the opposite. K) Company has recently accomplished a survey with landowners and neighbors of the pipeline, with the following results: 92% of this public knows the company; 83% considers the company very important to the country development; 81% are aware of security procedures (what is allowed or not) along the right-of-way; 62% perceives the company as close to them.	South America

5.2.4.2 Influence of the local habits and customs

Topics of concern may vary from one region to another depending on habits, sensitivity, and history.

In urban areas for example, the compatibility between the infrastructure and the urban development may be at stake.

5.2.4.3 Influence of existing gas infrastructure in the area

In areas with existing gas infrastructure, people are already used to the relationship with operator and generally are used to the infrastructure. The good or bad memories of the previous construction may also influence local acceptance.

The main characteristics of the infrastructure (nominal diameter, compression power installed, area of compressor station…) may also influence the perception of the public.

5.2.5 Environmental and Social Impact Assessment (SIA)

Environmental and social impact assessment (ESIA) is the systematic process of identifying and assessing the potential effects on the biophysical, socioeconomic, cultural heritage and environment as a consequence of a project or development. As a planning tool, the ESIA aims to ensure that environmental, social and cultural heritage issues throughout the entire project lifecycle are anticipated and considered by the project proponent. It also serves as a framework for establishing project controls to reduce or prevent adverse environmental, socio-economic and cultural heritage impacts and enhance positive impacts.

An ESIA is a must. Multilateral development banks, including the European Bank for Reconstruction & Development (EBRD), the Equator Principles Financial Institutions (EPFIs) and export credit agencies through the OECD Common Approaches are increasingly drawing on these kind of standards (EBRD or "equator" principles) in order to ensure that the projects they finance and advise on are developed in a manner that is socially responsible and reflects sound environmental management practices.

According to EC Directive the thresholds and/or screening applications determine whether or not ESIA is required:

- Oil/gas/chemical pipelines >40km and >800mm ➔ mandatory EIA
- Other oil/gas/chemical pipelines – Member States set thresholds

Who:

- Developer's responsibility
- Independent organisation
- Best practice, and mandatory in some countries
- May need to be registered as EIA assessors (e.g. Peru, Tanzania, Turkey)

When:

- Begin as early as possible
- Iterative process – ES submitted with application, but impact assessment continues throughout life of project

Timescale:

- Allow at least 1 year for ecological studies
- Consent takes usually 6 – 18 months depending on country and its legislation

(source: Swan, J., Identifying and Managing Environmental Issues, Onshore Pipeline Engineering Course, London, 12th June 2013, www.rsk.co.uk)

5.2.6 Social & Environmental Investment (SEI)

The Social Impact Assessment (SIA) is a fundamental part of the ESIA process and especially for cross-border pipeline projects often is connected to a voluntary social & environmental investment (SEI) program. SEIs are not mitigation or compensation measures for adverse impacts and aim to generate, as any other business investment, returns. Experience shows that up-front investments in relationship-building with local communities and partners pay significant dividends during times of conflict or crisis and will support the project´s effort to obtain and maintain an overall social consent to operate the pipeline.

In general pipeline projects contribute to the socio-economic advancement of its host regions or countries through the payment of tariffs, fees and taxes, through employment and through economic opportunities associated with the procurement of goods and services. As a rule international projects often commit themselves in their Policies on Corporate Social Responsibility (CSR) to enhance through social and environmental investments living conditions in neighboring communities and biodiversity as well as forest cover in and around critical habitats.

To assure that SEI provide sustainable benefits to communities and/or the environment as well as generate – non-monetary – revenues for the investors, the International Finance Corporation (IFC) for instance have distilled the following principles:

Strategic

- Activities flow from the CSR policy through this strategy to the entire supply chain
- A strategic mix of investments addresses both short and long-term objectives
- Focuses on key areas where the project can most effectively leverage its role/competencies
- Evolves with the business phase and uses different approaches along the project cycle

Aligned

- Aligns SEI with communities, civil society and government to create "shared value"
- Coordinates SEI with ESIA, land easement and acquisition / right of way (RoW) measures, stakeholder engagement and local content development
- Promotes cross-functional coordination and responsibility for supporting SEI objectives

Multi-stakeholder driven

- Positions the project as partner in multi-stakeholder processes as this adds value by building local ownership and complementarity around shared interests
- Supports partners in defining and meeting their own development goals and aspirations

Sustainable

- Seeks to avoid dependency, encourage self-reliance, and create long-term benefits
- Before commencement all activities require a viable exit or handover strategy
- Reinforces, rather than replaces, local institutions and processes where feasible

Measurable

- Measures returns to project, local communities and the environment
- Uses outcome/impact indicators to measure the quantity and quality of change
- Tracks changes to gain real-time feedback on performance
- Uses participatory methods to build trust and local ownership of outcomes
- Proactively communicates the generated value to internal and external audiences

Key social and health issues for pipelines *(source: Swan, J., Identifying and Managing Environmental Issues, Onshore Pipeline Engineering Course, London, 12th June 2013, www.rsk.co.uk)*

- Land-take and land appropriation
- Disruption to agriculture and other land uses
- Community safety – traffic, excavations, machinery
- Nuisance – noise, dust, traffic
- Sterilisation of mineral reserves
- Restrictions on building
- Communicable diseases
- Reduced remoteness for some communities
- Employment and trade opportunities

5.3 Stakeholder management

An approach of pipeline projects from Project Managers Institute (PMI) new Knowledge Area.

The objective of this chapter is, first of all, to share definitions, processes and descriptions of the Stakeholder Management according the Project Management Institute (PMI). The last edition of the Project Management Body of Knowledge (PMBOK) brings the recognition of the importance of this theme in project lifecycle. The ability of the project manager to correctly identify and manage these stakeholders in an appropriate manner can mean the difference between success and failure. Thus, we select some parts of the PMBOK, in the 5th Edition, where the Stakeholder Management assumes the status of a Knowledge Area. Second, we try to insert some connections to the gas pipeline projects. As any major infrastructure projects, the significance of the suitable Stakeholder Management increases, considering that the voices against always are louder than the voices in favor.

Everyone agree with the importance of a gas pipeline and how valuable it is for a country, a state or a municipality. Gas pipelines are an important energy transport way and means economic development for a region.

Natural gas is an AAA (achievable, affordable and acceptable) source of energy, and its use as energetics is important for industries that require rigid processes control to provide high quality to their products, as glass, chemical, pharmaceutical and many kinds of ceramics. Natural Gas is also a raw material for the fertilizers segment, fundamental to allow high efficiency to agricultural production.

From an environmental perspective, natural gas is friendly. It is the cleanest fossil fuel, and it allows a remarkable reduction in the emissions level. This reduction can reach about 60% for NOx compared to oil or coal, and is near zero for SOx emissions. Hence, Natural Gas is a key for a cleaner air in our world. The use as fuel in vehicles can make ours cities a better place to live. Beyond the well-being provided for better environmental conditions, there are savings in health care costs.

Thus, we can realize that everyone cheers for new pipelines. Well, unless it crosses your backyard.

This reaction is not an issue related exclusively to gas pipelines, but it’s not a rare phenomenon in many infrastructure projects. As a rule, people that lives too close to infrastructure projects doesn’t see them with good eyes. Obviously, some impacts are unbearable. Everyone likes good public transportation, but nobody would applaud a railway station near home if the price to pay is wake up with the bed rumbling. But, why even with the actions to avoid any disturbance, why even before a clear understanding of the benefits, in many cases the rejection precedes the the words in defense of the project? It’s imperative to realize people´s rationality behind this behavior, and reflect about how the effective Stakeholders Management allow the proper engagement.

Often, the reaction turns into explicit protests and complaints even in the very beginning. This situation often means delays, risks and increasing costs for the projects. In extreme situations, it can jeopardize a project that could bring concrete benefits even for those struggling against it.

Have we been doing the best to avoid these issues? How can we improve the public confidence in the technical solutions developed to provide safety and reliability to the gas pipelines' operations?

Even when in majority, the public that approve and recognizes the benefits and support a specific project never go out carrying banners, nor blocks roads for a manifestation. It's not a criticism for those who disagree, considering the principle of everyone can express his/her opinions, concerns and worries, respecting the law. The point is, whether these people are enough informed for a comprehensive judgment or not? If there's a lack of information, knowledge or a misunderstood point, Stakeholder Management can helps in solution.

An important aspect to be evaluated is: what level of information should be appropriate for each public? Technical jargon probably won't reach the target for non-technical people. When technical details are necessary – and they often are - for the comprehension of the entire process, they should be carefully "translated" to a common speech.

Gas pipelines have another particularity: people know they are there, but usually they are not visible. It means that many safety, operation and maintenance procedures are not seen, as well. Differently of a road or a railway, where almost everything is visible for the public, there are a lot of procedures in a gas pipeline that are not perceptible.

Cathodic protection and pipeline inlet gauges ("PIG") runs are, for example, costly and important routines that may be not enough known by the big audience. The same way, supervisory systems and remote controls using top technology are used to ensure that the operation meets rigid safety requirements and standards are not exposed to the public. This "invisible" operation and maintenance can result in a wrong impression about how things work in gas transportation. Many times, the perception of the surrounded population is that someone had buried a large pipe and just said "goodbye". Again, the key point is to find the right bias to make the information reaches the public in a crystal clear way. For sure, the confidence in the operation and maintenance of the system will reduce the concerns.

For example, special kinds of stakeholders are landowners and population near the pipeline. When people and gas pipelines are not too far each other, two points usually are in perspective: protect people from the gas pipeline and protect the gas pipeline from the people. From this perspective, the distance separating the pipeline system (gas pipeline and above ground installations, as well) is a good driver for stakeholders identification. The landowner are highly influenced, in particular concerning the restrictions for the use of their own property (heavy machines traffic, drilling for water sources, constructions, culture of plants with deep roots, etc). It's reasonable to realize a special effort in communication to stablish and control their engagement.

The objective of the Stakeholder Management is to allow the most precise view to everyone affected by the project, and try to fulfill their expectations in the best way. According to the PMI's definition, the Stakeholders Management includes:

- Identify Stakeholders
- Plan Stakeholders Management
- Manage Stakeholder Engagement
- Control Stakeholder Engagement

These points will be more detailed later in this material.

But what is a Stakeholder? According to the PMI "stakeholder is an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project. Stakeholders may be actively involved in the project or have interests that may be positively or negatively affected by the performance or completion of the project. Different stakeholders may have competing expectations that might create conflicts within the project. Stakeholders may also exert influence over the project, its deliverables, and the project team in order to achieve a set of outcomes that satisfy strategic business objectives or other needs. Project governance—the alignment of the project with stakeholders' needs or objectives—is critical to the successful management of stakeholder engagement and the achievement of organizational objectives. Project governance enables organizations to consistently manage projects and maximize the value of project outcomes and align the projects with business strategy. It provides a framework in which the project manager and sponsors can make decisions that satisfy both stakeholder needs and expectations and organizational strategic objectives or address circumstances where these may not be in alignment".

It's a long definition, and it reaches the project team as well as all interested entities that are internal or external to the organization. One of the most important role of the project manager should be manage the influences of these various stakeholders in relation to the project requirements to ensure a successful outcome. The Figure 5.16 shows a diagram of the relationship between the project, the project team, and various stakeholders.

Again, according to PMI, stakeholders have varying levels of responsibility and authority when participating on a project. This level can change over the course of the project's life cycle. Their involvement may range from occasional contributions in surveys and focus groups to full project sponsorship that includes providing financial, political, or other support. Every project will have stakeholders who are impacted by or can impact the project in a positive or negative way. While some stakeholders may have a limited ability to influence the project, others may have significant influence on the project and its expected outcomes.

Some stakeholders may also detract from the success of the project, either passively or actively. These stakeholders require the project manager's attention throughout the project's life cycle, as well as planning to address any issues they may raise.

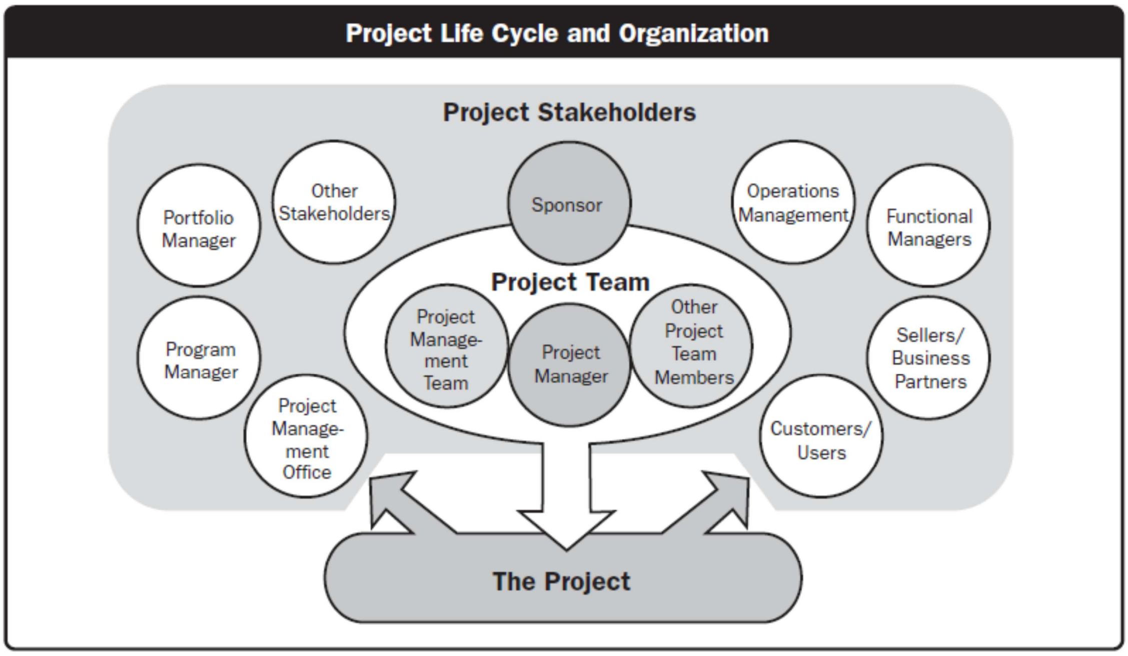


Figure 5.16 Relationship between stakeholders and project
(Source PMBOK 5h. Ed.)

Stakeholder identification is a continuous process throughout the entire project life cycle. Identifying stakeholders, understanding their relative degree of influence on a project, and balancing their demands, needs, and expectations are critical to the success of the project. Failure to do so can lead to delays, cost increases, unexpected issues, and other negative consequences including project cancellation. An example is late recognition that the legal department is a significant stakeholder, which results in delays and increased expenses due to legal requirements that are required to be met before the project can be completed or the product scope is delivered.

Just as stakeholders can positively or adversely impact a project's objectives, a project can be perceived by the stakeholders as having positive or negative results. For example, business leaders from a community who will benefit from an industrial expansion project will see positive economic benefits to the community in the form of additional jobs, supporting infrastructure, and taxes. In the case of stakeholders with positive expectations for the project, their interests are best served by making the project successful. In contrast, the interests of negatively affected stakeholders, such as nearby homeowners or small business owners who may lose property, be forced to relocate, or accept unwanted changes in the local environment, are served by impeding the project's progress.

Overlooking negative stakeholder interests can result in an increased likelihood of failures, delays, or other negative consequences to the project. As we said before, an important part of a project manager's responsibility is to manage stakeholder expectations, which can be difficult because stakeholders often have very different or conflicting objectives. Part of the project manager's responsibility is to balance these interests and ensure that the project team interacts with stakeholders in a professional and cooperative manner. Project managers may involve the project's sponsor or other team members from different locations to identify and manage stakeholders that could be dispersed around the world. The following are some examples of project stakeholders:

• **Sponsor.** A sponsor is the person or group who provides resources and support for the project and is accountable for enabling success. The sponsor may be external or internal to the project manager's organization. From initial conception through project closure, the sponsor promotes the project. This includes serving as spokesperson to higher levels of management to gather support throughout the organization and promoting the benefits the project brings. The sponsor leads the project through the initiating processes until formally authorized, and plays a significant role in the development of the initial

scope and charter. For issues that are beyond the control of the project manager, the sponsor serves as an escalation path. The sponsor may also be involved in other important issues such as authorizing changes in scope, phase-end reviews, and go/no-go decisions when risks are particularly high. The sponsor also ensures a smooth transfer of the project's deliverables into the business of the requesting organization after project closure.

• **Customers and users.** Customers are the persons or organizations who will approve and manage the project's product, service, or result. Users are the persons or organizations who will use the project's product, service, or result. Customers and users may be internal or external to the performing organization and may also exist in multiple layers. For example, the customers for a new pharmaceutical product could include the doctors who prescribe it, the patients who use it and the insurers who pay for it. In some application areas, customers and users are synonymous, while in others, customers refer to the entity acquiring the project's product, and users refer to those who will directly utilize the project's product. In the same way, for the gas industry, the customers for a new transmission pipeline can be the distribution companies and the final users.

• **Sellers.** Sellers, also called vendors, suppliers, or contractors, are external companies that enter into a contractual agreement to provide components or services necessary for the project.

• **Business partners.** Business partners are external organizations that have a special relationship with the enterprise, sometimes attained through a certification process. Business partners provide specialized expertise or fill a specified role such as installation, customization, training, or support.

• **Organizational groups.** Organizational groups are internal stakeholders who are affected by the activities of the project team. Examples of various business elements of an organization that may be affected by the project include marketing and sales, human resources, legal, finance, operations, manufacturing, and customer service. These groups support the business environment where projects are executed, and are therefore affected by the activities of the project. As a result, there is generally a significant amount of interaction between the various business elements of an organization and the project team as they

work together to achieve project goals. These groups may provide input to requirements and accept deliverables necessary for a smooth transition to production or related operations.

• **Functional managers.** Functional managers are key individuals who play a management role withinan administrative or functional area of the business, such as human resources, finance, accounting, or procurement. They are assigned their own permanent staff to carry out the ongoing work, and they have a clear directive to manage all tasks within their functional area of responsibility. The functional manager may provide subject matter expertise or their function may provide services to the project.

• **Other stakeholders.** Additional stakeholders, such as procurement entities, financial institutions, government regulators, subject matter experts, consultants, and others, may have a financial interest in the project, contribute inputs to the project, or have an interest in the outcome of the project. This group can be particulary difficult to handle, because it can encompass many different stakeholders with a great diversity of needs and expectations. Enviromental questions, safety concerns, issues involving licenses and authorizations will probably arise from this group.

For a gas pipeline company, we can identify many different stakeholders, for example:

- Shareholders
- Final customers
- Counselors
- Communities surrounding the right-of-way
- Scientific and Academic Community
- Steering Committee
- Gas Distributors
- Suppliers
- Workforce families
- Workforce
- Press
- Gas and Energy Industry entities
- Civil Society Organizations
- Regulation Agency
- Environmental Agencies
- Government
- Unions

The Stakeholder Management will help to address this complexity through the application of the processes required to identify the people, groups, or organizations that could impact or be impacted by the project, to analyze stakeholder expectations and their impact on the project, and to develop appropriate management strategies for effectively engaging stakeholders in project decisions and execution.

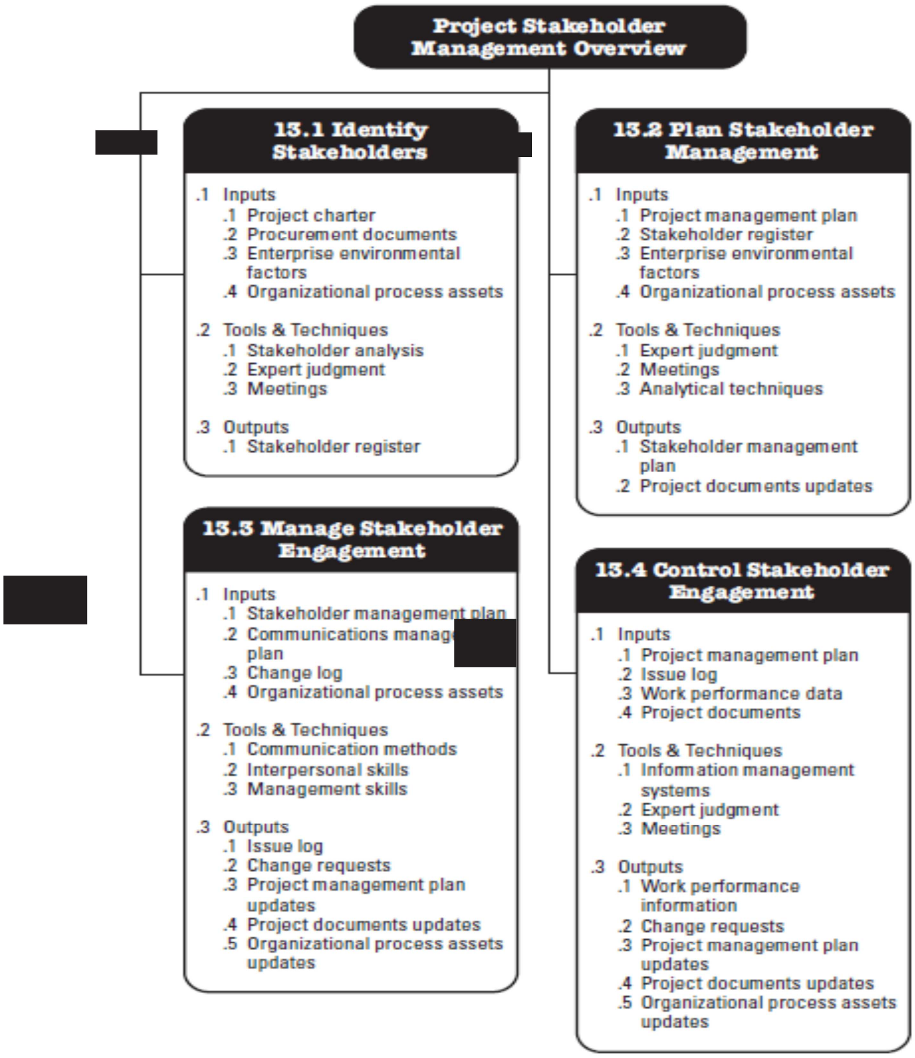


Figure 5.17 Project Stakeholder Management Overview
(Source PMBOK 5h. Ed.)

Stakeholder management also focuses on continuous communication with stakeholders to understand their needs and expectations, addressing issues as they occur, managing conflicting interests and fostering appropriate stakeholder engagement in project decisions and activities. Stakeholder satisfaction should be managed as a key project objective. Figure 5.17 provides an overview of the Project Stakeholder Management Processes.

We can detail each process according as below:

5.3.1 Identify Stakeholders

Identify Stakeholders is the process of identifying the people, groups, or organizations that could impact or be impacted by a decision, activity, or outcome of the project, analyzing and documenting relevant information regarding their interests, involvement, interdependencies, influence, and potential impact on project success. The key benefit of this process is that it allows the project manager to identify the appropriate focus for each stakeholder or group of stakeholders. The inputs, tools and techniques, and outputs of this process are depicted in Figure 5.18.

Figure 5.18 Identify Stakeholders: Inputs, Tools & Techniques, and Outputs (Source PMBOK 5h. Ed.)

Emphasizing the Stakeholder Analysis, that we consider the key tool of this process, it is described as a technique of systematically gathering and analyzing quantitative and qualitative information to determine whose interests should be taken into account throughout the project. It identifies the interests, expectations, and influence of the stakeholders and relates them to the purpose of the project. It also helps to identify stakeholder relationships (with the project and with other stakeholders) that can be leveraged to build coalitions and potential partnerships to enhance the project's chance of success, along with stakeholder relationships that need to be influenced differently at different stages of the project or phase. Stakeholder analysis generally follows the steps described below:

• Identify all potential project stakeholders and relevant information, such as their roles, departments, interests, knowledge, expectations, and influence levels. Key stakeholders are usually easy to identify. They include anyone in a decision-making or management role who is impacted by the project outcome, such as the sponsor, the project manager, and the primary customer. Identifying other stakeholders is usually done by interviewing identified stakeholders and expanding the list until all potential stakeholders are included.

• Analyze the potential impact or support each stakeholder could generate, and classify them so as to define an approach strategy. In large stakeholder communities, it is important to prioritize the stakeholders to ensure the efficient use of effort to communicate and manage their expectations.

• Assess how key stakeholders are likely to react or respond in various situations, in order to plan how to influence them to enhance their support and mitigate potential negative impacts.

There are multiple classification models used for stakeholders analysis, such as:

• Power/interest grid, grouping the stakeholders based on their level of authority ("power") and their level or concern ("interest") regarding the project outcomes;

• Power/influence grid, grouping the stakeholders based on their level of authority ("power") and their active involvement ("influence") in the project;

• Influence/impact grid, grouping the stakeholders based on their active involvement ("influence") in the project and their ability to effect changes to the project's planning or execution ("impact"); and

• Salience model, describing classes of stakeholders based on their power (ability to impose their will), urgency (need for immediate attention), and legitimacy (their involvement is appropriate).

Figure 5.19 presents an example of a power/interest grid with A-H representing the placement of generic stakeholders.

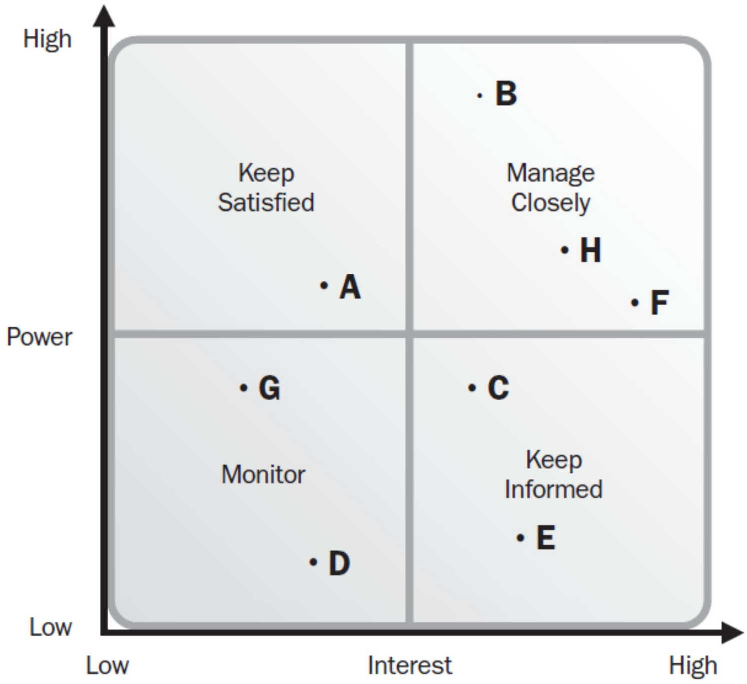


Figure 5.19 Example Power/Interest Grid with Stakeholders (Source PMBOK 5h. Ed.)

Each company can develop a specific tool to help the stakeholder mapping. One example of how to conduct is showed below:

1. List the stakeholders, asking, "who can influence the success of project implementation, and who can be impacted by project implementation?". Stakeholders should be grouped into meaningful clusters as appropriate.

2. Ask, "to what degree do they have the power to influence the success of the project?". The answer will be used to assign the stakeholder to one of the following groups.

1 = Little power/ influence over project outcomes;

2 = Some influence over project outcomes

3 = Moderate influence over project outcomes

4 = Major influence over project outcomes

5 = Without support from this stakeholder, the project is doomed to failure

3. After this step, ask: "what is this stakeholder's current level of engagement to the project? How Favorably do they view the project?" As the previous step, assign one of the following numbers:

1 = Negative, actively or subversively working against

2 = Moderately negative, passive resistance

3 = Neutral

4 = Moderately positive, passive support

5 = This is great, I'm in, an active supporter

4. Ask, "for this project, what does success look like to this stakeholder, what would they consider to be wins?"

5. Identify proactive actions to achieve these "wins", and to engage them to increase their favorability.

6. Add the actions to the implementation plan, communications plan, sponsor shaping or other tools that ensure these actions are incorporated into the plans to move these stakeholders forward.

The main output of the Identify Stakeholders process is the stakeholder register. This contains all details related to the identified stakeholders including, but not limited to:

• Identification information. Name, organizational position, location, role in the project, contact information;

• Assessment information. Major requirements, main expectations, potential influence in the project, phase in the life cycle with the most interest; and

• Stakeholder classification. Internal/external, supporter/neutral/resistor, etc.

The stakeholder register should be consulted and updated on a regular basis, as stakeholders may change — or new ones identified — throughout the life cycle of the project.

5.3.2 Plan Stakeholder Management

Plan Stakeholder Management is the process of developing appropriate management strategies to effectively engagement stakeholders throughout the project life cycle, based on the analysis of their needs, interests, and potential impact on project success. The key benefit of this process is that it provides a clear, actionable plan to interact with project stakeholders to support the project's interests. The inputs, tools and techniques, and outputs of this process are depicted in Figure 5.20.

Plan Stakeholder Management identifies how the project will affect stakeholders, which then allows the project manager to develop various ways to effectively engage stakeholders in the project, to manage their expectations, and to ultimately achieving the project objectives. Stakeholder management is more than improving communications and requires more than managing a team. Stakeholder management is about creation and maintenance of relationships between the project team and stakeholders, with the aim to satisfy their respective needs and requirements within project boundaries.

This process generates the stakeholder management plan, which contains detailed plans on how effective stakeholder management can be realized. As the project progresses, the membership of the stakeholder community and required level of engagement may change, therefore, stakeholder management planning is an iterative process that is reviewed on a regular basis by the project manager.

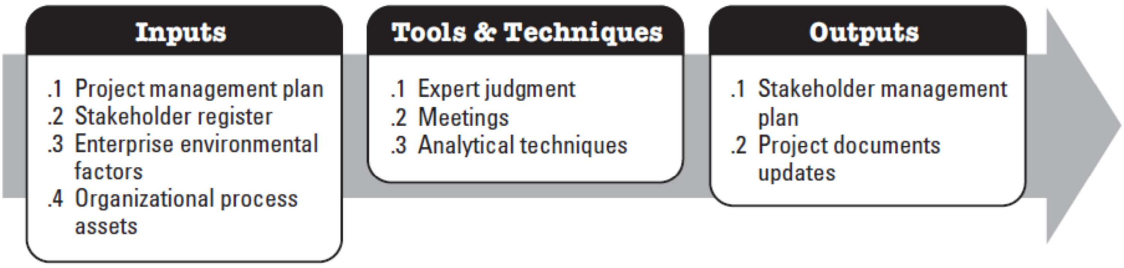


Figure 5.20 Plan Stakeholder Management: Inputs, Tools & Techniques, and Outputs (Source PMBOK 5h. Ed.)

One important technique involves the generation of an Engagement. The current engagement level of all stakeholders needs to be compared to the planned engagement levels required for successful project completion. Stakeholder engagement throughout the life cycle of the project is critical to project success. The engagement level of the stakeholders can be classified as follows:

• Unaware. Unaware of project and potential impacts.

• Resistant. Aware of project and potential impacts and resistant to change.

• Neutral. Aware of project yet neither supportive nor resistant.

• Supportive. Aware of project and potential impacts and supportive to change.

• Leading. Aware of project and potential impacts and actively engaged in ensuring the project is a success.

The current engagement can be documented using Stakeholders Engagement Assessment Matrix, as shown in Figure 5.21, where C indicates the current engagement, and D indicates the desired engagement. The project team needs to identify the desired engagement level for the current phase of the project, based on available information. The example shows that stakeholder 3 is at the desired engagement level, while stakeholders 1 and 2 require further communications and additional actions to move them to the desired level of engagement.

Stakeholder	Unaware	Resistant	Neutral	Supportive	Leading
Stakeholder 1	C			D	
Stakeholder 2			C	D	
Stakeholder 3				D C	

Figure 5.21 Stakeholders Engagement Assessment Matrix (Source PMBOK 5h. Ed.)

5.3.3 Manage Stakeholder Engagement

Manage Stakeholder Engagement is the process of communicating and working with stakeholders to meet their needs/expectations, address issues as they occur, and foster appropriate stakeholder engagement in project activities throughout the project life cycle. The key benefit of this process is that it allows the project manager to increase support and minimize resistance from stakeholders, significantly increasing the chances to achieve project success. The inputs, tools and techniques, and outputs of this process are depicted in Figure 5.22.

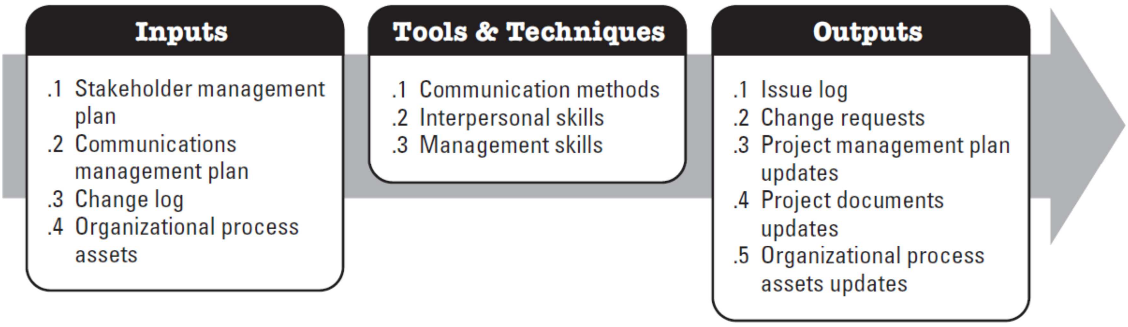


Figure 5.22 Manage Stakeholder Engagement: Inputs, Tools & Techniques, and Outputs (Source PMBOK 5th. Ed.)

Manage Stakeholder Engagement involves activities such as:

• Engaging stakeholders at appropriate project stages to obtain or confirm their continued commitment to the success of the project;

• Managing stakeholder expectations through negotiation and communication, ensuring project goals are achieved;

• Addressing potential concerns that have not yet become issues and anticipating future problems that may be raised by stakeholders. Such concerns need to be identified and discussed as soon as possible to assess associated project risks; and

• Clarifying and resolving issues that have been identified.

5.3.4 Control Stakeholder Engagement

Control Stakeholder Engagement is the process of monitoring overall project stakeholder relationships and adjusting strategies and plans for engaging stakeholders. The key benefit of this process is that it will maintain or increase the efficiency and effectiveness of stakeholder engagement activities as the project evolves and its environment changes. The inputs, tools and techniques, and outputs of this process are depicted in Figure 5.23. Stakeholder engagement activities are included in the stakeholder management plan and are executed during the life cycle of the project. Stakeholder engagement should be continuously controlled.

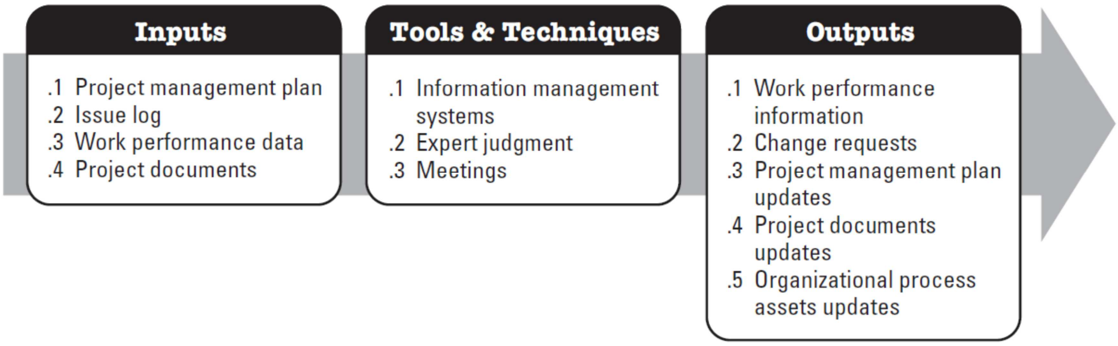


Figure 5.23 Control Stakeholder Engagement: Inputs, Tools & Techniques, and Outputs (Source PMBOK 5th. Ed.)

As a conclusion, we can consider that gas pipelines projects demand a rigid attention in managing the relationship with the stakeholders should start early in the project and have to be continuously monitored after the deployment, during the operations.

The four processes (Identy Stakeholders, Plan Stakeholders Management, Manage Stakeholder Engagement and Control Stakeholder Engagement) encompass the diverse aspects of a critical area for projects. For gas pipelines, considering the characteristics of these projects, it assumes more importance. Environmental concerns, regulatory framework and land property rights are some important aspects that should be addressed.

5.4 Effective communication with the public

The IGU/WOC3 issued a questionnaire on the subject and distributed it to all IGU/WOC3 members in autumn 2013. The focus of the research including the data collection and their analysis was on the following topics:

- internal processes of the public communication;
- interaction with the community around technological facilities;
- regulations on communication with the public.

The integrated results of the received data and the detailed answers from four member companies provide comprehensive overview in this area.

5.4.1 Internal processes of the public communication

Table 5.6 Please describe the internal processes your company has in order to communicate with the public.

A) One of our major rules is "we respect our neighbors" and therefore we organize neighbor days for the people living in the close vicinity of our stations. People know that they can ask for a visit and/or consult. H) Public meetings based on internal assessment for individual projects. For all new projects a communication plan is normally set up. General for installation in Operation we ensure that all stakeholders are informed of any activities that can have an effect. I) There is a department of Public Affairs and Sustainable Development (DAPDD) which is responsible for defining Strategies to promote the acceptability of infrastructure in the long term and to promote the role of the transportation of natural gas in the energy sector. Within this department, the director of sustainable development and that those responsible for institutional relations and communication strategy ensures the implementation of the strategy defined at the DAPDD. At each of the four regional divisions of the company, the strategy is relieved by a head of public affairs and communications manager. On national projects, communication and acceptability of projects are handled by the communications manager of engineering and consultation center cell under control DAPDD T) Communication with municipalities affected by operation of transmission system is direct on business level (regular business communication) or partially in cooperation with foundations. W) Our company communicates through several instruments: website, press releases, social networks. We also organize public meetings with local communities, "Open Day" in our operating sites, info point, educationals with primary and secondary schools. Finally, our company publishes books regarding specific projects and their impact on the environment and local community.	Europe
F) Yearly meeting with local authorities and public organizations. L) Meetings, trade fair, feeding the population by the gas energy (in certain cases)	Nord Africa
G) Networking / communication with the District Councilors / Local Representatives through the Company's District Council Focus Team	Asia

in various events over the years so that better communication / understanding between each others were established. O) Composing a brochure or document, the management confirms the contents, public communication with those documents.	
M) Public consultation is carried out for every project.	Australia
D) The communication with the public has different levels, from our neighbors to the public in general. In each case we develop a specific strategy in order to communicate in the most reliable way the message. K) Communication Plan which separates publics into two major subgroups: internal and external. These two segments of public are subdivided according to the subject of attention. The speech is adjusted to the target public in order to better fit in terms of understanding and language. For external public, every communication has to be submitted to the Communication Management who will analyze it and direct to the appropriate source inside the company.	South America

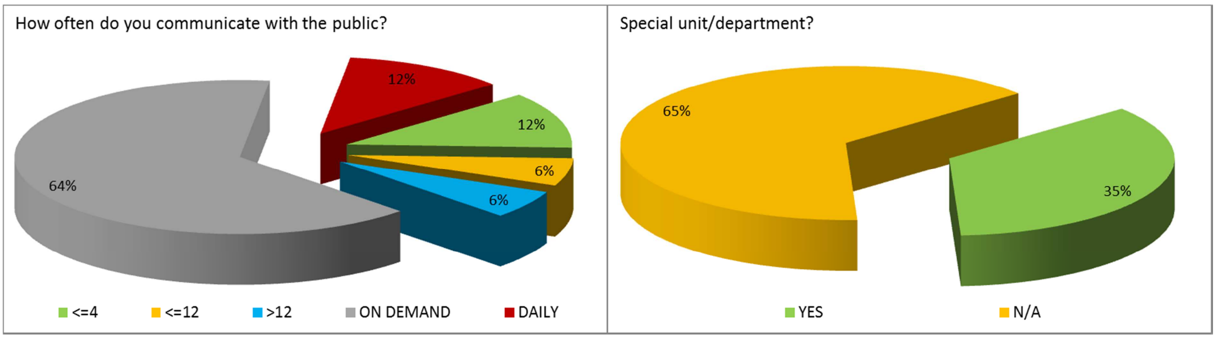


Figure 5.24 Way of communication

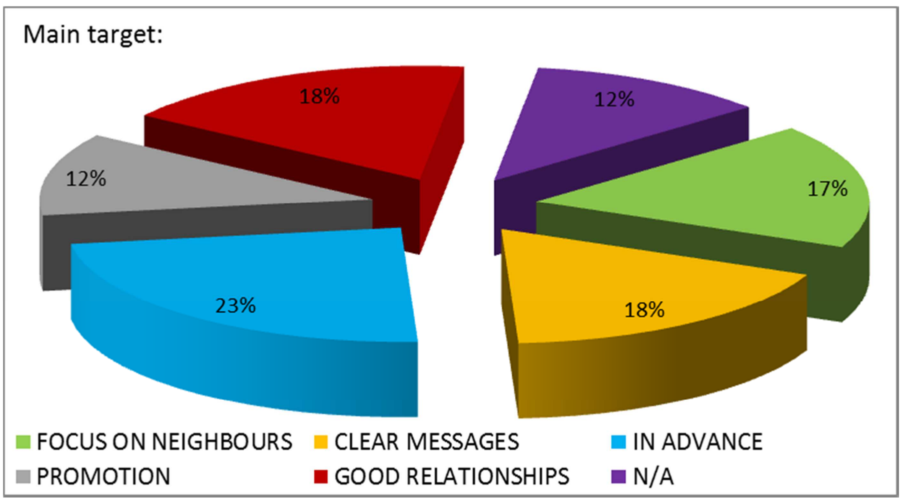


Figure 5.25 Main target of communication

5.4.2 Interaction with the community around technological facilities

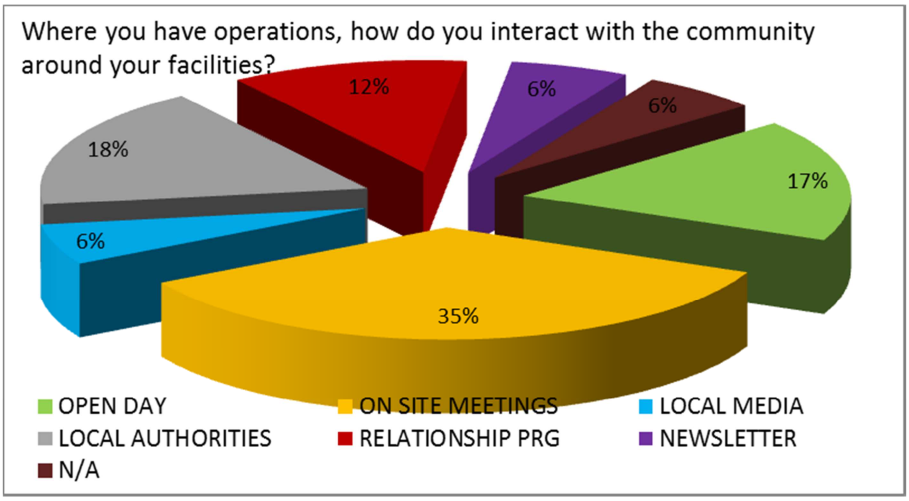


Figure 5.26 Interaction with the community

Table 5.7 Where you have operations, how do you interact with the community around your facilities?	
A) We invite them to come to neighbor days. H) Public meetings based on internal assessment for individual projects. For all new projects a communication plan is normally set up. General for installation in Operation we ensure that all stakeholders are informed of any activities that can have an effect. H) Normally, we invite the neighbors to one visit per year and have regularly briefings with the relevant approval authorities. I) We organize public meetings on the territories affected by our works to present the project answer questions from the public and consider how we can reduce the impact of our work in the area. These public meetings as held at different stages of the project: prior to the definition of a path, once a project defined route and before the start of construction. Between these public meetings, various meetings were held with stakeholders in our projects. They are organized in the form of bilateral or multilateral meetings. The meetings bring together civil society, environment and economic actors as well as representatives of the farming community and elected officials. Bilateral meetings are also held with residents of future work at the request of the latter and prélablement the signing of easement agreements. J) Meetings on each relevant location and through local media. In case of events through SMS to each household. T) Via Programe Municipality. This programme has been established	Europe

in cooperation with foundation as a part of their granting scheme. Its aim is to strengthen relationship and cooperation with municipalities via supporting of public good projects. Projects focused on: developing and improving the community life in the village, town and region; Preservation of cultural heritage; Protection, recovery or enhancement of environment are being supported within Programme Municipality. W) Public meetings with local community and Open Day in our operating sites.	
F) Through local authorities. N) By meetings with the community representatives.	Nord Africa
G) Mostly through the communication with the District Councilors / Local Representatives. O) We explain to neighborhood about the construction information in advance.	Asia
D) The communications are very different along the pipeline because of the different social environments we cross. The main interaction is face to face with our neighbors. K) We have a relationship program with communication guidelines and specific material containing details of our business and installations, and what is allowed or not in the surrounding area where the pipeline is buried, as well. A Safety Plans in case of an emergency is also included. The daily relationship occurs by our field technician professionals. These technical professionals are constantly trained in the communication processes and materials by Communication Management and have personal or remote support from the Communication Department.	South America

5.4.3 Regulations on communication with the public

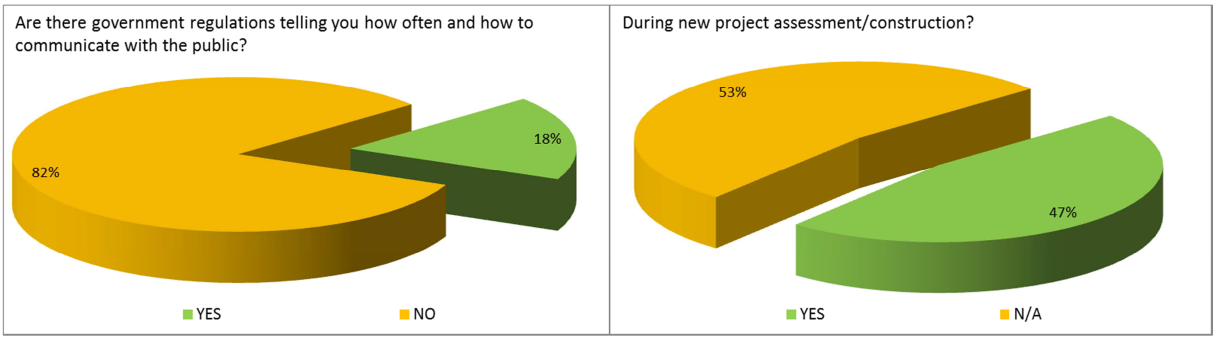


Figure 5.27 Regulations on communication with the public

Table 5.8 Are there government regulations telling you how often and how to communicate with the public?	
C) No regulations concerning how often to communicate during operation. During construction it is mandatory. H) No obligations for us to inform the public. However during the EIA process two public notifications are carried out by the authorities. Normally we, as the Owner/Builder are responsible for preparing the relevant documents and arranging the public meetings. T) In line with law and energy regulation is the company obliged to publish certain data (e.g. tariffs, capacities, financial statements) on the website. W) Regulations in our country impose arrangements for consulting the public only under the procedures of environmental impact assessment and integrated permit (construction permit and public utility).	Europe
N) The regulation asks an official communication when it is a commissioning, a shut down or any difficulty that affects gas delivery.	Nord Africa
M) No, for pipeline projects 30 days period is allowed to seek public view before the approval is granted. The regulation enforces to seek community and stakeholder consent and drives the implementation of consultation plan. The consultation plan includes a strategy on how often the consultation should be carried out.	Australia
D) The government does not establishes the frequencies neither how to communicate with the public. They only demand the operators to have a procedure and schedule. K) Yes, we do follow government regulations in communication aspects from the national environment institute and national oil and gas agency.	South America

5.5 Mitigation during and after technology construction

The analysis was conducted over five important pipeline projects in Europe and Asia. The total length of these pipelines exceeded 500 km. Their construction was carried out in 1998 - 2015.

5.5.1 Principal stakeholders

- Governments and governmental authorities in each country
- Regulatory and environmental authorities
- Regional, local and municipal authorities and representatives affected by the implementation
- Land owners and users affected by the implementation
- Residents in the relevant areas
- Investors and Contractors
- Specific adverse committees and initiatives

5.5.2 Management of construction site

The experience from the projects reveals a common approach of the investors which fully recognizes that economic development must coexist with the environment without neglecting the protection of the local area. Therefore the protection of environment is the basis of any corporate policy making processes. In fact, the criteria and procedures used for the location, design, construction, management and commissioning of pipelines, plants and related activities comply with high environmental protection standards, guaranteed usually by an HSE Policies and Environmental Management Systems, both the general and corporate ones.

High focus - from engineering phase till the operation - was put on environmental protection and re-instatement of the pipeline corridor; a dedicated environmental engineer as a member of the site crew was the benchmarking best practice. An involvement of independent expertise and supervision from independent institutions i.e. agricultural and environmental research had proven to be very useful.

During construction, many requirements and restrictions were respected. They were among others given by:

- Environmental Impact Assessment (EIA),
- Generally binding legal regulations,
- Further permits and statements of authorities, such as
  - ✓ suspension of the construction with respect to the nesting of birds in the working stripe,
  - ✓ change of the method of river crossing from an open-cut to the environmental friendly horizontal directional drilling technology,
  - ✓ restrictions regarding cutting trees down during vegetation period,
  - ✓ narrowing of the working strip in forest areas in order to reduce the impact on the environment,
  - ✓ environmentally protected areas were ordered to be crossed using a trenchless technology.

Health and safety at the workplace was being followed in accordance with the health and safety policies; more and more importance was given to the development of a culture of health prevention and risk protection. Safety supervision on the construction site is often provided by an external professional safety coordinator.

5.5.3 Major obstacles to overcome

- Weak support of general legislation – it gave no or limited power to overcome problems with land owners who had rejected to agree with easements at given conditions and compensations.
- No or limited space to mitigate excessive environmental restrictions (river crossings, bird protection zone, etc.).
- EIA – time consuming process.
- Lengthy permitting and authorization process.
- Requirements for prevention of siltation / turbidity in fresh water lakes and fjords.
- Pipeline installation on industrial contaminated seabed - seabed not to be disturbed during pipeline installation causing distribution of pollution.
- Resistance of specific adverse committees (locals, environmentalists, etc.).
- Many land owners and users (farmers) – excessive and time consuming negotiation about easements and conditions for handing the plots over after construction.
- Reconciliation of conflicts within reinstatement of the land to original state - farmers often wish to convert peat and heater land into a farmland.
- Restricted road-opening hours in urban areas resulted in limited time to work (night shifts).

5.5.4 Compensation for damages

Landowners are compensated for

- crop damages and losses,
- permanent right of access,
- restrictions to land use after pipeline installation,
- biological recultivation,
- any cost related to re-instatement and upgrade of agricultural drainage system,
- and last but not least for their attorneys.

All but one agreement were settled on voluntary basis; just one through the legal process of land expropriation.

Compensation for damages to crops and easements for private persons and businesses were usually paid on the basis of expert opinions and agreements.

Some investors were to ensure compensatory tree planting and landscaping work for affected areas.

Investors also paid environmental compensations to public bodies (Municipalities, Parks etc.) in these cases:

- Pipeline crossed protected areas;
- Local concern about an establishment of a compressor station.

5.5.5 Site revitalization after construction

In general, once a pipe has been positioned and buried, geomorphological and vegetative restoration is performed along the entire line. The final result of these projects is restoration of the soil to its original condition. The plots after reinstatement have to look as before construction. Where the land was converted to farmland it had been well planned to fit into the patchwork of existing landscape. Recovery of the land was monitored on a regular basis with an assistance of professional institutes.

It is common that a top soil (cca 30 cm) in the working strip must have been carefully put aside prior to the actual construction works. This topsoil was stored and protected, and finally spread back after the construction had finished.

5.5.6 Communication practice within and after construction

Investors presented the projects to the stakeholders adequately before the beginning of the authorization procedure. The communication was aimed to inform all stakeholders about the consequences and technical data of the project in a due time.

Intensive in-time communication is essential:

- To keep high level of interest of authorities and politicians to the project
- To gain incentives (regulatory/financial) for the project
- To establish and maintain good relations with land users and land owners

During the preparation and implementation of construction ongoing communication with:

- Regional and national medias
- Relevant regional offices and regional governors
- Municipalities nearby pipeline
- Deputies, senators, prime ministers, the government – ministries of economy, environment, interior etc.
- Community leaders - mayors, counsellors
- Professional and volunteer firefighters
- Police
- Civic associations

Investors communicate through several instruments:

- Website,
- Press releases,
- Social networks
- Written communication,
- Lobbying,
- Meetings.

There were also organized:

- Public meetings with local communities,
- "Open Days" on operational sites,
- Info points,
  On-site management team to communicate with the local stakeholders,
- Educational with primary and secondary schools.

Investors also published books regarding specific projects and their impact on the environment and local community.

5.6 Conclusion

5.6.1 Main points

- The gas transmission pipeline main impacts focus usually on landscape, bio diversity (forest, wet zone …) urbanization and agriculture.
- The gas transmission compressor station main impacts focus usually on landscape, pollution, noise.
- Comparing to other industries, the transmission gas infrastructures are often considered as acceptable and less pollutant. However, acceptation by the public is more and more complex and the image of gas industry could be affected by a bad experience or a serious incident.
- A negative opinion on a local project may have unusual consequences on the image of companies.

5.6.2 Recommendations

- Throughout the projects, to develop the communication with the public, based on information and dialog in order to favor the acceptation and the integration of the gas infrastructure in the crossed territories
- To suppress or reduce as much as possible the adverse impacts of gas infrastructures on landscape, bio diversity, urbanization, archaeology and agriculture, by adopting the best practices.
- To participate to the socio-economic development of the crossed territories
- To have an open-minded attitude and to integrate lessons learned by other companies in order to increase professionalism of the company.

Chap. 6 Technologies applied in gas transmission systems

The gas industry has to face new challenges due to the evolution of the market and of the regulatory framework. Therefore the new technologies applied to the transmission systems can play a crucial role. On one hand they can ensure the transportation of greater quantities of gas in the most flexible way. On the other hand they are essential to maintain and develop the systems in the most safe, efficient and environmentally sustainable way. Therefore, it is very important for the gas transmission companies to deal with new technology, keeping themselves at pace and implementing the most updated available technologies.

The objective of this section is to provide an overview of the new technologies and their application to the transmission systems. We focused on experience in the implementation of new technologies including the description of technologies successfully applied in the gas transmission.

6.1 Technologies in the area of Safety and Reliability

6.1.1 Electromagnetic acoustic technologies for in-line inspection of gas pipelines

Urgent need to increase reliability of stress corrosion cracking detection in ageing trunk pipelines served powerful incentive to active development of electromagnetic acoustic technologies (EMAT) by Spetsneftegaz scientists.

Due to extensive experience of using MFL and TFI in-line inspection tools during many years, it became evident that extra small shallow cracks with nearly zero opening were beyond detection capability of magnetic ILI tools. There are certain restrictions, which make detection of such defects impossible with required reliability.

It is noteworthy that "reliability" notion includes such notions as "reliability of detection", "reliability of identification" and "reliability of defect sizing" (including its depth measurement). Regarding that any detected crack is considered as severe defect, which must be immediately cut out of the pipeline, two reliability constituents must work without failures, i.e. a crack defect must be detected and correctly identified.

In practices, at least two classes of stress corrosion cracking damages of pipelines can be determined, being seriously problematic for magnetic in-line inspection.

1. The first class is represented by stress corrosion cracks with nearly zero opening, which are weakly detected by magnetic ILI tools (due to their minor opening, but not depth), so called high pH SCC. In fact, reliability of SCC detection by magnetic ILI tools is disputable. As a rule, even longitudinal cracks with nearly zero opening can give anomaly on the TFI tool record, though its amplitude is insufficiently high. Huge quantity of anomalies with similar amplitude, not associated with SCC, are recorded by TFI tools as metal structure features, and neither resources of ILI

data treatment specialists nor machine time will be enough to treat such quantity of anomalies.

2. The second class is also represented by stress corrosion cracking zones, which are spacious enough to be detected by TFI tools. However, it is difficult to identify them correctly, because they are covered by general corrosion defects. It is necessary to remind that the most reliable criterion of identifying longitudinal cracks is ability to be detected by TFI tools and invisibility for MFL tools. Other criteria, such as parameters of form, amplitude of signal, gradient of signal are insufficiently reliable and can be considered only as supplementary ones. Thus, when magnetic anomaly initiated by a crack becomes smaller than anomaly initiated by general corrosion that is spread on a crack, which is encountered quite often, the main identification criterion stops to work, and uncertainty appears.

Multiple attempts of Spetsneftegaz scientists to solve the above mentioned problems, using only magnetic in-line inspection methods, did not have reasonable success. So it was decided to start developing and inculcating so-called "dry" ultrasonic technologies. Electromagnetic acoustic method of ultrasound generation was chosen for in-line inspection of gas pipelines, because of extreme complexity to use ultrasonic technology that requires liquid contact with pipe walls.

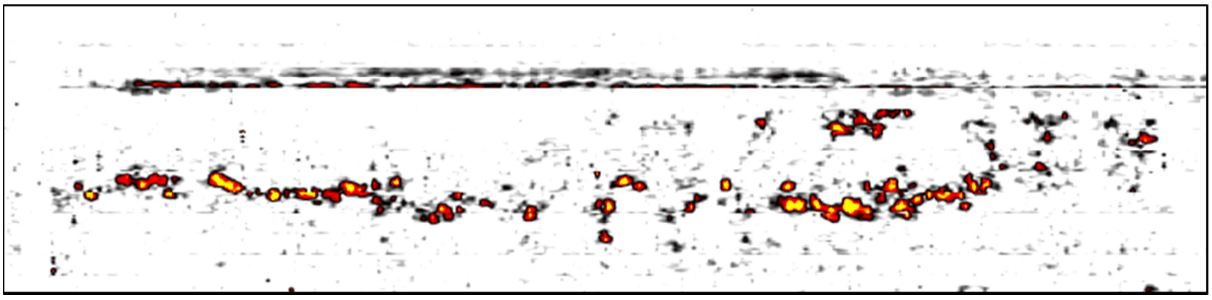


Figure 6.1 Colour reconstruction of EMAT-56" inspection (plot showing multiple shallow, less than 10% pipe wall thickness deep, stress corrosion cracks in Russian gas pipeline)

There are two mechanisms of electromagnetic acoustic generation of mechanical oscillations. The first one is the eddy current Lawrence mechanism. The second one is magnetic striction mechanism. Sometimes it is called piezo magnetic mechanism. It is not noteworthy to describe advantages and disadvantages of each of them. This topic was already discussed many times. It should be just mentioned that Spetsneftegaz uses magnetic striction method. Mechanism of magnetic striction becomes apparent in deformation of elementary volumes of a ferromagnetic subject under magnetic field impact. There is reverse effect of this mechanism: magnetic field appears as result of ferromagnetic subject deformation. Thus, if alternating magnetic field is locally initiated in a metallic subject, then that subject itself will become source of deformations, which are later transformed into a wave. Coils, called transmitters and receivers, are used to induce magnetic field into a subject and then to receive it.

Electromagnetic acoustic transmitter is a special coil, through which special impulse of ultrasonic frequency current with amplitude of about 100 amperes is induced as so called "acoustic shot". Ultrasonic wave is formed as packet of mechanical oscillations with duration of several (from 2 to 6 as a rule) periods, by a transmitter in the moment of impulse as result of electromagnetic acoustic transformation. Wave packet is propagated along a wall of inspected pipeline with velocity of about 3 km/sec. and received by EMA receiver. The receiver is a special coil, in which electric signal is formed as result of reverse electromagnetic acoustic transformation. Acoustic wave, in the process of its propagation in a pipe section, acquires specifications that can give important information (for example, information on abundance of defects in an inspected pipeline section).

Efficiency of EMA transformation (both direct and reverse one) is considerably lower than contact piezoelectric method and makes up 10^{-4} as compared to it. This fact was taken into consideration, when determining the scheme of creating ultrasonic in-line inspection system based on electromagnetic acoustic method.

EMA transformers can excite and receive all possible modes of acoustic waves. However, the method of excitation and reception of resonance waves is the most efficient one, being primarily prospective for further development. When such method is used, pipe wall plays role of wave guide, along which wave is propagated. Broad inspection spectrum is undisputable advantage of this method, besides its efficiency. Theoretically, one transformer pair is capable to scan full pipe length during ILI tool movement in a pipeline (excluding insignificant zone located in front of a transformer and shade zone). Increase of transformer pairs, regularly distributed on ILI tool circumference, does not increase resolution ability of an EMAT tool. Its operation is based on the resonance method, which is principally different from magnetic and contact ultrasonic ILI methods, being chosen due to necessity to overcome such unpleasant effects as wave attenuation in the process of its propagation, reverse dispersion effect (repeated reflection, etc.) that accompany guided wave ultrasonic sounding. Resonance ultrasonic sounding method has capability of echo shade method of pipeline defects sizing and check up of wave attenuation in the process of its propagation.

Ability to check up resonance wave attenuation degree enables to obtain new information layer (not accessible for other inspection methods) for assessment of condition and type of pipeline coating. The physical principle that serves basis for technology of detecting disbonded coating zones of pipelines is quite simple. As it was mentioned above, resonance wave attenuates in the process of its propagation. Attenuation is considerably associated with transfer of energy to pipeline coating. Various types of coatings are characterized by various energy absorption factors. Application of EMA technology made it possible to identify type of pipeline coating. When a propagating wave crosses disbanded coating zone, it is recorded as the zone with anomalously low attenuation, and anomaly value characterizes distortion degree.

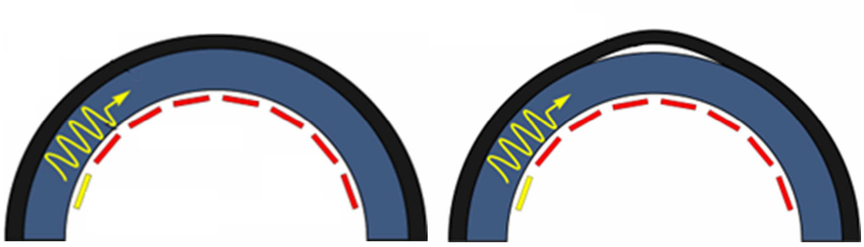


Figure 6.2 EMAT wave in the pipe with well bonded coating (left) and pipe with disbonded coating (right)

However, resonance wave has its disadvantages, the main of which is relatively big wave length (as big as pipe wall thickness of an inspected pipeline), and as consequence, low frequency (as a rule, not more than 500 kHz). Contact ultrasound works at several MHz frequencies, wave lengths being several milimeters. It is well known from the ultrasonic inspection theory that the less wave length is, the higher is resolution ability of an ILI tool, and the smaller can be detectable defect. Thus, it could be expected that contact ultrasound considerably exceeds resonance electromagnetic sound, at least in sensitivity.

