MEDGAZ: THE NEW DIRECT GAS LINK BETWEEN ALGERIA AND EUROPE VIA SPAIN

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0. Abstract

2011 saw the start of commercial operations of the MEDGAZ deep offshore pipeline, the new direct link between Algeria and Europe, via Spain. The MEDGAZ project successfully overcame the challenges of laying a 24inch ultra deep water gas pipeline (2,155 meters) in the west area of the Mediterranean Sea, finally achieving a project conceived already during the 70s. This paper summarizes the key technical challenges faced during the design and construction phases of the project. These technical challenges range from design engineering considerations to pipe lay technology and to onshore installations start-up. Design issues discussed include offshore pipe route optimization taking into consideration geo-hazards and sea bed characteristics. Pipe lay of a 24-inch gas pipeline below 2,000 meters depths was, without doubt, the most complex part of the entire work. Commissioning of the offshore pipeline and the onshore installations represented the last challenges before commercial operations. The solution to the technical problems encountered have contributed to consolidate the technology faced by trunk lines in ever great depths and will most likely be beneficial to future similar projects.

This paper presents as well a summary of the non-technical challenges faced by an international major gas pipeline project. The alignment of all related Stakeholders defined the critical path of the project in terms of timing. A strong and committed shareholding allowed defining clear targets and principles. Support from the related Authorities, those in Algeria, in Spain and at the European Union level, was a key element for success.

Finally current operational challenges are presented, both short term and long term. Short term challenges seek to consolidate MEDGAZ as an international gas pipeline operator. Long term challenges seek to expand the current transportation capacity.

Figure 1: The MEDGAZ pipeline route Algeria -Spain West Mediterranean – NASA satellite view

1. Background

MEDGAZ is the company responsible for the design, construction and operation of the new direct gas link between Algeria and Europe, via Spain. It is the first ultra-deepwater pipeline laid in the Mediterranean Sea, in the west side of the Mediterranean, directly linking a producing country, Algeria, to the European gas market.

The idea of an offshore direct gas pipeline linking Algeria to Spain dates from the 70s, when sea corridors were studied by the Segamo project. At that time there was no technology available for laying an ultra-deep gas pipeline, as depths in the west Mediterranean Sea corridor are close to 2,000 m. It was in the year 2000 when during a high management level meeting between the national oil company (NOC) Sonatrach and the Spanish oil company CEPSA the foregone project of a direct gas link was brought back on the table upon the realisation that improved pipe lay technologies allowed now for construction of that project already conceived 30 years before.

In 2001 the company MEDGAZ S.A. was created by Sonatrach and Cepsa, and rapidly incorporated new Shareholders to the challenge. During the period 2001-2004 preliminary studies were conducted on the feasibility of the project first and foremost from the technical perspective, but also from the gas market perspective. Once feasibility was confirmed, in 2004 the Shareholders moved forward changing the object of the company to the construction and operation of the new gas pipeline. During the period 2004-2006 all the technical documentation, the commercial tenders and all the required permits were obtained, leading to a Final Investment Decision (FID) date on 21st December 2006.
In the period January 2007 to March 2011, MEDGAZ constructed and fully commissioned the offshore and onshore installations of the new deep offshore gas pipeline. Commercial operations started on 1st of April 2011.

Initial annual gas transportation capacity is 8 billion normal cubic meters (bcm) with the possibility of expanding the capacity up to 16 bcm. Having been included in the European Union Trans-European Networks (TEN) priority projects, it is part of the European strategy to diversify gas supply sources while constituting the most cost-effective and direct route of delivering natural gas into Southern Europe.

MEDGAZ S.A. is currently the owner and operator of the MEDGAZ gas system covering a compression station in Algeria, an offshore pipeline running from the compression station in Algeria to the reception terminal in Spain, and a reception terminal in Almeria, Spain. It is incorporated in Spain as an independent gas operator, totally independent from its Shareholders. It operates in Algeria under a concession granted by the Algerian Ministry of Energy

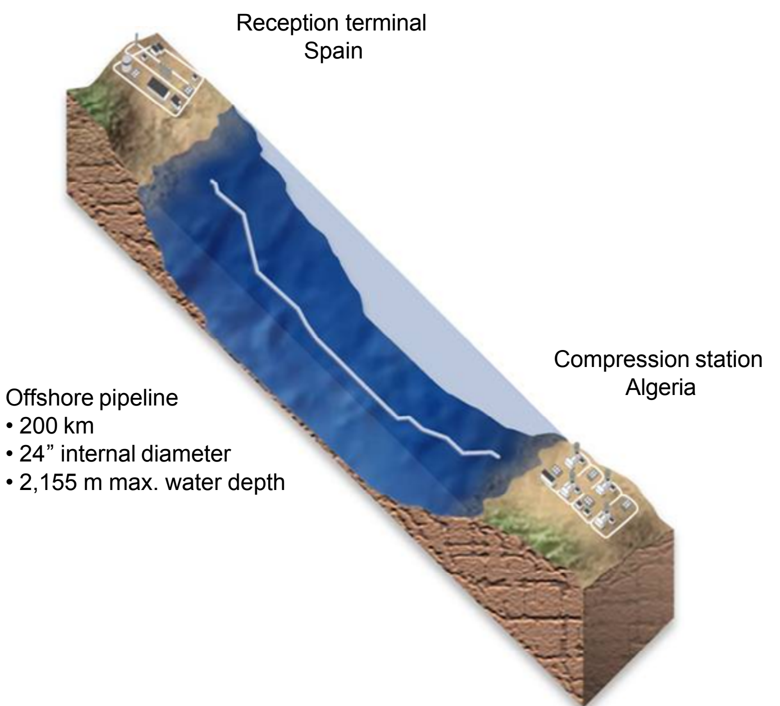

Figure 2: The MEDGAZ system

and Mines.

Current Shareholders of MEDGAZ S.A. are: CEPSA, Endesa, GDF Suez, Iberdrola and Sonatrach.

2. The MEDGAZ challenges

The aim of this paper is to present the challenges faced by the MEDGAZ project during its design, construction and now operational phases.

The challenges in building an international project like MEDGAZ can be differentiated in two categories:

- Technical challenges
  The main technical challenges in the MEDGAZ project relate to the offshore construction. Maximum depth (2,155 m) and its ratio with pipeline diameter (24-inch), place the MEDGAZ pipeline at the technology limit of deep water pipeline design and installation. Challenges faced during the offshore project design included route optimization, minimization of geo-hazards and the unevenness characterizing the Algerian and Spanish continental slopes. The pipe lay operations required a number of specialized vessels. The commissioning of the offshore pipe required a dedicated compression spread.

