INTERNATIONAL GAS UNION

The Contribution of the

# Natural Gas Industry to Climate Change Mitigation - Natural Gas Unlocking the Low Carbon Future

## What is IGU?

The International Gas Union (IGU) was founded in 1931. It is a worldwide non-profit organisation registered in Vevey, Switzerland with the present Secretariat located in Oslo, Norway. The objective of IGU is to promote the technical and economic progress of the gas industry. The members of IGU are associations and entities of the gas industries in 71 countries. It cooperates with many global energy organisations. IGU's working organisation covers all domains of the gas industry from exploration and production of natural gas on- or offshore, pipeline and piped distribution systems to customers' premises and combustion of the gas at the point of use.

The programme towards the World Gas Conference, which takes place every three years, is implemented by Working Committees. It may vary from time to time but for the triennium 2006-2009 the areas of interest are covered by the following Working and Programme Committees and Task Forces:

- Exploration & Production of Gas;
- Gas storage;
- Transmission of Gas;
- Distribution of Gas;
- Utilisation of Gas;
- Sustainable Development;
- Strategy, Economics and Regulation;
- Developing Gas Markets;
- LNG;
- Task Force on Research and Development;
- Task Force on Gas Market Integration (GMI)

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# 1. Summary of main findings

Energy is fundamental to the quality of our lives. Today, we are totally dependent on an abundant and uninterrupted supply of energy for living and working. It is a key ingredient in all sectors of modern economies and without abundant energy supplies the Earth would not be anyway near feeding today's 6,8 billion people or the 9 billion that are expected by 2050.

On the other hand, climate change is a key challenge facing humanity. While secure and affordable energy supplies are needed for economic development worldwide, we know that nearly 70 percent of all $CO_2$-emissions are energy related. Under an IEA baseline scenario (IEA, 2008a), $CO_2$ emissions increase from 20,6 Gt in 1990 to 62 Gt in 2050, more than tripling in 60 years.

Natural gas is, together with oil and coal one of the fossil fuels and will - when burnt - contribute to increasing the $CO_2$-concentration in the atmosphere. This is the downside, and a rare one for this otherwise clean burning fuel. The aim of this report is to illustrate how natural gas is not only part of the climate change problem, but also becoming an equally important part of its solution. The report tells about the many ways that the natural gas industry can and do clean up its own operations. Important as this is, however, we find that the main contribution of natural gas lies in making it possible for our customers to reduce their greenhouse gas emissions. This happens for instance when we replace much more $CO_2$-emitting coal in the market place. Gas customers can also reduce emissions through the use of very efficient technology (e.g. gas turbines, fuel cells) that works well with gaseous fuel and less well – or not at all - with coal, oil or biomass. The gas business is also the pioneering industry in the area of $CO_2$-capture and -storage (CCS) that is expected to be an important technology for mitigating climate change. The twin energy carriers electricity and hydrogen – both $CO_2$-free at the point of end-use – can be produced from natural gas with CCS with low emissions to the atmosphere.

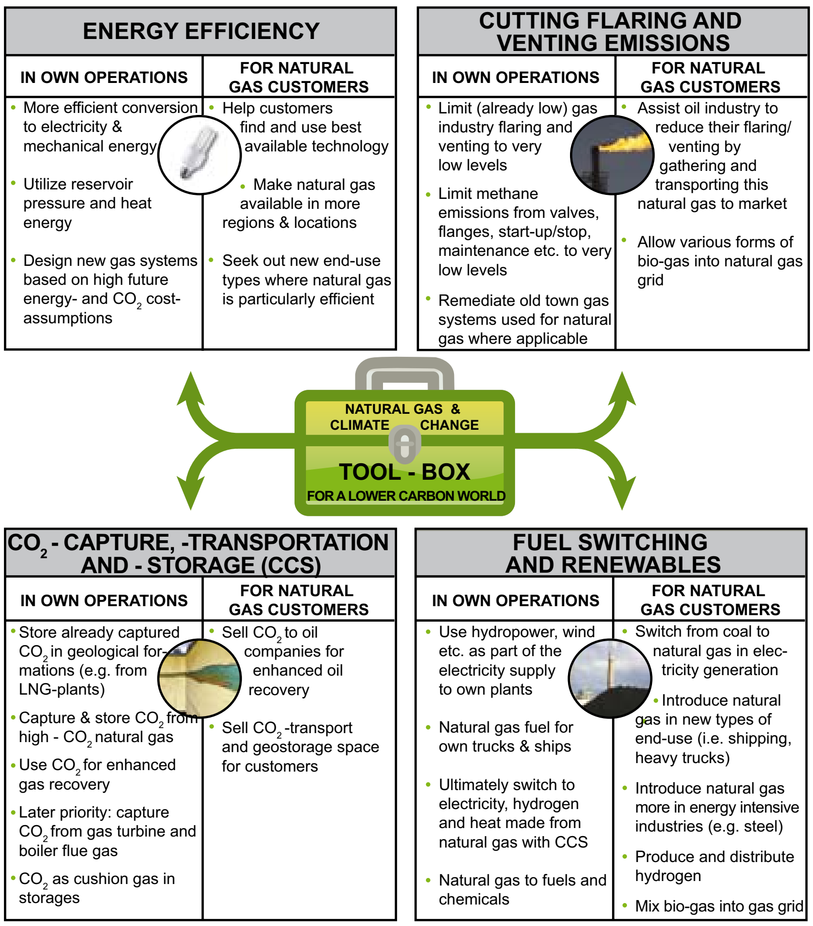



**Figure 1.1** The tool-box for natural gas related mitigation of climate change. We differentiate between what the natural gas industry can do within its own operations and what this industry can do for its present and emerging customers. The focus in this report is on reduction of carbon dioxide and methane emissions to atmoshere.

Natural gas has long been the fuel of choice because of the efficiency of this form of energy distribution, gas's flexibility and controllability in use, and on account of its low emissions of $CO_2$ and low levels of pollutants. These qualities make gas attractive in direct utilisation in homes and businesses, in centralised power generation, in local CHP plant (including micro-CHP), and in some countries also in the transport sector.

In discussions about sustainable energy policy, it is important that the positive contribution that natural gas is already making in the evolving energy market is not overlooked.

Among all the fossil fuels, natural gas – as well as being the cleanest and most controllable at the point of use - is also the most environmentally-friendly, producing the lowest $CO_2$ emissions per unit of energy. Depending on the quality of fuel, the combustion of natural gas results in at least 25-30% less $CO_2$ than oil and at least 40-50% less than coal. The $CO_2$ emissions can be further reduced by using natural gas in high efficiency applications such as in gas turbine based electricity generation.Natural gas thus offers unique advantages in terms of greenhouse gas benefits.

Today 41 percent of global energy-related $CO_2$ originates in electricity generation (IEA, 2008a). It is important to note this important role of electricity that has been growing for decades partly based on natural gas fuel. Electricity's role is expected to increase steadily also in the future as more and more countries are industrialised. It is a widely published fact that some 1.6 billion people - about one in four of the world's population – live without access to electricity. Unlike electricity, we do not know with any degree of precision how many people globally lack access to clean-burning natural gas. An indication is that in 2006 EU-25 with 200 million households had 105 million customers connected to the gas grid, giving coverage of about half the population. In USA natural gas is used in 61 percent of the 160 million households. In Japan about 27 million households (out of a total of 52 million) have access to natural gas. These three regions with about 14 percent of global population are known to have the world's most developed and dense gas-grids. Few other countries and regions are anywhere near this gas-grid coverage at the present time. From this we can draw a tentative conclusion that perhaps as few as 10 percent of global households have direct access to natural gas to use for heating, cooling and cooking.

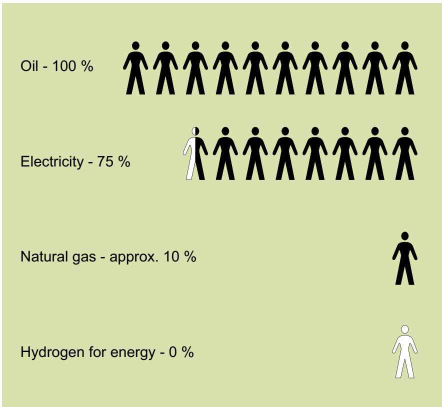



**Fig. 1.2:** Shares of the global population having access to the various forms of energy. Electricity has coverage of about ¾ of the global households while the global degree of physical access to oil products is close to 100%. Natural gas is physically available to perhaps 10% of global households while for hydrogen the percentage is zero. Those without access to natural gas or electricity, have their options in general limited to more polluting fuels.

If we by magic could switch all the world's coal fired power plants to modern natural gas fired combined cycle plants, we would experience a reduction of emissions by over 5 $GtCO_2$/yr. This reduction is 1/5 of global $CO_2$-emissions. This thought experiment illustrates the huge potential for fuel switching to natural gas in the electricity generation sector.

The use of natural gas as a fuel for vehicles (NGV's) are increasing rapidly around the world. It is projected that this end-use sector will increase ten-fold, to 65 million vehicles by 2020. This many NGV's would consume about 400 $GSm^3$ of natural gas, amounting to 14 percent of today's natural gas consumption.

The most important barrier-breakers are removal of institutional (mostly government) barriers, deployment of better technologies as well as expectations of increasing costs of emissions of greenhouse gases to the atmosphere. High energy prices - such as those experienced for some time now - will also work in the direction of energy an energy efficient energy system both in the industrialised and in the industrialising countries of the world.

The degree to which natural gas has succeeded in gaining a favourable public and policy attention regarding climate change mitigation varies from country to country and from region to region. Where natural gas and coal compete in a growing market, the opinion will often be in favour of natural gas. Elsewhere attention is turned more in the direction of energy efficiency measures or various forms of renewable energy to the detriment of all fossil fuels, including natural gas. The nuclear industry is also experiencing a renaissance due to the threat of climate change.

The gas industry cannot afford to be complacent in a world increasingly worried about climate change and its effects on the human society. This report illustrate that there is still a way to go. Much is already being done, however, that will transform both the gas industry and the way consumers use natural gas in the 21st century to the benefit of a reduced global carbon footprint. The best practice examples described in chapter 6 show the surprisingly wide arena on which natural gas can mitigate climate change.

In chapter 7 we attempt to illustrate why many of the climate change mitigation actions involving natural gas have not already happened or are only slowly falling into place. Some of these are challenges specific to certain governments or regions, but most are global in character. In sum the most important barrier-breakers are removal of institutional (mostly government and international treaty) barriers, deployment of better technologies as well as a shared

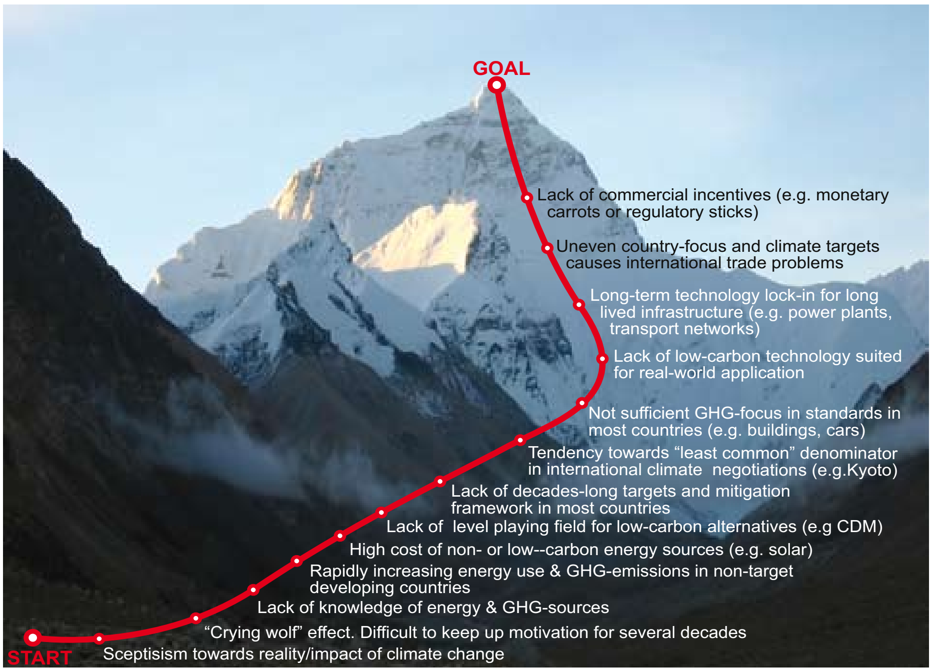



**Fig. 1.3** How a mountaineer might view barriers to climate change mitigation. Not all the indicated barriers are equally relevant to specific countries, companies or individuals, but the route to the top contains a number of difficult obstructions between the valley and the top of the mountain.

expectation of increasing costs over time of putting greenhouse gases into the atmosphere. Shared expectations of high energy prices - such as those experienced up until the autumn of 2008 - work in the direction of an energy efficient system globally.

### Natural gas - the short version:

- Natural gas, the cleanest fossil fuel, is a highly efficient form of energy. It is composed chiefly of methane; the simple chemical composition of natural gas is a molecule of one carbon atom and four hydrogen atoms (CH4)
- When methane is burned completely, the products of combustion are one molecule of carbon dioxide and two molecules of water vapour
- Natural gas delivered to customers is almost totally free of impurities, is chemically less complex and its combustion therefore results in less pollution than other fuels
- In most applications the use of natural gas produces near zero sulphur dioxide (the primary precursor of acid rain), very little nitrogen oxides (the primary precursor of smog) and far less particulate matter (which can affect health and visibility) than oil or coal
- Technological progress allows cleaner energy production today than in the past for all fuels, although the inherent cleanliness of gas means that environmental controls on gas equipment, if any are required, tend to be far less expensive than controls for other fuels.

| **Pollutant** (relative; coal 100%) | **Natural Gas** | **Oil** | **Coal** |
|---|---|---|---|
| **Carbon Dioxide** | 56% | 79% | 100% |

- Natural gas is highly efficient. About 90 percent of the natural gas produced is delivered to customers as useful energy. In contrast, only about 27 percent of the energy converted to electricity reaches consumers
- Due to its cleanliness natural gas will normally be used in substantially more efficient machinery or appliances (e.g. gas turbines) than other fossil fuels, thereby increasing the environmental gap to coal or oil

**References chapter 1**
BP Statistical Review of World Energy 2008 IEA (2007), World Energy Outlook 2007, IEA/OECD, Paris IEA (2008a), $CO_2$ Capture and Storage. A key Carbon Abatement Option, IEA Paris

# 2. Intro-duction

Global climate change is no longer considered to be abstract results from the computers of climate scientists. Dr. R.K.Pachauri, the chairman of the International Panel on Climate Change (IPCC) said when presenting the IPCC Fourth Assessment Report towards the end of 2007:

- Climate change is a serious threat to development everywhere
- Today, the time for doubt has passed. The IPCC has unequivocally affirmed the warming of our climate system, and linked it directly to human activity
- Slowing or even reversing the existing trends of global warming is the defining challenge of our ages

Figure 2.1 illustrates these challenges faced by society due to the global growth in population and the secondary effects that march in step with this main driver.

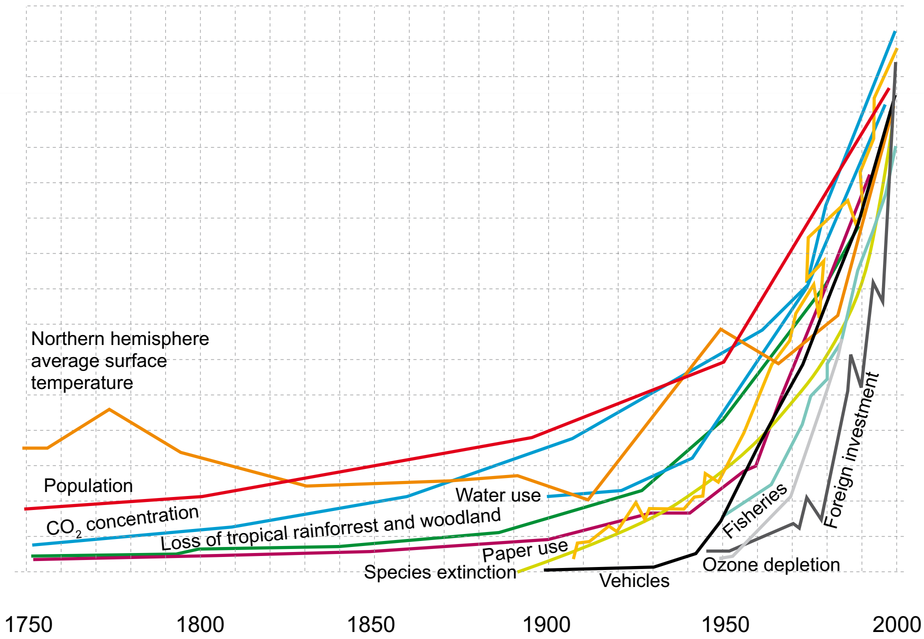



**Fig. 2.1** The problems of global growth – including $CO_2$-levels and northern hemisphere temperature - from 1750 to 2000 (Adapted for this report from New Scientist 16 October 2008, special report)

**The Intergovernmental Panel on Climate Change (IPCC, 2007) says:**

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level
- Global atmospheric concentrations of $CO_2$, $CH_4$ and $N_2$ have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years
- The atmospheric concentrations of $CO_2$ and $CH_4$ in 2005 exceed by far the natural range over the last 650,000 years
- Global increases in $CO_2$ concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution
- It is very likely that the observed increase in $CH_4$ concentration is predominantly due to agriculture and fossil fuel use
- The increase in $N_2O$ concentration is primarily due to agriculture.
- Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations
- There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers

Natural gas is at this early stage in the climate mitigation effort performing well compared to other fossil energy sources. Continued efforts will, however, be essential to keep this position in a changing global market heavily influenced by climate change concerns. Other fossil fuels are working on their environmental impacts with coal making a comeback in both developing and already industrialised countries. Nuclear power is again on the rise in many countries, riding on the wave of climate change concern. Renewable energy together with energy efficiency is likewise at the forefront of energy policies in most industrialised countries. With the exception of hydropower, however, renewables are generally growing from a very low base. This make their contribution less prominent than we could be led to believe based on reported high growth percentages.

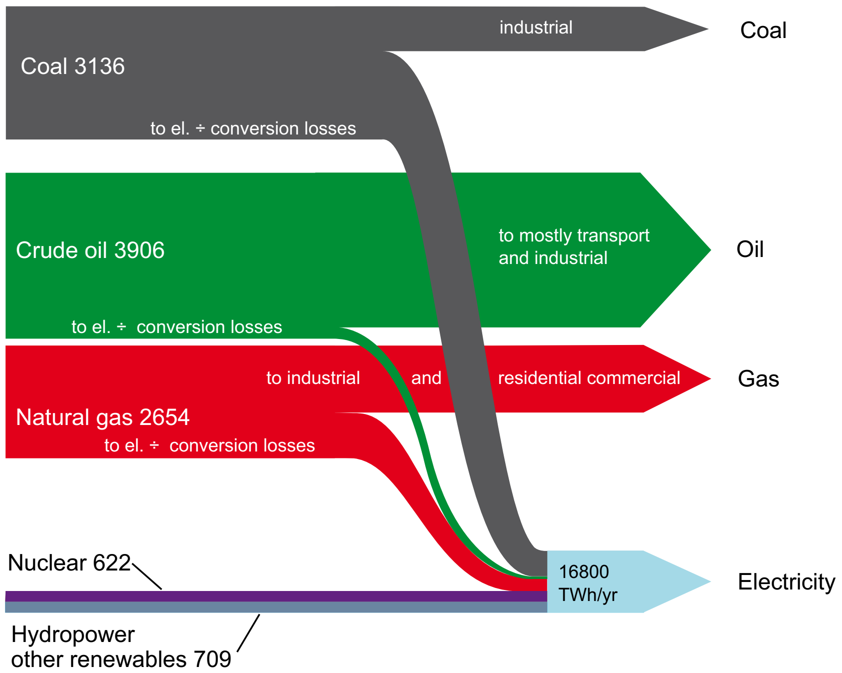



**Fig. 2.2** Simplified global energy flow diagram showing (to the left) primary energy inputs (coal, oil, natural gas) plus uranium and hydropower plus other renewable resources converted into electricity. The share of the various primary energy forms being converted to electricity is illustrated (Sources: BP Statistical Review of World Energy 2008, EIA World Energy Outlook 2007, IEA World Energy Outlook 2006)

Figure 2.2 serves to illustrate that the conversion of primary energy forms to electricity is of major importance. The share of electricity in end-use (final consumption) has been growing for several decades. Due to electricity's intrinsic ease of use for the final consumer, it is likely to keep growing its share even if the costs is higher than for coal, oil products or grid supplied natural gas. Natural gas may, however, keep increasing its attractiveness compared to electricity by promoting energy efficient and easy-to-use devices for the industry sector as well as for the commercial/residential and transportation sectors. Figure 2.2 also shows that coal today is used primarily for electricity generation (the rest being mostly cement and iron/steel). Oil has since the 1970's been phased out of electricity generation and is increasingly identified with fuel supplies for motor-vehicles, ships and airplanes. Natural gas, on the other hand, continues to serve a rather differentiated group of consumers, the largest of which is the power industry as well as a broad customer base in industry and in the residential and commercial sectors.

## The Kaya Equation and natural gas as a low carbon energy carrier

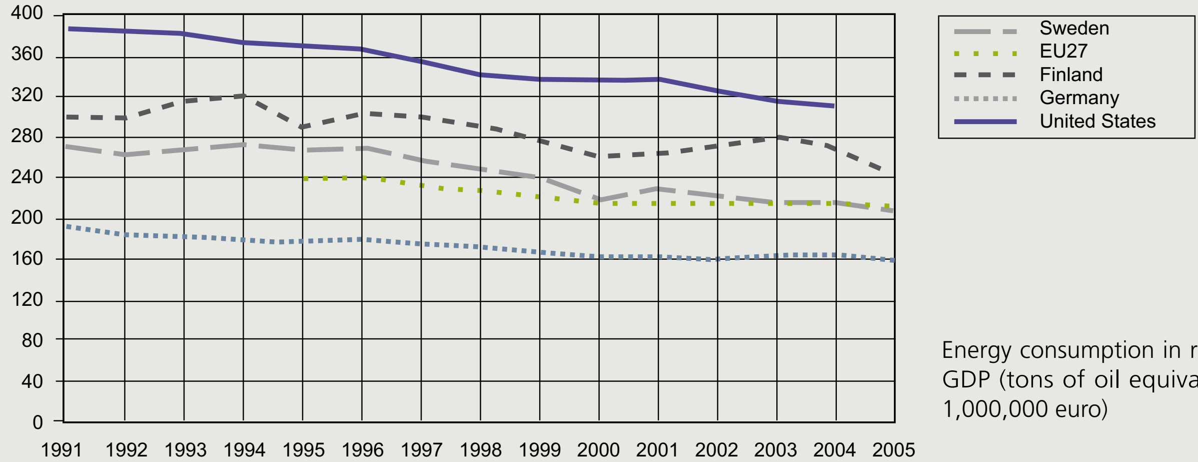
Professor Yoichi Kaya is the Director-General of the Japanese Research Institute of Innovative Technology for the Earth (RITE) just outside of the old city of Kyoto. He is the originator of the following illuminating equation:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **$CO_2$ emissions** | **=** | **Carbon content of the energy** | **X** | **Energy intensity of economy** | **X** | **Production per person** | **X** | **Population** |

The mathematics is not hard – it is just multiplication, but what does it mean? Firstly there are a couple of factors in the equation that is guaranteed to increase. Starting from the right hand side of the equation, we are reasonably sure that **population** will continue to increase towards 2050 by a perhaps 40%, thereby driving $CO_2$-emissions.

Secondly we expect to see **production per person** increasing considerably - in developing countries in particular - towards 2050, thereby driving $CO_2$-emissions further.

Can we divide the **energy intensity of our economy** by a large factor to 2050? The energy intensity has indeed gone down substantially in most industrialised countries as illustrated by the below graph. More efficient use of energy explains much of the decline. It is not, however, nearly enough by itself to counter global population growth or growth in economic output per person.




Energy consumption in relation to GDP (tons of oil equivalents per 1,000,000 euro)

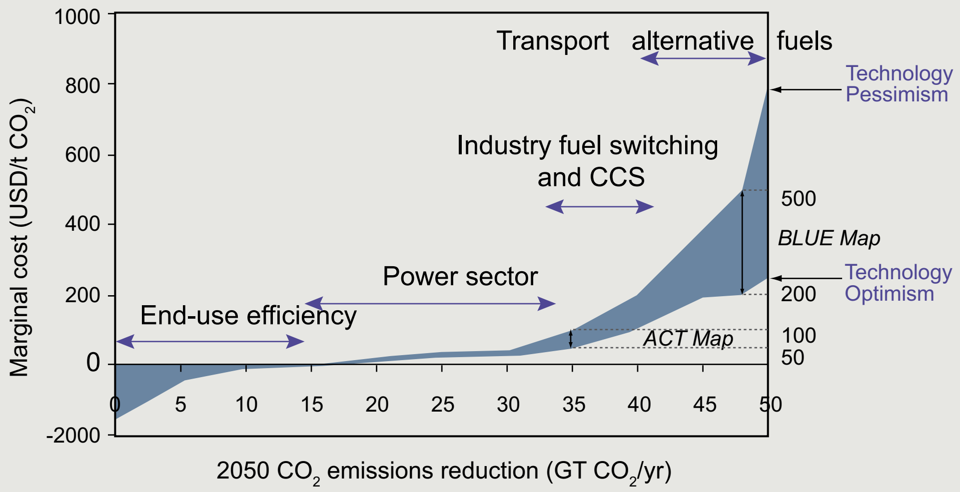
In conclusion it seems that the brunt of the needed $CO_2$-reductions for the next decades will have to be taken by substantially reducing the carbon content of energy in the Kaya equation. In the future delivered energy will have to be decarbonised.

Natural gas ($CH_4$) with its low carbon and high hydrogen content as well as its global reach is a prime candidate for throwing a bridge to this lower carbon future. Other low carbon primary energy sources are renewables and nuclear energy. Capturing $CO_2$ for underground geological storage is a fourth candidate for lowering the amount of carbon (in the form of $CO_2$) that reaches the atmosphere from use of energy.

### Climate mitigation cost curves

Numerous cost curves for emission reduction of the type shown in the below graph from IEA (2008) have been made for specific countries, for branches of industry and so forth. Such cost curves have several things in common that are relevant also for the natural gas industry and its customers:

- Energy efficiency measures are generally shown to be economic in their own right (below zero on the x-axis)
- Then there will be a relatively low-cost part just above the x-axis of varying size. In the graph indicated by the power sector, but fuel switching to lower carbon fuels and emission reduction of the non- $CO_2$ greenhouse gases such as methane are often found here




- As we move towards the right end of the graph we find the more costly technologies – often immature – such as alternative transport fuels, CCS, geothermal and so forth

At present no attempt has been made to assemble a global cost curve for the use of natural gas as a climate mitigation tool, but its general shape (if not content) will be as illustrated by this IEA graph.

*Source: IEA Energy Technology Perspectives 2008*

**References chapter 2**


BP Statistical Review of World Energy 2008
EIA World Energy Outlook 2007
IEA World Energy Outlook 2006-08
IEA Energy Technology Perspective 2008 (IEA 2008)
IPCC Climate Change 2007: Synthesis Report


**Useful web-sites for this chapter:**

- Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch/index.htm
- RealClimate (FAQ's on climate from climate scientists): http://www.realclimate.org/

# 3. The gas industry

It is often overlooked that the gas industry is a major consumer – as well as a producer – of energy. The industry is inherently quite energy-intensive. That is, large amounts of energy are needed to extract gas resources from the ground and process, transform, transport and deliver those resources to the final users.