Fortunately for scientists that develop EMA in-line inspection methods, major quantity of longitudinally oriented cracks are encountered as zones of cracks. So interaction occurs not with a single crack, but with a group of cracks. Sizes of zones are, as a rule, bigger than resonance wave length. Moreover, stress corrosion cracking causes change of anisotropy of stresses in pipe wall, and, consequently, local change of resonance specifications of a pipe crack zone. It may also cause increase of amplitude of reflected signal. Spetsneftegaz scientists performed comparative statistic studies of efficiency of resonance and volumetric waves reflection from several stress corrosion cracking zones that proved the same sensitivity efficiency of EMA resonance technology as contact ultrasonic technology.

Another disadvantage of a resonance wave is necessity to solve identification problem aimed to separate anomalies caused by cracks from anomalies caused by other pipeline features, predominantly not dangerous from the point of view of pipeline integrity. Such pipeline features can be insignificant corrosion defects or metallurgical defect.

In spite of the fact that resonance EMA technology as compared to magnetic ILI technology is much more sensitive to cracks and less sensitive to corrosion, the problem of their discrimination remains. It was reasonable to solve this problem by using a scheme of pipe wall ultrasonic sounding in two perpendicular directions. Anomalies of isotropic shape caused by corrosion give reflections in both ultrasonic sounding directions, while cracks give reflections only in one direction. Thus, the criterion of anomalies discrimination, which is applied in practices of magnetic in-line inspection (MFL, TFI), can be also applied in EMAT ILI tool.

Laminations are also considerable hindering factor, when solving identification task. Due to the fact that they appear in the process of metal sheet rolling into a pipe, they acquire anisotropy of shape, like “tongues” elongated in rolling direction. Application of the mentioned criterion of bi-directional ultrasonic sounding does not give positive result and requires another approach.

As result of tests in pull-through test stand, containing SCC as well as laminations of natural origin, criterion of discrimination was developed on the basis of modal analysis. Certain correlations of amplitudes of signals obtained from various types of waves were used as criterion.

Determination of depth of crack zone is not trivial task. Both for magnetic and resonance EMA methods, amplitude of anomaly caused by SCC depends first of all on opening of cracks, then on density of cracks location and their interaction in the zone and only then on depth. So it is impossible to develop certain monotonous depth function with desired accuracy for anomaly amplitude. Uncertainty is too high. In case resonance EMA method is applied, solution can be found in modal analysis. Various modes differ by distribution of oscillations by thickness. Knot surfaces are available in modes higher than zero, where stresses are equal to zero, and defects that coincide with them are badly detectable. Thus, analysing correlation of amplitudes of signals initiated by modes of various orders, it is possible to obtain significant information on depth of cracks.

Since 2005 till nowadays, Spetsneftegaz has produced already four generations of EMAT ILI tools diameters 24, 30, 40, 42 inches. Now production of the fifth generation of high resolution EMAT ILI tool diameter 56 inches is being finished (this EMAT tool has 896 echo channels and 224 electromagnetic-acoustic transmitters).

EMAT ILI tool of the first generation, created in 2007, demonstrated principal capability to perform in-line inspection of trunk gas pipelines, using electromagnetic acoustic technology without requirement of super clean inner pipe walls (this problem was solved by choosing the proper wave length). It was proved that the first generation EMAT tool had much higher sensitivity to high pH stress corrosion cracking detection, than magnetic TFI ILI tools. Nevertheless, it was found out that this EMAT tool required further development of more reliable system of pipeline defects identification and more power.

Development of EMAT ILI tools of the second generation continued till year 2009. Sensor system was considerably upgraded, ultrasonic sounding in perpendicular directions was inculcated, the tool became several times more powerful. Number of sensors was increased.

EMAT ILI tool of third generation was ready in 2010. Sensor system was upgraded to increase reproducing ability of in-line inspection results (obligatory requirement of criteria identification analysis). System of modal analysis was inculcated.

Thus, creation of the first generation of EMAT ILI tool solved the problem of reliable SCC detection in gas pipelines. Creation of these generations of EMAT ILI tools solved both problems of SCC detection and identification. Accuracy of EMAT ILL tool of the third generation to size depth of cracks became much higher. So EMAT tools of the second and third generations enabled to perform multi-directional in-line inspection of pipelines, having inherited the main resonance principle of measurements. Such inspection tools got advantage independent data on availability of both longitudinal and transverse cracks as well as possibility of higher rate of sending acoustic signals that enables to inculcate modal analysis at acceptable resolution ability. Disadvantage of those generations of EMAT tools was big quantity of EMAT transmitters and big energy reserve on board, which made those EMAT tools and their service very expensive.

EMAT tools of the fourth generation (40 and 42 inches diameter) were further upgraded in design, became less expensive and easier in service. They required less energy resource. They have already successfully run more than 2000 km in Russia and the Middle East countries, having found a lot of stress corrosion cracks.

Now production of the fifth generation of high resolution EMAT ILI tool diameter 56 inches is being finished (this EMAT tool has 896 echo channels and 224 electromagnetic-acoustic transmitters), which is first of all intended to be used in Gazprom pipelines.

In conclusion it is noteworthy to mention that it is not easy to develop electromagnetic acoustic technologies for in-line inspection application, not only because of huge expenses. Most problems arising in the process of EMAT tool development can be solved only after this tool is fully produced and tested in a real pipeline. Many processes can't be observed during laboratory tests. It is extremely difficult to choose optimum ways of solving certain problems. In fact, EMAT technology is very young. However, we hope that soon EMAT ILI tools will be serially produced, be accessible and wide-spread as MFL ILI tools.

6.1.2 Flow meters

6.1.2.1 Introduction

In this section, recent topics of flow metering technologies are introduced. This section discusses hybrid ultrasonic flow meters, conditioning orifice meters and V-cone meters.

6.1.2.2 Ultrasonic flow meters

Ultrasonic flow meters have high range ability and less pressure loss for metering the flow of natural gas. They come in various types including clamp-on, insertion type and spoolpiece. There are two types of ultrasonic flow metering technology, Doppler meters and transmit-time meters. Recently, hybrid type ultrasonic meters that combine these two types are available.

6.1.2.2.1 Doppler effect ultrasonic flow meter

The Doppler Effect Ultrasonic Flow meter use reflected ultrasonic sound to measure the fluid velocity. By measuring the frequency shift between the ultrasonic frequency source, the receiver, and the fluid carrier, the relative motions are measured.

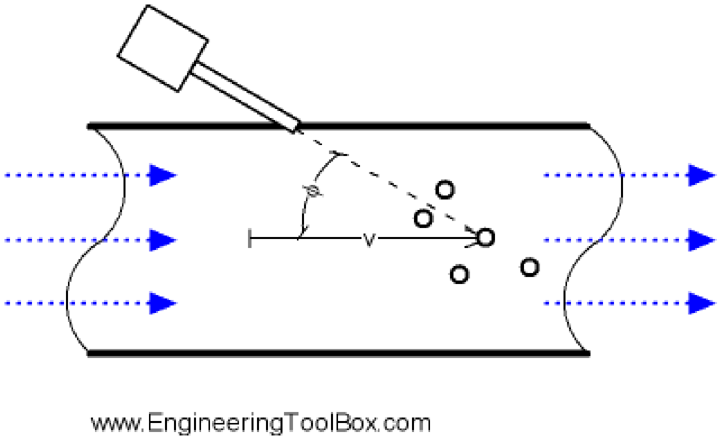


Figure 6.3 Measurement principle of Doppler effect ultrasonic meter

(source: http://engneeringtoolbox.com/)

6.1.2.2.2 Transmit-time ultrasonic flow meter

With the Time of Flight Ultrasonic Flowmeter the time for the sound to travel between a transmitter and a receiver is measured. This method is not dependable on the particles in the fluid.

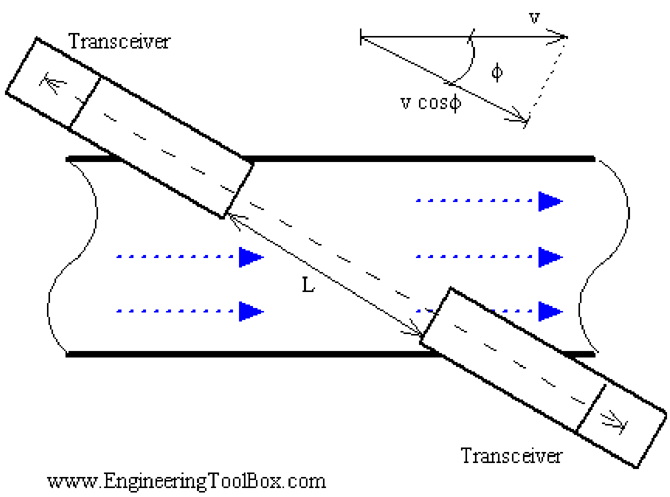


Figure 6.4 Measurement principle of transmit-time ultrasonic flow meter

	Doppler effect type	Transmit-time type
Advantages	• Obstruct less flow • Can be installed outside the pipes • The pressure drop is equal to the equivalent length of a straight pipe • Low flow cut off • Corrosion resistant • Relative low power consumption	• Obstruction less flow • Pressure drop equal to an equivalent length of straight pipe • Unaffected by changes in temperature, density or viscosity • Bi-directional flow capability • Low flow cutoff

		• Corrosion-resistant • Accuracy about 1% of flow rate • Relative low power consumption
Limitations	• Highly dependent on physical properties of the fluid, such as the sonic conductivity, particle density, and flow profile • Too sensitive to changes in fluid's density and temperature	• Liquid slurries with excess solids or with entrained gases may block the ultrasonic pulses

Table 6.1 Advantages and limitations of measurement principles
(source: http://engneeringtoolbox.com/)

6.1.2.2.3 Hybrid type ultrasonic flow meter

Hybrid type ultrasonic flow meter has both flow measurement functions, Doppler effect and transmit-time type, and it can switch these two functions depending on the flow conditions. This meter has more advantages and less limitations in comparison with conventional ultrasonic meters.

6.1.2.3 Conditioning orifice meters (Rosemount)

An ordinary orifice plate is a thin plate with a hole in the middle, and it only works well when supplied with a fully developed flow profile. This is achieved by a long upstream length (20 to 40 pipe diameters, depending on Reynolds number), so orifice plates are small and inexpensive but need a lot of space to be installed. Rosemount's conditioning orifice has four small holes and it is designed for ease of installation because it needs less straight-run piping compared with an ordinary one.

Figure 6.5 Conditioning orifice meter

(source: http://www2.emersonprocess.com/)

Figure 6.6 Conditioning orifice plate

Figure 6.7 Standard orifice plate

Conditioning orifice can maximize performance by eliminating the need of any special flanges or piping modifications. Conditioning Orifice can provide reduction of straight-run piping, requiring only 2D upstream and 2D downstream and superior performance of up to +/-0.5% accuracy in short straight-run installations and cost savings in excess of 50% compared to a traditional orifice plate installation.

Upstream(inlet) side of primary	Beta	0.20	0.40	0.65
	Single 90 deg. Bend or tee	2D	2D	2D
	Two or more 90 deg. Bends in the same plane	2D	2D	2D
	Two or more 90 deg. Bends in different plane	2D	2D	2D
	Up to 10 of swirl	2D	2D	2D
	Reducer (one line size)	2D	2D	2D
	Butterfly valve (75% open)	2D	2D	2D
Downstream side (outlet) of primary		2D	2D	2D

Table 6.2 Necessary length of straight-run piping

(source: http://www2.emersonprocess.com/)

6.1.2.4 V-cone flow meters

The V-Cone Flow Meter is an advanced differential pressure instrument, which is ideal for use with liquid, steam or gas media in rugged conditions where accuracy, low maintenance and cost are important.

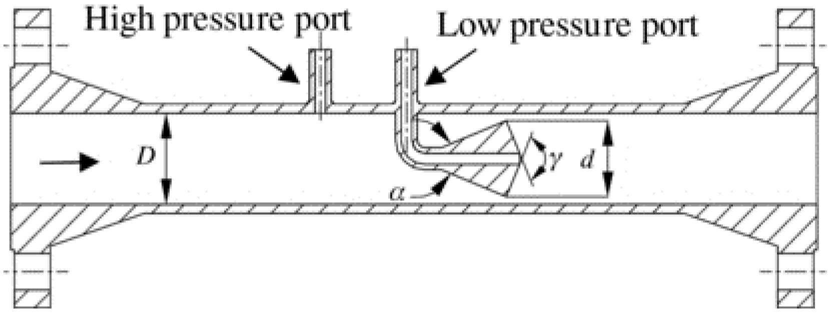


Figure 6.8 V-cone flow meter

(source: http://m.iopscience.iop.org/0957-0233/23/12/125305)

Characteristics of V-cone meter can be summarized to:

- Need small length of straight-run piping
- Stable DP output and wide range ability
- Very low pressure loss

	Reynolds number <200,000		Reynolds number >200,000	
	Upstream side	Downstream side	Upstream side	Downstream side
Single 90 deg. bend	0D	0D	1D	1D
Two 90 deg. bends	0D	0D	1D	1D
Tee	0D	0D	1D	1D
Butterfly valve (flow controlling)	3D	3D	10D	5D
Butterfly valve (100% open)	3D	0D	5D	3D
Gate valve (100% open)	0D	0D	1D	1D
Reducer (3D->1D)	1D	1D	1D	1D

Table 6.3 Necessary length of straight-run piping

(source: http://www.tokyokeiso.co.jp/products/flow/12v_co/v-cone/index.html)

6.1.3 Gas quality tracking: toward an improvement of energy consumption data accuracy

6.1.3.1 Context

The security of supply on one hand, and the will to develop gas markets flexibility on the other hand, leads countries to build new gas infrastructures, and to create new gas roads. This trend is also strengthened by LNG facilities developments, which make available new gas production sources to markets.

Therefore, gas markets have increasing alternative sources of supply that allow gas grids configurations previously unseen. As a consequence, the gas quality, which could be in the past relatively steady, gets more and more variable through the pipes.

In France for instance, with the arrival of the Algerian LNG, richer than the former sources gas, variations of H gas GCV (Growth Calorific Value) up to 10% have been observed (7% for the Wobbe index).

In the meantime, gas markets, customers and regulators demand more and more accuracy of final consumption data. Thus, in some countries like France, TSOs are incentivized on energy consumption data quality. Therefore, TSOs continually have to improve their data production methods and results.

The gas energy consumption data not only relies on metering station and gas chromatographers accuracy, ruled by the legal metrology framework, but also on the gas assignment process, that ensures the association of the gas quality parameters to the volumes in cubic meters measured by every metering stations.

Thus, gas quality assignment becomes a more and more critical aspect of the energy consumption data calculation. The process, which used to be generally static (not taking into account the gas velocity through the pipes) and often performed on daily basis, is evolving in order to improve the accuracy of the assigned gas quality parameters.

There is currently no international regulation, and even sometimes no national regulation on gas quality assignment process. It explains why gas quality assignment practices can be different from a country to another.

In the most advanced countries, the regulation asks TSOs to guarantee the gas quality data accuracy in any delivery point of their network. These regulations are in line with the IOLM (*International Organization of Legal Metrology*) R140 recommendation, which defines a maximal inaccuracy of the GCV in any metering point of the network.

To fulfill this requirement, without installing a gas chromatographer in each metering point, TSOs have only one option: calculate the propagation of the GCV along the network with a dedicated simulation tool.

6.1.3.2 Gas quality assignment existing methodologies

In simplified terms, gas accounting processes consists in producing energy data, for every metering point, multiplying volumes and Growth Calorific Values (GCV) collected on the field from the metering stations and the gas chromatographers.

Metering stations are positioned throughout the transmission networks to measure all the entering and exiting gas flows. Gas chromatographers are less numerous, situated in particular at the entries of the network. Their measures are assigned to every metering point in order to produce the final energy data on every metering point.

Gas quality assignment has to take into account the physical gas flows in order to make the right associations between gas chromatographers and metering stations. These associations change with every network configuration, defined by the dispatching department.

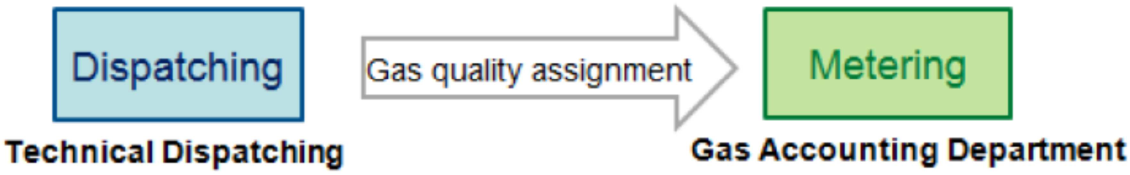


Figure 6.9 Gas quality assignment relies on the gas flows defined by the physical dispatching department

We can distinguish two kinds of gas assignment methods:

- Gas quality assignment through same gas areas definition:
  - Gas quality parameters are measured by a gas chromatographer positioned at the gas area entry
  - Throughout the same gas areas, GCV and others gas quality parameters are considered identical at the same instant
  - The dispatching department defines the same gas areas in accordance with gas flows set in the SCADA system
  - In most cases, this task has to be carried out manually, when changes of network configuration occur
  - This method have several weaknesses
    - In most cases, configuration changes are taken into account, at best, on a daily basis, i.e. the changes of configuration have to be performed exactly at the beginning of a gas day to ensure the concomitance of their parameterization
    - Only major configuration changes can be parameterized. Indeed, configuration changes relevant for several hours and made for maintenance works purposes for instance, won't be taken into account
    - Using same gas areas is a static method of gas quality assignment, as it doesn't take into account the gas velocity in the pipes. The wider the same gas areas are, the less accurate the gas quality parameters assigned throughout the area are.
- Gas quality tracking with a gas flow simulation tool:
  - Gas flows are reconstituted along the network by the simulation tool
  - The gas quality parameters are propagated along the network and assigned dynamically to any point of the network, taking into account the velocity of the gas
  - The simulation tool is interfaced with the SCADA system and inherits gas flows configurations from it, which ensures that all the configuration changes are taken into account
  - This method can be based on processes mainly automatic; the only manual interventions consist in setting, in the simulation tool, changes of the

network parameterization that couldn't be transcribed automatically from the SCADA system
  - The quality of the assigned GCV can be ensured by the use of controlling gas chromatographers, positioned in the most unfavorable points for the simulation tool calculation. They provide measured GCV that can be compared with the assigned GCV. Therefore TSOs can guarantee maximum inaccuracy of GCV in any point of the network
  - Beyond gas quality assignment, simulation tools provide two features most useful to metering processes :
    - the line pack calculation, using the pressure profile along the network
    - simulated volumes calculation at major entries and exists of the network, that can permit to detect metered data anomalies, by comparison

Among Europe, more and more TSOs perform gas quality tracking. This method allows them to limit the number of gas chromatographers. They are also able to guarantee the gas quality accuracy in any point of the network. In some countries, TSOs also have their simulation tool and their gas quality assignment system certified by a regulatory body.

6.1.3.3 Perspectives

Dynamic gas quality assignment with a simulation tool appears to be more efficient that the use of same gas areas in terms of accuracy of the data, of ability of TSOs to demonstrate and undertake the accuracy of the data, and even possibly in terms of cost, as it may permit to lower the number of gas chromatographers.

The last remaining question is the frequency of the gas quality assignment. Once again, the practices appear to be quite different from a country to another, and even between TSOs of a same country:

- Some TSOs assign hourly gas quality data, some calculate average daily value they assign either to hourly or to daily volume data
- In some countries, gas quality assignment is an hourly process. In this case, TSOs often use a lot of gas chromatographers and assign the gas quality using the method of same gas area. The more often, the gas quality is assigned once a day, and still sometimes, once a month.

In Europe, the Balancing Network Code, to be applied in October 2015, imposes to all countries to provide energy consumption data in an intraday frequency, at least twice a day.

To ensure the best quality of the data, TSOs should therefore switch to intraday data assignment.

Moreover, some TSOs pursue the objective to ensure hourly gas quality assignment using the gas quality tracking method. This could be possible with a high performance interface between SCADA – Simulation Tool – Gas Accounting System, and a high rate of hourly remote metering stations. This should allow producing hourly a very high quality energy consumption data.

6.1.4 Gas treatment plants

6.1.4.1 Kårstø gas processing plant in Norway

6.1.4.1.1 The Kårstø History

The Kårstø processing plant started up in 1985, processing rich gas from the Statfjord fields, located in the North Sea west of Norway. The sales gas was sent to Emden, Germany, through Europipe via the offshore Draupner riser platform hub. Since 1985 several plant expansions have been executed. In order to process condensate from the Sleipner field a condensate treatment facility was built in 1993. Rich gas from several Norwegian Sea fields has been processed in the Åsgard plant since 2000. A new pipeline, Europipe II, to Dornum, Germany, was put in operation as part of this expansion. The rich gas processing capacity in the Åsgard facility was further increased in 2003 and 2005 as part of new field tie-ins offshore. Currently, the total rich gas processing capacity at Kårstø is 88 MSm^3/d and the condensate treatment capacity is approx. 12 500 tonnes/day.

6.1.4.1.2 Owners and Operatorship

The Kårstø plant is part of Gassled, a joint venture established by the owners (companies). The Gassled system consists of pipelines and platforms on and from the Norwegian continental shelf, onshore process facilities in Norway and gas receiving terminals abroad. The system is used by all parties transporting gas on the Norwegian Continental Shelf. Gassled is organised in different access zones with different tariff levels.

Gassco is the Operator at Kårstø on behalf of Gassled. Statoil is responsible for the day-to-day operation of the plant on the basis of a technical service agreement with Gassco.

6.1.4.1.3 Kårstø's Location and Role in the Gas Value Chain

Kårstø is a key location in the gas value chain from the reservoir to the markets (customers) on the European Continent. Over 20 different offshore production installations export their rich gas to the Kårstø plant. At Kårstø, the rich gas is split into separate products; sales gas (methane), ethane, propane, i-butane and n-butane and naphtha. Unstabilised condensate from the Sleipner field is stabilised at Kårstø. The NGL recovery at Kårstø is significant, thus adding value to the overall gas value chain.

Of an area of approximately 208 hectares, physical installations occupies 108 hectares.

Gas from Kårstø accounts for around 20-25 percent of all Norwegian gas deliveries.

6.1.4.1.4 The Kårstø processes

Rich gas, a commingled feed of hydrocarbons C_1 – C_5, from offshore production fields is transported to Kårstø via the Statpipe and Åsgard Transport pipelines.

Pre-treatment

The pre-treatment facilities at Kårstø consist of removal of small amounts of trace components (impurities) in the rich gas. These trace components are H_2S, water, glycols and mercury. Conventional solid bed adsorption and separation technologies are applied in these processes (e.g. mol sieve, solid catalyst). In addition, the arrival pressure and temperature are adjusted.

Extraction

Extraction of sales gas (methane) from the rich gas is achieved by pressure reduction. NGLs are condensed to liquid phase during the pressure reduction while sales gas remain in vapour phase. Turboexpanders are used to extract sales from rich gas. The rapid reduction of pressure in turboexpanders generates work which is converted to compression power in the attached compressor.

The sales gas is further compressed and sent to Germany via pipelines. Both gas turbine driven and electric driven sales gas compressors are in operation at Kårstø.

Fractionation

The NGL mixture from the extraction step is sent to the fractionation trains. A fractionation train consist of a series of distillation columns. By distilling the incoming NGL in sequential order the mixture is separated into individual products due to their different boiling points. Similarly, unstabilised condensate is stabilised by fractionation.

Storage and loading

Ethane, LPGs, naphtha and stabilised condensate are stored in dedicated storage tanks in the harbour area at Kårstø. These products are transported from Kårstø by ship to worldwide customers. The production leads to approximately 700 ship calls each year. The harbour, which consists of three jetties and 11 loading arms, is specially equipped for LPG ships and is described as the largest of its type in Europe. A dedicated harbour office handles daily traffic, and three tug boats are permanently stationed at Kårstø to provide necessary assistance.

Utility systems

In addition to the actual processing plant, Kårstø rely on extensive utility systems such as steam generation and distribution system, water treatment (boiler feed water), fuel gas system and work and instrument air supply.

Figure 6.10 Kårstø Processing Plant, Facilities Pictorial Locations

6.1.4.2 The Kollsnes History

Troll is the largest gas field on the Norwegian Continental Shelf. The Kollsnes plant was originally part of Troll Gass. Troll Gass originally also consisted of the Troll A platform and the two pipelines between the platform and the onshore facility. The decision to build a processing plant for the gas from Troll at Kollsnes was made after the Troll partners decided to move the processing plant to an onshore location.

Shell was the development operator for the processing plant at Kollsnes, while Statoil took over operator responsibility when the plant started operations in 1996. At that time, gas treatment capacity was 84 million standard cubic metres per day (Sm3/d). Shortly after, the gas from Troll B, C and later Fram were connected to this system. In 2004 and 2005, gas from

Kvitebjørn and Visund, respectively, were transported in a separate pipe to Kollsnes. A separate facility for the production of wet gas was also built and put into operation in 2004, treating gas from Kvitebjørn and Visund.

Today, 350 people work at Kollsnes on a daily basis. In addition to the functions performed by permanent Statoil employees,

modification and maintenance services, security services, cleaning services, catering and camp operation are provided by external service suppliers. The occupations represented at Kollsnes include engineers and skilled workers such as process operators, electricians, mechanics and laboratory personnel and mercantile and administrative personnel.

6.1.4.2.1 Owners and present Operatorship

The Kollsnes plant is part of Gassled, a joint venture established by the owners (companies). The Gassled system consists of pipelines and platforms on and from the Norwegian continental shelf, onshore process facilities in Norway and gas receiving terminals abroad. The system is used by all parties transporting gas on the Norwegian Continental Shelf. Gassled is organised in different access zones with different tariff levels.

Gassco took over Operator responsibility at Kollsnes on behalf of Gassled in 2004. Statoil is responsible for the day-to-day operation of the plant on the basis of an technical service agreement with Gassco.

6.1.4.2.2 The Kollsnes Processing Plant

The expansion that has taken place since the plant opened in 1996 has resulted in the Kollsnes processing plant now having a capacity of 143 million standard cubic metres per day (Sm3/d). The plant’s capacity is optimally utilised.

The Kollsnes area covers an area of 500 acres, of which 175 have been levelled. This allows room for potential expansion. The plant is subject to ongoing technological upgrading in order to ensure safe operation and high gas deliveries. The plant’s operation is based on the use of electric power via the distribution system in the region. Kollsnes is, therefore, an industrial facility with minimal emissions to air and sea. The area is under constant environmental monitoring.

The gas that is processed at Kollsnes accounts for almost 40 per cent of total Norwegian gas deliveries to Europe and meets the energy requirement for households and businesses in a number of European countries. After the gas leaves the processing plant, Gassco's transport control centre on Karmøy manages its transportation to receiving terminals for Norwegian gas on the Continent and in the UK.

The Kollsnes processing plant is a 24-hour site – a machine that can operate all day and all night. And the safety of employees going about their work at the plant is also a constant focus. In the work on health, safety and the environment, risk management, risk control and the prevention of accidents are given top priority.

Condensate Stabilisation

The main purpose is to separate the MEG/Water and to process the condensate to export specifications. The stabilised condensate is pumped and commingled with the extracted NGL before metering and export. Flash gas is re-compressed and sent to the NGL extraction facilities. The MEG / Water proceeds to the MEG facilities.

Dew Point Control

The Dew Point Control facilities are part of the Gas Conditioning Trains and mainly processes gas from the Troll field, rich gas from the Kvitebjørn / Visund can also be routed through these facilities. The facilities are arranged in three identical trains consisting of an Inlet Gas Separator, a Gas/Gas Exchanger, a Turboexpander Suction Drum, a Turboexpander / Recompressor and a Dewpoint Control Separator. MEG from the onshore MEG facilities is injected into the process at various points to prevent hydrate formation. The conditioned gas is fed forward to the Gas Export Facilities, whereas liquids (Hydrocarbon and MEG/Water) are sent to the Onshore MEG/Condensate Separation system within the Condensate Stabilisation Facilities.

Export Compression

The Export Compression Facilities take conditioned feed gas via a common manifold from the Dew Point Control trains and the NGL Extraction train. The facilities compress the sales gas up to the necessary pressure for export via the Zeepipe II A and B pipelines, and meter the flow. The Export Compression Facilities consists of six large electric driven compressors with adequate capacity to meet the Kollsnes design export rate which is limited by the export pipelines.

MEG

The MEG facilities regenerate, de-contaminate and export the MEG used offshore and distribute to Dew Point Control and NGL Extraction trains.

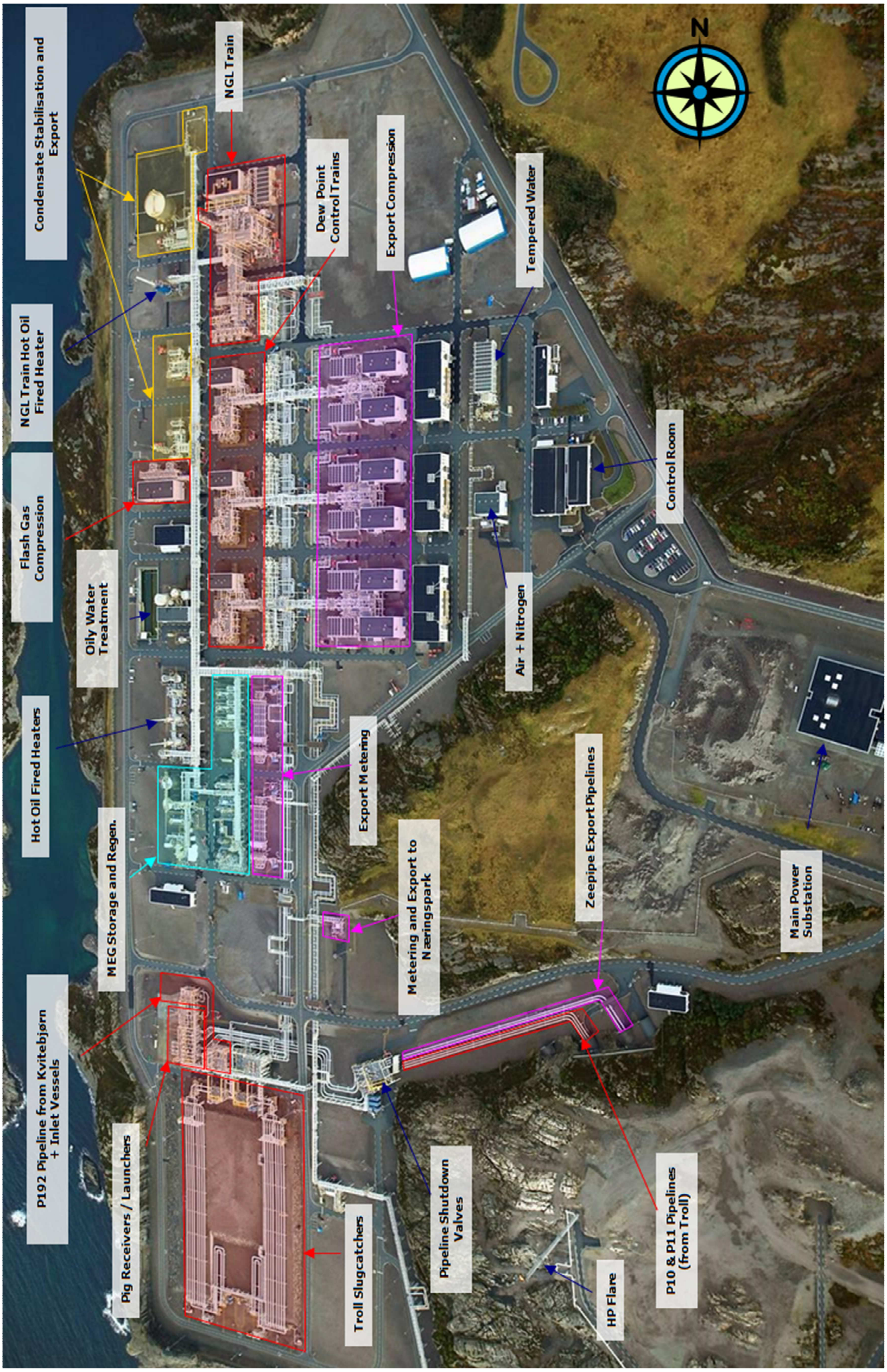


Figure 6.11 Kollsnes Processing Plant, Facilities Pictorial Locations

NGL Extraction

The NGL Extraction facilities are part of the Gas Conditioning Trains and normally process rich gas from the Kvitebjørn / Visund pipeline and gas recovered by the Flash Gas Compression system. Troll gas can also be routed through these facilities to utilise spare capacity. The facilities are designed to remove NGL from the rich gas feed in order to create a sales gas within specification and an NGL stream. The facilities are arranged in a single train.

Rich Gas Inlet

The Rich Gas Inlet facilities receive gas from the Troll field via three pipelines and from the Kvitebjørn / Visund fields via the one pipeline. The Troll Receiving Facilities consist of two Feed Pipeline Pig Receivers and two Slug Catchers. In the slug catchers condensate and MEG/Water are separated from the gas and after filtering the liquids are then sent at a controlled rate to the Condensate Stabilisation Facilities. The gas is fed forward to Gas Conditioning Facilities.

Utilities

The Kollsnes plant is supported by numerous utilities that are the support systems that provide the necessary heating, cooling, control, power and safe disposal of by-products that are required to operate the process facilities

6.2 Technologies in the area of Environmental Footprint Reduction

6.2.1 Repumping of natural gas during maintenance activities of Eustream's gas transmission network

To provide for operational safety and facilitate maintenance, sectional route closures (ball valves) are usually utilized in gas transmission pipelines, spaced in 20 – 25 km distances. During maintenance of the individual sections and compressor station pipe system components, the pressure in the shutoff sections must frequently be released by venting. In this, corporate priorities are focused on economical handling of natural gas present in the vented section, along with adherence to the company´s environment-related technical policy: ***minimum release of gas to the atmosphere.***

Eustream, as one of the first companies, applied the technical solution of applying mobile compressors to repump natural gas. Such mobile equipment represents a piston compressor, a gas engine, gas cooling unit and supportive technology, all of which is installed on a standard trailer. This provides mobility as well as excellent flexibility to this solution.

Repumping is applied in repair works of major sections, usually 20 - 50 km long (2 sections), thereby saving 12 - 31 million Sm^3 of natural gas.

6.2.1.1 The natural gas repumping principle, using mobile compressors

Repumping of natural gas is defined as the relocation of gas present in shutoff, separated and sealed pipeline section(s) into a different line section. Eustream has 2 standard mobile compressors available, i.e. one ***Dresser Rand (KOA)*** and one ***Cameron C-Force 34 (CFA34)*** unit, applied individually or in parallel as needed. The units pump natural gas at pressures ranging from 70 barg at suction to 5 - 7 barg at discharge, with operating pressures up to 70 barg. Mass flow in the compressor decreases gradually with the decreasing entry pressure, until reaching a minimum when the compressor is shut down. Maximum flow rate in the KOA unit is 24,000 Sm^3/hour at 7 barg technical minimum suction pressure, with this unit having been - in our conditions - in operation nearly 20 years. The CFA unit, operating since 2008 with improved parameters, has 38,000 Sm^3/hour maximum flow rate and 5 barg minimum suction pressure.

The main advantage of these repumping compressors is their mobility; they may be connected at any point to the pipeline through min. DN100 (4 ANSI600) diameter flanges and flexible pressure hoses, combined with rigid PN100 piping. The comparatively rapid (up to 4 hours) assembly/disassembly of the connections is an additional advantage. The compressors´ instantaneous output (gas flow) depends on the momentary pressure ratios (suction vs. discharge). Suction pressure diminishes exponentially. In the past, residual gas in the section remaining at 5 barg used to be released into the atmosphere, or burned uselessly in powerful burners.

Figure 6.12 Compressors used by Eustream + booster unit

type	KOA (1995)	CFA (2008)	Booster (2012)
engine	CATERPILLAR gas engine CAT 3412	CATERPILLAR gas engine CAT G3412 TA130	gas engine DOOSAN GV222TIC generatorMARELLI MJB355SB4
own gas consumption	75 Sm^3/hour	150 Sm^3/hour	100 Sm^3/hour
compressor	DRESSER RAND USA RVMKO2	CAMERON USA C-FORCE 34	el.motorMARELLI D5F 355 LB6 compress. SAFE SW250BM40
design	2-cylinders compressor two-stage, double-acting	4-cylinders compressor two-stage, double-acting	3-cylinders compressor two-stage, single-acting
working pistons	1 x 5,25“ and 1 x 7“,	2 x 3,75“ and 2 x 4,125“	2 x 10,16“ and 1 x 9,45“ stroke 4,33“/ 1000 rpm std.
suction pressure	70 – 7 barg	75 – 5 barg	40 – 0,1 barg
max. discharge pressure	72,4 barg	75 barg	40 barg
power it depend on the prompt pressure ratio in suction & discharge lines	24000 – 2500 Sm^3/hour	38000 – 2500 Sm^3/hour	16000 – 1380 Sm^3/hour
chassis	40 t FLOOR	40 t SVAN	40 t ZORZI
advantage / disadvantage	still in operation	lower vibration, more power, shorter time of pressure relief	suction ability up to 0 barg, works only as tandem before CFA

Table 6.4 Essential parameters of Eustream’s repumping compressors

6.2.1.2 Sophisticated approach to the repumping process and its improvement

Based on our long-standing experience with repumping of natural gas using mobile compressors, along with a multitude of hydraulic simulations, we have elaborated a highly efficient procedure in the preparation and application of mobile compressors, including the following:

- Use of hydraulic simulations in the preparation and optimization of repumping
- Parallel use of several compressors to optimize the duration and cost of repumping
- Application of a booster compressor.

6.2.1.2.1 <u>Use of hydraulic simulations in the preparation and optimization of repumping</u>

Since the gas transit system operates several parallel pipelines, the repumping technology may be applied in line section shutoffs, as the remaining operated lines are

capable of receiving and transporting parts of the flow in the line designed for shutoff. However, this results in increased power requirements in the compressor stations. The required increase of compressor power depends on the specific position, limitation and, mainly, on the instantaneous flow in the system: higher flow means elevated hydraulic resistance in the pipeline system with the closed-down section, requiring higher additional power to surpass the resistance.
For this reason we have focused our efforts in the optimal use of hydraulic properties of the transport system. Previously, the repumping compressor connection points had been selected so as to provide for easy access of, and easy physical connection to the line point. However, analyses have shown that the time necessary for repumping could be considerably shortened when the following rules are taken in account:

- The first ball valve BV1 must be closed first to shut off entry to the given section, then the downstream part is used to dry-suction the line, followed by closing the other end of the section with the second BV2 valve.
- If possible from operating viewpoints, the power output of the next compressor station downstream to the gas flow direction should be increased at the time when only the first BV1 is closed. This will enhance the dry-suction effect in the closed section.
- The repumping compressor should be preferentially connected to the lower end of the closed section (viewed from the gas flow direction):

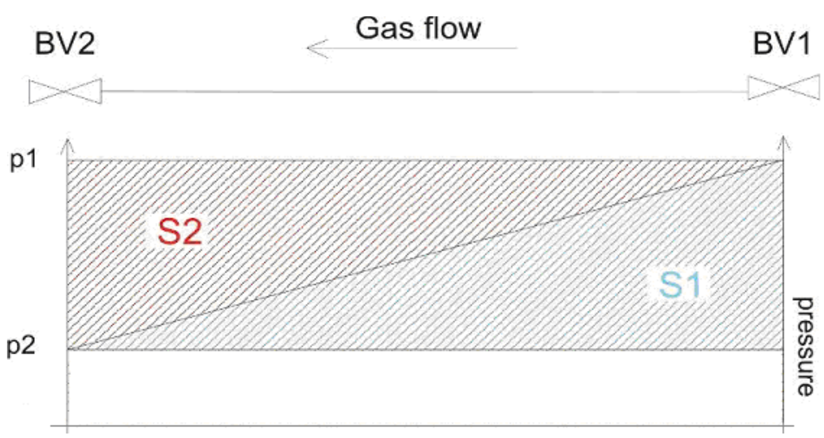


Figure 6.13 The course of gas pressure, proceeding along the pipeline

Due to the line hydraulic resistance depending on the real-state physical properties of gas, pressure gradually diminishes with increasing distance from the compressor station. The course of pressure decline between two route closures is shown in Figure 6.13. By first closing BV1, gas - in amounts given by S1 surface area - is vented from the closed line, and pressure in the section will reach the value p2. Should BV2 be closed first, then additional gas, in amounts given by S2 surface area, would be pressed into the closed section and pressure will reach p1. In case of simultaneous closure of both BV ball valves the pressure and amount of gas will stabilize somewhere between p1 and p2. When the repumping compressor is installed at the BV1 closure, its output pressure equals p1, which is the higher value, and the gas flow will decrease. Conversely, should the repumping compressor be installed at BV2, its discharge pressure will be p2, and the gas flow will increase

This method allows the use of hydraulic simulations, which provides an important tool in the preparatory phase of repumping. Such simulations also are used in determining the required number of mobile compressors and the time of linkage of the booster compressor to join the repumping process. The exceptional efficiency of this tool is proven by the fact that there is a less than 5% deviation in comparison of the simulation results with real repumping data.

6.2.1.2.2 Parallel use of several compressors to optimize the repumping duration and cost

Based on technical – economic calculations, the company Eustream elaborated a system using several mobile compressors (i.e. including external units) according to their availability in the market. There are presently 5 mobile compressors available in Central Europe whose operation at a lower capacity enables to lease them out for the repumping duration. The new model takes in account all technical – operational parameters of the transmission network and of the individual available compressors, thereby facilitating selection of the optimal variant.
Figure 6.14 shows a comparison of the repumping times, in cases of parallel connection of two (black curve), three (yellow and red curves) and four (grey curve) mobile compressors in a 22 km long section, designed for maintenance shutoff.

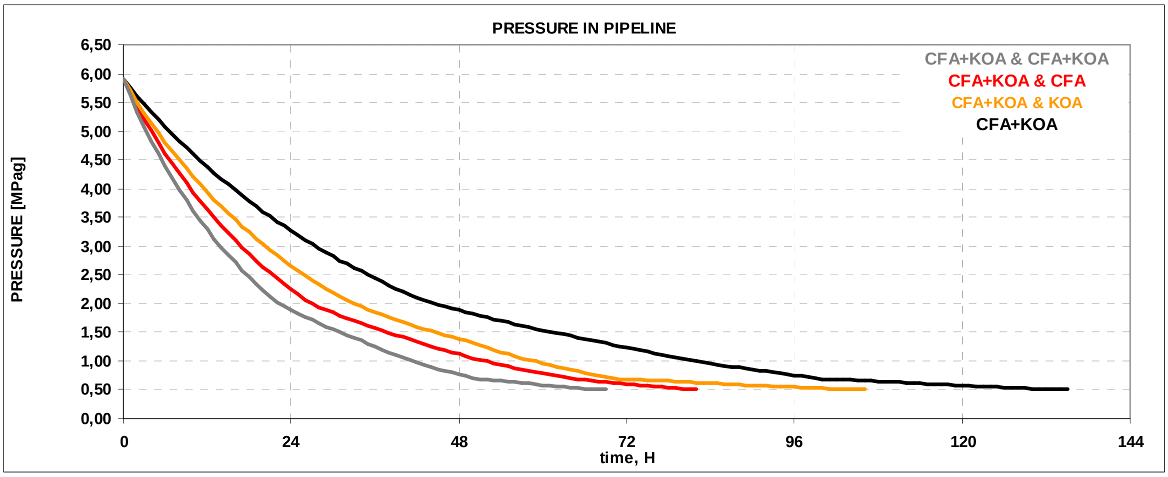


Figure 6.14 The repumping process, using several compressors

Lease of a compressor will reduce shutdown duration but introduce excessive costs. Therefore technical - economic analyses must be carried out to decide whether it would be worthwhile to lease additional repumping compressor(s), or not. The simplified principle of these analyses lies in a cost/benefit evaluation – comparison of compressor leasing costs to the benefits offered by reduced repumping duration. This evaluation must relate to the entire time period in the repumping - instantaneous system flow data must be primarily taken in account. Having considered all inputs, the individual results of analyzed alternatives can be graphically compared (Figure 6.15), and the graphic output used to decide about the optimal variant, i.e. the number of repumping mobile compressors used in the given shutoff section, along with the optimum time for terminating the operation from economical and ecological aspects.

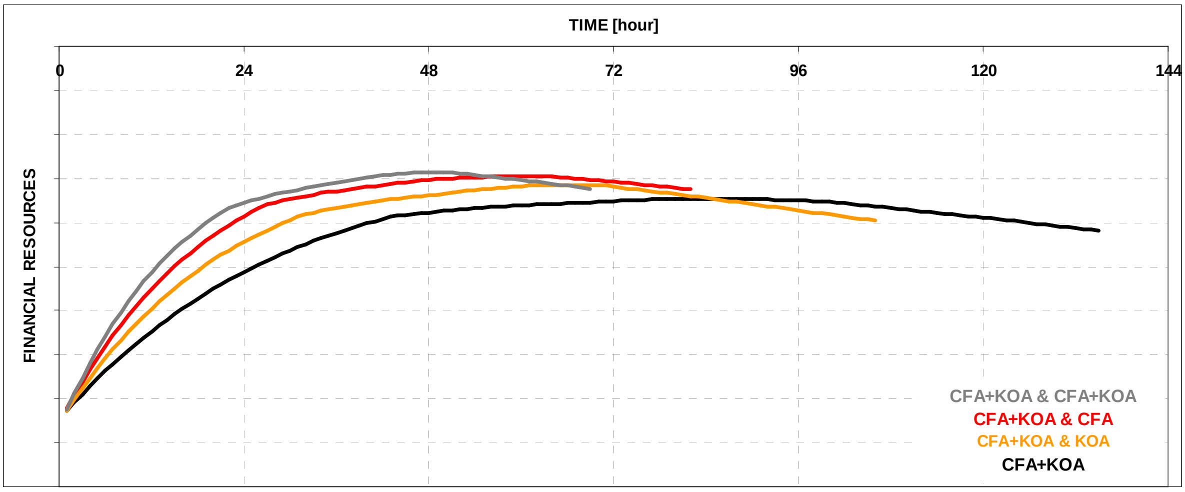


Figure 6.15 Technical-economic analysis of the repumping process

6.2.1.2.3 Application of the booster compressor

European gas companies usually do not release residual natural gas into the atmosphere after termination of the repumping process, but burn it in mobile combustion units. The essential environmental idea in the use of such equipment is that burning of the residual methane to CO_2 is less environmentally damaging, in comparison with the atmospheric release of the same amount of methane gas; thus, burning is a more ecological solution. However, the use of this technology extends the repumping time, and the volume of gas cannot be recovered anyway.

The simplified booster compressor principle lies in pre-compression of the gas before entry to the standard mobile compressor, enabling the latter to operate at input pressures exceeding 5 barg. The main advantage of the resulting system of compressors is its capability to accept gas at a minimum - close to atmospheric - suction pressure, while the booster compressor output pressure still remains above 5 barg. This enables operation of the series-connected standard CFA mobile compressor, resulting in the possibility to remove almost all gas from the shutoff line; its release into the atmosphere or combustion in mobile burners is no more necessary. This brings economic effects in the form of recovered gas, as well as the environmental advantage that atmospheric pollution does not occur. The solution was successfully tested in practice in the year

2011, when the tests proved the CFA compressor´s collaboration parameters, and the final suction pressure was equal to atmospheric pressure.

Figure 6.16 shows a comparison between repumping with the standard CFA mobile compressor (black curve) and repumping by means of collaboration of the CFA in series with the booster compressor (grey and yellow curves). The grey curve represents pressure in the suctioned-off line, while the yellow curve stands for discharge pressure of the booster compressor, i.e. input pressure of the CFA compressor. Clearly, the booster compressor, up to a certain pressure, operates in bypass mode; and work is only done by the CFA compressor. Upon start of the booster's operation the gas is pre-compressed for the series-connected CFA compressor, enabling the latter to work in a pressure area with better parameters (yellow curve) compared to its operation without the booster compressor (black curve). The results also showed that the booster enabled to reach near-atmospheric pressure conditions in the shutoff line more rapidly, in this case, than the CFA compressor was able to reach 5 barg pressure.

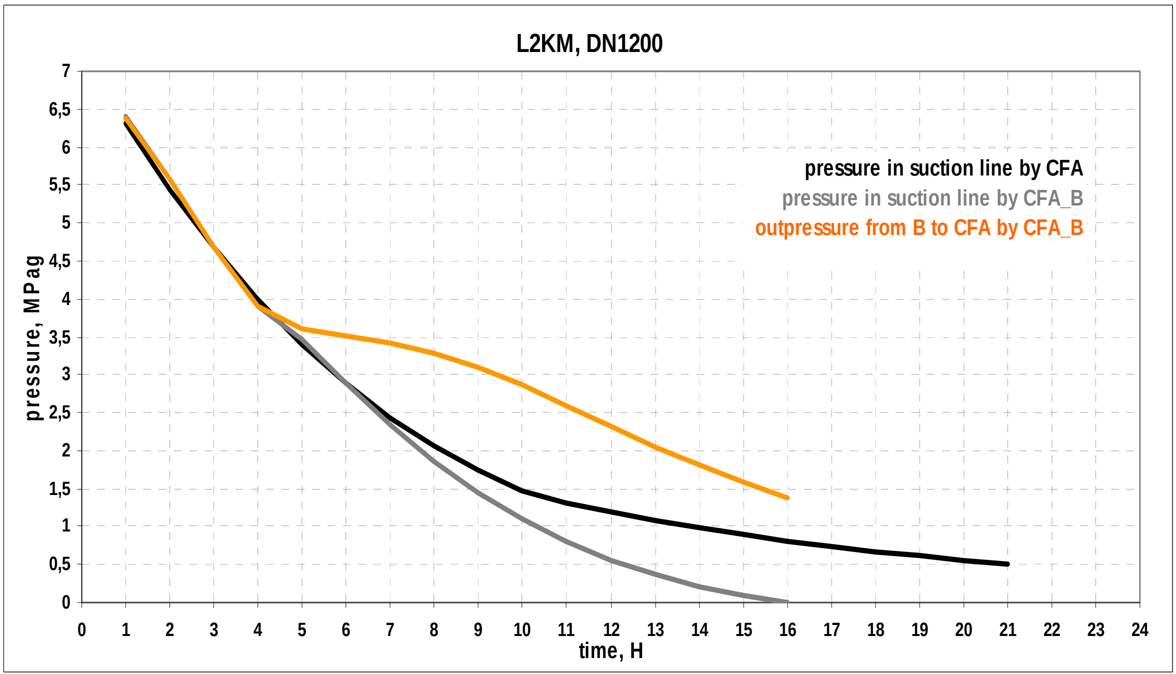


Figure 6.16 Repumping without and with the booster compressor

6.2.1.3 Benefits of repumping natural gas with mobile compressors

The benefits of using mobile compressors in the repumping of natural gas in the company Eustream can be summed up as follows:

- In 18 years of using mobile compressors, approx. 45,202 tons (61,499,000 m^3) of natural gas could be saved.
- This amount of natural gas equals to approx. 1,130,000 tons of carbon dioxide.

Table 6.5 reviews the essential data in Eustream´s repumping activities during 18 years of use of mobile compressors.

year	Gas evac. tasks	KOA period [h]	CFA period [h]	Booster period [h]	losses [%]	CH4 emission [t]	CO2 emision ekvivalent [t]
1995	1	55			64%	887	22 166
1996	8	526			32%	1 415	35 371
1997	10	1599			25%	2 887	72 165
1998	10	1388			20%	1 271	31 769
1999	9	1014			38%	5 080	126 996
2000	10	1788			29%	3 385	84 629
2001	10	2084			21%	3 071	76 766
2002	7	1221			31%	3 001	75 024
2003	9	1474			30%	4 315	107 865
2004	9	1325			27%	2 772	69 302
2005	5	771			49%	3 005	75 125
2006	5	862			32%	2 738	68 438
2007	3	236			46%	1 179	29 472
2008	10	667	707		16%	1 152	28 798
2009	13	696	1109		18%	1 853	46 322
2010	12	905	1007		26%	3 238	80 945
2011	14	1084	1129		15%	2 367	59 163
2012	19	1243	1678	725	8%	1 450	36 253
2013	15	906	1360	1194	1%	139	3 480
TOTAL	179	19 844	6 990	1 919	▼	45 202	1 130 048
		28 753					

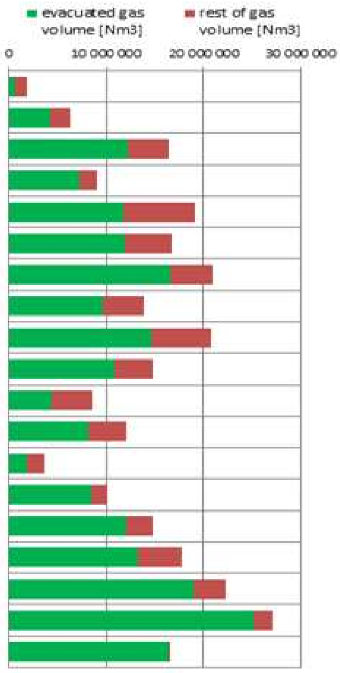


Table 6.5 Repumping activities at Eustream

6.2.1.4 Evaluation

Repumping of natural gas with mobile compressors in the company Eustream, a.s. resulted in the following benefits:

- ***Minimization of costs*** related to pipeline venting losses in sections under maintenance
- ***Minimization of adverse environmental consequences*** by minimizing the amount of vented gas (loss in 2013 amounted to only 1%)
- ***Reduced shutoff time during maintenance*** by parallel use of several compressors and a booster compressor (up to 50% time savings)
- ***Decreased requirements for supplementary compression*** to provide for smooth supply of natural gas during maintenance works.

6.3 Technologies in the area of pipelines

6.3.1 Pipe materials

6.3.1.1 Pipe materials utilized in new projects

Strain based pipeline design has been employed to ensure pipeline integrity of high pressure gas pipeline in harsh environments such as seismic zones, fault zones, cold regions, and mountain areas as presented in Figure 6.17. Pipeline shall be subjected to axial deformation due to ground shaking and bending deformation due to permanent ground deformation in fault zones, cold regions, and mountain areas. How to improve strain capacity in compression or bending shall be one of the key issues to ensure pipeline integrity. An advanced method of improving strain capacity by stress-strain (s-s) curve control method has been utilized. The method shall be useful to improve strain capacity without increasing wall thickness and effective in reducing the pipeline construction costs. The advanced method is briefly explained in this section focusing on the strain capacity in bending and the pipeline integrity in the hash environments.

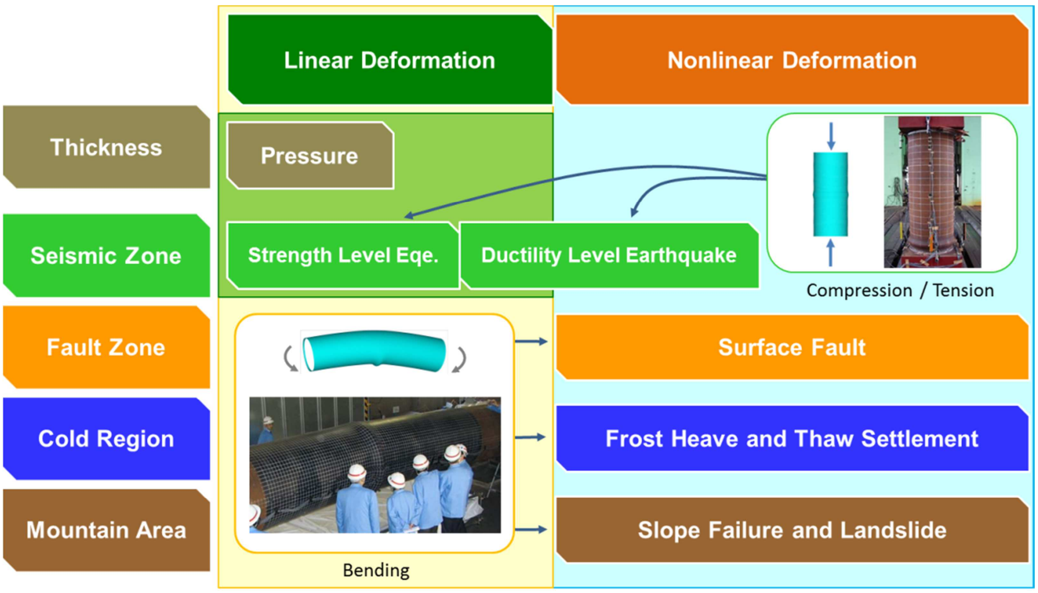


Figure 6.17 Pipeline design in harsh environments

6.3.1.2 How to improve strain capacity of line pipe

The relationships between the strain capacity in bending and D/t ratio (D: diameter, t: thickness) are presented in Figure 6.18 where the strain capacity in bending is presented in terms of the critical compressive strain in the longitudinal direction. The open circles present bending test data reported by former researchers and the curves express semi-empirical design formula applicable to pipeline design using standard line pipes. The solid squares and triangles present strain capacity of line pipes subjected to bending and the line pipes were manufactured with the advanced s-s curve control technology. As presented in the figure, the s-s curve controlled line pipes present high strain capacity compared to those of the standard line pipes.

The left side equation presented in Figure 6.18 shall be applied to the standard line pipe to predict the strain capacity which is expressed in terms of diameter and thickness. It is important that the tensile properties are not included in the left side equation and the thickness shall be increased to improve the strain capacity. On the contrary, the right side equation in the figure shall be applied to the s-s curve controlled high-strain line pipe to predict the strain capacity taking into account the material tensile properties other than diameter and thickness. The tensile properties are expressed in terms of the stress ratio $\sigma_{2.0}/\sigma_{1.0}$, where $\sigma_{1.0}$ and $\sigma_{2.0}$ are 1.0% yield strength and 2.0% yield strength, respectively. Furthermore it shall be mentioned that the right side equation directly connects the tensile properties to the strain capacity therefore line pipe can be endowed with the required high-strain capacity by controlling the shape of s-s curve or the stress ratio. It shall be advantageous for the s-s curve controlled high-strain line pipe to improve strain capacity without increasing pipe wall thickness and consequently the high-strain line pipe shall be beneficial to ensure pipeline integrity in the harsh environments.

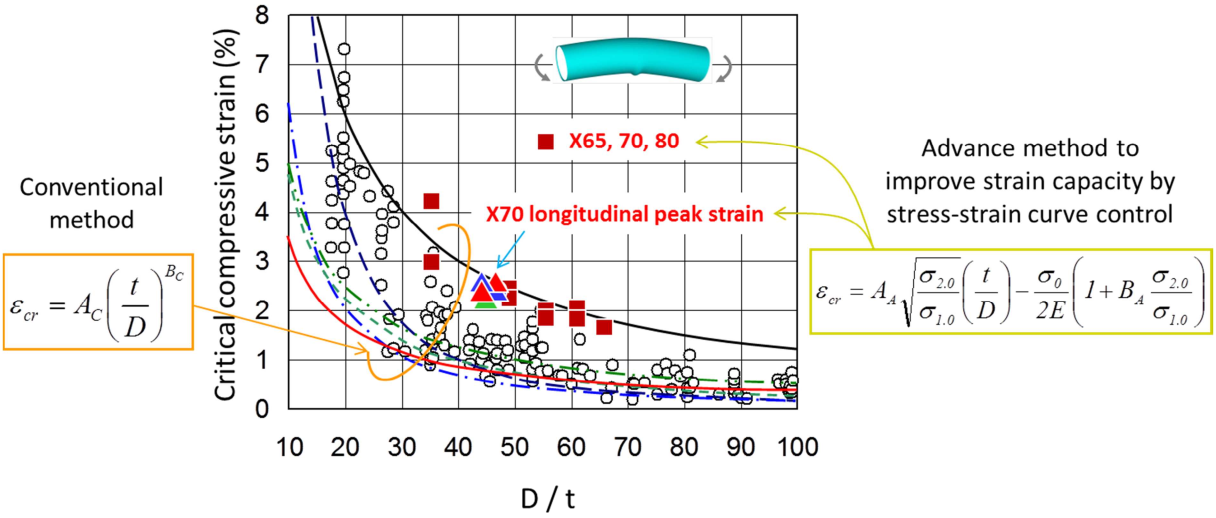


Figure 6.18 Strain capacity of line pipe subjected to bending

6.3.1.3 Stress-strain curve controlled high-strain line pipe

The longitudinal tensile properties of the s-s curve controlled high-strain line pipe and those of the standard line pipe are schematically compared in **Figure 6.19**. As shown in the figure, the s-s curve controlled high-strain line pipe and the standard line pipe present a Round-House (RH) type s-s curve and an Yield-Plateau (YP) type s-s curve in the longitudinal direction, respectively, after conducting the corrosion protection coating at 250 degrees C for 5 minutes. It has been generally recognized that the RH type standard line pipe tends to change the s-s curve to the YP type s-s curve and increase the yield strength due to the effect of the high temperature coating, the thermal aging. Also the YP-type standard line pipe tends to increase the yield strength and extend the yield plateau as the effect of the thermal aging. However the s-s curve controlled high strain line pipe will be able to maintain the RH type s-s curve even after experiencing the aging effect.