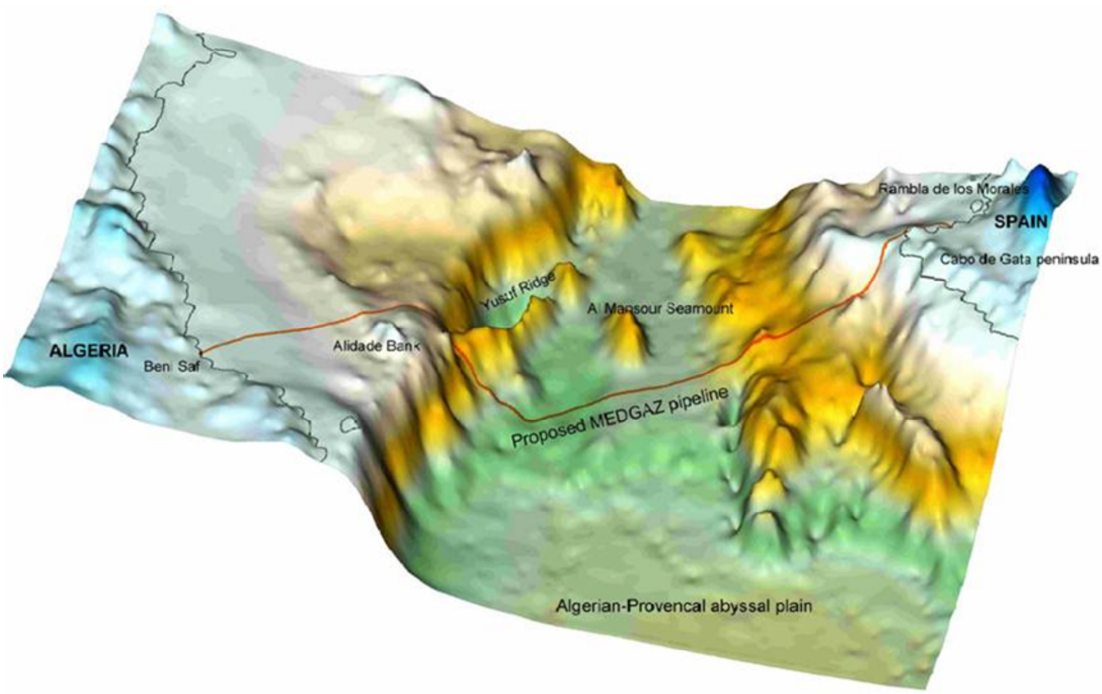

Figure 3: MEDGAZ Offshore pipeline route – 3D view

The onshore project consisted on two stations: a gas compression station in Algeria and a reception terminal in Spain.
The final challenges consisted in the commissioning and start up of the whole system, comprising both onshore and offshore installations.
The project was designed using state-of-the art technology with a special emphasis on minimizing environmental impact and highest quality and Health, Safety and Environmental (HSE) standards.

- Non-technical challenges
  An international project like MEDGAZ linking two countries (and two continents) required a complete alignment not only of Shareholders but of all related Stakeholders: European Union, Spain and Algeria. Without the support of all the related Stakeholders, MEDGAZ would have never become a reality. It is to be noted that these non technical issues defined the critical path of the project.

Operational challenges started with the commercial operation in 2011. They are related to guaranteeing at all times the availability of gas transportation capacity, via an efficient operation and maintenance. The operation is managed as one unique system, in Spain and Algeria, in a multi-cultural and multi-lingual operation managed by MEDGAZ S.A., independent operator of the MEDGAZ system.

This paper covers each of the above challenges, presenting the solutions adopted.

3. The Technical project

3.1. The offshore project

MEDGAZ was considered by its promoters, Sonatrach and CEPSA, a potential project upon the development of the Blue Stream project in the Black Sea, a large diameter (24-inch) gas pipeline project reaching depths beyond 2,000 meters. It was because of this project that Sonatrach and CEPSA created in 2001 the company MEDGAZ, in order to study the possibility of re-launching the 70’s project of a direct gas link between Algeria and Spain. The original project had been laid to oblivion due to the important depths encountered in the West Mediterranean Sea, as pipe lay technology was not available at the time.

The design technical specifications required for the offshore project were defined starting from very basic parameters:

- Diameter: big enough to represent important volumes even during its initial phase of one offshore pipeline.
- Operational flow rate: 8 bcm per year nominal capacity target for the initial phase.
- Flexibility: defined as capability of expanding capacity in the future up to double that of the initial phase.
- Arrival pressure at Spanish gas system: 80 bar.
- Design target life: 50 years.

With these basic design parameters, at very early stages the target internal diameter of the pipeline was defined similar to that of Blue Stream, 24-inch (564.2 mm), while the maximum design pressure was defined at 220 bar. In terms of specifications and in the absence of relevant national regulation, the DNV OFS 101 standard was used as the project reference standard for the offshore works.

Route selection and geohazards
The selection of the route started from the corridors already studied during the 70s. In 2002 a survey campaign defined what was considered the optimum route between Algeria and Spain targeting to limit the length of the offshore construction and to minimize encountered geohazards.
The selected route departs a landfall at Beni-Saf, on the Algerian coastline crossing a 20 km wide continental shelf. Beyond the shelf break, there are two slopes separated by a plateau, the Alidade Bank. Towards the base of the lower slope, the route traverses a narrow submarine ridge, the Yusuf Ridge, crossing the Yusuf fault prior to descending onto the Algerian-Provençal abyssal plain where deepest section if found at approximately 2,150 m.

The route then ascends the Spanish continental margin to a 10 km wide continental shelf on the western side of Cabo de Gata, moving then in parallel to the coast up to the landfall in Spain, in El Perdigal.
In 2002 as well an assessment of geohazard by Snamprojetti showed already the main challenges faced, apart from the important depths encountered. The main geohazard encountered refers to evidences of large landslides and debris flow, notably at the lower part of the Algerian margin. Geophysical data highlighted that faulting occurs in numerous locations along the pipeline route although only one fault system, that of the Yusuf fault is considered to be active. The last movements are deemed to be 4,000 to 6,000 years old. Modelling studies demonstrated that the route crossing of the Yusuf fault system was acceptable with an allowable compressive fault displacement of 4.7 m. Fault movements of this magnitude have a return period of 4,500 years which is considerably higher than the design 475 year event. On mass sediment expected movement, even the 1,000 year earthquake event, was not considered to reach the pipeline.
Marginal risk remains for low probability earthquake events to generate deep seated, rotational slope failure either in the Algerian or Spanish slopes, with the potential to cause significant pipeline displacement. Modelling on the unconstrained pipeline showed no safety unacceptable concerns on this risk.