This does not mean that the gas industry is inefficient compared with other industries: efficiency can only be compared for processes involving the same inputs and outputs. This can be shown by comparing for instance the production of one kilowatt-hour of electricity from a coal or alternatively from natural gas when taking into account the whole chain from the mine/reservoir through transportation to the final conversion to electricity. In fact, the gas companies have been investing heavily in the efficiency of their operations, thereby freeing up gas to be sold to customers.

## The natural gas chain

A natural gas chain starts with a gas field contained in a geological structure such as a sandstone perhaps several thousand meters underground. Sometimes natural gas is produced together with oil, which is separated and marketed through other infrastructure and commercial channels. The gas chain typically terminates at the burner tip, motor or turbine at the site of the consumer. What happens between the gas field and the burner is mostly hidden from the public eye. Buried pipelines, remote gas fields and gas processing facilities or gas ships plying the oceans are not often seen and rarely receive media attention. Gasoline or diesel can be seen at petrol stations and electricity - where the high voltage lines and distribution grid is very visible – are more real to most of us. Energy - and in particular natural gas – is society's invisible commodity.

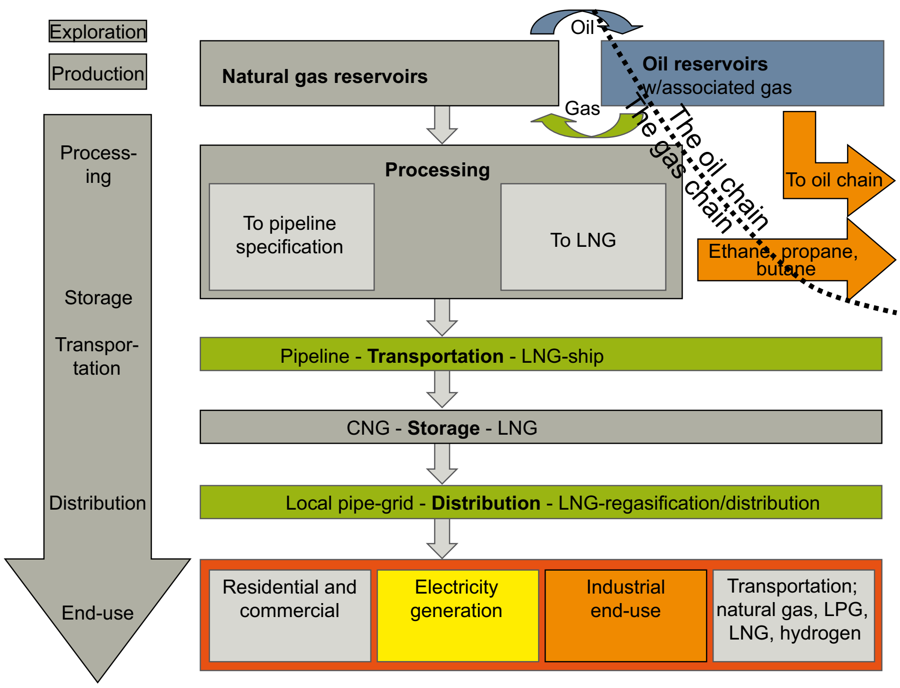



**Fig. 3.1** Natural gas occur both in gas reservoirs and as so-called associated natural gas in oil reservoirs. Transportation of natural gas is primarily by pipelines, but transport in ships as liquefied natural gas (LNG) is on the increase from a modest beginning in the 1960s. At the present time nearly 8% of global natural gas is moved in the form of LNG (for part of the route to the end-user), the rest is pipelined all the way from the reservoir to the consumer.

**Methane – the main component of natural gas**

The main constituent of natural gas is the methane molecule - $CH_4$ - which contains four hydrogen atoms clustered around one carbon atom. Methane is a colourless gas with a molecular weight of 16 and a density of 0,717 kg/m³ in the gas phase (at 25 °C, 100 kPa). Methane has a boiling point of –161 °C (LNG-condition) at a pressure of one atmosphere. As a gas it is flammable only over a narrow range of concentrations (5–15%) in air. Its flammability is a desired feature for a fuel, but less desirable for instance in a coal mine where "firedamp" released from the coal may cause dangerous explosions.

One molecule of methane burns with two molecules of oxygen ($O_2$) in the air to form carbon dioxide ($CO_2$) and water ($H_2O$) according to the equation: $CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$ (+ 809 kJ of energy per mole). When burning fuels such as coal (containing little hydrogen), more $CO_2$ is produced during combustion per produced unit of energy, resulting in substantially more climate effect.

Methane in combination with water is also used extensively in the chemical industry to make so-called "synthesis gas" through steam reforming according to the equation: $CH_4 + H_2O \rightarrow CO + 3\,H_2$. This synthesis gas mixture of carbon monoxide (CO) and hydrogen is used for producing ammonia for fertilizer production, for making methanol, plastics and numerous other chemicals and materials. Steam reforming is currently the least expensive method of producing pure hydrogen.

Today, most hydrogen in the United States, and about half of the world's hydrogen supply, is produced through steam reforming of natural gas. Most of the rest is produced from the gasification of coal and heavy oil in somewhat similar processes to steam reforming of natural gas.

Natural gas as found in a gas reservoir can vary considerably in composition from field to field. In some cases it can consist of almost 100% methane with only a few percent of other components. In extreme cases natural gas fields can be so contaminated by hydrogen sulphide ($H_2S$), $CO_2$ or nitrogen as to be very difficult and costly to develop.

When producing a typical oil field, some natural gas will be found dissolved in the oil. This so-called associated gas is separated from the oil and processed to the same customer specifications as natural gas from pure gas fields.

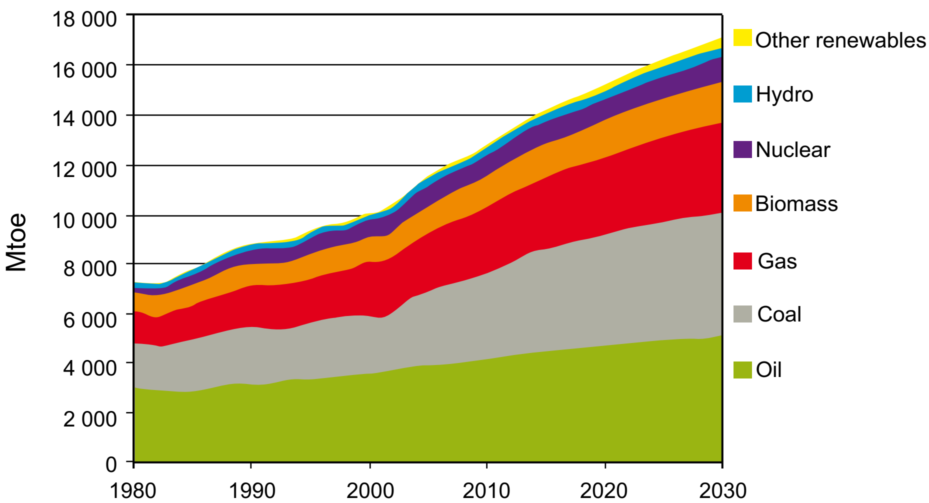
After production from the geological reservoir, the gas is processed to remove so-called petroleum gases (LPG; ethane, propane, butane), heavier hydrocarbons and any impurities such as water, sand, $CO_2$ and $H_2S$ depending on the local conditions.

Most natural gas is transported through high pressure pipelines to local and lower pressure distribution pipeline (grids) that eventually extend into buildings, power plants and the sites of industrial consumers. In heavily inhabited regions with extensive natural gas consumption the invisible gas grid is almost as dense as the more visible electricity grid.

In those cases where moving natural gas by pipelines is not topographically possible or economical, gas can be transported by specially designed cryogenic (low temperature) ships (LNG vessels; -161°C, at near atmospheric pressure) or cryogenic road tankers. The ship alternative is used mostly for international movement over several thousand kilometres. The relatively rare cryogenic road tankers are mostly used for low volumes for short distances.

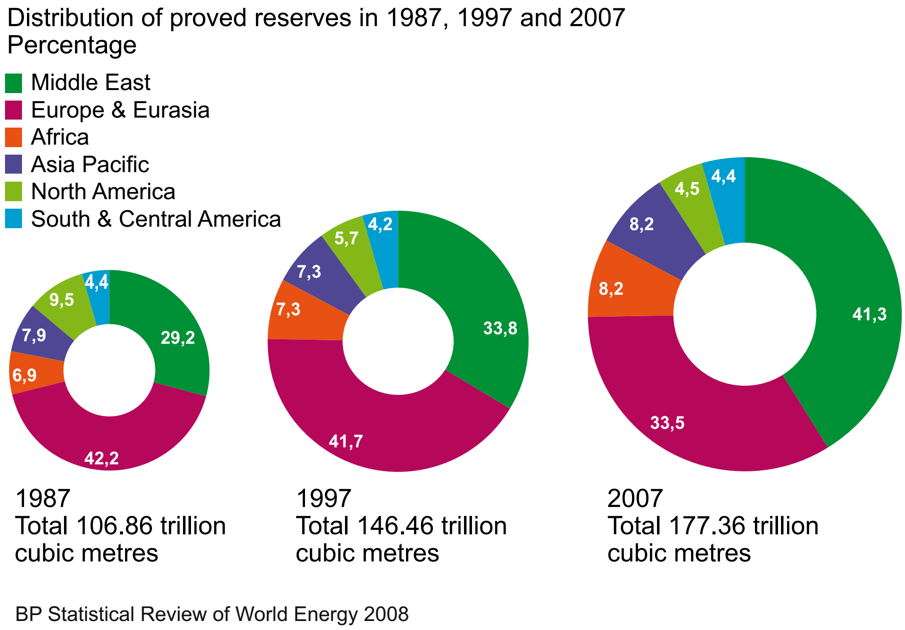
**1 part carbon + 4 parts hydrogen**

**Fig. 3.2** Development of world energy consumption from 1980 with projections to 2030 in the IEA 2008 reference scenario (Redrawn based on: IEA World Energy Outlook 2008)



**Reserves and production**

Global proved natural gas reserves have grown about 2 ½ times since 1980 based on growth of non-OECD gas. Proved reserves rose by 1 trillion cubic metres (Tcm) in 2007 to a total of 177 Tcm. Almost three-quarters of the world's natural gas reserves are located in the Middle East and Eurasia. Russia, Iran, and Qatar combined accounted for about 58 percent of the world's natural gas reserves. Reserves in the rest of the world are more evenly distributed on a regional basis. Despite high rates of increase in natural gas consumption, particularly over the past decade, most regional reserves-to-production ratios are substantial. Worldwide, the reserves-to-production ratio for natural gas is estimated at 60 years (BP RWE 2008).



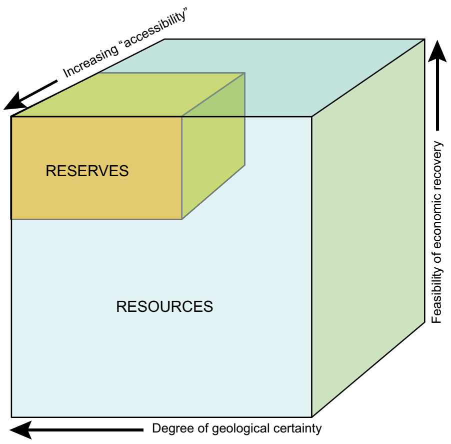



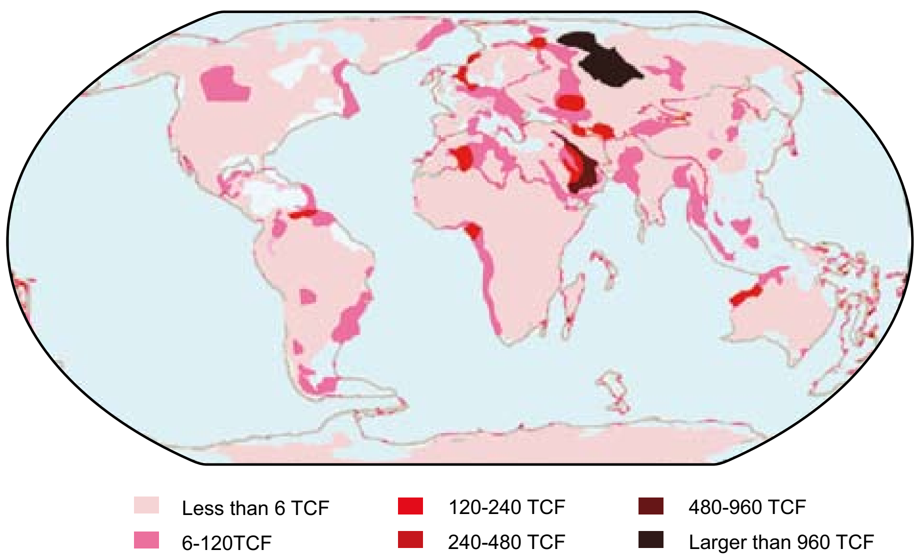

**Fig. 3.3** Resources are always much larger than proved reserves. One example of how geological resources such as oil and natural gas are characterised; the main aim of such classification systems for geological resources (minerals, coal, oil, natural gas) is to differentiate between reserves that can be economically produced with today's technology and commodity prices and those resources (contingent or prospective) that may – or may not – be produced at some future time with improved technology or higher prices or both in combination.

As indicated in fig. 3.3, the amount of natural gas resources in the ground will always be substantially larger than what can be recovered economically at any point in time. There is no fixed cut-off, however. With improved technology - such as enabling the move into deep water offshore- and not least higher energy prices, there will be a substantial shift from resources towards proved reserves.

Figure 3.4 illustrates both the growth and the geographical shift of proved reserves that has taken place since the 1980's.

**Fig 3.4** Distribution of proved natural gas reserves and their development over time (1987, 1997 and 2007). (Redrawn based on: BP SRWE, 2008)

**Fig. 3.5** The United States Geological Survey (USGS) map of the conventional natural gas endowment of the world (2000). The USGS released an updated assessment of gas resources north of the Artic circle in July 2008. The mean estimate of natural gas in this region was 1670 Tcf (47300 GSm3), amounting to about 30% of remaining undiscovered natural gas. Most of this located in the west Siberian Basin, the East Barents Basin and Artic Alaska (Source: USGS)



The International Energy Agency (IEA), BP and others provide year-by-year data on production, consumption, imports and exports of natural gas. In Figure 3.6, the production is given as a percentage of the global production for major regions.

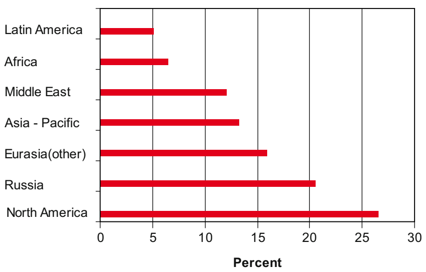



Fig. 3.6 Share (%) of global natural gas production for different regions of the world in 2007 (Source: BP SRWE, 2008).

Natural gas is produced in a large number of countries around the globe, but a few of them provide a large percentage of the total volume. Then largest are USA, Canada, Russia, Iran, Norway and Algeria. The seventeen countries in table 3.1 provide nearly 80% of the total world production of natural gas.

**Table 3.1** Natural gas production volumes in mill tons of oil equivalent (Mtoe) and proved reserves (in Tcm) of the 17 largest natural gas producing countries. (1 Tcm equals about 800 Mtoe. Data-source: BP SRWE 2008)

| Production & reserves 2007 | | | |
|---|---|---|---|
| | Production (Mtoe) | % of global production | Proved reserves (Tcm) |
| Russia | 547 | 20,6 | 44,65 |
| USA | 499 | 18,8 | 5,98 |
| Canada | 165 | 6,2 | 1,63 |
| Iran | 101 | 3,8 | 27,80 |
| Norway | 81 | 3,0 | 2,96 |
| Algeria | 75 | 2,8 | 4,52 |
| Turkmenistan | 61 | 2,3 | 2,67 |
| Saudi Arabia | 68 | 2,6 | 7,17 |
| UK | 65 | 2,5 | 0,41 |
| China | 62 | 2,4 | 1,88 |
| Indonesia | 60 | 2,3 | 3,00 |
| Netherlands | 58 | 2,2 | 1,25 |
| Malaysia | 55 | 2,1 | 2,48 |
| Qatar | 54 | 2,0 | 25,60 |
| Uzbekistan | 53 | 2,0 | 1,74 |
| United Arab Emirates | 44 | 1,7 | 6,09 |
| Argentina | 40 | 1,5 | 0,44 |
| SUM LISTED COUNTRIES | 2088 | 79% | 140,27 |
| SUM WORLD | 2654 | 100% | 177,36 |

## Transportation and storage

Major natural gas trade movements are shown in Figure 3.7 and 3.8. The largest flows in 2007 were from Russia and Algeria to Europe, from Canada to USA and from the Middle East and South-East Asia (Indonesia, Malaysia) to Japan. Some large producers such as US and Russia are also the largest consumers. Only USA, through being the second-largest producers of natural gas after Russia, are in fact the largest importer as well (fig. 3.8).

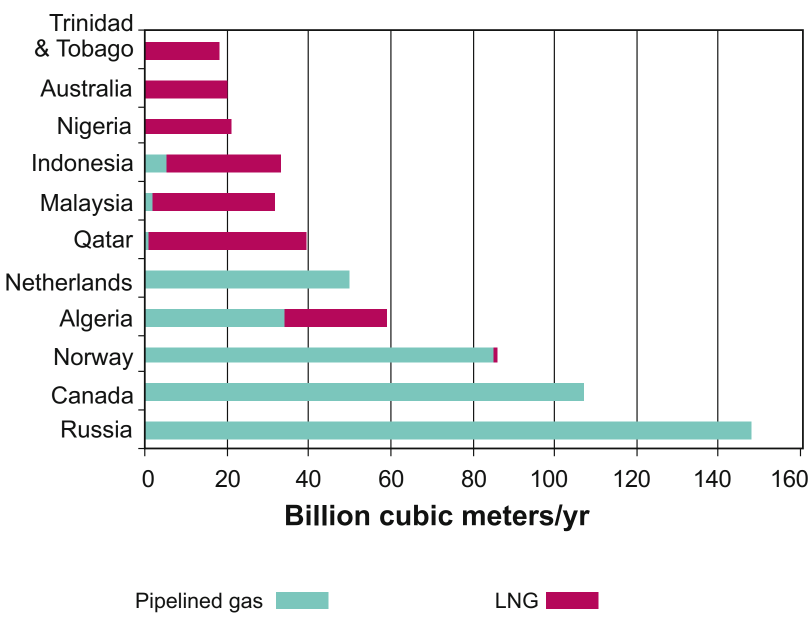



**Fig. 3.7:** Major natural gas exporters in 2007. While most natural gas is still being transported by pipelines, LNG is a form of transport of increasing importance (Data-source: BP SRWE, 2008)

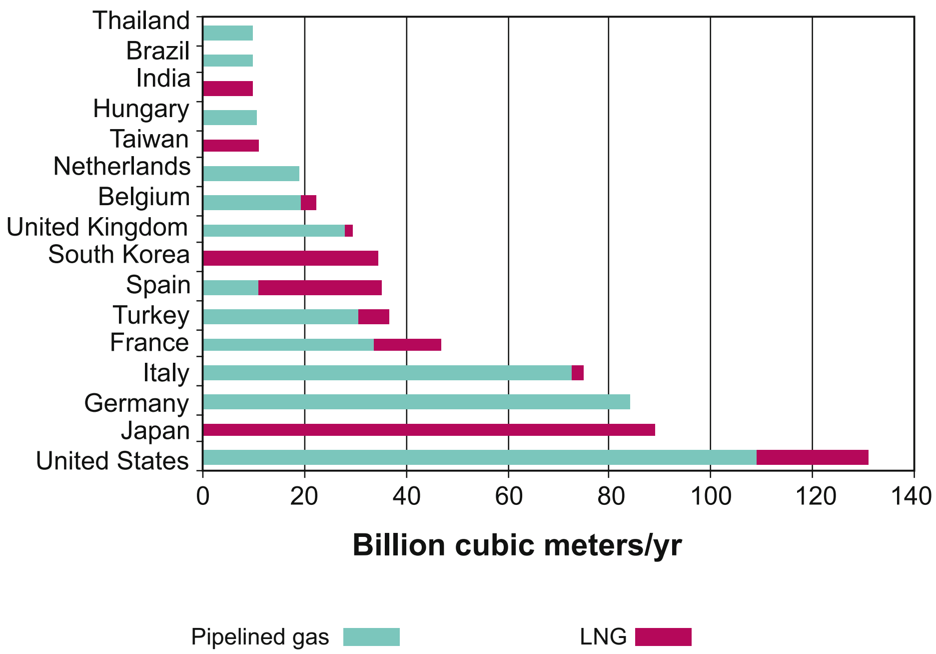



**Fig. 3.8:** Major natural gas importers 2007. Also shown is the extent to which LNG-imports differs between mostly land-locked economies and sea-based economies (e.g. Japan, South Korea) (Data-source: BP SRWE, 2008).

In total, about a quarter of the global production is exported to be consumed in a different country. This also tells us that 3/4 of all natural gas production is consumed in the same country as it is produced. The global gas market consists of a number of fairly coherent and separate regions that consume natural gas that originates from only a few countries. These major natural gas consuming regions are North America, EU, Russia, the Middle East and Asia including China. With LNG on the increase, the gas market is, however, slowly becoming more globalised and more resembling the oil market.

LNG is a medium size energy commodity at present as it makes up nearly 8 % of the total global gas market. It is, however, fast becoming a more important part of the international trade flow with 29% of total international gas exchange in 2007. LNG is a typical outlet for remote gas fields with no sufficiently large consumer market in the vicinity and with no access to nearby long distance pipelines. It is a capital intensive activity requiring high investments for both liquefaction plants, ocean-going tankers, regasification terminals and cryogenic tank farms in both ends of the chain. LNG is for this reason most competitive for markets at distances larger than about 4.000 kilometres such as Japan and South Korea being supplied from South-East Asia. LNG is, however, an energy commodity undergoing rapid growth as well as technological development.

The global natural gas market is expected to become more complex over time. Deregulation, growing concerns over climate change, improved LNG-technologies and long term anticipations of high gas prices are expected to be the main drivers for change in the gas markets. Most notably, we have seen the expanding market for LNG. For 2030, the International Energy Agency expect more than half of international gas trade to be in LNG. Another likely development is an increased use of underground gas storage to increase flexibility of the supply chain (daily, seasonal) as well as for energy security reasons.

Pipelines are generally the most economical way to transport large quantities of natural gas or oil over land. Compared to trucks or rail, pipelines have lower costs per unit and higher capacity. Pipelines are constructed of carbon steel and varying in size from 2 inches (51 mm) to 56 inches (1,40 metres) in diameter, depending on the capacity required for the pipeline. Natural gas pipelines are in most cases buried a couple of metres below ground to protect them from external damage. Such burial also means that the visual foot-print is minimised and interference with nature and infrastructure are kept to a minimum. The long distance trunk lines over land will normally transport gas at a pressure limited upward to between 60 and 100 atmospheres pressure. Offshore pipelines on the other hand carries gas at up to 240 atmosphere pressure. Pressure reduction stations will then take the pressure down to suit the distribution grid extending into industrial plants, commercial buildings and residential areas.

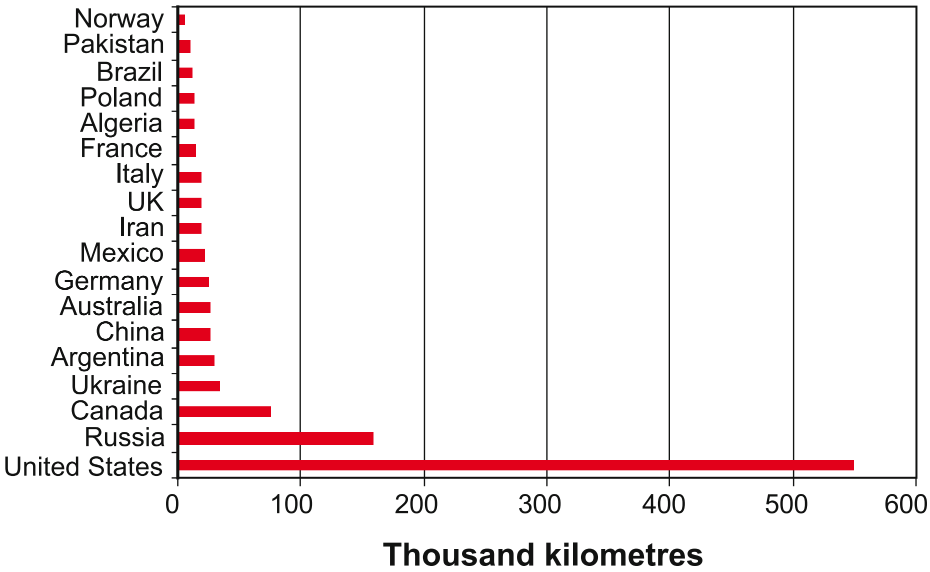



**Fig. 3.9:** The most extensive natural gas pipeline networks of the world are located in USA, Russia, Canada and Ukraine. This list does not differentiate between size and pressure rating of the pipelines. Taken together, the pipelines listed above could be laid 27 times around the Equator (Source: World Fact Book).

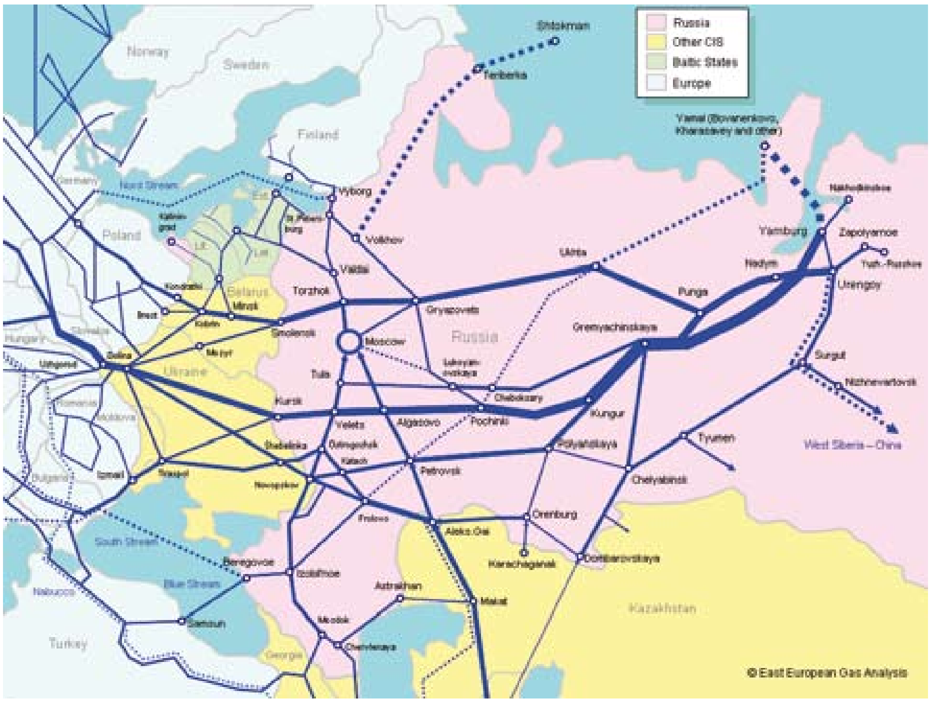



**Fig. 3.10:** An outline map of the Russian natural gas pipeline system with some of the compressor stations indicated. (Source: Gazprom)


**Fig. 3.11:** From the laying of the Gazprom Bluestream pipeline (left). The pipeline is buried in a deep trench and leaves only a limited visual footprint once buried. The map to the right shows the incredible concentration of large diameter (56"; 1,40 meter diameter) pipelines in the Urengoy and Yamburg areas of northern Russia. This is part of the huge infrastructure of gas pipelines around the world. (Source: Gazprom).