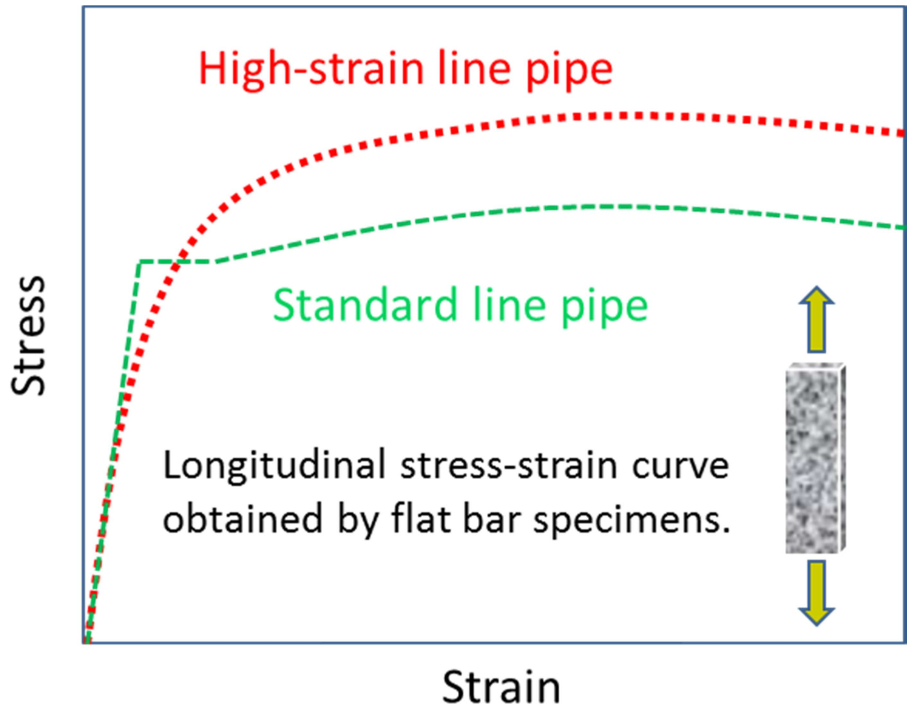


Figure 6.19 Longitudinal stress-strain curves of s-s curve controlled high-strain line pipe and standard line pipe
(after corrosion protection coating at 250 degrees C for 5 minutes)

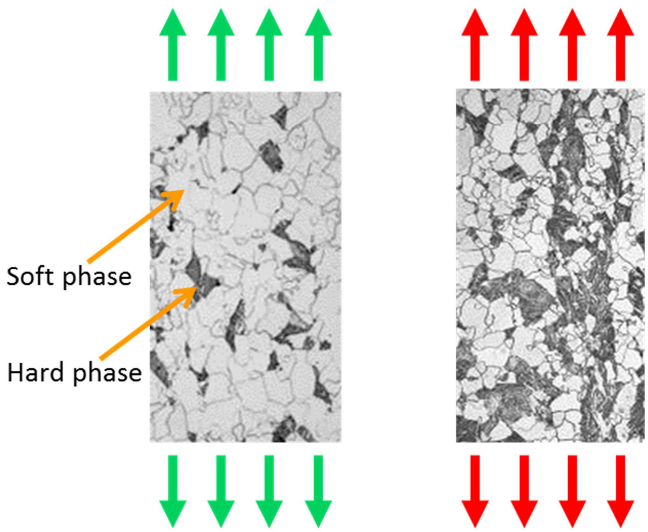


Figure 6.20 Different microstructures of tensile test specimens
(tensile test specimens shall be taken in the longitudinal direction)

The shape of s-s curve or the tensile properties of line pipe, which shall be obtained by tensile test of specimens, depends on the constituent of the dual-phase microstructures as illustrated in Figure 6.20. The tensile test specimens shown in the figure consist of a soft phase and a hard phase, which phases are distinguished in the bright and dark, respectively. The left side test specimen contains a high percentage soft phase, on the other hand the right side a high percentage hard phase. The test specimens taken from the pipe in the longitudinal direction may present different s-s curves. In addition, a sequential variation of the microstructure constituents is presented in Figure 6.21. And the microstructures are consistent with the s-s curves plotted in Figure 6.22, where the yield stress and tensile strength of the s-s curves tend to increase as the percentage of the hard phase microstructure increases. However the uniform elongation tends to decrease with increasing percentage of the hard phases. As mentioned above the stress ratio $\sigma_{2.0}/\sigma_{1.0}$ shall be the key parameter to predict strain capacity of line pipe. The stress ratio of the s-s curves presented in Figure 6.22 also increases as the percentage of hard phase increases, in other words, the strain capacity of pipe tends to increase with increasing percentage of the hard phases.

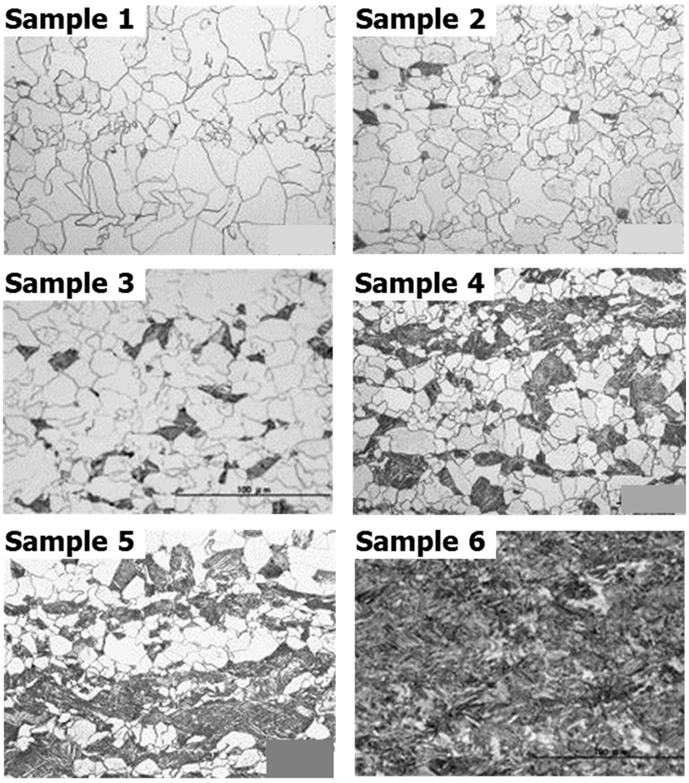


Figure 6.21 Variations of microstructures
(sample number increases with increasing volume fraction of hard phases)

Two types of the dual-phase microstructure are used in the s-s curve control which are the ferrite-bainite type, which shall be applied to X60 to X65 grade steels, and the bainite-MA type (MA: Mertensite-austenite constituent), which shall be applied to the high strength steels of X70 and higher. The corrosion protection coating shall be applied to line pipe and the aging effect of heating during high-temperature coating may increase the yield strength compared to that of as-manufactured line pipe. The content of solute carbon of the bainite-MA type high-strain steels can be reduced by fine precipitation of carbide during heating by HOP (Heat Online Process). Furthermore the dislocations in the bainite can also be reduced by tempering which results in the slight effect on the strain aging hardening and very small change in shape of s-s curve. Therefore the bainite-MA microstructure shall be suitable for application to the high strength line pipes with the pipe grade of X70 and higher. The HOP has been applied in the plate manufacturing process with the aim of achieving a bainite-MA fraction controlled to 5% or more in order to obtain the required stress ratio.

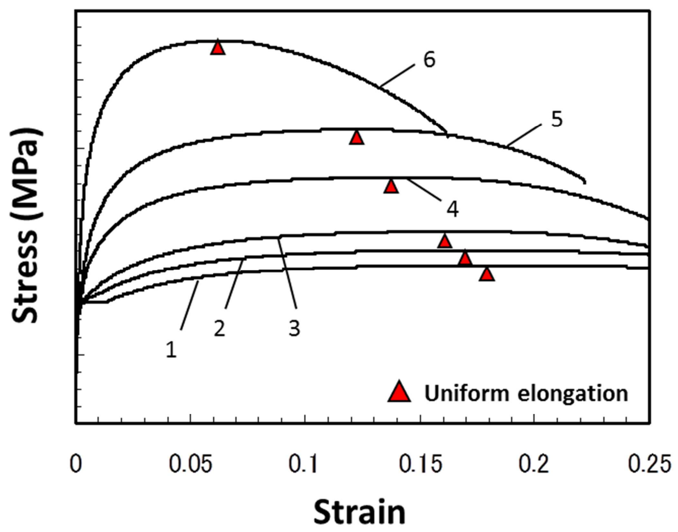


Figure 6.22 Variation of the longitudinal s-s curves

6.3.1.4 Comparison of strain capacity in bending of the line pipes

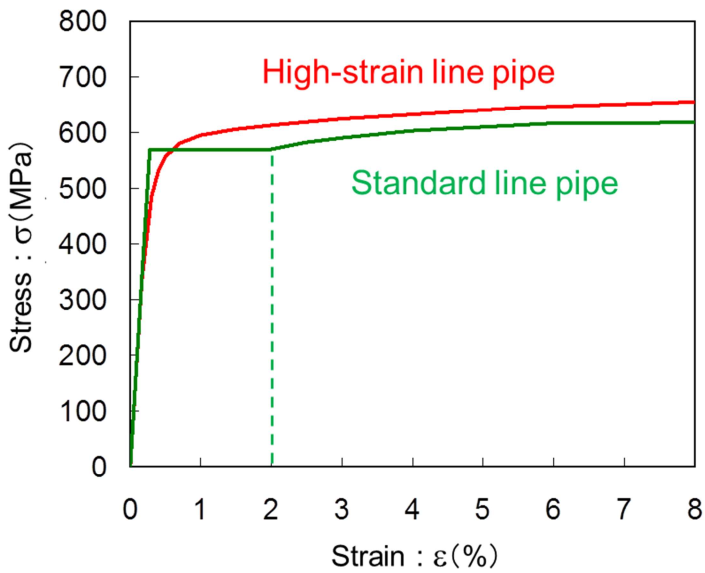


Figure 6.23 S-s curves of high-strain and standard line pipes (X70)

The X70-grade s-s curves of the standard line pipe having a yield plateau up to 2% and the high-strain line pipes with the stress ratio of 1.030 are presented in Figure 6.23.

Strain capacity of the standard line pipe and the high-strain line pipe subjected to bending are compared in Figure 6.24, where pipe diameter of 1420mm, wall thickness of 32mm, and operating pressure of 9.80MPa were assumed. The strain capacity of the high-strain line pipe is predicted as 1.67% which is 1.72 times as high as the strain capacity 0.97% of the standard line pipe. Hence if we use the standard line pipe for the construction, the strain capacity shall be improved to be the same as that of the high-strain line pipe increasing the wall thickness by 70%. Therefore it is obvious that the high strain capacity of the high-strain line pipe shall be advantageous for high pressure gas pipeline to endure the permanent ground deformation in the harsh environments.

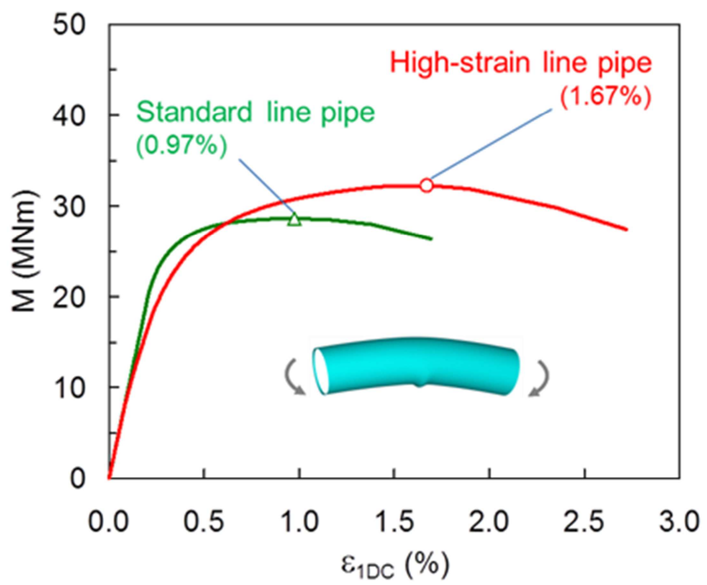


Figure 6.24 Strain capacity of high-strain and standard line pipes subjected to bending (1420mm, 32mm)

6.3.1.5 Comparison of pipeline integrity of the pipelines

In order to compare the seismic integrity of the standard pipeline and the high-strain pipeline using the s-s curve controlled high-strain line pipe, deformation of the pipelines induced by the strike-slip fault and lateral spreading are discussed, whose deformations are illustrated in Figure 6.25 and Figure 6.26, respectively.

The FEA results at the fault crossing are plotted in Figure 6.27. The left side figure plots the 1D average longitudinal compressive strain of the standard pipeline, which increases with increasing fault dislocation and reaches its strain capacity, critical compressive strain of 0.97%, at the fault dislocation of 2.7m. The right side figure plots the longitudinal compressive strain of the high-strain pipeline however the maximum pipe strain develops to 1.20% at the fault dislocation of 5m, which strain is small compared to the strain capacity of 1.67%. Hence the standard pipeline will not be able to survive the strike-slip fault with the dislocation of 5m however the high-strain pipeline will be able to survive the fault with the dislocation up to 5m.

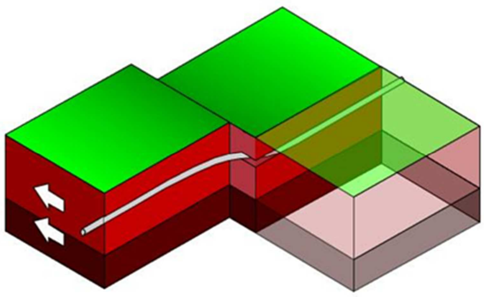


Figure 6.25 Strike-slip fault

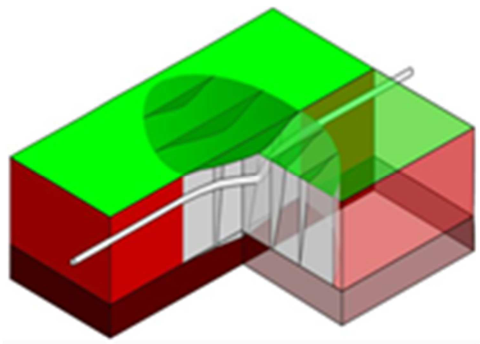


Figure 6.26 Lateral spreading

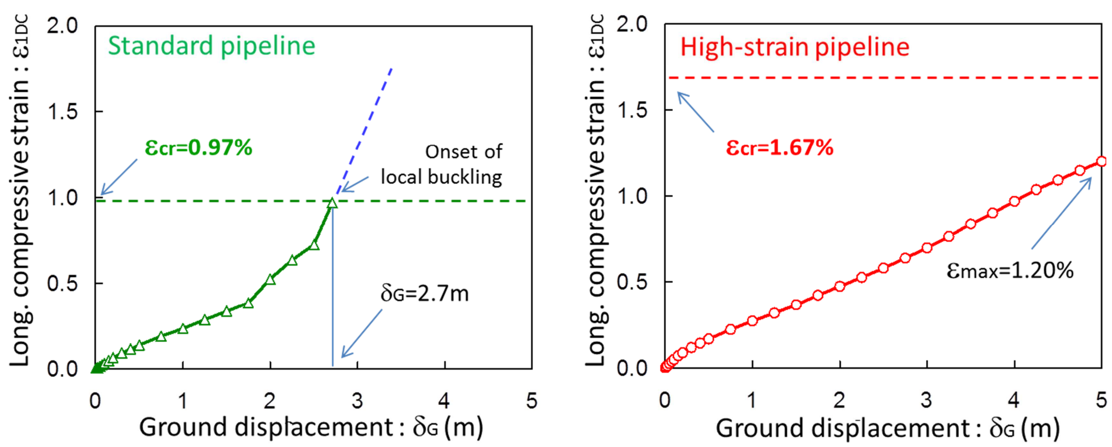


Figure 6.27 Pipeline integrity at a strike-slip fault (X70, 1420mmOD, 32mmWT, 9.8MPa) (left: standard pipeline, right: high-strain pipeline)

FEA results of deformation of the pipelines induced by the lateral spreading are plotted in Figure 6.28. The ground deformation of the lateral spreading can be expressed in terms of the breadth B and the maximum ground displacement. The left side figure explains the deformation of the standard pipeline in terms of B. The 1D av. longitudinal compressive strain increases with increasing maximum ground displacement and the strain reaches the strain capacity of 0.97% at the maximum ground displacement of 2.9 and 4.0m in the cases of 70 and 100 m in breadth, respectively. The right side figure presents the variations of the longitudinal compressive strain induced in the high-strain pipeline. The figure clarifies that all of the cases with a different breadth survive the lateral spreading with the maximum ground displacement up to 5m as the maximum strain induced in the pipeline at ground displacement of 5m shall be a half of the strain capacity.

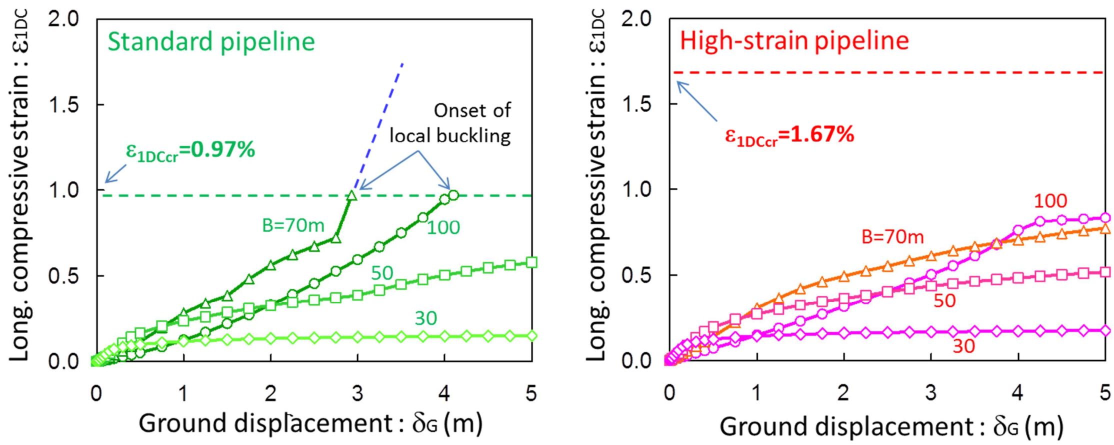


Figure 6.28 Pipeline integrity to withstand lateral spreading (X70, 1420mmOD, 32mmWT, 9.8MPa),

(left: standard pipeline, right: high-strain pipeline)

6.3.1.6 Summary of the effectiveness of the stress-strain curve controlled high strain line pipe

It shall be mentioned here that the stress-strain curve controlled high-strain line pipe was developed to improve the integrity of high strength pipeline to the same or a high level compared to that of standard pipelines with conventional line pipes. The high-strain line pipe can make it possible to improve strain capacity without increasing wall thickness. Application of the high-strain line pipe to natural gas pipelines will also make it possible to ensure pipeline integrity in harsh environments such as seismic zones, fault zones, and cold regions while minimizing increases in construction costs. As features of the s-s curve controlled high-strain line pipe, since the pipe weight, transportation costs, welding time, quantity of consumables, non-destructive inspection time, and construction period can all be reduced, corresponding to the amount by which the pipe wall thickness is not increased, this is an environmental-friendly product with a large CO_2 reduction effect.

6.3.2 Overview of Pipeline Welding Technology

6.3.2.1 Introduction

Welding is the process that joins the various sections of pipe together into one continuous length. Welding is required for double-jointing, preparing sections for crossings, mainline welding, tie-ins, and fabrication. The welding process used to make on-site pipeline girth welds has a significant bearing on the total cost.

The long-distance pipeline for transportation of the natural gas is now under construction in the worldwide range, due mainly to the expansive requirement of the energy resources. One of the major difficulties is that, usually, the production area is far from the usage area, resulting in higher transport costs of the natural gas. The higher grade pipeline has been highlighted to seek the low cost transport. The API 5LX80 grade material was used twenty years ago. In addition, in the last decade, the X100 grade material was first used in Canada to build a pipeline. In the future, under investigation of the long-distance pipeline, the transport cost of the X100 grade material is likely to decrease through high pressure and thin wall thickness of the pipeline. Welding technology is one of the tasks of the related higher grade materials.

The majority of welded steel pipe is produced from coil or plate. To produce pipe, the coil is cut to length and the edges are mechanically slit. Then a subsequent forming process is applied. The choice of welding process is largely dependent on the steel grades to be welded. Pipes are manufactured at the pipe mils by different welding techniques, such as submerged arc welding (SAW) process and electric resistance welding (ERW) process. Both have been widely used in the manufacturing of linepipes for many years. Although the welding speed and productivity are lower than ERW, in recent years, SAW is frequently used to produce the X100 and X120 high-grade pipelines, taking into consideration the toughness and tensile properties. The requirement for the properties of a weld joint increase as the grade of the linepipe increases, thus the applicability of the new welding method was investigated.

The pipeline can reach 2 to 3 kilometers every day, although a few ten meters in some places. The famous spread welding method, includes the edge preparation, axis alignment, root-pass, filler pass and cap pass welding, simultaneously. This inner-outer welding system was typically realized in 1969 by CRC-EVANS Company, and is used continuously until now.

6.3.2.2 Pipeline welding process

Welding processes that are commonly used for pipeline applications are Shielded metal arc welding (SMAW), or gas metal arc welding (GMAW). Either a mechanized welding technique or manual welding may be used for mainline welding.

GMAW is done using a consumable wire that melts when an arc is struck and maintained between the wire and the material being welded (Figure 6.29, Figure 6.30). The welding wire is fed continuously into the arc during the welding process. The arc and weld pool are shielded from the atmosphere by a concentric flow of gas. A number of gases/gas mixtures are used for shielding, with 100% CO_2, or 75% argon and 25% CO_2, being two of the most common. If the welding procedures are not followed or the operator technique is not correct, welding defects may result. The continuous nature of the wire electrode and virtual absence of slag leads to high productivity and is ideally suited to mechanization. The mechanized GMAW process is invariably used in CANADA, USA and EUROPE for major large-diameter, cross-country pipeline construction. The dual-tandem GMAW provides the greatest productivity with four welding arcs operating simultaneously on each welding carriage.

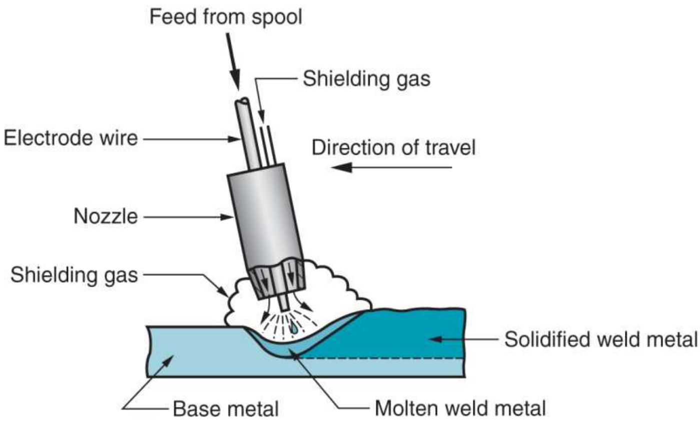


Figure 6.29 Outline of GMAW
(M P Groover, Fundamentals of Modern Manufacturing 4/e, 2010, John Wiley & Sons)

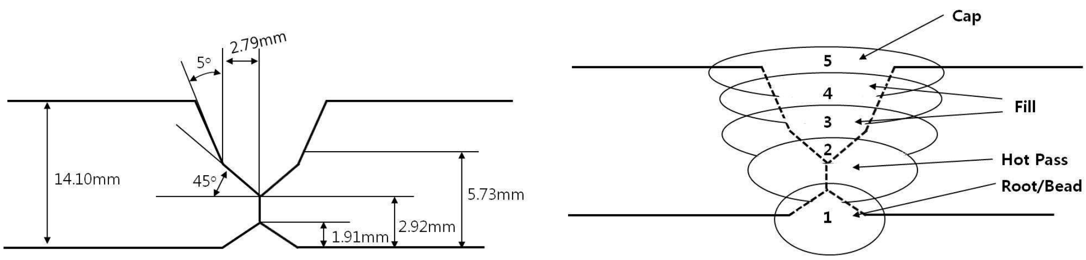


Figure 6.30 Typical Joint design and number of passes for GMAW

SMAW is done using consumable stick electrodes that melt when an arc is struck and maintained between the electrode and material being welded (Figure 6.31, Figure 6.32). These electrodes are composed of two main parts, one being the core wire and the other the external flux coating. The core wire, and sometimes iron powder within the coating, provides the necessary metal to fill the weld joint. The flux coating is required the shield the arc and molten metal from the atmosphere, add alloying elements to the weld metal, and provide a protective layer (slag) during and after solidification of the weld metal.

This slag is subsequently removed between passes. SMAW remains the most widely used and versatile process for general pipeline applications. With the correct choice of consumable and welding technique the SMAW process can be applied to all welding positions and will allow a wide range of mechanical property requirements to be met. However, the process is very dependent on the welders' manual skills for attainment of defect-free welds with acceptable properties.

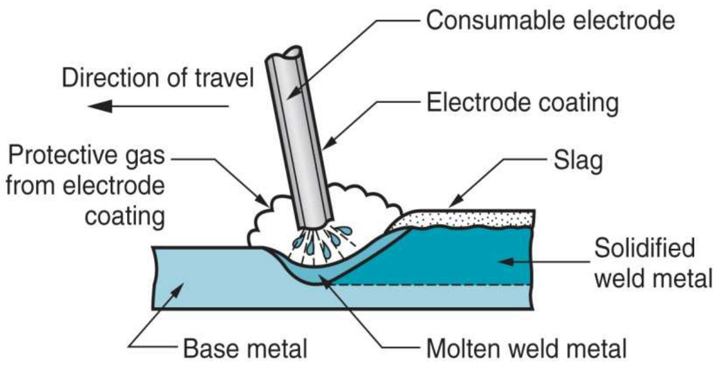


Figure 6.31 Outline for SMAW

(M P Groover, Fundamentals of Modern Manufacturing 4/e, 2010, John Wiley & Sons)

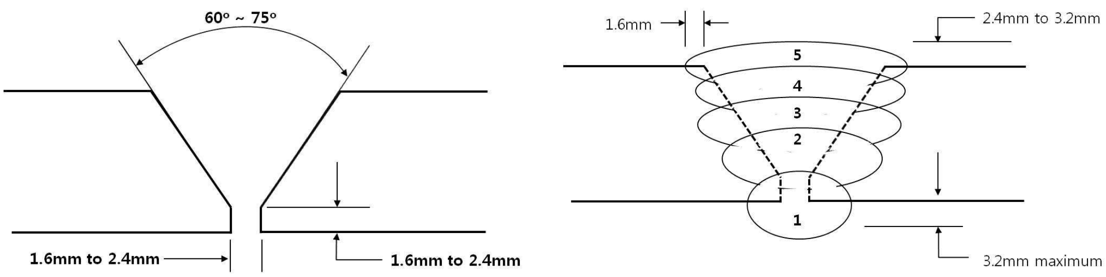


Figure 6.32 Typical Joint design and welding passes [3]

Laser welding, and in particular fibre-delivered laser welding, has now been developed to a stage where it presents opportunities for cost savings, which arise from reductions in labour content, despite perceived high capital costs. It has been demonstrated that the concept of high-power laser welding of land pipelines is entirely feasible. Welding procedures have been developed that produce good quality welds with satisfactory tolerance to joint fit-up. Additionally, techniques have been developed for welding around 360° and for ensuring a good weld at the start/stop weld overlap position.

Until recently, there have been two main types of industrial laser used at high powers for deep penetration keyhole welding. These were CO_2 gas lasers and Neodymium-doped Yttrium, Aluminium Garnet (Nd:YAG) lasers. In terms of materials processing, the principal difference between Nd:YAG lasers and CO_2 lasers is the difference in wavelength of the light emitted. Nd:YAG lasers produce light that can be transmitted to the workpiece by a fibre optic cable. This is a much more flexible system of beam delivery than for CO_2 lasers which require more cumbersome reflective or transmissive optical systems.(Figure 6.33) Nevertheless, Nd:YAG lasers have a significant drawback in that they are inefficient, only converting around 3% of the input energy to produce the laser beam power. This is not a major issue for some manufacturing applications, but the use of lasers for welding cross-country pipelines relies on the portability of the process, and the Nd:YAG laser process is therefore very difficult to justify economically. One of the major advances in laser technology in recent times is the introduction of Ytterbium (Yb) fibre lasers. The lasing medium for these lasers is contained within a fibre and individual units generating 200-300W can be combined to produce single lasers with up to 10kW power and beyond. The wavelength of light generated is similar to that from Nd:YAG lasers and hence fibre delivery of the energy is used.

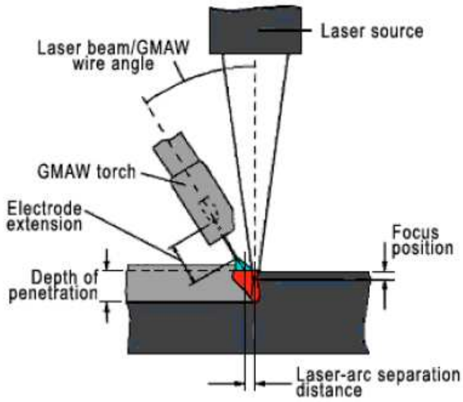


Figure 6.33 Hybrid laser-arc welding
(D.Howse, R.Scudamore, A.Woloszyn, G.Booth and R.Howard; International Pipe Dreamer's Conference, Yokohama, Nov.2002, pp.763-784.)

Electron beam (EB) welding offers many advantages for thick-section fabrication, particularly when applied to large structures, where significant savings are anticipated because of the rapid joining rate achievable.(Figure 6.34) Examples of this include the use of EB welding for the future fabrication of structures such as monopole foundations for offshore wind-turbines fabricated from rolled steel with thicknesses in excess of 80mm. Appropriate application of EB welding in a single pass is anticipated to lead to cost and time saving in excess of 50% compared with more conventional fabrication practice. To date, however, the full potential of the EB process has not been realised commercially for thick-section welding and large structures because of restrictions associated with working at a high-vacuum, with the entire structure to be welded enclosed in a vacuum envelope.

The ability to weld thick section material (25-150mm) in a single pass has been one of the driving forces behind the development of high-power EB welding systems with potential for high-productivity and high-accuracy fabrication. The requirement to operate in high vacuum has precluded the use of the process in the fabrication of very large structures as the construction and operation of large vacuum chambers can be difficult to justify economically. The possibility of having portable local vacuum equipment which can be delivered to site and operated on a lease/hire basis improves practicality and economics of thick section EB welding. Operation at reduced pressure where process reliability and performance is better than at high vacuum make this now a practical proposition and work is currently underway to manufacture an industrial system which will realise this opportunity. Similarly, the possibility to operate at atmospheric pressure with a non-vacuum system is equally attractive particularly where thinner materials are concerned (*i.e.* <50mm). With recent developments in beam pulsing and gun configuration, it is likely that high-speed welding of even thicker materials will be realised at atmospheric pressure in the near future.

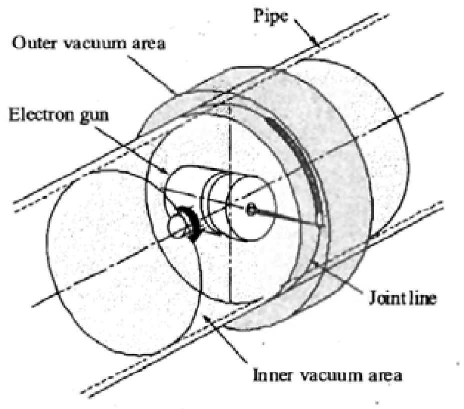


Figure 6.34 Basic concept of EBW system layout for pipeline uints (S.Koga, M.Inuzuka, M.Nishio, S.Aomi and A.Nishida; International Pipe Dreamer's Conference, Yokohama, Nov.2002, pp.753-762)

Magnetically Impelled Arc Butt Welding (MIAB), one of the single shot methods, is developing in Australia, in which the magnetic coil is rotated around the arc. The MIAB welding process is a forge-welding process similar to other processes such as electric resistance welding, and flash butt welding, except that a different method of heating is employed prior to the forging cycle. The square edged pipe ends to be welded are separated by a small gap, and a welding arc is established in the gap. A radial magnetic field is then superimposed upon the gap and this causes the arc to rotate. By using this method, a pipeline with a thickness of 15 mm can be welded in little more than 15 s. Furthermore, in the freezing area of Russia, flash butt welding is frequently used as a substitute for arc welding, because another pre-heating process is not needed. The pipelines can be joined due to friction heat, when the sander ring is rotated between the pipes.

This is called the friction and explosion (FRIEX) welding process, one of the friction welding methods. The major difference of this variant with the classic friction welding process is that a filler material in the form of a solid ring is used. This welding ring is placed between the pipes, and rotating the ring under an axial pressure generates the required friction and associated heat. The friction welding process is controlled by the rotation speed, upset force and upset distance.

6.3.2.3 Weldment quality assurance

Before commencing site welding, the contractor must develop or obtain qualified welding and repair procedures for any method proposed, and for all combinations of pipe diameter, wall thickness, and grades involved. As part of the quality assurance process, each welder must pass qualification tests to work on a particular pipeline job, and each weld procedure must be approved for use on that job in accordance with adopted welding standards. Welder qualification takes place before the project begins. Each welder must complete several welds using the same type of pipe as that to be used in the project. Radiographs and destructive tests are done in the qualifying welds in accordance with the applicable code or standard as specified. Each qualified welder is assigned a number to be used to identify each individual's work.

Multiple welding passes are requires to complete each weld. The number of passes is dependent upon the pipe wall thickness and the welding process used. The first pass is called the stringer bead, which is followed by the second, called the hot pass. The required number of fill passes are then conducted, which are succeeded by a cap pass to complete the weld. An internal clamp, operated and propelled by compressed air, is used to hold the correct alignment during the placing of the stringer bead. On a large-diameter pipe, the stringer bead will be made using at least two and as many as four welders working simultaneously. The hot pass will also be done by one or two pairs of welders. The fill and cap passes will be completed by individual welders.

Mechanized welding makes the stringer bead internally, using gas metal arc equipment built into the line-up clamp. Subsequent passes are made suing "bugs" that run on bands placed on the pipe at a preset distance from the weld bevel. These bugs are operated in pairs and require a shelter carried by a side boom to prevent the shielding gas from being blown away by prevailing winds. Mechanized welding has a consistently superior weld quality and welders can qualify with less training than manual welders. The disadvantages of mechanized welding include increased need for repair and maintenance of equipment, additional equipment requirements for welding shelters, and the need for end preparation machines.

In recent years, contractors have used semiautomatic welding units to move down a pipeline and complete the welding process. Semiautomatic welding must be completed to strict specifications and still requires qualified welders, and personnel are required to set up the equipment and hand-weld at connection points and crossings.

A second quality assurance test ensures the quality of the ongoing welding operation on-site. In this test, qualified technicians take X-rays of the pipe welds to ensure that the completed welds meet prescribed quality standards. All welds found to be unacceptable by non-destructive testing are cut out and replaced or repaired using a qualified procedure. Another type of weld quality inspection employs ultrasonic technology (Figure 6.35).

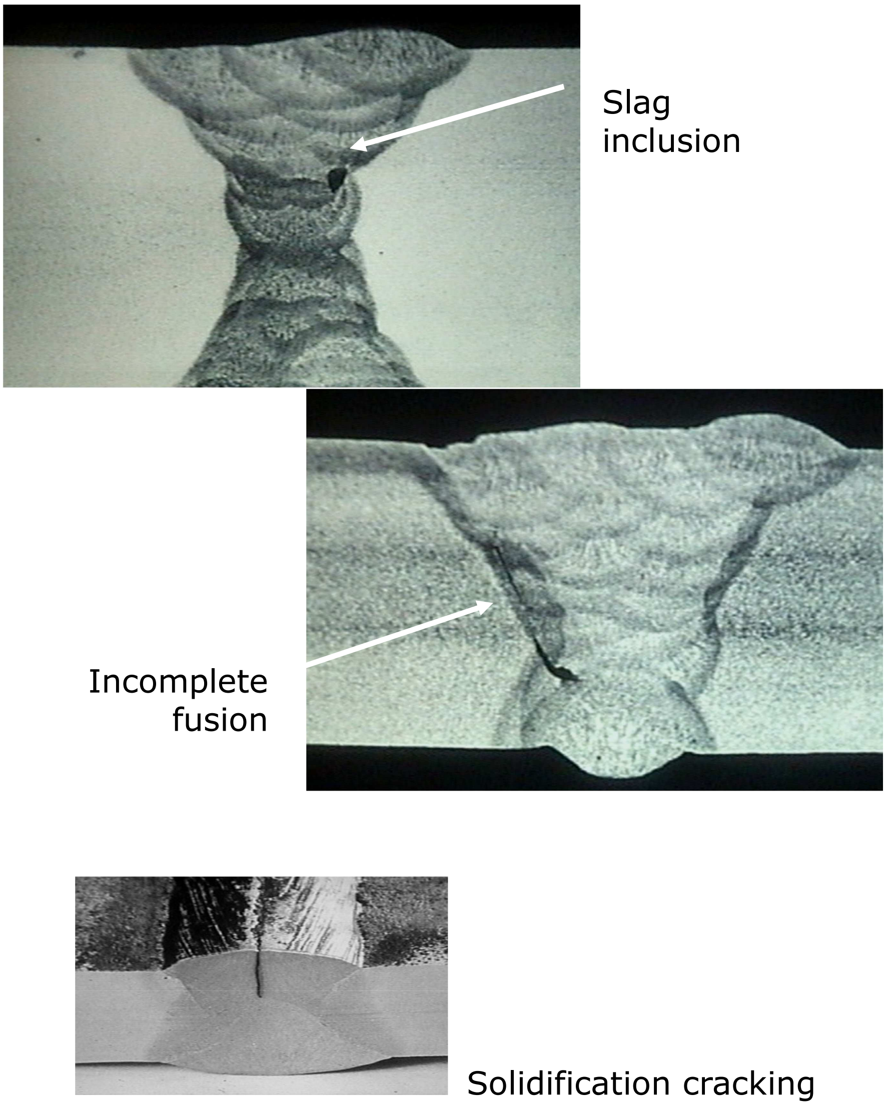


Figure 6.35 Various welding defects (from Internet web.)

A protective epoxy coating or mastic is applied to the welded joints once the welds are approved. Line pipe receives an external coating, which inhibits corrosion by preventing moisture from coming into direct contact with the steel. This process is normally completed at the coating mill where the pipe is manufactured or at another coating plant location before it is delivered to the construction site. All coated pipes, however, have uncoated areas 3 to 6 inches from each end of the pipe to prevent the coating from interfering with the welding process. Once the welds are made, a coating crew coats the field joint, the area around the weld. Pipeline companies use several different types of coatings for field joints, the most common being fusion-bond epoxy, polyethylene heat-shrink sleeves, or heated mastic tape. Prior to application, the coating crew thoroughly cleans the bare pipe with a power wire brush or a sandblast machine to remove any dirt, mill scale, or debris. The coating of the entire pipeline is inspected to ensure it is free of defects. The pipeline is then electronically inspected, for faults or voids in the epoxy coating and visually inspected for faults, scratches, or other coating defects. Damage to the coating is repaired.

6.3.2.4 Reference

1) Christoph Wiesner, "Overview of recent welding-related pipeline technology advances at TWI", International Symposium 'From welding and fracture mechanics to pipeline technology', June 2008

2) Komizo Yu-ichi, "Overview of recent welding technology relating to pipeline construction", Transactions of JWRI, vol 37 (2008) No 1

3) M.Mohitpour et al, "Pipeline Design and construction", 2000, ASME

4) Sindo Ku, "Welding Metallurgy", 2003, John Wiley & Sons

6.3.3 Hot taps / Grouted Tee

The Grouted Tee is a novel method of installing a branch connection onto a live pipeline. The technology was developed in 1997 based on the well-established epoxy filled repair sleeve. Welding new connections onto live pipelines is hazardous and in some cases impossible due to high flow rates. The Grouted Tee connection is bonded to a live pipeline without interrupting or adjusting the pipeline product supply. Since the initial development of the Grouted Tee it has been further developed for application on thin wall pipelines, cast iron pipelines and subsea to depths of 200m. The Grouted Tee Connection does not require any onsite welding which makes the installation process safer. The Grouted Tee accommodates much larger pipeline ovality. Hot tapping using the Grouted Tee connection offers zero disruption to production during installation and has been designed to be simple and quick to install compared to alternative connections. The technique involves two half shells. The branch half shell incorporates a saddle seal, which eliminates the need for longitudinal and circumferential seals, typical of current bolt-on mechanical fittings. The shells are then placed around the main pipeline and bolted together. The fitting is sized to allow an even gap between the bore of the shell assembly and the outside diameter of the parent pipe. This annular gap is filled with the same epoxy grout as that of the repair sleeves. Extensive analysis and full-scale testing have successfully addressed all technical and safety issues relating to live pipeline intervention. The Grouted Tee is designed to have a minimum of 40-years design life.

The Grouted Tee technology has been recommended as a suitable repair for dealing with illegal hot tapping. Various methods have been adopted for encapsulating or removing an illegal hot tap. For the option of localised removal all welding operations can be eliminated with the use of the Grouted Tee technology. The Grouted Tee can be implemented to support a cut out and replacement operation or a single hot tap repair, and will eliminate the requirement of flow reduction during the repair. Cost comparisons between welded and Grouted Tee connections are generally comparable. Welded fittings are more hazardous to install and require specialist contractors to undertake installations. The Grouted Tee has been developed to be quickly and simply installed. Local contractor or in-house technicians are trained and can therefore react quickly in the event of an illegal tapping. Overall cost savings are generated through maintaining product delivery.

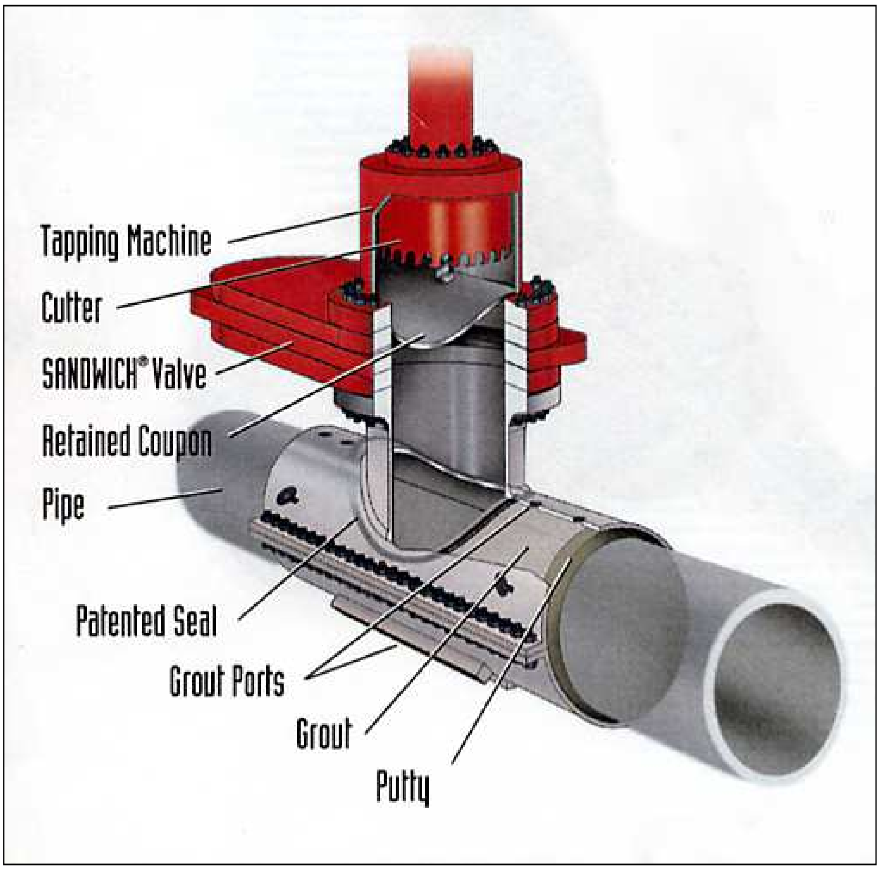


Figure 6.36 Component parts of the grouted tee

Figure 6.37 42” x 18” Class 600 grouted tee

6.3.4 Cold Sleeves

The gas transmission companies pay an extreme attention to maintaining its key technologies as well as pipeline systems. This segment has been its long-term focus of attention not only in terms of following up on global trends of systems designed for repairs of typical pipeline damages (e.g. corrosion defects, welds, incorrectly applied coatings, landslides etc.,) and their consequent use in practice, but also in terms of development and testing of pipeline systems repairs. A typical example of such repairs tool, continually developed over the past 15 years, is a cold sleeve, which has been applied successfully on the Slovak product pipelines (Eustream transmission network, Brotherhood gas pipeline, Transpetrol a.s.).

The cold sleeve (STO) is a cold (glued) joint between the pipe, which is being repaired, and the steel shell of the sleeve produced without any thermal effect using an adhesive polymer with penetration capabilities. Its principle lies in fabrication of a hermetic shell aiming at increasing the load capacity of the pipe affected by the impermissible defect. The space between the pipe and sleeve shell is being filled in by a special composite material (Figure 6.38).

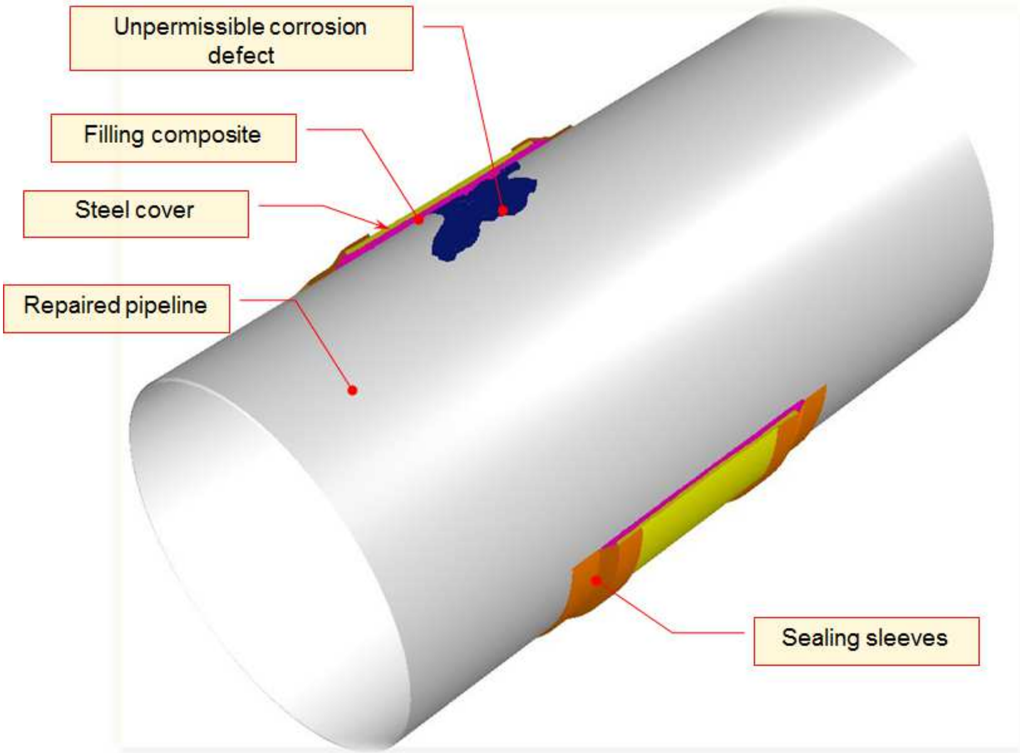


Figure 6.38 Cold sleeve

An undisputable advantage of this high-pressure pipelines repair method is the fact that the repair can be carried out under full operating pressure, i.e. *without any limitation to medium transmission*. The method can be used for repair of *all kinds of corrosion or material losses* up to the yield point R_e of the repaired material. *The length of the repaired pipe is not limited* since sleeves can be arranged continually one after the other.

In respect to safety of high-pressure pipeline operation the current version of the cold sleeve has been characterized by the following limitations:

- STO can be used as a permanent repair *only for corrosion defects*,
- STO *is not suitable for use as a permanent repair for anomalous welds,* since the filling material after polymerization becomes fragile and in case of pressure changes under certain conditions the filling is cracking, or possibly separates / detaches from the basic material,
- high price of the filling material as well as demanding maintenance of the filling device.

When compared with the operation situation, during depressurizing the gas pipeline shrinks and due to the fact that the cold sleeve shell keeps its dimensions acquired during installation, there generates internal tension in the adhesive layer between the polymer and metal of the gas pipeline, as well as the STO shell. This results in detachment of the filling material as well as in integrity disruption of the glued joint – filling material (composite) – pipe (Figure 6.39).

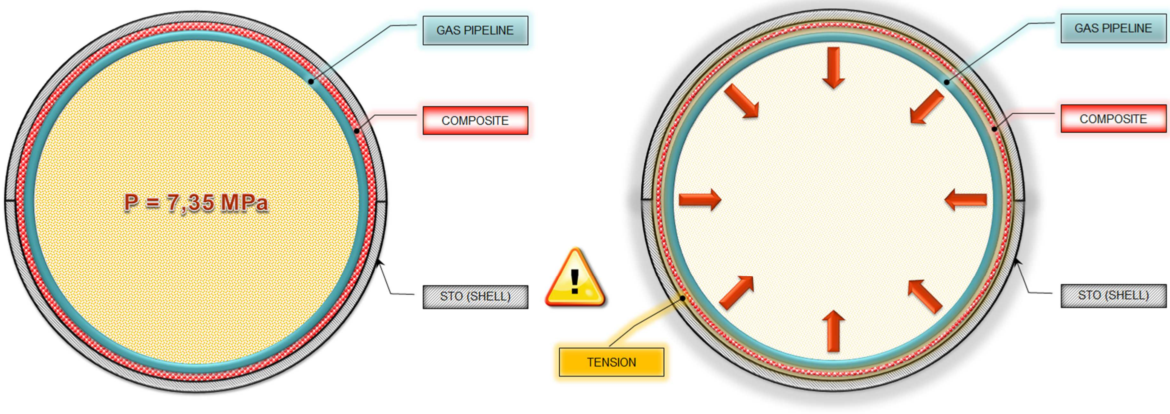


Figure 6.39 Effect of the pipe depressurizing

6.3.4.1 Specification of the Anomalous Weld

For the sake of better understanding one has to state the following:

Over the whole period of defect identification in welds construed during the Eustream Gas Pipeline Network (former "Transit gas pipeline") construction there has been detected a great number of defects of the type of an incomplete root penetration maximally up to the depth of 1 mm. This defect has never occurred on both edges of the weld root, neither was it identified along the whole weld circumference. For purposes of safe proving of new filling material suitability of the innovated STO technology we have opted for **a conservative approach,** which means that the strength analysis included an anomalous weld in respect of which the incomplete penetration was defined at both edges of the root up to the depth of 1 mm as well as along the whole weld periphery (Figure 6.40).

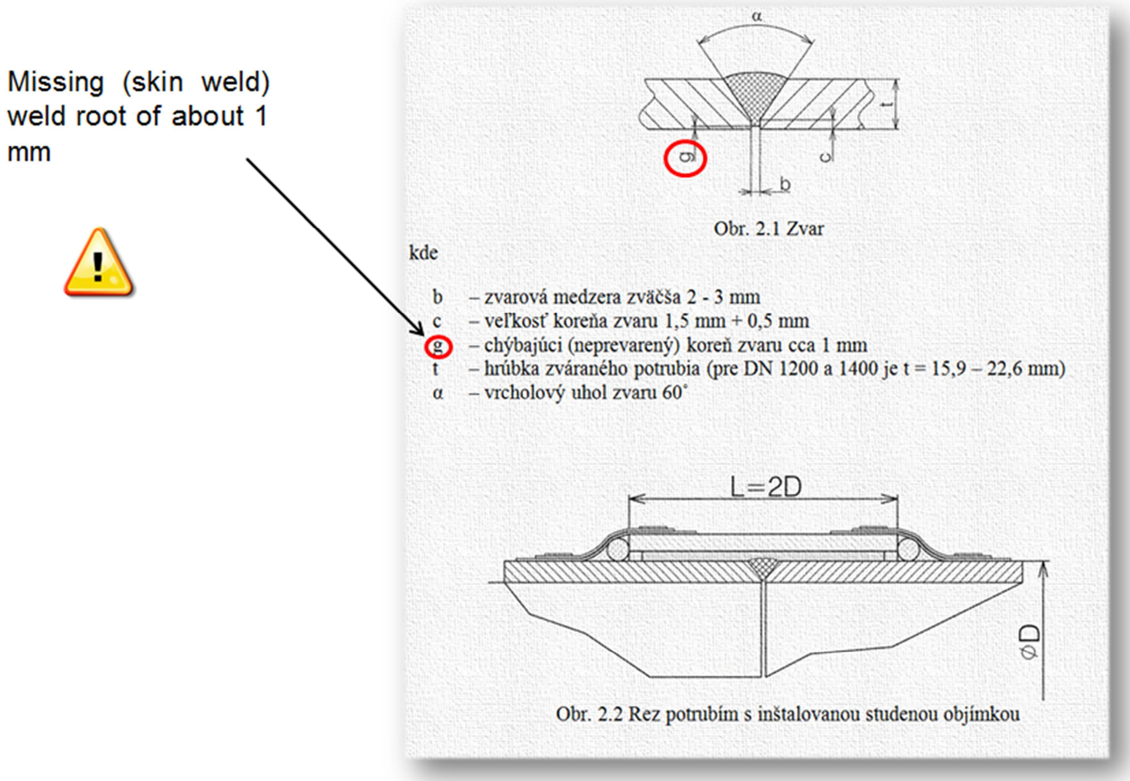


Figure 6.40 Anomalous weld specification

Due to the above reasons, just as well as due to the new ambitious objective to eliminate limitations and to extend applications of the cold sleeve it was decided to continue in developing the new STO by way of implementation of a research and development task. The task has been named " *Verification of the new filling material for STO as a permanent repair of the high-pressure gas pipelines according to TC.R.90.01.06 (Development of a new technology, Annex 1, chapter 3, Art. 1.2, letter B)"*.

The expected objective and concurrently required result was to:

- propose a filling material with the required properties (adhesive and cohesive strength, viscosity, ductility, processability time, chemical resistance, el. breakdown strength etc.),
- achieve that the innovated repair system by the STO method is recognized as permanent repair also for anomalous welds of the high-pressure gas pipeline.

The task was assigned to employees of the centralized maintenance in Senica. Upon a thorough analysis of weaknesses of the currently used STO technology they proposed a procedure divided to the following stages:

6.3.4.2 First stage

6.3.4.2.1 To define the qualities of the new filling material

For the new filling material there have been defined basic parameters as follows:

- compressive, tensile and shear strength,
- adhesive strength,
- flexibility module,
- hardness, ductility
- viscosity, penetration ability
- chemical resistance
- application time (pot life).

6.3.4.2.2 Mechanical testing

Upon selecting the most suitable material and its modification by the manufacturer there were produced testing samples (Figure 6.41) for:

- adhesion tests,
- cohesion tests,
- corrosion tests.

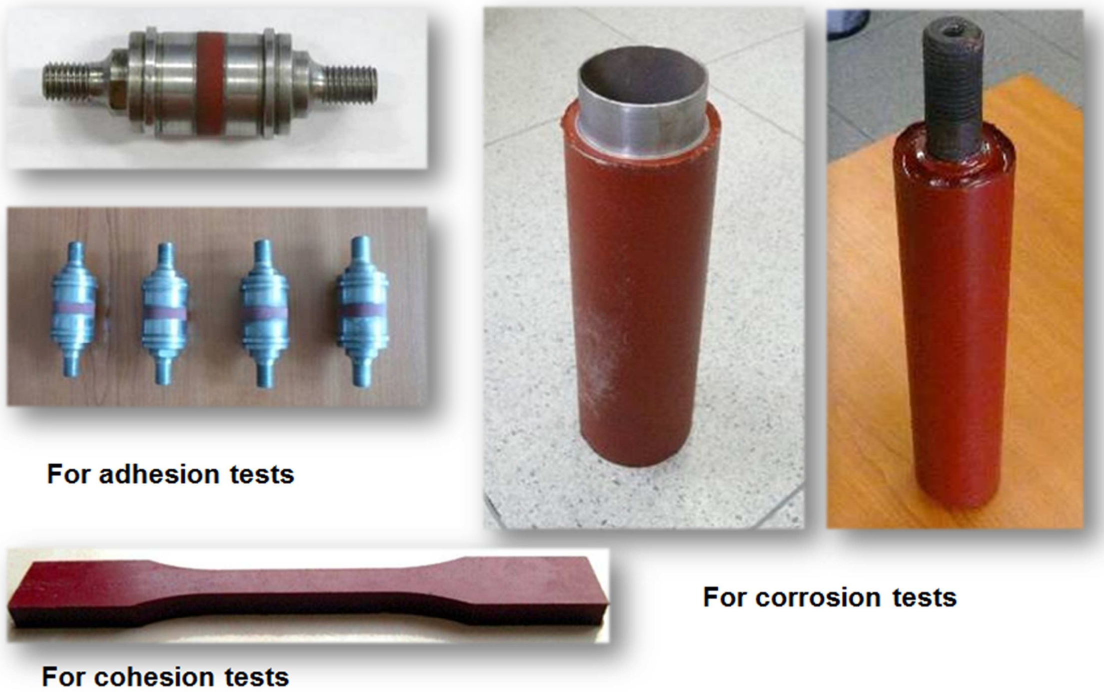


Figure 6.41 Testing samples for mechanical and corrosion tests

In Figure 6.42 one can see a broad force dispersion necessary for detachment for a normal load of the filling and maximal force at the tensile test of the filling material. Results of these tests show statistical behavior of the testing samples with big dispersion of maximal force. For example the maximal force necessary for tearing of the sample moves within <200, 500> [N]. It is caused mainly by chemical composition, surface as well as internal inhomogeneity of the material, way of polymer processing as well as sample manufacturing.

It is very important to note that also in case of mechanical testing results evaluation, due to the safety of high-pressure gas pipelines operation, there was selected the ***conservative approach*** and the values that were entered in the strength analysis were *the lowest ascertained values of the mechanical testing.*

Another level of the conservative approach was the fact that the strength analysis also considered the axial loading of the whole system. (*Axial loading F_O produced by the gas operating pressure in the closed pipe. This load is calculated as $F_O = P \, . \, S$, wherein P represents the operating pressure and S the internal circular area of the pipe.*)

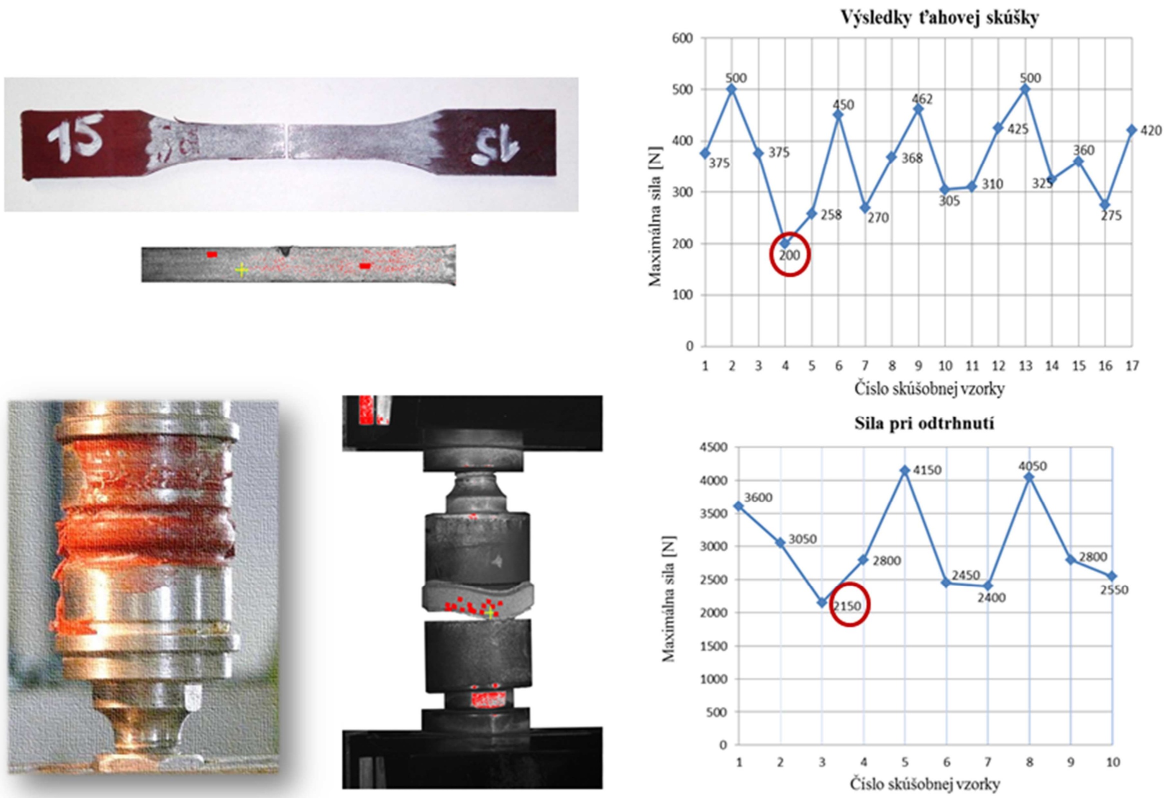


Figure 6.42 Mechanical tests evaluation

6.3.4.2.3 Technological testing

Upon evaluation of the results of the mechanical tests there followed technological tests (Figure 6.43) that were implemented in the laboratory conditions of the centralized maintenance in Senica (with the aim to reach real conditions as close as possible) (Figure 6.43). The technological tests included:

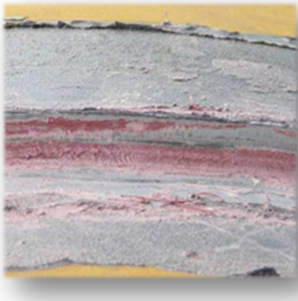
- leakage test,

- model test,
- measuring of radial stress on the external surface of the STO shell as well as the pipe under repair,
- final visual check.

Leakage test
Shell made of transparent material

Tension measuring
Installation of tensimeters

Model test
Actual conditions



Visual check
Joint integrity upon depressurizing

Figure 6.43 Technological tests

6.3.4.3 Second stage

Upon successful completion of the material as well as technological testing the results of the tests were submitted to two independent authorities: "ÚVP - protikorozní ochrana, s.r.o., Praha" and "SjF Žilinskej univerzity" in Žilina.

"ÚVP Praha" studied the anticorrosive reliability of the newly developed polymer and they confirmed it by a *Protocol*.

The University in Žilina elaborated *a strength analysis of the new STO applied to an* anomalous weld (as per Figure 6.40), and they arrived to the following conclusions:

- from the strength calculations of the finite elements method, in consideration of the ultimate load-carrying capacity there derives that the *least favorable alternative is the one with the biggest diameter of the pipe and the smallest wall thickness (Ø 1 420 mm with the wall thickness 15,6 mm) also in consideration of the axial force*,

- the pipe as well as the sleeve are stressed in the *elastic area under the yield point* of the utilized steel types,
- results of the detachment (separation) simulation imply that *the cohesion of the plastic filling and the sleeve or pipe will not be disrupted even in case of the most critical stress*,
- ***from the point of view of the plastic filling separation, the repair of the anomalous weld by the cold sleeve is safe***.

The overall assessment of the technical solution of the given task was requested from the Technical Inspection that eventually confirmed that the solution was successful by issuing the Certificate (Figure 6.44).

TECHNICKÁ INŠPEKCIA, a.s.
SLOVENSKÁ REPUBLIKA

OSVEDČENIE
č. 00621/4/2013-PZ

o skúške vyhradeného technického zariadenia
vydané podľa vyhlášky č. 508/2009 Z. z.

Dátum skúšky:	11.02.2013, 18.02.2013 a 22.02.2013
Druh skúšky:	Úradná skúška (§ 12 ods. 1 vyhl. č. 508/2009 Z. z.)
Názov zariadenia:	Rozvod plynu s pretlakom plynu nad 0,4 MPa - časť skúšobný polygón DN 700
Zaradenie zariadenia:	plynové zariadenie skupiny A písm. g) (podľa vyhlášky č 508/2009 Z. z., príloha č.1)
Výrobca:	eustream, a.s., Železničná 356/134, 905 01 Senica
Prevádzkovateľ:	eustream, a.s., TMUP Senica
Umiestnenie zariadenia:	eustream, a.s., Železničná 356/134, 905 01 Senica
Žiadateľ o vydanie osvedčenia:	eustream, a.s. Votrubova 11/A 821 09 Bratislava
Podklady r a vydanie osvedčenia:	IZ č. 00621/4/2013

Po posúdení dokladov, po prehliadke a vyhodnotení skúšok zariadenia Technická inšpekcia, a. s.

osvedčuje, že

Zariadenie spĺňa základné požiadavky bezpečnosti technických zariadení overených skúškou. Zariadenie je spôsobilé na bezpečnú prevádzku vrátane jeho bezpečnej obsluhy a zodpovedá konštrukčnej dokumentácii, ku ktorej bolo vydané odborné stanovisko k dokumentácii.