These findings on the selected route were later further studied during the FEED phase (2003-2004) by Intec and the Spanish research institute CSIC. The main target of this second phase was to optimise the route, minimising freespans and stress on the pipeline and the need for mitigation works. A detailed mapping of the sea bed as well as efficient digital data processing including stress analysis of the curved routes became essential. This phase delivered the optimum route signalling which areas were more sensible to pipeline inaccuracy, in terms of stress or freespan deviating from the optimum configuration. Fatigue analysis following the DNV RP 105 recommendations was performed both pre-lay and post-lay to check on the fatigue damage accumulation during the 50 years pipeline life. A full touch down monitoring during pipe lay operations was deemed important to insure the close follow up of the pipe laid route and to properly conduct this fatigue analysis.

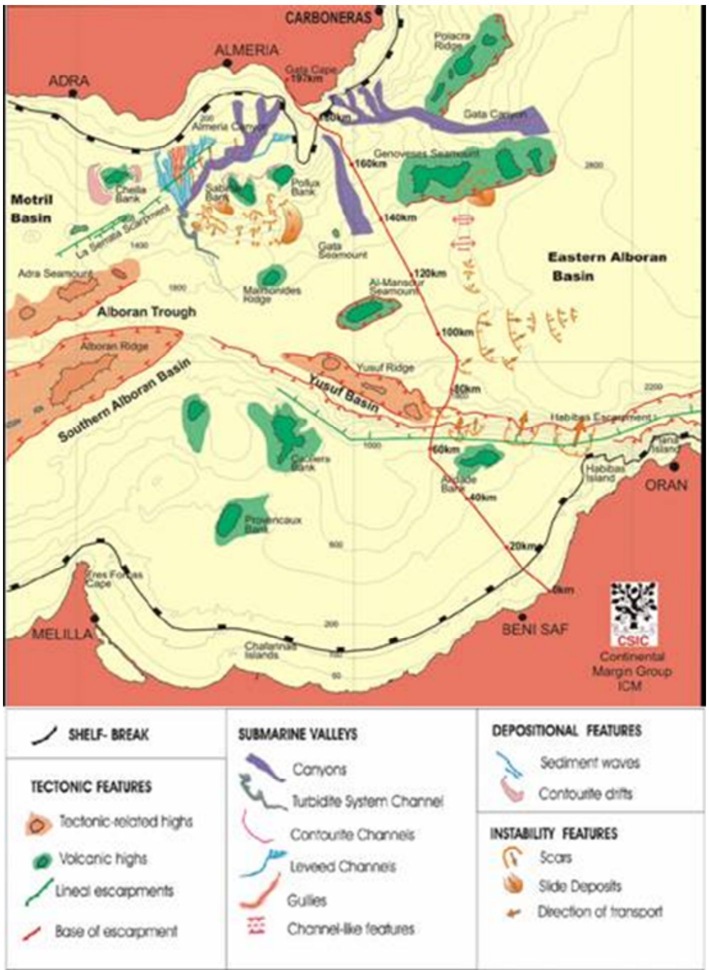

Figure 4: Offshore pipeline route geohazard studies

Other hazards studied included global buckling, notably at the Algerian landfall and near shore during gas operations and at the Spanish landfall during offshore pipeline commissioning. The Algerian landfall is the exit point of the gas, at maximum pressure and temperature. For this section of the pipe an axially anchored pipe concept was implemented, meaning the division of the pipeline into a number of flexural and axially independent sections by using rock cover to axially anchor the pipeline, thus limiting the bending movement developed in the buckle. The Spanish landfall during gas operations is the point where gas pressure and temperature are at the minimum, but during offshore pipe commissioning is the head pressure point for the pigging operations using compressed air that will drive the pig trains; for this commissioning phase it was decided to reduce the pig velocity to such a level where the buckle was anticipated to remain within acceptable levels.

The final pipe route is characterized by:

- non-steep continental slopes on either side of the Alboran Sea;
- quaternary clay soil for the major part of the route;
- stable sea-bed conditions.
- Maximum water depth 2155m (49% below 1000m water depth)
- 19 curvature points
- 5 crossings of telecommunications cables (all at water depth greater than 1000m)
- 1 geological fault crossing : Yusuf Fault
- Critical zone KP71 – KP77: Slopes <14 degrees
- More than 95% of the route: slopes less than 4 degrees
- Critical zone KP71 – KP77: Habibas escarpment

A historical reference is due to the route studies carried out during the 70s and mentioned above as the first project idea to directly link Algeria and Spain via a gas pipeline. The final pipeline route follows precisely the same route already identified already during the 70s as the best possible route. This shows how the time span of 30 years between initial conception and project feasibility marked a remarkable progress in terms of pipe lay technology, while that same time span was insignificant in terms of changes at the sea bottom level, where geological time scale is applicable.

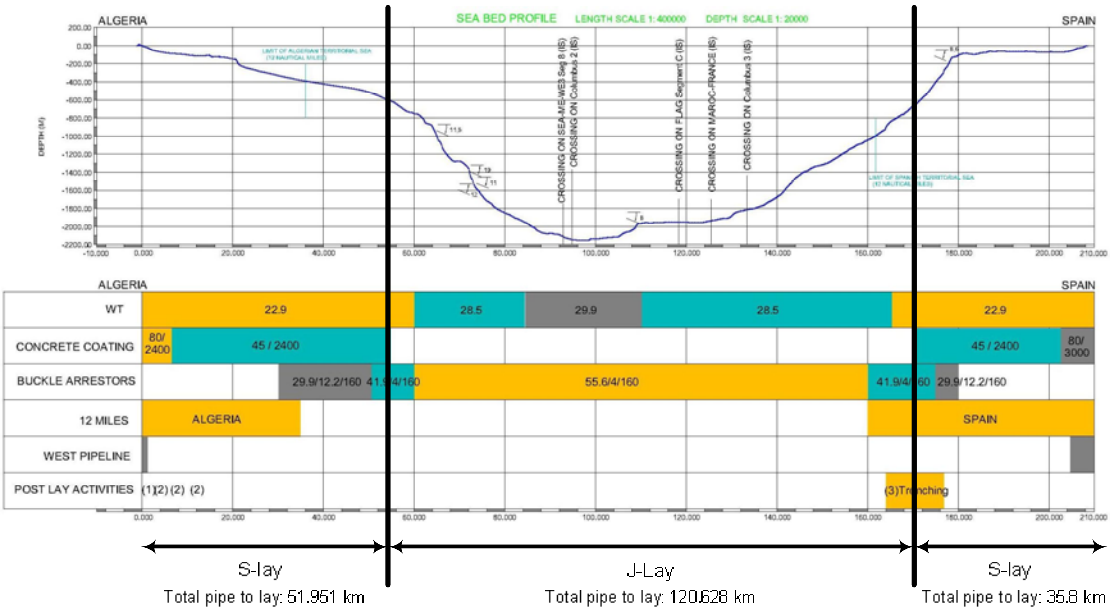

Figure 5: Offshore pipeline route vertical profile and pipe-lay details

Technical design final data for the offshore pipeline is:

- Length: 210 km
- Diameter: 24”
- Capacity: 8 bcm/year

- Maximum depth: 2,155 m
- Design Pressure: 220 barg
- Upper design temperature: 60º C
- Lower design temperature: -5º C
- Design Code: DNV F101
- Steel Grade X70: SAWL 485 I DUF
- Pipe Thickness: 22.9 / 28.5 / 29.9 mm
- The pipeline is laid on the seabed throughout most of its route and buried at near shore approaches.
- An external anti-corrosion multi-layer polypropylene coating is applied for the entire pipeline length.
- External concrete coating is applied in shallow waters (above 550 meters' water depth).
- The pipeline is applied with an internal flow coating.

Offshore works tendering

The tendering strategy for the offshore project was defined by the MEDGAZ Shareholders under the following premises:

- Pipe quality was of essence
- MEDGAZ should be continuously monitoring quality along the project
- The project should in as much as possible be accelerated
- Pipe lay operations should be awarded to one contractor only, in order to minimize battery limits' discussions.

Under these premises, MEDGAZ opted to launch two separate tenders:

- One for the purchase of the offshore pipes finally awarded to Sumitomo and Mitsui in 2006. This contract covered the fabrication of the steel pipes in all diameters (internal diameter is constant at 24-inch or 564.2 mm, while wall thickness varies with depth from 22.9 mm to 28.5 mm and to a maximum of 29.9 mm), the provision of buckle arrestors (double wall thickness sections of 4 m length, that also provide anchoring to the pipe) and the concrete coating of the low water sections (above 550 m water depth). The contract was awarded in 2006. Pipes were fabricated in Japan, concrete coating completed in Malaysia and were then delivered to the port of Almeria, which became the logistical centre of offshore operations. Pipes were totally delivered in Almeria by February 2008. At the Almeria port the pipes were handed onto the offshore pipe lay contractor.
- One for the offshore pipe lay, finally awarded to Saipem. This contract covered the detailed and installation engineering, procurement of anodes, insulating joints and consumables during installation, offshore construction and logistics, post lay offshore works (survey, trenching, rock dumping) and commissioning (hydro-testing) of the offshore pipe.

Offshore pipeline installation preparatory works

The offshore installation works commenced with the storage at the Almeria port of the pipe materials. The storage area at the Almeria port covered approximately 100,000 m^2. A total of three cargoes with pipes were received totalling approximately 18,700 pipes and 110,000 tons. A remarkable logistical work was performed to accommodate 12 different types of pipes (three steel wall thickness, two concrete coating thickness, pipes with buckle arrestors and pipes with anodes) at the port premises.

The speed of offshore pipe lay is a direct function on how many pipes can you weld in one day. In order to accelerate the offshore works at the deeper section (beyond 550 m depth), Saipem opted to make quadruple joints so that each weld made at the deep section vessel accounted for 48 meters of advancement. Quadruple joints were welded and stored at the

Almeria port by using the vessel Castoro Sei berthed at the port. They were welded in the normal offshore construction cycle: the single 12 m pipes were welded to form double joints that were placed on the lay ramp and then welded together to form the quadruple joint. The welding, non-destructive testing (NDT) and the coating of the field joint were carried out in the usual manner at the respective workstations. When all phases were completed the quadruple joint was removed from the outer ramp in a horizontal position and then stored at the logistical area at the port. Manufacturing of quadruple joints was carried out between March and May 2008.

Shore approach works and landfall

Installation operations started with the preparation of the trenches close to both shores. By construction sequence the first shore approach was performed in Spain at the location of El Perdigal, close to the city of Almeria, where special environmental requirements had been imposed by the Spanish Authorities. In the environmental permit, a severe limit to water turbidity and maximum sedimentation were imposed to insure minimum impact on the Cymodocea Globosa aquatic plant population. This plant, like Posidonia, forms extensive meadows on the seabed at water depths between 5 and 20 m, and is very important in the nutritional chain of local sea species. To be able to develop and reproduce, this plant requires well lighted environment and therefore very clear water without any sediment deposition beyond 5 cm. Excavation and backfilling methods were selected to minimize impact. All operations were directly surveyed onboard by an authorized inspection agency. The second shore approach was performed in Algeria, at the Sidi-Djelloul beach in the wilaya of Aïn-Temouchent.

Figure 6: Pull -in operations – Spanish side

The dredging works targeted a trench deep enough to bury the pipeline at 2 meters at the sea shore. The pipe goes buried down to a depth of -35 to -40 meters in both shores, in order to minimize influence of waves and tides. At that depth, the pipe surfaces and is laid there onwards on the bottom of the sea with no anchoring, its weight being enough to keep it in place.

At the shore, the offshore works extended up to the fence of the stations, for approximately 300 m in Spain and 2 km in Algeria. These landfall works were performed by local pipeline contractors under the supervision of Saipem. The pipes arrive to the stations buried surfacing inside them.

It is to be noted that landfall and shore approaches have been done for two pipelines, although at present only the East pipeline reaches Spain from Algeria. The second pipeline stubs, both in Algeria and Spain, have been laid in order to allow for the future expansion of MEDGAZ without any interference to the coast line and shallow waters. The West pipeline stubs are buried and secured at the pipe surfacing water depth around -35 m by means of rock dumped over them, fully covering them.

Pipe-lay vessels

Saipem split the offshore pipe lay operations between two pipe lay vessels: Castoro Sei was used for the two shore pull operations and for concrete coated pipe lay operations above -550 m depth. For depths beyond 550 m in the central section, the Saipem 7000 was used. Last weld was completed by the Crawler. Other spread support vessels included three anchor handling tugs, three pipe carriers, one survey vessel, one post-trenching vessel and one pre-commissioning support vessel.