A high pressure trunk-line for long distance transmission of high natural gas volumes will normally be equipped with compressor stations every 250 kilometres or so to counter friction losses resulting from the gas flow in the pipes. These compressor stations are normally driven by gas motors (for small duty applications) or by gas turbines, both sources of combustion $CO_2$. In fig. 3.10 and 3.12 it is possible not only to see the extent of the pipeline system itself, but also the numbers and locations of these compressor stations.

While long gas pipelines may act as short term storage to tackle part of the daily swing in consumption, larger swings such as seasonal differences in end-use of gas are tackled by building large natural gas storages. These are either depleted oil or natural gas fields, leached salt caverns or other geological storage reservoirs. Most of the over 600 natural gas storage sites of the world are located in USA and Europe/Central Asia as shown in fig. 3.13. All such storage facilities are equipped with compressors and their associated drivers which can be electric motors, but more usually with gas turbines, thereby becoming sources of combustion-$CO_2$. Another type of natural gas storage – not shown in fig. 3.13 – is LNG production and regasification facilities where there are substantial cryogenic storage tanks to allow the logistic challenges of discontinuous shipping.

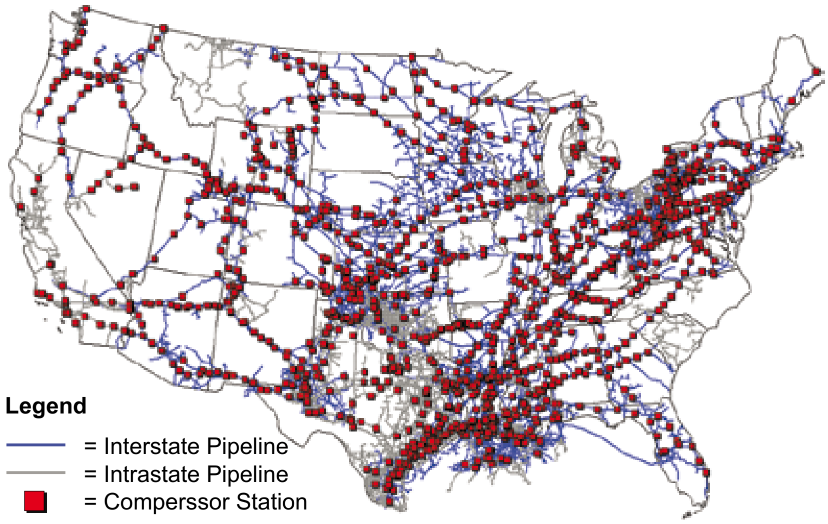



**Fig. 3.12:** Example of an extensive national (US) pipeline transmission grid with compressor stations indicated. These compressors are driven by gas fuelled motors or gas turbines which are the main sources of $CO_2$-emissions for a pipeline system. (Source: EIA)

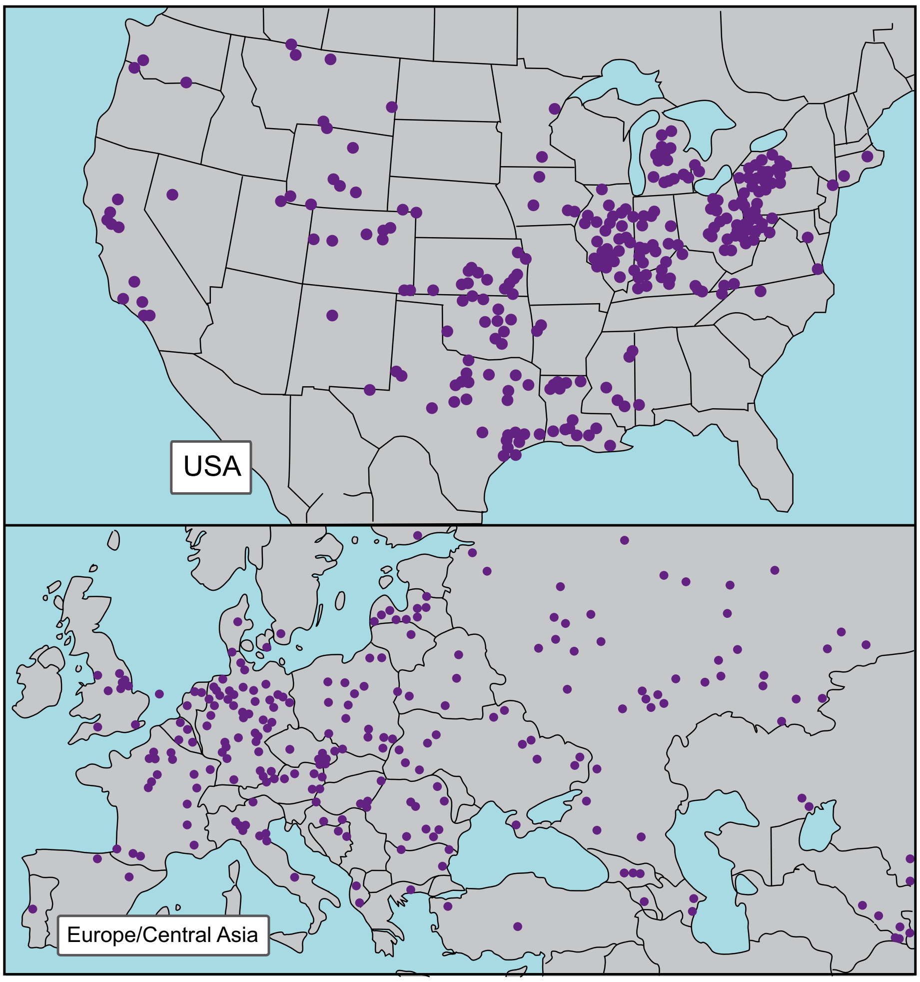



**Figure 3.13:** Underground natural gas geological storage sites in Europe (plus part of Asia) and USA. In the US the southern storage sites are mostly salt caverns, in the Mid West many aquifers and the rest are mostly converted oil or gas fields. These storage sites can also be considered as analogues for geological storage of $CO_2$, so-called CCS. Operators of natural gas storage facilities have a key role to play, based on hands on experience from 610 storage projects and feedback from day to day design, construction and operation (technical, monitoring, permitting, communication with the public etc...) gained over many years by the storage operators community. (graphics source : Keeping the Lights on, Freund and Kaarstad, 2007).

Imports to North America are expected to increase substantially between now and 2030. The Middle East will become a major supplier to several regions. Production in Europe will decline, while demand in India and China is growing rapidly because of the fast economic growth in these countries. Apart from an expected major shift to LNG, the production of "gas to liquids" (GTL; converting natural gas to oil products through chemical processing) is expected to become a part of the oil market over the next decades. The technology has existed for several decades, but its economic viability was uncertain at low oil prices and therefore current production is negligible.

### Utilisation

The end-use part of the natural gas chain is highly diverse, due to a large variety of applications and for each application a wide assortment of technologies. In some ways we can compare natural gas end-use complexity with that of electricity end-use which we are more familiar with.

The main applications are:

- Electric power generation, often as co-generation of electricity and heat (CHP; combined heat and power)
- Industrial applications such as drying, heating and mechanical drives (turbines, gas motors) as well as industrially integrated CHP
- Residential and commercial (heating, cooking, cooling)
- As fuel for buses, trucks, cars, trains or ships in the form of compressed natural gas (CNG), LPG or LNG
- Hydrogen production for energy purposes (e.g. refineries)
- Material (non-energy use, chemical industry, plastics, fertiliser etc.)

World wide, some 35% of consumed natural gas goes toward power generation (IEA WEO, 2004) and 25% toward residential and commercial heating, cooling and cooking. Transport applications for buses, trucks, cars and ships only consume some 3% of the gas supply within OECD (IEA WEO, 2002). The remaining third goes primarily toward energy (plus some non-energy) applications in industry.

Natural gas today competes with all the other energy carriers, but more so in certain applications. (e.g. electricity generation) and less in other such as transportation fuels and cement production.

### Electricity generation vs direct use of natural gas

The worldwide transformations of the energy market and the merging of large energy utilities make questions about the future role of natural gas less relevant than in the past. Many electricity and gas utilities have become multi-energy providers. The electricity or district heating delivered to homes or commercial premises might very well be produced by burning gas in larger plants. The natural gas may be delivered to you by a former purely electric utility along with fibre optic cables for broad-band communication. Therefore the fact that the end consumers are not directly using gas does not necessarily mean that they are not contributing to the gas market expansion. Electricity and natural gas are twins in the energy market. Today 41 percent of global energy-related $CO_2$ originates in electricity generation (IEA, 2008a). It is important to note this important role of electricity, a share that has been growing for decades and is expected to increase steadily also in the future.

The reasons why electricity is universally employed as a medium of energy transfer and use are:

- It can be produced from any form of primary energy (fossil, renewable, nuclear)
- It can be efficiently transported in a grid from generators to the point of use
- It is emission-free at the point of end use (except for electric fields)
- It can be converted at high efficiency into heat, mechanical, and chemical energy
- It can be applied equally well to the nano-scale as to industrial smelter scale
- It powers electronic devices
- It provides light
- It is instantly controllable at the point of use - it takes only a flick of a switch

There are, however, also draw-backs to electricity. Since it has to be produced from other primary fuels at moderate conversion efficiencies (typically between 30 up to a rare 60 percent) and high conversion costs, its price per delivered unit of energy is high. The electric grid - in particular the high-voltage grid for

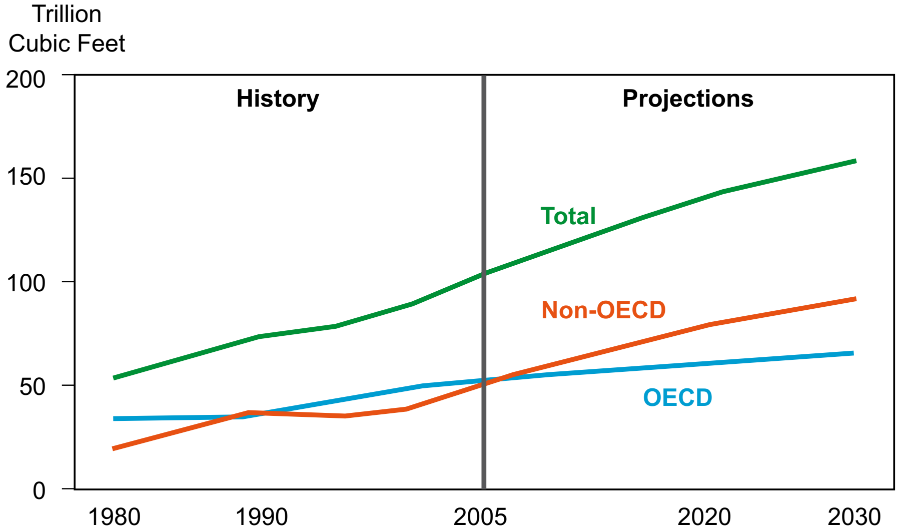



**Fig.3.14:** History and forecast of natural gas consumption by world region. While the consumption in the OECD countries are expected to level out, the non-OECD countries are expected to grow fast over the period to 2030. (Redrawn based on: US EIA, World Energy Outlook 2008)

long distance transport – is both costly, of limited capacity, can have high losses and are highly visible and therefore controversial. Building new grids is becoming difficult in many countries. A third and important draw-back is that the costs of medium and large scale storage of electricity are prohibitive. This is why electric cars so far have had a draw-back compared to petrol or diesel fuelled cars and that intermittent renewable electricity needs costly back-up from other – mostly fossil fuelled - capacity.

Despite its draw-backs, electricity is growing faster as a share of energy end-uses than other energy carriers. The result is that electricity intensity (kWh per unit of GDP) has remained relatively constant even though the overall global energy intensity continues to decrease.

While electricity as an energy carrier has excellent qualities at the end-use stage, it is necessary to examine closely the total primary energy chain leading up to consumer before it is possible to draw environmentally related conclusions.

What are the areas where natural gas can compete with electricity today – and tomorrow? Firstly it is cheaper than electricity per unit of energy. Since natural gas pipeline grids are buried, they are also much less conspicuous than above-ground electric transmission lines, in particular for large energy volumes.

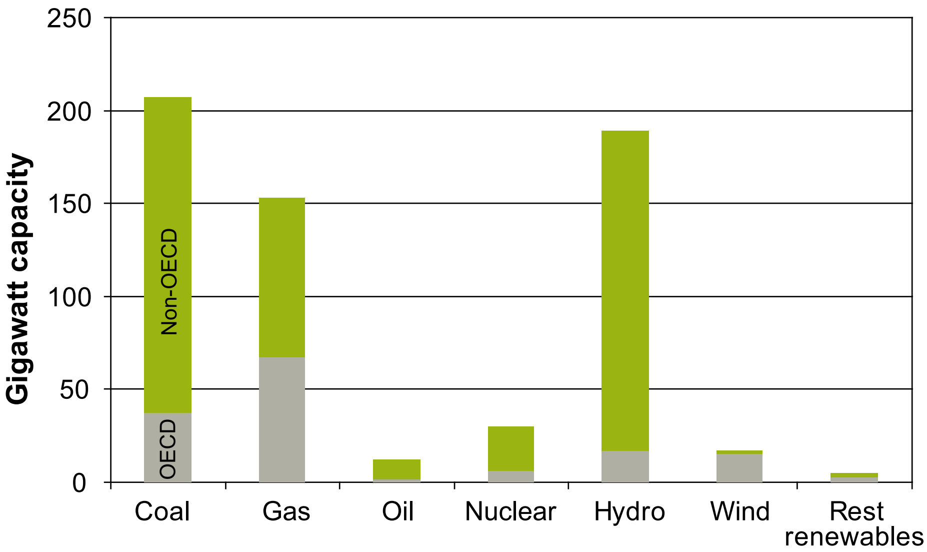



**Fig. 3.15:** Power generation capacity under construction worldwide 2007 (Redrawn based on IEA World Energy Outlook 2008)

Thirdly natural gas is more easily stored both on large scale (e.g. underground storage) and even on small to medium scale (e.g. CNG in buses) than electricity. Natural gas technologies are – or may be developed to be – equal to electricity with respect to ease of control (flip of a switch). Natural gas technologies could make even larger inroads into heating (e.g. natural gas fired heat pumps) and cooling as well as becoming the fuel of choice for on-site electricity generation at commercial facilities (e.g. shopping malls), schools, hospitals down to individual homes (Fig. 3.17).

**Fig. 3.17:** Micro-CHP equipment (internal combustion engine) fuelled by natural gas provides electricity and heat to small and medium premises. The electric efficiency of such devices are not particularly high, but in applications with considerable heating (or cooling) loads this does not matter since the combined electricity plus heat efficiency will be high (Picture: EC Power, Denmark)

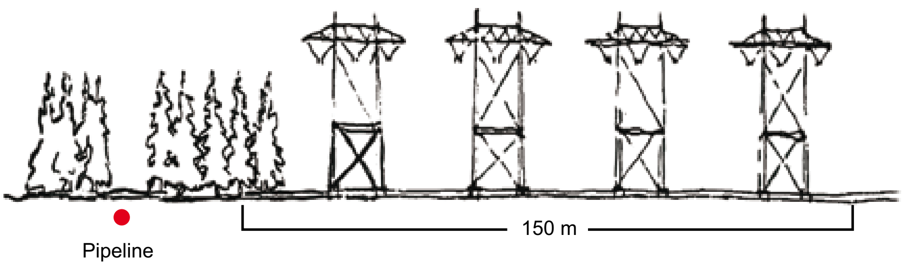
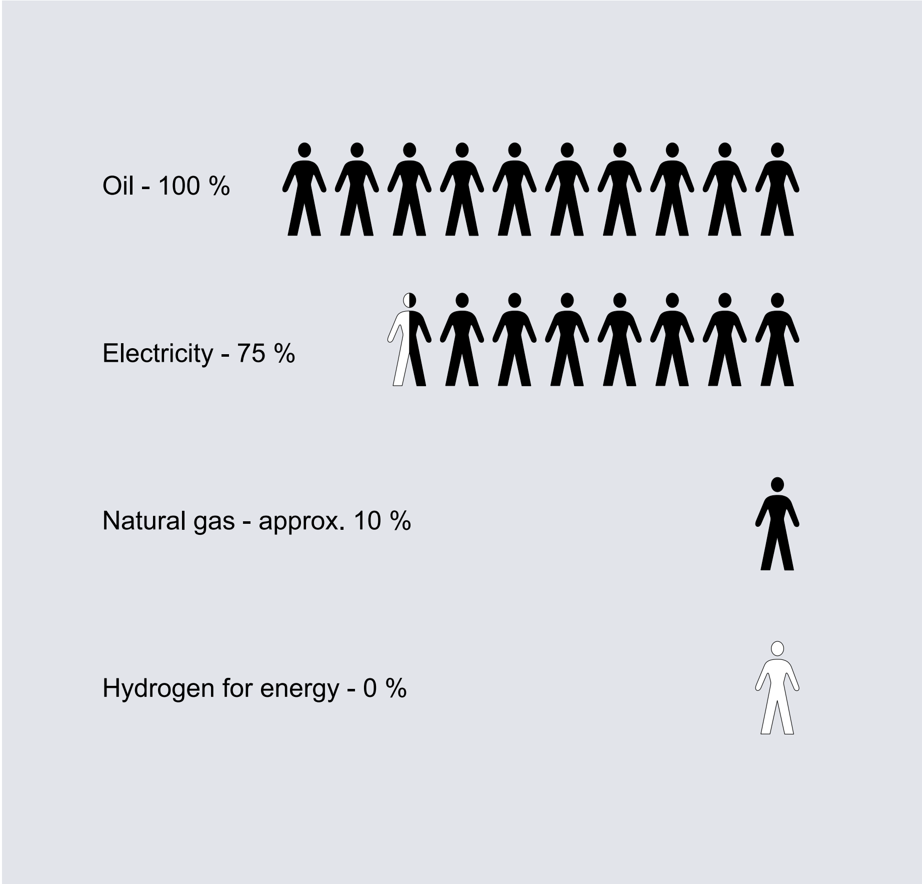



**Fig. 3.16:** An example of the foot-print of energy transmission. The drawing shows a case where 40 TWh of electricity is wanted by the end-user based on natural gas from a distant source. Should the power station(s) be located at the gas production or at the end-use site? In this example 6 Bcm/yr as gas carried in the pipeline versus 40 TWh/yr electricity produced from the same amount of gas. The foot-print is very different. This is of particular importance when the energy is to be transmitted for hundreds or even thousands of kilometres or through populated areas. There are several gas pipelines (existing or under construction) with capacities exceeding the above mentioned by five to ten times carrying an amount of energy totally unrealistic for electricity transmission (Source: Statkraft 1988).

**The degree of access to oil, electricity, natural gas and hydrogen**

Not far from 100 % of the global population has some level of access to oil, even if affordable only in very small quantities for oil-lamps or similar. In comparison there are at present some 1.6 billion people - about one in four of the world's population - living without access to electricity. As an example, in India the share of households with access to electricity is about 55 percent. Altogether eighty percent of all people without electricity live in rural areas of the developing world, mainly in South Asia and Sub-Saharan Africa where rapid urban migration and population growth will occur over the next decades. On a global scale over 90 percent of urban population has access to electricity while the rural electrification rate is estimated at 62 percent. Without electricity or clean burning fuels such as natural gas, it is virtually impossible to carry out productive economic activity or improve health and education.

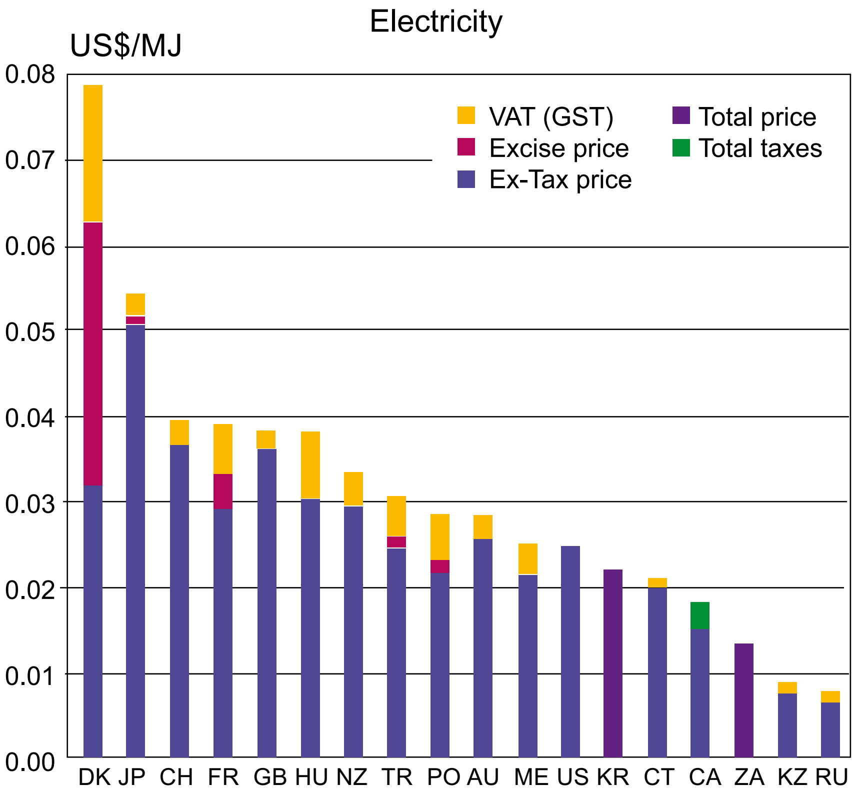



Unlike access to electricity, we do not know with any degree of precision how many people globally lack access to clean-burning natural gas. An indication is that in 2006, EU-25 with 200 million households had 105 million customers connected to the gas grid, giving a coverage of about half the population. In USA natural gas is used in 61 percent of all homes. In Japan about 27 million households (out of a total of 52 million) have access to natural gas. These three regions – which taken together have about 14 percent of global population – have the world's most developed and dense gas-grids. Few other countries and regions are anywhere near this gas-grid coverage at the present time. From this we can draw the informal conclusion that perhaps as few as 10 percent of global households have direct access to natural gas to use for cooking, heating, cooling or small scale electricity generation.

**The costs of energy**

Energy customers - in particular the larger customers – take great interest in the costs of the various energy carriers from which they can choose. Fig. 3.19 indicates that these cost to end-users can be quite different between countries and energy carriers. In the case of energy intensive industries, the costs of energy will often be the most important factor deciding the location of such industries. When deciding to switch from a high carbon fuel (e.g. coal) to a lower carbon fuel (e.g. natural gas) the difference in end-user price (incl. taxes and any $CO_2$-costs) will be an important part of the decision. Another route for energy prices to influences emissions is that high prices will result in customers investing in more efficient energy technologies (e.g. increased car mileage) and to some extent also in reducing activity level (e.g. less driving).

**Fig. 3.18:** How large shares of the global population has access to which forms of energy? The global degree of access to oil products, electricity, natural gas and hydrogen for energy purposes as illustrated here. Those without access to natural gas (or hydrogen in the future), have their options limited to more polluting fuels.



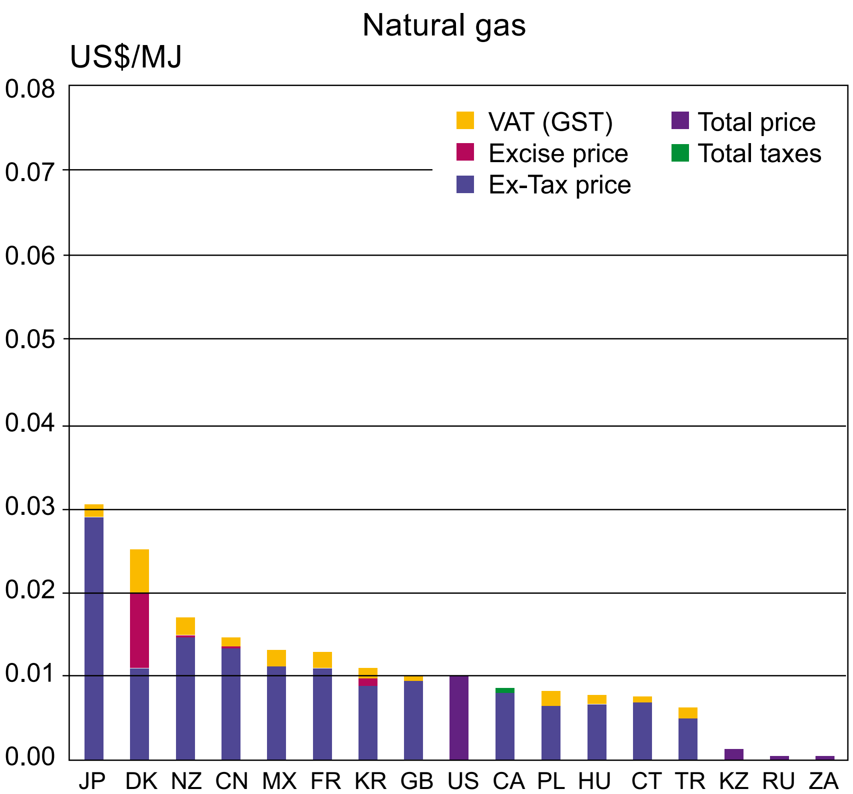




**Fig. 3.19:** The costs of energy to consumers: Electricity and natural gas prices, including taxes for households. From these charts it is evident that the costs of energy to consumers varies a lot, but also that taxation plays an important role in many countries (Source: http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter6.pdf )

**References chapter 3**

BP Statistical Review of World Energy 2008 CIA, The World Fact Book 2008 IEA WEO (2007), World Energy Outlook 2007, IEA/OECD, Paris IEA WEO (2008), World Energy Outlook 2008, IEA/OECD, Paris IEA, (2008a), $CO_2$ Capture and Storage. A key Carbon Abatement Option, IEA Paris, Freund, Kaarstad; Keeping the Lights On, Oslo University Press, 2007

**Useful web-sites for this chapter:**

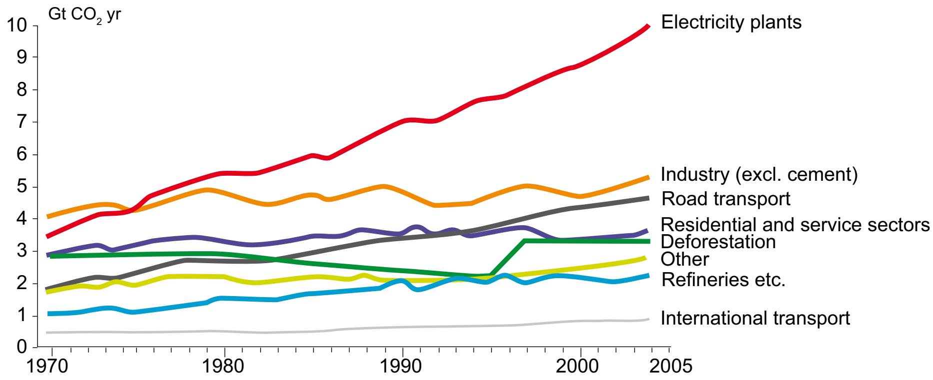
EIA International Energy Outlook 2008: http://www.eia.doe.gov/oiaf/ieo/index.html

BP Statistical Review of World Energy: http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

# 4. Global emission

There has been a steady growth of global $CO_2$-emissions over the years as illustrated in fig. 4.1 which shows the global aggregate from 1970 up to today. The $CO_2$- emission growth from electricity generation plants has been formidable, hinting at the importance of this sector when planning climate mitigation efforts. Another highgrowth sector is road transport.