Toto osvedčenie sa musí priložiť k sprievodnej technickej dokumentácii zariadenia.

V Nitre, dňa: 25.02.2013

za Technickú inšpekciu, a. s.
Dušan Vašek
vedúci oddelenia plynových zariadení

235167

OSV10-018

Figure 6.44 The independent authority

6.3.4.4 Final Conclusions

- The repair of the high-pressure gas pipelines by the innovated cold sleeve method (STO®) can be implemented ***under full operating pressure without any limitation to transmission capacities***,
- the repair can be applied ***to all kinds of corrosion defects or material losses up to the yield point of the material , while the length of the pipe which is being repaired is not limited***,
- the repair can be applied also to ***anomalous welds with a defect of the type of an incomplete root penetration***,

- cost saving for the repair represents more than 40 %,
- elimination of problems with instability, quality and filling of the old filling material, as well as with the maintenance of the filling device.

As derives from the above, by the new STO the company Eustream acquired an exceptional original repair tool for repairing of a broad spectrum of defects of the high-pressure gas pipelines practically of any possible dimension. Due to its extraordinary qualities, especially the possibility of repairing the weld defects, as well as extensive corrosion defects, upon its patenting *(the process is currently successfully under way*, a note of the author) it will be possible to use this repair tool also on the pipeline systems of other European gas companies.

6.3.5 Insulation coatings of steel gas pipelines

Frequently, the best solutions to problems are those simplest. One of these concerns the passive anticorrosion protection principle of the external surface of steel pipelines, buried in soil and water. What could be easier than to separate the pipeline, that is, to insulate it from an aggressive environment? Apply a coating of bitumen, and that's it. Paper, jute, glass fibre, high-strength plastic tape – all of them should improve the resistance of asphalt (bitumen) and its capacity to stay on the surface of the soil-imbedded pipe for as long as possible, and in best-possible conditions. However, elevated pipe temperatures and forces acting in the soil are persisting enemies. The times of training courses of insulators, concentrating on Pebit, Korobit, Bitagit, are long gone.

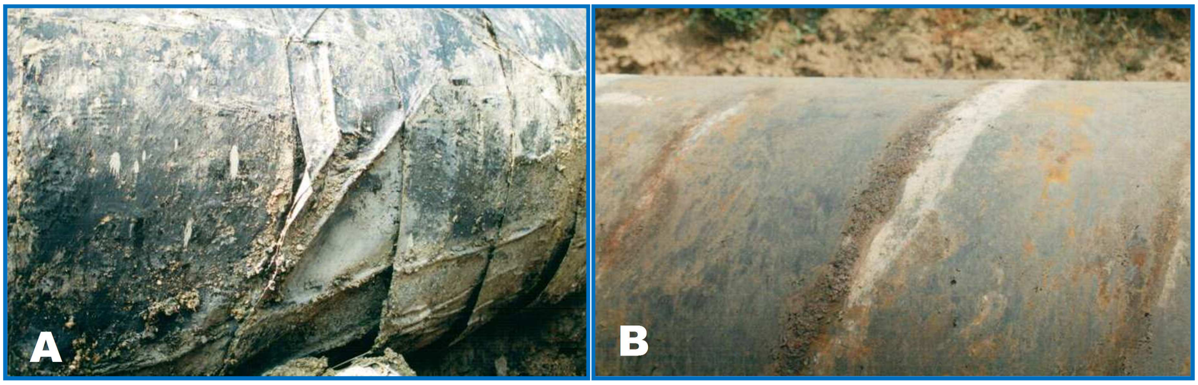


Figure 6.45 Field installed PE tape (DN1200, continuous cathode protection). Conditions after 30 years in the soil (A) and spiral corrosion of the pipe, observed upon tape removal (B)

The onset of epoxide powder (FBE – fusion bond epoxy) for application on steel pipelines represented a major discovery in Western countries and, in addition to plastic tape combined with butyl rubber and various primer modifiers, an important contribution, mainly in regard of factory-applied insulation of large-size pipelines. Such insulation, as opposed to tape, does not form bags and creases in the soil; however, it is rather brittle and prone to water soaking.

The introduction of extruded polyethylene, a material that is flexible and mechanically resistant, comparatively cheap and has low water permeability, represented a significant technological step. Its combination with epoxide resin established the basis of use of multilayered coatings, which are much more resistant to a broad spectrum of conditions which the anti-corrosion coat is exposed to in soils. Presently, factory-made as well as field-applied cold-wrap tape systems, thermally shrinked strips and sleeves, dual-component polyurethane and epoxide coatings and their various combinations are used in the supplementary insulation of transversal welds, fittings, bends and tees. The manufacturers of such products usually offer everything conceivably necessary, and more, in their portfolios. Theoretically, the full range of all products (mainly of reputable producers) available in the market should be able to meet, in long-term conditions, their declared parameters in tests required by applicable technical standards. Unfortunately, the predictability of theory is found to confirm, in practice, the proverb *„all is not gold that glitters"*. Ease of a solution can, after its implementation in real conditions, differ from expectations and pose new technical challenges.

Presently, the insulation most frequently sold in Europe is the factory-applied three-layer polyethylene system (3 Layer PolyEthylene, sometimes referred to as 3LPO–PolyOlefin), which however is frequently open to discussion. It has been in production for several years according to specifications of the German industrial standard DIN 30670. All fifth-line loopings in the DN1400 gas transmission lines installed between 1994 and 1998 in Slovakia use insulation coatings in compliance with this norm.

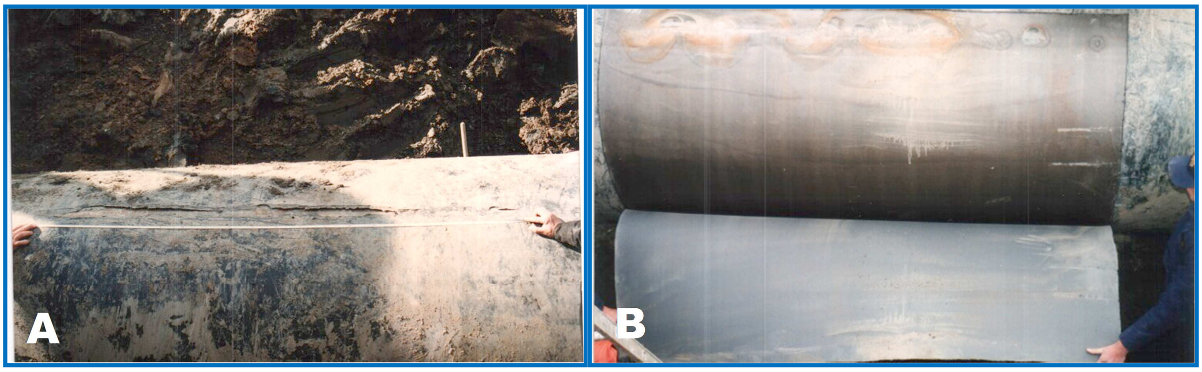


Figure 6.46 Damage to insulation due to a continuous optic-cable blow conduit deposition equipment

(determined by external inspection of the buried pipe (A) and its consequences (B); 3 LPE to a DN1400 pipe with continuous cathode protection)

However, rumours have started by end of the nineties concerning three-layer coats that delaminated, shortly upon embedment in soil, on large sections of the pipe surfaces. This was found also at several locations in Slovakia, and the manufacturer was duly notified. Claims were, however, frustrated by the manufacturer's affirmation that separation of the insulation had occurred in consequence of incorrect handling of specific pipes, while the same fault could not be demonstrated in stowed pipes. Later, however, a German gas transmission operator claimed occurrence of the same problem. Manufacturers have admitted the existence of the epoxide primer separation problem in 3LPE insulation systems only as late as in 2004, reasoning soil humidity in combination with cathodic protection as the suspect. At the same time they have conceded that, except in case of mechanical damage to the polyethylene sheathing, the function of insulation was retained even under conditions of reduced or nonexistent adhesion. This problem still lacks an unequivocal explanation.

Figure 6.47 Tear test of the rehab shrink cuff

Contribution to the improved reliability of factory-applied 3LPO insulations is expected from application of the long-due European standard EN 21809-1, in force since 2011. This norm specifies the parameters of materials used to produce individual layers – epoxide, adhesive, polyolefin – and prescribes complex control of their properties during the production process. Increased attention is paid mainly to the epoxide component.

Shrinking sleeves (cuffs) need heat to be correctly applied. Lots of heat! The problem is that they require properly distributed thermal exposure, as opposed to its local concentration. All standard shrinking cuffs have prescribed surface temperatures of the steel pipe which must be complied with during the entire installation process in order to ensure melt of the adhesive, and to reach the specified adhesion strength of the insulation.

Figure 6.48 Conditions of the rehab shrink cuff after several years of operation

This requirement, however, is very difficult to meet in large diameter pipes with propane-butane burners. When using a standard cuff in pipeline insulation repairs under operating line conditions, the gas flow cools the heated location. Although the installed cuff would then shrink, the adhesive would fail to properly bind to the pipe. In tear tests of such cuffs negligible or zero adhesion is likely to be found. The installation temperature specified by the manufacturer could be reached with burners in the pipeline construction phase, when gas flow in the line is absent, but it will drop very rapidly. To obtain satisfactory result while insulating a weld head with a single shrinkable cuff in a 1400 mm diameter pipe, coordinated work of up to four skilled insulators is required. In 1997, shrinkable cuffs for supplementary insulation of about 200 transversal welds, supplied by a manufacturer wishing to establish his position in the Slovak market, were used in the construction of one fifth-line looping in a gas transmission line. The supplier’s technicians, finding that, at that time, post-internal inspection repairs of insulation were carried out in a gas transmission pipeline in an 8 km long trench under full line operating conditions, offered a special three-layered shrinking cuff designed to eliminate the cooling effect of gas flow in the operating line. The epoxide primer, with its cure duration extended to 24 hours, was designed to bind with the cuff adhesive. Three weeks of successful tests of application and adhesion parameters of the rehab shrink cuffs were followed with insulation technicians´ training courses in documented training trenches. Three years thereafter, non-bound cuffs started to appear in subsequent insulation repair works. At first, shoddy work of insulators unwilling to apply thick epoxide coats on cold pipes was suspected. After consultations with the supplier of the repair works one of the training trenches was uncovered for inspection of cuffs originally installed by the manufacturer’s specialist.

The findings were shocking, as the cuffs, while remaining shrinked and bonded together in longitudinal overlaps, showed epoxide in decomposed conditions and the pipe surface uniformly covered with powdered rust. We have been unable to obtain an explanation from the manufacturer. Could this finding indicate a random-only similarity with the previous case involving the factory-made 3LPE insulation?

Correct installation of standard shrinkable cuffs requires, in addition to the standardized pipe surface preparation process, compliance with the specified installation temperature of the base material, i.e. of the steel pipe, which is only possible with the use of induction heating that transfers heat directly into the steel. Manufacturers are aware of this, offering supplementary programs applicable to preheating and cuff-shrinking equipment in order to minimize faults due to the human factor. However, such equipment, with pipeline diameters increasing, has been taking on quite monstrous dimensions whose use in field conditions is more than questionable.

The use of polyisobutene, a visco-elastic anticorrosion material, shows very promising results. Its low surface tension and fluid properties guarantee the wetting of all contact surfaces. The permanent fluidity effect of polyisobutene warrants for absence of underlying corrosion due to adverse consequences of the cathodic protection. Its proper combination with the polyolefin tape offers another advantage by manifesting a self-healing effect in cases of mechanical damage to the tape. The solution of using shrinkable cuffs to mechanically protect the polyisobutene pipeline insulation combines excellent anti-corrosion properties, elegance of application without necessary line preheating, minimization of failures due to the human factor, and long-term reliability in a soil electrolyte environment. This solution is innovative and, although exceeding the conservative framework of technical standards, is very promising. Time will show whether it will be praised or condemned by future generations of corrosion experts.

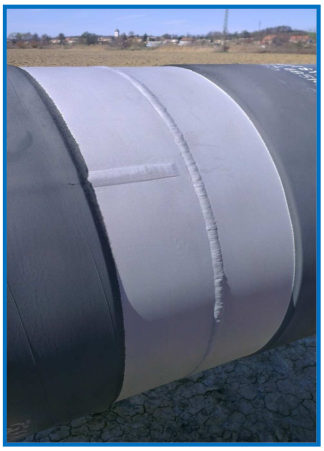


Figure 6.49 Transversal weld, prepared for insulation

(DN 800, 3LPE, surface preparation level Sa 2½ - EN ISO 8501-1)

Figure 6.50 Polyisobutene tape with shrink cuff, installed on a transversal pipe weld

Globalization, open markets, public procurement, rapid access to information and many other factors brought by our modern era create, on the one hand, the basis of deeper understanding of passive anti-corrosion mechanisms but, on the other hand, generate pressure for gambler-like price reductions in electronic auctions, frequently victimizing anti-corrosion protection. In Slovakia, nobody issues centrally registered insulators´ certificates any more, and responsible officials deem it sufficient to be shown affirmations of the applicant that they are experts, able to complete the given job. However, anti-corrosion insulations of underground and underwater buried steel pipelines have their specific rules, technical standards and requirements, terminologies used by manufacturers, customers, isolators and, in short, their own lives whether applicable to shell life, pot life or operational life in a live pipeline. The world holds discussions, innovates, applies and takes also risks, learning from mistakes and rejoicing success in spite, fortunately, of political pitfalls and economic crises.

Specific technical standards related to the text:

1. DIN 30670, Umhüllung von Stahlrohren und -formstücken mit Polyethylen, 1991-04
2. STN EN ISO 21809-1, Oil and Gas Industry. External coatings of pipelines laid in soils or used in transportation systems. Part 1: Polyolefin coatings (ISO 21809-1:2011)
3. STN EN ISO 21809-2, Oil and Gas Industry. External coatings of pipelines seated in soils or used in transportation systems. Part 2: Hot-melt epoxide adhesive coatings (ISO 21809-2: 2007)
4. STN EN 12068, Cathodic protection. External organic coatings protecting steel pipelines against corrosion laid in soils or water, and used in conditions of cathodic protection. Tapes and shrinkable materials, 2001
5. STN 03 8332, Cathodic protection. Testing of tape insulations and shrinkable plastic materials, 1993
6. STN EN 10289, Steel pipes and fittings used in coastal and offshore pipelines. External liquid epoxide coatings, 2002
7. STN EN 10290, Steel pipes and fittings for pipelines laid in soils or water. External liquid-applied polyurethane or modified polyurethane coatings, 2012

Chap. 7 Construction of pipelines in areas of high population density

7.1 Case study in Korea: Pipeline construction in areas of heavy road traffic condition

7.1.1 Introduction

Korea Gas Corporation (KOGAS) operates 3,562km of natural gas transmission pipeline network in South Korea, a geographically small country with a high population density. KOGAS has been constructing additional pipeline network in order to expand the country's gas supply capability. According to KOGAS, it has a plan to construct 1,058km additional pipeline during the first phase until December 2014 and 378km more in the second phase until December 2016 to supply natural gas to unreached areas due to economical reasons.

Typically, the demand for natural gas increases in winter season and decreases in summer, so causing pressure imbalance KOGAS has devised another plans in order to prepare for pressure drop at the end of pipeline network for winter in Metropolitan area.

7.1.2 Status

This is the introduction of the pipeline construction in areas of heavy road traffic condition. Anyone who wants to excavate roads to lay pipeline or other underground utilities in Korea must get a permit from the local government

Here, The case study of a pipeline section between Namyangju and delivery stations in Seoul with a pipeline length of 13.7 km is examined in this report.

KOGAS had a plan to lay a pipeline to this new section in order to compensate for pipeline pressure losses at the end of the pipeline network in Seoul city. The diameter is 26" and thickness is 12.7t. The construction started in 2007 June and ended in 2008 November (18months).

KOGAS obtained the permit to dig the city road under the condition of working night shifts due to the heavy traffic during daytime. It is written in the permit that working hours are from 23:00 to 06:00. The excavation and backfill must be done on the same day. It means that after the construction work, restoration of pavement must be completed before 6 AM for smooth traffic flow and therefore work is very limited.

This is because this section is usually jam-packed with heavy traffic.

Figure 7.1 Traffic jam on the working section

The hourly volume of traffic is as follows. Road 'A' consists of 4 lanes and road 'B' has 2 lanes. Please refer to Figure 7.2. There were as many as 12 crossroads and traffic lights in this B road.

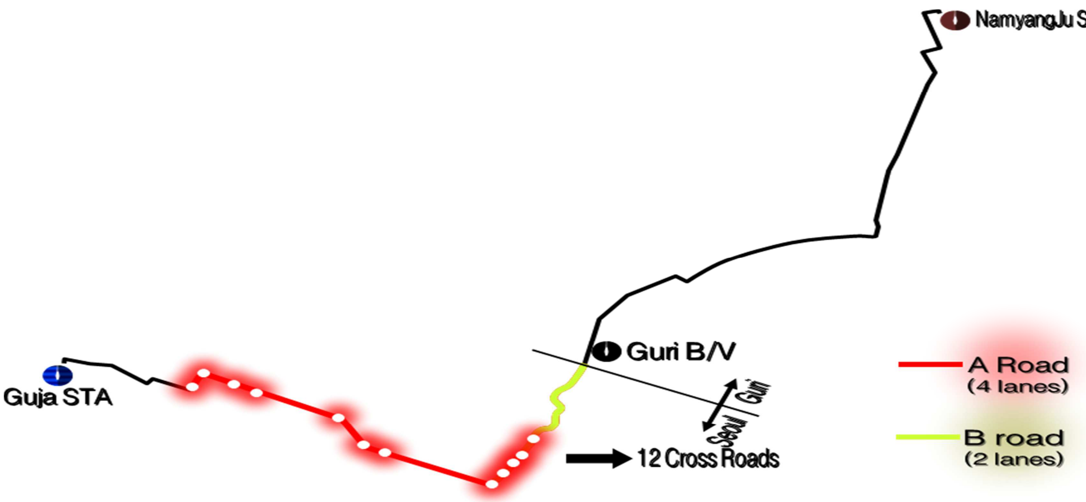


Figure 7.2 Pipeline route plan

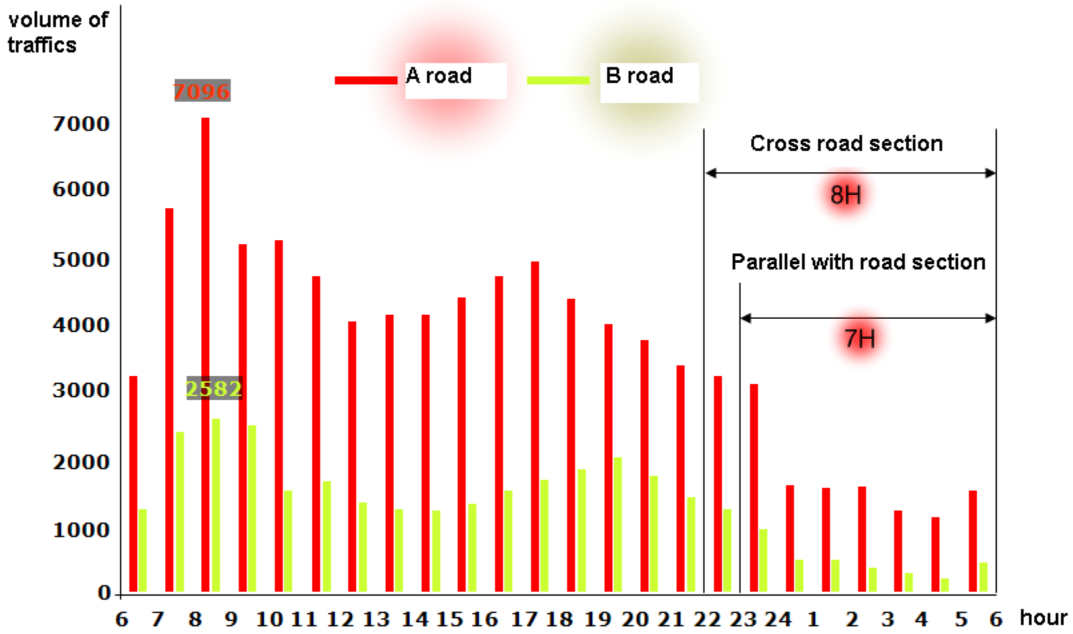


Figure 7.3 Hourly volume of traffic

Therefore, KOGAS had to take the items below into consideration:

- All welding should be done by manual in trench
- Minimize the space of road occupied for work.
- Waiting space of equipment and material to work on road
- Pedestrian safety issues
- Control of traffic flow
- Working hours are from 23:00 to 06:00
- The excavation and backfill must be done on the same day
- There are many existing underground utilities and old structures
- Insufficient space of aboveground for pipe handling
- There are rocks within depth of trench for digging
- Safety prevention training
- Traffic safety signs

These working conditions meant that construction efficiency is very low.

In order to secure worker's safety from accidents, the Construction team positioned flagmen and robotic flagmen in front of the construction site. They also put up Self-emitting traffic safety signs on the road.

Figure 7.4 Safety measures

According to the permit, excavation and backfill must be done within the same day that digging occurred. Seoul City emphasized that entire pavement work must be completed before 6 o'clock. This meant that working hours would be very limited and insufficient.

In cases like this, the establishment of traffic control plan is vital. These practices and construction method follows the typical procedure. First, line marking should be done on the pavement surface prior to excavation and the surface of the road should be removed by an excavator.

If the trenches are dug by a machine, then KOGAS should try to avoid a lot of shovel work as it would take a lot of time. In addition if there are areas where the trenches had accumulated water, dewatering also would take a considerable amount of time.

7.1.3 Construction Technologies

KOGAS had created special tools that could be substituted for road pavement to reduce time consumption.

The pipe welding in the trench typically takes time to prepare for fit-up before welding. After welding, it needs NDT of welding joints, Coating & Wrapping, Holiday tests etc.

This construction technology uses "Welding House" which is set up in underground welding joint locations. Just before backfilling, the construction team installs sandbags around welding locations and puts up "welding house" at welding areas. The other parts should be backfilled with sand/soil and paved with asphalt.

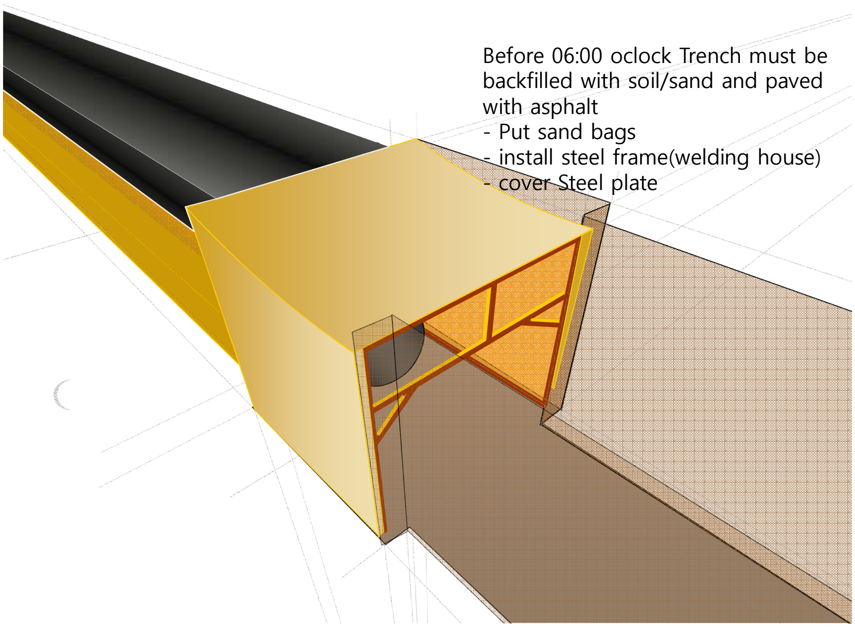


Figure 7.5 Welding house at underground welding joint area

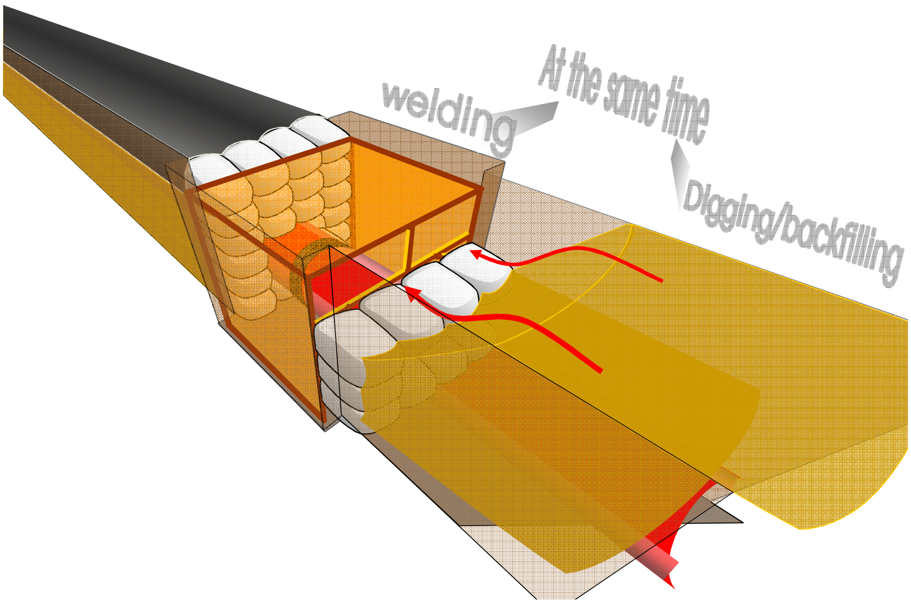


Figure 7.6 Welding and digging can be done at the same time

The improved method is to replace asphalt pavement with a steel cover plate. The steel cover plate is installed on the welding house at the welding locations instead of asphalt pavement. On the next night, the construction team would have to remove the cover plate only instead of having to go through re-excavation, and continue the work of previous day's work subsequently.

This method can be time efficient for the construction team.

Figure 7.7 Welding works

However, they found out that there are some problems when they applied this method, using welding house and steel cover plate. There were noise, vibration and bending of steel plate caused by heavy vehicles passing by. These problems had been improved by adding steel bar welded under the steel plate. When the surface of steel plate is wet, there is a chance for vehicles to slide so the solution is to put slag steel on the surface of steel plate and chamfer the edge of the steel plate.

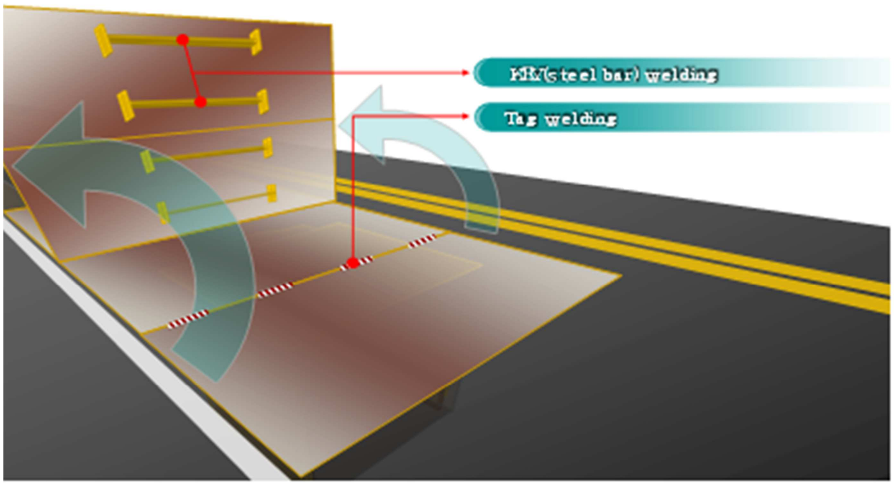


Figure 7.8 Improvement for problems

7.1.4 Concluding remarks

This construction technology brought much efficiency, good progress, and also better driving performance for vehicles passing by the working site. This technology gave the construction team a lot of advantage. Pipeline work can be continually carried out on site and the digging and backfilling of the welding areas can also be avoided. The purpose of this new method does not only prevent pipe coating damage but also save construction time and cost.

Figure 7.9 Works on the construction site

Using this method, Construction team could easily abide by the permit restrictions. In addition, this brought us to minimization of asphalt waste in the environment and we can reduce unforeseeable risk factors.

Construction team can finish piping work before 6 AM so the work would not induce complaints, and would also reduce inconvenient traffic situation.

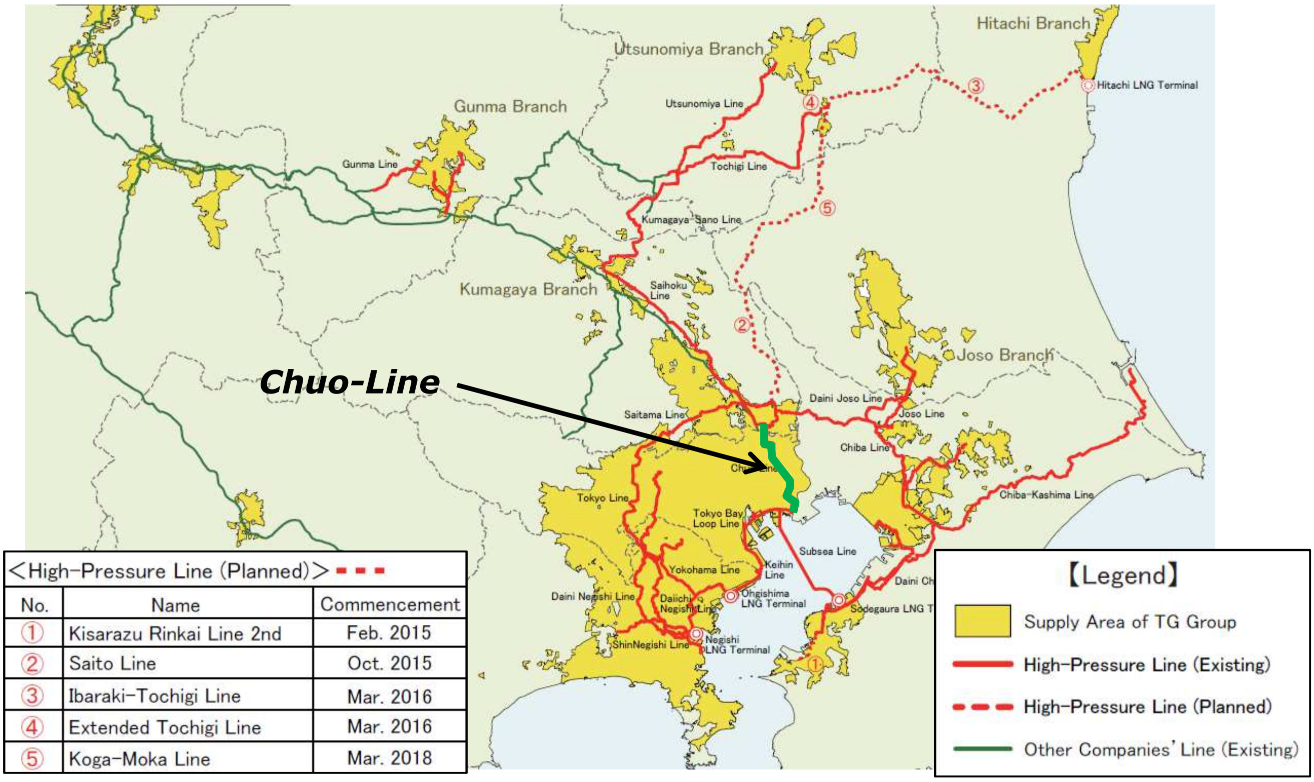
7.2 Case study in Japan: Pipeline construction in long and deep tunnel in urban area

7.2.1 Introduction

Tokyo Gas completed the construction of the Chuo-Line in 2008. This line was planned to meet the growing gas demand in the northern parts of the Tokyo metropolitan area and to improve the energy security of existing pipeline networks. Figure 7.10 shows a schematic diagram with the Chuo-Line indicated in green along with existing pipelines

The Chuo-Line is designed to have a transportation capacity of 1 million m^3N per hour and to operate at a maximum internal pressure of 7 MPa. The line-pipe is made of API 5L X65 with mill-applied three-layer extruded polyethylene coatings produced by Japanese steel and pipe manufacturers. The nominal outer diameter and nominal wall thickness of the line-pipe are 610 mm (24 inches) and 15.1 mm, respectively.

The Chuo-Line has a total length of 23.1 km, and it passes through vertically at almost the central axis of the densely inhabited district of the Tokyo metropolitan area, which starts from the southern end at Kasai in Edogawa Ward of Tokyo and is connected to another trunk line at the northern end at Souka in Saitama Prefecture. Figure 7.11 and Figure 7.12 show typical scenes along the line-route. This route was planned to pass directly through highly populated residential and commercial areas including heavy traffic areas, and to go across four rivers, five railroads, three elevated highway bridges, and many other underground substructures.



<High-Pressure Line (Planned)>

No.	Name	Commencement
①	Kisarazu Rinkai Line 2nd	Feb. 2015
②	Saito Line	Oct. 2015
③	Ibaraki-Tochigi Line	Mar. 2016
④	Extended Tochigi Line	Mar. 2016
⑤	Koga-Moka Line	Mar. 2018

Figure 7.10 Schematic diagram of Chuo-Line with existing pipelines

(source: http://www.tokyo-gas.co.jp/Press_e/20140326-01e.pdf)

When constructing the Chuo-Line, therefore, it was assumed that significant problems such as heavy traffic congestion and/or noise pollution would possibly occur when using a traditional approach such as the open-cut method for installing line-pipes. In addition, there would be an extremely high possibility of delays in completion because of the time that may have been required to obtain permission for construction from the road authority and the neighborhood.

Feasibility studies concluded that the Chuo-Line should be constructed by applying a tunneling method to install line-pipes inside long and deep shield tunnels along the line-route to reduce adverse impacts on social activities and the environment. A vertical cross section along the line-route is shown in Figure 7.13. 61% of the construction cost was allocated for constructing the shield tunnels; 21%, for manufacturing and installing line-pipes; and the balance, for constructing pits, etc.

This report describes the major characteristics of the advanced techniques applied for tunneling, optimization of the structural design of the pipeline, and maintenance philosophy for the Chuo-Line.

Figure 7.11Typical scene along Chuo-Line route: heavy traffic road

Figure 7.12 Typical scene along Chuo-Line route: crossing a river

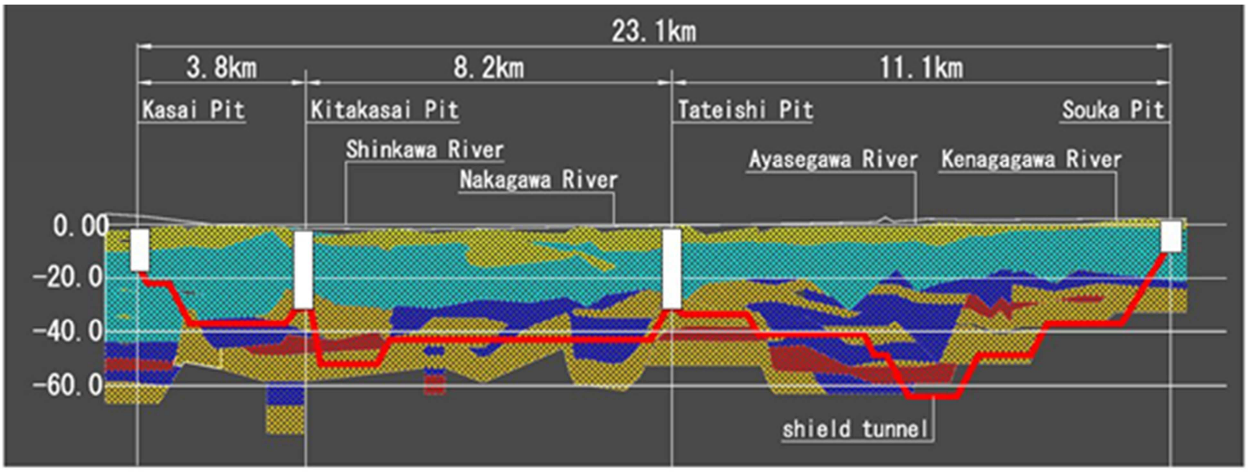


Figure 7.13 Vertical alignment of Chuo-Line and soil profile

7.2.2 Basal design

Tokyo Gas conducted a design competition among leading Japanese construction companies to determine the most appropriate design and construction method for this challenging pipeline project. The competitors were only informed of the start place, end place, pipeline diameter, and internal gas pressure and then asked to develop their proposals along with a detailed line-route. Two main construction approaches emerged as a result: open-cut installation method and long and deep underground tunnel method.

A comprehensive evaluation was conducted by scoring the (1) project feasibility, (2) time and cost savings, and (3) established unique technologies and new technologies. With regard to the project feasibility, the key success factors for the project were minimum environmental impact, safe and low-profile structure, short-term construction period, and minimum interaction with other underground structures in light of strong concerns for the safety of the local society and the environment. Based on the proposals, a deep and long tunnel excavation methodology using a high-speed slurry shield tunneling boring machine (TBM) was adopted to install the line-pipes.

A typical cross-sectional view of the pipeline and tunnel for the Chuo-Line is schematically shown in Figure 7.14. This tunnel was structured from steel plate segments (L = 1000 mm, W = 400 mm, t = 100 mm, inner diameter = 2,000 mm or 80 inches). The maximum and average cover depths of the tunnel are 65 m and 40 m, respectively. The line-pipes were located inside the tunnel. The space remaining between the line-pipes and the tunnel is filled with foam mortar as an electrolyte to provide cathodic protection currents to the carrier pipes within the tunnel. The foam mortar consists of cement and an organic blowing agent that is added to reduce the weight of cement and to fill the space uniformly.

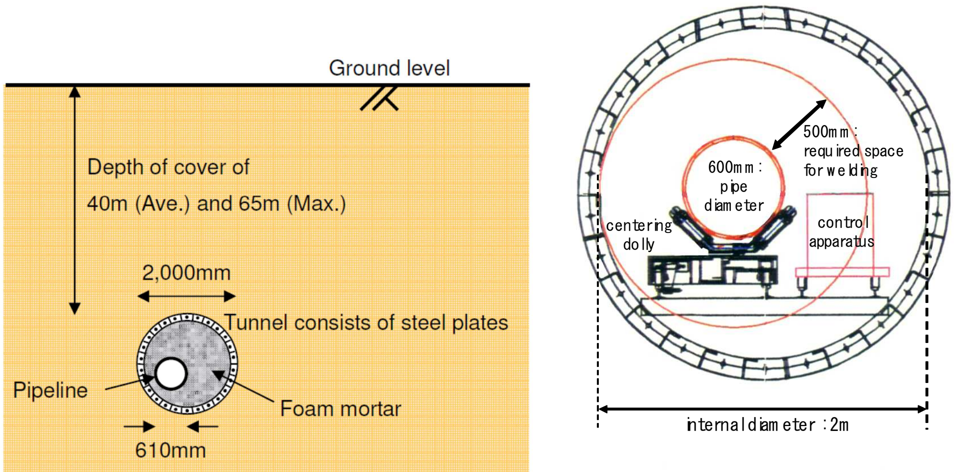


Figure 7.14 Typical cross-sectional view of Chuo-Line

7.2.3 Advanced techniques applied to tunneling process

The tunneling boring machine (TBM) shown in Figure 7.15 was the most advanced of its time and was developed to realize long-span tunneling at high speed. Figure 7.16 shows a magnified photo of the front face of the TBM. Three types of teeth are set on the round cutting plate at different heights. After the highest teeth are worn down, the second-highest teeth start to work. Thus, because new teeth appear at the front face one after another, long-span tunneling can be achieved without replacing old teeth. The maximum allowable span of the developed TBM is 6.3 km, which was the longest allowance at the time in Japan for tunneling with such a large diameter.

Additionally, the following three advanced techniques were widely applied to the tunneling process. These resulted in a remarkable reduction in the construction period and cost.

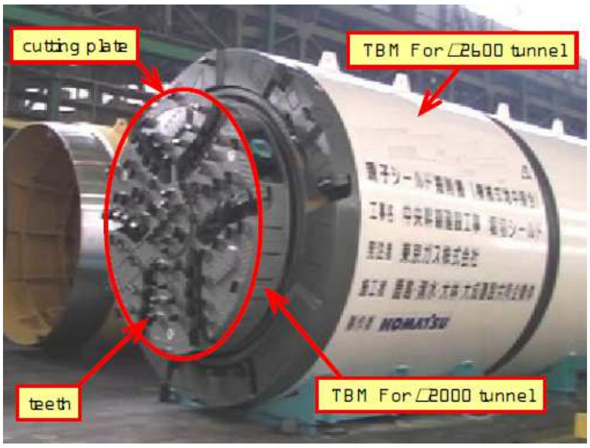


Figure 7.15 Advanced tunneling boring machine (TBM)

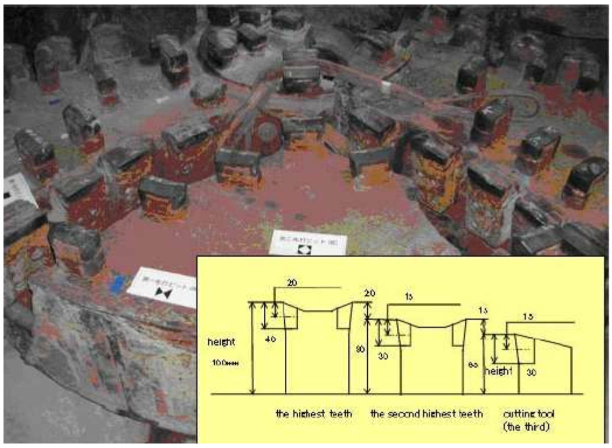


Figure 7.16 Cutting teeth with three different heights at front face

7.2.3.1 Underground face-to-face docking process of TBMs

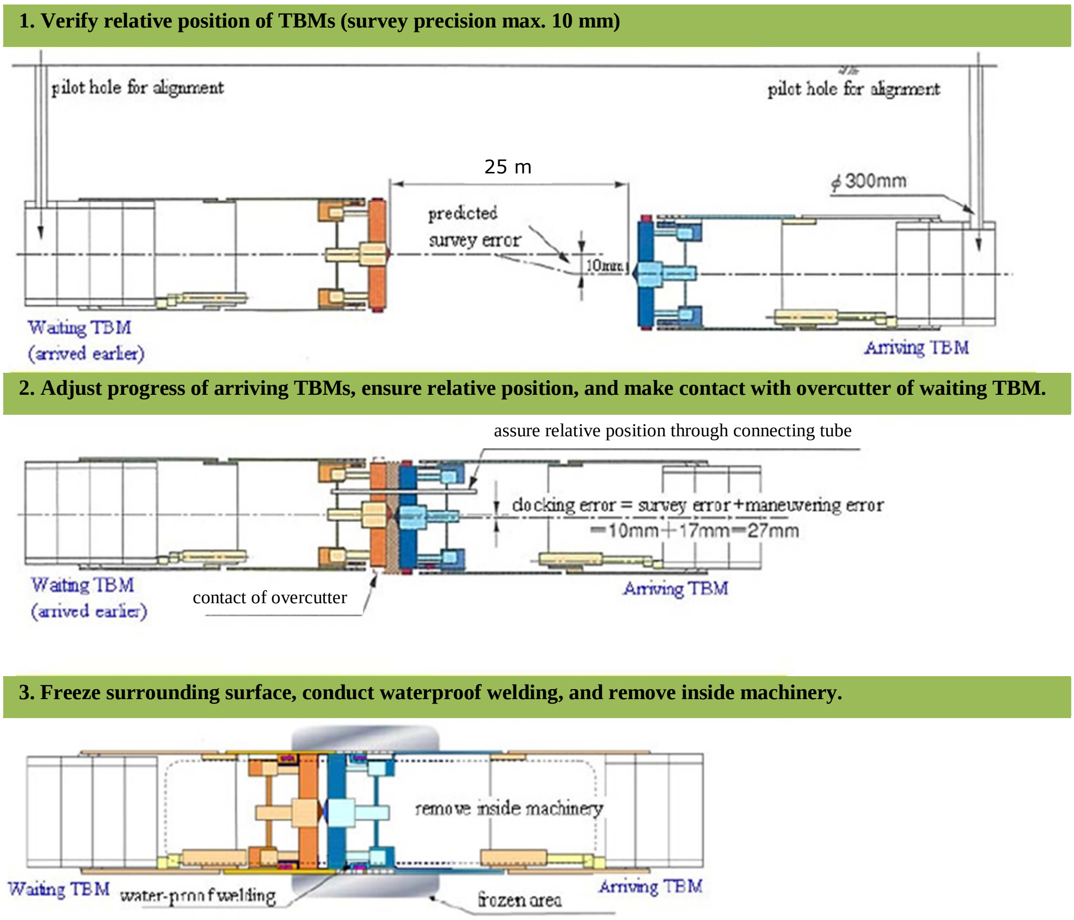


Figure 7.17 Advanced face-to-face docking process of TBMs

To install the TBM for the tunneling, it is necessary to prepare the land for vertical shafts. However, it is very difficult and time-consuming to acquire temporary construction sites in the congested Tokyo downtown area. Furthermore, the land price is very high, and therefore, the number of shafts and the space they occupy should be reduced.

One of the effective breakthroughs is to apply a face-to-face docking procedure of TBMs approaching from both directions, resulting in the long-span tunnels being connected using the TBMs without the need for shafts. The docking process is schematically shown in Figure 6.3. Soil around the docking area was necessarily frozen to prevent water penetrating the tunnels during docking. This was achieved using a high-resolution locating system, and it enabled the 23.1-km-long Chuo-Line tunnel to be constructed using only two intermediate shafts, as shown in Figure 7.18. While the entire route was divided into 5 tunnel sections, the need for two shafts was avoided by applying the face-to-face docking process deep underground. The longest span between the shafts was 11.1 km, which consists of 6.3 km and 4.8 km tunnel sections excavated simultaneously in face-to-face directions.

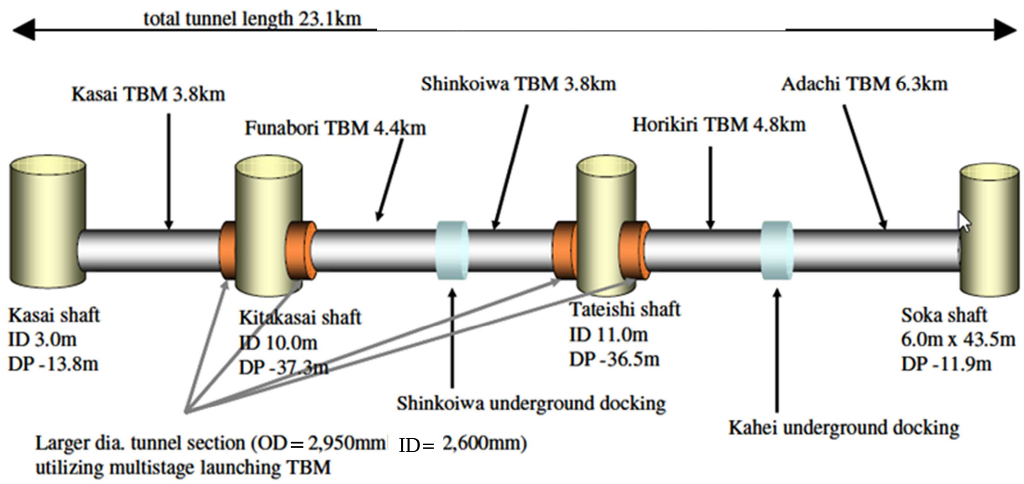


Figure 7.18 Location of shafts and underground dockings along line-route

7.2.3.2 Effective use of limited space in shafts

Private land was acquired for the sites of two intermediate shafts: Kitakasai shaft and Tateishi shaft. Nonetheless, limited land area was available in the high-population-density area. Figure 6.17 shows a photo of a slurry processing plant, which was compactly installed in the shaft by using a three-story deck structure with a high-capacity waste-soil pit. To stock and deliver a sufficient number of segments for around-the-clock excavation using the TBM, the computerized segment stock system shown in Figure 7.20 was developed and introduced. This system was crucial in solving the complex problems of material handling and transportation attributable to the limited shaft area in the residential area, where truck deliveries were not allowed at night.

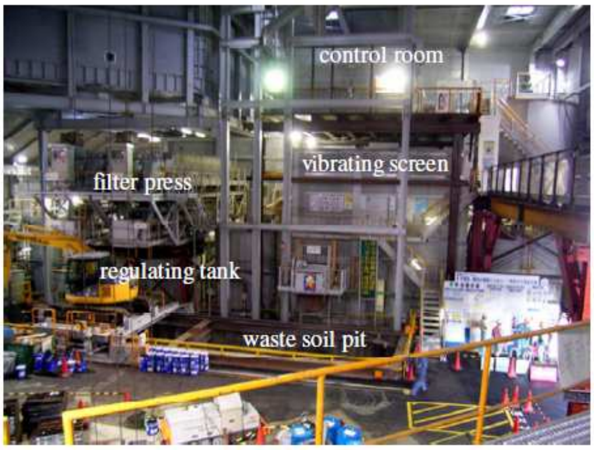


Figure 7.19 Compacted slurry processing plant

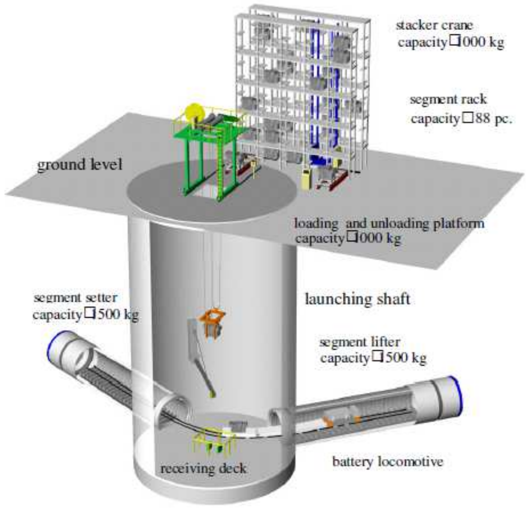


Figure 7.20 Computerized segment stock system

7.2.3.3 Dual-diameter TBM

To demonstrate the maximum excavating speed using the above-described high-speed-TBM, sufficient transportation capacity for the tunnel segments from the storage site to the excavating site is needed. In fact, the tunneling speed was governed by the transportation speed of the segments for the construction, and the developed "dual-diameter" TBMs, which had two different diameters of 2,000 mm and 2,600 mm, enabled high-speed tunneling at 400 m/month on average.

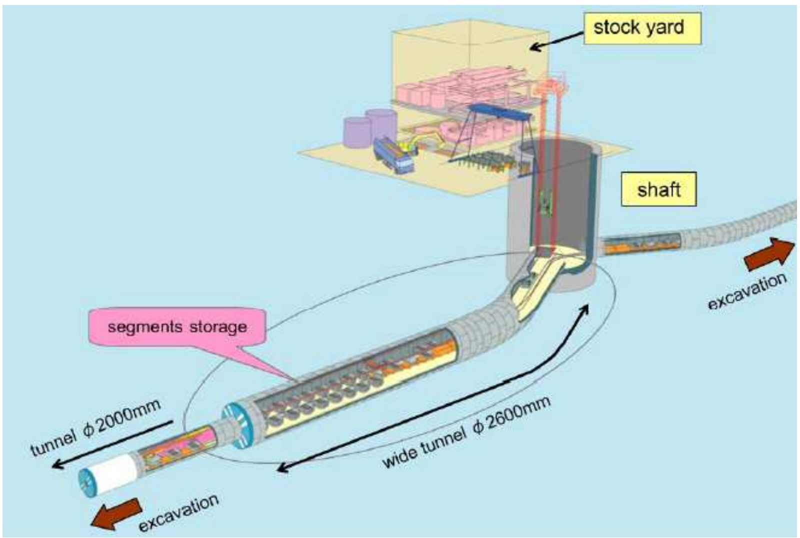


Figure 7.21 Dual-diameter tunneling from shaft

The schematic of the dual-diameter tunnel is shown in Figure 7.21. After the TBM started tunneling from the shaft and a tunnel with a wider diameter of 2,600 mm and length of 50 m was excavated, the inner TBM with a smaller diameter of 2,000 mm was launched from the outer TBM and continued to excavate alone. The wider-diameter tunnel section served to accommodate double tracks for the segment transportation train and a switching yard for the train to utilize as a temporary segment stock yard. As shown in Figure 7.22, the steel plate segments were continuously and efficiently transported using electric motor tracks within the tunnels by preparing a loading area at the shafts.

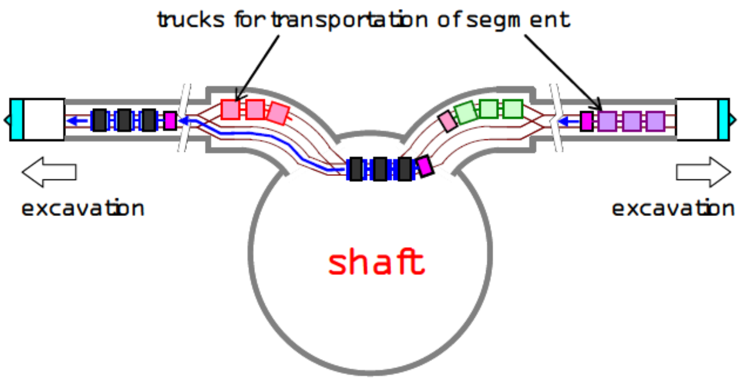


Figure 7.22 Continuous transportation of steel plate segments

7.2.4 Optimized structural design of pipeline

The shield tunnel constructed in the Chuo-line project was designed as a "permanent structure"; the structural design philosophy of the tunnel is that earth pressures continue to act forever on the tunnel segments as a casing pipe and never on the gas pipeline itself. Therefore, the structure of the tunnel segment, such as the wall thickness, framework pattern of ribs, etc., was designed to have sufficient strength to withstand earth pressures. On the other hand, only the internal pressure of the gas was taken into account to determine the wall thickness of the line-pipes because it is not necessary to consider an external load such as earth pressure. The technical notification specified by the Gas Utility Industry Law in Japan allows for the external load to be excluded from the design premises if the line-pipes are protected by tunnels or casings. Based on the notification and an internally determined tolerance, the nominal wall thickness of the line-pipe was determined as 15.1 mm for the Chuo-Line.

In Japan, an essential design premise for pipelines is earthquake resistance, which can be evaluated according to the Earthquake Resistance Design Standard of Pipelines in Japan. However, evaluations using this standard are based on an impractical assumption for the Chuo-Line because the pipeline in the standard is assumed to be installed directly underground without casings or tunnels; nevertheless, the Chuo-Line was installed within the tunnel. Moreover, the space between the line-pipes and the tunnels was filled with the foam mortar. Evaluations were therefore conducted for the following two approaches: simplified numerical calculations applying the allowable displacement method as specified in the standard and finite element (FE) analyses under the practical condition of the in-tunnel piping model, as shown in Figure 7.23.

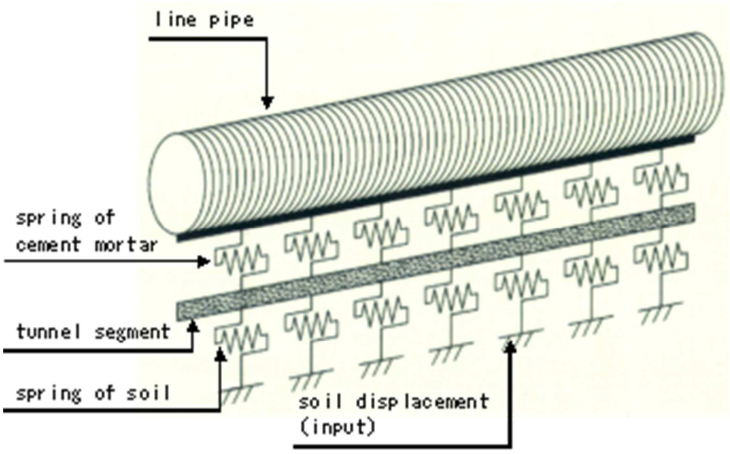


Figure 7.23 In-tunnel piping model for FE analyses

As shown in Figure 7.24, the results of the FE analyses were 50%–70% lower than those of the simplified numerical calculations based on the standard for a straight section. The FE analyses also indicated that it was safe enough for a curved section and for a riser pipe section surrounded by a pit structure. The evaluated results clearly showed that pipe deformation must be much lesser than the maximum allowable displacement of 0.9% for earthquake level 1 (L1) and 2.7% for earthquake level 2 (L2), which were provided by the standards for all possible cases. Here, earthquake levels L1 and L2 indicate the intensity of seismic waves: L1 represents the intensity level of an earthquake that would possibly occur one or two times during the operating life and L2, that which has little possibility of occurring during the operating life but is considered to have a larger impact than L1.

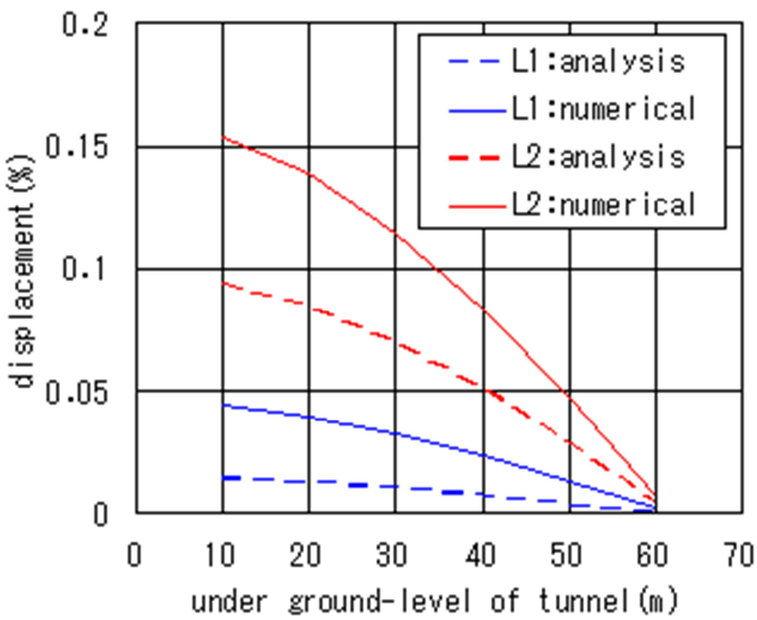


Figure 7.24 Earthquake resistance of Chuo-line evaluated from simplified numerical calculations and FE analyses for L1 and L2 seismic waves

7.2.5 Maintenance philosophy

As described above, the Chuo-Line is installed in the shield tunnel ~40 m under the ground on average, and the space between the pipes and the tunnels is filled with a form mortar along the whole line. This means that pipeline repair will be almost impossible after the completion of construction. The Chuo-Line was therefore designed to be as free from maintenance as possible.

All possible measures to ensure the long-term integrity of the pipeline were taken at the design and construction stages. In particular, corrosion is the most likely threat during operation because there is almost no possibility of third-party damage owing to the installation being deep underground. An in-situ coating technique with double-layered polyethylene was developed and applied to prevent the field welded joints from corrosion. In addition to the coating material itself, an impressed current protective system was employed for cathodic protection, putting three stations for protective facilities at both ends and at the middle of the pipeline. These two protective measures are expected to keep the Chuo-Line free from maintenance during operation.

7.2.6 Concluding remarks

The construction of the Chuo-Line was challenging because it was a long and deep shield tunnel in a densely populated area and because the planned line-route passed through vertically at almost the central axis of the densely inhabited district of the Tokyo metropolitan area.

The advanced tunneling techniques used at the time enabled a remarkable reduction in the construction period and cost as well as environmental impact, and the construction of the tunnels was successfully completed in March 2007. The line-pipes were installed in narrow tunnels and connected together using a semi-automatic girth welding device. The welded joints were coated using the developed in-situ joint coating system. The construction was eventually completed in December 2008.

During the entire construction period, no claims of adverse effects on other underground structures, ground settlement, noise, vibration, and pollution were reported. Furthermore, no worker injuries occurred. This was considered a remarkable result in light of the magnitude of the construction project in the heart of an urban area. The many advanced techniques employed should promote the construction of pipelines in highly congested areas independently of offshore or onshore pipeline construction projects, and this is expected to contribute toward the expansion of efficient and reliable gas transmission networks worldwide.

Chap. 8 Alternative utilization of pipelines for CO2 transportation

8.1 Technical challenges of the CO2 transportation

8.1.1 Abstract

CO_2 emissions from various sources are pointed out as one of the causes of global warming, fossil fuels may play a strong role on it; renewable energy sources may in the future cope with the problem, in the meantime fossil fuels are fundamental to assure a reliable energy supply. However mitigating plans have been already taken in account, as increasing overall efficiency, bio fuels, developing clean measure to reduce CO_2 footprints on residential, domestic and transportation consumptions. Among the emerging technologies, CCTS (Carbon Capture Transportation & Storage) appears to be the most promising to be applied to concentrate emitters as Power Plants (coal or gas fired) or Industrial Mills. This section specifically deals with transportation challenge when carbon dioxide is gathered in liquid phase (dense or supercritical) via pipelines, at the same time the report updates on the experimental efforts to define carbon steel pipes requirement when exposed to the mixture of CO_2 plus impurities, with the aim to create specifically addenda to the existing Oil&Gas pipeline standards.

8.1.2 Introduction

Carbon dioxide (CO2) acts as one of the major contributor in "Global Warming" among the green house gases GHG; it has been evaluated that up to seventy percent of CO2 emissions come from fossil fuel power plants. CCTS (Carbon Capture Transportation & Storage) is a technical option to reduce the fossil fuel use impact on global warming by separating CO2 from power plants flue gases and either sequestrate it in proper stable geological locations (Saline aquifers) or in depleted reservoirs (oil&gas) or use it for Enhanced Hydrocarbon Recovery (EHR) in over mature oil and gas fields.
There are three stages, Carbon Dioxide Capture at fossil fired plants and other fuel conversions plans, Carbon Dioxide Transmission from the place where it is captured to the place where it is to be stored underground, i.e. Storage. In the last ten years or more Capture and Storage attracted large funding and several R&D initiatives were launched on these two topics, mainly with the aim to reduce the cost at the capture stage (in term of energy penalties) and make the storage permanently secure. However the existing gaps in CO2 transportation have been not resolved yet, probably because of the existence of a discrete network (about 5000 km long) of "CO2 pure" pipelines, laid since the 70' for EOR (Enhanced Oil Recovery) aims mainly in the US. Unfortunately it is not proper and safe transferring this know how to anthropogenic (i.e. produced by human activities, as in power plants) carbon dioxide transportation. In fact must be highlight that power plants emit flue gases with a large variety of impurities related to their own actual capture technology used and depending on the fossil fuel used and from the

combustion process

Nevertheless, there is significantly less experience for CO2 than for hydrocarbon transport. Furthermore all of the currently operating CO2 pipelines in the US are onshore, and many are routed through sparsely-populated areas, with single source transport systems. CO2 pipelines are subject to diverse local, state, and federal regulatory that sets minimum safety standards for pipelines transporting hazardous liquids, including carbon dioxide. For CO2 pipelines don't exist, in Europe, similar or comparable rules. Natural gas pipeline transport regulation is left to the national level as is not further regulated at EU level. It's to believe that the risk framework used for natural gas transport by pipeline is adequate to regulate CO2 transport; in fact identified hazards posed by CO2 transport are "broadly" comparable to those of natural gas (but the explosion).