Figure 7: Pipe-lay operations - Algerian side

Pipe-lay sequence

Castoro Sei started the pipe lay by performing the shore pulls of the East and West lines in Spain. She was positioned at a depth of 11m using a 350 tons winch placed onshore. Both East and West lines were left at a depth of approximately 40 m. The West line stub in the Spanish side ended here.
Because of trench programming, Castoro Sei then moved to Algeria where a similar operation was performed, leaving both the East line and the West line stub at approximately 30 m water depth.
Once both near shore approaches were completed, Castoro Sei moved back to Spain to lay the East line from the 40 m water depth to the planned abandonment position at approximately 550 m water depth, laying 32 km of concrete coated pipe.

Once the East pipeline was ready at the 550 m water depth, Saipem 7000 started the deep water section. Saipem 7000 started operations by recovering the East Line on the Spanish side, moving towards Algeria. While Castoro Sei laid concrete coated double joints fabricated on board while laying operations, Saipem 7000 laid polypropylene coated only quadruple joints previously fabricated by Castoro Sei at the Almeria port as described above. Saipem 7000 was capable of positioning the pipeline with a precision of less than one meter, even at depths exceeding 2,000. This precision allowed for the successful crossing of the five operating communications cables encountered along the route. All laying operations were continuously monitored by the onboard computerized Pipe Line Guidance (PLG) system, which integrated the vessel and pipe positions with the seabed contour. Saipem 7000 left the East pipeline at a water depth of 550 m on the Algerian side.

Castoro Sei then continued the East Line pipe lay by recovering the pipe left by Saipem 7000 and continuing its way towards Algeria, where the pipe was laid down pending only the final connection.

The final connection was conducted via an above water tie-in operation performed by the vessel Crawler, as approximately 30 m water depth in front of the Algerian coast. Last weld was completed in December 2008.

Post pipe-lay operations
Two main post lay operations were carried once pipe lay operations were completed.

The first affected trenching of the pipe along the main fishing ground crossed by the pipeline off the Spanish coast. The pipe was trenched and buried in water depths ranging from 200 to 900 m using the under water post trenching Saipem remote operated vehicle Beluga. A total of 15 km were buried to minimize any interference with trawling fishing activities in the area.

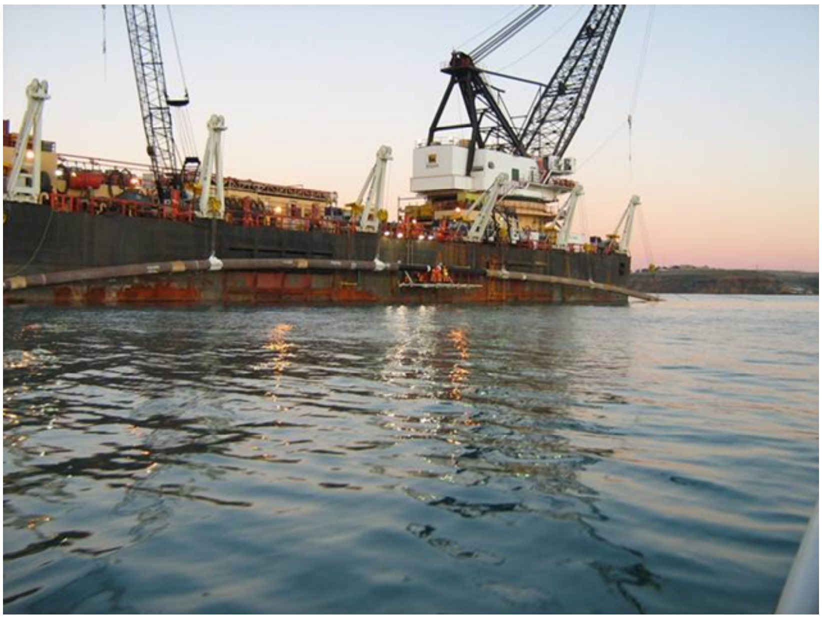
Figure 8: Last offshore pipeline weld – Algerian coast behind

The second affected the commissioning of the pipeline. During pipe lay operations a temporary air compression station had been erected for dewatering the line in case of accidental flooding during pipe lay. A total of 84 air compressors in two pressure stages were arranged, as well as water filtration and air drying facilities. As pipe lay operations headed from Spain to Algeria, the temporary compression facility was built in Almeria, thus rendering a continuous dewatering capability while the East line was laid all the way to Algeria. This same facility was used to conduct a hydro-test up to 330 bar and the subsequent dewatering operation. Once the hydro-test was successfully achieved, several pig trains were launched from Almeria all the way to Algeria for de-watering operations. We have commented above the restrictions imposed in terms of buckling of this operation. It is to be noticed the compression capacity required to lift the whole water column from the lowest point in the pipe route to Algeria (approximately 25,000 m3 of water from a water depth of -2000m to a landing point at +60 m above sea level). Once dewatering was completed the pipe was dried by blowing extra-dry air through the pipeline, once again using the temporary compression facility. Once dried, the offshore pipe was inerted using nitrogen and left isolated until tie-in with the onshore facilities. This last inerting operation was the


Figure 9: Temporary air compression facility during offshore construction and commissioning

end of the offshore project and was successfully achieved in March 2008.

It is to be noticed that this period from offshore project completion until the start up of gas operations was in itself a test period for the offshore pipe at the deeper sections, as external water pressure was over 200 bar while internal nitrogen pressure was very low, way below the natural gas internal average pressure during operations.

3.2. The onshore project

The design technical specifications required for the onshore project were much more standard than the offshore project. They were defined starting from very basic parameters:

- Operational flow rate: 8 bcm per year nominal capacity, at least equal to the offshore pipeline.
- Operational parameters in the offshore pipeline must ensure no hydrates formation and no deposition of liquid hydrocarbons.
- Flexibility: defined as capability of expanding to double capacity.
- Consistent back-up capacity to insure continuous flow via the single offshore pipeline.
- Arrival pressure from the Sonatrach gas system: 45 bar.
- Maximum design pressure: 220 bar.
- Maximum gas temperature at entry to offshore pipeline: 60ºC.
- Arrival pressure at Spanish gas system: 80 bar.
- Design target life: 50 years.
- Gas quality was not an issue, as Algeria has historically supplied most of the Spanish gas market with a very consistent and well known standard quality.

Onshore works tendering
The tendering strategy for the onshore project was defined by the MEDGAZ Shareholders under the following premises:

- Gas compressor packages were of essence.
- MEDGAZ should be continuously monitoring quality along the project.
- The project should in as much as possible be accelerated.
- Onshore stations in both countries should be awarded to one contractor only, under one unique set of technical specifications (thus using the most stringent specifications imposed on either country).
- Battery limits with the offshore project and with upstream and downstream gas connected operators were to fall within the onshore contract(s).
- Final commissioning and start-up of the system, including the offshore pipeline, should fall under MEDGAZ operational responsibility.