**Fig. 4.1:** Historical development of each source of global $CO_2$-emissions (1970–2004). The most remarkable sectors with respect to growth over time are electricity generation, road transport and deforestation. Cement manufacture is not shown in this graph. This sector emitted 1,8 Gt $CO_2$ in 2005, about 6 percent of total global $CO_2$-emissions (Source: IPCC AR4, WG3, chapter 1).




What will the future bring? World carbon dioxide emissions are increasing steadily in a business-as-usual case, from 28.1 billion metric tons in 2005 to a projected 34.3 billion metric tons in 2015 and growing to 42.3 billion metric tons in 2030 (EIA, 2008). This is more than a 50 percent increase from today until 2030. With strong economic growth and continued heavy reliance on fossil fuels expected for most of the non-OECD economies, much of the increase in carbon dioxide emissions is projected to occur among the developing, non-OECD nations. In 2030 non-OECD emissions are projected to exceed OECD emissions by 72 percent (fig. 4.2).

Due to the lower $CO_2$-emission from natural gas (compared to coal and oil) per unit of energy (see fig. 5.5), gas comes out as a moderate global emitter as seen in fig. 4.3.

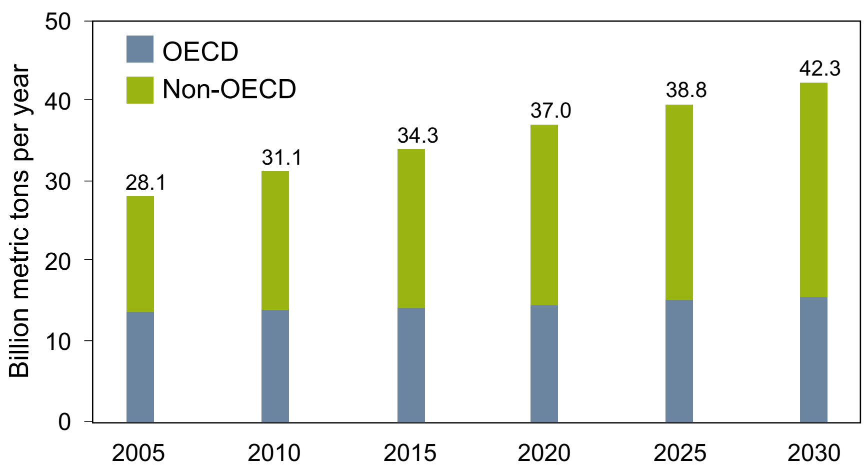



**Fig. 4.2:** World carbon dioxide emissions and business-as-usual projections 2005 – 2030. (Redrawn based on: EIA CO2, 2008)

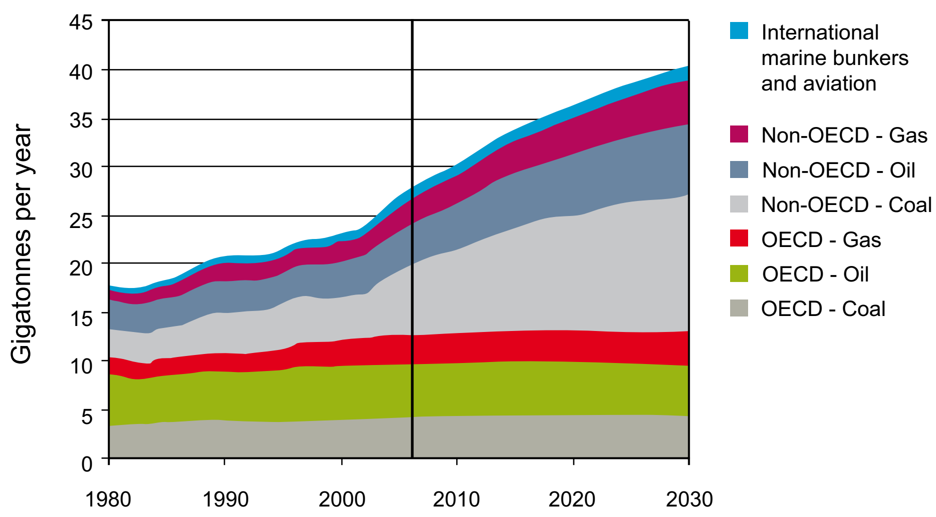



**Fig. 4.3:** World energy-related carbon dioxide emissions by fuel from 1980 with projections to 2030 in the IEA 2008 reference scenario. Coal is – in this projection – the primary fuel that increases $CO_2$-emissions the most to 2030, continuing a trend that has been seen for a number of years already. An increased switch from coal to natural gas would be highly beneficial from the point of view of CO2-load on the atmosphere. (Source of graph: IEA World Energy Outlook 2008)

In order to better understand the sources of $CO_2$ and the other greenhouse gases, we need to go below the levels of regions, countries and the share of the primary fuels. Fig. 4.4 illustrates – on a global basis – which sectors contributes what type of greenhouse gas and in what relative amount.

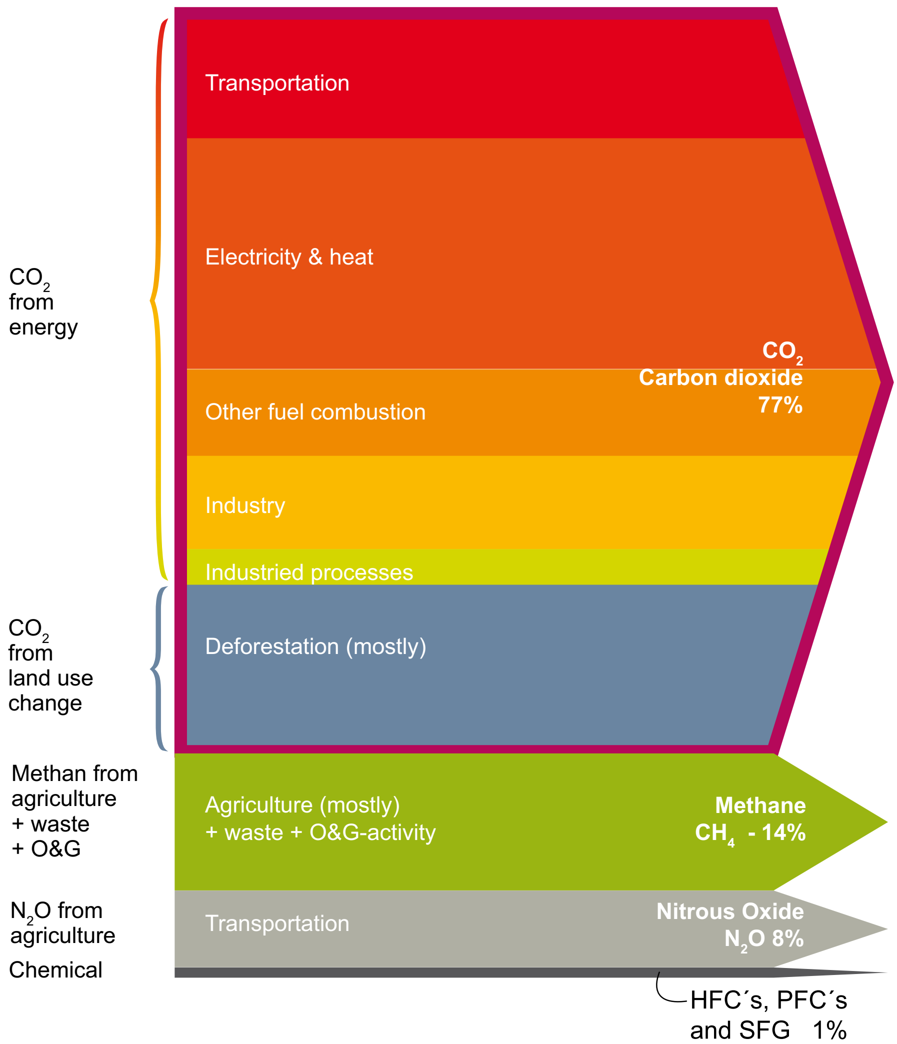



**Fig. 4.4:** Where do the global greenhouse gases come from? This much simplified world greenhouse gas emissions flow chart tries to illustrate the main contributing sectors and their relative weight. Land use change includes both emissions and absorptions. US EPA estimates that about one in twelve anthropogenic methane molecules entering the atmosphere arise from the oil and gas industry (more in chapter 6). (Redrawn and updated from a World resources Institute graph from 2005).

**The global warming potential of various greenhouse gases:**

The two most abundant gases in the atmosphere, nitrogen (comprising 78% of the dry atmosphere) and oxygen (comprising 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common. Water vapour is the most important greenhouse gas, and carbon dioxide ($CO_2$) is the second-most important. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. In the humid equatorial regions, where there is so much water vapour in the air that the greenhouse effect is very large, adding a small additional amount of $CO_2$ or water vapour has only a small direct impact on downward infrared radiation. However, in the cold, dry polar regions, the effect of a small increase in $CO_2$ or water vapour is much greater. The same is true for the cold, dry upper atmosphere where a small increase in water vapour has a greater influence on the greenhouse effect than the same change in water vapour would have near the surface.

Normally the 100 year time horizon (see table) is used for evaluating the efficiency of a particular gas for its potential for climate change (global warming potential - mass basis - or GWP). $CO_2$ is assigned the strength 1 as reference gas. Methane and nitrous oxide then have 25 times and 298 times the global warming effect per kilogram respectively than the $CO_2$ reference.

| Gas | Global warming potential (GWP) time horizon | | |
|---|---|---|---|
| | 20 years | 100 years | 500 years |
| **Carbon dioxide $CO_2$** | 1 | 1 | 1 |
| **Methane $CH_4$** | 72 | 25 | 7,5 |
| **Nitrous oxide $N_2O$** | 289 | 298 | 153 |

Sources: IPCC WG 1 (http://ipcc-wg1.ucar.edu/wg1/FAQ/wg1_faq-1.3.html) and IPCC WG1 Fourth Assessment Report

Without understanding energy flows and the associated greenhouse gas flows through society, we cannot make good plans for their reduction. Figure 4.5 is an example of CO2-flows from coal, oil and natural gas use in the United States.

When considered from a natural gas viewpoint, figure 4.5 can give rise to questions such as: Why is the natural gas share of total energy supply so low compared to coal and oil? Why is the natural gas share of electricity generation so low compared to coal when the environmental benefit is so large? Why is the natural gas share in the transportation sector so low? Graphical representations like fig. 4.5 may help us ask the "large" questions before going on to the more detailed issues within the residential/commercial, industrial and transportation sectors.

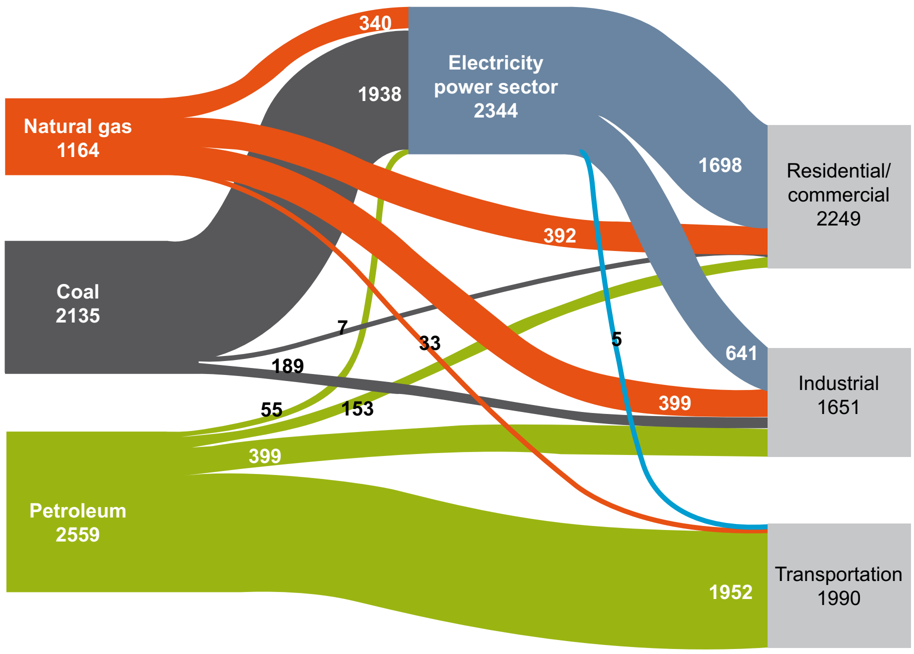



**Fig 4.5:** An example of energy flows for one of the largest natural gas consuming countries (USA) with a substantial share of gas in its residential, commercial and industrial sectors. Natural gas consumption arises in almost equal amounts from electricity generation, residential/commercial use and for industrial consumption. There is a small discrepancy between figures on the left and right hand side due to losses and rounding (Source: Updated from 2002 to 2006 figures on the basis of a LLNL original, https://eed.llnl.gov/flow/carbon02.php).

**The electricity generation sector**

Today 41 percent of global energy-related $CO_2$ originates in electricity generation. Generating electricity from coal accounted globally for 72 percent of all $CO_2$ emissions in this sector in 2005. Natural gas based plants accounted for 20 percent with oil fired power plants accounting for the rest. Total emissions from about 1000 coal fired power plants globally were 7,9 Gt $CO_2$ in 2007, this being about 27 percent of global total. The 100 largest plants each emitted on the average 21 Mt $CO_2$ per year.

The average efficiencies of existing coal-based power generation is below 35 percent, while new-built plants are typically 48 % (LHV) for coal fired plants and 57% (LHV) for gas turbine combined cycle plants fired with natural gas (IEA, 2008a).

**Fig. 4.6**: Coal fired power plants generates 72% of all power generation $CO_2$. Here the Eggbourough power station in UK. Modernising the power sector by replacing aging coal fired power plants by state of the art natural gas fired power plants can drastically reduce $CO_2$-emissions through increased energy conversion efficiency and use of low carbon fuel.

**The industrial sector**

Industrial sector GHG emissions globally are currently estimated to be about 12 $GtCO_{2eq}$ per year. The developing nations' share of industrial $CO_2$ emissions from energy use grew from 18 % in 1971 to 53 % in 2004 following the globalisation of production of goods. Industrial sector emissions of greenhouse gases include carbon dioxide from energy use, from non-energy uses of fossil fuels and from non-fossil fuel sources such as cement manufacture as well as non- $CO_2$ gases. Energy-related $CO_2$ emissions (including emissions from electricity use) from the industrial sector grew from 6.0 $GtCO_2$ in 1971 to 9.9 $GtCO_2$ in 2004. Direct $CO_2$ emissions totalled 5.1 Gt, the balance being indirect emissions associated with the generation of electricity and other energy carriers. However, since energy use in other sectors grew faster, the industrial sector's share of global primary energy use declined from 40% in 1971 to 37% in 2004. Approximately 85% of the industrial sector's energy use in 2004 was in the energy-intensive industries: iron and steel, nonferrous metals, chemicals and fertilizers, petroleum refining, minerals (cement, lime, glass and ceramics) as well as pulp and paper. Developing countries accounted for 42% of iron and steel production, 57% of nitrogen fertilizer production, 3/4 of cement manufacture and about half of primary aluminium production.

The production of energy-intensive industrial goods has grown dramatically and is expected to continue growing as population and per capita income increase. Since 1970, global annual production of cement increased 271%; aluminium, 223%; steel, 84% (USGS, 2005), ammonia, 200% (IFA, 2005) and paper, 180% (FAO, 2006). Much of the world's energy-intensive industry is now located in developing nations. China is the world's largest producer of steel (IISI, 2005), aluminium and cement (USGS, 2005).

**Fig. 4.7:** Energy intensive industries are responsible for about 10 $GtCO_2$-emissions (10 000 million tons of $CO_2$ per year) through using about 37 percent of global energy. The contribution of renewables to this already highly energy-efficient sector is – and will stay - low.

## Residential and commercial

The direct emissions from the buildings sector (2004) were about 3 $GtCO_2$. As mitigation in this sector includes a lot of measures aimed at electricity saving, it is useful to compare the mitigation potential with carbon dioxide emissions, including those through the use of electricity. When including the emissions from electricity use, energy-related carbon dioxide emissions from buildings were 8.6 Gt/yr, or almost a quarter of the global total carbon dioxide emissions. This exemplifies the importance of efficient and low-carbon production of electricity, such as from natural gas fired heat and power (CHP) plants.

From fig. 4.8 we see that direct heating through combustion in residential and commercial buildings represents only 1/3 of all building energy consumption. The reminder comes from electricity and (to a much lesser extent) from district heating and cooling.

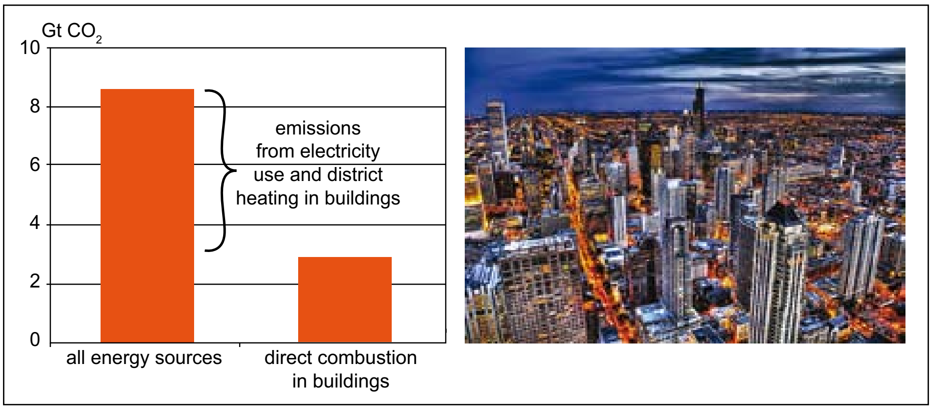



**Fig. 4.8:** The graph (left) shows the estimated emissions of $CO_2$ from energy use in buildings from two different perspectives. The bar at the left represents emissions of $CO_2$ from all energy end-uses in buildings. The bar at the right represents only those emissions from direct combustion of fossil fuels. The picture to the right is "A town of Energy" indicating the many ways energy is consumed in an urban environment (Graphic source: IPCC AR4, WG3).

## The transportation sector

Transport of goods and people in today's world predominantly relies on oil that supplies 95% of the total energy used in this sector. Transport is responsible for 23% of world energy-related GHG emissions with about 3/4 of this coming from road vehicles. Over the past decade GHG emissions from this sector have increased at a fast rate (fig. 4.1).

Transport activity will continue to increase in the future as economic growth fuels transport demand and the availability of transport drives development, by facilitating specialization and trade. The majority of the world's population still does not have access to personal vehicles and many do not have access to any form of motorized transport. This situation is, however changing at a fast pace.

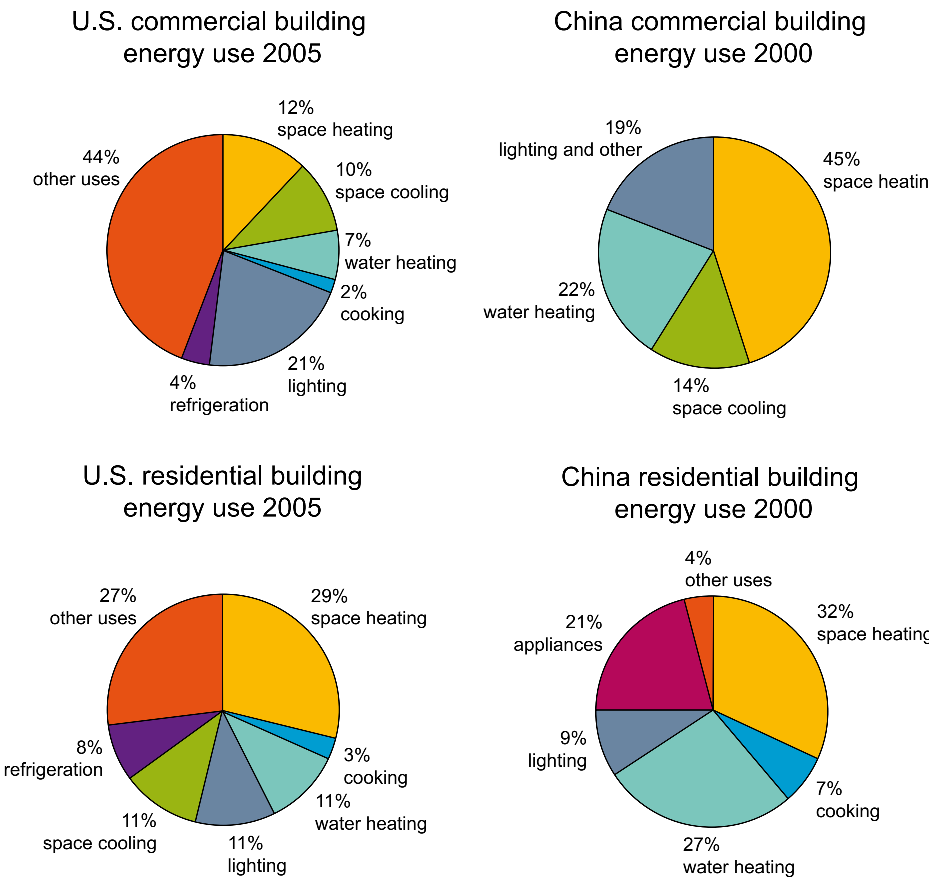



**Fig. 4.9:** A comparison of the United States (2005) and China (2000) with respect to residential and commercial sector energy use. As shown by these graphs, there are great differences in what energy consumption in commercial (upper) and residential (lower) buildings are used for in USA and China. In China water heating and space heating dominates while in the US the uses are more diverse (Source: IPCC AR4, WG3).

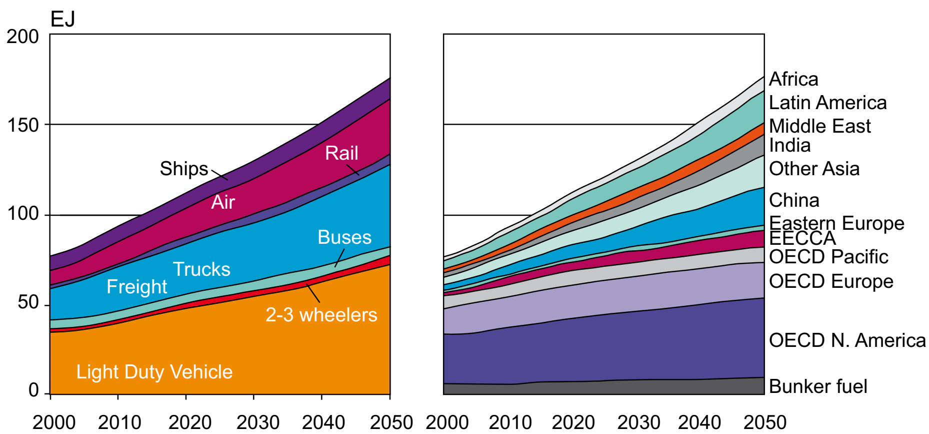

**Fig. 4.10:** Gasoline and diesel fuelled cars, freight trucks and buses are major culprits not only with respect to $CO_2$-emissions, but figures very heavily in smog generation, NOx- and fine particle emissions and other local pollution. More natural gas fuelling of the transport sector can help alleviate both global and local pollution.

The transportation of freight has been growing even more rapidly than passenger transport and it is expected to continue to do so. Freight movements in cities are dominated by trucks, while international freight movements are dominated by ocean shipping. Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, world transport energy use is projected to increase at the rate of about 2% per year, with the highest rates of growth in the emerging economies, and total transport energy use and connected carbon emissions is projected to be about 80% higher than current levels by 2050 (fig. 4.11).

## Gas flaring in the oil industry

Gas flaring is not a large problem in the natural gas industry itself, but is rather a byproduct of the production in the oil industry. When so-called associated gas are produced together with oil - in larger or lesser amounts -, the gas is sometimes flared. According to the World Bank Global Gas Flaring Partnership (GGFRP), the oil industry globally flares 150 billion cubic meters (Bcm) of natural gas. For comparison, the gas flared globally on an annually basis is equivalent to 25 per cent of the United States' gas consumption or 30 per cent of the European Union's gas consumption. The annual 40 bcm of gas flared in Africa alone is equivalent to half of that continent's power consumption. Flaring of gas has a global impact on climate change by adding an estimated 400 million tons of $CO_2$ in annual emissions. Numerous technical and practical barriers complicate efforts to put the gas to good use. Oil wells are often located in remote locations far from pipelines, markets and customers. Gas cannot be as easily stored and shipped as oil. Pumping the gas back into an underground reservoir for storage for possible later utilisation is not always possible. A lot of gas is flared in developing countries where there is little or no infrastructure to use the gas, or a legal framework to regulate the market. Each year the oil industry flaring is thereby responsible for emitting roughly 1,5 % of the world's $CO_2$ emissions. Fewer than 20 countries account for nearly 90 percent of gas flaring and venting as shown in table 4.1.

**Fig. 4.11:** Historical and projected $CO_2$-emissions from the transportation sector globally 1970 to 2050 (LDV; Light Duty Vehicle). Road transport is set to dominate with light duty vehicles and freight taking the most sizable share and growth. Air transport is also projected to grow fast. Among regions Asia is projected to have the fastest growth (Redrawn based on: IPCC AR4, WG3)



| Rank | Top 20 Countries | Flared, Bcm/yr in 2007 |
|---|---|---|
| 1 | Nigeria | 16,8 |
| 2 | Russia | 50* |
| 3 | Iran | 10,6 |
| 4 | Iraq | 7.0 |
| 5 | Kazakhstan | 5,3 |
| 6 | Angola | 3,5 |
| 7 | Saudi Arabia | 3,4 |
| 8 | Venezuela | 2,1 |
| 9 | Qatar | 2,9 |
| 10 | Algeria | 5,2 |
| 11 | USA | 1,9 |
| 12 | Kuwait | 2,1 |
| 13 | Indonesia | 2,4 |
| 14 | Kazakhstan | 5,3 |
| 15 | Libya | 3,7 |
| 16 | China | 2,5 |
| 17 | Uzbekistan | 2,0 |
| 18 | Mexico | 1,7 |
| 19 | Congo | 2.2 |
| 20 | United Kingdom | 1.6 |
| | Total top 20 | 132,2 |
| | Rest of the World | 14,8 |
| | World Total | 147 |

Table 4.1: The natural gas industry can sometimes assist the oil industry in reducing the amount of gas (produced with oil) that is flared. This table shows the 20 largest flaring countries as of 2007 and their flaring measured in billion cubic meters per year (Bcm) based on estimates derived from satellite data * Figures and estimates for gas flaring in Russia vary substantially. Much lower figures are found in some sources. In general flaring figures are not very reliable. (Source: World Bank GGFRP).