The basic key points on carbon dioxide transportation by pipeline will be touched, they deal with the :

- need for CO2 pipelines (amount and timeline),
- set of issues due to the different CO2 composition sources,
- pipeline integrity and HSE matters.
- current R&D actions on these topics.

8.1.2.1 Need for CO_2 pipeline

The International Energy Agency in 2012 has indicated, within possible scenarios to examine, ways to reduce energy emissions having as a goal to cut energy-related CO2 emissions in half by 2050, by implementing three key strategies:

a) improving a decentralised energy system,
b) enhance energy efficiency, smart energy,
c) evolution of electricity generation.

a and b targets are based on the hypothesis of decoupling energy consumption and economic activity both technologically and behaviorally more efficient ways. But it is the decarburization of the electricity system, by 2050, that is the most important technological challenge required, and here CCS has a fundamental role, together with renewable and nuclear technologies. At the same time energy sector is not the only one responsible for large CO2 centralized emission, and CCS is the only technology currently available or that can decarbonizes sectors such as cement, or iron and steel industries. See figure 3 showing, as almost half of the Carbon Capture by 2050 is expected to come from "non energy related" sectors.

Unfortunately, as concerns the development of Large-Scale Integrated Projects (LSIPs)*, since the last year eight previously-identified LSIPs were cancelled, put on hold or restructured for diverse reasons , as insufficient revenues for carbon trade to un-appropriate storage regulations. These were offset by nine new projects, and of these, five ones are in China, where the progress of CCS should to be strong [*Global CCS Institute 2012, The Global Status of CCS :2012, Camberra Australia, appendix C page 178*]. However the potential evolution of the CO2 transport network on the European scale for the period 2015-2050, in terms of size should grow steadily until 2030, to 8800 km followed by a step-change towards 2050, up to 20000 km. This is based on a CCS deployment conservative scenario as the amount of CO2 captured in 2050 does not meet the goal for the decarburization of the European society by 2050, as can be seen in Figure 8.1.

* LSIP means projects having the capture, transport and storage of CO2 at a scale not less than:

800 ktonnes for a coal-based power plant,

400 ktonnes for other emission-intensive industrial facilities (including natural gas-based power generation) of CO2 annually sequestrated.

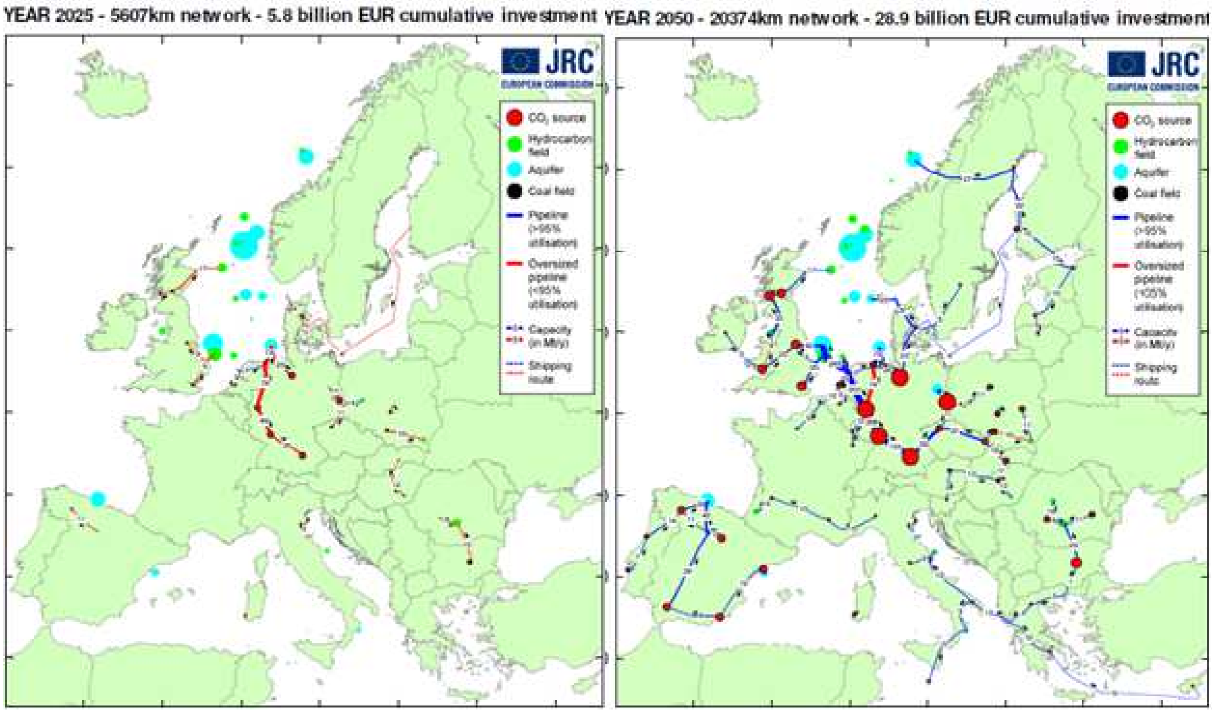


Figure 8.1 Development of CO2 netgrid in Europe according to the European Commission Joint Research Centre Institute for Energy [7].

8.1.2.2 Issues with different CO2 composition sources

CO2 purity is desirable both to maximize transport and storage inventory and to assure public confidence that Carbon Capture couldn't be used to waste disposal. So requirement that no wastes or other material will be introduced in the stream for the aim of disposal is accepted. Of course a certain level of contamination, for instance by materials involved in the capture process (such as the capture solvents) is unavoidable and shall be allowed for.

The main critical point of issue is to what extent the stream is allowed to be poisoned by combustion exhaust impurities such as sulphur oxides & nitrogen oxides (SOx and NOx). It appears that the EU Commission position is to positively accept when the same level of denitrification and desulphurization is required for the captured and stored anthropogenic CO2 as it is required, under current air pollution legislation, if the flue gases were vented to the air at the power plant stack. However, it must be highlighted that the current limits are based, when potential risk from releasing to the atmosphere are taken in account for air pollution requirements, and not on the potential risks coming from transport and geological storage.

Being a variety of capture techniques, this may result in heterogeneous gas stream compositions; having an unique purity requirement this may create significant economic penalties for certain capture technologies and slowing down the development of CCS both in the energy and industrial sector. On another point of view, the development of CO2 transport networks may be obstructed by the implementation of multiple 'CO2 purity classes' and make difficult the establishment of a 'captured carbon' commodity market. Having some minimum threshold or compositional ranges for impurities may then be required to facilitate the co-utilisation of transport and storage infrastructures.

8.1.2.3 Pipeline integrity and HSE

If in the future an integrated pipeline network, in Europe for CCS aims, will be built it will exploit the know how established and the large experience coming from the long lasting safety record along with the past 60 years in natural gas transportation.

As a matter of fact, CO2 (and in particular the anthropogenic CO2) shows significantly different physical properties and behaviour, in the pipeline transportation process. From natural gas and this was the reason to start up several actions to fill the knowledge gaps. However the design (pressure containment plus limit state design) approach, the pipe materials choice as laying and construction methods (in field welding and pipeline back filling) applicable for natural gas transportation systems must be exploited as much as possible for an economically viable carbon dioxide netgrid infrastructure.

The natural gas European transportation netgrid is, mainly, operated up to a maximum allowable operative pressure of 8 MPa in onshore applications and up to 30 MPa in subsea applications; pipes are made by carbon and low alloy steel according to detailed specifications taking into account different levels of strength (up to 555 MPa of Yield Strength in Europe and above 900 MPa as international standard) and are available by different production routes from some diameter inches up to 64", with wall thickness above 40 mm. Main requirements for pipeline safety long term operation are based on the assumption to contain the fluid shipped, to withstand the external loads and to resist to the aggressiveness of the internal fluid, as well as from the external environment. Furthermore in case of accident the extent of the failure should be minimized by steel toughness even at low temperature. Millions of km of natural gas pipelines are currently operated in the world accordingly to this well established technology. It must be highlighted that the chance to "re-use" existing natural gas pipeline for CO2 transportation doesn't appear an option because the minimum operative pressure for a dense phase carbon dioxide transport (7,4-8 MPa) is in the range of the maximum operative pressure for the gas onshore network.

So there's a lack of reference background for anthropogenic carbon dioxide massive amount by pipeline transportation coming from electrical power generation; the peculiarities for this application are:

- large amount of CO_2 inventories (i.e pipes with diameter above 16" (406mm),
- different capture systems (maily post-combustion process is going to be the most diffused one as it can retrofit existing power plants),
- carbon dioxide transportation in supercritical phase.

The variety of CO_2 captured compositions has an impact on several areas from the pipeline design to the operation as can be seen in Figure 8.2.

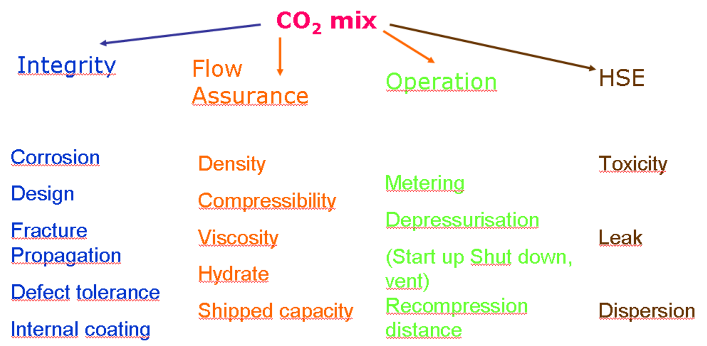


Figure 8.2 Effect of CO_2 mix on integrity, flow assurance, operation & maintenance and health safety and environment issues

8.1.3 European projects on CO2 transportation issues

The following picture (Figure 8.3) shows the integrated network of the main European Projects dealing with CO2 transportation by pipeline.

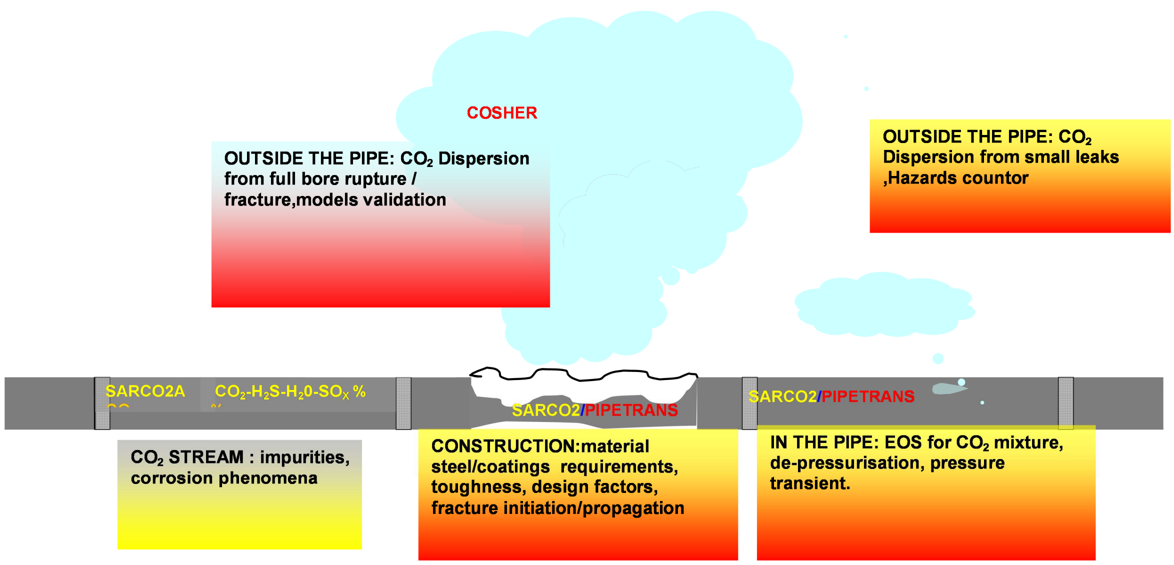


Figure 8.3 Integrated network of carbon dioxide transportation projects in Europe

8.1.3.1 SARCO2 Project

SARCO2 project (REQUIREMENTS FOR SAFE AND RELIABLE CO2 TRANSPORTATION PIPELINE) is an European RFCS (Research Funding Coal and Steel) project; it involves an integrated team of pipe producers (Europipe, Salzgitter Mannesmann Line Pipe, V&M Deutschland, Corinth Pipeworks), energy companies (eni S.p.A, GdF Suez, National Grid) and research centres (Centro Sviluppo Materiali, Salzgitter Mannesmann Forschungsinstitut), with the support of EPRG (European Pipeline Research Group). The general aim of the project is to contribute to the engineering design of pipelines from the long-term integrity point of view, through the development of specific requirements and design criteria for anthropogenic carbon dioxide transportation using steel pipeline systems. Specific goals of SARCO2 initiative are:

- to generate reliable data for determining the feasibility of using steel pipeline systems for the transport of anthropogenic CO2;
- to contribute to the future development of a guideline for safe design and operation of a CO2 pipeline network in Europe;
- to develop specific know-how to verify the possibility of employing existing gas pipeline systems for the safe transport of CO2.

The use of oil & gas pipeline material and construction approaches (based on conventional pipeline steel grade L415M/Q – L485M/Q according to ISO 3183 and EN 10208 part 2 and EN 1594) and the incorporation of contemporary approaches with crack arrestor (or ultra-high "equivalent toughness" reinforced composite pipes) solutions will be pursued in order to meet the stringent structural integrity demands for transportation of anthropogenic CO2. In this respect the following topics are faced:

- Definition of toughness requirements to control initiation (leak vs. break) and long-running ductile fracture propagation using large and full scale test on real sections of pipeline. To achieve this goal specific experimental and analytical activities are in progress at the CSM full scale laboratory tests of CSM located in Perdasdefogu (Military Firing Range, Italy); in particular crack initiation/leak event tests and two unstable ductile fracture propagation tests will be performed. About these last two full scale fracture propagation tests the geometry of pipes is the same for both tests (fixed at 24", with thickness in the range 12- 20 mm) while the chemical composition of the gas and/or service conditions (as usage factor i.e. pressure) will be changed. This experimental activity will provide vital data which is essential for the development and verification of adequate approaches and failure modelling. They will also enable measurements of in-field real-scale dispersion behaviour of anthropogenic CO2 which will contribute to the development of realistic hazard scenarios.
- Collection and analysis of existing and available data and knowledge about the corrosion and/or stress corrosion resistance of both pipe body and welded zone working in the anthropogenic CO2 environment, with different level of impurity as

H2S. Improvement of this know-how database, through specific laboratory-based activities, is in progress in the SZMF and CSM laboratories. In particular the following experimental activities on the above indicated steel pipes (and girth welded joints also) are planned:

- Autoclave corrosion testing under stagnant and simulated flow conditions;
- Stress corrosion tests at constant stress level on four point bending specimens;
- Stress corrosion tests at variable stress level. Slow-strain-rate (SSR) and cyclic SSR tests.

In agreement with the general aim of SARCO2 project, CSM, in collaboration with the University of Cagliari, is involved on the investigation of the physical phenomena that guide the accidental release and subsequent dispersion of CO2 from a pipeline. The issues that are currently in the study are:

- the driving force related to the CO2 decompression behaviour inside a fractured pipeline that supports the fracture propagation;
- the dispersion around the pipeline failure zone of great amounts of CO2.

About the first point, in order to predict the decompression curve of an anthropogenic CO2 gas, the CSM has implemented his numerical code, GASMISC; so this last is able now to calculate the fracture driving force and to characterize the carbon dioxide source originates by the pipeline rupture. This tool will be used to predict the drive force of fracture in the above two full scale fracture propagation tests.

The prediction of all the phenomena which take place in release of anthropogenic CO2 and dispersion provided by the numerical codes is fundamental in order to perform a risks assessment analysis, based on the possibility to anticipate major accident scenarios and to anticipate the consequences of the unlikely, but potentially hazardous, events. The risk assessment analysis, in fact, is one of the most important tools which could facilitate the achievement of suitable safety levels for the transport of carbon dioxide in CCTS, especially for applications in dense populated areas. The dispersion study of the anthropogenic carbon dioxide, is conducted by CSM using commercial numerical tools based on two different approaches, whose application is mainly related to the level of conservativeness required:

- the Gaussian model ALOHA, that allows to obtain highly conservative but quick results (by solving the governing equations of fluid dynamics in a simplified form);
- the Computational Fluid Dynamics (CFD) code Ansys Fluent that solves the governing equations of fluid dynamics for three dimensional flows, unsteady and turbulent.

This last model (CFD) also admits to obtain more accurate results in the presence of complex orography, release sources at high pressure, specific atmospheric conditions and potential obstacles. Moreover, the adopted CFD numerical code Ansiys Fluent has been improved by CSM, through the implementation of new models dedicated to particular aspects of the physical problem. At the scope, the GASMISC code, is used for evaluating the chocked conditions which guide the release phase (including also the Joule-Thomson effect). Therefore, all the influencing parameters of the fluid dynamic problem are taken into account, gravitational effects and fluctuating wind included, and the new implemented models increase the accuracy of the prediction both for the fluid release and the subsequent dispersion phases.

Actually, the available CFD code, with the new implemented models, allows to predict the dispersion of anthropogenic CO2 from various source configurations (i.e. pipeline leakage or fracture) and under different atmospheric conditions, eventually characterized by a fluctuating wind intensity and/or direction. The results of CFD model allow a complete evaluation, both in space and time, of all the physical phenomena occurring during the release and the subsequent dispersion phases, including the possible interaction between the CO2 jet and the environment (atmosphere, soil, obstacles). In particular, the results from the CFD simulations are used, inside the experimental activity planed in the SARCO2 project, in order to provide 3D "clouds", picturing the evolution of CO2 concentration in time and space, for particular levels of CO2 concentrations. An example of these clouds is shown in Figure 8.4 in which the extension of high CO2 concentration region is reported for a fixed time (60 s), after the release starting, for the fracture propagation tests scheduled in the SARCO2 project. The study of the maps allows to define the hazardous area near the release point in terms of maximum distance from source and time after the release starting at which it is possible to detect a CO2 concentration above a safeguard level.

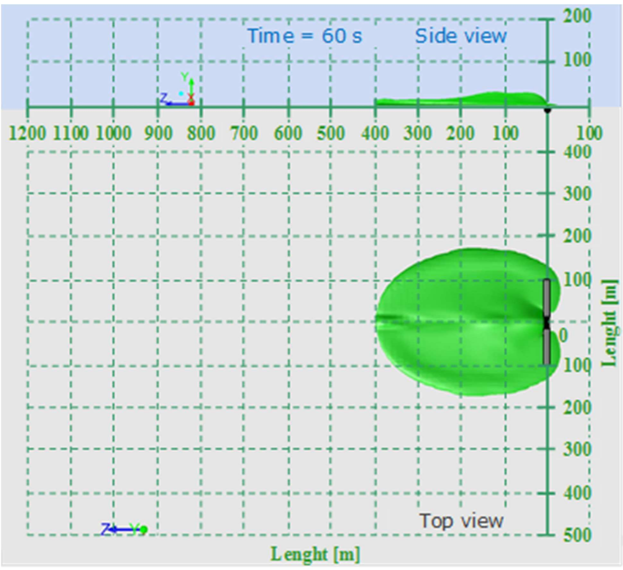


Figure 8.4 CO2 Dispersion in atmosphere, a snapshot after 60 s from the fracture propagation onset on a test line.

8.1.3.2 SARCO2A Project

The project SARCO2A (REQUIREMENTS FOR SAFE AND RELIABLE CO2 TRANSPORTATION PIPELINE-A) deals with several of the above mentioned aspects of the pipeline transportation issue for CCS. The project, as a Joint Industry Project (JIP), is carried out by a consortium of EPRG member companies encompassing an electricity and gas transporter (National Grid), two energy providers (GdF SUEZ and Open Grid Europe), an oil & gas company and energy provider (eni), three pipe manufacturers (EUROPIPE, Salzgitter Mannesmann Line Pipe and Vallourec & Mannesmann Tubes) and two research centres (Centro Sviluppo Materiali and Salzgitter Mannesmann Forschung) all contributing to individual aspects of transporting carbon dioxide.

The specific characteristic of SARCO2A is that the aspects faced in the work packages are complementary to the work performed within the EU funded SARCO2 project. The experimental part performed within SARCO2A encompasses investigation of different corrosion phenomena like general and localised corrosion and corrosion modes related to certain impurities in anthropogenic CO2. Corrosion protection concepts in shape of inhibitor systems or coatings are studied in small and full-scale tests for classifying their applicability in CO2 pipelines. For conducting safety and reliability analyses of such pipelines, the leakage behaviour of CO2 upon release is assessed, with experimental data facilitating the simulation of CO2 release phenomena.

Besides the other aspects of CO2 pipeline transport, the focus of SARCO2A is devoted to the investigation of different corrosion phenomena and corrosion protection concepts. Prior to determining a test matrix for the project, an in-depth study on likely composition of CO2 mixtures coming out of the different capture processes and the potential effect of change in presence and amount of impurities in the CO2 mixtures on transport in pipelines, was carried out. This fundamental study was used as a basis for the experimental work in the project. Test parameters with respect to pressure, temperature and flow velocity of the fluid as well as composition and water content of the different tested CO2-mixtures were defined based on this analysis. The composition of the CO2 mixtures was derived from the three major capture techniques for power plant applications currently under consideration.

The issue of general and localised corrosion was addressed by means of autoclave tests on small specimens exposed to stagnant, laminar or turbulent flowing CO2-based fluids. Next to general and localised corrosion also the risk of stress corrosion cracking is being addressed for the first time due to the fact that simultaneous presence of the system CO2/CO/H2O or H2S/H2O bears the threat of SCC formation under appropriate conditions. Testing was performed on standard seamless and welded pipe material. Welded pipes included both SAWL and HFI welds. All investigated pipes were of API 5L grade X65 with outer diameters of 323.9 mm and 678 mm taking short and long distance pipeline transport of CO2 into account. All small-scale laboratory tests as well as full-scale corrosion tests under cyclic loads are performed on the same pipes in order to assess the transferability of small-scale lab test results to (simulated) in-service performance of the pipe materials. In order to accomplish full scale corrosion testing as closely as possible to the expected CO2 in-service transportation scenario, a unique full scale test plant has been constructed.

Another important topic of this JIP covered the leakage behaviour of CO2 from leaks in a pipeline. This is of high significance for both evaluation of dispersion of the released gas and, because of the decrease in temperature, especially for the toughness requirements of a damaged pipe. The investigation of these risks provides useful information for prediction of fracture propagation and spreading of anthropogenic CO2 from a damaged transport pipeline. The leakage behaviour was investigated in terms of small scale tests, where volume flow, pressure, temperature distribution and cooling rate were measured. Combined with the likewise recorded dispersion into the atmosphere, the results were used as a basis for calibrating computer models for a comprehensive simulation of CO2 release from a damaged pipeline. The simulations included computation of one- and two-phase flow within the pipe and the different forms of dispersion including phase transitions upon release. Together with additional data on dispersion measurements these results can be used as background for a well-founded risk assessment and setting up guidelines for categorising safety zones for the transport of anthropogenic CO2.

The aspects highlighted in SARCO2A will contribute in defining guidelines and standards for operating a pipeline network for the transport of anthropogenic CO2. Being complementary to the "sister project" SARCO2 ensures that duplicating theoretical and experimental work is avoided. Additionally, agreements to exchange with other projects such as the DNV project CO2PIPETRANS have been achieved with the focus on corrosion related issues, so that partial thematic overlap could be identified and considered for advancement in each individual project.

8.1.3.3 DNV KEMA COSHER project

The COSHER Project (CarbOn Dioxide, Safety, Health & Environmental Risk, see website http://www.cosher.net/en/) is a collaboration between European stakeholders to support the development of validated models for the determination of safety zones around CO2 pipelines. The focus of the COSHER project is on releases from underground CO2 transmission pipelines simulating loss of containment as a result of a pipeline rupture arising from third party interference. It seeks supporting the development of CO2 safety models by gaining data from well-defined experiments to study and understand the CO2 outflow from pipelines and the dispersion of CO2 clouds. In combination with existing knowledge of for instance the impact of carbon dioxide on human health and the failure rate of pipelines, risk estimates can be made.

The scope of the project is defined as:

- Gaining data that will support the further development of existing models of the partners and third parties active in the field of CO2 modelling;
- Developing models for the determination of safety zones of CO2 transmission pipelines, carrying dense carbon dioxide (pressure > 8,0 MPa);

- Focus is on large scale releases from ruptures of carbon dioxide transmission pipelines, representing intentional releases and un-intentional/accidental releases due to third party interference and corrosion;
- COSHER concerns physical/health/technical issues, and does not concern the acceptability of risk levels.

Of particular interest are:

- Pipelines operating at high pressure (typically up to 15 MPa)
- The hazards presented by large failures
- The behavior as the CO2 is released (mass release rate, phase change)
- The potential loss of momentum due to impact on the sides of a trench
- The atmospheric dispersion of the CO2
- The chilling effect on the pipeline wall due to sudden depressurization

The project also helps in creating a network and knowledge infrastructure will help stakeholders better understand and support a complex long-term transition process towards large-scale deployment of CCS. A prime project characteristic is that all major stakeholders and multidisciplinary groups work together; this is essential, because system implementation depends on the (potential) performance and impacts of all integrated system elements.

The project is actually in the execution phase with the first pipeline rupture test expected by the end of February 2013. Additionally, the COSHER project may also extend its interest to the hazards presented by punctures in a long pipeline, including the subsequent outflow, dispersion and pipeline depressurization.

8.1.3.4 DNV KEMA Pipetrans Phase 2

During execution of the CO2PIPETRANS Phase 1, which resulted in the DNV-RP-J202, a number of significant gaps in knowledge were identified. If left unfilled these knowledge gaps will slow the implementation of CCS on an industrial scale. Phase 2 of the CO2PIPETRANS project is aimed at filling these knowledge gaps through experimental research funded by a Joint Industry Project (JIP). The CO2PIPETRANS partners are: Arcelor Mittal, BP, DNV, Endesa, eni, E.on Ruhrgas, Gassco, Gassnova, Health and Safety Executive (HSE) UK, Maersk Oil, Petrobras, Petroleum Safety Authority (PSA) Norway, Shell, V&M Tubes, and Vattenfall.

The scope of work includes three technical areas where further R&D is being conducted to gain an improved understanding and /or data:

a) **Dense Phase CO_2 Release Modeling Validation Data.** Objective is to make available suitable information and data from experimental work to assist development and validation of robust dense phase CO2 depressurization, release, and dispersion models. Data collected during two complimentary programmes of medium scale CO2 release experiments conducted by BP and by Shell is part of the CO2PIPETRANS project and has been made available to the public through www.dnv.com/ccs. As a part of this program a series of n° 8 pipeline depressurisation experiments have been undertaken and a series of large releases of CO2 will be undertaken during 2013. See figures Figure 8.5, Figure 8.6, Figure 8.7.

b) **Fracture Arrest.** Objective is to provide confirmation of theoretical models by performing full scale fracture arrest testing. As part of this experimental program CO2PIPETRANS has undertaken two full scale 16" fracture propagation experiments in Norway. See Figure 8.8. CO2PIPETRANS is also using partly funding the SARCO2B experiments with the EPRG, CSM and European Commission. These 24" burst experiments will be undertaken in Sardinia during 2013.

c) **Corrosion.** Objective is to determine the corrosion mechanism and the corrosion rate in dense phase CO2 for various amounts of impurities like O2, SOx, NOx and H2S. CO2PIPETRANS has undertaken approximately 50 experiments with different carbon steels, and stainless steel to establish corrosion rates with different combinations of the impurities mentioned earlier with and without water present.

CO2PIPETRANS is scheduled to be completed in 2013 with the final output being publication of an update of DNV RP-J202 recommended practice for "Design and Operation of CO2 Pipelines". Furthermore in August 2011 DNV KEMA initiated the CO2 Risk Management (CO2RISKMAN) Joint Industry Project (JIP) to develop a publicly-available guidance on major accident risk management of the carbon dioxide (CO2) stream within CSS projects. This guidance is now complete and provides the CCS industry with clear and comprehensive information to help in the development of effective CO2 risk management across the whole CCS chain from capture facilities through to underground injection.

It must be recognized that there is no reason why the major accident risks from a CO2 handling system within a CCS operation cannot be low and well within acceptable limits but to achieve this will require the application of existing rigorous hazard management processes combined with an adequate understanding of the properties and behaviours of CO2. A significant leak from a large inventory CO2 handling system has the potential to be life threatening to people caught within the ensuing dispersing cloud or could pose local environmental harm. In the same way as the risks from other better known hazards are managed, the risks from the CO2 stream also need to be well managed and the new guidance will help this happen.

Figure 8.5 Depresurisation rig at Spadeadam GL Noble Denton

Figure 8.6 CO_2 release from the ring

Managing risks. There is little experience handling very large quantities of CO2 outside the US, where carbon dioxide is used to enhance oil production. With the introduction of CCS this will change. CCS engineers, project management, system operators, hazard management specialists, and others who have a key role in delivering a safe operation need to have adequate understanding of the potential CO2 hazards so that they can effectively manage the associated risks,; aspects of CO2 such as the rapid corrosion that can occur if H20 enters a CO2 system, the very cold temperatures that can occur if a CO2 system is depressurised, the effect of impurities, the difficulties associated with modelling leaks, and the toxicological effects on humans when air with a high CO2 concentration is inhaled, all need to be adequately understood.

Figure 8.7 Snapshot of the rupture disk

Figure 8.8 Full scale burst test with CO_2 at Giksak (SINTEF) test side an the DNV-Sintef team

The CO2RISKMAN guidance systematically presents and explains all the main issues and aspects associated with CO2 that need to be considered within a robust hazard management process. It discusses the potential safety and environmental hazards, their causes, escalation routes and possible consequences. In addition, for each link of the CCS chain the guidance provides assistance on hazard identification, risk assessment and what can be done to reduce the risks down to an acceptable level. Recognising that the guidance needs to be readily assessable to a wide range of people with different backgrounds and requirements, the guidance has been developed into four ‘Level’ documents. Level 1 provides a concise executive summary whereas Level 4 is a 300 page, in-depth, knowledge source that is sub-divided to address each link of the CCS chain.

8.1.3.5 Other Projects ongoing with the EC support

Under the umbrella of European Community, in response to the FP7-ENERGY-Call, are currently ongoing other Europen projects dedicated, in whole or in part, to the transport of anthropogenic CO_2 In particular:

- at the end of 2008 the following three proposals focusing on specific aspects of transportation of anthropogenic CO_2 , including ship transportation, have been accepted and are under way:

  Quantitative failure hazard release of next generation of CO_2 pipeline (Coord.: UCL, UK).

  Safe Marine transportation by shipyard, (Coord.: DNV KEMA, NT).

  Integrated infrastructure for CO_2 transportation and storage (Coord.: INITE, SP).

- at the beginning of 2013 a new FP7- Project started:

  The impact of the quality of CO_2 on transport and storage behavior (Coord.: SINTEF, Norway).

Currently all these projects, lasting 3-5 years, are in progress. The results will be disseminated in dedicated workshop planned specifically inside each project.

Finally, within the EC framework of the Zero Emissions Platform (ZEP), Task Force Technology, a group of experts from European industries concerned with carbon dioxide transport in the context of Carbon Capture and Storage, has worked to identify the key cost elements and to forecast the long term costs of CO_2 transport by ship, onshore and offshore pipelines, both as pressurized and liquefied gas. The results of this "state of the art" study are been presented in the ZEP spring 2011 meeting, the final report is now available in the ZEP web-side.

8.2 Hydraulic simulations of the CO2 transportation

8.2.1 Nomenclature:

A – area, m^2,

c_p – specific heat at constant pressure, J/(kg K),

D – pipe diameter, m,

f – Darcy friction factor,

g – the acceleration of gravity, m/s^2,

h – specific enthalpy, J/kg,

k_L – linear heat transfer coefficient, W/(m K),

m – element mass, kg,

M – mass flow rate, kg/s,

n – number of heat-transfer area discrestization sections,

N – number of pipeline discrestization sections,

p – gas pressure, Pa,

q - rate of heat transfer per unit time and unit mass of the gas, W/kg,

R – specific gas constant, J/(kg K),

Re – Reynolds number,

t – time, s,

T – gas temperature, K,

T_{ground} – temperature of the ground surface, K,

w – flow velocity, m/s,

W – compressor work input, J,

x – spatial coordinate, m.

X – distance coordinate of moving grid node, m.

Greek symbols:

α – angle between the direction x and the horizontal,

Δ_X – spatial derivative approximation,

ε - pipe roughness, mm,

λ – heat conductivity, W/(m K),

ρ – density of the gas, kg/m^3.

Subscripts:

d – compressor discharge state,

is – isentropic process,

s – compressor suction state.

8.2.2 Introduction

The transport of CO2 is a mature technology as the technical requirements are similar to those applied to other gases transport. Commonly, the CO2 is not stored in the same place where it is captured. To transport large volumes of CO2, the pipelines are considered to be the most cost-effective and reliable method (McCoy and Rubin, 2008; Haugen et al., 2009). However, in some situations or locations, CO2 transport by ship may be economically attractive. Additionally, quantitative risk assessment for CO2 pipeline transportation was evaluated in several studies, some of them in the context of CCS projects (Chrysostomidis et al., 2009; Koornneef et al., 2009; Koornneef et al., 2010b).

Several millions of tonnes of CO2 are already transported by pipelines, most of it being transported to enhanced oil recovery (EOR) fields. Pipelines linking several industrial regions can be shared, allowing the greatest emission reductions for the lower cost. An engineering- economical model was proposed to evaluate the cost per ton of transporting CO2 for a range of CO2 flow rates, over a range of distances in the United States (McCoy and Rubin, 2008). Atmospheric dispersion of carbon dioxide after sublimation from a dry ice bank is of concern when dealing with safety criteria for the transportation of carbon dioxide in Carbon Sequestration projects.

Pipelines are the preferred mode of transportation for CO_2 when large volumes of captured CO_2 are to be stored in geological formations at short to medium distance from the capture location (Svensson et al., 2004). In the field of pipeline and compression facilities, the technical problems to be resolved involve pipeline integrity, flow assurance, safety and operational considerations. For a comprehensive review of the current development in CCS, see recently published review paper by Pires et al. (2011), while for commentary on the previous research work on CO_2 pipeline transportation, see the report by Oosterkamp and Ramsen (2008) and the paper by Vandeginste and Piessens (2008). It is beyond the scope of this article to make a detailed review of CO_2 transportation systems. Instead, the most recent research in the field of pipeline transportation with application to CCS will be mentioned briefly.

Carbon dioxide pipeline transport for enhanced oil recovery is a mature technology, however relatively little work has been carried out on CO_2 pipelines for CCS applications. Some research effort has been put in the area of steady-state flow modeling. Examples of such studies include those conducted by Zhang et al. (2006), McCoy and Rubin (2008), Seevam et al. (2008), Vandeginste and Piessens (2008) and, more recently, Nimtz et al. (2010).

Regarding the dynamics of CO_2 pipeline systems, there is very little work reported in the literature. Mahgerefteh et al. (2008) presented the results of the transient simulation of CO_2 pipeline rupture, obtained from the numerical solution of the conservation equations using the method of characteristics. Peng-Robinson Equation of State (EOS) (Peng and Robinson, 1976) was used to describe the carbon dioxide properties. The comparison of the outflow data for the rupture of two identical pipelines each containing CO_2 and natural gas showed that the depressurization behavior of both pipelines was very similar, whereas the discharge rates maintained by the CO_2 pipeline were noticeably higher compared to those of the natural gas pipeline.

Munkejord et al. (2010) investigated the transport and depressurization parameters of a two-phase carbon dioxide-methane mixture using the Soave-Redlich-Kwong EOS (Soave, 1972). The multi-stage centered (MUSTA) scheme was employed for the numerical solution of the drift-flux model. The results indicated that mixture composition has an influence on mixture sonic speed and the cooling rate during depressurization.

Liljemark et al. (2011) evaluated the risk of phase transition during flow transients and pipe cooling of the transported CO_2/N_2 fluid mixture, consisting of 98% CO_2. Operation modes of load change, start-up, shout down and compressor trip were simulated using commercially available modeling environment. The Span and Wagner EOS (Span and Wagner, 1996) for carbon dioxide properties and GERG-2004 mixture model (Kunz et al., 2007) were used in the simulations.

In the study by Klinkby et al. (2011) the transient two-phase flow of carbon dioxide in the pipeline and well was investigated using a commercially-available multiphase flow simulator with Span and Wagner EOS. The modelling software package was shown to be a useful tool for integration of the transmission system and reservoir design activities, and allowed prediction of the phase conditions along the pipeline and in the well head.

Generally, there is an agreement that large volumes of CO2 should be transported either as liquid or as a supercritical/dense phase fluid (Shafen and Carter, 2010). Dense phase is a preferable condition for transporting CO2 in pipelines. This state is characterized by fluid viscosity similar to that of a gas, but a density closer to that of a liquid. Transmission in gaseous phase is not economical, as is the case with two-phase flow, in which high-pressure losses, particularly in hilly terrain, can occur.

The primary purpose of this work is to examine the hydraulic parameters of the CO_2 pipeline by solving the rigorous single-phase, compressible fluid flow model, suitable for supercritical and dense-phase CO_2 pipeline calculations, with relevance to CCS applications. The model is represented by one dimensional version of the Euler equations with source terms representing viscous dissipation of energy and heat transfer to the surroundings. Furthermore, it incorporates high precision reference equations of state explicit in the Helmholtz free energy from REFPROP 8.0 database (Lemmon et al., 2007) with GERG-2004 mixture model. The effect of different CO_2 mixture composition on flow properties in the pipeline is investigated. Finally, the energy demand for the compression processes is studied, which provides more insight into the operational costs of pipeline CO_2 transmission depending on the sequestration method in use.

8.2.3 Basic equations

8.2.3.1 Pipeline model

The basic equations are derived from the conservation principles. For one-dimensional, compressible fluid flow we have

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho w)}{\partial x}=0 \tag{1}$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial\left(p+\rho w^2\right)}{\partial x}=-\frac{f\rho w|w|}{2D}-\rho g\sin\alpha \tag{2}$$

$$\frac{\partial}{\partial t}\left[\left(u+\frac{w^2}{2}\right)\rho\right]+\frac{\partial}{\partial x}\left[\left(h+\frac{w^2}{2}\right)\rho w\right]=\rho q-\rho wg\sin\alpha \tag{3}$$

where ρ is the density of the gas, *w* is the flow velocity, *p* is the gas pressure, *f* is the Darcy friction factor, *D* is the internal pipe diameter, *g* is the acceleration of gravity, α is the angle between the direction *x* and the horizontal, *u* is the internal energy, *h* is the enthalpy of the gas, and *q* is the rate of heat transfer per unit time and unit mass of the gas. Eq. (2) can be converted using Eq. (1) to the following form

$$\frac{dw}{dt}+\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{fw|w|}{2D}+g\sin\alpha=0 \tag{4}$$

Substituting Eqs. (1) and (4) into the Eq. (3) and rearranging we obtain

$$\rho\frac{\mathrm{d}h}{\mathrm{d}t}-\frac{\mathrm{d}p}{\mathrm{d}t}-\frac{f\rho w^3}{2D}=\rho q \tag{5}$$

Eqs. (1), (4) and (5) need to be rewritten with pressure, temperature and mass flow rate as the dependent variables, since the above parameters are typically measured and used in pipeline operations. Furthermore, we assume that the transmission pipeline will be operated with given CO_2 production rate and with the assumption of maintaining the storage site minimal delivery pressure. To obtain ρ and *w* in terms of *p*, *T*, and mass flow rate *M*, we use the identity $w=M\rho^{-1}A^{-1}$ and the relation for density $\mathrm{d}\rho=(\partial\rho/\partial T)_p\,\mathrm{d}T+(\partial\rho/\partial p)_T\,\mathrm{d}p$ obtained from the appropriate EOS. The relationship for enthalpy is

$$\mathrm{d}h=c_p\mathrm{d}T+\left[1+\frac{T}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p\right]\frac{\mathrm{d}p}{\rho} \tag{6}$$

where c_p is the specific heat at constant pressure. The final form of continuity, momentum, and energy equations for one-dimensional pipeline flow is

$$E(p,T)\frac{\partial p}{\partial t}+F(p,T)\frac{\partial T}{\partial t}=G(p,T) \tag{7}$$

$$H(p,T)\frac{\partial M}{\partial t}=I(p,T) \tag{8}$$

$$J(p,T)\frac{\partial p}{\partial t}+K(p,T)\frac{\partial T}{\partial t}=N(p,T) \tag{9}$$

where:

$$E(p,T)=\left(\frac{\partial \rho}{\partial p}\right)_T,\ F(p,T)=\left(\frac{\partial \rho}{\partial T}\right)_p,\ G(p,T)=-\frac{1}{A}\frac{\partial M}{\partial x},\ H(p,T)=\frac{1}{A},$$

$$I(p,T)=\left[\left(\frac{M}{\rho A}\right)^2\left(\frac{\partial \rho}{\partial p}\right)_T-1\right]\frac{\partial p}{\partial x}-\frac{2M}{\rho A^2}\frac{\partial M}{\partial x}+\left(\frac{M}{\rho A}\right)^2\left(\frac{\partial \rho}{\partial T}\right)_p\frac{\partial T}{\partial x}-\frac{2fM\left|M\right|}{D\rho A^2}-\rho g\sin\alpha$$

$$J(p,T)=\frac{T}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p,\ K(p,T)=\rho c_p,\ N(p,T)=-\frac{MT}{\rho^2 A}\left(\frac{\partial \rho}{\partial T}\right)_p\frac{\partial p}{\partial x}-\frac{c_p M}{A}\frac{\partial T}{\partial x}+\frac{2fM^3}{D\rho^2 A^3}-\frac{k_0}{A}\left(T-T_1\right)$$

where A is the pipeline cross-section area, and k_0 denotes heat transfer coefficient between the gas and the first element. Eqs. (7), (8) and (9) constitute the set of nonlinear partial differential equations (PDE) of hyperbolic type governing one-dimensional flow of compressible fluid. For closure of the above set of equations, an equation of state must be used. The process of heat transfer from the gas to the surroundings of the pipeline has been described using unsteady heat transfer model, so that the effect of heat capacity of the surroundings of a pipeline could be taken into consideration. An axisymmetric heat transfer model has been adopted, and the surroundings of the pipeline were modelled by four coaxial cylindrical layers as heat capacitors.

$$\frac{m_1 c_{p1}}{\mathrm{d}x}\frac{\partial T_1}{\partial t}=k_0\left(T-T_1\right)-k_1\left(T_1-T_2\right) \tag{10}$$

$$\frac{m_2 c_{p2}}{\mathrm{d}x}\frac{\partial T_2}{\partial t}=k_1\left(T_1-T_2\right)-k_2\left(T_2-T_3\right) \tag{11}$$

$$\vdots$$

$$\frac{m_n c_{pn}}{\mathrm{d}x}\frac{\partial T_n}{\partial t}=k_{n-1}\left(T_{n-1}-T_n\right)-k_n\left(T_n-T_{\mathrm{ground}}\right) \tag{12}$$

where n is the number of discretization sections of heat-transfer area (equal to number of elements), m_i is element mass (i = 1, ... n), c_{pi} is the is the specific heat of element i, $m_i \cdot c_{pi}$ is the element heat capacity per pipeline unit length, dx is the discretization section of a pipeline, T_i is the element temperature, and k_i is the heat transfer coefficient between elements (i–1) and i.

Eqs. (10)-(12) are the heat balance equations of the coaxial cylindrical layers representing the heat-transfer model of the surroundings of the pipeline. An assumption was made in this study that for every discretization section of the pipeline there are four such layers (n = 4), serving as heat capacitors, with the temperature T_1 through T_4, while the temperature T at the internal radius of the first layer is the gas temperature, and the temperature T_{ground} at the external radius of the last layer is the surface air temperature. The three governing equations for gas pressure, temperature and mass flow-rate were coupled with four heat balance equations and solved simulataneously as one system of PDEs.

The initial values for the partial differential equations were obtained by setting the time derivatives in Eqs. (1)–(3) equal to zero, and solving the resulting set of ordinary differential equations.

$$\frac{\mathrm{d}p}{\mathrm{d}x} = \left(SV - BZ\right)\left(PV - QU\right)^{-1} \tag{13}$$

$$\frac{\mathrm{d}T}{\mathrm{d}x} = \left(PZ - SU\right)\left(PV - QU\right)^{-1} \tag{14}$$

where coefficients P, Q, S, U, V, Z are known functions of temperature and pressure:

$P = \frac{1}{\rho} - \left(\frac{M}{A}\right)^2 \frac{1}{\rho^3}\left(\frac{\partial \rho}{\partial p}\right)_T$, $Q = -\left(\frac{M}{A}\right)^2 \frac{1}{\rho^3}\left(\frac{\partial \rho}{\partial T}\right)_p$, $S = -\frac{f}{2D}\left(\frac{M}{\rho A}\right)^2 - g\sin\alpha$, $U = \frac{T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)_p$, $V = c_p$,

$Z = \frac{f}{2D}\left(\frac{M}{\rho A}\right)^2 - \frac{k_L}{M}\left(T - T_{\mathrm{ground}}\right)$, and k_L is the overall linear heat-transfer coefficient. The values of ρ, $\left(\partial\rho/\partial p\right)_T$ and $\left(\partial\rho/\partial T\right)_p$ are determined from the equation of state.

The overall linear heat-transfer coefficient for onshore pipelines is calculated from the expression:

$$k_L = \left(\frac{1}{\pi D_1 h_{\mathrm{conv}}} + \sum_{i=1}^{m} \frac{1}{2\pi\lambda_i} \ln\left(\frac{D_i}{D_{i-1}}\right) + R_{\mathrm{ground}}\right)^{-1} \tag{15}$$

where h_{conv} is the convection heat transfer coefficient, λ_i is the thermal conductivity of the i-th pipe wall layer, and R_{ground} is the thermal resistance of the ground. Eq. (15) shows that the overall heat transfer resistance is equal to the sum of three individual resistances resulting from the convection between the gas and the inner pipe wall, the conduction in the pipe wall, and the conduction in the ground. It can be shown, that the surface resistance on the inner pipe wall, and the conduction resistance of the pipe wall are less than 1% of the total heat transfer resistance (Gersten et al., 2001). Therefore, it is sufficient to consider the heat transfer within the ground only. A well-known analytical solution for heat conduction problem between the pipe with depth *H* below the ground surface and the surroundings of the pipe (semi-infinite solid) leads to the following formula for the ground resistance

$$R_{\text{ground}} = \frac{1}{2\pi\lambda_{\text{ground}}} \ln\left(\frac{H}{D} + \sqrt{\left(\frac{H}{D}\right)^2 - 1} \right) \tag{16}$$

where λ_{ground} is the thermal conductivity of the ground, and *D* is the pipe outside diameter.

For the purpose of heat-transfer area discretization, the assumption was made that every cylindrical element (*i* = 1, …*n*) has the same thermal resistivity, i.e. $k_0 = k_n = \left(R_{\text{ground}}/(2n)\right)^{-1}$, $k_i = \left(R_{\text{ground}}/n\right)^{-1}$, $i = 1,\ldots n\text{-}1$, thus the temperature differences between consecutive ground sections under steady-state conditions were equal, and the initial condition could be accurately modelled.

8.2.3.2 Compressor model

The required work input to a compressor for a defined control period is obtained from the following equation

$$W_{comp} = \int_{t_0}^{t_1} \dot{W}_{comp,i} \cdot \mathrm{d}t \tag{17}$$

The sum of power input to all stages of compression is determined form

$$\dot{W}_{comp,i} = \sum_i M \cdot \left(h_d - h_s\right) \tag{18}$$

The exit enthalpy of the *i*-th stage is calculated using isentropic efficiency of the compressor

$$h_d = h_s + \left(h_{is,d} - h_s\right)/\eta_{comp} \tag{19}$$

The exit enthalpy for the isentropic process is determined from flash calculation given pressure and entropy $h_{is,d} = h\left(s_d, p_d\right)$, while the exit entropy is calculated from the requirement that the entropy of the gas remains constant $(s_d = s_s)$, i.e. $s_d = s\left(p_s, T_s\right)$. The exit temperature of the *i*-th stage is determined from the flash calculation given pressure and enthalpy $T_d = T\left(p_d, h_d\right)$.

8.2.4 Solution method

Method of lines (MOL) was selected for the numerical solution of the system of the conservation equations. MOL proceeds with two separate steps: (1) spatial derivatives approximation, and (2) time integration of the resulting ordinary differential equations (ODE). In this study finite difference scheme with two techniques for spatial discretization is used, namely the fixed-grid method and the moving grid method, in the solution of slow transient and fast transient processes, respectively.

The system of PDEs was converted to the system of discrete in space and continuous in time ODEs, by solving the Eqs. (7), (8) and (9) for the derivatives of pressure, flow rate and temperature

The governing equations for gas pressure, temperature and mass flow rate are coupled with the heat balance equations of the coaxial cylindrical layers representing the heat transfer model of the surroundings of the pipeline, and solved simultaneously as one system of PDEs in each time step.

8.2.5 Conclusions

The results of the transient simulation of the CO_2 pipelines indicate that the CO_2 mixtures from different capture technologies show different dynamic behaviour during pipeline transport. In particular, the CO_2 mixture from separation plants using Oxyfuel technology presents considerable different pressure-temperature conditions, as well as compressor station capacity and fuel consumption, in comparison to Post-combustion and Pre-combustion processes.

Given the intermittency of the renewable sources, it seems reasonable to assume variable delivery rates of CO_2 in separation plants, since fossil fuel based power plants will have to provide the necessary swing capacity. Therefore, the detailed design of pipeline infrastructure for CO_2 sequestration should be on the premise that the flow is unsteady. The length and the size of the potential transmission networks causes that the prediction of operational data should be done using modelling and simulation techniques to ensure cost effective design, as well as safe and efficient operation of CO_2 pipelines.

8.2.6 References

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Chap. 9 Summary, Conclusions and Recommendations

Main aim of the work of SG3.1 and SG3.2 during the three-year period 2012 – 2015 was to identify key factors in the field of gas transmission, gather available information and subsequently analyse current status in selected fields based on experience of individual members of the study groups. Scope of work was relatively wide and that´s why individual attitude to particular topics was selected.

From the viewpoint of new strategic projects (Chapter 2) emphasis was placed on the projects on which the members of working groups have relevant information. For ease of reference, Chapter 2 includes description of main transmission corridors along with details of chosen projects. Subsequently Annex 1 includes more detailed information on projects being implemented in relevant countries/companies of our members. For the purpose of this Annex, a template containing detailed structure for project description has been prepared and available information for chosen projects are presented using the same structure. Main conclusions from this field can be summarized as follows:

- The time of the big new-built pipelines in Europe is over; there is a potential for development in Russia (e.g. Eastern Gas Program), Middle East and Asia;
- "Walk the talk": Keep promises given to people involved in projects, with regards to compensation, benefits, local content, employment, etc.;
- Technical challenges can be solved; it´s a question of money and intelligence, anyway: Do not underestimate efforts and time for permitting / ESIA processes / procurement, which often bring a project on the critical path;
- A project is implemented locally; bring local people into the project company, use their special know how and domestic market intelligence;
- Strong partnership between shareholders is important - international projects with different shareholders ensure exchange of best practices and implementation of the latest technologies.

In Chapter 3, the improvements of compression process, turbo machineries, performance optimization and emissions have been analysed. Analysis is based on data on installation of 99 compressor units with total power of 1146 MW, as well as on information obtained from questionnaires within our research. The results of this analysis include the recommendations concerning basic design parameters of the compressor units, as well as possibilities for improvement of efficiency, emission reduction and enhancement of operational flexibility of the systems intended for gas transmission. This chapter includes also comparison of two basic drives of compressors used at gas transmission that is gas turbine versus electric drive. Summary and recommendations for the field of compressor technology are as follows:

- To determine the proper working area of a compressor, first of all it is necessary to identify its individual working points following expected modes of operation of the whole transmission system, in which the compressor will work;
- According to distribution of working points, it is necessary to optimize compressor performance maps; maximum efficiency of the compressor should correspond to the points where the operation is most likely to occur;
- In terms of compressor efficiency, based on analysed installations with the power within the scope of approximately 1 up to 38 MW it can be stated that the efficiency of a compressor isn´t strongly dependent on installed power (mean value is 81.6 %);
- In terms of gas turbine efficiency, based on analysed installations with power within the scope of approximately 5 up to 33 MW it can be stated that the efficiency of a gas turbine is strongly dependent on installed power (efficiency at 5MW is approximately 28 % and efficiency at 33 MW is approximately 39 %);
- If the systems serving for emission reduction (NOx and CO) are used, a design should consider limitation of working area of a compressor due to limited area, in which these system are able to ensure low emissions;
- A design should clearly take into account impact of ambient air temperature (summer/winter) on power of a gas turbine.

Chapter 4 is dedicated to optimization of transmission systems in terms of their performance. Considering the complexity of the transmission systems, hydraulic simulations are used for determination of key parameters, such as course of pressure, transmitted flow and power necessary for transmission. Within the framework of this field, we have compared the results of simulations with real data from transmission system operation for dynamic changes connected with start of compression station. Impact of the ambient air temperature and the soil temperature (where pipeline is laid) on technical capacity of a model system with compression stations has been analysed, too. In terms of optimization, we focused on reducing power necessary for gas transmission, as well as optimum distance between the compression stations. Outputs from this chapter are as follows:

- Hydraulic simulations represent a trustworthy tool for calculation of key parameters of the transmission systems and it can be stated that the results of simulations identify clearly physical nature of gas flowing not only at stationary but also at dynamic, transient statuses of a transmission network;
- To obtain necessary accuracy, it is important to know the system and to specify it technical parameters, as well as initial and boundary conditions for the hydraulic simulation itself as accurately as possible;

- When calculating maximum technical capacities, it is very important to take into account impact of ambient air temperature on gas turbine power, as the difference between the capacities of examined systems at air temperatures -20 °C versus 35 °C was approximately 9 %.
- In terms of soil temperature the difference at the temperatures of 4 °C versus 18 °C was approximately 1 % when using the same systems; such difference doesn´t represent significant impact (of course, if a pipeline is located on the seabed, this impact can be fundamental);
- In terms of optimum distance between the compression stations for 56′′ (DN1400) or 48′′ (DN1200), 100 bar system with the capacity of approximately 30 bcm/a or 20 bcm/a (assumed load factor is 0.9), this corresponds to an average distance between the compressor stations of approximately 250 km. Countries or projects where fuel gas costs are charged rather at production costs (the "lowest value principle") and, moreover, if it is possible to include any tax reliefs using market prices, shorter distances for compressor stations, e.g. 125 km could be economically viable;
- If required technical capacity of a system or nature of its operation is changed, the optimization to new conditions will be necessary. Through optimization to new conditions it is possible to obtain significant reduction of power required for transmission (by about 50 %) while maintaining relatively large technical capacity (approximately 75 %).

In the field of Public Acceptance (Chapter 5), based on experience of our members and discussions at the meetings, we defined possible aspects of gas infrastructure interaction with its vicinity in planning, construction, as well as operational phase of the project.

Planning phase of the project includes consultations and negotiations with the public, mainly with institutions, which comment, for example, the planned route of the gas pipeline. In that respect, this phase is less visible to the public, as particular authorities are responsible for the approval process.

By contrast, the construction phase itself is physically visible and can directly lead to local protests, which should stop the construction or change the gas pipeline route in given location.

In the case of operational phase, the gas pipelines have another particularity: people know they are there, but usually they are not visible. It means that many safety, operation and maintenance procedures are not noticeable, as well. In contrast to road or railway, where the public can see everything, a lot of procedures concerning a gas pipeline are not perceptible. The public often knows that someone had buried a large pipeline and just said "goodbye". The key point is to find the right way how to inform the public in a clear way. For sure, the confidence during the operation and maintenance of the system will reduce the concerns.

Public acceptance of technologies or technical construction is not easily visible; what is visible is the resistance of the public and its resistance to new infrastructure projects and their operation. As a conclusion, we can consider that gas pipelines projects require a rigid attention when managing the relationship with the stakeholders; they should start at the beginning of a project and during the operations they have to be continuously monitored. Main results from this part can be summarised as follows:

- It is necessary to ensure effective communication with the public in all areas;
- It is necessary to enhance public support of the technology and the support of authorities and politicians to the specific projects;
- To use the advantage of the first impression, it is necessary to involve the public within the planning stage;
- During the implementation of the projects, it is necessary to develop communication with the public, based on information and dialogue, in order to improve the acceptation and integration of the gas infrastructure in crossed territories;
- It is necessary to suppress or reduce as much as possible the adverse impacts of gas infrastructures on landscape, bio diversity, urbanization, archaeology and agriculture, through adopting the best practices;
- It is necessary to participate in socio-economic development of the crossed territories;
- It is necessary to engage early in local discussions about particular projects (e.g. at social networks) and present ourselves in a good manner;
- During the construction phase it is necessary to mitigate ASAP potential protests in order to avoid delays, extra costs, change of route or abandonment of the project;
- It is necessary to keep an open-minded attitude and to integrate lessons learned by other companies in order to increase professionalism of the company.

The technologies (Chapter 6) that have been taken into consideration in this report represent inevitably just a limited selection of all the technologies, which are already 'on the shelf' or under development, chosen by the members of the working groups in accordance with their interest and importance, as well as with the application of these technologies in their countries. The objective of this chapter is to provide an overview of the new technologies and their application to the transmission systems. We focused on experience concerning the implementation of new technologies including description of the technologies successfully applied in the gas transmission in the following areas:

- Safety and reliability;
- Environmental footprint reduction;
- Pipelines.

In the countries where the transmission tariffs are subject to regulations it is important that the structure of the tariffs, as defined by Regulators, can stimulate, and not hinder, the investments, namely those in technologies.

Two interesting case studies related to construction of pipelines in areas with high population density are reported in Chapter 7. The first case study concerns the construction of a new pipeline section in order to compensate the pipeline pressure losses at the end of the pipeline network in Seoul city in Korea and describes the pipeline construction in areas with heavy road traffic using welding house at underground welding joint area. The construction of the second one was challenging because it was a long and deep shield tunnel in a densely populated area and the planned line-route passed through vertically at almost the central axis of the densely inhabited district of the Tokyo metropolitan area in Japan.

Utilization of advanced techniques promotes the construction of pipelines in highly congested areas independently of offshore or onshore pipeline construction projects, and this is expected to contribute toward the expansion of efficient and reliable gas transmission networks worldwide.

The last Chapter 8 is dedicated to alternative utilization of pipelines for CO2 transmission. Carbon dioxide is one of the major greenhouse gas contributing to "Global Warming"; it has been found out that up to seventy percent of CO2 emissions come from fossil fuel power plants. Carbon Capture Transmission & Storage is a technical option, which should reduce the impact of fossil fuel use on global warming through separating CO2 from power plants flue gases and sequestrating it in proper stable geological locations (Saline aquifers) or in depleted reservoirs (oil & gas) or through using it for enhanced hydrocarbon recovery in over mature oil and gas fields. First part of the chapter summarizes technical challenges of CO2 transmission and the main European projects dealing with CO2 transmission through a pipeline. Main equations of the hydraulic simulations of CO2 transmission and the method of their solution are included in the second part of this chapter. Main outcomes in the area of utilization of pipelines for CO2 transmission are as follows:

- The chance to "re-use" existing natural gas pipeline for CO2 transmission doesn't appear to be an option because the minimum operating pressure for a dense phase carbon dioxide transmission (7.4 - 8 MPa) falls within the range of maximum operating pressure of the gas onshore networks (usually 8 MPa);
- Results of the transient simulation of the CO_2 pipelines indicate that the CO_2 mixtures from different capture technologies show different dynamic behaviour during the pipeline transmission;
- Considering the intermittency of renewable sources, it seems to be reasonable to assume variable delivery rates of CO_2 in separation plants, since the fossil fuel based power plants will have to provide necessary swing capacity;
- Therefore, detailed design of pipeline infrastructure for CO_2 sequestration should be on the premise that the flow is unsteady.

In the previous section common conclusions resulting from our work during the three-year period 2012/2015 has been mentioned; the following part will include personal conclusions of the members of working groups SG3.1. and SG3.3 addressing chosen topics from particular fields of our report.

Personal conclusion 1, study group member from Europe

In Western Europe, the installed capacities are considered as sufficient, so, except for some local interconnectors, no major developments are expected in the near future.

The situation is different in other continents such as Asia, America, Africa or Australia where increasing gas demand or connections of new sources lead to the need for new gas transmission infrastructures.

Communication with the public based on regular information and dialogue may support the acceptation and integration of the gas infrastructures in the territory. For strategic pipes, ESIA (environmental and social impact assessment) process is more and more implemented. The use of new technologies may contribute to reduction of environmental footprint, increase of safety and reliability and optimization of operational flexibility of the gas transmission system.

Due to SG 3.1 and SG 3.3 IGU reports, experiences and lessons learnt can be shared among the gas transmission companies.

Personal conclusion 2, study group member from Asia

Transmission pipeline is the main part of natural gas transmission from the gas production sites to the gas consumption areas. Therefore there have been various efforts to diversify natural gas supply routes leading from natural gas sources to the markets. Due to the decline of the indigenous Europe gas production, increase of gas import from outside Europe seems to be necessary.

A lot of new transmission projects have been surveyed and studied and it a big new project in Europe seems to be almost done apart from the fact that that new project may be caused by shale gas development.

The perception of a gas infrastructure by general public is complex because it can be affected by many factors. From the very beginning of a project, open communication and dialogue with all parties are very important. It is necessary to perform a social, risk and environment assessment; the socio-economic/cultural and health characteristics should be analysed, too.

The pipeline construction project has to meet and prepare a lot of requirements such as legal issues, risk assessment, permitting conditions, shareholder engagement, environmental issues and waste & disposal activities, etc. Stakeholder engagement program should be performed as a process between a company and its project stakeholders. It is very important to put emphasis on the fact that the benefits of a new transmission project are much greater than the short-term environmental impacts.