Under these premises, MEDGAZ opted to launch two separate tenders:

- One for the procurement of the gas compressor packages, awarded to Rolls Royce by end of 2006. The selected gas compression configuration included three units (two in operation and one as back up) comprising: a Rolls-Royce RB211 6761 Gas Turbine, a Renk gear box, capable of doubling the rotational axial speed to over 10,000 rpm; a Dresser-Rand DATUM D10R6B gas double stage single shaft compressor capable of lifting the gas pressure from 40 bar to 220 bar.
- One for the engineering, procurement, construction and commissioning for both onshore stations in Algeria and in Spain. The gas compression package purchase contract was assigned to the onshore contractor, so as to minimize battery limits. This contract was awarded to a consortium of Tecnicas Reunidas-Initec and Spie-Capag, the former leading on engineering, procurement and Spanish station issues, and the later managing the Algerian station construction.

Onshore stations' description

The station in Algeria is the largest onshore installation in MEDGAZ. It comprises:

- gas filtering facilities (2 +1 configuration)
- gas analyzers (1+1 configuration)
- gas compression units with air-cooling trains after each compression stage
- electrical generation facilities (1+1 configuration)
- utilities: instrument air, nitrogen, electrical substation, fire water ring, control room building, flare/vent.
- Maintenance building and warehouse

The plant layout is prepared to accommodate the MEDGAZ expansion to double the capacity via the installation of three additional gas compression units. Process pipes and utilities are already dimensioned to accommodate this double future volume.

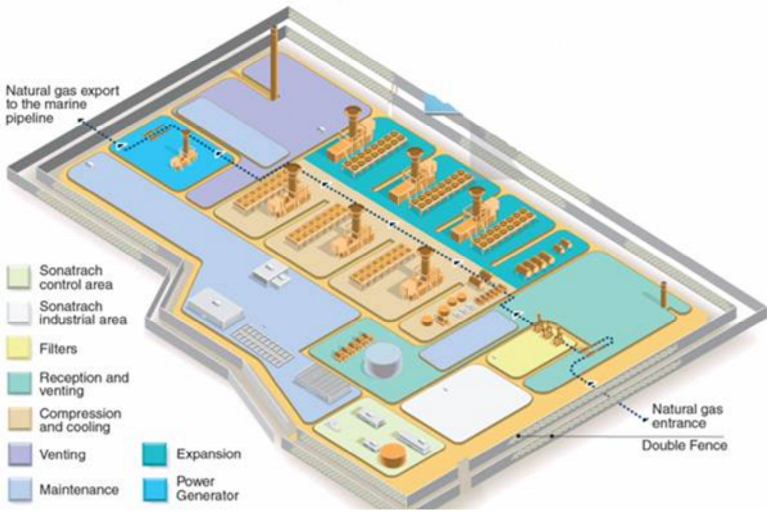

Figure 10: Algerian compression station layout

The onshore plant in Spain has a much smaller footprint than the Algerian one. It comprises only:

- gas filtering facilities (2 +1 configuration)
- gas analyzers (1+1 configuration)
- pressure regulation (2 + 1 configuration)
- utilities: electrical substation, control room building, vent.
- gas heating facilities (1+1 configuration): these facilities are needed in the case of offshore pipeline de-packing.

The plant layout is prepared as well to accommodate a future expansion to double the capacity.

Other onshore support projects relate to the headquarters' in both countries: a living camp in Algeria where the administrative offices are located and the main offices in Spain hosting the central control room. Both of these projects were outside the scope of the onshore contractor, exception made of the central control room wiring and configuration.

Onshore upstream and downstream projects

MEDGAZ is a new export route for Algeria and a new import route into Spain. As such new route new projects were launched both upstream and downstream the MEDGAZ system to accommodate the new gas entry.

Upstream, the gas into MEDGAZ is brought by Sonatrach from the giant Hassi R'Mel gas field and main dispatching centre located approximately 600 km away. Sonatrach built a 585 km, 48-inch single gas pipeline, named GZ-4 for this purpose. During the first 480 km it runs parallel with other three gas pipelines, GZ-1/2/3, that bring the natural gas to the Arzew petrochemical and liquefied natural gas (LNG) export facilities. The last 120 km are dedicated to feed the west region where the main consumption centres are the MEDGAZ pipeline and a new 1,200 MW electrical power plant. It is to be noticed that the upstream project could accommodate the expansion of MEDGAZ to double capacity without any further investment.

Downstream, the gas from MEDGAZ enters a new 42-inch pipeline built by the Spanish gas grid operator Enagas, running north 285 km from Almeria to Chinchilla, where it links to the previously existing network. Enagas is currently completing a compression station located at the exit point in Chinchilla, allowing for full flexibility of destination of the gas entering by MEDGAZ both to the central and to the East gas axis. If MEDGAZ were to double its capacity in the future, a new compression station along the 285 km route would be necessary to accommodate the full volume.

Both upstream and downstream projects' were constructed in parallel to MEDGAZ, both being readily available by summer 2010, by the time MEDGAZ started commissioning of the onshore stations.

3.3. Flow studies, commissioning and start-up

Flow studies

MEDGAZ has relied on the use of modelling systems from the early design phases of the project where steady state and transient simulators were used to aid in the design and in the verification of the expected hydraulic performance of the pipeline.

Steady state hydraulic analysis was performed in HYSIS. A model based on a Peng Robinson equation of state was developed to represent the pipeline route, pipeline construction (internal and external coatings), burial conditions and environmental conditions both offshore and onshore. The model was then developed in Pipeline Studio for verification of results. The results from both models verified that the maximum offshore pipeline capacity for this first phase was over the nominal 8 bcm/year minimum requirement, as maximum throughput could reach up to an equivalent of 10 bcm/year at maximum exit pressure from the compression station. Sensitivities were run to a number of variables, notably related to delivery pressure and temperature, marine conditions and gas composition. The results of these sensitivities showed that only major variations in pipeline internal roughness resulted in significant changes in pressure drop. This was the reason behind opting for an internal flow coating all along the offshore pipeline as described above.

Dynamic hydraulic analysis was performed using the pipeline model constructed for steady state work as the basis plus equipment, controllers & valves at the pipeline boundary. The objective of this analysis was to:

- Define design requirements during start-up, changes in flow, emergency shut-in, and blow down.
- Examine pipeline settling out conditions.
- Examine pipeline de-packing conditions and requirements for defining the gas heating facility at receiving terminal
- Study the flow/pressure control interface with Spanish grid
- Assess pipeline survival time at various cases

This dynamic analysis did not reveal any critical issues associated with transient behaviour of the marine pipeline and onshore stations.