For the past 20 years, overall global flaring levels have remained virtually constant at around 150 Bcm/yr, despite many individual governments and companies successes in reducing flaring. These efforts have been limited not only because of the increase in global oil production and the associated gas production, but also because of the major constraints that hinder the development of gas markets, gas infrastructure, and flaring reduction projects. The on the average higher prices for natural gas in recent years have, however, made more flaring reduction projects economically feasible and large projects are underway. More about this in chapter 6.

**References chapter 4**

EIA 2008: US Energy Information Administration, World Energy Outlook 2008 BP Statistical Review of World Energy 2008 IEA, (2008a), $CO_2$ Capture and Storage. A key Carbon Abatement Option, IEA Paris IEA Greenhouse Gas R&D Programme, Cement Report (draft), 2008 World Bank Global Gas Flaring Reduction Partnership

**Useful web-sites for this chapter:**

**IPCC:** http://www.ipcc.ch/ EIA International Energy Outlook 2008: http://www.eia.doe.gov/oiaf/ieo/index.html

**BP Statistical Review of World Energy:** http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

**World Bank on gas flaring:** http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTOGMC/EXTG GFR/0,,menuPK:578075~pagePK:64168427~piPK:64168435~theSitePK:578069,00.html

**EIA $CO_2$, 2008:** http://www.eia.doe.gov/emeu international/carbondioxide.html

**IISI** - International Iron and Steel Institute: http://www.worldsteel.org/

**IPCC AR4, WG3:** http://www.ipcc.ch/ipccreports/ar4-wg3.htm

# 5. Greenhouse gas emissions from the natural gas industry

**Fig. 5.1:** Natural gas processing plant with gas/liquids separation columns, compressors, storage tanks etc. at Kårstø, Norway (Picture: Øivind Hagen/StatoilHydro).

This chapter surveys the present status of the natural gas industry's own emissions of greenhouse gases in the form of carbon dioxide and methane. It draws heavily on a previous International Gas Union work on life cycle assessment from 2006 (IGU LCA, 2006) , updated with more recent data when available.

**Energy and emissions at the production and processing stage**

Unlike oil fields, there is as a rule no attempt to increase the recovery of natural gas from a pure gas field through energy intensive increased recovery methods in the reservoir (increased condensate recovery through recirculation of gas being the exception). When gas fields are emptied, their pressure is reduced and the lower wellhead pressure will at some point in time require installation of a compressor facility that is usually driven by a gas turbine or a gas motor. Energy consumption and emissions at the processing stage depend on the composition, pressure and temperature of the raw natural gas, the age and quality of the technology of the plant, availability of cooling water (if any) as well as on operational practices. This is indicated in table 5.1. When comparing own consumption of energy as well as fugitive emissions between countries, regions and companies, it is necessary to take such differences and uncertainties into account.

No two natural gas fields are alike with respect to in-situ reservoir pressure and temperature and gas composition (including LPG and liquids content). In those instances where natural gas and liquids are co-produced, it is necessary to allocate part of the emissions to gas and part to the liquids, usually on the basis of their respective energy content.

| Type of emission source | NW Europe | Russia | USA | Average |
|---|---|---|---|---|
| Energy | 1,2 - 1,5% | 0,6 - 1,0% | 5,4% | 2,7% |
| Fugitive and venting | 0,04 - 0,13% | 0,44 - 0,5% | 0,81% | 0,58% |
| Flaring | 0,12 - 0,29% | Uncertain | 0,55% | 0,48% |
| Total gas consumption and losses | 1,3 - 1,7% | 1,1 - 1,5% | 6,7% | 3,5% |
| Greenhouse effect (g $CO_{2eg}$/Nm3) | 25 - 44 | 120 | 250 | 150 |

**Table 5.1:** Consumption and losses of natural gas (volume percentage) at the production stage (non LNG) (Source: IGU LCA-report 2006).

In USA between 5 and 6 % of the natural gas is used for energy at the processing stage. Methane content of the raw natural gas may in the US be as low as 75%, which goes a long way towards explaining the relatively high energy consumption in that country. In NW Europe, energy consumption is higher than for Russian gas processing, but considerably lower than in USA. The emissions of methane and the amount flared do not depend on the gas quality but rather reflect the technology used throughout the gas chain. In the north-western part Europe, the total of fugitive and venting emissions and gas flared may range from 0.16% up to 0.3%, compared to more than 1.3% in USA. In total, gas consumption and losses in the processing step amount to 1.3-1.7% for EU/RU and almost 7% for the USA. The averaged total for these countries and regions is about 3.5%.

Despite the low energy consumption in the Russian case, the greenhouse effect of US and Russian gas production is higher than the West European case due to fugitive emissions. In determining the greenhouse effect of the processing step, the fugitive emissions are an important factor, as methane itself has a 25 times higher greenhouse impact per kg emitted (see text box on global warming potentials – GWP – in ch. 4) than the $CO_2$ resulting from flaring/combustion of the same weight of natural gas.

From time to time in the past, confusion has arisen with respect to own consumption and fugitive emissions in the gas industry. Some parties has counted own consumption as fugitive emissions of methane, resulting in huge (and very wrong) estimates of greenhouse gas effect from the gas industry. In reality own consumption is burnt in turbines, motors and burners and ends up as $CO_2$. For LNG, the amount of energy needed for processing is higher due to the additional cooling and liquefaction step. Data have been collected for several individual existing production locations as well as locations under construction. In Table 5.2 the relative gas consumption is listed for those. The Japanese mix consists of LNG produced in Brunei, Australia, Malaysia and Indonesia.

| LNG process step | Capacity under construction | Existing capacity | Japan mix (existing) | Average (existing) | Ecoinvent study (altn. source) |
|---|---|---|---|---|---|
| Refrigeration cycle | 6,2 - 6,9% | | 8,8% | | 14,94% |
| Auxiliary electricity | 1,5 - 1,4% | | | | |
| Hot oil system | 0 - 0,3% | | | | |
| Venting | (0,005%) | | 0,2% | | 0,05% |
| Flaring | | 0,2 - 0,4% | 0,7% | 0,5% | |
| Total | 7,9 - 8,7% | 9,9 - 12,9% | 9,6% | 10,3% | 15% |

**Table 5.2:** Gas consumption in LNG processing (Source: IGU LCA-report 2006)

The data for existing capacity cover approximately 3/4 of the global LNG production. The average gas consumption over these plants is about 10% of the plant natural gas throughput. For the LNG-capacity under construction, this figure is about 8% with the best – typically benefiting of cold cooling water - about 6%.

As indicated there is a trend toward higher efficiency in LNG production. The actual emissions arising from LNG production are listed in Table 5.3.

Corresponding to the tendency towards higher efficiency, the specific $CO_2$ emissions are also lower for the planned capacity than for the existing capacity. The emissions associated with best available technology (BAT) is 116 g/Nm3. As a result, there is a potential reduction by a factor of 1.7 in total greenhouse effect between existing and future processing plants. As is the case for processing to pipeline gas, the methane emissions are an important contributor to the total climate impact potential. When comparing normal natural gas processing (for pipelines) and LNG processing, it is clear that LNG takes more energy on average. The average gas consumption today is about 4 % in the former case and about 10 % in the latter.

| Type of emission | Capacity under construction | Existing capacity | Japan mix (existing) | Average (existing) |
|---|---|---|---|---|
| Carbon dioxide - $CO_2$ | 214 - 221 | 202 - 280 | 299 | 280 |
| Methane - $CH_4$ | (0,036) | (5,9) | | |
| Oxides of nitrogen - $NO_x$ | 0,14 - 0,19 | (0,99) | | |
| Sulphur dioxide - $SO_x$ | (0,0011) | (0,0029) | | |
| Greenhouse effect pf $CO_2$ and CH4 (g $CO_{2eq}/Nm^3$) | (222) | (377) | | |

**Table 5.3** Emissions and climate impacts for LNG production in g/Nm3 natural gas (between brackets if only one data set available) (Source: IGU LCA-report 2006).

**$CO_2$-rich natural gas in reservoirs**
Increased interest in hydrocarbon gas exploration in some geological basins is tempered by the risk of encountering high levels of non-hydrocarbon gases which reduce energy density and increase production costs. This is especially true for gas occurrences in Southeast Asia where $CO_2$ abundance can range from less than 10% to greater than 90% in fields from the same basin and occasionally among reservoirs in the same field. On average, the global risk of encountering more than 1% concentrations of $CO_2$ in a gas accumulation is less than 1 in 10, and the risk of encountering a higher than 20% concentrations of $CO_2$ is less than 1 in 100.

Accumulations of large volumes of $CO_2$ in sedimentary basins are also found in places like the Central European Pannonian Basin in Hungary, the Australian Cooper-Eromanga Basin, the Iblea platform in Sicily, the Taranaki basin in New Zealand, in the Gulf of Thailand and in the South Viking Graben in the North Sea.

In some other gas regions $CO_2$-contamination will be less, but still sufficient to cause removal at a gas processing plant. Sometimes such contamination by $CO_2$ occur together with hydrogen sulphide ($H_2S$). These contaminants are normally removed to a low level in order to fulfil a gas customer specification or to make it technically possible to produce LNG. Production plants for LNG are of particular interest because they need to reduce $CO_2$-content down to part per million concentrations in order to avoid clogging up the heat exchangers with so-called dry ice (solid $CO_2$). Since they process very large volumes of natural gas, the extracted $CO_2$ may be of substantial tonnage even if the $CO_2$-concentration in the incoming natural gas is moderate. The natural gas industry therefore has available a number of concentrated $CO_2$-sources that may be suitable for underground storage if the frame conditions are right. Today such frame conditions exist in only a few countries (e.g. Norway, West-Australia).

Carbon dioxide captured from natural gas has an important place in climate mitigation even if the amount of this $CO_2$-contamination does not amount to great tonnages. This is because these sources consist of almost 100% pure $CO_2$ in volumes ranging from a fraction of a million ton to several million tons per source. The first geological $CO_2$- storage projects (CCS-projects) for climate change reasons are in this category (Sleipner, In Salah, Snøhvit, and Gorgon). These CCS-projects are further elaborated in chapter 6.

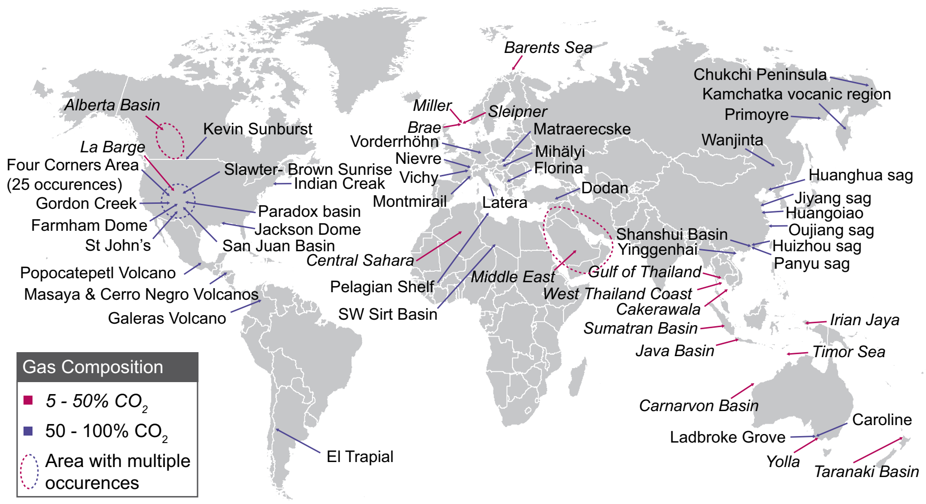



**Figure 5.2:** Examples of some natural accumulations of $CO_2$ around the world. Regions containing many occurrences are enclosed by a dashed line. Natural accumulations can be useful as analogues for certain aspects of $CO_2$-storage and for assessing the environmental impacts of any leakage from such storage sites. Data quality is variable and the apparent absence of accumulations in South America, southern Africa and central and northern Asia is likely a reflection of lack of data rather than a lack of $CO_2$ accumulations (Redrawn based on: IPCC SRCCS, 2005).

**Energy and emissions at the transportation stage**
The energy consumption and $CO_2$-emissions arising from transportation of natural gas is closely connected to the distance covered both for pipelines and for the shipping part of an LNG-chain.

Trading is approx 750 BNm³/year of which 540 BNm³ is transported by pipeline and 210 BNm³ as LNG.

Emission data for pipeline transmission are available for several European countries as well as from USA, Canada, Russia, Australia, Iran, Algeria and Argentina. Together these countries are responsible for about 80% of the global production volume, hence an almost equivalent percentage of global pipeline transportation is covered.

**Fig. 5.3:** A gas pipeline in Tierra del Fuego, South America. The world's most southerly natural gas production facility was put into operation in June, 2005 by the ownership consortium (Photo: BASF)

Regional averages are shown in table 5.4, as well as the total average and spread per consumption and emission. For Europe, the data are taken from Eurogas- Marcogaz.

**Table 5.4:** Regional data for energy use and emissions for natural gas transmitted by pipelines (Source: IGU LCA-report 2006)

| Type of emission | Europe | North America | Asia | Other | Average | Max |
|---|---|---|---|---|---|---|
| Gas (energy) | 0,39% | 2,19% | 8,67% | 0,96% | 4,1% | 9,08% |
| Gas (fugitive and venting) | 0,02% | 0,35% | 0,67% | 0,08% | 0,4% | 0,74% |
| Carbon dioxide - $CO_2$ (g/Nm$^3$) | 7,81 | 51,02 | 310,59 | 20,83 | 132,12 | 332,77 |
| Methane - $CH_4$ (g/Nm$^3$) | 0,11 | 2,51 | 6,67 | 0,11 | 3,35 | 7,39 |
| Nitrogen oxides $NO_x$ (g/Nm$^3$) | 0,02 | 0,06 | | 0,10 | 0,05 | 0,34 |

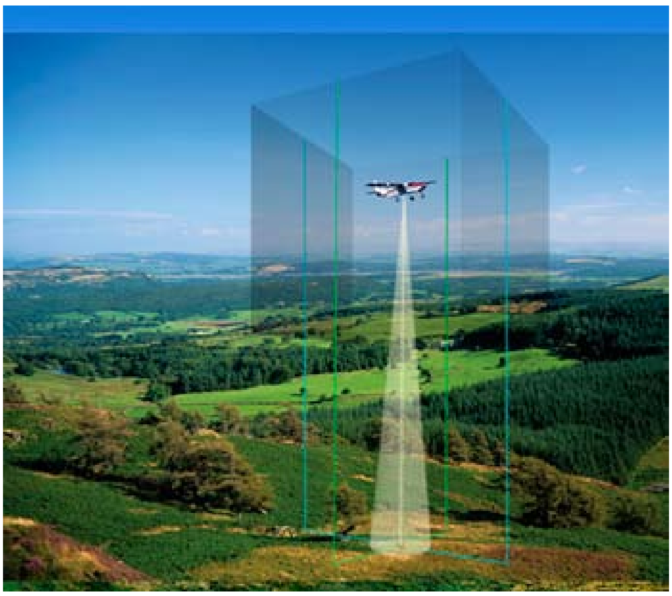
As indicated in table 5.4 there is a wide range in consumptions and emissions, much of it due to large variations in the average distance of transportation in the various regions. The variation in gas consumption for underway compression (to counter frictional pressure losses in the pipelines) is in general closely related to the distance of the transmission.

## A global overview of the natural gas chain

In order to identify the most attractive options for improvement in the production, transportation and end-use of natural gas, further expansion of the in-depth knowledge of the whole natural gas chain globally is desirable. The data we have available today are somewhat fragmented, but still cover a fair fraction of the global volume and give useful insights into issues and options along the gas chain.

In the last couple of decades one of the issues in the natural gas chain was the loss of product through fugitive emissions plus intentional gas venting. Natural gas – mostly methane – has a high global warming potential (GWP 25 times of $CO_2$) and loss of methane to the atmosphere and climate impact are therefore closely related. This means that reducing losses leads to improved environmental as well as economic performance. While venting – or flaring - may not always be easy to avoid, the fugitive emissions can be substantially reduced, as have been shown in many projects around the world. The energy efficiency of processing and transporting natural gas may always be improved as plants are refurbished and better technology introduced. Most of this energy is provided by the natural gas itself and thus also results in the undesirable loss of saleable product.

**Fig. 5.4:** Airborne systems are used to quickly and efficiently detect and locate concentrations of natural gas associated with leaks from transmission pipelines with a high degree of confidence (Source: NETL)



At this point in time it has not been possible to assemble emission data from all natural gas producing companies and countries (see percentage coverage in table 5.5), but it is believed that the assembled data are reasonably representative for the situation in the global natural gas industry.

As can be seen from table 5.5, the production and transmission stages are the most energy-consuming parts of the existing natural gas chain (excluding end-use) and have the highest climate impact. In general the newer gas infrastructure performs better than the older. Plants on the drawing board today will emit markedly less greenhouse gases than today's average.

| | Production | Transmission | LNG production | LNG transport | LNG regasification | Storage | | Distribution |
|---|---|---|---|---|---|---|---|---|
| | Average | Average | Average (existing) | BAT (1000 km) | Average | Min | Max | Average |
| Percentage covered | 54% | 79% | 69% | N.A. | 27% | N.A. | | 34% |
| Natural gas consumption: | 3,52% | | 10,3% | | | | | |
| - Energy | 2,73% | 4,1% | 8,8% | 0,21% | 0,43% | 0,13% | 2,0% | 0,16% |
| - Fugitive/venting | 0,58% | 0,4% | 0,2% | | 0,00% | 0,00% | 0,10% | 0,42% |
| - Flaring | 0,48% | | 0,5% | | | | | |
| Electricity ($MJ/Nm_3$) | | | | | 0,042 | 0,047 | 0,205 | 0,003 |
| Fuel oil ($MJ/Nm_3$) | | | | 73,8 | | | | |
| Emissions ($g/Nm_3$) | | | | | | | | |
| $CO_2$ | 62,05 | 132,12 | 280,22 | 9,59 | 8,88 | 3,39 | 10,80 | 0,16 |
| $CH_4$ | 4,01 | 3,35 | 5,90 | | 0,03 | 0,16 | 0,75 | 4,32 |
| $NO_x$ | 0,07 | 0,05 | 0,99 | 0,01 | 0,004 | 0,002 | 0,10 | |
| $SO_2$ | | | 0,003 | 0,01 | | | | |

**Table 5.5** A global look at the natural gas chain. Empty cells indicate lack of sufficient data, not necessarily zero value (Source: IGU LCA-report, 2006).

LNG production has a climate impact per unit of energy produced almost 3 times larger than for production of pipeline quality natural gas. When looking at the combination of production and transport, however, the impact of LNG is only 35% higher than for pipelined natural gas when assuming a transport distance of 5,000 kilometre.

## Energy and emissions at the end-use stage

For emissions in the utilization phase, a set of IPCC emissions factors for $CO_2$ exists for use in national greenhouse gas monitoring. Figure 5.5 shows these factors for a range of fuels. Natural gas has the lowest emission factor for utilization of all solid, liquid and gaseous fossil fuels.

Figure 5.5 does not tell the whole story, however, since natural gas in many important end-uses can be used in more efficient machinery than coal or heavy oil. The best known example is electric power generation where a gas turbine based plant can achieve efficiencies of conversion approaching 60% (LHV), while a modern supercritical coal fired plant will be in the 42-45% efficiency range. The combined effect of emission factors and efficient technology cuts $CO_2$-emissions more than in half from natural gas compared with coal for electricity generation.

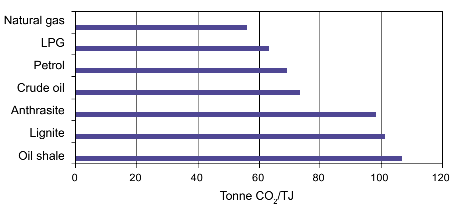



**Fig. 5.5:** IPCC default emissions factors (Source: ETC/ACC technical paper 2003/10).

The world of energy is decarbonising on a slow, but persistent track as illustrated by figure 5.6. Decarbonisation in this context means the amount of carbon per unit of primary energy consumed. This decarbonisation has been going on for a long time without any conscious decision to make this happen for any climate related reason.

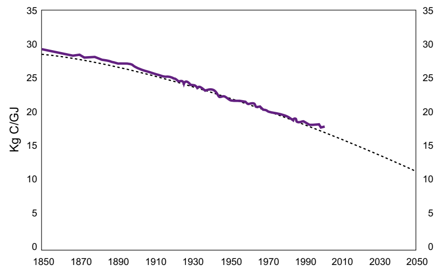



**Figure 5.6:** Decarbonisation as falling global carbon intensity of total world primary energy (Source: IIASA)

The explanation for this decarbonisation is multifaceted, but an important reason can be found in the global proportion of urban population which has risen dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to over 50% today and is likely to rise to 60% (4.9 billion) by 2030. Rich, dense cities tend to accept only electricity plus clean-burning natural gas and LPG. These clean fuels reach consumers easily through pervasive infrastructure grids, right to the electric switch or burner tip in the kitchen. Much decarbonisation has occurred already, but it is not a law of nature and cannot be relied on to solve our climate change concerns. The main reason for this is the growth in global population as well as the growth of per capita energy use in the large developing economies of Asia and other continents.

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The Natural Gas Chain. Toward a global life cycle assessment, CE, Delft, 2006
Useful web-sites for this chapter:
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IPCC SRCCS, 2005:
http://www.ipcc.ch/ipccreports/srccs.htm
IIASA: http://www.iiasa.ac.at/
NETL: http://www.netl.doe.gov/
ETC/ACC technical paper 2003/10 on emission factors:
http://airclimate.eionet.europa.eu/reports/ETCACC_TechPaper2003_10_$CO_2$_E F _ fuels

# 6. Opptunities today and tomorrow

Natural gas is the most benign and clean burning of the fossil fuels with respect to both global $CO_2$-emissions as well as local and regional pollution effects. Both the global and the more local aspects should be factored in. This we see clearly illustrated in this chapter through the example of natural gas as a fuel in city traffic in New Delhi and other crowded metropolitan areas.

We live in a world of steeply climbing energy demand, in particular from the developing world aspiring to the level of living standard enjoyed by the already industrialised countries. In this situation the real competition for the next few decades is not between fossil fuels, renewables and nuclear, but between the three fossil fuels coal, oil and natural gas. The result of this competition will over the decades have large consequences for global $CO_2$-emissions.

The natural gas industry contributes- in this situation of inter-fossil-fuel competition - in two principal areas to mitigate climate change:

- the first is through cleaning up the gas industry's own operations
- the second being to help our customers to clean up their emissions

Of these two broad groups the gas industry has most control over mitigation efforts within own operations. On the other hand, most climate change mitigation effect from natural gas is expected to be at the premises of our current and prospective natural gas customers.

The natural gas industry is able to reduce emissions of greenhouse gases through four basic measures:

- energy efficiency
- fuel switching and renewables
- cutting methane and flaring emissions
- $CO_2$-capture and –storage

This is shown in the "Tool-box for a lower carbon world" (fig. 6.2) and illustrated by examples throughout this chapter.

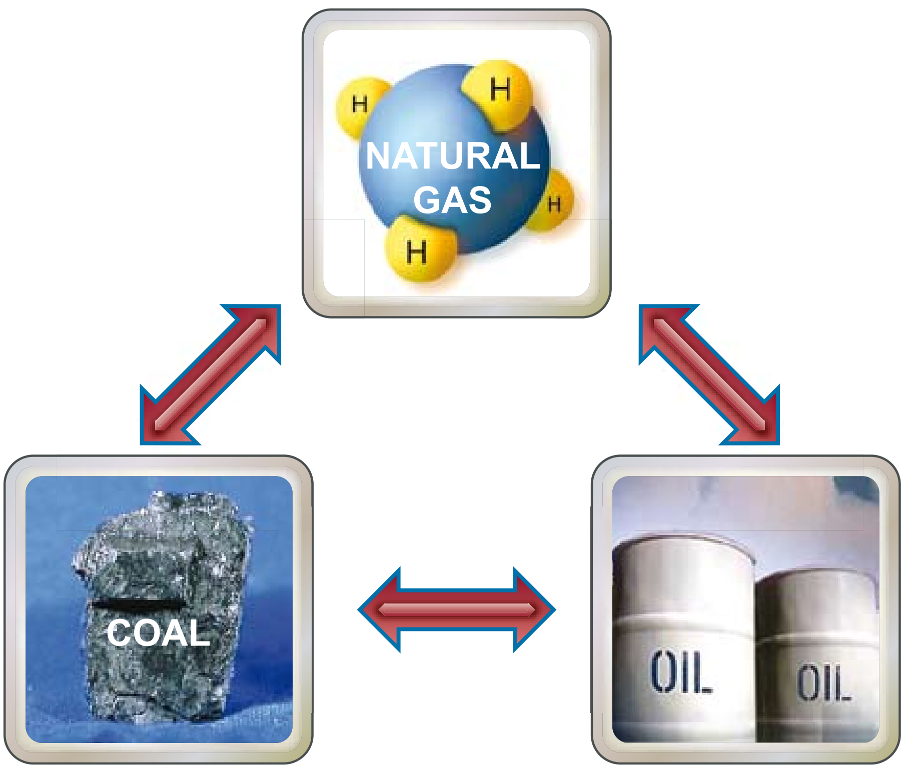



**Fig. 6.1:** In a fast-growing global energy market, the next few decades will see more of a competition between coal, oil and natural gas than a competition between fossil fuels as a group and nuclear plus various renewables on the other. Renewables will grow fast, but from a low base. Nuclear is likely to grow in certain countries while at the same time struggle to replace aging reactors in several of the already industrialised countries.

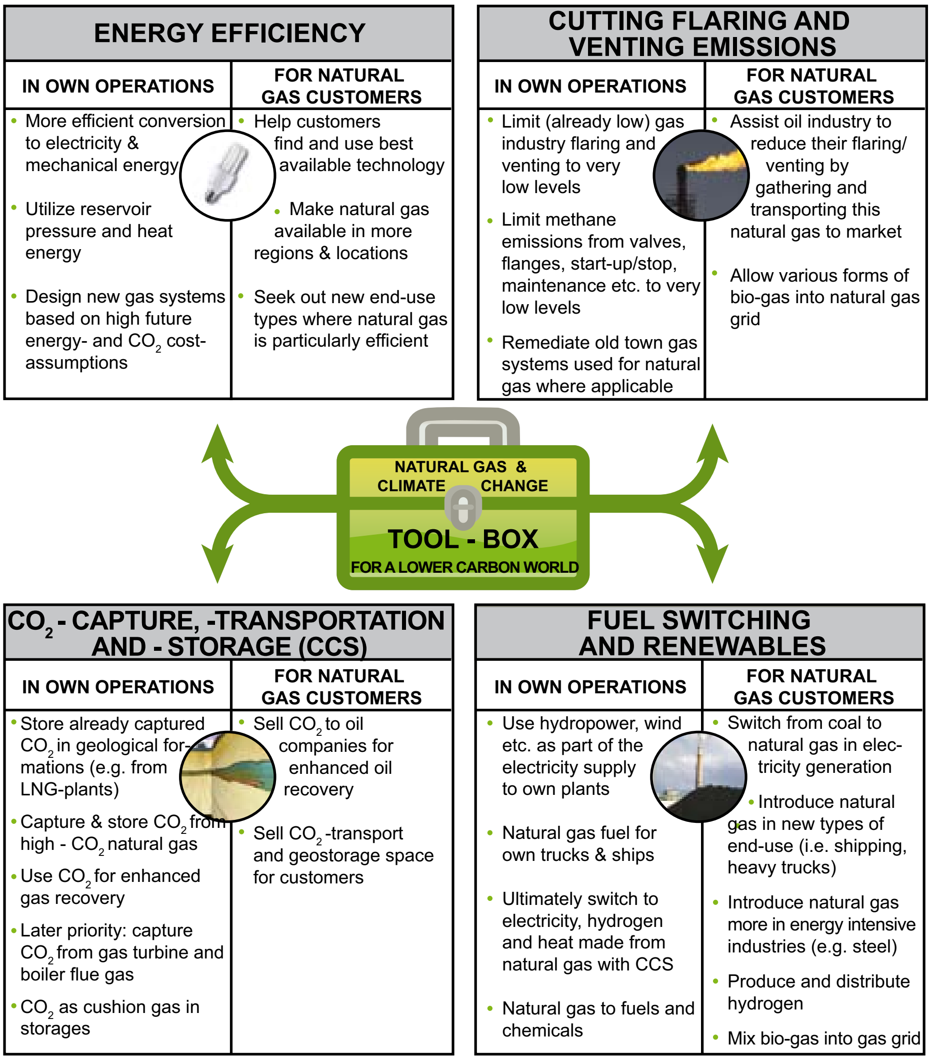



**Fig. 6.2:** Tool-box for a lower carbon world. The tools are energy efficiency, fuel-switching & renewables, $CO_2$-capture and -storage (CCS) as well as cutting methane & flaring emissions. The two principal areas for applying these tools are within the natural gas industry's own operations and with the gas customers themselves. This chapter is structured according to the logic of this tool-box.