Personal conclusion 3, study group member from Europe

Currently, many of the major strategic pipeline infrastructure projects should to bring new gas supplies into Europe. As the European gas demand seems to have peaked now, the future major projects will likely focus on areas of economic growth like Asia & Africa.

When deciding on using of gas powered or electric powered compressor drives, the choice is likely to be heavily affected by the proximity of suitable electric power supplies. Where such a supply is readily available, electric drives are likely to be the optimal choice.

To obtain public acceptance for major new pipeline infrastructure projects, effective communication with the public and other key stakeholders is crucial.

It is important that the Transmission System Operators keep themselves up to date with the latest technological advances to allow them to operate safely and to help optimize their costs of operations.

Where it is necessary to lay new pipelines in densely populated areas, it is often not possible to use standard pipe laying techniques. Innovative ideas such as tunnelling can improve the efficiency and safety of these operations.

Personal conclusion 4, study group member from Eurasia

The company Gazprom creates new transmission capacities for gas supplies from new production regions to domestic and export markets, debottlenecks the existing gas transmission corridors and diversifies gas transmission routes.

According to different forecasts, European demand will grow moderately. There is enough pipeline capacity to meet European demand.

There are several projects to diversify import routes to Europe, i.e. the South Corridor. But most European gas pipeline projects should develop European gas transmission system according to Third package requirement. It means construction of interconnectors or bidirectional pipelines.

As regards European direction, the company Gazprom launched new gas pipeline across the Black Sea towards Turkey. This project is another real step in pursuing the Gazprom strategy to diversify the Russian natural gas supply routes.

Gas demand in Asia is growing rapidly, especially in China. Asian region is becoming the main region where gas transmission system is developing.

The strategy of the company Gazprom as a global energy company takes into account access to new promising markets. Demand for Russian gas in Asia-Pacific countries, primarily China, is highly potent.

In May 2014, contract to supply pipeline gas from Russia to China via the eastern route was signed. In full compliance with contractual obligations, Chinese consumers will receive 38 billion cubic meters of gas per year. To provide this delivery, the gas pipeline project Power of Siberia was launched in September 2014

Personal conclusion 5, study group member from Asia

Many transmission projects are mentioned in this report. The report provides a database of outline and characteristics of the pipeline projects all over the world. Various kind of new technologies are under development and these technologies can make transmission pipelines safer and more efficient. These technologies and knowledge can apply alternative utilization of the pipelines such as CO2 and Hydrogen transmission pipelines.

Personal conclusion 6, study group member from Europe

Today, new technologies are extremely important for the gas transmission sector. On the one hand, operation of the gas transmission systems in the safest, efficient and environmentally friendly way becomes increasingly important and this goal can be achieved only through implementation of new technologies.

On the other hand, many elements (e.g. market evolution, new sources, security of supply) are driving factors of transmission system extensions.

It is generally recognized that one of the main factors for the realization of the new pipelines and plants is the public acceptance by local communities.

Therefore it is very important to make everyone aware that the transmission of natural gas through pipelines is not only safe and reliable, but it respects the environment at all phases of the project, from its construction to its operation.

Moreover, the market and regulators force the transmission operators to operate the network in a more flexible way; the technology should therefore be considered as a key factor of success in the gas transmission sector.

Personal conclusion 7, study group member from Asia

Technologies have played an important role in operations and management of transmission; they should have high economic efficiency while considering a safety and reliability. These requirements has been applied to various equipment, facilities and transmission systems. Considering radical changes of the environment, the technologies will become more crucial for sustainable growth of gas industries in the future. This report provides an overview of new technologies and their applications to transmission. These new technologies, which have been gathered by Study Group and presented by technologies suppliers, will contribute to the advancement of gas industries.

Personal conclusion 8, study group member from Europe

Survey on new transmission projects has revealed that the following new projects are planned:

- It is necessary either to increase security of natural gas supply through netting the existing transmission systems into reversible multidirectional systems (Europe);
- Or to connect newly explored gas fields with consumers - urban and industrial areas and LNG plants across countries, borders and continents (rest of the world).

Quality, predictability and stability of a regulatory framework, wherever it exists, is a very important factor that supports or brakes the development of the projects.

Development of new technologies for pipeline systems is subject rather to calm evolution than to revolutionary inventions. It considers the following aspects:

- Lifetime (materials, protection, inspections);
- Safety and reliability;
- Efficiency (compressor units);
- Environmental and social impact (emissions, drilling instead of digging).

To pass through Public Acceptance successfully, it requires transparent and timely communication with all and any stakeholders. Advanced planning of a campaign has become a must; an involvement of professional PR manager is advisable.

Personal conclusion 9, study group member from Europe

There is a growing comprehension of the possibilities when designing energy requiring installations where a mix of available energy carriers is taken into consideration. Comparison of costs seems to reflect general impression/experience that operating an electric drive is less expensive than purchasing and installing an electric drive. There is a potential for Smart Grid/Energy operation, where the gas compression can play an active role. Smart Grid/Energy operation is an area where the gas industry can play a role on the way "towards a friendly planet".

Personal Conclusion 10, study group member from South America

The new technologies applied to the pipeline construction, operation and maintenance ratify them even more as an efficient and safe pillar of the transmission sector. The technological advances play a key role in the future, regarding the ever-rising rigor in environmental and social responsibility. Therefore, new technologies and stakeholder management are subjects strongly connected, considering the enhancements in safety and reliability will provide clear benefits for the society, environment and further stakeholders.

The relevant contribution of natural gas in the world energy matrix is a consensus in the market. But it's important recognize that the growth speed depends on the development of new technologies and how the players will succeed in keeping the public well informed about them, as well. This the convergence point between New Technologies and Public Acceptance.

Annexes

1. ANNEX 1 – Project characteristics of selected natural gas transmission projects
2. ANNEX 2 – GE OIL & GAS: Retrofitability of DLN/DLE systems
3. ANNEX 3 – Solar's Dry Low Emissions Technology, Capability and Experience

Annex 1: Project Characteristics of selected natural gas transmission projects

1. Poland-Czech Republic Interconnection within the North-South Corridor (STORK II)

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Poland-Czech Republic Interconnection within the North-South Corridor (STORK II)	***Project ID:***	
Sponsoring Organization:	NET4GAS, s.r.o. (CZ) / GAZ-SYSTEM S.A. (PL)	***Sponsor Representative:***	
Prepared by:	NET4GAS, s.r.o. (CZ) / GAZ-SYSTEM S.A. (PL)		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Spokesman Mr. Milan Řepka	+420 739 537 461	milan.repka@net4gas.cz
Customer / User Representative(s)	NET4GAS, s.r.o.		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The STORK II interconnector pipeline will be part of the Czech and Polish transmission system and will increase cross-border capacity between these two countries by establishing a large transportation corridor that will allow flexible transport of gas in Central Europe in direction North-South. The development of the physical interconnection between Poland and Czech Republic will contribute to reinforcement of the effective operation of the gas transmission systems, efficient gas exchange between the markets, as well as increase of the security of supply not only for Poland and Czech Republic, but also for the CEE region by enabling the supply link with the European gas market (NCG, CEGH Baumgarten, Gas Pool) and global LNG market via the Terminal in Świnoujście.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Location of the project is planned in direction Libhošť (CZ) to Hať (CZ/PL border) to Kedzierzyn (PL). Project will be bidirectional.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore project
Overall Length (km):	107 (CZ + PL)
Capacity (bcm/a):	5 – 7
Pipeline Diameter (inch):	39.37 inch (1000 mm)
Design Pressure (barg):	73.5
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

Right of way process, repeated Land Permit process, clear conditions for investment decision.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Study of environmental impact assessment (EIA) completed 2012.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Not yet applicable

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Estimated date of commissioning	2020

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Open public tenders for Design, Long Lead items and General constructor.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
	Not applicable yet.		

8. Costs / Budget

Provide the Project Budget.

Purpose	Amount
-	$ -
-	$ -
Total	$ Confidential

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Company owner	Final investment decision	NET4GAS, s.r.o.	
EU member state	Permitting, TEN-E program, 10Y national development plan	NET4GAS, s.r.o.	
Regulatory office	Regulatory issues	NET4GAS, s.r.o.	
Regional institutions	Permitting	NET4GAS, s.r.o.	
Owners/Public	General information	NET4GAS, s.r.o.	

10. Authorization process

10.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
State authorization	Ministry of industry and trade	Required by Energy Act2-3	
Regional land planning principles	Ministry of regional development	Planned pipelines are incorporated to the national spatial plan and than to the regional zoning plans	2 – 4 years
EIA	Ministry of environment	EIA statement is released after the negotiation with stakeholders by the authority	8-12
Land Permit	Ministry of regional development	Land permit is released after the negotiation with third parties	4 - 6
Building permit	Ministry of industry and trade	Building permit is released for buildings, for pipeline and other equipment is not necessary according the current law	4 - 6
Final Operational Permit	Ministry of industry and trade	After final inspection and positive statement from the authorities is released the final operational permit	2 - 3
Expropriation, Easements	*Expropriation authority*	*In case the construction is in public interest*	*6-9*
Court case	*Respective court*	*Legal recourse against the authorization*	*years*

10.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?

General information in 10Y national plan, route details are in Regional land planning principles (updated 1 x 4years), and public attention is usually initiated by EIA approval process.

b) Are there any decisional powers delegated to Public opinion?

No particular powers are delegated to Public opinion. Some influence is given to non-profit organizations and organized activists.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?

Central authority must assess relevance of appeals and decide if will be taken into consideration. If not accepted, then the risk is in situation, when appeals are transformed to court cases with impact to project timing.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes. Complicated cases can take longer. In case of court case there is no limit.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
Please see the table at 11.1.

f) Are any legal recourses admitted after an authorization act has been released?
Yes.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Participants of the process, e.g. land owners, activists. Even the term for court decision is some way given, in practice no exact limit exist, as the court decision itself can be subject of another appeal.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes.

i) If yes, can you describe an example or a real case occurred.
Project BACI, activists presented a legal recourse against already issued Land Permit for a new pipeline, after it went into legal power. They were successful and Land Permit was canceled.

11. ***List of attachments.***

Report number / ID	***Description***
http://www.net4gas.cz/en/1261/	European 10Y Network Development Plan CEE GRIP - Gas Regional Investment Plan for Central and Eastern Europe National 10Y Network Development Plan

2. Bidirectional Austrian Czech Interconnection (BACI)

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Bidirectional Austrian Czech Interconnection (BACI)	***Project ID:***	
Sponsoring Organization:	NET4GAS, s.r.o (CZ) / GAS CONNECT AUSTIRA GmbH (AT)	***Sponsor Representative:***	
Prepared by:	NET4GAS, s.r.o (CZ) / GAS CONNECT AUSTIRA GmbH (AT)		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Spokesman Mr. Milan Řepka	+420 739 537 461	milan.repka@net4gas.cz
Customer / User Representative(s)	NET4GAS, s.r.o.		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The BACI will be a new infrastructure directly connecting the Austrian and Czech market. It will be connected to the existing Czech transmission system via CS Břeclav (NET4GAS, s.r.o.) and to the Austrian transmission system via Baumgarten (GAS CONNECT AUSTRIA GmbH). The BACI will enable capacity transmission for the first time between these two member states and it will facilitate better market integration and security of gas supply also for adjacent countries like Hungary, Poland, Germany, Italy, France, Slovenia, Croatia and Slovakia due to the creation of additional transportation opportunities. The project will also increase the overall flexibility of the Czech, Austrian and also Polish system by diversification of gas supply routes and by connecting UGS in the Czech Republic and Austria.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Location of the project is planned in direction Břeclav (CZ) to Reinthal (CZ/AT border) to Baumgarten (AT). Project will be bidirectional.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore project
Overall Length (km):	appr. 58 (CZ + AT)
Capacity (bcm/a):	6.5 – 8.3
Pipeline Diameter (inch):	31.5 inch (800 mm)
Design Pressure (barg):	73.5
No. of Compressor stations (CS):	1 (in AT)
Installed power (total, each CS – MW):	24 (in AT)
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

Right of way process, Land Permit process, clear conditions for investment decision.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

This project is a below limit intent of point 3.7. category 1, of appendix no. 1 of Act no. 100/2001 Coll., on environmental impact assessment and amending some associated act, as amended.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Not yet applicable

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Estimated date of commissioning	2019

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Open public tenders for Design, Long Lead items and General constructor.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	***Description***	***Need by Date***	***Procurement Strategy***
	Not applicable yet.		

8. Costs / Budget

Provide the Project Budget.

Purpose	**Amount**
-	$ -
-	$ -
Total	$ Confidential

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	**Information Needed**	**Source / Provider**	**Timing**
Company owner	Final investment decision	NET4GAS, s.r.o.	
EU member state	Permitting, TEN-E program, 10Y national development plan	NET4GAS, s.r.o.	
Regulatory office	Regulatory issues	NET4GAS, s.r.o.	
Regional institutions	Permitting	NET4GAS, s.r.o.	
Owners/Public	General information	NET4GAS, s.r.o.	

10. Authorization process

10.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	**Competent authority**	**Description**	**Months**
State authorization for gas pipeline construction	Ministry of industry and trade	Required by Energy Act	2-3
Regional land planning principles	Ministry of regional development	Planned pipelines are incorporated to the national spatial plan and than to the regional zoning plans	2 – 4 years
EIA	Ministry of environment	EIA statement is released after the negotiation with stakeholders by the authority	8-12
Land Permit	Ministry of regional	Land permit is released after the	4 - 6

	development	negotiation with third parties	
Building permit	Ministry of industry and trade	Building permit is released for buildings, for pipeline and other equipment is not necessary according the current law	4 - 6
Final Operational Permit	Ministry of industry and trade	After final inspection and positive statement from the authorities is released the final operational permit	2 - 3
Expropriation, Easements	*Expropriation authority*	*In case the construction is in public interest*	*6-9*
Court case	*Respective court*	*Legal recourse against the authorization*	*years*

10.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
General information in 10Y national plan, route details are in Regional land planning principles (updated 1 x 4years), and public attention is usually initiated by EIA approval process.

b) Are there any decisional powers delegated to Public opinion?
No particular powers are delegated to Public opinion. Some influence is given to non-profit organizations and organized activists.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Central authority must assess relevance of appeals and decide if will be taken into consideration. If not accepted, then the risk is in situation, when appeals are transformed to court cases with impact to project timing.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes. Complicated cases can take longer. In case of court case there is no limit.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
Please see the table at 11.1.

f) Are any legal recourses admitted after an authorization act has been released?
Yes.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.

Participants of the process, e.g. land owners, activists. Even the term for court decision is some way given, in practice no exact limit exist, as the court decision itself can be subject of another appeal.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes.

i) If yes, can you describe an example or a real case occurred.
Project BACI, activists presented a legal recourse against already issued Land Permit for a new pipeline, after it went into legal power. They were successful and Land Permit was canceled.

11. ***List of attachments.***

Report number / ID	***Description***
http://www.net4gas.cz/en/1261/	European 10Y Network Development Plan CEE GRIP - Gas Regional Investment Plan for Central and Eastern Europe National 10Y Network Development Plan

3. Connection to Oberkappel

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Connection to Oberkappel	***Project ID:***	
Sponsoring Organization:	NET4GAS, s.r.o. (CZ) / potential partner in Austria (in discussion)	***Sponsor Representative:***	
Prepared by:	NET4GAS, s.r.o. (CZ) / potential partner in Austria (in discussion)		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Spokesman Mr. Milan Řepka	+420 739 537 461	milan.repka@net4gas.cz
Customer / User Representative(s)	NET4GAS, s.r.o.		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The project will interconnect the existing transmission pipelines in the Czech Republic with AT/DE border at Oberkappel. It will be the first interconnection between these states and it will be connected to Penta West as well as WAG pipeline (AT) and to the Southern branch of the N4G transmission system (CZ). Connection to Oberkappel is a part of the "5 Gas-market Link - 5GL" of the partners Tauerngasleitung GmbH (AT), Bayernets GmbH (DE), Plinovodi s.r.o. (SLO) and NET4GAS, s.r.o. (CZ). As part of the 5GL Project the Oberkappel project would be interconnected indirectly also to the TGL pipeline project, the storages 7Fields and Haidach (AT) as well as to the gas grid in Southern Germany at Haiming/Burghausen.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Location of the project is planned in direction the South Bohemia region (CZ) to Upper Austria, District Rohrbach (AT) to Oberkappel (AT). Project will be bidirectional.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore project
Overall Length (km):	appr. 110 (depending on the final route design, CZ+AT)
Capacity (bcm/a):	appr. 2 – 3
Pipeline Diameter (inch):	appr. 31.5 inch (800 mm)
Design Pressure (barg):	73.5
Installed power (total, each CS – MW):	appr. 2 – 5
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

Right of way process, Land Permit process, clear conditions for investment decision.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Under development.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Not yet applicable

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Estimated date of commissioning	2020-2022

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Open public tenders for Design, Long Lead items and General constructor.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
	Not applicable yet.		

8. Costs / Budget

Provide the Project Budget.

Purpose	Amount
-	$ -
-	$ -
Total	$ Confidential

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Company owner	Final investment decision	NET4GAS, s.r.o.	
EU member state	Permitting, TEN-E program, 10Y national development plan	NET4GAS, s.r.o.	
Regulatory office	Regulatory issues	NET4GAS, s.r.o.	
Regional institutions	Permitting	NET4GAS, s.r.o.	
Owners/Public	General information	NET4GAS, s.r.o.	

10. Authorization process

10.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
State authorization	Ministry of industry and trade	Required by Energy Act2-3	
Regional land planning principles	Ministry of regional development	Planned pipelines are incorporated to the national spatial plan and than to the regional zoning plans	2 – 4 years
EIA	Ministry of environment	EIA statement is released after the negotiation with stakeholders by the authority	8-12
Land Permit	Ministry of regional development	Land permit is released after the negotiation with third parties	4 - 6
Building permit	Ministry of industry and trade	Building permit is released for buildings, for pipeline and other equipment is not necessary	4 - 6

		according the current law	
Final Operational Permit	Ministry of industry and trade	After final inspection and positive statement from the authorities is released the final operational permit	2 - 3
Expropriation, Easements	*Expropriation authority*	*In case the construction is in public interest*	*6-9*
Court case	*Respective court*	*Legal recourse against the authorization*	*years*

10.2. ***Information to Public / Public Debate / Debat public***

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
General information in 10Y national plan, route details are in Regional land planning principles (updated 1 x 4years), and within EIA approval process.

b) Are there any decisional powers delegated to Public opinion?
No particular powers are delegated to Public opinion.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Central authority must assess relevance of appeals and decide if will be taken into consideration. If not accepted, then the risk is in situation, when appeals are transformed to court cases with impact to project timing.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes. Complicated cases can take longer. In case of court case there is no limit.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
Please see the table at 11.1.

f) Are any legal recourses admitted after an authorization act has been released?
Yes.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Participants of the process, e.g. land owners, activists. Even the term for court decision is some way given, in practice no exact limit exist, as the court decision itself can be subject of another appeal.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes.

i) If yes, can you describe an example or a real case occurred.
Project BACI, activists presented a legal recourse against already issued Land Permit for a new pipeline, after it went into legal power. They were successful and Land Permit was canceled.

11. *List of attachments.*

Report number / ID	***Description***
http://www.net4gas.cz/en/1261/	European 10Y Network Development Plan CEE GRIP - Gas Regional Investment Plan for Central and Eastern Europe National 10Y Network Development Plan

4. SK-HU Interconnector DN800

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	SK-HU Interconnector DN800	***Project ID:***	SK-HU Interconnector
Sponsoring Organization:	eustream, a.s.	***Sponsor Representative:***	***Rastislav Ňukovič***
Prepared by:	Vladimír Olej *Vladimir.Olej@eustream.sk*		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Rastislav Ňukovič		
Program Manager	Michal Ľalík	+421262507320	*Michal.Lalik@eustream.sk*
Project Manager	Vladimír Urban		
Customer / User Representative(s)	Ján Janus		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The Project aims at establishing a new bi-directional high pressure (75 bar) gas interconnection between the gas transmission system in Slovakia (at Veľké Zlievce) and Hungary (at Vecsés) – see fig. No.1. The length of this new interconnection will be approximately 111 km (of which 19 km in Slovakia). Investor of the Slovak subproject is eustream, a.s. (EUS, http://www.eustream.sk) and the investor of the Hungarian subproject is Magyar Gáz Tranzit Zrt.(MGT, http://www.gaztranzit.hu).

The maximum technical capacities are going to be 12 MCM/D in direction from Slovakia to Hungary and 4.8 MCM/D in direction from Hungary to Slovakia after the first phase of project accomplishment. The second phase of the project depends on the future demand regarding the transmission capacity in direction from Hungary to Slovakia and it is connected with addition of the compressor units at compressor station Szada (Hungary). The technical capacity after accomplishment of the second phase is 12 MCM/D in both directions.

This Project will contribute to increasing the security of supply in the region and in particular in Hungary and Slovakia by enabling solidarity cross-border actions in case of gas crisis, as well as the diversification of gas supply sources (via the Adria LNG terminal in Croatia and Świnoujście LNG terminal in Poland). The Project will also contribute to the implementation of the North-South gas corridor (Fig. No.2).

Fig. No.1 Main scheme of the interconnector

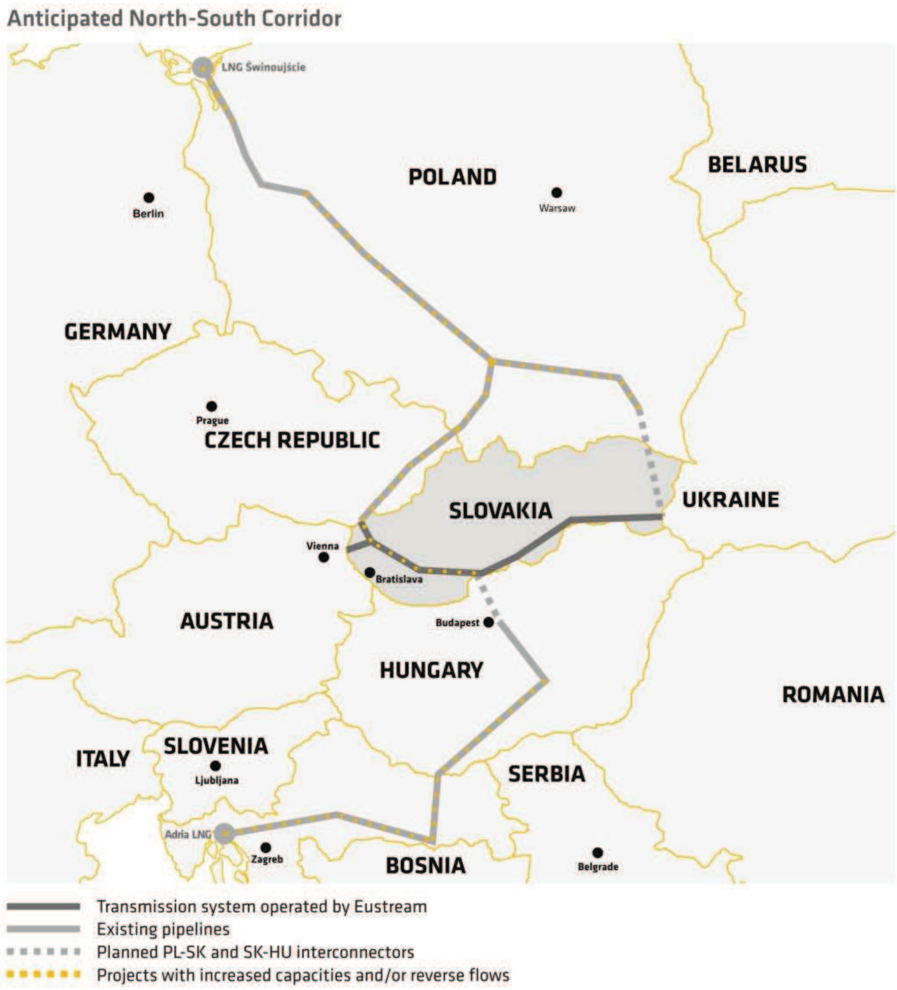


Fig. No.2 Overall picture of the North-South gas corridor

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Scope of the Slovak subproject is to construct:

- 19 km pipeline between the existing compressor station Veľké Zlievce and the Ipeľ River Crossing Section at the Slovakia-Hungary border.
- Ball Valve Station Slovenské Ďarmoty.
- Cathodic Protection Station close to Slovakia-Hungary border.

Scope of the Hungarian subproject is to construct:

- 92 km pipeline on the Hungarian side including the Ipeľ River Crossing Section at the Slovakia-Hungary border.
- New compressor Station at Szada.
- Balassagyarmat Metering Station for both countries.
- Two Ball Valve Stations Romhány and Rád.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	19 km (Slovak part) + 92 km (Hungarian part)
Capacity (bcm/a):	4
Pipeline Diameter (inch):	32" (DN800)
Design Pressure (barg):	75
Steel grade (X70/X80 etc.):	X70 (L485MB)
Transit Countries:	Slovak Republic, Hungary
Highest point of pipeline (m MSL):	326,4 m
Deepest point of pipeline (mMSL):	118,3 m
No. of Compressor stations (CS):	1 existing (Slovak part), new one (Hungarian part)
Installed power (total, each CS – MW):	112 MW (EUS), 3.5 + 3.5 MW (MGT)
Distance between CS (km):	84 km

Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.

3.4. *Constraints*

List the project constraints identified in the Project

1. NATURA 2000 protected area Poiplie – special conditions for construction works.
2. Ipeľ River Crossing Section – need to move the pipeline route and implement the section with Horizontal Directional Drilling after the Environmental Impact Assessment.
3. Archeological findings in the Kiarov locality – findings from the Stone Age.

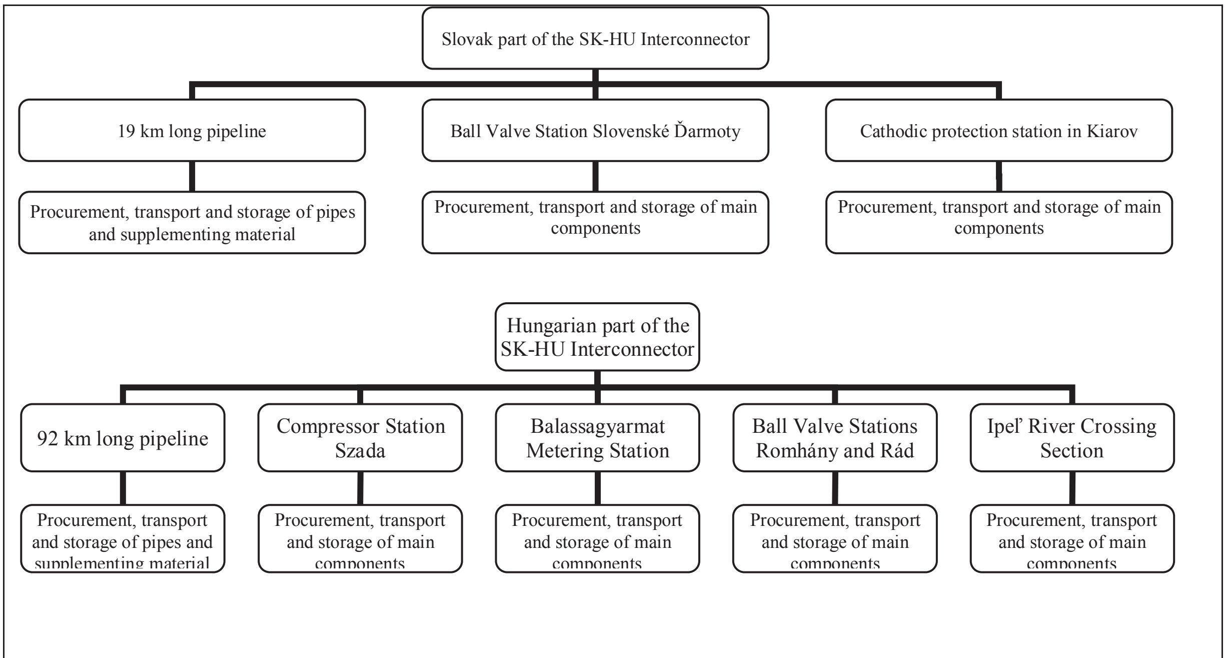
3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

1. Environmental Impact Assessment performed between 2009 and 2010.
2. The main environmental impacts are: steel pipes production and vegetation removal.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.



5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Milestones of the Slovak part	Estimated Date
1. Environmental Impact Assessment	August 2010
2. Building permit	March 2012
3. Procurement	November 2012
4. Start of construction works	January 2013
5. Completion of the entry-exit interconnection point at Compressor Station Veľké Zlievce	August 2013
6. Completion of pipeline and its interconnection with the Ipeľ River Crossing Section	November 2013
7. Completion of telemetry and control systems	February 2014
8. Completion and handover of the construction	March 2014
9. Test operation	April/July - December 2014
10. Commercial operation	January 2015

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

The main contracting strategy in Slovakia was to split the supplies to more specific suppliers and by that way to optimize the construction costs. The results of the tenders have proved that it was a right decision because there was a high competition in the tender for construction works and the overall result was excellent. The cost of material deliveries were also optimized by that way.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
1	Engineering works	05/2012	Direct order to engineering Engineering company based on Framework Contract.
2	Pipe material supplies	03/2013	The selection was done according to the Slovak Public Procurement Act with use of the method Negotiated procedure with publication. For qualification of the bidders the C4GAS (F) qualification systems was used. Criterion for evaluation of the bid was the price 100%.
3	Construction works and pipe material supplies up to 24"	03/2013-02/2014	The selection was done according to the Slovak Public Procurement Act with use of the method Negotiated procedure with publication. Criterion for evaluation of the bid was the price 100%. Final order was determined by e-auction with participation of 7 bidders. Criterion for evaluation of the bid was the price 100%.
4	Border river Ipel' crossing section (at the border in between Slovakia and Hungary).	06/2013-02/2014	EUS signed the contract directly with MGT upon General agreement on pipeline construction. MGT´s EPC contractor company was selected by MGT in the open public tender for Engineering, Planning and Construction of the

			interconnector pipeline on the Hungarian side.

8. Costs / Budget

Provide the Project Budget.

Slovak part of the SK-H Interconnector	21 mil. EUR (investment plan)
Hungarian part of the SK-H Interconnector	171 mil. EUR (investment plan)
Total	192 mil. EUR

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
EUS	Construction/Operation	MGT	continuous
MGT	Construction/Operation	EUS	continuous
European Commission	Union financial grant	EUS / MGT	continuous

10. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

10.1. Support of general public to the technology	
Strategy	Eustream's strategy was to establish and maintain good relations with land users and land owners.
Action points	EUS informed land users and land owners about open issues.
Lessons learned	EUS benefited from good communication with land users and land owners by increasing their helpfulness.

10.2. Support of authorities and politicians to the project	
Strategy	To keep high level of interest of authorities to the project and try to gain incentives (regulatory/financial) for the project from the state/EC.
Action points	Project of the SK-HU Pipeline Interconnector has from the beginning strong support on the political level in both countries. This is moreover underlined by the fact, that Hungarian project party, MGT, is fully state owned company. Strong political support to the project has been endorsed by signature of the Intergovernmental agreement between governments of Hungary and Slovak republic in early 2011. Due to its importance from the regional point of view, the project has also strong support from the European Commission. The Interconnector creates a backbone of the so called North-South Corridor which is a highly important set of infrastructure projects with strategic aim in endorsing of the security of supply to the countries in the Central and Central-East Europe. In the 2010, the project of SK-HU Pipeline

	Interconnector has been supported by financial grant of 30 mil.EUR from the European Energy Programme for Recovery and being shortlisted on the EU Project for Common interest.
Lessons learned	Support from politicians and authorities can have a significant impact on FID and implementation.

10.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	Eustream's strategy was and is to inform the public through press releases, articles and information tables installed at the construction site about the project implementation necessity for its security of supply importance.
Action points	Continuously issuing press releases, articles in natural gas industry oriented magazines and installation of information tables at the construction site.
Lessons learned	Informing the public is beneficial for land users, land owners and other involved citizens.

10.4. Local discussions about / against project (e.g. at social networks)	
Strategy	Eustream's strategy was to help the process of public discussions with hosting a meeting with local citizens.
Action points	EUS hosted a discussion with local citizens at the Compressor Station Veľké Zlievce as part of the Zoning and Building permit proceedings.
Lessons learned	Discussions with public prior to construction start allow the investor to learn about citizen's concerns and desires.

10.5. Mitigation of the protests during permitting, planning and construction phase	
Strategy	Eustream's strategy was to deal with potential problems according to valid laws.
Action points	No protest arose during the permitting, planning and construction phase.

11. Authorization process

11.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
Certification of	Ministry of Economy of	Certificate of compliance of	2

compliance of investment plan.	the Slovak Republic	investment plan with the long-term Energy Policy concept of the Slovak Republic.	
Environmental Impact Assessment – EIA.	Ministry of Environment of the Slovak Republic	EIA is one of the main instruments of international environmental policy of sustainable development.	12
Statement of situating the construction.	local municipal office	Statement that is expressing all minor statements of institutions and people affected by the construction.	4
Permanent exemption of soil from the soil fond.	local district land office	Permanent change of the land use from agricultural to non-agricultural after purchasing the land from land owners.	3
Temporary exemption of soil from the soil fond.	local district land office	Temporary change of the land use from agricultural to non-agricultural for 1 year after getting agreements from the land users.	3
Permanent exemption of soil from the forest fond.	local district forest office	Permanent change of the land use from forest to non-forest area.	3
Building permission.	local municipal office	Permission that is expressing all minor statements of institutions affected by the construction.	4
Registration of the land burden.	local cadaster office	The gas pipeline route crosses parcels and this has to be written on the parcel ownership lists.	2

11.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
The information to public occurs in the authorization process of issuing the statement of situating the construction.

b) Are there any decisional powers delegated to Public opinion?
There are no decisional powers delegated to the public opinion, but the public opinion has to be considered in the authorization process.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Yes, the competent central authority can ignore them in final authorization.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes, they are defined by law and respected by authorities.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
The maximum allowable time for releasing/rejecting an authorization is 60 days prior to the delivery of the application form with all necessary annexes.

f) Are any legal recourses admitted after an authorization act has been released?
Legal recourses are admitted after authorization act has been released.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Legal recourses can be only admitted in the period of 15 days after the authorization act has been released and delivered to all participants of the authorization process. The usual length of resolution of such legal recourses is 30 days after delivery.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes, it is possible to present a legal recourse against the authorization itself.

i) If yes, can you describe an example or a real case occurred.
Example: A legal recourse against the authorization itself can be presented only if a person/local authority/stakeholder did not give up this right in the authorization process. The appeal shall be delivered within the prescribed period of 15 days from receipt of the authorization decision and has the effect of suspending the contested decision. This means that the act decided by the administrative authority in the decision cannot be made (e.g. felling of trees in the route of the pipeline) until a review of the appeal and the issuing of a final statement.

12. Risk Management

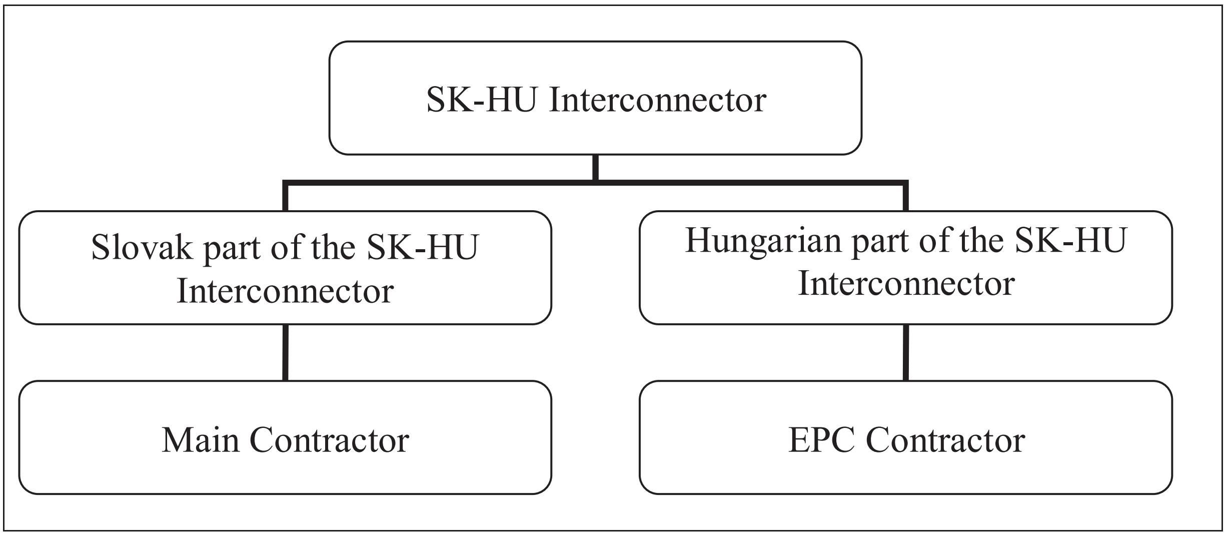
Either provide the Risk Management Plan information here or provide a reference to the project's Risk Management Plan. Identify the risks to the project's success, including the probability of their occurrence, level of impact, and a brief description of the Mitigation and / or Contingency Strategy for each.

#	***Description***	***Probability 1= low 5 = high***	***Impact 1= low 5 = high***	***Mitigation / Contingency Strategy***
1	Procurement of materials and works	2	3	Creating transparent tender rules and discussions with participants for the tender for works in the first stages of the tender.
2	Delay of material deliveries	2	3	Intensive communication with suppliers.
3	Delay of construction works	3	4	Intensive communication with the contractor for works.

13. Project Organization

13.1. *Project Organization Chart*

Provide the organization chart from the Project Charter and any changes to it. The project's organization chart begins with the project sponsor and includes all project stakeholders.



13.2. *Roles & Responsibilities*

Describe the Roles and Responsibilities of all project stakeholders identified for this project.

Stakeholder Title	Name	Roles & Responsibilities
Slovak Investor	EUS	Permitting procedure, procurement of main components, performing hot welds
Slovak Contractor	BMS Bojnanský, s.r.o.	Procurement of supplementing materials and performing of works
Hungarian Investor	MGT	Investor of the Hungarian subproject
Hungarian Contractor	OLAJTERV (OTF)	EPC Contractor of the Hungarian subproject including Ipeľ River Crossing Section at the Slovakia-Hungary border.

5. GAZELLE project

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	GAZELLE project	***Project ID:***	
Sponsoring Organization:	NET4GAS, s.r.o. (CZ)	***Sponsor Representative:***	
Prepared by:	NET4GAS, s.r.o. (CZ)		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Spokesman Mr. Milan Řepka	+420 739 537 461	milan.repka@net4gas.cz
Customer / User Representative(s)	NET4GAS, s.r.o.		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The project creates together with the projects Nord Stream and Opal the so called Northern Route for Russian gas supplies to Europe and it has important influence on increasing security of supply through the diversification of gas routes

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

This new route connects the Czech Republic to Russian gas supplies coming into Europe by the "Northern Route" - i.e. the Nord Stream pipeline running along the bed of the Baltic from Russia to Greifswald, Germany. This then connects to the OPAL pipeline, which runs as far as the village of Brandov on the German-Czech border. In the place is OPAL pipeline connected to Gazelle pipeline, which runs through territory of the Czech republic to Waidhaus, Germany.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore project

Overall Length (km):	160
Capacity (bcm/a):	30
Pipeline Diameter (inch):	56
Design Pressure (barg):	84
Steel grade (X70/X80 etc.):	X70
Transit Countries:	N/A
No. of Compressor stations (CS):	N/A
Installed power (total, each CS – MW):	N/A
Distance between CS (km):	N/A
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

Right of way process, Land Permit process, clear conditions for investment decision.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Study of Environmental Impact Assessment (EIA).

4. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Date of commissioning	January 2013

5. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Open public tenders for Design, Long Lead items and General constructor.

6. Costs / Budget

Provide the Project Budget.

Purpose	Amount
	$
	$
Total	$ 500 M

7. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Company owner	Final investment decision	NET4GAS, s.r.o.	
EU member state	Permitting, TEN-E program, 10Y national development plan	NET4GAS, s.r.o.	
Regulatory office	Regulatory issues	NET4GAS, s.r.o.	
Regional institutions	Permitting	NET4GAS, s.r.o.	
Owners/Public	General information	NET4GAS, s.r.o.	

8. Authorization process

8.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
State authorization	Ministry of industry and trade	Required by Energy Act	2-3
Regional land planning principles	Ministry of regional development	Planned pipelines are incorporated to the national spatial plan and than to the regional zoning plans	2 – 4 years
EIA	Ministry of environment	EIA statement is released after the negotiation with stakeholders by the authority	8-12
Land Permit	Ministry of regional development	Land permit is released after the negotiation with third parties	4 - 6
Building permit	Ministry of industry and trade	Building permit is released for buildings, for pipeline and other equipment is not necessary according the current law	4 - 6
Final Operational Permit	Ministry of industry and trade	After final inspection and positive statement from the authorities is released the final operational permit	2 - 3
Expropriation, Easements	*Expropriation authority*	*In case the construction is in public interest*	*6-9*
Court case	*Respective court*	*Legal recourse against the*	*years*

		authorization	

8.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
General information in 10Y national plan, route details are in Regional land planning principles (updated 1 x 4years), and public attention is usually initiated by EIA approval process.

b) Are there any decisional powers delegated to Public opinion?
No particular powers are delegated to Public opinion. Some influence is given to non-profit organizations and organized activists.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Central authority must assess relevance of appeals and decide if will be taken into consideration. If not accepted, then the risk is in situation, when appeals are transformed to court cases with impact to project timing.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes. Complicated cases can take longer. In case of court case there is no limit.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
Please see the table at 11.1.

f) Are any legal recourse admitted after an authorization act has been released?
Yes.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Participants of the process, e.g. land owners, activists. Even the term for court decision is some way given, in practice no exact limit exist, as the court decision itself can be subject of another appeal.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes.

i) If yes, can you describe an example or a real case occurred.

Project BACI, activists presented a legal recourse against already issued Land Permit for a new pipeline, after it went into legal power. They were successful and Land Permit was canceled.

9. ***List of attachments.***

Report number / ID	***Description***
http://www.net4gas.cz/en/1261/	European 10Y Network Development Plan CEE GRIP - Gas Regional Investment Plan for Central and Eastern Europe National 10Y Network Development Plan

6. Capacity Expansion Ellund-Egtved

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Capacity Expansion Ellund-Egtved	***Project ID:***	Froeslev – Egtved II
Sponsoring Organization:	EU and Energinet.dk	***Sponsor Representative:***	Peter A. Hodal and Ivar Albertsen (Energinet.dk)
Prepared by:	Paddy Krishnaswamy (Energinet.dk)		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Vice President Gas Division, Peter A. Hodal, Energinet.dk	+45 44 87 33 80	PAH@energinet.dk
Program Manager	Head of Project Dept., Anette B. Skibsted Soerensen. Energinet.dk	+45 44 87 33 30	ABS@energinet.dk
Project Manager	Chief Project Manager, Nina F. Vendelboe, Energinet.dk	+45 44 87 33 39	NIV@energinet.dk
Customer / User Representative(s)	Head of Gas Transmission Dept., Per S. Jakobsen, Energinet.dk	+45 76 22 47 85	PSJ@energinet.dk
Other	N/A		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

Construction of a second pipeline from the Danish/German border to the base at Egtved (in Denmark) parallel to the existing pipeline. The pipeline diameter is 30” and length is approximately 94 km.

This new transmission pipeline is named Froeslev - Egtved II.

The pipeline will form part of the gas transmission system and supply gas from the German gas system to Denmark in order to ensure the gas supply to the Danish market once the reserves in the North Sea in the future will be insufficient.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

See 3.1.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	93.3
Capacity (bcm/a):	6
Pipeline Diameter (inch):	30
Design Pressure (barg):	80
Steel grade (X70/X80 etc.):	L485MB or APL 5L X70
Transit Countries:	Denmark and Germany
Highest point of pipeline (m MSL):	75
Deepest point of pipeline (mMSL):	2
No. of Compressor stations (CS):	See questionnaire on "Compressor stations".
Installed power (total, each CS – MW):	See questionnaire on "Compressor stations".
Distance between CS (km):	See questionnaire on "Compressor stations".
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

N/A

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

- Environmental (and Social) Impact Assessment (EIA) including two public hearing processes prior to start of construction works carried out under the auspices of Environment Centre Odense under the Danish Ministry of the Environment.
- During construction the impact on nature was minimized by suitable route selection and reducing working area from 22m to 14m when passing plantations and forests.
- Requirement and approval by Energinet.dk of manual from pipeline constructor outlining procedures, precautions and guidelines to protect the environment during construction works.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

See answer to 5.

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
EIA approval	Ultimo 2010
Design completed	June 2011
Procurement of pipes	March 2012
Construction completed	December 2012
Initialization of operation	May 2013

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Separate EU Tenders for pipes and pipeline construction respectively.

Pre-qualification, Tender, Negotiation meetings, Tenders evaluated based on principle of "best value for money".

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
Line Pipes and Bends		March 2012	See 6.
Gas Pipeline Construction Works		December 2012	See 6.

8. Costs / Budget

Provide the Project Budget.

Purpose	Amount
N/A	$
N/A	$
Total	98 Million EUR

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Danish Ministry of the Environment	EIA	Environment Centre Odense (ECO) and Energinet.dk	1½ years prior to start of construction works
General public	Two public Hearings	Energinet.dk	Part of EIA process
General public	Project information	Newsletters from Energinet.dk	During construction works.
General public	Site visit	Organized visits/ Energinet.dk	During construction works.

10. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

10.1. Support of general public to the technology	
Strategy	Openness and information
Action points	Public hearings, newsletters and site visits
Lessons learned	Professional communication is a must.

10.2. Support of authorities and politicians to the project	
Strategy	N/A

10.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	See 10.1.

10.4. Local discussions about / against project (e.g. at social networks)	
Strategy	See 10.1.

10.5. Mitigation of the protests during permitting, planning and construction phase	
Strategy	See 9 and 10.1

11. Authorization process

11.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
EIA approval	Environment Centre Odense	Environmental conditions of importance for the construction	12 to 18

		phase as well as during operation of the pipeline system.	
Construction permit	National Working Environment Authority	Permission to construct the pipeline.	N/A

11.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
EIA

b) Are there any decisional powers delegated to Public opinion?
Public hearings, evaluation of request and oppositions.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Not ignore, response required and reject is possible

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
No upper time limit.

f) Are any legal recourses admitted after an authorization act has been released?
No.

g) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
No.

12. Risk Management

Either provide the Risk Management Plan information here or provide a reference to the project's Risk Management Plan. Identify the risks to the project's success, including the probability of their occurrence, level of impact, and a brief description of the Mitigation and / or Contingency Strategy for each.

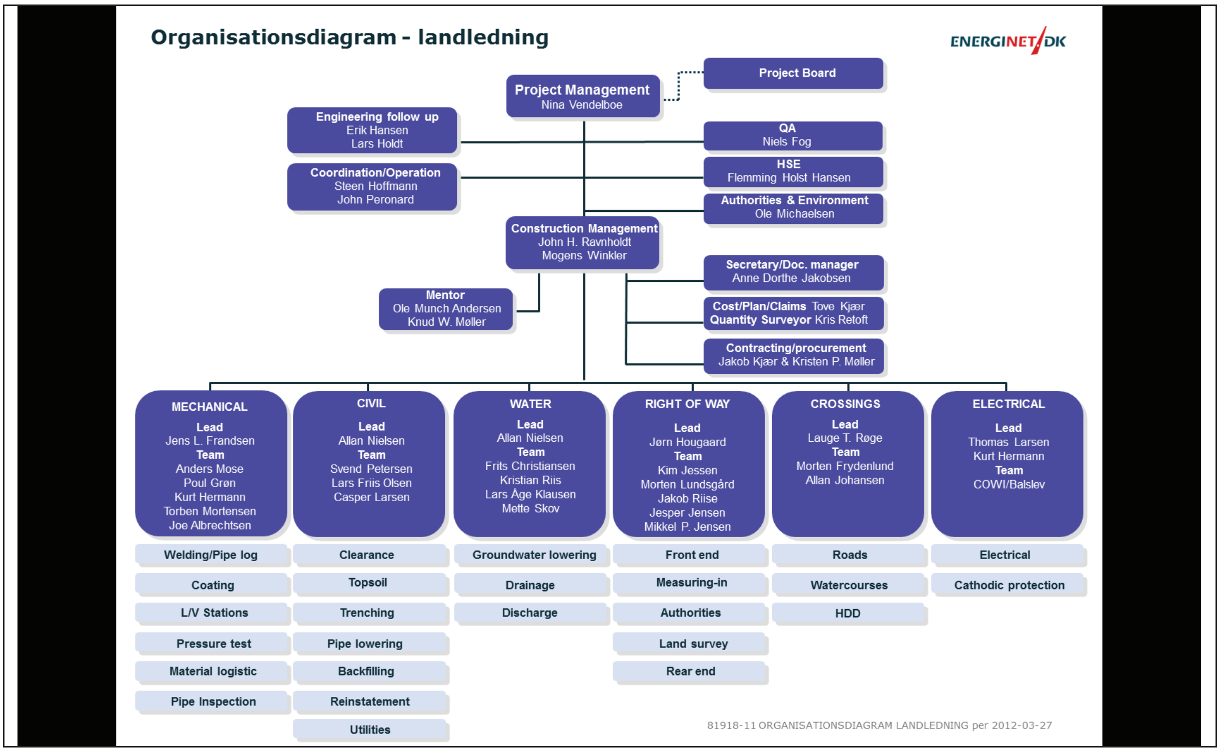
#	*Description*	*Probability 1= low 6 = high*	*Impact 1= low 6 = high*	*Mitigation / Contingency Strategy*
1	Weather conditions delay construction work	3	5	4 week float in time schedule; constant communication between Energinet.dk and pipeline constructor.

2	All necessary General permits not available.	3	5	Ongoing monitoring based on overview lists and expected dates of availability.
3	Delivered product is not according to specifications.	3	5	N/A

13. Project Organization

13.1. *Project Organization Chart*

Provide the organization chart from the Project Charter and any changes to it. The project's organization chart begins with the project sponsor and includes all project stakeholders.



7. Moravia

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Moravia	***Project ID:***	
Sponsoring Organization:	NET4GAS, s.r.o.	***Sponsor Representative:***	
Prepared by:	NET4GAS, s.r.o.		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Spokesman Mr. Milan Řepka	+420 739 537 461	milan.repka@net4gas.cz
Customer / User Representative(s)	NET4GAS, s.r.o.		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The Moravia pipeline will be a part of the Czech intrastate transmission system (connection to system via CS Břeclav). The project will secure the exit capacity for the North Moravia Region, where the current system does not have any redundancy and is not able to cover gas demand during winter period without UGS. The current system was not designed for further expansion of the distribution grid, industry and UGS facilities. The project will connect and increase flexibility of utilization of new withdrawal capacities of UGS located in the North and South Moravia to the existing system. The Moravia pipeline also enable the possible transition of the North Moravian industrial zone to low-emission combustion technology (from coal to gas).

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Location of the project is planned in direction Tvrdonice (CZ) – Libhošť (CZ).

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore project

Overall Length (km):	155
Capacity (bcm/a):	3.3 – 4.4
Pipeline Diameter (inch):	35.43 – 47.24 inch (900 – 1200 mm)
Design Pressure (barg):	73.5
No. of Compressor stations (CS):	0
Installed power (total, each CS – MW):	0
Distance between CS (km):	0
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

Right of way process, Land Permit process, clear conditions for investment decision.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Study of environmental impact assessment (EIA) completed 2012.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Not yet applicable

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Estimated date of commissioning	2018

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Open public tenders for Design, Long Lead items and General constructor.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
	Not applicable yet.		

8. Costs / Budget

Provide the Project Budget.

Purpose	Amount
-	$ -
-	$ -
Total	$ Confidential

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Company owner	Final investment decision	NET4GAS, s.r.o.	
EU member state	Permitting, TEN-E program, 10Y national development plan	NET4GAS, s.r.o.	
Regulatory office	Regulatory issues	NET4GAS, s.r.o.	
Regional institutions	Permitting	NET4GAS, s.r.o.	
Owners/Public	General information	NET4GAS, s.r.o.	

10. Authorization process

10.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
State authorization	Ministry of industry and trade	Required by Energy Act2-3	
Regional land planning principles	Ministry of regional development	Planned pipelines are incorporated to the national spatial plan and than to the regional zoning plans	2 – 4 years
EIA	Ministry of environment	EIA statement is released after the negotiation with stakeholders by the authority	8-12
Land Permit	Ministry of regional development	Land permit is released after the negotiation with third parties	4 - 6
Building permit	Ministry of industry and trade	Building permit is released for buildings, for pipeline and other equipment is not necessary according the current law	4 - 6

Final Operational Permit	Ministry of industry and trade	After final inspection and positive statement from the authorities is released the final operational permit	2 - 3
Expropriation, Easements	*Expropriation authority*	*In case the construction is in public interest*	*6-9*
Court case	*Respective court*	*Legal recourse against the authorization*	*years*

10.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
General information in 10Y national plan, route details are in Regional land planning principles (updated 1 x 4years), and public attention is usually initiated by EIA approval process.

b) Are there any decisional powers delegated to Public opinion?
No particular powers are delegated to Public opinion. Some influence is given to non-profit organizations and organized activists.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Central authority must assess relevance of appeals and decide if will be taken into consideration. If not accepted, then the risk is in situation, when appeals are transformed to court cases with impact to project timing.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes. Complicated cases can take longer. In case of court case there is no limit.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
Please see the table at 11.1.

f) Are any legal recourse admitted after an authorization act has been released?
Yes.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Participants of the process, e.g. land owners, activists. Even the term for court decision is some way given, in practice no exact limit exist, as the court decision itself can be subject of another appeal.

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes.

i) If yes, can you describe an example or a real case occurred.
Project BACI, activists presented a legal recourse against already issued Land Permit for a new pipeline, after it went into legal power. They were successful and Land Permit was canceled.

11. ***List of attachments.***

Report number / ID	***Description***
http://www.net4gas.cz/en/1261/	European 10Y Network Development Plan CEE GRIP - Gas Regional Investment Plan for Central and Eastern Europe National 10Y Network Development Plan

8. Eridan

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Eridan	***Project ID:***	
Sponsoring Organization:	GRTgaz	***Sponsor Representative:***	Thierry Trouvé
Prepared by:	Gaëtan Quesnel		

2. Key Stakeholders: *List the principal project stakeholders, if possible.*

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	GRTgaz		
Program Manager	Thierry Trouvé: Managing Director of GRTgaz	01 55 66 40 10	Thierry.trouve@grtgaz.com
Project Manager	Georges Seimandi: Project Director	04 91 28 33 17	georges.seimandi@grtgaz.com
Customer / User Representative(s)	La CRE (regulator)		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

Eridan is the name of a 220 km pipeline project in the south-east of France that crosses four departments.
It responds to the need to develop the capacity to transport natural gas between south and north. Particular, it will transport natural gas from the LNG terminal in Fos-sur-Mer (Bouches du Rhone). Facilitating access to new supply routes, the Eridan project will strengthen the security of the natural gas supply in France and Europe. This is why he received a grant from the European Commission for 74 ME.

The first field studies began in 2007 and commissioning of the pipeline is scheduled for 2016.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

The project scope has a European vocation as a secure supply and to streamline the exchange of natural gas in France and Europe. It is also a prelude to the merger of two existing tariff zones currently in France. This merger will improve the functioning of the wholesale market in the country.

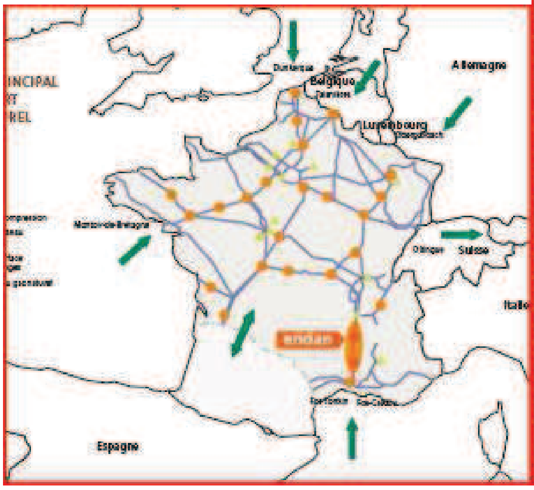
3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	220 km
Capacity (bcm/a):	650 GWh / day
Pipeline Diameter (inch):	ND 1200 (48 inches)
Design Pressure (barg):	80 bar
Steel grade (X70/X80 etc.):	L485 (at the moment) - WT : 15 to 27 mm
Transit Countries:	France
Highest point of pipeline (m MSL):	About 500 m
Deepest point of pipeline (mMSL):	0 m
No. of Compressor stations (CS):	0
Installed power (total, each CS – MW):	0
Distance between CS (km):	0
2 interconnections stations (St Martin de Crau and St-Avit)	

3.4. *Constraints*

List the project constraints identified in the Project



- The Rhone Valley, through which the Eridan pipeline must pass is very constrained by the existing urbanization and different infrastructures that have been built :
  - ➢ The range of possibilities to define the route is restricted and compromises are necessary to reach a path of least impact.
  - ➢ Even so these compromises are hard to find.
  - ➢ The inhabitants of the territories crossed express a certain saturation in relation to all infrastructure projects and the constraints they have caused

- The existence in the territory of the multi-culture high monetary value (including vines).

- The very strong presence of biodiversity and exceptional landscapes.

- A project schedule constrained by elections in early 2014

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

The main environmental impacts concern rivers and landscapes.
GRTgaz realizes several studies and takes specific measures to reduce these impacts:

- Environmental impact assessment with specific files for sensitive species
- Hydrogeological studies in preparatory phase in the most sensitive (perceptible) zones
- Most pipeline are laid under the rivers (horizontal drillings or others)
- The landscape is taken into account by development of the plot (ONF / GRTgaz agreement)
- For the flora and fauna, 400 days of inventory were completed between January, 2009 and April, 2012

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Project director in charge of the strategic project. He defines the needs and success of the project. He is responsible for project communication

Project manager: in charge of the operational project. He ensures the implementation of the project until its completion. A project team mobilizes, facilitates and assists the project manager in the different phases of the project .

Coordinator of studies: Under the supervision of the project manager, coordinates the studies on the project, including external service providers

Draughtsman: assists the project manager in the search path of least impact

Communication and consultation manager: assists and advises the project manager for communication at each stage of the project

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Public debate	The second half-year 2009
Deposit of the administrative file (the beginning of the administrative instruction)	September 2012
Public inquiry	October 2013
Autorization and declaration of public utility	mid 2014
At the beginning of the construction site	Early 2015
Commissioning of the pipeline	End 2016/Early 2017

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction

There is a distinction between "sensitive" contracts and those that are not considered "sensitive." "Sensitive" contracts are the contracts defined by the project manager as such mainly because of the impact of the purchase on the cost and time of the project. These contracts are approved by the Project Director and subject to specific monitoring. Other purchases are delegated to the Project Manager. The first step is to launch a tender. In a second step, a technical analysis of the bids received is performed. The project owner then proceeds to technical alignment so that companies that bid can readjust their technical proposal. Following the technical alignment, the client is able to compare all bids.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	***Description***	***Need by Date***	***Procurement Strategy***
Pipes procurement	With the construction procurement, this is the biggest purchase of the project.	Planned for early 2014 Construction is planned for beginning 2015	After the management decision to commit expenditure and prior to ministerial approval to build and operate the facility, GRTgaz launches tender about buying pipes with technical alignment between the two rounds of consultation . The goal is to anticipate land authorizations to avoid delaying the start of construction
Selection and award of the companies for construction of the pipe	select the company that will be responsible for laying the pipeline	At the beginning of the construction site Is planned for early 2015	After the management decision to commit expenditure and prior to ministerial approval to build and operate the facility, GRTgaz launches consultation about buying pipe construction with technical alignment between the two rounds of consultation . The goal is to anticipate land authorizations to avoid delaying the start of construction

8. Costs / Budget

Provide the Project Budget.

Purpose (objet)	**Amount**
Pipe	About 40%

Construction	About 40%
Total	$ 820 m

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Note : GRTgaz does not consider the local administration as stakeholder . A specific administrative process enables the local administration to express requirements according to the national regulation.

Stakeholder	Information Needed	Source / Provider	Timing
Environmental stakeholders (environmental associations, managers of natural areas : several administrations)	-Whether the project moves into areas of high ecological issues -Know the measures taken to reduce or compensate for impacts	-Public debate	-At the stage of time
		-Thematic Workshop	-Prior to the delineation
		-Meetings with institutional stakeholders	-Just before the filing of the administrative record
		-newsletter	-every 6 months
		-Charter-territorial commitments	-After the public discussion (includes GRTgaz commitments to improve integration of the project within the territory)
Economic actors (Chamber of Commerce and Industry, employment center, Chamber of trades)	-Know economic benefits for local businesses	-Public debate	-At the stage of time
		-meeting with institutional stakeholders	-before the filing of the administrative record
		-bi lateral meetings	-Two years before the start of work
Local authorities (cities, departments …)	-Whether there will be economic benefits to their communities -Whether the pipeline will prevent the development of projects - Know what will be the impacts on their citizens	-Public debate	-At the stage of time
		-Bilateral meetings	-From the 1st studies defining the delineation
		-Meeting with institutional stakeholders	-Prior to the filing of the administrative record
		-newsletter	-Every 6 months
Chambers of agriculture	-know where the route will pass -know-what will be the impact for farmers - Find fair compensation for farmers	-*b*ilateral meetings	-From the earliest studies and at each stage of the project
		-public debate	-At the stage of time
		-Meeting with institutional stakeholders	-Prior to the filing of the administrative record
		-newsletter	-every 6 months
The Directorate General of GRTgaz	News of the project in terms of cost, schedule, image ...	Project Management	3-4 times per year

10. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

10.1. Support of general public (grand public) to the technology	
Strategy	➢ Analyze and understand the political, social, economic and environmental context of the territories ➢ Establish with the project stakeholders a shared territory issues diagnosis. ➢ Explain to stakeholders and the public issues of the project and the regulatory, technical and economic constraints of the project owner in the delineation. ➢ Work with stakeholders to define a path of least impact on the territories ➢ Present and interact with all residents concurring the path of least impact
Action points	➢ Meet with stakeholders to analyze them with the different sensitivities of the territory (objective determination of a time study 2-3km wide) ➢ Meet the public to update them about the ongoing studies answer their questions about the impacts of a pipe and their suggestions . ➢ Dialogue with representatives of local authorities, professional associations and environmental representatives to determine a path within the time having a minimal impact on the activity of the territory and the environment. ➢ Meet again with the general public to introduce them to the proposed route, answer their questions about the impacts of a pipeline and possibly discuss with them possible modifications of the route before the public inquiry. ➢ Throughout the project, make ourselves available via the project email address to respond to requests from the public. ➢ Throughout the project, inform, via the website, any news of the project and the steps taken by GRTgaz to improve integration within territory.
Lessons learned	➢ Before the presentation of the route for residents, working with stakeholders is essential because it gives additional strength to the arguments presented by the client to justify the plot. Having worked with their representatives (political, professional associations) generally contributes to reassure residents on taking their issues into account . ➢ Work with stakeholders and analyze studies conducted by the client so as not to exhaust all the possibilities of passing the pipe. It is important to engage as soon as possible with residents on a proposed route to take time to consider their comments before the filing of the administrative file.