A major concern with offshore deep pipelines is the formation of hydrates, as crystals might cause plugging of the line at deep offshore locations. Although the base case was the transportation of dry gas sales quality natural gas, hydrate formation control studies were carried out for flow assurance with the following objectives:

- Examine conditions that may cause hydrate formation in the offshore pipeline;
- Assess upsets and incidental events that might cause hydrate formation in the offshore pipeline;
- Establish a hydrate prevention and mitigation philosophy.

The basis for the hydrate formation control studies included gas flow rates, composition range, pipeline and environmental data as defined for the above mentioned hydraulic analyses studies. The results from these studies concluded that only in the cases of off specification gas, with water contents over 120 ppm (.vs. the maximum on spec of 40 ppm), there could be combinations of flow levels which could lead to a concern on hydrate formation. A clear correlation flow level-risk of hydrate formation was established, thus defining a mitigation procedure in the unlikely case of high humidity in the gas. With these results, the use of hydrate inhibitors was deemed not recommended, as the risk was low and the implications on operations could be important.

MEDGAZ has also developed an online simulator that includes:
- a pipeline leak detection system
- an offline model to run simulations
- onshore stations' simulation model
- operator trainer model
- look-ahead pipeline model
- dew point and hydrate formation tracking
- survival pipeline model
- predictive pipeline model.

Current operational data are serving to better calibrate the models, which are an operational tool at the central control room.

Commissioning and start-up

The offshore pipe commissioning, as described above, comprised hydro-testing, drying and inerting.

On the onshore project, detailed engineering for the onshore stations started in 2007, main equipment was at the sites in between 2008 and 2009 and construction achieved by summer 2010. The end of 2010 saw the completion of the commissioning sequence and the start of gas trials. Testing of each of the compression units was carried out between October and January 2011.

Gas entered the offshore pipeline early in 2011, displacing the nitrogen that had insured inertization after offshore pipeline completion. During an initial period, gas trials were conducted at the Spanish reception station in coordination with the Spanish operator Enagas. Commercial operations started on 1st April, 2011. Since that day, MEDGAZ has fulfilled all the daily gas nominations from its clients. Volumes delivered by the MEDGAZ pipeline into Spain may be consulted in the Enagas web page (www.enagas.es) and the International Energy Agency web page (www.iea.org).

MEDGAZ is today a reality, achieved within budget after 10 years during which the project was conceived, developed and built.

4. The non-Technical project

An international project like MEDGAZ linking two countries (and two continents) required a complete alignment not only of Shareholders but of all related Stakeholders: European Union, Spain and Algeria. Without the support of all the related Stakeholders, MEDGAZ would have never become a reality.

It is to be noted that these non technical issues defined the critical path of the project, as is the case with most major international projects. We can differentiate three different periods in this "non-technical" project:

- 2001-2004: presentation of the project to all Stakeholders.
- 2004-2006: permitting period
- 2007-2011: construction period

2001-2004: Presentation of the MEDGAZ project
In parallel to the feasibility studies and to the offshore pipe route selection programme, the project was presented to the major Stakeholders. From the very beginning, the original promoters of the project realized that this project needed strong institutional support and a wider base of partners. Institutional support was received on three fronts:

- At the European Union (EU) level, MEDGAZ was included in the Trans-European Energy Network programme as a relevant infrastructure to fulfil the EU targets of security and diversification of supply in the south-north axis.
- At the Spanish level, MEDGAZ was included in the medium term gas infrastructure planning.
- At the Algerian level, MEDGAZ was included in the medium term gas infrastructure planning.

New Shareholders were incorporated into MEDGAZ to form an initial shareholding comprising major oil and gas and electricity players by July 2001. A Shareholders' agreement for this initial phase was signed.

2004-2006 Permitting period
Once technical feasibility was demonstrated and the project counted on the support of the relevant Stakeholders, MEDGAZ moved onto a second phase. While the detailed technical studies and the tendering documents were developed, at the non-technical level major developments occurred.

At the MEDGAZ Shareholders' level:

- A new Shareholders' agreement was signed now with the object developing the construction of the pipeline.
- Dedicated work groups from the Shareholders started developing the commercial agreements for the construction and operations phase, notably the Shareholders' Agreement and the gas transportation contract. They were ready by second half of 2006.
- Dedicated work groups from Shareholders defined as well legal (company structure), fiscal and financial matters. All these dedicated work groups were structured around an Advisory Committee which reported to the Board of Directors, in parallel to the technical dedicated team.

At the Stakeholder level:

- In Spain:
  - MEDGAZ became a critical and urgent gas infrastructure, meaning one that needed to be built in the short term. The onshore project studies, linking the landing point in Almeria to the main gas grid in Chinchilla (300 km), were concluded; it was initially promoted by MEDGAZ but sold in 2006 to the Spanish gas operator Enagas who in turn completed its development.
  - All relevant permits, notably those related to the environment, were obtained for the landing of the pipeline in the Spanish coast avoiding the grounds, both onshore and offshore, of the Cabo de Gata National Park.
- In Algeria:
  - the MEDGAZ project was also launched as part of the national gas grid projects, under the GZ-4 name.
  - All relevant permits were obtained. Special mention is required to the MEDGAZ Algerian Concession for the construction and operation of the MEDGAZ system in Algerian territory. It was the first such concession granted to a non-Algerian based company for a gas installation in Algeria under the

2005 Hydrocarbon Law. The Algerian Concession was approved in October 2006, completing all the required permits and authorizations needed to start construction.

- Both the Algerian and Spanish authorities granted MEDGAZ a special status in the sense that MEDGAZ is not considered part of the Algerian national gas system (therefore not operated by Sonatrach) and it is not considered either part of the Spanish national gas system (therefore not subject to Third Party Access). This equilibrium, in parallel with a total transparency of MEDGAZ, allowed for the construction of the project without any disputes on sovereignty, notably at the offshore level.

2007-2011 Construction period

By the end of 2006, all technical documentation was ready, the tenders launched and awaiting award and all the permits and authorizations had been obtained.
On 21st December, 2006, the MEDGAZ Shareholders declared the Final Investment Decision (FID). This major milestone defined the non-return point in the project, as Shareholders then committed to finance the construction of the MEDGAZ project up to a total of 900 millions of Euros. Simultaneously the current Shareholders' Agreement and gas transportation contract (under a Ship-or-Pay scheme) were signed.