These four tools in our tool-box and their areas of application stretches from the most routine energy efficiency effort in industry and in the home through huge industrial projects to switch from coal to gas, and – not the least – to a future of large scale $CO_2$- capture and geo-storage (CCS) and hydrogen-to-energy production. The natural gas industry cannot predict the future more than anyone else. There are, however, some recognisable – and sometimes surprising - contours to be seen in the crystal ball.

Natural gas will certainly play an important bridging role when it comes to shaping our common low-carbon future.

Natural gas plays an important climate mitigation role in reducing the industry's own climate foot-print. More importantly, however, the gas industry will make it possible for existing and future gas customers to reduce their climate impact. Sometimes this can happen in ways not well known to the general public, by people formulating energy policies or even by people employed in the gas industry itself. Let us follow the logic of the tool-box and start by seeing what the gas industry can do on its own plot of ground.

## 6.1 Mitigation within the natural gas industry's own operations

The natural gas industry is a global and complex branch of industry with many decades of experience of cooperation with regard to practical issues common to the gas chain. This is also the case with regard to environmental issues among which climate change has come to take the centre stage in recent years. The gas industry is highly technologically oriented with a huge knowledge base about geology and reservoirs, process technologies, the development of mega-projects, continent spanning pipelines and end-use of natural gas in industries, commercial buildings and homes.

### Energy efficiency in own operations

Production, processing and transportation of natural gas is quite energy consuming as we have seen in chapter 5. Much of this has to do with the compression of relatively low density natural gas being inherently less efficient than pumping of liquids (e.g. water or oil). Another explanation is that most of the equipment driving these compressors are gas turbines fired by natural gas. For new plants these gas turbines are state of the art equipment comparable to the gas turbines hanging under the wings of modern jet planes, but only about 1/3 of the energy in the gas is converted to mechanical energy driving the compressor. On a processing plant some of this rejected energy – in the form of exhaust heat converted to steam or hot oil – are utilised for process-heating, distillation and for other process purposes. In the case of a pipeline compressor, however, there is often no large consumer of heat nearby and the exhaust heat is lost.

Energy efficiency in the natural gas industry – as in most other process industries – is very much a question of the costs of energy. The normal life-span of capital equipment before replacement is also an important factor and for some companies also the access to capital for refurbishment of existing plants. Recently – in some regions of the world – the costs of emitting greenhouse gases to the atmosphere has been added to the energy efficiency equation.

High energy prices will normally lead to more energy efficiency measures being implemented earlier than with lower energy costs. All energy companies have their own opinion of future energy costs which guides their priorities with respect to energy efficiency measures. It may also take years before even highly profitable measures are implemented since modifications have to take place during a planned shut-down perhaps 2-4 years down the line.

### Fuel switching & renewables in own operations

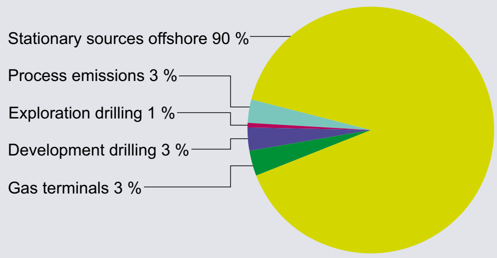
Within the natural gas chain most of the self-consumption of energy is covered by natural gas itself. Often there are few, if any other choices given the remoteness (e.g. offshore, the Arctic or deserts) of many such plants and the large size of the energy needs. On occasions, however, it has been found possible to utilise electricity from the grid in the region on a normal commercial basis. On other occasions local frame conditions are such that extraordinary measures have been implemented. One such is the electrification from the hydro-powered Norwegian land-grid of the large North Sea Troll gas platform and its associated land terminal at Kollsnes (text-box).

**Example of energy efficiency in gas industry operations:**

- Combined gas turbine & steam turbine solutions for Oseberg, Snorre and Eldfisk offshore platforms

About 75 % of the $CO_2$ from the Norwegian continental shelf oil and natural gas activity is produced during the generation of electricity and 90% is from stationary sources in total (pie-graph below). Combined cycle power plants represent a new solution for offshore platforms whereby heat from turbine exhaust gas is used to produce steam.

The steam in turn is used to generate electric power. Combined cycle power plants increase the energy efficiency by about 30% and are currently in operation on the Oseberg field (picture), Snorre and Eldfisk fields on the Norwegian continental shelf. These plants are so far unique in a global offshore context. The added cost can be justified by the high tax on $CO_2$-emissions offshore Norway.

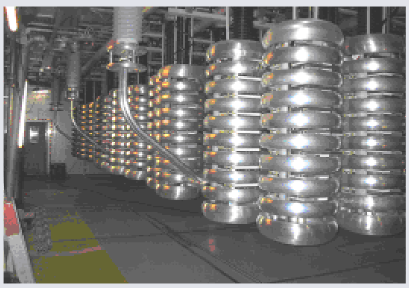



### $CO_2$-capture and –storage (CCS) in own operations

The global natural gas industry has pioneered the climate mitigation concept of $CO_2$- capture and –storage (CCS). It is also likely that the gas and oil industries will continue to spearhead this effort for quite some time even if the coal industry and electric utilities are eager to be seen as front-runners.

**Example of renewable energy powering gas industry operations:**

- Hydro-powered Troll natural gas platform. The Troll Offshore Gas Platform (picture), located off Norway in the North Sea, is the heaviest man made mobile object ever made, with a dry weight of the gravity base structure at 656,000 tons. Standing 369 m tall, it was made from 245,000 m3 of concrete, and 100,000 tons of steel (approximately 15 Eiffel towers). In addition to being the world's largest offshore platform, it also have the unusual feature of being supplied by electricity from a hydro-powered land grid. The platform is supplied by high voltage direct current (HVDC-Light; picture) from the shore-grid 60 kilometres distant. The driver for the electrification was reduced operating expenses in cooperation with the Norwegian $CO_2$-tax.



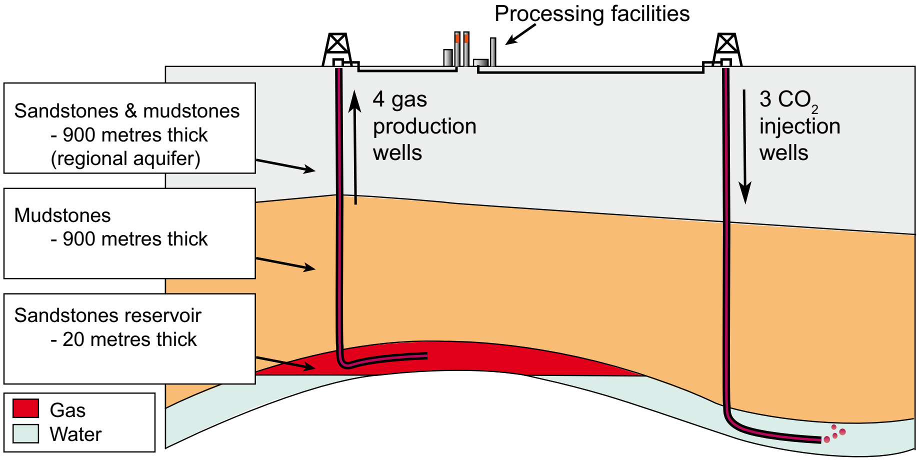



**Fig. 6.3:** The left part of this illustration shows the $CO_2$-capture and –storage of nearly one million tons of carbon dioxide extracted from natural gas at the In Salah gas field in Algeria. Many types of sandstone have up to 30% pore-space, enabling such reservoirs to store surprisingly large amounts of $CO_2$.

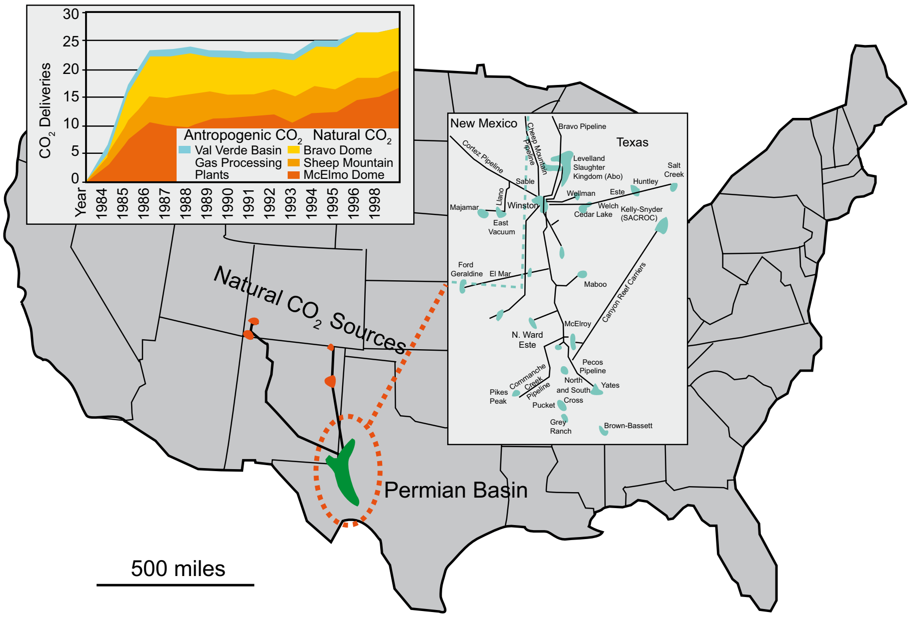



**Fig. 6.4:** Since the 1970's $CO_2$ has been injected into aging oil reservoirs in order to get more oil out (EOR- Enhanced Oil Recovery). The main, but not the only arena for this has been the US where at present over 80 oilfields are using this methode. A large pipeline system has been laid between naturally occurring $CO_2$-reservoirs and the oil fields. Since the $CO_2$ comes from pure $CO_2$-fields, this type of enhanced oil recovery cannot be said to have climate mitigation effect. It is, however, a great source of practical learning for building and operating carbon dioxide infrastructure.

Within the domain of CCS, there are some so-called "low-hanging fruits", also called early opportunities. Of these the lowest hanging – meaning least expensive - fruits are large $CO_2$-point sources which are already captured and concentrated to almost 100% concentration. Figure 6.5 illustrates where these are to be found.

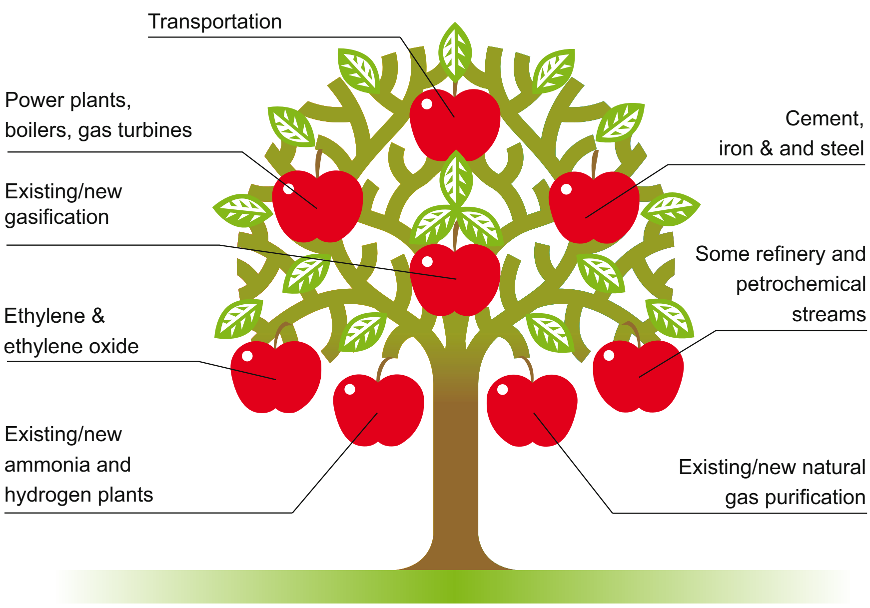



**Figure 6.5.:** The low-hanging fruits. The large, already captured and almost 100% concentrated $CO_2$ are to be found in natural gas purification, ammonia and hydrogen plants and sometimes in gasification of coal and heavy oil (Sources: IPCC SRCCS 2005 and Kaarstad, 2007).

Globally there are estimated to be about 200 such low hanging fruits of concentrated $CO_2$. The importance of these is not their combined tonnages (moderate), but as sources for early CCS-projects and early learning. Experience from already realised projects is that they also provide a source of motivation for industries and governments involved to spearhead this climate mitigation concept.

**The natural gas industry as CCS-pioneers:**
There are at present three natural gas industry projects in operation spearheading the concept of CCS. These are Sleipner (Norway), In Salah (Algeria) and Snøhvit (Norway). It is expected that several more will follow in the coming years, with the Australian Gorgon natural gas project as a likely major addition.

All three projects shown in the pictures are in operation and injects in the order of one million tons of $CO_2$ per year each. This means that they are full scale demonstration projects for CCS. The Sleipner $CO_2$-injection has been going on since 1996, while In Salah came on stream in 2004 and Snøhvit in 2008.

In these cases – as in a number of other inside and outside the natural gas industry the costly $CO_2$-capture stage has been taken for commercial reasons (such as achieving a particular natural gas customer specification). This leaves just the less costly final stages of transportation and storage to be paid for as climate mitigation.


## Reduction of fugitive methane emissions in the gas industry

The mitigation of non-carbon dioxide (non-$CO_2$) greenhouse gas emissions can be a relatively inexpensive supplement to $CO_2$-only mitigation strategies. Worldwide, the potential for "no-regret" or "low-regret" non-$CO_2$ greenhouse gas abatement is significant (US EPA International Analysis). Methane ($CH_4$) mitigation has the largest potential across all the non-$CO_2$ greenhouse gases as illustrated by fig. 6.6.

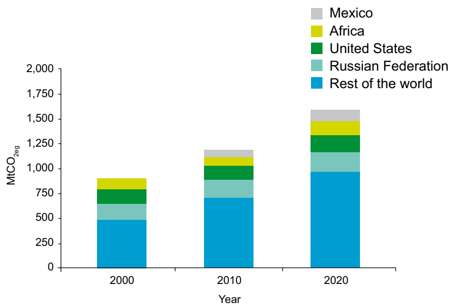
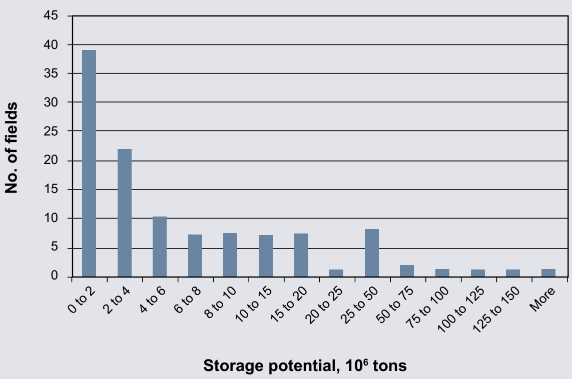



**Fig. 6.6:** Methane from natural gas systems by country 2000 – 2020 in million tons of $CO_{2eq}$ per year. (Source: US EPA http://www.epa.gov/climatechange/economics/international.html).

Natural gas systems are a leading source of anthropogenic $CH_4$-emissions, accounting for more than 970 $MtCO_{2eq}$ (US EPA, 2006). The US Environmental Protection Agency estimates that natural gas systems account for 8 percent of total global $CH_4$ emissions. The Russian Federation, the United States, Africa, and Mexico account for more than 43 percent of the world's methane emissions in the natural gas sector.

**Poland: Using experience from acid gas injection to estimate CO2-storage**
Over the past decade the Polish Oil and Gas Company have implemented technology for acid gas ($CO_2$ + $H_2S$) injection as an efficient way of avoiding emitting these gases to atmosphere. Such acid gas injection operations constitute a perfect analogue for large scale geological storage of $CO_2$ into onshore continental sedimentary basins. The history of the fields in the Carpathians and the Carpathian Foredeep is long; this region is the world's oldest oil extraction area. In 2006, Poland had in operation 86 oil reservoirs and 254 gas reservoirs. Most of them were mature fields and some of them may be good candidates for $CO_2$ sequestration. The results from a decade of field measurements from acid gas injection have been used to estimate the $CO_2$-storage capacity on land in Poland. It was found that the storage capacity for most of the known depleted reservoirs was not huge but still interesting, especially for smaller power and chemical plants. The figure illustrates that both large and smaller fields may contribute to $CO_2$-storage in Poland.




Source: Paper by Stanisław Rychlicki, Jerzy Stopa and Paweł Wojnarowski, AGH University of Science and Technology

| Segment | Facility | Equipment at the Facility |
|---|---|---|
| **Production** | Wells, central gathering facilities | Wellheads, separators, pneu - matic devices, chemical injection pumps, dehydrators, compres - sors, heaters, meters, pipelines |
| **Processing** | Gas plants | Vessels, dehydrators, compres - sors, acid gas removal (AGR) units, heaters, pneumatic devices |
| **Transmission and storage** | Transmission pipeline networks, compressor stations, meter and pressure-regulating stations, underground injection withdrawal facilities, liquefied natural gas (LNG) facilities | Vessels, compressors, pipelines, meters/pressure regulators, pneumatic devices, dehydrators, heaters |
| **Distribution** | Main and service pipeline networks, meter and pressure-regulating stations | Pipelines, meters, pressure regulators, pneumatic devices, customer meters |

**Table 6.1:** Fugitive emissions from the natural gas industry come from diverse and numerous sources all along the gas chain as indicated by table 6.1. Fugitive emissions depend on the age, technical maintenance and operating procedures. This makes generalisation about the costs and size of mitigation of global gas industry methane emission difficult and unreliable until more experience is gained.

**Reduction of fugitive methane emissions – the European experience**

The Marcogaz – Eurogas has done a systematic mapping of practical methods for reduction from methane emissions from natural gas transmission and distribution systems in Europe.

*Transmission systems*

For gas transmission activities particular attention should be drawn to the use of methods for:

- Gas re-compression (left picture) to reduce emissions from gas venting during maintenance activities;
- Procedures to prevent emissions due to third party damage;
- Replacement of valves actuated by natural gas with others that are either air or electrically actuated
- Reduction of fugitive emissions by use of portable detectors to identify them during maintenance procedures.

*Distribution systems*

Opportunities for reduction of emissions from distribution systems relate to:

- Improvements in pressure management that enable significant cost effective reductions in methane emissions
- Conditioning of lead/yarn joints is required in many networks to prevent deterioration in emission factors for these components;
- Replacement of cast iron and ductile iron pipes with either steel or plastic pipes (right picture) as the long term solution to the most significant losses from the existing system;
- Procedures to prevent emissions due to third party damage.

One example of abatement technology is to switch from gas pneumatic controls to compressed instrument air systems. Some processing plants use natural gas instead of compressed air for pneumatic controls. Some pipeline valves also use gas for their actuators. As part of their normal operations, such devices release or bleed $CH_4$ into the atmosphere. Such equipment can substitute compressed air for natural gas within pneumatic systems.

An example of the abatement options available to the transmissions segment is maintenance at compressor stations. Compressor stations amplify pressure at several stages along a transmission natural gas pipeline to combat pressure loss over long distances. Over time, compressors and other related components become fatigued and may leak $CH_4$. Maintenance programs reduces such methane emissions at compressor stations by identifying leaks and focusing maintenance on the largest leaks.

An example among abatement options available to the distribution segment of the gas chain is the use of a pipeline pump-down technique when performing maintenance on segments of distribution pipeline. Operators routinely reduce line pressure and discharge gas from a pipeline during maintenance and repair activities.

Using a pumpdown technique means applying a compressors to depressurize the section of pipeline to be maintained and put the methane into another part of the pipeline, thereby avoiding the release of this greenhouse to the atmosphere. Another alternative is to utilise a mobile flaring unit to burn rather than vent methane.

**Stopping fugitive methane emissions from the gas network in the city of Kursk;- A Joint Implementation Project (JI) under the Kyoto Protocol**

The Kurskgaz company entered into an agreement with Danish Russian Carbon Fund (RCF) in 2005 to pave the way for Russia's first project to measure and eliminate methane leakage in a natural gas distribution system in the Russian city of Kursk. The project is viewed as a first step for carrying out similar activities in 15 regions of the country, including the Sverdlov Region, Tomsk, Omsk, Kurgan and Orel. According to RCF, the new technologies will trim the leakage by between 15 million and 30 million tons of $CO_2$ equivalent. The Danish party is the project investor, while Norwegian StatoilHydro is the buyer purchasing from Kurskgaz the released volumes of gas emission.

The purpose of this joint implementation project is to improve the integrity of regional distributional networks in the region of Kursk via reducing leakage of methane from the systems. The supply system covers approximately 7000 km of pipes with 2500 km of this pipeline situated within the city and with 4500 km situated outside of the city limits. There are 229 Gas Distribution Points and 1431 cabinet-type Distribution Points in the system. In total they contain 6178 valves and some 15361 flanges. Leaks are mostly found in plug valves, block valves, pressure relief valves and flanges. Methane Emission Reduction is accomplished by activities that detect measure and repair leaks at gas distribution points and cabinet type distribution points in the natural gas systems operated by Kurskgas.

Source: TÜV Monitoring report: http://www.netinform.net/KE/Wegweiser/Guide2 aspx?ID=4600&Ebene1_ID=49&Ebene2_ID=1436&mode=4

## 6.2 *Natural gas customers and climate mitigation*

### Energy efficiency for natural gas customers

On site production of heat and electricity direct from natural gas is seen as a possibility in the house of tomorrow. In a future house with a high insulation level and sometimes increased use of renewable energy, traditional gas heating and hot water production systems will be less attractive than today.

**Micro Combined Heat and Power for households;**
- integration of a high-efficiency boiler and a Solid Oxide Fuel Cell

The Australian company Ceramic Fuel Cells Limited (CFCL) is developing Solid Oxide Fuel Cells (SOFC) for many different applications. Combined Heat & Power (CHP) units based on SOFC appliances can produce heat for space heating and hot water directly from natural gas as well as electricity for own use and for selling into the electrical grid. Since January 2006 CFCL has installed and operated field trial units in Australia, New Zealand and Germany and is developing fully integrated mCHP (micro-CHP) units with leading utility customers and appliance partners. The fuel cell systems will be integrated into conventional boilers and thereby enable households and small businesses to generate both heat and electricity. The unit looks like a conventional high-efficiency boiler (picture). This means more efficient use of natural gas resources, while the $CO_2$ emissions are up to 25% lower than from a gas-fired power station and up to 60% lower than from a conventional coal-fired power station. The advantages of SOFC systems over low-temperature fuel-cells are that they operate at higher temperature, which reduces the need for expensive precious metals (such as platinum), that they can operate directly on natural gas and have very good electrical efficiency (up to 70%). When combined with heat recovery 85% efficiency is achievable.

A further development - 2kW unit – will provide ample power for the basic load of the average household as well as additional power for export to the grid, saving up to three tons of $CO_2$ per year. The fuel-cell boiler will be easy to install as it uses the same pipes as existing high-efficiency boilers.

### Residential and commercial buildings

Buildings play a surprisingly large role in energy consumption. In the U.S., the amount of energy used in buildings is 40% greater than in the transportation sector.

Since the lifetimes of buildings can approach the century mark, it pays to find ways of improving their energy use. Condensing boilers needs to be more widely spread, with focus on existing households. In addition to lowering costs of such systems, combinations with solar heat and biomethane should be explored.

In the most advanced energy markets - with Germany as an example – residential and commercial natural gas customers are increasingly switching to various forms of electrically powered heat-pumps and renewables, in particular in new buildings.

With the increasing requirements in building regulations for higher insulation standards as well as a profusion of heat-releasing devices in households and commercial premises, natural gas could be seen as not needed in buildings.

Policy may also turn against natural gas use in new buildings from 2020 in Germany. Natural gas is not seen as sufficiently "green" anymore.

These developments challenge the natural gas industry to come up with new technologies and new combinations that can compete on efficiency and climate sustainability.

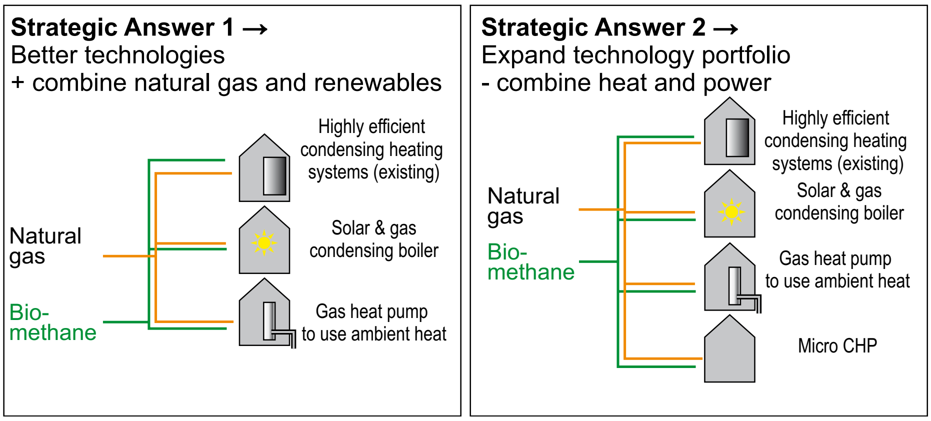



**Fig. 6.7:** How can the natural gas industry deliver customer-oriented solutions for residential and commercial premises? The strategy outlined in these two illustrations combines the best of natural gas, new technologies and renewables to satisfy future customers (Redrawn from: E.ON Ruhrgas, Gas Industry mCHP Workshop, Paris May 2008).


**Fig. 6.8:** A Dutch and a Japanese vision of natural gas fuelled fuel-cells based micro-CHP units for single occupancy buildings. Numerous firms are developing such appliances which are on test in many countries. (Sources: GasTerra and Tokyo Gas)

### Fuel switching & renewables for natural gas customers

The kind of fuel-switching that give climate mitigation effect is changing from high carbon/low hydrogen fuels (e.g. coal) to lower or zero carbon fuels such as natural gas or hydrogen gas. Nuclear power and renewables are often categorised as zero-carbon in a life-cycle view, even if this is usually only partly the case (e.g. large steel and cement quantity used in the construction of a nuclear power plant have given raise to release of $CO_2$).