10.2. Support of authorities and politicians to the project	
Strategy	➢ Adapt if possible the project schedule to the political calendar to avoid making the project an election issue (danger of an escalation between the candidates in opposition to the project) ➢ Involved as early as possible and at every stage of the project elected to conduct the project ➢ Avoid the project comes block projects of local authorities. ➢ Strengthen their role as elected "representative" to their citizens. ➢ Promote the creation of benefits for the communities in the project
Action points	➢ Analyze issues of elected officials, their sphere of influence and political agenda ➢ Meet at first the inevitable political actors territories to present the project, its challenges and collect their vision. ➢ Informed, prior to the general public, all elected officials involved in the project, its challenges, its timing. ➢ At the time of the delineation, the experience sets mayors of the municipalities concerned to take into account the problems and development project, they plan on their communities. ➢ The stage where a proposed route has been defined and prior to filing of the administrative record, meet all elected to explain the proposed route chosen, answer questions and discuss with them the possible arrangements of the route before the filing of folder. ➢ Elected to the privileged interlocutors for their common issues and providing regular information on the project.
Lessons learned	➢ The lack of impact on the future development of their community is a key outcome of elected officials about a project, hence the importance of working with them at the time of the development of the plot. ➢ Meet very early influential players and large elected from the territory to explain the challenges of the projects is very important. Even if the project does not concern them directly, they may find themselves challenged by a local elected official who asked them to intervene in the conduct of the project and a preliminary contact may confine the application

10.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	
Action points	
Lessons learned	

10.4. Local discussions about / against project (e.g. at social networks)	
Strategy	➢ Establish a day to be notified of positions in the press and on social networks. ➢ Analyze the arguments put forward and prepare some answers ➢ Do not meddle in local discussions about the project. Intervene only if the client is directly challenged through its communication tools ➢ Respond deferred various arguments advanced by the opponents through the tools of communication and cooperation of the client and not on the media communication and consultation opponents. This helps to maintain control of its communication. ➢ Apart from the tools of global communication throughout the project, using tools of communication and consultation very localized to effectively respond to the arguments of opponents
Action points	➢ Conduct public meetings localized (one meeting for 5 towns) ➢ The objections to the proposed pipeline often bear the mark of NIMBY syndrome. Be available to meet with any individual protesters and see if adjustments to the route are possible (without affecting the neighboring more). ➢ When the tools of communication and consultation own GRTgaz no longer sufficient to meet the intensity of discussions against the project, use the local press and respond to the arguments against the project are deferred.
Lessons learned	➢ The press tends to echo the local equity position. It is important that the position of the owner is also reflected in the articles on the project. This requires establishing cordial relations with the press. ➢

10.5. Mitigation of the protests during permitting, planning and construction phase	
Strategy	➢ Explain clearly and very early, at the stage of time, the different principles that will guide the delineation and relate to these principles throughout the project. If a conflict arises around the determination of the route, it helps to frame with pre-established rules, including view accepted. ➢ Establish early on and maintain throughout the project a close dialogue with key regional players (professional representatives, elected officials, community representatives). These key players can play the role of mediator, facilitating discussion with residents in conflict and soothe it. ➢ Closer actors challenging to study the existence of solutions in the field or to reassure the measures to be taken for the purpose of fears do not happen. ➢ If the challenge begins to expand, develop a communication located at the place where it took shape in response to the arguments of the protesters.
Action points	➢ During the first public meetings on the project, explain the

	principles and technical, regulatory, which guide the development of the plot ➢ Present route to key players in the area prior to the general public ➢ Meetings to present the course to the public, take up contact with participants concerned the route and thereafter honor these contacts by appointment on the ground ➢ In case of dispute located in an area, for example, give an interview to the local press to respond indirectly to the arguments of opponents
Lessons learned	➢ The protest really appears only when a path is defined and presented to the public. To investigate alternatives that may exist locally with residents challenging the course must submit a proposed route as early as possible to the public inquiry. ➢ Confidence in industrial infrastructure has declined since the recent disasters, including that of Fukushima. The justification for the safety of our books must now be rooted in a struggle images and figures with the use by the opponents of the project, data and illustrations from the Internet. In response, the speech focused on the different types of safeguards and monitoring of the pipeline and the low probability of accidents appear less effective

11. Authorization process

11.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
Declaration of public utility	A prefect (“government representative”)	The prefect must decide on the utility of the project (balance of benefits over costs thereof). It relies for this on the report of the commission of inquiry that examines the public inquiry file, the opinions expressed by the administrative departments and local authorities, the comments posted by residents during for the public inquiry and answers provided by the building owner. Declaration of Public Utility allows the client to benefit from legal easements to get the pipe in case of refusal of the owners to sign easement agreements amicable. It also allows the compatibility of planning schemes with the pipeline and the right of the owner to occupy the public domain and its dependencies.	Mi 2014
Authorization to construct and operate	Minister in charge of security of	The Minister responsible for the security of pipeline transportation and	Mi 2014

the infrastructure	pipeline transportation and energy minister	energy minister pronounced jointly permission to construct and operate the pipeline after consultation with the county board of Environment and health and technological risks and given the opinion of the prefect.	

11.2. ***Information to Public / Public Debate / Debat public***

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
The first public meetings are held two years after the start of field studies, three years before the filing of the administrative record and four years before the public inquiry. During these initial meetings, the client presents to the public a time study 3 to 5 km wide that has been defined following the first studies and meetings with key players in the area. It is in this time that will take place the technical and environmental studies to develop the plot future.

b) Are there any decisional powers delegated to Public opinion?
The public does not have its own decision-making power but an important advisory opinion on the project. It is available at several times during the project and the remarks he makes are part of the essential elements on which is based the decision to authorize the construction of the book: ➢ In the public debate, the owner is held by an independent administrative authority to answer questions from the public. These exchanges are transcribed and subject to a review of public debate that is inserted into the administrative record. Responses and commitments that GRTgaz bring to the public's questions are part of the components of the final decision. ➢ Through administrative instruction, the public is consulted during the public inquiry. The formulated remarks and responses that GRTgaz must provide are analyzed by the investigating commissioner (investigator) . The report of the investigator reflects the "public opinion". Before delivering the authorization and the public utility , the Minister and the prefect check if GRTgaz has taken into account the impacts of the project on the residents and will be more reluctant to grant the declaration of public utility if the impacts for residents have not been enough taken into account .

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Although the opinion of the public and local authorities is only advisory, in effect, a broad opposition raises the "political" costs an authorization decision for the decision-making authorities. They can accept these costs only if these costs are less than the benefits expected from the project (for countries, companies, citizens). Authorities are all the more sensitive as their decisions may be appealed in court. They make sure the client has properly informed the public and has taken “every” measures

to limit finally the impact of the project.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Yes

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
24 months

f) Are any legal recourses admitted after an authorization act has been released?
We are working since 2008 with the assistance of the Legal Department and a law firm.

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
At least 1 year

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes

i) If yes, can you describe an example or a real case occurred.
In 2012, a draft regional pipeline (laying 7 km pipeline with a diameter of 150 mm), a prefect (decentralized administrative authority) revoked the permission to construct the pipeline he had given five months before. It is therefore not a repeal after a judicial appeal by opponents of the project. The reason for the termination was that the dossier submitted to the inquiry did not allow full public information.

12. Risk Management

Either provide the Risk Management Plan information here or provide a reference to the project's Risk Management Plan. Identify the risks to the project's success, including the probability of their occurrence, level of impact, and a brief description of the Mitigation and / or Contingency Strategy for each.

#	***Description***	***Probability 1= low 5 = high***	***Impact 1= low 5 = high***	***Mitigation / Contingency Strategy***
1	Special river-crossing works - large complex crossings Risk: The implementation of these crossings do not go as planned during the studies.	2	3	1) Carry out geophysical and geotechnical studies. 2) Ask the OS installer to consider water risks

2	Switching stations planned in flood zone Risk: Risk of site safety	3	3	Study of flood (risk of hydraulic construction phases) in progress. Include the necessary provisions to PGCSPS and CPP
3	key commitments Risk Factor: Large number of commitment and take Risk: Commitments key not required	3	3	Establish a registry of commitments and monitoring reviews
4	Specific issues / singular Risk factor: Many special / unique project and points without feedback in 1200 Risk: Costs and time (estimated rate) allocated to the achievement of specific issues / singular undervalued	3	3	A study of installation, in addition to "ORT"

13. Project Organization

13.1. *Project Organization Chart*

Provide the organization chart from the Project Charter and any changes to it. The project's organization chart begins with the project sponsor and includes all project stakeholders.

1. <u>Personnes physiques ou morales concernées:</u>

Program manager	Thierry Trouvé	General dorector of GRTgaz
Project manager	Georges Seimandi	Project director
Assistant manager	Olivier Jouffrey	Project manager

The Project involves different skills GRTgaz, especially Experts various areas concerned. These experts will as assistants to the Owner.

2. <u>The steering committee of the project:</u>

The Project Steering is provided by the "Steering Committee which logistics is provided by the Engineering Center. The steering committee meets at least once every one except sérogation three months, or more frequently as needed.
Its mission are as follows:

- Monitor compliance with the objectives, budget, time and quality set by the sponsor
- Approve deliverables and monitor the achievement of the prerequisites for the following phases
- Approve the functional and organizational options
- Arbitrate budget guidelines, schedule and resource requirements of the project
- Monitor compliance with the commitments of the all parties
- Follow the action plan risk
- Provide assessments scope project
- Decide on changes in project quality measures
- Framing communication actions

Without derogating from the respective responsibilities of the Client's Representative and Assistant to the Owner, members of the Steering Committee ensure the achievement of the project goal. As such, and collectively:

- They provide better coordination of all entities involved in the Project,
- They anticipate the challenges and changes in the project environment.

3. Reporting-pilotage :

The Project Leader Project Manager to address a monthly report by the 15th of month m +1 at the latest with:

- Highlights (dashboard, costs, schedule, safety)
- Any alerts
- Risks
- Curves progress (indicators) ...

More a mission early warning is given to all assistants Client (Engineering center , Operators, procurement staff ...) to promptly alert the Project Manager in the event of apparent drift or problems causing significant implications safety, cost, schedule.

4. Information carrier :

A database allows sharing of documents and records.
The purpose of this database is to enable the exchange of information (reports, decisions, documents ...) within the Committee expanded project.
This database is hosted by CI.
The following tools are used to trace the elements of project management:

Activité	**Outil associé**	**Responsable**	**Fréquence**
Follow-up of the objectives of the project	Plan of the project director	Project director	Steering committee
Risk management	Risk register	Project manager	Steering committee
Planning management	report	Project manager	Monthly
Follow-up of the budget	Report excel table	Project manager	Monthly
Follow-up of the actions		Project director	Steering committee
Documentation management	Basis of the project	Project director	Step by step
Management of the modifications	Record of demand of modification on the basis of thee project	Project manager	Step by step
Management of the statutory requirements	File SSE on the basis project	Project manager Cordinator SSE	Step by step
Reporting for the project director	report	Chef de Projet	Mensuelle

5. Walkthroughs:

The stage of the Project identified as key by Project director planned by the project manager for a

Committee meeting.

13.2. *Roles & Responsibilities*

Describe the Roles and Responsibilities of all project stakeholders identified for this project.

Stakeholder Title	Name	Roles & Responsibilities
Economic actors	➢ Chamber of Commerce and Industry ➢ Chamber of Crafts ➢ Employment center	The role of partnership with the Chambers of Commerce and Industry is to promote local economic benefits. They have an important responsibility in creating gains for the country.
Environmental stakeholders	➢ Environmental Associations ➢ Managers of natural areas	The role of partnership with environmental stakeholders is to enrich the environmental studies and to identify, prior to the delineation, all the environmental issues of the area. Thematic workshops organized upstream reduce, at the presentation of the plot, challenges of environmental origin and consolidate the record before the administrative instruction.
Socio-professional representatives	➢ Chambers of Agriculture	Farmers represent the vast majority of residents affected by the pipeline. The work with its representatives upstream of the delineation avoids, to the extent possible, areas with high agricultural issues. For agricultural areas crossed by the pipeline, an agreement is made with the Chambers of Agriculture of each department concerned to identify measures to be implemented by the client to reduce the impact of the route in the plots. The agreement also defines the scale of compensation to be paid to farmers. This work with agricultural representatives is not a sufficient answer when a farmer is not satisfied with the route of the pipeline, but also reduces the number of protest and consolidates GRTgaz position on these issues.
Local authorities	➢ Regional, departmental and inter-community ➢ the common	The elect are the focal points through which residents apprehend the project, its challenges, how were taken into account their problems. The elected are gates entered the country that allow the project to introduce the general public. Considered as representing the interests of their community and its people, they can also play an intermediary role and channeler in case of disputes.

9. Nord Stream

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Nord Stream	***Project ID:***	
Sponsoring Organization:	Gazprom	***Sponsor Representative:***	
Prepared by:	Gazprom		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

For the engineering, building, operating and managing purposes Nord Stream AG company was established. As of December 31, 2012 shares in the company had been distributed in the following way: OAO Gazprom — 51%, Wintershall Oil AG (BASF Group) — 15.5%, PEG Infrastruktur AG (E.ON Group) — 15.5%, Gasunie Infrastruktur AG (Gasunie Group) — 9%, and GDF SUEZ Holding Switzerland AG (GDF SUEZ Group) — 9%.

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

Transportation of Russian natural gas to the Western EURpean countries under the Baltic Sea.
The Nord Stream gas pipeline is a fundamentally new route for Russian gas exports to Europe. The target markets for gas supplies via Nord Stream are Germany, the UK, the Netherlands, France, Denmark and others.
Back in December 2000 the European Commission had assigned the Nord Stream project the Trans-European Network (TEN) status which was confirmed once again in 2006. This means Nord Stream is a key project aimed at creating crucial cross-border transport capacities with a view to ensure sustainability and energy security in Europe.

3.2. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	offshore
Overall Length (km):	1224 km
Capacity (bcm/a):	55 bcm/a (two strings 27,5 bcm/a)
No. of Compressor stations (CS):	No provision

3.3. *Environmental impacts and assessment*

List the main environmental impacts and studies

Nord Stream is a transnational project and it was constructed in compliance with the international conventions and national legislation of each state, whose territorial waters and/or exclusive economic zone the pipeline crosses.

A detailed environmental impact assessment was performed prior to launching the construction operations.

Nord Stream was built in compliance with the most rigid environmental standards and without the Baltic Sea ecosystem disruption. In order to minimize the environmental impacts, the construction operations were halted for the herring spawning season as well as over the period of migratory birds' stopover in this region.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Start of construction

Putting into operation 1st string of the offshore gas pipeline, 27,5 bcm, start of operation

Putting into operation 2nd string of the offshore gas pipeline, 27,5, full capacity

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
Start of construction	April, 2010
Putting into operation 1st string of the offshore gas pipeline, 27,5 bcm, start of operation	November, 2011
Putting into operation 2nd string of the offshore gas pipeline, 27,5 bcm, full capacity	October, 2012

6. Costs / Budget

Provide the Project Budget.

Purpose	Amount
Offshore section	EUR 7,4 bn
Total	EUR 7,4 bn

10. Power of Siberia

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Power of Siberia	***Project ID:***	
Sponsoring Organization:	Gazprom	***Sponsor Representative:***	
Prepared by:	Gazprom		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

3. Project Overview

3.1 Project Description

Provide the Project Description.

Power of Siberia gas transmission system (GTS) one of the main project of Development Program for an integrated gas production, transportation and supply system in Eastern Siberia and the Far East. This GTS will become a unified gas transmission system for the Irkutsk and Yakutia gas production centers and convey gas from these centers to Vladivostok via Khabarovsk.

The Yakutia – Khabarovsk – Vladivostok gas trunkline will be constructed at the first stage, and at the second stage the Irkutsk center will be connected to the Yakutia center by the gas pipeline.

The GTS route will run in parallel with the Eastern Siberia – Pacific Ocean operational oil pipeline, thus enabling to streamline the infrastructure and power supply costs. The GTS route will pass, inter alia, through swampy, mountainous and seismically hazardous areas.

The bulk of pipes used in the construction will be domestically manufactured. Some 11,700 experts will be engaged within Phase 1 of the Power of Siberia project and some 3,000 employees will ensure the pipeline's operation.

3.2 Scope

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

3.3 Technical Key Features

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	onshore project
Overall Length (km):	about 4,000 kilometers (Yakutia – Khabarovsk – Vladivostok – some 3,200 kilometers, Irkutsk Region – Yakutia – nearly 800 kilometers);
Capacity (bcm/a):	61 bcm/a
Pipeline Diameter (inch):	56 inch

Design Pressure (barg):	100 barg
No. of Compressor stations (CS):	9
Installed power (total, each CS – MW):	1 330

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

The first section of the Power of Siberia GTS – the Yakutia – Khabarovsk – Vladivostok gas trunkline – will come onstream in late 2017.

11. Trans Adriatic Pipeline

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title: Trans Adriatic Pipeline ***Project ID:*** TAP

Sponsoring Organization: TAP a.g. (CH) ***Sponsor Representative:*** Kjetil Tungland

Prepared by: Sigurd Hamre

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Kjetil Tungland, TAP MD		
Project Manager	Sigurd Hamre Project Development Director TAP		

3. Project Overview

a. Project Description

Provide the Project Description.

The Trans Adriatic Pipeline (the pipeline) will transport gas via Greece and Albania and across the Adriatic Sea to Italy. The project is aimed at enhancing supply security as well as the diversification of gas supplies for the European markets. TAP will open a new southern gas corridor to Europe and a market outlet for natural gas from the Caspian Sea region and is initially designed to transport 10 BCMY, with the possibility for later expansion in transmission capacity to 20 BCMY per year as more gas becomes available.

The system design has been performed for both phases of the project, for 10 BCMY as well as for expanding to be able to transport double the capacity - 20 BCMY.
The pipeline will begin at the Greek / Turkish border near Kipoi in Greece, where it will tie in with TANAP's gas transmission system. TAP will be routed through northern Greece and enter Albania east of Korca. It will continue through Albania and reach the Adriatic coastline near the city of Fier. At this point, the pipeline will cross the Adriatic Sea and terminate at the pipeline receiving terminal (PRT) close to Lecce in Italy where the gas will be tied in into the Snam Rete Gas (SRG) network. The total length of the TAP System will be approximately 871 km including the offshore pipeline section of 105 km.

For Phase 1 of the project (10 BCMY), compressors are located in two places, namely at the head compressor station near Kipoi (GCS00), approx. 3 km from the Turkish / Greek border, and at Fier, close to the Albanian coast (ACS03). At this compressor station, the pressure will be boosted prior to entering the offshore pipeline. A pipeline receiving terminal (PRT) will be located near Lecce,

Italy. In Phase 1, the station ACS02 at Bilisht in Albania near the Greek / Albanian border will serve as a metering and pigging station only. For the final expansion to 20 bcm/y, it is necessary to upgrade the ACS02 station on the Albanian border and to install an additional compressor station GCS01 close to Serres in Greece. In compliance with the requirements of the Security of Supply Regulation, physical reverse flow has been implemented in TAP's design. Thus, in planned or emergency situations, the transmission of gas from Italy to Albania and Greece will be feasible.

b. Scope

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Please ref, to the above section 3.1

c. Technical Key Features

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	
Overall Length (km):	- Total Length: 871 Km - Length Onshore sec.: 766 Km - Length Offshore sec.: 105 Km
Capacity (bcm/a):	- Phase 1: 10 BCMY - Phase 2: 20 BCMY
Pipeline Diameter (inch):	- Onshore sec. Greece/Albania: 48" - Offshore sec.: 36" - Onshore sec. Italy: 36"
Design Pressure (barg):	- Onshore sec. Greece/Albania: 95 barg - Offshore sec.: 145 barg - Onshore sec. Italy: 145 barg
Steel grade (X70/X80 etc.):	- Onshore sec. Greece/Albania: 48", X70 - Offshore sec.: 36", X65 - Onshore sec. Italy: 36", X65
Transit Countries:	Greece, Albania, Italy
Highest point of pipeline (m MSL):	about 1,800 m above sea level
Deepest point of pipeline (mMSL):	about 820 m below sea level
No. of Compressor stations (CS):	- Phase 1: 2 CS (GCS00, ACS03) - Phase 2: 4 CS (GCS00, ACS03, GCS01, ACS03)
Installed power (total, each CS – MW):	Phase 1, tot installed power is 90 MW, each station: - GCS00: 45MW TOT - ACS03: 45MW TOT Phase 2, tot installed power is 365 MW, each station:

	- GCS00: 90MW TOT - GCS01: 100MW TOT - ACS02: 100MW TOT - ACS03: 75MW TOT
Distance between CS (km):	Phase 1: - From GCS00 to ACS03: 749 Km Phase 2: - From GCS00 to GCS01: 277 Km - From GCS01 to ACS02: 272 Km - From ACS02 to ACS03: 200 Km
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

d. Constraints

List the project constraints identified in the Project

- Coordinated completion of the whole value chain from SD to Italy
- Availability of Contractors

e. Environmental impacts and assessment

List the main environmental impacts and studies

- The ESIA Albania was submitted in January 2013. The approval has been received in April 2013.
- The ESIA Greece was submitted in June 2013 for completeness check. Final submission expected August 2013.
- The ESIA Italy is planned to be submitted in September 2013.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

Description
Onshore Pipeline Greece Onshore Pipeline Albania Onshore Pipeline Italy Infrastructure Albania
Subtotal Onshore Pipeline
Compressor Station CS0 Compressor Station CS2 Compressor Station CS3 Pipeline Receiving Terminal
Subtotal Compressor Stations and PRT
Offshore Pipeline incl. Landfalls Italy & Albania Offshore Fiber Optic Cable
Subtotal Offshore Pipeline
SCADA Commissioning
Subtotal SCADA Commissioning

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
• Shah Deniz selects TAP as export route to Europe – 28 June 2013 • TAP to take Resolution to Construct (RTC) – 4Q 2013 • Shah Deniz Final Investment Decision (FID) – 4Q 2013 • Construction of TAP to start – end 2014/early 2015 • Ready to receive first gas from Shah Deniz - 2019	

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

- Company Provided Items
  - Steel
  - Concrete Coating
  - Compressors
- Several EPC contracts for construction

7. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

7.1. Support of authorities and politicians to the project	
Strategy	Intergovernmental agreement between Greece, Albania and Italy

7.2. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	Following EBRD requirements

8. Authorization process

8.1. ***Information to Public / Public Debate / Debat public***

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

j) In which phase of the project does the information to Public occur?
According to EBRD requirements

9. Project Organization

9.1. *Project Organization Chart*

Provide the organization chart from the Project Charter and any changes to it. The project's organization chart begins with the project sponsor and includes all project stakeholders.

Currently being developed for the execution phase

12. Eastring

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Eastring	***Project ID:***	Eastring
Sponsoring Organization:	eustream, a.s.	***Sponsor Representative:***	Rastislav Ňukovič
Prepared by:	Michal Ľalík		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Rastislav Ňukovič		
Program Manager	Michal Ľalík		*info@eastring.eu*
Customer / User Representative(s)	Ján Janus		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

Eastring is a project of a new transmission pipeline, connecting existing interconnection point Veľké Kapušany on SK-UA border, where Eustream owns and operates the existing compressor station, with UA/HU-RO-BG transit pipeline. The main purpose of this project is to carry natural gas from:

(i) Western Europe to the Balkan countries, enabling those countries to diversify their natural gas sources;

(ii) Alternative gas sources, including but not limited to Russia, AGRI, TANAP, Caspian, Iran, Iraq, Egypt, Israel and Cyprus to Central, South and Western Europe.

Project connects IP Veľké Kapušany in Slovakia with UA/HU - RO - BG transit pipeline in following basic routing options:

- Slovakia (Veľké Kapušany) to Romania:
    - via Ukraine, using existing infrastructure, or
    - via Hungary, using new pipeline.

- Romania
  - Option A – new pipeline, which passes production and storage area of Transylvania and continues to existing IP Isaccea and then further to BG/TR border utilizing existing UA-RO-BG transit assets;
  - Option B – new pipeline, which passes both areas of production and storage (Transylvania and in the vicinity of Bucharest), and continues to BG/TR interconnection point Malkoclar.

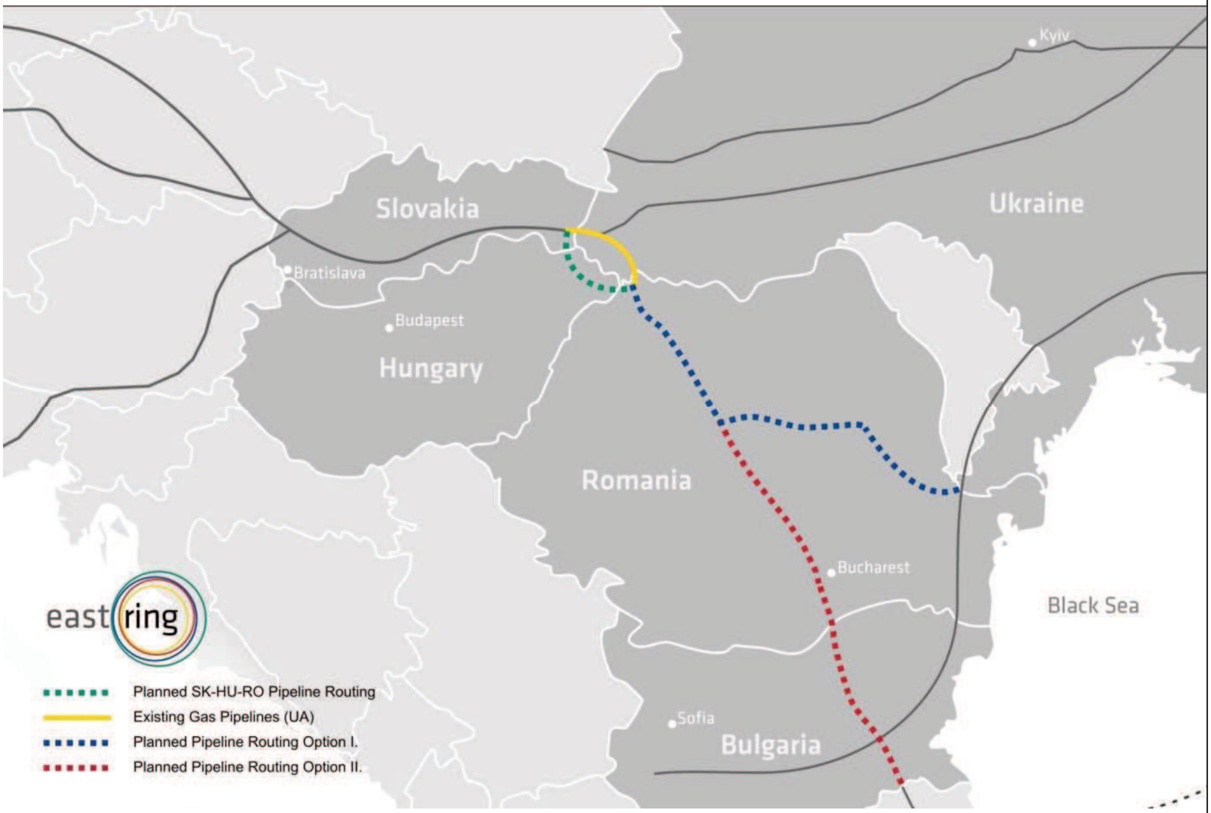


Fig. No.1 Main scheme of the Project

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

Scope of the Eastring project (Option A) is to construct:

- 832 km of new pipeline DN 1400 PN100 between the existing compressor station Veľké Kapušany and the metering station Isaccea (RO).
- Three metering stations along the new pipeline.
- Adjustment of the CS Veľké Kapušany (SK) from maximum operating pressure 73 bar to 100 bar (phase 1 – capacity 20 BCM/Y from SK to RO).
- One compressor station in the locality of Isaccea (RO) (phase 2 – capacity 20 BCM/Y from RO to SK)
- Ball Valve Stations.
- Cathodic Protection Station.
- Compressor stations along the pipeline Eastring (phase 3 – capacity (bidirectional) up to 40 BCM/Y).

Scope of the Eastring project (Option B) is to construct:

- 1015 km of new pipeline DN 1400 PN100 between the existing compressor station Veľké Kapušany and the metering station Malkoclar (TR).

• Four metering stations along the new pipeline. • Adjustment of the CS Veľké Kapušany (SK) from maximum operating pressure 73 bar to 100 bar (phase 1 – capacity 20 BCM/Y from SK to RO). • One compressor station in the locality of Stranja (BG) (phase 2 – capacity 20 BCM/Y from RO to SK) • Ball Valve Stations. • Cathodic Protection Station. • Compressor stations along the pipeline Eastring (phase 3 – capacity (bidirectional) up to 40 BCM/Y).

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	832 km (Option A), 1015 km (Option B)
Capacity (bcm/a):	20 BCM/Y (phase 1 and 2), up to 40 BCM/Y (phase 3)
Pipeline Diameter (inch):	56” (DN1400)
Design Pressure (barg):	100
Steel grade (X70/X80 etc.):	X70 (L485MB)
Transit Countries:	Slovak Republic, Hungary/Ukraine, Romania (Option A) Slovak republic, Hungary/Ukraine, Romania, Bulgaria and Turkey (Option B)
Highest point of pipeline (m MSL):	1050 m (Option A), 1350 m (Option B)
Deepest point of pipeline (mMSL):	0 m (Option A), 20 m (Option B)
No. of Compressor stations (CS):	1 existing (Slovak part), new one (Romania (Option A)/Bulgaria (Option B)) for phase 1 and 2
Installed power (total, each CS – MW):	Option A (phase 2) - 300 MW + new 66 MW (SK), 66 + 33 MW (RO). Option B (phase 2) - 300 MW + new 66 MW (SK), 66 + 33 MW (BG).
Distance between CS (km):	830 km (Option A – phase 2), 1010 km (Option B – phase 2)
Fill in please the enclosed table (worksheet “Compressor_stations” in “WOC3_questionnare”) with parameters of one compressor station at least.	

4. Costs / Budget

Provide the Project Budget.

Option A (phase 1) / Option B (phase 1)	1 260 mil. EUR / 1 520 mil. EUR
Option A (phase 2) / Option B (phase 2)	110 mil. EUR / 110 mil. EUR
Total	1 370 mil. EUR / 1 630 mil. EUR

5. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

5.1. Support of general public to the technology	
Strategy	Eustream's strategy is to establish and maintain good relations with land users and land owners alongside the project routing.

5.2. Support of authorities and politicians to the project	
Strategy	To keep high level of interest of authorities to the project and try to gain incentives (regulatory/financial) for the project from the states/EC.
Action points	Due to its strategic importance from the security of supply point of view, project Eastring has from the beginning strong support on the political level of all project countries as well as EC.

5.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	Eustream's strategy is to inform the public through press releases, articles and other way of communication about the project implementation necessity for its security of supply importance.

5.4. Local discussions about / against project (e.g. at social networks)	
Strategy	Eustream's strategy is to help the process of public discussions with hosting a meeting with local citizens.

5.5. Mitigation of the protests during permitting, planning and construction phase	
Strategy	Eustream's strategy is to deal with potential problems according to valid laws.

13. Eastern Transmission Pipeline

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Eastern Transmission Pipeline (Sample)	***Project ID:***	N/A
Sponsoring Organization:	The Hong Kong and China Gas Company Limited	***Sponsor Representative:***	Mr Edmond FONG
Prepared by:	Mr Edmond FONG		

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	Edmond FONG Transmission Project Manager The Hong Kong and China Gas Co Ltd	(852)29631272	edmond.fong@towngas.com
Program Manager	Same as above	Same as above	Same as above
Project Manager	Same as above	Same as above	Same as above
Customer / User Representative(s)	N/A	N/A	N/A
Other	N/A	N/A	N/A

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

The objectives of Eastern Transmission Pipeline (ETP) Project are :

- To increase linepack
- To provide a 3rd 7 bar supply source to reinforce the 7 bar network and also enhance the security of gas supply in Kowloon and Hong Kong Island
- To provide a 2.4 bar supply source at Sai O so as to enhance security of gas distribution of Shatin, Ma On Shan and Sai Kung
- To facilitate other strategic projects

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

To construct the followings : - 23km long 750mm NB High Pressure (35 bars) pipeline from Ma On Shan to Tseng Lan Shue via Sai Sha Road, Tai Mong Tsai Road, Hiram's Highway, and Clear Water Bay Road and including construction of Sai O Offtake & Pigging Station and to Tseng Lan Shue Offtake & Pigging Station.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	23km
Capacity (bcm/a):	6.4 bcm/a
Pipeline Diameter (inch):	24 inch, 30 inch
Design Pressure (barg):	35
Steel grade (X70/X80 etc.):	X42, X52
Transit Countries:	Hong Kong
Highest point of pipeline (m MSL):	237.0 m MSL (at Pik Uk)
Deepest point of pipeline (m MSL):	-6.2m MSL (at Ho Chung Nullah)
No. of Compressor stations (CS):	Nil
Installed power (total, each CS – MW):	N/A
Distance between CS (km):	N/A
Fill in please the enclosed table (worksheet "Compressor_stations" in "WOC3_questionnare") with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

1. Difficulties in securing the sites for the offtake & pigging stations because of locals' concern
2. Pipelaying work at various sections along carriageway hindered by road opening restriction
3. Some sections of pipelaying work located within country parks requires Environmental Permit
4. QRA is required by the Gas Authority for the pipeline section near Sai Kung Town
5. Difficulties in securing the working pits for trenchless work crossing Ho Chung Nullah and Tai Wan Stream.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Water quality, air quality, ecology, hazard to life, etc.

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

1. Environmental Permit (direct application) for laying a short section of pipe at Ma On Shan Country Park
2. Environmental Permit (direct application) for laying a short section of pipe at Sai Kung West Country Park
3. QRA as a pre-requisite of the Construction Approval for the pipeline section near Sai Kung Town
4. Planning Permission for Trenchless Pipelaying near Tai Wan Stream
5. Planning Permission for Tseng Lan Shue Offtake & Pigging Station
6. Material Procurement
7. Tender for the work
8. Land acquisition for Tseng Lan Shue Offtake & Pigging Station and Sai O Offtake & Pigging Station

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date (Date of Approval)
Planning Permission for the Tseng Lan Shue Offtake & Pigging Station	Dec 2003
Environmental Permit (direct application) for Pipelaying at Ma On Shan Country Park	Oct 2004
Planning Application for Trenchless Pipelaying near Tai Wan Stream	Jan 2005
Environmental Permit (direct application) for Pipelaying at Sai Kung West Country Park	Feb 2005
Land acquisition for the Sai O Stations Offttake & Pigging Station	July 2005
QRA for the 35 Bar Pipeline Section near Sai Kung Town	Sept 2005
Land acquisition for the Tseng Lan Shue Offtake & Pigging Station	Sept 2006
Tender for the work	In various stages
Construction Approvals for 35 bar pipeline Construction Approvals for Offtake & Pigging Stations	In various stages
Use Approvals for 35 bar pipeline Use Approvals for Offtake & Pigging Stations	Feb 2008

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Client to arrange :

1. Construction supervision (both in-house / external) for the work
2. Material procurement for line pipes, fittings, offtake & pigging equipment for the contractor's use
3. Contractors to carry out the construction of the landlines and the offtake & pigging stations

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	***Description***	***Need by Date***	***Procurement Strategy***
1	Construction Supervision	In various stages	Client to arrange if applicable ; or in-house
2	Material Procurement	In various stages	Client to arrange
3	Construction of Land pipeline / Offtake & Pigging Stations	In various stages	Client to arrange

8. Costs / Budget

Provide the Project Budget.

Purpose	**Amount**
	$
	$
Total	$ Over 400 Million HK

9. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	**Information Needed**	**Source / Provider**	**Timing**
Country Park Board	Elaboration on the background and rationales of the project, address public concerns on the pipeline alignment within the country park	The Hong Kong and China Gas Co Ltd	Nov 2003
District Council – Tai Po	Elaboration on the background and rationales of the project, address locals' concerns on the site selected for Sai O Station	The Hong Kong and China Gas Co Ltd	Jan 2004
District Council – Sai Kung	Elaboration on the background and rationales of the project, address locals' concerns on the site selected for Tseng Lan Shue Station	The Hong Kong and China Gas Co Ltd	May 2005

10. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

10.1. Support of general public to the technology	
Strategy	Enhance confidence of District Councilors through site visit to the

	existing offtake station
Action points	Arrange District Councilors to visit the existing offtake station and explain the safety precautionary measures taken in gas safety
Lessons learned	Seeing is believing

10.2. Support of authorities and politicians to the project	
Strategy	Demonstrate the design of the offtake & pigging station is the best option for implementation
Action points	Conduct meetings lobbying locals/sensitive group to bless the design of the Tseng Lan Shue and Sai O Offtake Stations
Lessons learned	Further enhancement of the design to address public concern

10.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	Same as 10.2
Action points	Same as 10.2
Lessons learned	Same as 10.2

10.4. Local discussions about / against project (e.g. at social networks)	
Strategy	Elaborate the purpose of the project, demonstrate the associated benefit to the public, and address the public concern
Action points	Same as 10.1 and 10.2
Lessons learned	Identify and agree measures with public to address their concern

10.5. Mitigation of the protests during permitting, planning and construction phase	
Strategy	Same as 10.4
Action points	Same as 10.4
Lessons learned	Same as 10.4

11. Authorization process

11.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
Planning Permission	Planning Department	Planning Application for Tseng Lan Shue Offtake & Pigging Station	3
Environmental Permit (direct application)	Environmental Protection Department	Environmental Impact Assessment for Pipelaying at Ma On Shan Country Park	5
Planning Permission	Planning Department	Planning Application for Trenchless Pipelaying near Tai Wan Stream	8
Environment Permit (direct application)	Environmental Protection Department	Environmental Impact Assessment for Pipelaying at Ma On Shan Country Park / Sai Kung Country Park	4
Private Treaty Grant	Lands Department	Land acquisition for the Sai O Offtake & Pigging Station	37
QRA	Electrical & Mechanical Services Department	35 bar Pipeline Section near Sai Kung Town	40
Private Treaty Grant	Lands Department	Land acquisition for the Tseng Lan Shue Offtake & Pigging Station	35
Construction Approvals	Electrical & Mechanical Services Department	Construction of 35 bar Pipeline Construction of Offtake & Pigging Stations	2
Use Approvals	Electrical & Mechanical Services Department	Use of 35 bar Pipeline Use of Offtake & Pigging Station	0.5

11.2. ***Information to Public / Public Debate / Debat public***

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
Planning Stage

b) Are there any decisional powers delegated to Public opinion?
Refer to the Legislation of Hong Kong (in particular, Town Planning Ordinance, Gas Safety Ordinance, Environmental Impact Assessment Ordinance, etc.) http://www.legislation.gov.hk/eng/home.htm

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Same as (b) above

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?
Same as (b) above

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?

Same as (b) above

f) Are any legal recourses admitted after an authorization act has been released?
Same as (b) above

g) If yes, who can present, after how much time and what is the usual length of resolution of such legal recourses.
Same as (b) above

h) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Same as (b) above

i) If yes, can you describe an example or a real case occurred.
N/A

12. Risk Management

Either provide the Risk Management Plan information here or provide a reference to the project's Risk Management Plan. Identify the risks to the project's success, including the probability of their occurrence, level of impact, and a brief description of the Mitigation and / or Contingency Strategy for each.

#	*Description*	*Probability 1= low 5 = high*	*Impact 1= low 5 = high*	*Mitigation / Contingency Strategy*
1	QRA for the 35 Bar Pipeline Section near Sai Kung Town	N/A	N/A	(1) Acceptable Region of FN Curve (2) Further enhancement : ➢ Remote control isolation valves at Sai O Offtake & Pigging Station ➢ 35 Bar Pipeline Section near Sai Kung Town : ■ at least 1.5m burial cover ■ install concrete slab above pipeline
2	Other section – based on IGEM/TD/1	-	-	Other section – based on IGEM/TD/1

13. Project Organization

13.1. *Project Organization Chart*

Provide the organization chart from the Project Charter and any changes to it. The project's organization chart begins with the project sponsor and includes all project stakeholders.

Project Manager – Senior Engineer – Engineer – Consultant /Supervision (if applicable) – Main Contractor

13.2. *Roles & Responsibilities*

Describe the Roles and Responsibilities of all project stakeholders identified for this project.

Stakeholder Title	Name	Roles & Responsibilities
Transmission Project Manager	Mr Edmond FONG	Overseeing transmission projects in Hong Kong
Senior Engineer	Mr Edward LEE Mr BM CHAI	Managing the project
Engineer / Assistant Engieer	-	Assisting the Senior Engineers for the project
Mott Connell	-	Construction Supervision
Kitak, Man Wah and U Tech, etc.	-	Contractors for the Construction Work

14. Relocation of the existing 300mm gas transmission pipeline to allow the construction of a new railway bridge

Applicable Processes/Procedures: *Identify the process for creating a project plan*

1. General Information

Provide basic information about the project including: Project Title – The proper name used to identify this project; Project ID – The working name or acronym that will be used for the project; Sponsoring Organization – The organization sponsoring this project; Sponsor Representative – The name of the person representing the Sponsoring Organization; Prepared by – The person(s) preparing this document.

Project Title:	Relocation of the existing 300mm gas transmission pipeline to allow the construction of a new railway bridge.	***Project ID:***	
Sponsoring Organization:	SP AusNet	***Sponsor Representative:***	

2. Key Stakeholders:

List the principal project stakeholders, if possible.

Position	Title/Name/Organization	Phone	E-mail
Sponsor Representative	DG		
Program Manager	SP		
Project Manager	AS		
Customer / User Representative(s)	SS		

3. Project Overview

3.1. *Project Description*

Provide the Project Description.

- The railway authority has proposed to construct a railway bridge at Anderson Rd. This construction will be in conflict with a section of the existing DN300 gas transmission pipeline. Therefore, the impacted section of pipeline is to be relocated at a suitable location enabling the bridge construction.
- The project includes constructing 600m section at an alternative location which will tie back into the exiting 6km transmission pipeline.
- The impacted section of the existing pipeline shall not be decommissioned prior to the installation of the newly proposed pipeline. The works will include obtaining approvals from the safety regulators Energy Safe Victoria and Department of Primary Industries.

3.2. *Scope*

Provide the Project Scope. If there are changes to the Scope because of Project Planning or unforeseen project events, clearly identify the changes or additions made to the Project Scope.

The scope is to design and construct 600 meters of DN300 section of the pipeline. The scope also includes decommissioning of the impacted section of the pipeline and commissioning of the newly constructed section by tying it into the main pipeline.

3.3. *Technical Key Features*

List the Assumptions made about the project and any changes to the original assumptions or additional assumptions made during project planning.

Onshore and/or offshore project:	Onshore
Overall Length (km):	600 m
Capacity (bcm/a):	10,000 cum/sec
Pipeline Diameter (inch):	12”
Design Pressure (barg):	28
Steel grade (X70/X80 etc.):	API 5L X42 (PSL2)
Transit Countries:	NA
No. of Compressor stations (CS):	0
Installed power (total, each CS – MW):	2
Distance between CS (km):	0.5
Fill in please the enclosed table (worksheet “Compressor_stations” in “WOC3_questionnare”) with parameters of one compressor station at least.	

3.4. *Constraints*

List the project constraints identified in the Project

1. Pipeline located in urban area
2. The existing pipe is located in the middle of the road
3. The new pipeline shall have easement if passing through private properties.
4. The new alignment will include a new railway crossing
5. Continuity of the supply shall be maintained at all times during construction, commissioning and decommissioning of the redundant section.

3.5. *Environmental impacts and assessment*

List the main environmental impacts and studies

Environmental Management Plan was prepared to identify and mitigate the impacts on :

1) Noise, Dust, Water Contamination
2) Flora and Fauna
3) Cultural and Aboriginal Heritage

4. Work Breakdown Structure (WBS)

Either provide the WBS here or provide a reference to the project's WBS in main components. The WBS is a hierarchical, deliverable-oriented decomposition of the work to be performed by the project team. The WBS organizes and defines the total scope of the work to be performed by the project.

1. Impact Assessment
2. Selection of the route
3. Design the pipeline
4. Regulatory approval for the selected route
5. Development of standard procedures
6. Regulatory approval for construction
7. Procurement of pipe and associated assemblies
8. Construction
9. Hydro-test
10. Commissioning
11. De commissioning

5. Schedule / Milestones

Either provide the Project Schedule here or provide a reference to the Project Schedule. For each event, provide the Estimated Date of completion.

Activity / Milestone	Estimated Date
1. Impact Assessment	Sept 2012
2. Selection of the route	Oct 2012
3. Design the pipeline	Oct 2012
4. Regulatory approval for the selected route	Nov 2012
5. Development of project specific standards and procedures	Jan 2013
6. Regulatory approval for construction	March 2013
7. Procurement of pipe and associated assemblies	March 2013
8. Construction	Sept 2013
9. Hydro-test	Oct 2013
10. Commissioning	Oct 2013
11. De commissioning	Nov 2013

6. Contracting Strategy

Describe the main contracting strategy for engineering, supply and construction.

Main strategic features which shall be included in the contract:

1) The turn/key contract shall be awarded to the approved contractor only.
2) The sub-contractors involved in this project shall have competencies in accordance with SP AusNet requirements.
3) All the equipment or material shall be procured from the approved suppliers only. Deviation can be permitted but will require SP AusNet approval.
4) All works shall have milestones and SP AusNet approval will be required at the completion

of each milestone. 5) The half of the security fees will be returned to the contractor at the practical completion of the works and the remainder will be refunded after the expiry of the guarantee period.

7. Procurement Plan

Either provide the Procurement Plan information here or provide a reference to the project's Procurement Plan. Include information about items to be procured procurement strategy, and projected need by dates.

Item	*Description*	*Need by Date*	*Procurement Strategy*
Implemented by the contractor.			

8. Communications Plan

Either provide the Communication Plan information here or provide a reference to the project's Communication Plan. Include information about information each project stakeholder needs, who provides that information and when / how often it is needed.

Stakeholder	Information Needed	Source / Provider	Timing
Residents	Progress, Impact	Project Manager	Weekly
City West Water	Impact on to Water mains	Project Manager	As required
PowerCorr (Power Company)	Impact on to power poles and lines	Project Manager	As required
Local Council	Traffic and impact to the local residents	Project Manager	Weekly
Department of Primary Industries	Approvals, Weekly construction meetings	Asset Manager	Weekly
Energy Safe Victoria	Approvals, Weekly construction meetings	Asset Manager	Weekly

9. Communication Strategy

Provide the Communication Strategy for the particular points in the tables below.

9.1. Support of general public to the technology	
Strategy	Weekly letter drop, Community Liaison program, newspaper advertisement with proper contact details. Approval from department of primary Industry.
Action points	Ensure weekly letter drops.
Lessons learned	This is to be shared with all the employees and staff after every near miss or incident. At the completion of the project, a project debrief shall be prepared as a learning for the organization.

9.2. Support of authorities and politicians to the project	
Strategy	Approval shall be sought from Energy Safe Victoria, Department of Primary Industries, Rail Authorities (Govt Authorities).

9.3. Involving the public in planning and project development to use the advantage of the first impression	
Strategy	Community Liaison program, Newspaper advertisement with proper contact details. Approval from department of primary Industry.
Action points	Consultation shall be well documented and closed off.

10. Authorization process

10.1. *Project Authorization plan*

Please provide, here or on a separate reference, the main authorizations requested for the projects, the issuing competent authority, a short description of the authorization and the expected/actual length of the authorization process.

Authorization	Competent authority	Description	Months
License Alteration	Department of primary Industry	The approval for license and route approval shall be obtained prior to start the construction.	01
Construction Safety Plan	Energy Safe Victoria	The approval for the construction shall be obtained prior to start the construction.	01
Commissioning	Energy Safe Victoria	The approval for commissioning shall be obtained prior to commission the pipeline.	0.5
Operation	Energy Safe Victoria	The approval for the operation shall be obtained prior to start the operation.	0.5

10.2. *Information to Public / Public Debate / Debat public*

The following questions are targeted to Public Information processes in general and investigate the relation between the Public Information and the Authorization processes.

a) In which phase of the project does the information to Public occur?
1) Planning Phase: This is inform the public of the project and resolve their reservations if any.

b) Are there any decisional powers delegated to Public opinion?
Decisional Power stays with the government authorities. Compensation related issues are dealt in the early phase and become a part of the feasibility study.

c) The competent central authority, after the evaluation of the requests/oppositions from public opinions and/or local authority, can ignore them in final authorization?
Yes, the Pipelines Act allow compulsory acquisition which is generally based on compensation the affected party.

d) Are the ultimate terms for releasing an authorization to build or operate a gas infrastructure defined by law and respected by competent authorities?

Yes, no works can proceed without the approval from the Department of Primary Industries and Energy Safe.

e) In case any terms are defined, which is the maximum allowable time for releasing/rejecting an authorization?
No firm guidelines. As applicable

f) Are any legal recourses admitted after an authorization act has been released?
No

g) Is it possible that any person/local authority/stakeholder already involved in a public acceptance process, after the positive conclusion of this public acceptance process, can present a legal recourse against the authorization itself?
Yes

h) If yes, can you describe an example or a real case occurred.
Not happened within SP AusNet. But people can seek additional compensation if they think the previously offered compensation was not adequate to compensate their impact.

11. Project Organization

11.1. *Roles & Responsibilities*

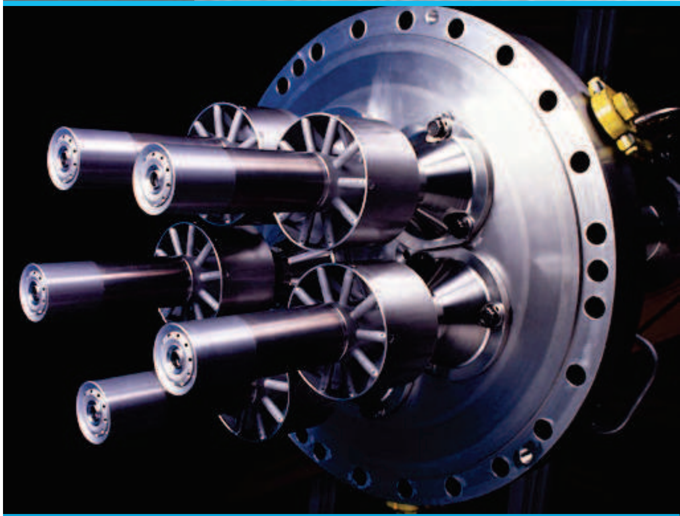
Describe the Roles and Responsibilities of all project stakeholders identified for this project.

Stakeholder Title	Name	Roles & Responsibilities
Project Manager	AS	Monitor implementation of the CSMP and all construction activities on behalf of the Pipeline Owners. Directly responsible for the management of the Project, including all environmental aspects. Reports directly to SP AusNet Management. • Review, approval and custody of the CSMP. • Participation as part of the Project Management Team. • Monitor and report on the discharge of the Licensee responsibilities by the Project Management Team. • Monitor implementation of the CSMP. • Coordinate with the Project Management Team on the implementation strategy of the project CSMP within the pipeline licence. • Directly responsible for overseeing and fulfilling commitments contained in this CSMP. • Sign off relevant hold points.

Project Design		Deal with any project design related issues. • Involvement in Contractor meetings to ensure design plans is being implemented.
Pipeline superintendent		• Responsible for applying the measures outlined within the CSMP. • Incorporate the CSMP actions and requirements into the task specific JSEA's. • Review and approve JSEA's. • Review and action any safety non-conformances and preventative measures. • Allocate resources to manage safety issues. • Ensure suppliers and contractors comply with safety requirements. • Halt construction activities in the event of inadequate • safety performance or unacceptable risk.

Annex 2:
GE OIL & GAS: Retrofitability of DLN/DLE systems

April 04, 2015



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Retrofitability of DLN/DLE systems

BY GIANNI CECCHERINI, DANTE MALQUORI, GIUSEPPE PETILLO, MATTEO FALSINI / GLOBAL SERVICES, GE OIL & GAS

Abstract

In recent years, local regulations on the acceptable limits of exhaust gas pollutant emissions from installed gas turbine plants have become increasingly stringent. In this scenario, GE Oil & Gas is continuing to develop combustion systems to reduce NOx emissions, introducing new solutions to improve the operability and the reliability of DLN systems. The experience built on a huge fleet of gas turbines originally equipped with diffusion combustors and the continuous improvement of Dry Low NOx combustor systems allows GE to offer conversion kits to meet new emission limit targets.

The scope of this article is to describe the available GE Oil & Gas DLN systems for its gas turbines and their retrofitability on existing standard combustion systems, and to explain the main modifications required to accommodate the new kits.

Introduction

All major international environmental authorities (US EPA, European Commission, local environmental ministries) are introducing increasingly stringent limits to the amount of pollutants emitted by industry. Gas turbines are an important contributor to pollutants such as NOx, SOx, CO, UHC, and as such, they are subject to regulatory restrictions applicable to new installations and, in many cases, also to units already installed and running for a long time.

The basic principle, which tends to be adopted for new unit applications, is compliance with the Best Available Technology (BAT), while for older, previously installed units, the regulations tend to be more tolerant. The increasing demand for power and the consequent introduction of new equipment, even complying with BAT, implies an increase of emissions which counts against the overall tons of pollutant reduction targets set by localities and countries in compliance with international directives. For this reason, gas turbine manufacturers are receiving an increasing number of requests for emission abatement retrofits to their installed fleet.

NOx is the main pollutant species produced by gas turbines, and its reduction is the primary objective of the emission reduction technologies developed. All gas turbines currently produced by GE have NOx abatement systems available, which in general can be divided in "DRY" and "WET" technologies, depending on whether NOx abatement is achieved through the use of water (wet technologies) or without water (dry technologies). In addition to the technologies developed to reduce emissions at the engine level, in particular within the engine combustion system,there are technologies which implement pollutant abatement at the engine exhaust system (Selective Catalyst Reduction Systems).

Nomenclature

DLN	dry low NOx
DLE_{tot}	dry low emission
CO	carbon monoxide
NOx	oxides of nitrogen (NO, NO_2)
CAV	combustion air valve

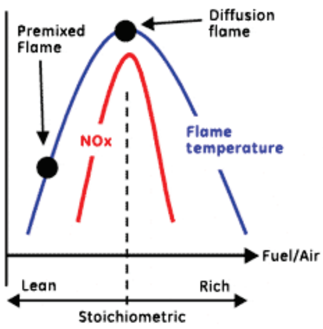

Figure 1
NOx production rate

This paper provides a description of the engine dry abatement systems developed for the GE Oil & Gas gas turbine fleet and their ability to be retrofit to installed units.

Gas Turbine Combustion systems

The gas turbine combustor is the device that provides thermal energy to the engine thermodynamic cycle by a combustion reaction. The combustion in a gas turbine is a continuous process and needs to be maintained stable over a wide range of operating conditions, e.g., air fuel ratio, pressure, reactant temperature and reactant composition. The fuel is burned with a large amount of excess air to keep the turbine inlet temperature at an appropriate level.

Gas turbine combustion systems can be of two types:

- Diffusion
- Premixed

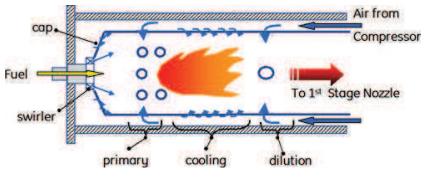

Figure 2
Diffusion combustor

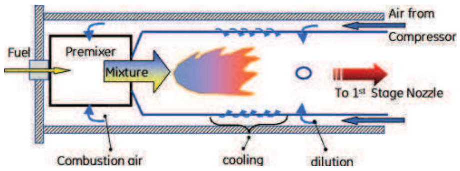

Figure 3
Premixed combustor

In diffusion combustors (Figure 2) fuel and air are injected separately into the reaction zone, the reactants combine by a diffusion process and as a result, the flame speed is limited by the rate of diffusion. These combustors were the standard until about 30 years ago. The geometry is relatively simple and can be regulated very easily, thanks to the capability of diffusion flames to sustain stable combustion over a wide range of fuel/air ratios.

The main drawback of diffusion combustors is the difficulty in controlling NOx emissions. As shown in Figure 3, the primary parameter affecting NOx formation is the reaction temperaure, which is strongly dependent on the fuel/air ratio. In these combustors, due to the diffusion process, the reaction stabilizes in stoichiometric regions where the temperature and consequently, NOx formation, are high.

In this system, NOx reduction is possible by injecting steam or water. The injected diluent provides a heat sink that reduces the combustion zone temperature. As the combustion zone temperature decreases, NOx production decreases exponentially. The main drawback of these traditional systems is that they require large quantities of water that often are not available, especially in oil and gas applications.

To overcome this limitation of diffusion combustion systems, DLN sytems with premixed combustion were introduced for gas turbines (Figure 3).

In DLN systems, the fuel and the air necessary for combustion are mixed together prior to being injected into the reaction zone (Figure 3). Thus, the fuel/air ratio at which combustion occurs can be controlled and the flame temperature reduced by lean combustion to achieve a very low level of NOx production.

To obtain low NOx without blowout and high CO, the fuel/air ratio must be maintained within a relatively narrow range. Since from ignition to full load, the overall fuel/air ratio of a gas turbine varies much beyond the optimal range of a premixed flame, the implementation of special control and operating mode strategies is necessary. In the following, the possible strategies and associated combustor configurations are described.

Hybrid chamber

This chamber is able to operate in both diffusion and premix modes. Transient states accompanying ignition and startup occur in the diffusion mode. Starting from a sufficiently high load value, when the fuel/air ratio is able to sustain a stable premixed flame, the combustor switches to the premix mode.

Variable geometry

This chamber is equipped with a device, which varies the distribution of air within the chamber in relation to the load to control the fuel/air ratio in the combustion zone. This method handles partial load operation without any problems and has, in principle, no contra-indications. Its application is quite simple for turbines equipped with a single can combustion chamber but is mechanically more complicated for multi-can and annular combustion systems.

Multiple burners

The load is divided among a number of burners, each of which can operate independently of the others. At partial load, some of the burners are extinguished. One advantage of this system, which operates only on the fuel, is the absence of moving parts.

All these concepts are used in GE gas turbine combustion systems.

DLN-1 Combustion system

The DLN-1 combustor is used on all GE frames for firing temperatures below 2,100°F and is a typical two-stage premixed hybrid combustor. This is the typical DLN system used on the FR51 and FR52 C/D.

As shown in Figure 4, the main components of the combustion system are the primary and secondary fuel nozzles, liner, venturi and centerbody.

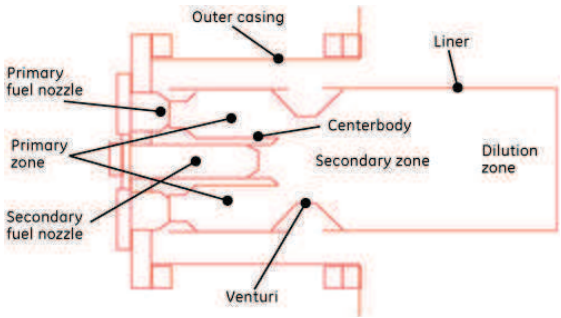

Figure 4
DLN-1 combustor

The GE DLN-1 combustion system operates in four distinct modes, illustrated in Figure 5:

1. **Primary mode –** Fuel is sent to the primary nozzles only. The flame is only in the primary zone and is a diffusion flame. This mode of operation is used to ignite, accelerate and operate the machine over low- to mid-loads.
2. **Lean-Lean –** Fuel is sent to both the primary and secondary nozzles. The flame is in both the primary and

secondary zones; the flame in the secondary zone is premixed. This mode of operation is used for intermediate loads.

3. **Secondary –** Fuel is sent to the secondary nozzle only and the flame is in the secondary zone only. This mode is a transition state between lean-lean and premixed and is used to extinguish the flame in the primary zone. After that, the fuel is re-introduced into the area that will become the primary premixing zone.
4. **Premix –** Fuel is sent to both the primary and secondary nozzles. The flame is only in the secondary zone. This mode of operation is achieved at and near the combustion reference temperature design point. Optimum emissions are generated in the premix mode.

The venturi plays a key role in the combustion process. In the primary and lean-lean modes, it provides a confined space for the diffusion flame, while in the premix mode, it separates the premixing zone from the combustion zone. In the premix mode the acceleration in the venturi throat prevents flashback and the downstream strong recirculation zone is essential for combustion stability.

The load range associated with these modes varies with the degree of inlet guide vane (IGV) modulation. With IGV modulation down to 42°, the premix operating range is 50% to 100% of the load. The 42° IGV minimum requires an inlet bleed heat system.

The spark plug and flame detector arrangements in a DLN-1 combustor are different from those used in a conventional combustor. Since the primary zone must be re-ignited at high load in order to transfer from the premixed mode back to lean-lean operation, the spark plugs do not retract. The system uses flame detectors to view the primary zone of selected chambers (similar to conventional systems) and secondary flame detectors that look through the centerbody into the secondary zone.

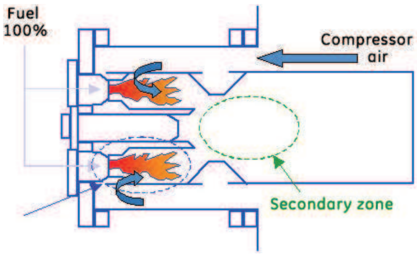

Figure 5a
Primary operation (diffusion flame) – ignition to 20% load

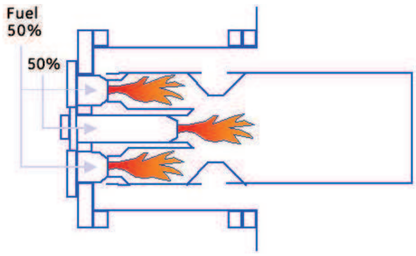

Figure 5b
Lean-lean operation – 20% to 50% load

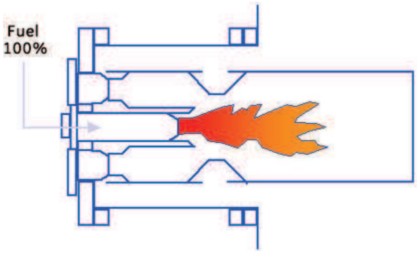

Figure 5c
Second-stage burning – transient during transfer to premixed; promary zone extinguished

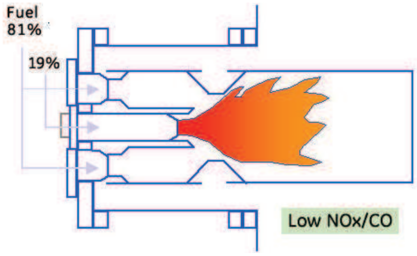

Figure 5d
Premixed operation – 50% to 100% load; primary zone converted to premixer

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DLN-2 Combustion system

The DLN-2 combustor is typically used on turbines with a higher firing temperature, for example, the MS5002E. For turbines with a high firing temperature, the use of air in the combustor other than for mixing with fuel (e.g., for cooling) would have to be strictly limited in order to have an optimal air fuel ratio in the combustion zone. In the DLN-2 system, the venturi and centerbody assemblies, which require cooling air, are eliminated in order to maintain an optimal air fuel ratio in the combustion zone.