This period saw on the technical side the construction and start-up of MEDGAZ. On the non-technical side, MEDGAZ S.A. started to develop as an independent gas operator setting up all the company structures independently from Shareholders and hiring not only the construction team but also the operations' team that would take over to run the system once the project was constructed.
With the vision of a smooth transition into operations, MEDGAZ started hiring the operational team as early as 2008, with most of the operators entering the company by 2009. These operators were the main team supporting commissioning activities. This policy allowed for a very easy transition into operational mode.
During this period MEDGAZ moved its headquarters from Madrid to Almeria in Spain. In Algeria, the branch headquarters were constructed as well in Beni-Saf, at the Aïn-Temouchent wilaya.

During this phase of the project, the support from Spain, Algeria and the EU continued at all levels. A special mention must be made to the European Investment Bank (EIB), who granted MEDGAZ a 500 million Euros loan at EIB interest rate with a repayment period of 19 years after the start-up.

Figure 11: European Investment Bank financing

5. Operational challenges

Once entered into commercial operations in April 2011, MEDGAZ faces a number of future challenges.

Internal challenges to MEDGAZ relate to guaranteeing at all times the availability of gas transportation capacity, via an efficient operation. The business plan targets a minimum of 35 years of operation, with an expected 50 year technical life.

MEDGAZ S.A. is a Spanish company, operating in Algeria under the Algerian Concession granted to the Spanish company via a branch. The operation is managed as one unique system, in Spain and Algeria, in a multi-cultural and multi-lingual operation managed by MEDGAZ S.A., totally independent operator of the MEDGAZ system.
The operational personnel are hired and work full time for MEDGAZ. Although during the construction phase a number of seconded Shareholders' personnel was present to support the project, during the operational phase the only relevant presence of Shareholders' personnel is at the very senior management level and in Algeria, where Sonatrach has seconded most of the technical personnel to the operator.

MEDGAZ has set targets for achieving world class operating standards:

- HSE best industry practices
- Quality and certification: MEDGAZ targets to attain highest industry standards and is convinced that, to achieve this target, certification by internationally recognized standards is of essence. In this line, MEDGAZ is already certified under ISO 9001:2008 (quality), ISO 14001:2004 (environment) and OSHAS 18001:2007 (operations) standards and is seeking to obtain ISO 27001 (information security) certification in 2012.
- Operational excellence is sought via a continuous reporting and feedback of past events (troubleshooting reports). Personnel continuous training is encouraged.
- A well defined long term maintenance strategic plan, including both onshore and offshore installations. For the offshore, it includes latest technology available for the repair, in case of need, of ultra-deep pipelines. A first offshore pipeline inspection has been completed early in 2012. It consisted in a full external visual inspection, analysing as well the corridor along the pipeline and a close inspection of the cathodic protection. The results of this first inspection post -lay and post-start of operations are very encouraging as there have been no surprises in the findings. Regular offshore pipeline inspections are programmed in the coming years.
- Continuous monitoring on offshore pipe parameters using a state-of-the-art online pipeline model
- Implementation of a state-of-the-art risk based management inspection tool to complement the legal and predictive maintenance programs. MEDGAZ has auto-imposed on itself the most stringent conclusions from these three approaches to insure a good inspection coverage.

Long term challenges relate to the capacity of expanding the gas transportation capacity. The expansion of MEDGAZ can be developed in two phases:

- An addition of a fourth gas compressor in the current compression station, would bring, with a minimum investment (estimated below 5% of total current investment), an additional constant 2 bcm/year, or an increase on capacity of 25%. This fourth compressor would allow maximizing the offshore pipeline flow, while insuring current reliability via a 3 (+1) compressor configuration, with three units running simultaneously and one in stand-by.
- The addition of a second marine pipeline and up to a total of six gas compression units would allow doubling the current nominal capacity of the pipeline. The onshore stations' layout is already conceived for this expansion, requiring investment only for the additional units to add. While the offshore west pipeline stubs are already in place down to approximately -35m water depth. These investments already made would allow to double the capacity (+100% additional capacity to a total of 16 bcm/year) at an estimated cost of 60% of current investment.

These long term challenges link well to the current EU energy policy targets for gas, notably:

- security of supply: from producing country (Algeria) to EU – direct route from a proven reliable supplier
- diversification of supply via the south-north Mediterranean axis
- enhancement of the internal EU market.

MEDGAZ is also a direct route to Europe for future gas projects in Africa like the Trans-Saharan Gas Pipeline from Nigeria.

The advantage of being today a reality with much lower incremental costs to increase capacity configure MEDGAZ as an optimum choice for increasing gas supplies to Europe in the south-north axis.

6. Conclusions

MEDGAZ evolved from a dream in the 70s to a feasible project in 2001 and to a reality today. An international project linking Algeria and Africa to Spain and Europe, it constitutes a new gas supply permanent route, capable of transporting 8 bcm/year and with a possibility of expanding up to 16 bcm/year.

Total project duration of 10 years, from initial stages in 2001 to the commercial start-up of operations in April 2011, can be considered an overall remarkable success to the MEDGAZ Shareholders. Overall project budget was respected, and in particular the construction budget agreed by the Shareholders in 2006. MEDGAZ is today the cheapest gas transportation route to bring natural gas to the South-West of Europe.

Numerous technical challenges, notably those related to ultra deep water route definition and pipe lay, but also including onshore installations' design and operational flow studies, were successfully faced to finally achieve start-up of commercial operations in April 2011. MEDGAZ is today in the technology limit of large diameters gas pipelines laid in ultra-deep waters.

Connected systems operators, both upstream and downstream, completed projects totalling 870 km to transport the additional volumes from Algeria to Spain. The coordination with these connected system operators was essential to the smooth start-up of the project.

The support of all related Stakeholders, was a key to success and defined the project critical path. An alignment of interests among Spain, Algeria and the European Union allowed for solving all the obstacles faced during the project definition and permitting phases. Worth signalling are the flexibilities shown by the Authorities in accommodating a new direct route in terms of legal matters, where a number of first time issues were raised. A key element in this alignment was a MEDGAZ total and constant transparency with regards to Authorities while on the technical front common international best industry standards helped to develop comfort. The financing granted by the EIB contributed to the final outcome of the project guaranteeing a long term competitive debt.

On the operational front MEDGAZ is an example of an independent operator, supported by a NOC, targeting best operational practices. Short term targets seek to guarantee continuous transportation capacity and to develop an internal culture where operation excellence is promoted by adopting best international standards. Long term targets include the capacity expansion, as already incurred investment render the incremental additional transportation capacity at a much lower absolute cost to the one already installed. MEDGAZ is today the cheapest transportation cost route to bring additional natural gas into the European Union.

For the European gas market, MEDGAZ reinforces the security and diversification of supply and promotes the further development of an integrated EU gas market, by allowing direct access to new gas players.

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