After the advent of efficient gas turbines for large scale power generation two-three decades ago, fuel switching from coal fired power to natural gas fired power plants became the trend in countries with a liberalised energy market and access to gas. In some countries – with UK as a primary example - the switching from coal to gas was dramatic (see text-box). Many other countries have experienced similar, but less dramatic power sector shifts from coal to natural gas.

Other, more everyday forms of fuel switching is ongoing all around the globe all the time. Commercial and residential premises have been and are switching from oil to natural gas for heating, cooking and cooling purposes. Other examples are less developed or wide-spread geographically, but could play important roles in the future as exemplified in separate text-boxes (e.g. gas in the transportation sector). The ultimate switch – as seen from a natural gas point of view – would be to convert natural gas to the twin energy carriers electricity and hydrogen with $CO_2$-storage incorporated.

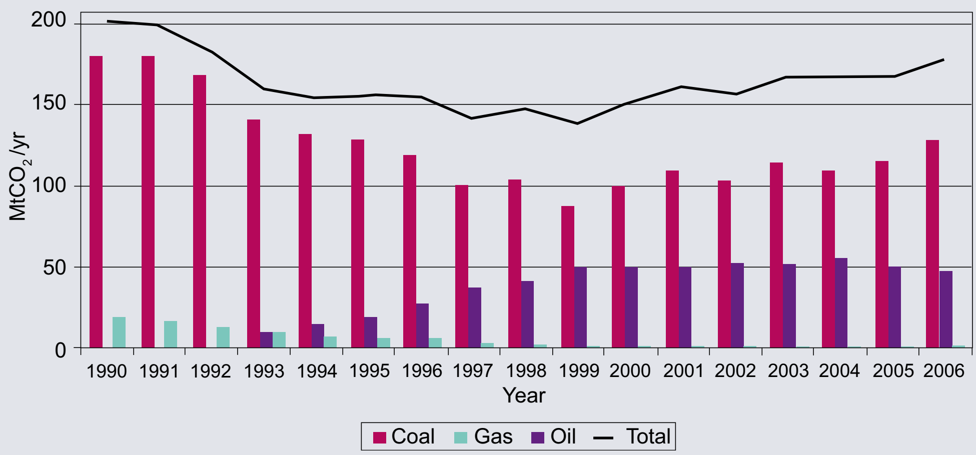
**When UK converted from coal to natural gas for power generation**

Electricity generation is the biggest single source of $CO_2$ emissions in the UK with178 Mt $CO_2$ in 2006 (see graph), responsible for approximately a third of total emissions.

In UK a vast nationalised coal based power industry kept the lights on, the factories running and hundreds of thousands of families in reliable, if backbreaking, work in the coal mines in the decades after WW II..

The arrival of North Sea oil in the mid 1970s was a welcome boost to a cashstrapped government, turning the UK into a significant exporter of energy. Energy policy was at the time seen as far too important to leave to the market. That changed in the 1980s, with the Conservative privatisation of oil, coal and electricity generation. The newly privatised power companies to a large extent switched from coal to natural gas reducing their demand for coal. This heralded the start of a rapid decline of the UK's coal pits - leading eventually to the closure of all Scotland's mines and all but one in South Wales. Gas was the cleaner and cheaper alternative.

The coal industry has continued to shrink. There are 12 working pits - compared with 170 in 1984. These days the UK power stations are just as likely to get their energy supplies in the form of gas from Eastern Europe or Norway as from the country's own coal pits. The trend is, however, to some extent turning back due to the increasing cost difference between natural gas and coal in the later years.




To the gas industry it is important to learn from the cost based phasing out of oil in the electricity generation sector as indicated in the left part of this graph.

(Graph redrawn from: UK Power Sector Emissions – Targets or reality (Report to WWF, 2006)

The electric grid in many countries will receive any electricity that fulfils certain specifications to be transported to customers. It does not matter if this electricity comes from a coal fired power plant, a gas fired combined cycle plant, a hydro power stations in the mountain or a wind-mill by the coast. The natural gas grid may in the future become more like the electric grid also in this respect. Methane-rich biogas are produced from fermentation and treated sewage gas, landfill gas and gases manufactured thermally from biomass may also serve the purpose. In 2008 there were in EU about 5 plants in Switzerland, 4 in Sweden, and 5 in Germany injecting biogas into gas grids, with others to follow.

In a carbon constrained future, this way of transporting bio-gas may become a substantial part of a grid-owners business, in particular in the distribution grid close to the end-user (see text-box).

**Europe's largest bio-methane plant in operation**
E.ON together with Schmack AG has commissioned Europe's largest bio-methane plant at Schwandorf in Bavaria.

Since the beginning of 2008 biogas has been produced there from regional raw materials. This biogas is then treated to reach natural gas quality and fed as biomethane into the natural gas pipeline system of E.ON Bayern. "In the field of renewable energies, bio-methane plays an important role in our portfolio of promising technologies," said Dr. Frank Mastiaux, managing director of E.ON Climate & Renewables GmbH. "The commissioning of the Schwandorf plant is another milestone in our programme for growth, which we will systematically implement by 2010 with an investment volume of up to 6 billion."

At the Schwandorf plant, about 16 million $m^3$ of biogas can be obtained annually from roughly 85,000 tons of local renewable resources. Not only maize, but also grass and intercrop silage is used. The output of filtered biogas upgraded to natural gas quality, i.e. bio-methane, is approx. 1,000 $m^3$ per hour. Mr. Mastiaux: "With this plant we can cover the entire natural gas needs of some 5,000 households."

The decisive advantage of bio-methane is that, as a climate-neutral fuel, it can be used everywhere by distributing it through the gas network. There are many options for efficient use of bio-methane: in the transport sector, in cogeneration plants or in packaged cogeneration systems.

By expanding these activities E.ON is involved in a market which is said to have great growth potential. "We assume that by 2030 about 10 % of existing natural gas consumption in Germany can be covered with bio-methane," said Fritz Wolf, managing director of E.ON Bioerdgas. "And this can be done without adversely affecting areas needed to grow food and feedstuff. The bio-methane consumption anticipated in 2030 corresponds to the energy needs of 5 million households."

**Trash to treasure – the Doña Juana landfill gas to energy project**
Municipal waste generates a lot of methane - the main ingredient in natural gas – when disposed as landfill. Due to the mostly organic waste inputs to the landfill, the gas from such projects is viewed as a renewable source of energy. The Doña Juana Landfill belonging to the city of Bogotá in Colombia receives 2 million tons of household waste every year. By the end of October in 2007 the owner of the landfill, the Unidad Administrativa Especial de Servicios Públicos (UAESP) awarded a biogas consortium – the Biogas Doña Juana S.A. ESP - a public concession contract for the collection, treatment and energy use of the landfill gas for 23 years. Included in this contract was the gas collection system, the treatment facilities as well as supply into a dedicated landfill gas distribution grid for industrial users operated by gasNatural ESP, a natural gas distributor in Colombia. This is one of the largest projects of its kind in the world.

The landfill gas results from the organic waste degradation under anaerobic conditions. It is usually composed of more than 50% methane and less than 50% carbon dioxide $CO_2$ . Both of these are greenhouse gases with methane 25 times more potent than $CO_2$. In most of the world's landfills the methane is still allowed to diffuse to the atmosphere. In others the methane is collected in special wells and flared at the site, a methode that substantially reduces the greenhouse effect. Collection and flaring of landfill gas are usual in landfill sites in order to prevent local risks like fire in waste, instability or stenches. The Doña Juana project goes one major step further by distributing the gas to be burnt usefully by industrial customers along a dedicated landfill gas grid. It has been calculated that the project reduces the greenhouse effect by 700 000 $tCO_2$ equivalent per year.

The project involves the thermal use of the landfill gas in the ceramic industries near to the landfill site where powdered coal has been used up to now. The potential market for landfill gas are about thirty brick factories. The customer's kilns will be converted to burn gas instead of coal. Another opportunity will be the introduction of gas based drying technologies for ceramic products in these factories. A third customer is the landfill gas project itself that generates electricity from gas engine driven generators in order to supply power to compressors and other energy consumers in landfill gas processing plant.

The project is being developed under the guidelines of the Kyoto Protocol CDM procedures. Due to this, extensive monitoring and recording equipment will be installed to keep track of gas volumes and composition as well as the performance parameters for the complete system. The project will support not only the climate, but also the economic and social development as well as the local environment in the area.

Source text: Mr. Ignasi Mallol Sangra, gasNatural SDG S.A, personal communication.

**Spain: Where intermittent solar energy and natural gas work together**
Spain is one of the major players in the world with respect to solar energy. Located on the Guadix plateau in the southern Spanish province of Granada, Andasol 1 went into operation in the summer of 2008 as Europe's first parabolic trough power plant. Glass tubes filled with oil stream through that focus point along a long loop of troughs. With a gross electricity output of around 180 GWh per year and a collector surface area of over 510, 000 square meters - equal to 70 soccer pitches - they are the largest solar power plants in the world.The mirrors slowly track the sun from east to west during daytime hours, and the oil reaches about 400 degrees Celsius.

This solar plant is supported by natural gas, used when a stretch of rainy or overcast days prevent the plant's full operation and the stored energy cannot stretch far enough through the end of the rainy phase. It is thereby able to maintain stability, not be stopping and starting up the turbines more than once a day, as they're designed to do. This is an example of how clean burning natural gas and a renewable source of energy may play together to the benefit of all involved.

## Natural gas as vehicle fuel

As the number of vehicles in the world rises from around 800 million to 2 billion in 2050, the amount of fuel consumed will increase considerably. At present about 7 million out of the 800 million vehicles of the world are fuelled by natural gas (natural gas vehicles - NGV's). Between 1991 and today NGV-growth has averaged 18% per year, but for the last 3 years the growth has been 30% per year. The International Association for Natural Gas Vehicles (IANGV) is projecting that this will increase ten-fold, to 65 million vehicles by 2020. This many NGV's would consume about 400 GSm$^3$ of natural gas, amounting to nearly 14 percent of today's natural gas consumption. There are today about 11 000 refuelling stations globally to fill up these vehicles.

Natural gas can be used to fuel almost any kind of vehicle - motorcycles and three wheelers, cars, vans & pickups, lift trucks, buses, trucks, trains, boats, even aircraft. Three wheelers, being stable and having sufficient space, are well suited for CNG (compressed natural gas) and are used extensively in Thailand, India, Bangladesh and other mostly Asian countries. Most three wheelers fitted out for CNG are used as taxis or light delivery vehicles.

Urban buses are one of the most popular uses for natural gas, usually utilizing CNG but occasionally using LNG (liquefied natural gas). Because the amount of mileage an urban bus travels doesn't vary much from day-to-day, the fuel requirements can be catered for quite easily. Storage cylinders for CNG are often installed on the roof of a bus, allowing the weight to be distributed evenly over the chassis.

The best fuel choice for a heavy truck depends on the duty cycle of the vehicle. Trucks that do lower mileages or that return to a base frequently will often be suited for CNG, while trucks that do higher mileages might be more suited for LNG.

Transportation by road and sea may become an area of substantial growth for the natural gas industry in the coming decades since this fuel gives rise both to less local pollution (e.g. NOx, particles) as well as reducing the global warming impacts.

The U.S. DoE Alternative fuels & Advanced Vehicles Data Centre have measured the potential benefits of CNG versus gasoline based on the inherently cleaner-burning characteristics of natural gas. The findings are:
- Reduced carbon monoxide emissions 90%-97%
- Reduced carbon dioxide emissions by about 25% (see below table)
- Reduced nitrogen oxide emissions 35%-60%
- Potentially reduced non-methane hydrocarbon emissions 50%-75%
- Emit fewer toxic and carcinogenic pollutants, emit little or no particulate matter, eliminate evaporative emissions

**Fig.6.9:** Greenest Vehicle of 2008. The natural gas fuelled Honda Civic GX was voted the greenest car of the year by Greenercars.org which is part of the American Council for an energy Efficient Economy (ACEEE).

| Petroleum use and GHG emissions reductions (relative to baseline light-duty vehicle fuelled with reformulated gasoline) | | |
|---|---|---|
| **Fuel** | **Percent reduction in petroleum use*** | **Reduction in GHGs** |
| **CNG** | ~100% | 21-26% |
| **LNG** | ~98% | 21-25% |

**Table 6.2** Greenhouse gas emission reduction from use of natural gas (as CNG or LNG) in light-duty vehicles (Source: A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas: (http://www.eere.energy.gov/afdc/vehicles/emissions_natural_gas.html)

**Cleaning up city-air with natural gas; – an ongoing Indian success story**
Rapid urban growth in India has resulted in very serious air pollution in many metropolitan areas. In Delhi alone, the numbers of vehicles have increased from 235 000 in 1975 to 2,1 million in 1991 and 5,1 million at present.

The first trials with natural gas vehicles (NGV's) in India started in 1992 with the aim of improving urban air quality and to resolve technical and safety issues.

The current status for compressed natural gas (CNG) fuelled vehicles is that slightly over 3% out of India's 14,5 million vehicles run on gas. There are 383 CNG-filling stations - in 16 major cities - and over 450 000 CNG vehicles in India as a whole.

The large cities of Delhi, Ahmadabad, Mumbai and Surat have all now developed CNG-infrastructure on a fairly large scale, with Delhi and Ahmadabad the first cities in the world to have their entire bus fleet on CNG. The effect on the air pollution has been very marked for the inhabitants and visitors to these cities.

The current handicap to the growth of natural gas vehicles in India is the limited availability of natural gas as well as the immature development of the gas pipeline network. Both of these will be addressed in the coming years.

Source: Gumber, Ashwani, GAIL (India). Paper at World Petroleum Congress in Madrid, June 2008

The reduction in $CO_2$-emissions of 25% is important in itself and the focus of this report, but it is the combined effect of local, regional and global effects that makes natural gas a real challenger to gasoline and diesel as a vehicle fuel.

## LNG as a maritime fuel

The world's merchant fleet carry some 90% of all world trade and shipping is a very efficient way of transporting goods on a ton-kilometre basis. The real size of carbon dioxide emissions from the global shipping industry is disputed, but seems to be between 3 and 4 percent of global total $CO_2$. The consensus estimate is about 1000 million tons per year today (see table 6.3) and is set to increase in parallel with the growth of the global economy.

The shipping industry needs to further reduce harmful emissions from their operations. Historically the bunker fuel used by large segments of shipping has been "bottom of the barrel" from the oil refineries. Those days will come to an end over the next decades given recent regional rulings by some countries and such global institutions as IMO. One embryonic answer to this challenge may lie in the introduction of LNG-fuelled vessels. Switching from diesel to natural gas has at least a 20% $CO_2$ reduction potential and is being pursued as a measure for inland ferries and offshore supply vessels. The main obstacle to the increased utilization of natural gas is the lack of access to LNG-fuelling facilities in most harbours.

A co-benefit of a switch from diesel to natural gas is that it also reduces emissions of SOx, NOx and particles that contribute to local air pollution in ports.

| | Low bound | Consensus estimate | High bound | Consensus estimate % Global $CO_2$ emissions |
|---|---|---|---|---|
| Total shipping emissions | 854 | 1019 | 1224 | 3,3 |
| International shipping | 685 | 843 | 1039 | 2,7 |

**Table 6.3** Consensus estimate 2007 $CO_2$ emissions (million tons $CO_2$) from shipping. (International Maritime Organization IMO, 2008)

Norwegian ship-owners have been forerunners for LNG-fuelled ships (see text-box) and the interest for such solutions is growing globally.

**Fig. 6.10:** LNG may in the next decades become a fuel of choice for some segments of the shipping industry. Among the driving forces for this will be local environmental concerns (e.g. NOx, SOx, soot) in harbours and along coastlines as well as new rules from the International Maritime Organisation (IMO). Left picture is LNG-fuelled car ferry Bergensfjord. The right picture is the small LNG-carrier Pioneer Knutsen which distributes LNG to terminals along the coast of Norway.

**Ship-owners spearheads LNG for fuel**

In early spring of 2000 an LNG-powered car ferry called Glutra was put into operation in Norway. This pioneering ferry was fuelled from a small-scale LNG production plant at the nearby natural gas plant. Later three more small and large scale LNG production plants were built in Norway to serve various types of gas customers. These distribute to 20 – mostly coastal - LNG-stations by truck and small LNG-carriers in this country criss-crossed by deep fjords and rugged terrain unsuitable for overland pipelines.

The availability of LNG in combination with factors like an enthusiastic R&D community focussing on ship motors, similarly engaged ship owners and road authorities (responsible for ferries) to keep momentum. Also important were the government regulatory developments and the role of the ship classification society DnV. The focus on NOx-reduction in Norway in order to achieve a national reduction target was an underlying factor. At the present time the ship-owner Eidesvik has four LNG-fuelled supply vessels serving the offshore oil and gas activity in the North Sea. Furthermore 6 LNG-fuelled car ferries are in operation and several are at the planning stage. One LNG distribution vessel is also LNG-fuelled and the Norwegian Coast Guard has 3 partly LNG-fuelled vessels on order.

Table comparing emissions from two ships on diesel and LNG fuel. NOx is reduced by 87% and CO2 is reduced by 29% in comparable cases.

| Emissions to produce 1 MWhe | Viking Energy- Gas mode | Viking Energy- Diesel mode | Viking Avant- Diesel with SCR |
|---|---|---|---|
| Total energy consumption | 11214 MJ | 11356 MJ | 12072 MJ |
| Emission of NOx | 1,29 kg | 12,4 kg | 3,66 kg |
| Emission of $CO_2$ | 621 kg | 822 kg | 872 kg |
| Emission of SOx | 0,15 kg | 1,94 kg | 2,05 kg |
| Total energy efficiency | 32,1 % | 31,7 % | 29,8 % |

A process is underway for establishing regulations for gas powered cargo ships in IMO. The next step in technology development related to LNG-ships is to test out a 320 kW fuel-cell unit during 2009 for power generation on one of Eidesvik's ships.

Source: WPC 2008a

Natural gas has for a long time played an important role in heating and cooling of commercial premises as well as in residential buildings (see figure 4.8). The technology to serve this end-use sector is already quite efficient. Can we make it even more efficient? One of the ways to progress end-use efficiency to the next level is by introducing natural gas fired heat pumps that can replace existing boiler technology (text-box) and at the same time serve as a cooling appliance.

The pictured heat pump is a highly efficient single piece of equipment that can produce chilled water as low as 3 °C for cooling or water at up to 60 °C for heating. In effect, it is a 2-pipe arrangement that operates as either a chiller or as a heater – dependent on the application requirements.

Each air cooled module of this type produces 16.9 kW of cooling or 35.3 kW of heating with a nominal heating efficiency as high as 140 per cent. This means that heating is produced at a substantially higher efficiency compared to a conventional gas-fired boiler operating at typically 90% efficiency. Unlike conventional electric powered heat pumps, the heat output and heating efficiency is less affected by external ambient temperatures.

**Heat and cool with new gas fired heat pumps**

Over the last decade, advances in natural gas cooling technology made large cooling units available to business and industry, allowing them to take advantage of the efficiency, economy, reliability and superior performance of natural gas. Now, this same technology has been applied to smaller packaged units in sizes suitable for commercial and residential premises.

The heat pump is the technology that is ready now and can be a first step in replacing the existing boiler technology at higher efficiency and at the same time bring a new function (cooling).

A heat pump is a highly efficient single piece of equipment that can produce chilled water as low as 3 °C for cooling or water at up to 60 deg C for heating.

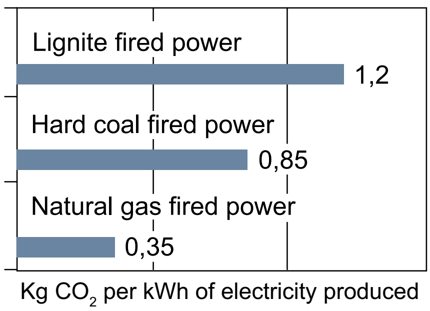
Each air cooled module of this type produces 16.9 kW of cooling or 35.3 kW of heating with a nominal heating efficiency as high as 140 per cent. This means that heating is produced at a much higher efficiency compared to a conventional gas-fired boiler, saving almost 50 per cent running costs and almost halving $CO_2$ emissions.

Unlike conventional electric powered heat pumps, the heat output and heating efficiency is hardly affected by external ambient temperatures. Heat pumps are considered by many the next large development of gas application in the residential ad commercial sector.

## Switching from coal to natural gas in electricity generation

When an electric utility has a decision to make with regard to choice of fuel for a new power plant, many factors enter the consideration including projections of fuel costs decades ahead, technology, markets and so forth. A new factor coming to the forefront in the last few years is the amount of $CO_2$ emitted per unit of electricity with the different fuels and their associated technologies.

**Fig. 6.11:** Approximate $CO_2$-emissions per unit of electricity produced from the three fuels natural gas, internationally traded coal and brown coal (lignite). The latter is usually not traded over distance, but used in a power plant close to the mine. The large gap between coal and natural gas (0,85 vs 0,35 kg/kWh) is explained partly by less $CO_2$ per unit of energy in natural gas than in coal. Another reason is that natural gas is fired in a highly efficient gas turbine based combine cycle plant, while coal is usually being fired in a less efficient boiler-based power plant in a steam-cycle.




Fossil fuelled power plants globally emit 78 percent of all large point-source $CO_2$ (fig.6.16). At present these 78 % are shared with 60 %-points as coal fired, 11 % natural gas and 7 % oil. If we by magic and overnight could switch all the world's coal fired power plants to modern natural gas fired combined cycle plants, we would experience over 5 $GtCO_2$/yr, a reduction in global $CO_2$-emissions by 1/5. While in itself not very realistic, this thought experiment illustrate the huge potential for fuel switching to natural gas in the electricity generation sector.

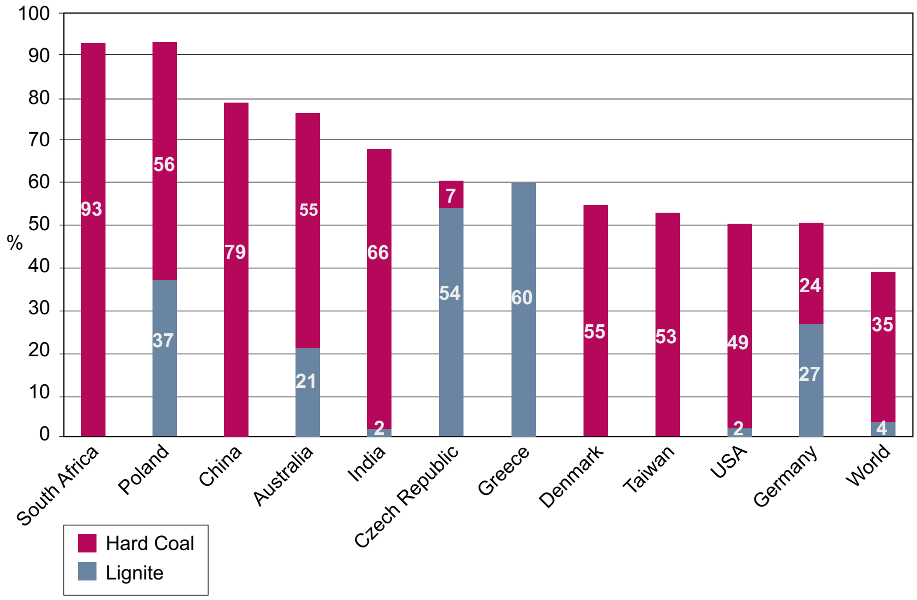



**Fig. 6.12.** Contribution of coal to power generation in selected countries (2003 data). Switching from coal to natural gas in the power generation sector give rise to only half as much $CO_2$-emission per kilowatt-hour electricity generated. The power sector in the countries listed in this graph could be prime targets for such fuel switching in climate driven world (Redrawn based on IEA source material).

**Switching to hydrogen made from natural gas**

The further end-use decarbonisation of energy will – together with carbon neutral renewables - ultimately depend on switching to electricity and hydrogen ($H_2$), the two energy carriers that do not carry carbon to the point of use.

In the 1970's journalists called hydrogen "the Tomorrow Fuel", and critics have worried that hydrogen – like fusion - will remain forever on the horizon. Invisible to the public, however, hydrogen is already very much part of the world of energy. Hydrogen is a thriving young industry. Hydrogen production is a large and growing. Globally some 50 million metric tons of hydrogen, equal to about 170 million tons of oil equivalent are produced annually.

In an energy comparison, this is just about 7% of the global natural gas production. The growth rate for hydrogen production is around 10% per year. Currently, global hydrogen production is about half from natural gas, 30% from oil, and most of the rest from coal. Water electrolysis - contrary to widespread belief - accounts for only 4%.

There are two primary uses for hydrogen today. About half is used to produce ammonia ($NH_3$) for fertilizers via the Haber process. The other half is used to convert heavy petroleum sources into lighter fractions suitable for use as vehicle fuels. Ammonia is instrumental in feeding the global population, the fuel upgrading is already contributing to decarbonisation of the transport sector. Very little hydrogen is today used directly for energy purposes.

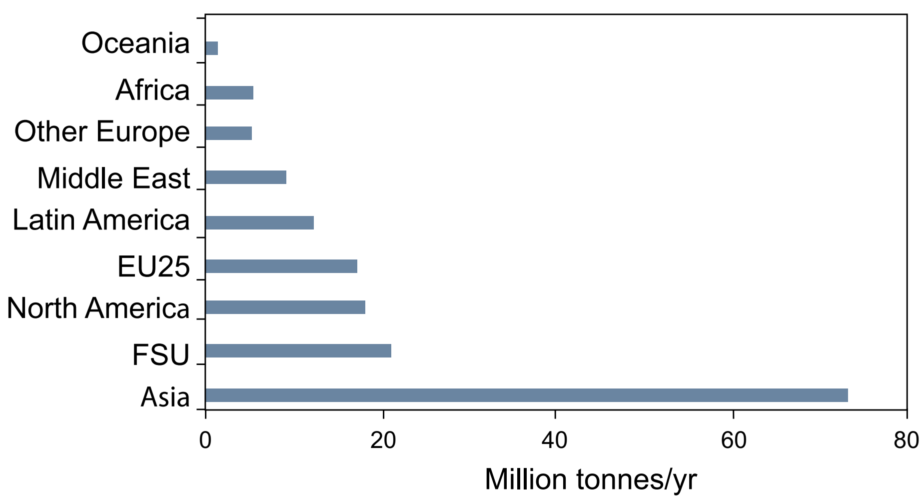



**Fig. 6.13:** About half of global hydrogen production is used for the production of ammonia ($NH_3$) for the fertiliser industry. Most of the capacity is to be found in Asia. The production of ammonia goes through a step where pure hydrogen is made with $CO_2$- removal an integrated part of the process (Data: Fertecon, PottashCorp, 2005). The global potential for already captured $CO_2$ is around 100 Mt per year (IEA, 2008a)

When hydrogen is made from natural gas (or coal, oil), the process involves removal of $CO_2$ from the hydrogen stream. This means that the expensive $CO_2$-capture stage is already part of the existing industrial practice, making the transition to underground storage of $CO_2$ (CCS) less costly for hydrogen production than for electricity generation.