A DLN-2 Combustion system is shown in Figure 6. The combustor system has a single burning zone formed by the combustor liner and the face of the cap. Several nozzle/premixer tube assemblies are located on the head end of the combustor and are part of the cap assembly. If the combustion system in each can has several premixers/burners, it does not take advantage of the fuel staging concept and can be considered to be a hybrid single-stage combustor. In fact, the combustor is able to operate in both diffusion and premix modes.

Figure 7 shows a typical section of a DLN-2 burner with diffusion and premixed fuel lines.

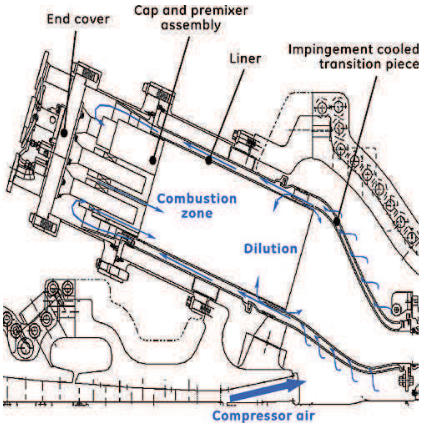

Figure 6
DLN2 combustion system

The diffusion mode is used to ignite, accelerate and operate the machine up to medium load; at higher loads, the system switches to premixed mode.

The fuel and air feeding the premix line are thoroughly mixed and flow out of the mixing tubes at high velocity to enter the burning zone where lean, low-NOx combustion occurs. Flame stabilization is provided by the recirculation zone at the premixer exit due to swirling flow and sudden expansion in the liner.

In the premix mode, an optimal fuel/air ratio in the combustion zone is maintained by regulating the IGV in a single-shaft engine or by overboard bleed in a double-shaft engine.

Figure 8 shows the endcover and burner assembly layout of the MS5002E. The MS5002E combustion system consists of 6 cans, each combustion can being equipped with five burners.

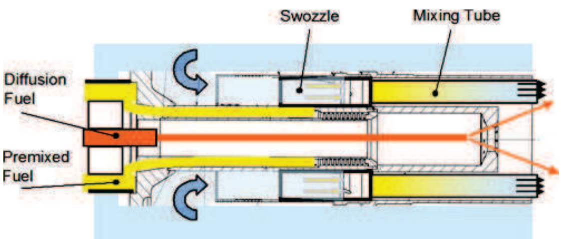

Figure 7
DLN2 premixer

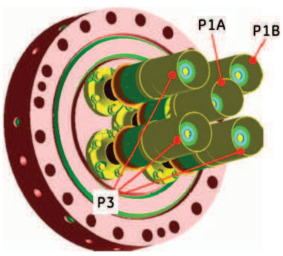

Figure 8
MS5002E endcover & burner

The five burners in each MS5002E combustion can are connected to four fuel gas adductionlines, called D5, PM1A, PM1B and PM3. There is a single diffusion fuel circuit (D5) feeding all five nozzles. Each swozzle (or swirler nozzle) has a single premixed fuel circuit. The center fuel nozzle premixed circuit (PM1A) and a single outer fuel nozzle (PM1B) are individually fed and the remaining three outer fuel nozzles (PM3) are fed from a third premixed fuel circuit.

In the diffusion mode, all five burners operate together through each burner center nozzle and generate a diffusive flame. This mode of operation is active from engine startup to 50% load. When the gas turbine reaches 50% load, an automatic transfer to the premix mode is performed, allowing a substantial reduction in NOx and CO emissions. In the premix mode, fuel gas goes through each burner swozzle to be premixed with air, and the percentage of gas through each line is optimized to reduce the overall dynamics and emissions.

Kone Combustion system

The Kone combustor is a variable geometry type, which is ideal for small gas turbines with a single can combustor. It is used in the

GE10 and PGT5 engines.

The Kone Combustion system is shown in Figure 9.

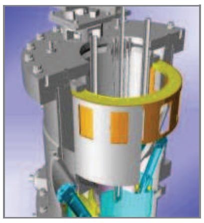

Figure 10
Combustion air valve

The compressor discharge air is introduced into the premixing channel via a variable geometry intake called a combustion air valve (CAV). This device (Figure 10) consists of two cylindrical coaxial parts, one fixed and the other movable. Both cylinders have 12 rectangular slots. By rotating around the main combustor axis, the movable cylinder makes the slots overlap by a variable amount, thereby modulating the passage area. Acting on the CAV, the control system changes the split between dilution and combustion air, optimizing the combustion fuel/air ratio at partial load.

This particular feature provides the turbine with excellent operability and turndown capability. The main fuel premixes with air and the resulting mixture is introduced into the combustion chamber, generating a flame that is stabilized by a precise amount of pilot fuel; the pilot fuel is injected at the throat and surrounds the main flame.

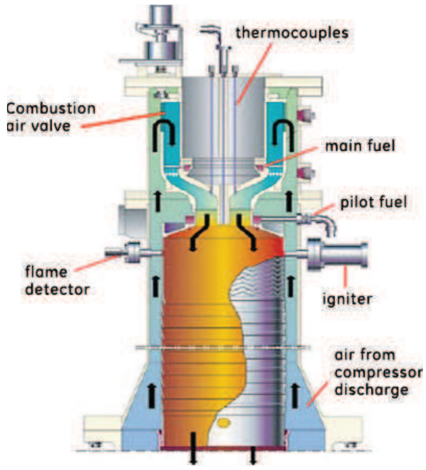

Figure 9
K-1 combustion system

To meet lower NOx emissions, an updated version of the Kone, the Kone+, was developed.

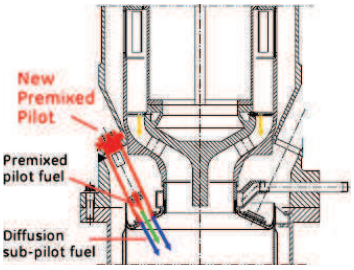

Figure 11
Kone+ combustion system

In the Kone the main flame is stabilized by the pilot fuel that burns as a diffusion flame. Due to the high temperature generated by the diffusion flame, about 90% of the total NOx is produced by the pilot fuel. To reduce this NOx source in the Kone+ combustor, the stabilization of the main flame is achieved through premixed pilot flames.

Figure 11 shows a cross section of the new layout. The new configuration consists of four premixed burners located on the cap, at intervals of 90°. In this geometry, the four premixed flames converging on the main flame provide the desired stabilizing effect.

The four new premixed burners are not fully premixed, as they in turn need stabilization; a very small amount of fuel is injected for this purpose. However, in this new configuration, the overall result is a reduction of diffusive burning fuel mass flow and consequently, a reduction of NOx emission from 25 ppm to 15 ppm.

DLE Combustion systems

DLE 1

The premixed combustion system for aeroderivative engines such as the PGT25 is typically referred to as DLE (Dry Low Emission) while the standard diffusion combustor is referred to as a Single Annular Combustor (SAC).

A section of a DLE combustor is shown in Figure 12. This is an annular type combustor with a typical multi-burner configuration. It uses the fuel staging concept to optimize the combustion air/fuel ratio at partial load.

The combustor dome (Figure 13) consists of three annular rings of premixers. The outer two annular zones each have 30 premixers while the inner annular zone has 15. This arrangement of 75 premixers facilitates fuel staging during part load power of gas turbine operation.

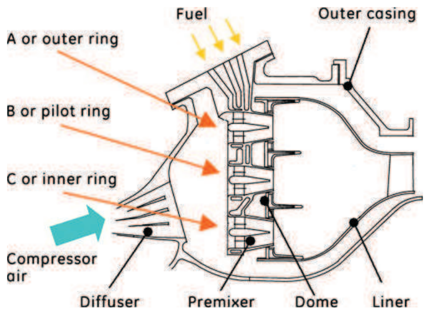

Figure 12
DLE combustor

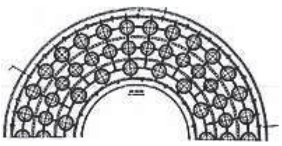

Figure 13
Combustor dome

During full load power operation, fuel flows to all premixers, and the flame temperature is at its design point. As the power is reduced, air bleed is used to maintain a nearly constant flame temperature. When the bleed limit is reached, the fuel to the inner ring of premixers is shut off. The fuel that was flowing to these premixers is then routed to the outer two rings of premixers. Simultaneously, the compressor bleed is shut off and the flame temperature downstream of the fueled premixer is restored to near its design point value to keep emissions low. As power is reduced further, this sequence is repeated until only the middle ring of premixers is fueled. Using this control strategy, it is possible to operate from start to full power in a premixed mode with the flame temperature varying little from its design point value.

Figure 14 shows the fuel stage mode of the combustor at several loads.

Figure 15 gives a cross section of a single premixer. Air enters and passes through a set of axial flow swirlers that induce highly sheared counter-rotating flow. The resulting turbulent flow mixes the fuel and air. The fuel enters the premixers through the hollow axial swirl vanes and then passes through trailing edge orifices before mixing with the air. Residual swirl remaining at the exit of the premixer helps stabilize the downstream premixed flame.

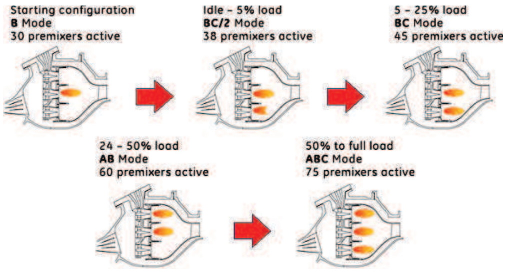

Figure 14
DLE fuel stage mode

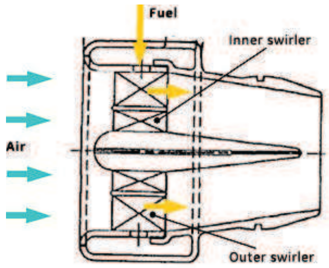

Figure 15
DLE premixer

In addition to conventional system elements, the DLE system includes solenoid actuated fuel staging valves to feed or shutoff the burner rings, a compressor bleed valve to control the average flame temperature of the active burners and metering valves to control the fuel split between the burner rings.

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DLE 1.5

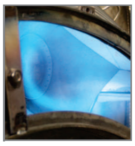


Figure 17
DLE flame

As a consequence of constantly ongoing research, a new combustor technology, the DLE 1.5, has been introduced. This combustion system, which is capable of reaching 15 ppm of NOx, has already been introduced in the LM2500 base model.

Referring to Figure 16, it may be seen that the combustor architecture has been modified in four main areas, derived from the configuration of the LM2500+ G4.

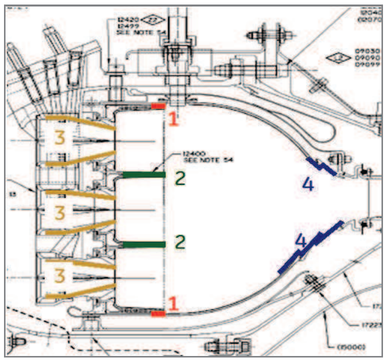


Figure 16
DLE 1.5

At the locations indicated by numeral 1, the A and C heat shields have been reduced in length and the B cup shield (#2) has been removed. These changes have led to improved uniformity of the flame temperature profile.

In addition, the premixer resize (#3) and the nugget resize (#4) contribute to modifying the cooling air flow in order to decrease the flame temperature to keep NOx values down.

These modifications to the combustion chamber are combined with the introduction of a five-metering-valve system to allow the control of additional fuel gas manifold sectors.

This translates into very high retrofitability for existing packages:

- The baseplate is generally compatible with the installation of the 5-valve single skid
- The ability to provide the combustion chamber conversion kit only
- No impact on the power transmitted along the line axis

Retrofit

All the gas turbines produced by GE Oil & Gas are retrofitable with an emission reduction system. For the engine models still in production, the emission targets are the same as the new units, but older machines can. in most cases, also be retrofitted with a Dry Low Emission combustor.

As for new unit applications, it is necessary to analyze the fuel gas composition to verify that the DLN combustion parameters are satisfied.

Turbine Model	Combustion System	NOx (ppmvd)
PGT5/PGT10	Kone	25
GE10	Kone+	15
MS3002J RC	DLN-1	35
MS5001PA	DLN-1	25
MS5002 C/D	DLN-1	35
MS5002E	DLN-2	15
PGT25	DLE 1.5	15
PGT25+	DLE 1.0	25
PGT25+G4	DLE 1.5	25

Emissions given at Base Load, ISO conditions, @ 15% O2, Simple Cycle (except MS3002 RC), Natural Gas Fueled

The items involved in the gas turbine package modification depend on a number of factors, the main ones being the following:

1. Engine model / vintage
2. Fuel system configuration
3. Enclosure / ventilation configuration
4. Control panel model / vintage
5. Inlet system configuration (for inlet bleed system in case extended turndown is requested)

The core item of the conversion is the combustion hardware of the engine and in particular, the following components:

- Combustion chamber
- Fuel nozzles
- Combustionliners
- Transition piece (where applicable)

In general it is possible to carry out the engine modification with a site activity equivalent to a combustion inspection.

The modification to the fuel gas system is done to bring the configuration to the latest standard necessary for the correct operation of the engine. On a gas fuelled engine, the items involved are the following:

- Fuel gas control valves and instrumentation
- Fuel gas lines and manifolds (package)

- Hydraulic oil lines and controls (for HD)
- Electrical Instrumentation and drivers (for jet engines)

On heavy duty gas turbines the modification to the gas control valves can be done either inside the package, adding the necessary hardware, or outside adding a dedicated fuel gas module and minimizing the impact on the existing equipment. On jet derivatives, the fuel gas system modifications are kept inside the package to respect the limits of fuel gas volumes from valves to engine.

DLN conversion generally also requires a more advanced control system, especially for speed in signal analysis and to assure the fastest response to the combustion dynamics. Therefore, another typical area of investigation, possibly requiring upgrading, is the control system:

- Control panel upgrade
- New instrumentation
- New flame detectors and igniters

Another area requiring assessment is the Balance-of-plant, especially along the inlet system and focusing on the following key items:

- Inlet system (where applicable)
- Anti-ice modification (if axial compressor bleed is used)
- Inlet bleed heating system (FR51/FR52 and larger frames)
- Ventilation for cooling purposes
- Ventilation for area classification purposes (because of the additional fuel gas connections introduced)

It is clear that, depending on the extent of the necessary modifications, the downtime will vary. In particular, in the case of a new control system (Mark VIe for a heavy duty or an aeroderivative or a Woodward Micornet for an aeroderivative), the shutdown schedule will increase accordingly.

To summarize, we can say that the base scope for the installation of a DLN/DLE system involves activities which are more invasive than a combustion inspection and less invasive than a major inspection, so it can usually be implemented within the span of a major inspection.

The following section presents a description of recent Dry Low NOx emission system retrofit projects.

PGT25

GE Oil & Gas has carried out a significant number of retrofits (about 35 projects) on the LM2500 family. Some of these projects have also involved a revision of the package to upgrade the safety systems to the latest standards. The typical application for these retrofits is in the pipeline industry.

It is important to mention that the current trend for this technology is to extend the turndown capability to 50% load while maintaining 25 ppmvd NOx. At the same time, the technology available for the LM2500 is evolving toward lower targets of 15 ppmvd with the DLN 1+ design, which is a direct flowdown of the LM6000 DLE system.

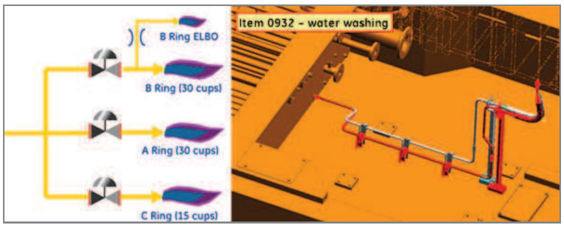


Figure 18
Three metering valves on existing baseplate

Though it is possible to retrofit the combustion section from Single Annular Combustor (SAC) to Dry Low Emission (DLE), in most cases, the approach taken is to replace the entire engine allowing a rejuvenation and the leveraging of economic incentives normally available with this option. This has no impact on the engine footprint, simplifying this portion of the scope. The number of manifolds around the machine increases and the main impact is on the arrangement of the new fuel gas skid that needs to be placed on the baseplate, generally below the engine. The skid moves from a one-valve configuration to three metering valves (for DLE 1.0) or to five metering valves (DLE 1.5).

The modification has an impact on the engine air bleeding system operation to achieve the correct combustion behavior. The control system needs to be upgraded to the latest Mark VIe. In most cases, neither the inlet system nor the exhaust system are affected, with the exception of cases where inlet bleed heating is requested for the extension of the operability range, which requires the installation of an inlet diffusor on the inlet system.

Typical NOx decreases achieved on the PGT25 fleet and exhaust temperatures are indicated below:

	NOx	Fuel gas	Exh Temp
SAC	220	Nat Gas	522°C
DLE 1.0	25	Nat Gas	529°C

Emissions given at Base Load, ISO conditions, ppmvd@15%O2, Simple Cycle

PGT5, PGT10 and GE10

Small rating gas turbines represent a large portion of the GE Oil & Gas fleet. As of today about 16 conversions have been carried out on the fleet involving the PGT5, PGT10 and GE10.

The two primary approaches that have been used are:

- Engine/Package retrofit
- Entire engine/package replacement

The GE10 in particular was installed in seven applications as a replacement for the existing gas turbine (MS3002). This approach gave a total plant rejuvenation along with the NOx emission reduction. The scope of work was quite extensive due to the removal of an existing gas turbine and compressor baseplate in lieu of a new package installation. The installed GE10-2s are equipped with the latest technology available and are capable of meeting 15ppm of NOx with a turndown capability of up to 50% of the load.

In the other projects where an engine retrofit was done, the main flange-to-flange component that was changed with respect to the previous configuration is the combustion chamber as highlighted in Figure 20.

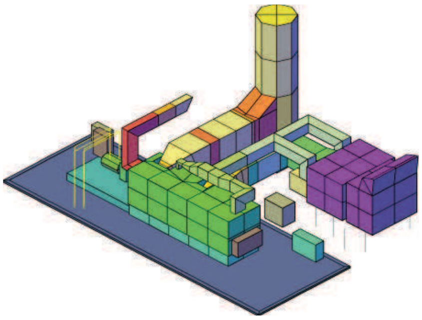


Figure 19
SOW FR3 to GE10 conversion

With this modification, the emissions were improved as indicated in the table below.

	STD	DLN	Fuel gas
PGT52/1	130/140	25	Nat gas
PGT10	270	25	Nat gas

Emissions given at Base Load, ISO conditions, ppmvd@15% O_2 Simple Cycle

All these projects involved the replacement or upgrade of the control panel. The scope depended on the model and vintage of the existing control system installed.

The actuation system of the adjustable geometries of the combustor (K-ONE) and, in general, the actuation systems involved with the modification, is preferentially electrical.

The enclosure ventilation system was verified to ensure proper cooling of the actuation system to maintain high reliability. Because of the additional fuel gas control valves and manifolds, verification of the area classification is normally requested through a CFD study. Depending on the results of the study, an increase in the number of air volumes exchanged and hence, upgrading of the ventilation system, may be required.

Figure 20
PGT5 section

MS3002J regenerative cycle

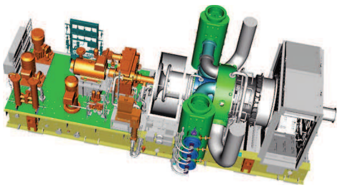


Figure 21
MS3002J RC

The MS3002 is a reliable heavy duty gas turbine widely used on pipeline applications. Recently GE Oil & Gas revisited the existing DLN system of this engine to make it compliant with the recent European regulations. This development was done in conjunction to a large rejuvenation project involving the turbo-compressors of a European pipeline owner.

The goals of the project were to extend the life of the existing fleet so that it could operate for another 20 years and to upgrade from the diffusion combustion system to DLN in order to meet 35 ppmvd of NOx from 70% to 100% of the full load.

The MS3002 model for which the Dry Low NOx system is currently available is the regenerative cycle. The existing fleet was composed of a mix of standard diffusion systems in regenerative cycle application and others in a simple standard combustion cycle. The full scope of work included brings all the FR3s to the DLN regenerative cycle configuration. Since the gas turbines were built from the 1970s to the 1990s, part of the scope of supply was the rejuvenation of the entire gas turbine train with particular attention to the following components:

- Entire new baseplate with its auxiliaries
- Inlet air system
- Recuperator and interconnecting piping
- Oil coolers
- Control system modification
- New flange-to-flanges or engine rejuvenation

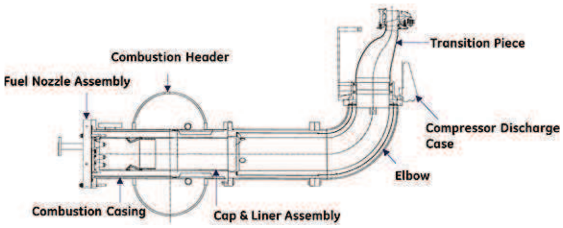


Figure 22
MS3002J RC component

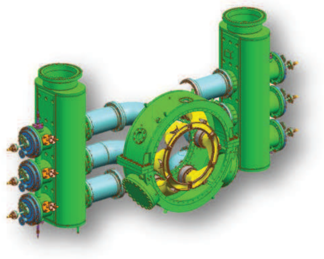
With reference to the engine modifications to the DLN system, the components involved were all the combustion items shown in Figure 22.

All the packages were extensively renewed with the replacement of all the auxiliaries. The fuel gas system was fit inside the new packages as part of the overall scope of supply.

The final results of the modification brought the NOx level into compliance with the regulations, as shown in the table below.

	Before	After
NOx	>200 ppmvd	35 ppmvd

Emissions given at Base Load, ISO conditions, @15% O_2 Simple Cycle



These limits were successfully demonstrated during the complete string test performed on the first unit at the GE Oil & Gas Massa plant at the end of 2011.

Figure 23
RC cycle on MS3002J

MS5001, MS5002, MS6001, MS7001 and MS9001

GE has been upgrading a significant number of MS5001, MS5002, MS6001, MS7001 and MS9001 gas turbines to DLN-1 systems. In general, a similar approach and the same critical factors discussed for the other models are applicable.

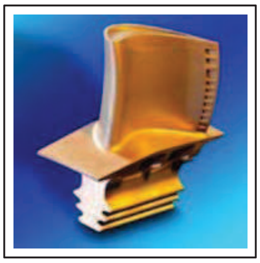
It should be noted that this large installed fleet of GE gas turbines is composed of several different models with a large variation in combustor operating temperatures. Over the years, combustor operating temperatures have been increased, allowing higher firing temperatures, through the introduction of improved materials in the new generation of machines. The conversion to DLN is usually facilitated by higher firing temperatures because this allows larger operating ranges; hence, there is always the opportunity, when converting an older GE Frame to DLN, to bring the engine hardware to the latest standards available. This has the additional benefit of allowing an increase in the output power of the engine. The increased turbo-compressor or genset output might be an added value for the site.

Conclusions

Research on new technologies to protect the environment is always underway. This continuous development has led to a NOx abatement system capable of limiting NOx emission levels to 25 ppm and in many cases even lower. This offers customers a path to reduce the impact on the environment and to be in compliance with government regulations by upgrading existing gas turbines with the latest DLN/DLE technology.

Annex 3:
Solar's Dry Low Emissions Technology, Capability and Experience

April 04, 2015



Solar's Dry Low Emissions Technology, Capability and Experience

Solar Turbines

A Caterpillar Company

Contents

Solar's Dry Low Emissions Technology, Capability and Experience

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INTRODUCTION

The trend to lower gas turbine emission levels over the last 35 years has been driven by regulation, competition, and customer needs. Regulatory requirements are ever changing and vary significantly around the world. The gas turbine industry has responded to the need of the industry to meet these lower emission levels. Since the early 1990s, gas turbine manufacturers have introduced dry low emissions (DLE) gas turbine products based on lean-premixed combustion. Solar has been a leader in low emissions combustion systems and has placed more than 3000 gas turbines into service that incorporate its *SoLoNOx*™ DLE system.

Despite the significant improvement in gas turbine emissions, regulatory agencies continue to consider and implement more stringent requirements. As technology advances and regulatory levels continue to ratchet down, Solar is positioning itself to be technically prepared for future emissions requirements by continuing its significant investment in the development of technologies that will meet the anticipated market needs.

This paper provides a broad overview of Solar's low emissions technology and the recent developments that are enabling Solar to provide products that meet custom emissions requirements.

LEAN-PREMIXED COMBUSTION

Solar's *SoLoNOx* system employs lean-premixed combustion to reduce nitrogen oxides (NOx) emissions. Lean-premixed combustion reduces the conversion of atmospheric nitrogen to NOx by reducing the combustion flame temperature. Since NOx formation rates are strongly dependent on flame temperature, lowering flame temperature (by lean operation) is an extremely effective strategy for reducing NOx emissions (Figure 1). Further reductions in emissions are achieved by premixing the fuel and combustor airflow upstream of the combustor primary zone. This premixing prevents local hot spots within the flame.

There are five aspects of lean-premixed combustion that are discussed in the subsequent sections:

- CO / NOx Tradeoff
- Operating Range
- Combustor Instability
- Ambient Operating Range
- Fuel Composition Variation

CO / NOx Tradeoff

Since the optimum flame temperature of a lean-premixed combustor is close to the lean flammability limit, lean-premixed combustor performance is characterized by a CO / NOx tradeoff (Figure 2). At the combustor design point, both CO and NOx are below target levels. However, deviations from the design point flame temperature cause emissions to increase. A reduction in temperature tends to in- crease CO emissions due to incomplete combustion; an increase in temperature will increase NOx. This tradeoff must be addressed during part-load turbine operation when the combustor is required to run at an even leaner condition overall. The tradeoff also comes into play in development efforts to reduce lean-premixed combustor NOx emissions by further reducing the primary zone design point temperature.

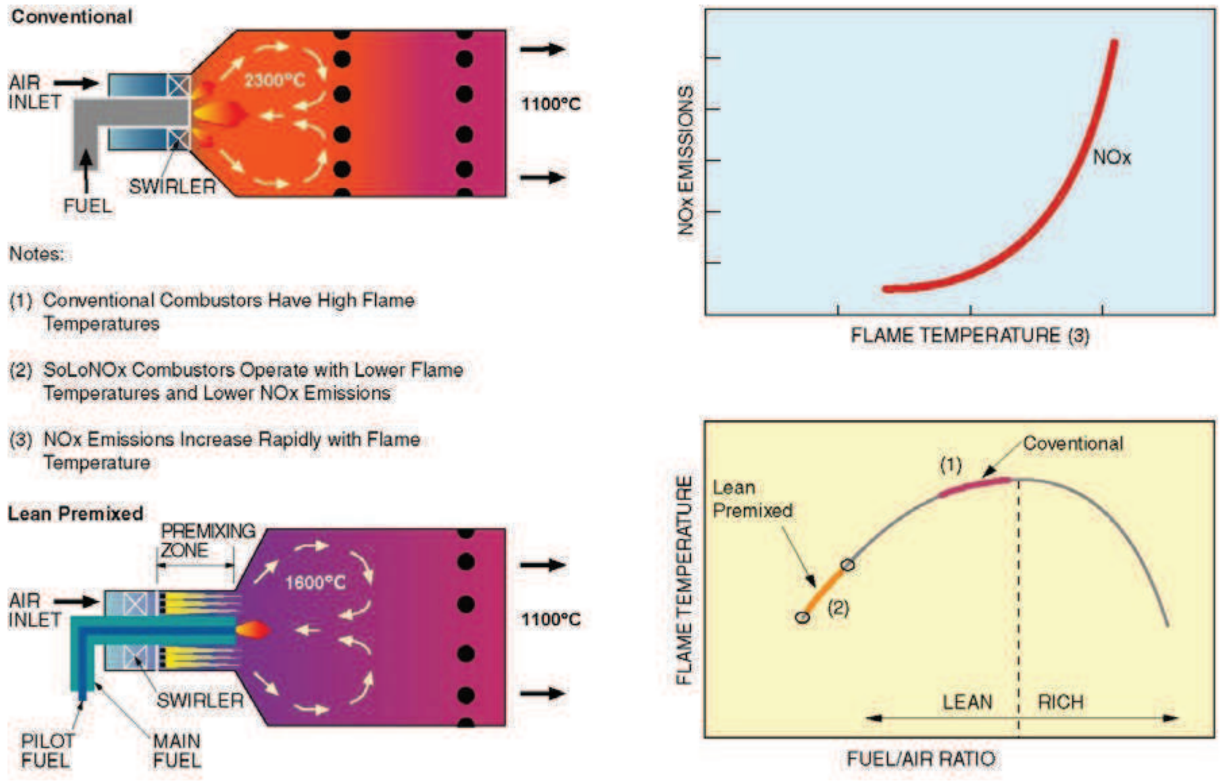


Figure 1. How Lean-Premixed Combustion Reduces NOx Emissions

Combustor Operating Range

Without any engine control to maintain a constant flame temperature, as a gas turbine moves away from full-load operation, a lean-premixed combustor will quickly produce increased CO emissions, the combustion will become unstable, and flame-out will ultimately occur. To broaden the operating range, low emission gas turbines use combustor air-flow control within the gas turbine to maintain a nearly constant flame temperature.

Combustor airflow control is achieved with compressor air bleed at part-load for two-shaft engines. Compressor bleed air is vented to the exhaust stack of the gas turbine package. Single-shaft gas turbines use the inlet guide vanes (IGV) to restrict airflow entering the combustor at part load. Unfortunately, regulating the IGV is not effective on two-shaft gas turbines.

Combustion Instability

A characteristic of lean-premixed combustion systems, experienced by all gas turbine manufacturers, is combustion instabilities. These occur as either low-frequency combustor "rumble" or higher-frequency combustor pressure oscillations.

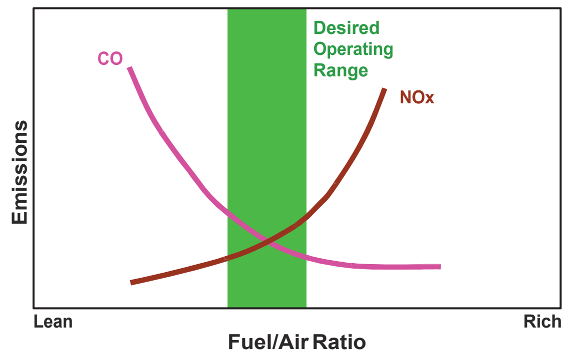


Figure 2. Typical Lean-Premixed Combustor Emissions

Simply put, lean flames have a greater tendency to cause combustion instabilities that can lead to engine damage if not addressed. It is recognized that the reduced stability of a lean-premixed flame contributes to these oscillations.

A successful DLE gas turbine has addressed combustor instabilities during product development to be certain that high level pressure oscillations do not occur during normal operation at any operating condition. Solar has been very successful at dealing with both combustor rumble and pressure oscillations with *SoLoNOx*.

Ambient Operating Range

The lean-premixed combustion system must be capable of operating over a broad range of ambient conditions. Changes in ambient conditions that affect the combustor primary zone temperature can influence emissions. Based on experience with conventional combustion, the ambient conditions that have the potential to impact emissions performance on DLE combustion systems include relative humidity, barometric pressure, and ambient temperature. Factory testing and field experience has shown that relative humidity and barometric pressure have only a minor effect on the combustor primary zone temperature and, thus, a nearly negligible influence on emissions from DLE gas turbines.

The influence of ambient temperature on emissions can be more significant. Ambient temperature has a direct impact on the primary zone temperature, but also influences how the DLE gas turbine is controlled. The gas turbine power and speed are limited differently as ambient temperature is reduced, which has a direct impact on full-load combustor primary zone temperature. In practice, emissions from *SoLoNOx* packages typically vary less than a few ppm from -29° to 38°C (-20° to 100°F). Figure 3 illustrates the relation between NOx and ambient temperature for a Titan™ 130 *SoLoNOx* operating at a compressor station in Canada. Similar data have been collected on Mars®, Taurus™70 and Taurus 60 *SoLoNOx* gas turbines.

For colder conditions, *SoLoNOx* packages are generally configured to increase pilot fuel flow at temperatures below -20°C (0°F) to augment flame stability. Therefore, below -20°C (0°F) the NOx and CO emissions increase. Because of this, the standard emissions warranty is limited to ambient temperatures above -20°C (0°F).

In order to compensate for changes in ambient conditions, *SoLoNOx* packages are required in factory test to operate with an emissions margin below the warranty level. For part-load operation, the engine low emission control system includes biasing for ambient temperature.

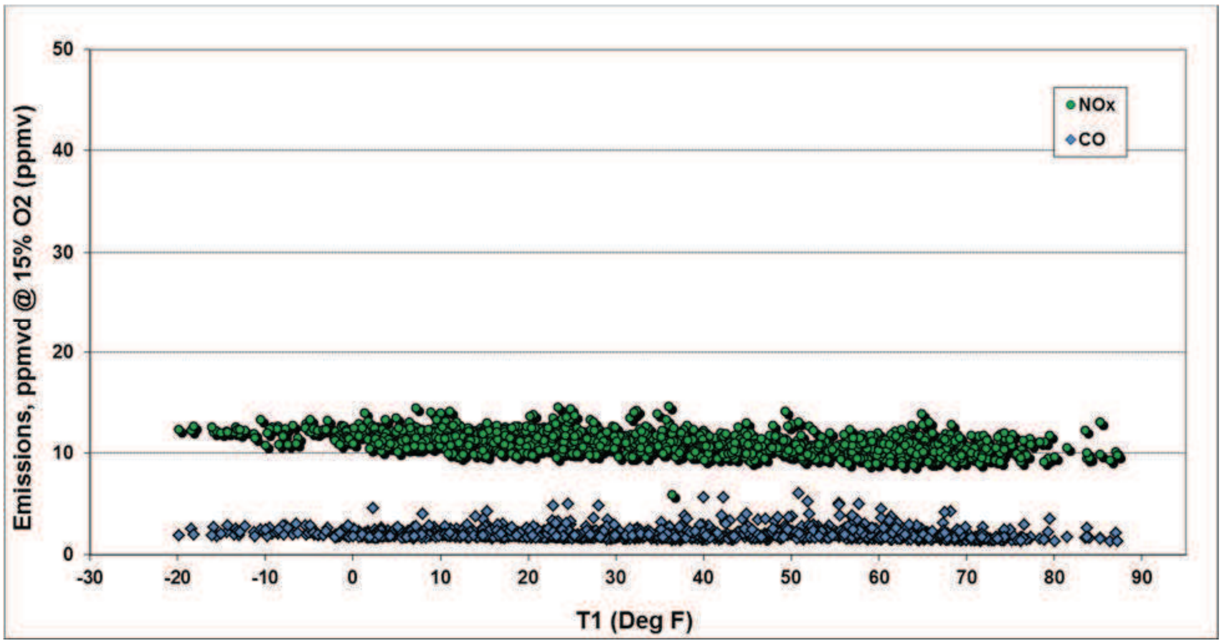


Figure 3. Emission Trends with Variation in Ambient Temperature on Titan 130 SoLoNOx Gas Turbine

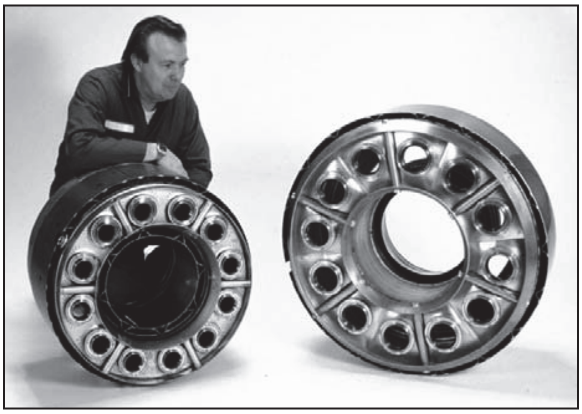


Figure 4. Conventional and SoLoNOx Combustor Liners

FUEL COMPOSITION VARIATION

The lean premixed combustion system must be capable of using fuels with variation in composition and properties. *SoLoNOx* gas turbines were designed to operate on "pipeline quality" natural gas and liquid distillate fuels such as #2 Diesel and kerosene as defined in Solar's Fuel Specification (ES9-98).

For lean premixed combustion systems gas fuels are characterized by Wobbe Index, auto ignition delay time, laminar flame speed and dew point. *SoLoNOx* engine testing has been completed with different gaseous fuel blends to represent the range of fuels found in pipeline applications with little measureable effect on emissions. Gas blends with broader variations in gas composition to simulate raw natural gas and gases associated with oil recovery have also been successfully operated in *SoLoNOx* gas turbines. A slight increase in NOx emissions is evident with more extreme variations in gas composition.

COMBUSTION SYSTEM DESCRIPTION

The unique *SoLoNOx* gas turbine components compared to a conventional combustion turbine include:

- Combustor liner
- Fuel injectors
- Combustor air management (bleed valve and inlet guide vane control)
- Control system
- Fuel delivery systems

Combustor Liner

The lean-premixed combustor liner is generally similar to a conventional liner in terms of geometry, materials and construction. The most significant difference is an increase in combustor volume (Figure 4). The larger volume is required to ensure complete combustion and low CO and UHC emissions at the lower overall flame temperature of the lean-premixed combustor. The increased combustor volume was achieved by increasing the outer liner diameter. The larger liner required an increase in the diameter of the combustor housing (Figure 5).

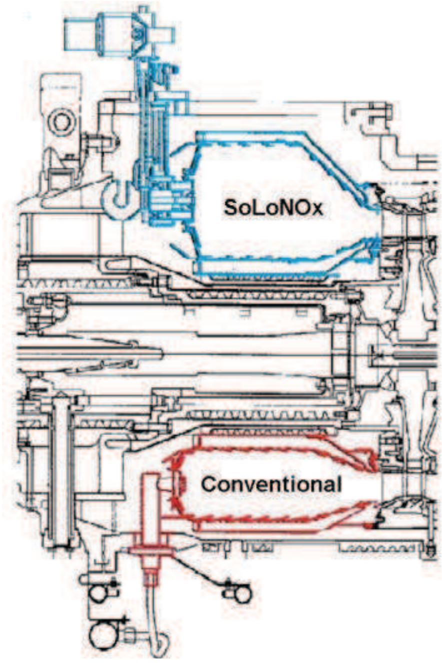


Figure 5. SoLoNOx and Conventional Combustion Systems.

A second difference in the lean-premixed liner is the absence of large air injection ports in the combustor primary zone. All air used in the combustion process is introduced through the air swirlers of the fuel injectors. The remaining air delivered by the compressor is used for cooling the walls or for dilution to achieve the specified radial temperature profile and pattern factor at the combustor exit.

Combustor liner cooling techniques used at Solar include film (louvered and effusion) and backside cooling.

Louver Cooling

First-generation production *SoLoNOx* combustors use louvers on the inside of the liner to direct air axially along the walls to produce a protective film of cooling air between the wall and the hot combustion gases (Figure 6). Combustor liners with louver cooling were used in Centaur® 50, Taurus 60, Taurus 70, and Mars gas turbines and many are still in service. The Centaur 40 is still produced with these combustor liners. The cooling air film gradually mixes with the hot gas stream;

thus, a succession of louvers must be placed along the liner to maintain the required temperatures. This method of wall cooling uses relatively high levels of cooling air because the wall just downstream of the louver must be overcooled in order to keep the wall adjacent to the next louver below the maximum temperature limit.

Effusion Cooling

A second generation combustor liner using effusion cooling was in production for Taurus 70, Mars and Titan 130 gas turbines and is still in use in many units in the field. Effusion cooling of the combustor walls uses 20% less cooling air compared to the louver cooled liner.

Reducing the liner cooling air resulted in a significant reduction of CO and UHC emissions. The injection of cooling air along the combustor wall can quench the combustion reactions in the wall region, thus contributing to CO and UHC emissions. This quenching process leads to high CO emissions because the CO, a combustion intermediate, is prevented from oxidizing to CO2.

The basic geometry of the effusion-cooled liner is the same as the louvered version. Effusion cooling is obtained by starting a film of air with a cooling louver at the front of the combustor and then continuously feeding this film with additional air through a multitude of small diameter holes drilled at a shallow angle to the wall surface (Figure 7).

Augmented Backside Cooled (ABC)

The current generation of combustor liners used in *SoLoNOx* Centaur 50, Mercury 50, Taurus 60, 65 & 70, Mars, Titan 130, and Titan 250 gas turbines applies Augmented Backside Cooling technology. The ABC technology does not promote reaction quenching and so, provides a two-fold benefit in terms of emissions. First, CO emissions are greatly reduced. Second, the lower CO levels allow combustor re-optimization to a lower flame temperature. This produces lower NOx levels along with the lower CO concentrations. Figure 8 shows how the ABC liner reduces CO emissions and the corresponding optimum fuel/air ratio reduces NOx emissions.

ABC liners forego cooling air injection into the combustor volume completely. Instead, combustor wall temperatures are controlled solely through convective cooling by a high velocity airstream on the cold side of the liner (Figure 9). In most instances, the high heat flux from the flame requires augmenting of the backside convective process to keep liner wall temperatures.

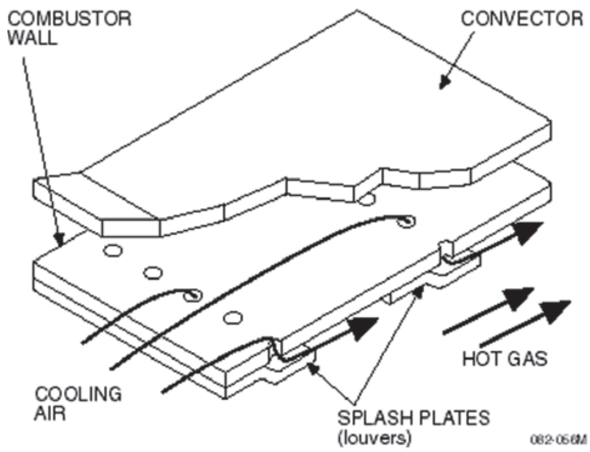


Figure 6. Louver Cooling Design

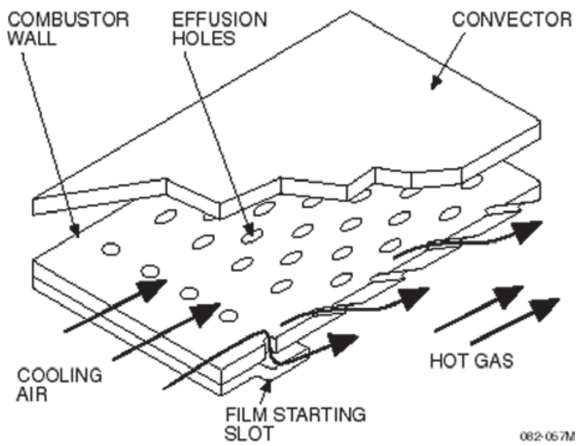


Figure 7. Effusion Cooling Design

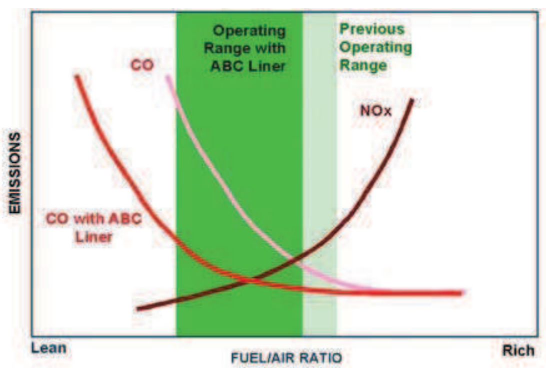


Figure 8. Extension of Design Range with ABC Combustor Liner for Low Emissions

This is accomplished with the use of impingement jets or turbulence generators in the form of trip strips, fins, and pins, which act to increase the cooling flow turbulence at the liner wall and augment the heat removal process.

An additional degree of liner protection is achieved through the application of a thermal barrier coating (TBC) on the hot sides of the liner walls. These TBCs are frequently composed of zirconia-based materials that are plasma-sprayed on the liner.

Acceptable liner durability is a key requirement of any liner cooling technique. It is determined by two factors: temperature and temperature gradient. Wall temperatures must be kept sufficiently low to prevent long-term oxidation or thermal creep. Solar's experience indicates that, in most circumstances, a wall temperature limit of 872°C (1600°F) provides excellent life. This criterion is applied to the design of all Solar gas turbine liners.

Excessive thermal gradients along the liner wall can lead to high stress concentration gradients that cause buckling or cracking. The thermal gradients in Solar's liners have been determined to be acceptable for long liner life. All three liner cooling configurations have demonstrated durability in excess of design targets.

Fuel Injectors

Incorporating lean-premixed combustion into gas turbines also required significant change to the fuel injector. As seen in Figure 10, *SoLoNOx* injectors are significantly larger than the conventional combustion counterpart. The size increase is required to accommodate higher airflow through the injector air swirler and the larger volume of the premixing chamber used to mix the fuel and air. The injector module includes a premixing main fuel injector and a pilot fuel injector.

SoLoNOx engine models use two different injector platforms based on the air swirler configuration. The Centaur 40 & 50, Mercury 50, Taurus 60 & 70, Mars, and Titan 130 gas turbines use an axial swirler where air enters axially along the injector centerline. The Taurus 65 and Titan 250 engines use a radial air swirler where the air enters perpendicularly to the injector centerline. The injector pictured in Figure 10a uses an axial swirler. Figure 10b is a photograph of a Titan 250 injector with a radial air swirler.

Main Fuel Circuit

The premixing main fuel injector uses the swirler to impart a high degree of swirl to the primary zone air. Natural gas is injected into the air through multiple spatially distributed orifices. Uniform mixing of the fuel and air occurs within the annular premixing chamber prior to reaching the combustor primary zone. The strong swirl stabilizes the combustion process in the primary zone by establishing a recirculation zone that draws reacted hot gases back upstream, thus providing a continuous ignition source. Lowest emissions are achieved at higher engine load, when more than 90% of the fuel is introduced through the main fuel circuit.

Pilot Fuel Circuit

The pilot fuel circuit within the injector provides partial premixing of air and fuel prior to combustion. During light-off and low-load operation, a substantial percentage of the fuel passes through the pilot circuit, providing a rich fuel/air mixture.

Combustor stability is enhanced in this mode compared to lean-premixed operation, although NOx and CO emissions are higher. Above 40 to 50% engine load, the pilot fuel is reduced to less than 10% of the total fuel flow to optimize emissions performance. The pilot fuel may also be momentarily increased during significant load transients to help stabilize the flame.

Figure 9. ABC Combustor Cross Section

Figure 10a. Comparison of Taurus 60 SoLoNOx and Conventional Combustion System Fuel Injectors

Figure 10b. Titan 250 Fuel Injector

Combustor Air Management

Three techniques are currently used on *SoLoNOx* engines to control the airflow to maintain the primary zone fuel/air ratio to its optimum, low-emissions level during part-load engine operation. Two of the techniques, used on all the engine models except the Mercury 50, are applied based on the engine shaft configuration. For reference two shaft engines are generally used for compressor set or mechanical drive package applications while single shaft engines are typically used for generator sets. The exceptions are for the Mars and Titan 250 gas turbines that are only available in a two shaft configuration and hence are used for all package applications.

In two-shaft gas turbines, the amount of air entering the combustor is regulated by bleeding air from the combustor casing at part load. The amount of bleed air is regulated by a specialized bleed valve. Bleed air bypasses the turbine and is readmitted to the flow path in the exhaust collector. A consequence of air bleed, however, is a reduction in engine part-load thermal efficiency since the compressed bleed air no longer enters the turbine section of the engine.

Single-shaft gas turbines, maintain optimum primary zone fuel/air ratios by modulating the compressor inlet guide vanes (IGV). Closing the IGVs reduces the airflow through the engine compressor and combustor. Regulating IGVs for single-shaft engines to control combustor airflow has a minor reduction in part-load thermal efficiency. Unfortunately, IGV airflow management is not effective on two-shaft machines since, with a separate power turbine shaft, the gas producer turbine speed cannot be maintained with a reduction in compressor airflow at part load.

The resulting variation in emissions with engine load is shown in Figure 11a. The combustor airflow management is active from approximately 50 - 100% load. The system is operated to maintain the optimum flame temperature over this load range. At lower loads, the pilot is increased and the combustor air management control algorithm is curtailed. A corresponding increase in emissions is evident.

For the Titan 250 the bleed valve control has been improved to extend combustor air flow to 40% load. In addition, the bleed valve is actively controlled down the idle. The pilot is increased at a slower rate as engine load is decreased from 40% load to idle. The corresponding emissions signature for the Titan 250 is significantly lower at lower loads when compared to the other engine models as depicted in Figure 11b.

The third combustor air management technique is used exclusively by the Mercury 50. This recuperated gas turbine makes use of an air diverter valve (ADV) located in the engine flow path to directly control the split of airflow between liner and injectors over the engine load range. This technique allows more precise control of primary zone temperature, and is an integral part of the Mercury 50's ability to guarantee single digit NOx emissions. The design also allows the Mercury 50 to operate with a high thermal efficiency over the full load range.

Control System

Engine controls have also been changed to incorporate *SoLoNOx*. This includes the capability to regulate the combustor airflow and pilot fuel flow over the engine operating map. The requirement to control these two parameters has added modest complexity to the *SoLoNOx* control system that is not required for a conventional engine, but can be easily handled by modern control systems.

During start-up and low-load operation, the pilot flow rate has been optimized to achieve maximum flame stability for the most rapid and flexible transient capability. Over the low emissions load range the control system modulates either the bleed valve or IGV to keep the combustion primary zone temperature within a specified range to operate with a low emissions signature.

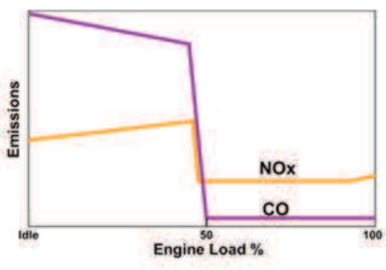


Figure 11a. Emission Trends with Variation in Engine Load for all SoLoNOx Engine Models Except Titan 250.

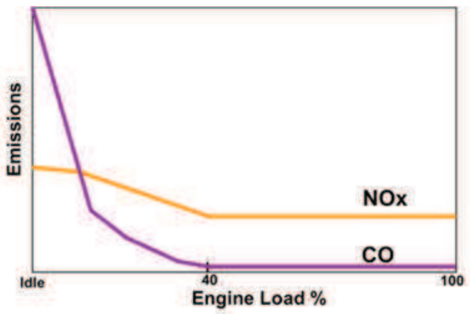


Figure 11b. Emission Trends for Titan 250

Accurate control of the primary zone temperature is critical to controlling NOx and CO emissions. *SoLoNOx* requires highly accurate electric actuators to ensure repeatable and precise emissions control. The benefits of using precise actuators extend beyond emissions to other elements of engine performance and transient response. The *SoLoNOx* gas turbine controls use the power turbine inlet temperature (T5) as an indirect measurement of the primary zone temperature to control the bleed valve or IGV position as a function of engine load.

A robust system for measuring combustor instabilities is included with *SoLoNOx* packages to measure combustor pressure oscillation and rumble amplitudes. The Burner Acoustic Monitor (BAM) alarms when oscillations or rumble exceed threshold values. *SoLoNOx* gas turbines go through extensive development and qualification to validate that combustion instabilities will not occur under normal operating conditions. Solar's experience is that when instabilities occur in the field they are most often due to fuel quality issues causing injector plugging or incorrect set-up or functioning of the fuel and bleed system hardware or controls.

FUEL DELIVERY SYSTEMS

Solar's SoLoNOx gas turbines also included changes to the fuel system.

Gas-Only Fuel System

The natural gas fuel system for *SoLoNOx* gas turbines includes two separate fuel circuits: one for the pilot system and one for the main. Separate fuel manifolds are used to supply pilot and main gas to the respective fuel circuits of each fuel injector. The fuel flow split between main and pilot is controlled with an accurate and fast response electronic valve on the pilot line. High quality, accurate, precise and fast fuel valves are required for *SoLoNOx*. During start-up and low-load operation, higher flow rates of pilot are used. When the engine is in the low-emissions mode, the pilot fuel valve throttles the pilot fuel flow to low levels. The low-pilot flow is still required to stabilize the flame.

Dual Fuel Systems

SoLoNOx gas turbines with dual fuel capability are designed to accommodate natural gas and light distillates. These systems employ unique fuel injectors with main and pilot fuel delivery flow paths for both gas and liquid. The injector design basis is similar to the gas only injector previously described, with many of the gas injection features identical on both. As with gas injection, the main liquid is premixed with the injector swirler air to burn in a lean premixed, low-emissions mode. Liquid fuel is injected into the premixing passage through multiple points for uniform distribution. Liquid pilot fuel is introduced through an airblast atomizer that injects directly into the primary zone of the combustor and burns as a stable diffusion flame. Liquid pilot is used to augment flame stability and support engine transients, as was described for the gas only engines.

The gas turbine package fuel system for dual fuel *SoLoNOx* is based on the conventional dual fuel gas turbine package fuel system and controls. Controls and a fuel distribution system have been added for pilot fuel injection capability. A pilot fuel splitter valve is used to regulate the amount of fuel flow between the main and pilot fuel passages.

A robust liquid fuel purge system has also been implemented for the *SoLoNOx* gas turbine package. Removing liquids from the injector after liquid fuel operation is essential to prevent injector fouling. Liquid remaining within the injector will form carbon and tar deposits that can block liquid passages.

EMISSION CAPABILITY

SoLoNOx gas turbines operate with a 10 to 20 fold decrease in NOx emissions when compared to the same engine model with conventional combustion. This benefit is shown graphically in Figure 12. The emissions options available for *SoLoNOx* engines models operating on pipeline natural gas for new production shipments are included in Table 1.

DLE GAS TURBINE FUEL FLEXIBILITY

Solar's *SoLoNOx* engines have been designed to operate on "pipeline quality" natural gas, diesel and kerosene. While these fuels are readily available in the industrialized world, large markets exist in developing countries and on offshore oil and gas platforms where the fuel composition is not as refined. Typically, these gas fuels contain higher concentrations of ethane, propane, and butane than a pipeline quality natural gas fuel. In addition, liquid fuels such as NGLs and naphtha's are also commonly used.

The fuel flexibility of *SoLoNOx* gas turbines has been extended to allow the use associated and raw natural gas fuel. Figure 24 indicates current *SoLoNOx* fuel capability for gas fuel Wobbe Index. With Solar's conventional combustion gas turbines an even broader range of fuels can be used both in terms of wobbe range and fuels composition. The challenges associated with using these fuels in DLE gas turbines include their influence on flame location within the premixing injector, combustor oscillations, and emissions performance. The *SoLoNOx* combustion system is being evaluated with these fuels.

Fuel Quality Considerations

In order to minimize gas turbine operational problems and maximize availability, the gas turbine manufacturer and the end-user must work closely together so that both parties fully understand what fuels will be used in the gas turbine to define the best combustion configuration for a specific application. Solar defines fuel quality requirements in the Engineering Specification ES 9-98. In addition, recommended fuel handling practices to control fuel contaminants are described in Product Information Letter (PIL 162).

DLE EXPERIENCE

Production Centaur, Taurus, Mars, Titan and Mercury *DLE* gas turbines are used extensively in the Oil & Gas and Power Generation industries. Applications include natural gas transmission, oil and gas platforms, continuous and peaking-duty simple-cycle and cogeneration power generation, and mechanical drives for many varieties of industrial and gas transmission applications. In these applications, *SoLoNOx* engines have offered reduced emissions capability from extremely low ambient temperatures in Alaska, Canada and Siberia to very hot conditions found in the deserts of the Arabian Peninsula. In addition, *SoLoNOx* applications using alternative fuels have become common with hundreds of applications using associated gases, and raw natural gases. The Mercury 50 has been used extensively in landfill and digester gas applications.

As of January 2015, cumulative *SoLoNOx* operating experience for all engine models has surpassed 209 million hours. This operating time has been gained on more than 3000 engines. This considerable experience illustrates how complete the market acceptance of *SoLoNOx* gas turbines has been. In addition, more than 375 dual fuel and liquid only *SoLoNOx* units have been sold.

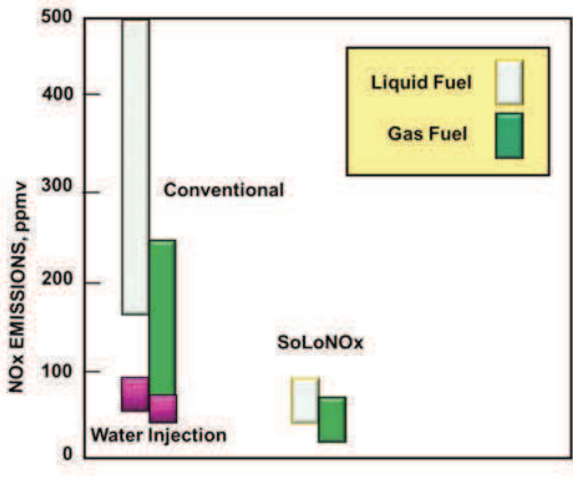


Figure 12. Comparison of NOx Emissions Performance between SoLoNOx and Conventional Combustion Gas Turbines

DLE GAS TURBINE ADVANCES

Emission regulations for industrial gas turbines continue to drive reductions in NOx, CO and UHC. Solar is continuing to invest in future DLE gas turbines that will be needed to meet these lower levels and to increase operating range with low emissions and fuel flexibility. The product strategy is that Solar continues DLE combustion development work as the preferred approach to meet these future requirements as opposed to using exhaust clean up. From a life-cycle cost perspective, preventing pollutant formation has been shown to be more cost effective.

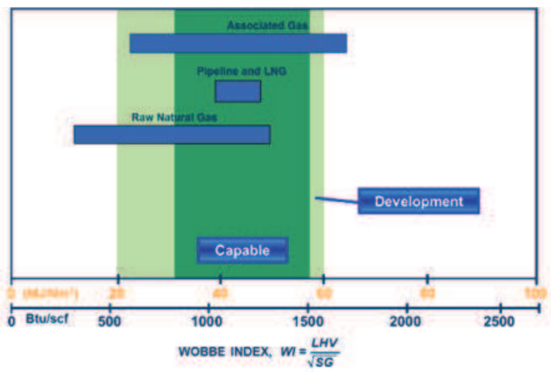


Figure 24. Gas Fuel Flexibility of Current (dark) and Future (light) SoLoNOx Gas Turbines

SUMMARY

Solar's *SoLoNOx* gas turbines and packages utilizing lean-premixed combustion have been in operation for more than 23 years. With an experience base of more than 3000 units, Solar remains an industry leader in DLE technology. *SoLoNOx* gas turbines are in service using a broad range of gas fuels (pipeline natural gas, associated gas, raw natural gas, digester and landfill gases) and liquid fuels including diesel #1 and #2 and kerosene. With pipeline natural gas standard emissions warranties are commonly offered as low as 15-ppm NOx and 25-ppm CO. It should be noted that the emission level that can be provided is contingent on review of site-specific project details such as fuel composition, ambient conditions, and operating profiles; ongoing support of warranty levels requires strict adherence to fuel quality requirements and gas turbine maintenance schedules.

Solar's emissions strategy continues to be focused on pollution prevention as the preferred approach to exhaust clean up. Development of the *SoLoNOx* combustion system is continuing to improve reliability, extend operational flexibility with low emissions, and increase fuel flexibility.

Solar is committed to remaining a DLE leader, offering gas turbine products that are environmentally compliant, durable, and cost effective. Solar intends to have gas turbine products available with the required emission reduction capability when customers need them.

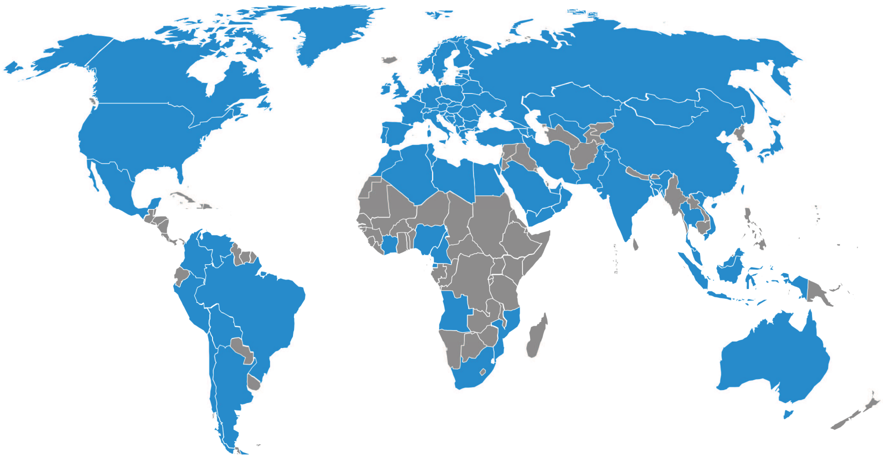
Table 1. Gas Available Emissions Options – Natural Gas[1]

	Mercury™ 50		*Titan™ 250* *Titan 130* *Mars® 100* *Mars 90* *Taurus™ 70* *Taurus 65* *Taurus 60* *Centaur® 50*		*Titan 250* *Titan 130* *Mars 100* *Mars 90* *Taurus 70* *Taurus 65* *Taurus 60* *Centaur 50* *Centaur 40*		*Titan 250* *Titan 130* *Mars 100* *Mars 90* *Taurus 70* *Taurus 60* *Centaur 50* *Centaur 40*	
	ppm	mg/Nm^3	ppm	mg/Nm^3	ppm	mg/Nm^3	ppm	mg/Nm^3
NOx	5	11	15	30	25	50	38	80
CO	10	13	25	30	50	64	50	64
UHC	10	8	25	18	25	18	25	18
Load Range[2]	50-100%		50-100%		50-100%		50-100%	
Ambient Temperature	0 to 120°F (–20 to 49°C)		0 to 120°F (–20 to 49°C)		0 to 120°F (–20 to 49°C)		0 to 120°F (–20 to 49°C)	

Notes:

1. Gas fuel must meet or exceed the requirements of Solar's engineering specification ES9-98 "Fuel, Air, and Water (or Steam) for Solar Gas Turbine Engines"
2. The load range for the *Titan* 250 is 40-100%

NOTES



The International Gas Union (IGU) was founded in 1931 and is a worldwide non-profit organisation promoting the political, technical and economic progress of the gas industry with the mission to advocate for gas as an integral part of a sustainable global energy system. The IGU has more than 142 members worldwide and represents more than 97% of the world's gas market. The members are national associations and corporations of the gas industry. The working organisation of IGU covers the complete value chain of the gas industry from upstream to downstream. For more information please visit **www.igu.org**

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