Hydrogen is very much part of our daily life, but even more invisible than natural gas since it is being used almost exclusively in the petrochemical, fertilizer and refinery industries. The map shows an example of an existing hydrogen pipeline network (in red) covering over 700 km in three countries owned by the industrial gas provider Air Liquide. In total there are globally nearly 3000 kilometres of hydrogen pipelines, equally shared between North America and Europe.

| Performance and cost measures | New hydrogen plant | | |
|---|---|---|---|
| | Range | | Representative value |
| | Low | High | |
| Emission rate without capture ($kgCO_2/GJ$) | 78 | 174 | 137 |
| Emission rate with capture ($kgCO_2/GJ$) | 7 | 28 | 17 |
| Percent $CO_2$-reduction pr GJ (%) | 72 | 96 | 86 |
| Plant efficiency with capture, LHV basis (%) | 52 | 68 | 60 |
| Capture energy requirement (% more input pr GJ) | 4 | 22 | 8 |
| Cost of hydrogen without capture (US$/GJ) | 6,5 | 10 | 7,8 |
| Cost of hydrogen with capture (US$/GJ) | 7,5 | 13,3 | 9,1 |
| Percent increase in H2 cost with capture (%) | 5 | 33 | 15 |
| Cost of net $CO_2$ captured (US$/tCO2) | 2 | 56 | 15 |
| Capture cost confidence level | Moderate to high | | |

**Table 6.4:** The costs of producing hydrogen from natural gas with and without $CO_2$-capture (transport and storage not included in figures). The incremental costs of CCS for a hydrogen plant (including existing plants) is much lower than for an electricity generation plant. This is due to $CO_2$ being already captured in the hydrogen plant as part of the normal process (Source: IPCC SRCCS 2005)

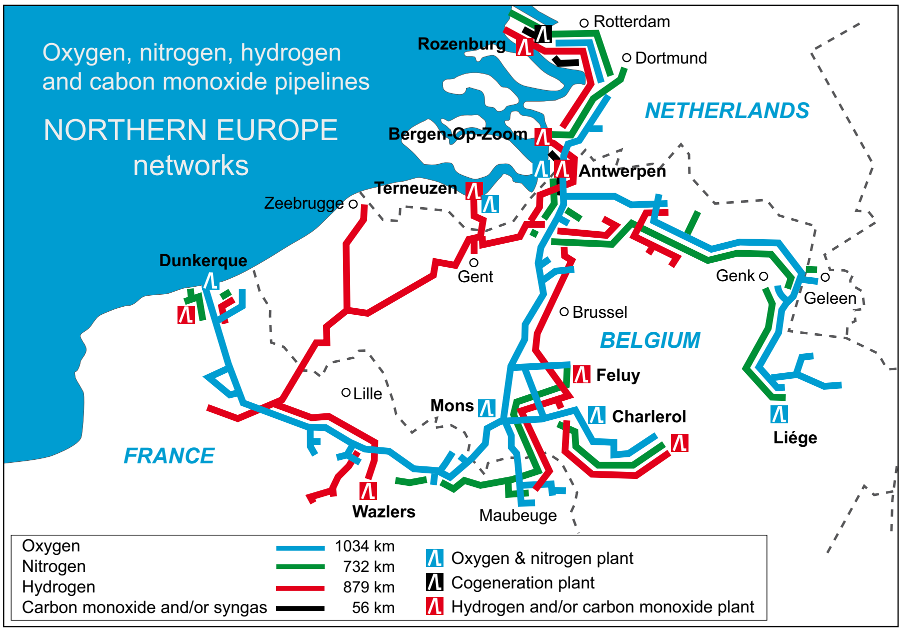



**Fig. 6.14:** Hydrogen pipelines (in red). This map shows the pipeline network in the three countries France, Belgium and the Netherlands of the industrial gases supplier Air Liquide. Similar pipeline grids of varying length exist in USA, Germany and a few other countries serving industrial consumers (Redrawn based on an Air Liquide original).

## Mixing hydrogen into natural gas

In a parallel development to mixing bio-methane into the natural gas grid, the "NaturalHy" R&D project in the European Union has for some years been researching the possibility of injecting pure hydrogen into natural gas pipelines.

It is not yet possible to say conclusively what level of hydrogen may be safely added to existing natural gas networks, but current indications are that it may be possible to transport in excess of 30% hydrogen in high pressure transmission lines with existing steel materials.

In the same way as a chain is only as strong as its weakest link, however, the maximum level of hydrogen will depend on a careful analysis of impacts across the whole gas chain and in particular the end-use part. The modern pre-mixed domestic boilers tested in the NaturalHy project can tolerate mixtures containing more than 50% hydrogen in natural gas, apparently with slightly lower NOx levels.

These are potentially very important results, obtained both in laboratory tests and in year-long field trials. It must be kept in mind, however, that these results are derived using new pre-mixed boilers. Many of the domestic appliances in use today are not new, are not of the pre-mixed design and are not subject to rigorous maintenance.

There is a large variation in the quality (gas composition) of natural gas used within EU countries and consequently this would lead to a significant variation in maximum allowable hydrogen. Taking these factors into account, the maximum allowed percentage of hydrogen in natural gas may turn out to be 10 percent or less.

**$CO_2$-capture and –storage (CCS) for natural gas customers**

Gas customers and other actors within the energy industry are already turning up on the doorsteps of the natural gas industry asking for advice and help to carry out underground storage projects for their $CO_2$. CCS projects so far materialised, however, are few and far between. The barriers are many (high costs, legal, public acceptance) while at the same time dependable, long-term financial incentives for CCS are mostly absent.

CCS is mostly discussed in connection with the large industry sectors of coal and electricity generation. There are, however, numerous other large industrial point sources of $CO_2$ that are candidates for CCS. These can be found in the petrochemical industries, the fertiliser industry, refineries, iron and steel production, cement plants and so forth.

Globally there is a large, but finite number of large point sources of $CO_2$ as shown by fig 6.16.

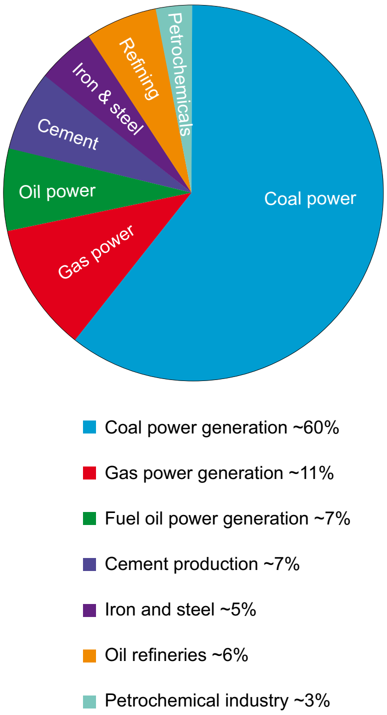
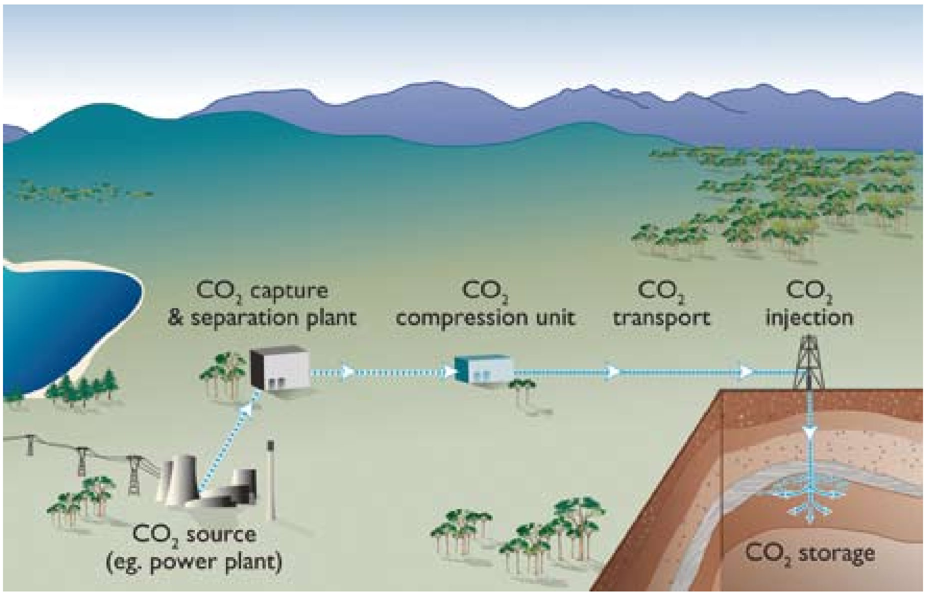



**Fig. 6.16:** The global number of point sources for $CO_2$ larger than 0,1 million tons per year are limited to about 7500. Taken together these 7500 large point sources represent 56% of all fossil fuel derived $CO_2$- emissions (Data source: IPCC SRCCS, 2005).

**Fig. 6.15:** The illustration shows a typical power-plant and $CO_2$-capture scheme in combination with underground $CO_2$-storage. There are several capture technologies that can be applied to power plants depending on circumstances. The capture-, separation and – compression plant will usually be collocated and integrated with the power plant in order to facilitate heat and other utility integration. $CO_2$- storage will usually take place below a depth of over 800 meters (below the surface) in order to store the dense, socalled supercritical $CO_2$.




A similar graph focussing only on point sources above one million tons of $CO_2$/yr would show a significantly smaller number of plants, but not an equivalent reduction in $CO_2$-volumes.

**Will the natural gas industry be transporting and storing $CO_2$ for others?**

The natural gas industry has started to use CCS to clean up its own operations. A number of indicators are pointing towards the natural gas industry over time taking a wider CCSrole.

The gas industry has been pioneering the concept of CCS, it has an abundance of knowledge of geology, drilling, reservoirs, pipeline transportation as well as experience from over 600 underground natural gas storage sites.

The natural gas industry is therefore uniquely positioned to transport and store $CO_2$ in geological formations also for own gas customers as well as other in need of such services. For this to happen it is necessary to have regulatory and legal frameworks in place making $CO_2$-transport and -storage an attractive commercial prospect.

The first projects among natural gas customers that lends themselves to CCS are $CO_2$ from hydrogen and ammonia plants which has already captured the CO2 for process reasons. Further along the time-line is capture from natural gas fired and other thermal power plants as well as sources in the petrochemical industry etc.

### Cutting methane & flaring emissions for the oil industry

For the natural gas industry to assist in reducing methane emissions and flaring in the oil industry is one area where two related, but different industries can cooperate to tackle connected problems.

The oil producing industry has for years struggled with how to curb the practice of burning the natural gas that often comes out of the reservoirs along with crude oil. The controversial and visible practice, called flaring, has declined in parts of the world, but such reductions have been offset by increases in flaring elsewhere.

Higher natural gas prices and improved technologies have widened the range of options for reducing gas flaring.

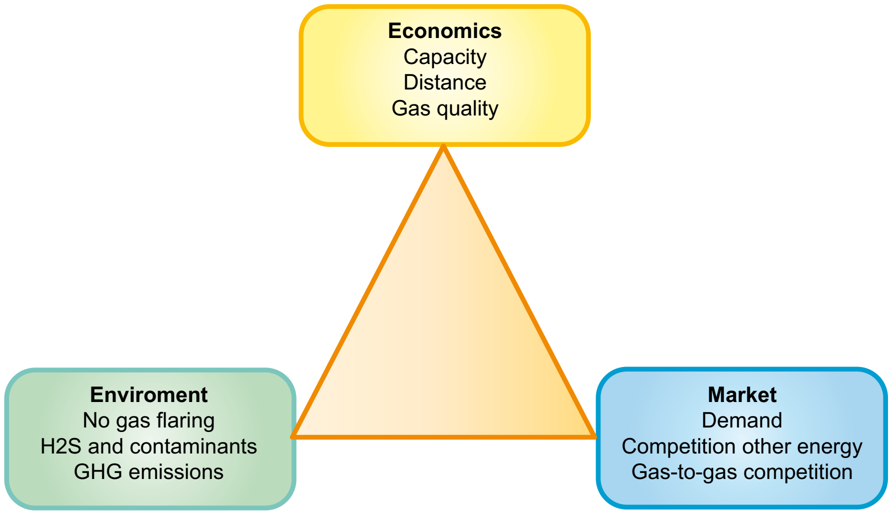



**Fig. 6.17:** Flaring reduction projects have to take into account the three major factors indicated in this triangle. The economics are influenced by gas volume (economics of scale), by transportation distance and by the presence of contaminants in the gas. Environmental aspects of any hydrogen sulphide ($H_2S$) content in the gas as well as how much energy and $CO_2$ the flaring reduction gives rise to must be factored in. Finally there must be a market willing to pay for the gas or product made from gas (e.g. electricity). Redrawn based on a GGFRP original.

Much ingenuity has gone into developing ways to avoid gas flaring. Among those are:

- Inject the natural gas in a local geological reservoir awaiting future technologies and or gas prices making it possible to transport the gas to market
- Gather several small gas sources to make it economically possible to invest in a gathering pipeline to a paying market
- Transport non-flared natural gas as LNG (e.g. mini-LNG) or CNG on trucks, trains, barges or ships to a paying market
- Convert gas to electricity (gas-to-wire) to make transportation more economical over longer distances. Over very long distances direct current (DC) may be preferred to alternating current (AC).
- Convert the gas to a more transportable fluid such as synthetic oil (GTL), methanol, DME, oxygenates, ammonia and so forth

Local circumstances will to a large extent determine which of these options, if any, can be applied to a specific flaring case.

Often there is a lack of coordination and a lack of policy/strategy between actors. In many cases there is a lack of data with respect to production profiles for different fields, making forward planning difficult.

In 2007, the World Bank and Rosneft signed a memorandum of understanding to jointly develop a gas flaring reduction program, under which emission reduction units could be bought by the bank. The program will be implemented in the framework of a gas utilization project currently underway at the Komsomolskoye field in the Yamal-Nenets Autonomous District of Russia.

The project has the following main objectives:
a) Implementation of the Rosneft gas utilization program increasing the associated gas utilization efficiency up to 95%, b) collection of associated gas at the Komsomolsk oil field and transportation into Gazprom Unified Gas Transmission System for retail to end consumers and c) reduction of associated gas and/or its flaring products emissions into the atmosphere, and improvement of the regional air quality.

The project will have large positive environmental impacts which are related to the reduction of GHG emissions (about 2.4 million tons of $CO_{2eq}$ annually). Apart from emission reductions due to the reduction of flaring, the expected benefits from the project include the decrease of other environmental pollutants, such as $SO_x$, $NO_x$ and others. It also decreases considerably thermal (the flare burns at an average temperature of 1700°C), visual (light) and noise pollution to the local environment.

Source: World Bank

President Putin's 2007 State of the Union speech called for a reduction in the country's gas flaring and the government today has plans to establish a 95% utilization requirement for associated gas. The Rosneft flaring reduction project (textbox) - and others like it - illustrates that Russia is tackling the flaring problem in a businesslike manner.

PFC Energy has conducted the study "Using Russia's Associated Gas" on behalf of the Global Gas Flaring Reduction Partnership (GGFR) and the World Bank. The study was made public in 2008 assessing that Russian oil producers annually flare 38 billion cubic meters (Bcm) or 1.3 trillion cubic feet (Tcf).

The PFC study compared the economics of five options for increasing associated gas utilization in Russia, including:

- Generation of electricity to provide power to the oil field
- Generation of electricity for the regional market
- Process into LPG (propane, butane), petrochemicals and dry gas
- Process into diesel or methanol (Gas To Liquids - GTL)
- Re-injection for Enhanced Oil Recovery

The PFC Energy analysis demonstrates that:

- The optimal use of associated gas varies with the size of the producing field.
- For small fields, the most attractive option is through small-scale power production to meet the needs of the field itself (electric submersible pumps, etc.) and other local users.
- For medium-sized fields, the most economic utilization option is through extraction of the LPG in gas processing plants, and sale of the LPG or petrochemicals and dry gas.
- For large fields, the most attractive option is electric power generation through a large power plant selling power wholesale to the grid.

At the end of the day gas flaring is mostly about economics, but there are also strong elements of technology, incentives (e.g. CDM and JI) and regulations. The additional revenue stream from CDM or JI for flaring reduction is expected to get a substantial amount of otherwise flared or vented gas to the market.

**References chapter 6**

BP Statistical Review of World Energy 2008

IPCC SRCCS, Special Report on $CO_2$-capture and –storage, 2005

WPC (2008a), Paper at World Petroleum Congress, 2008; Sandaker, Kjell Martin, Eidesvik Offshore ASA

IEA, (2008a), $CO_2$ Capture and Storage. A key Carbon Abatement Option, IEA Paris

**Useful web-sites for this chapter:**

-US EPA on methane emissions:
http://www.epa.gov/climatechange/economics/international.html

GGFRP - World Bank Global Gas Flaring Reduction Partnership:
http://web.worldbank.org WBSITE/EXTERNAL/TOPICS EXTOGMC/ EXTGGFR/0,,menuP K:578075~pagePK:64168427~piP:64168435 ~theSitePK:578069,00 html

US DoE Alternative Fuels & Advanced vehicles data Centre:
http://www.afdc.energy.gov/afdc/

International Association of Natural Gas vehicles (IANGV):
http://www.iangv.org/

Green Car Congress:
http://www.greencarcongress.com/2008/06/iangv-sees-pote.html

International Maritime Organisation (IMO):
http://www.imo.org/

CDM – Clean Development Mechanism : http://cdm.unfccc.int/index.html

# 7. Challenge

The opportunities for climate change mitigation in the natural gas industry itself as well as among existing and future customers are numerous as we have seen in the previous chapters. One obvious question is: Why have these opportunities not been adopted to a greater extent already? This chapter attempts to highlight some of the important technical, economical, regulatory, geographic and attitude related barriers that in the past have come in the way of implementing actions involving natural gas as a way of reducing climate impact. The listing will not be complete given the difference in circumstances between countries and regions. Some of the challenges are, however, globally relevant.

On the more positive side we have attempted to describe a few cases where barriers have been encountered and tackled in a way that others can learn from.

**Motivators**

In fig. 7.1 we seek to illustrate that there are many and varied ways of motivating climate change mitigation, in particular when we look as far ahead as fifty years. Classically we have divided the motivators into "carrots" and "sticks" since both are needed and complement each other across sectors and cultures. The least effective – often having the opposite effect - is shown in the lower left corner named "empty declarations". The most effective (upper right corner) are establishing frameworks such that climate change mitigation makes commercial sense in competition with other commercial projects. In a fifty year time-frame we see that long term activities such as countries and companies setting good examples may become important. When thinking in terms of decades we find that better climate and energy information in lower grade schools also become efficient motivators.

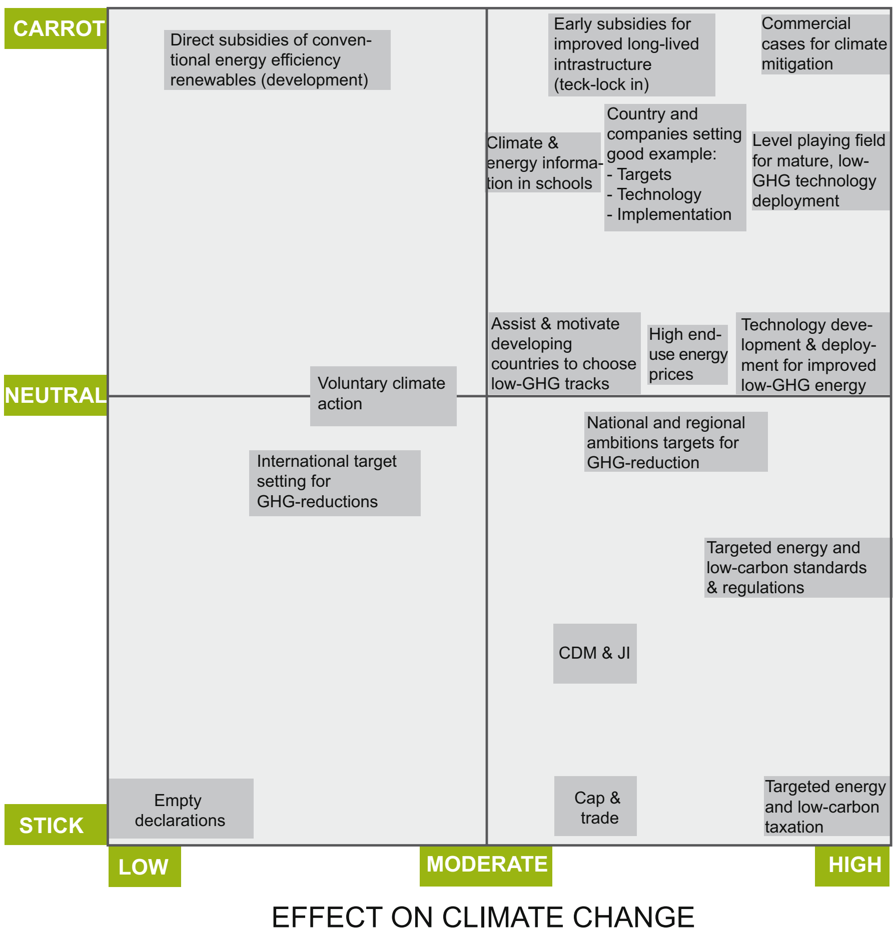



**Figure 7.1** What motivates climate change action? This figure attempts to sort the major motivators (sticks and carrots) and their effects (low, moderate or high) on different actors. There are many more motivators at work than shown in this figure and some of them may have different effect in one culture compared to another.

**Barriers**

Why is climate change mitigation so slow to come into place? Part of it can be seen in the motivator's figure (fig. 7.1), but there are also other reasons why mitigation is taking time to happen. In the energy industry there are for instance decade's long turnover times for plants and equipment. Without very strong climate-incentives, relatively small changes will happen with respect to energy efficiency or other reduction measures until the slow natural plant replacement cycle has made its next turn.

Many other barriers of a technical, educational, motivational or institutional nature stand in the way of speedy realisation of climate change mitigation. This is illustrated for natural gas industry related reduction measures in fig 7.2 and table 7.1.

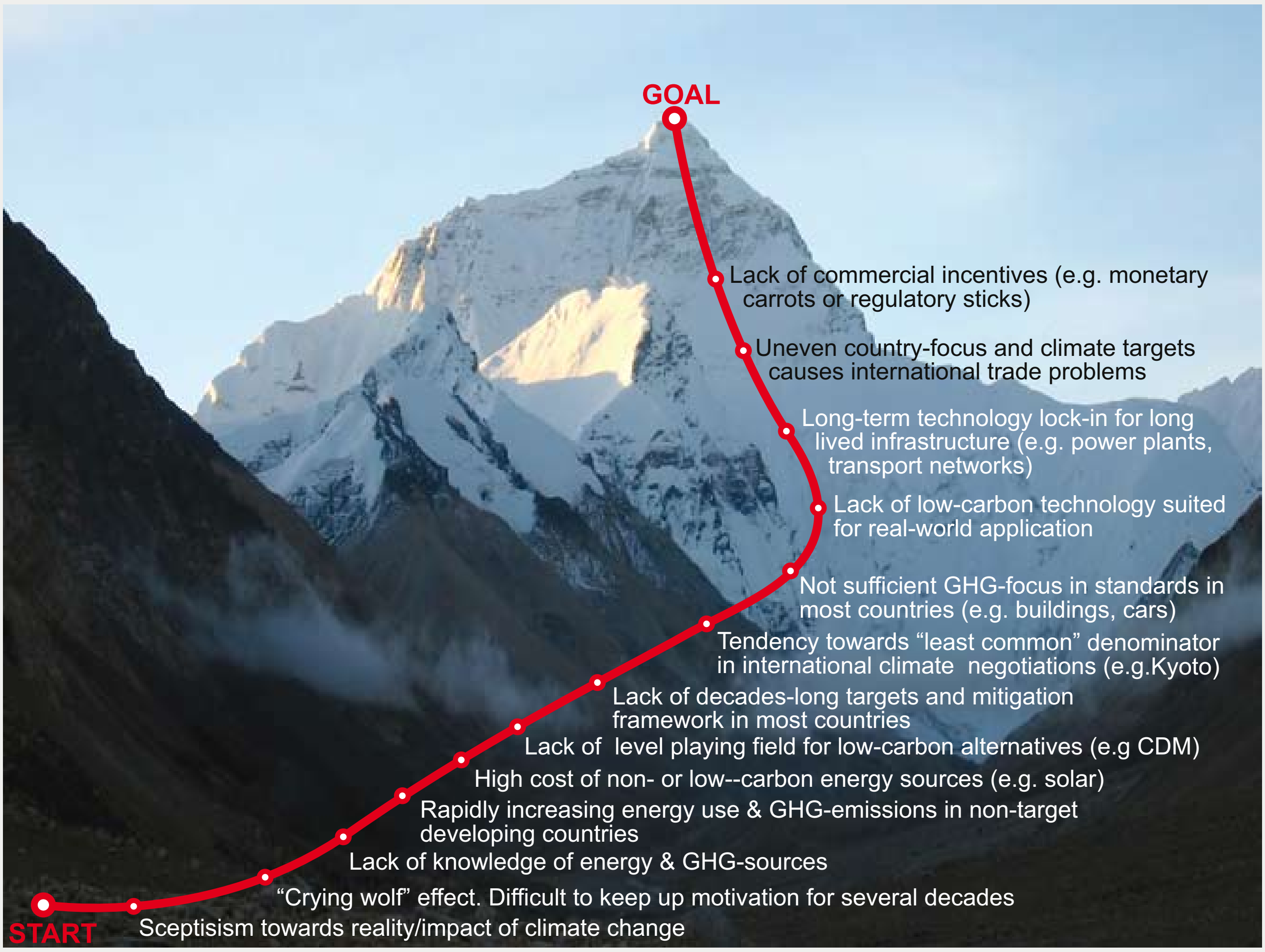



**Fig. 7.2** How a mountaineer might view barriers to climate change mitigation. Not all the indicated barriers are equally relevant to specific countries, companies or individuals, but the route to the top contains a number of difficult obstructions between the valley and the top of the mountain.

| Mitigation areas and tools | Potential barriers or enablers | Expected time until removal of barrier | | |
|---|---|---|---|---|
| | | Before 2015 | Before 2025 | Later than 2025 |
| Energy efficiency in natural gas industry | Long turn-over time for plants | 🟡 | 🟢 | 🟢 |
| | High gas- and el.-prices benefits efficiency | 🟢 | 🟢 | 🟢 |
| Energy efficiency for natural gas customers | Change of public attitudes to efficiency | 🟡 | 🟡 | 🟢 |
| | More efficient end-use technologies | 🟡 | 🟢 | 🟢 |
| | New end-use areas. New technologies for end-use | 🟡 | 🟡🟢 | 🟢 |
| | Make natural gas available in more regions and locations to replace coal, oil | 🟡 | 🟢 | 🟢 |
| | Government regulations for efficiency | 🟡 | 🟡🟢 | 🟢 |
| Switch from coal to gas in electricity generation | Price gap between coal and gas (incl. CO2-price) | 🟡🔴 | 🟡 | 🟢 |
| | Superior gas-fired technologies available | 🟢 | 🟢 | 🟢 |
| Switch to natural gas in new types of end-use (e.g. ship-fuel, trucks) | Price diff. between oil and LNG/CNG | 🟡🔴 | 🟡 | 🟢 |
| | Gas compatible motors, turbines, systems | 🟡 | 🟢 | 🟢 |
| Switch to natural gas in energy intensive industries (e.g. steel) | Price difference between coal/heavy fuel oil and natural gas (incl. CO2-price) | 🟡 | 🟡 | 🟢 |
| | New technologies needed for efficiency | 🟡 | 🟡🟢 | 🟢 |
| Hydrogen from natural gas for distribution | Price diff. between hydrogen production w/CCS and natural gas | 🔴 | 🟡🟢 | 🟢 |
| | Compatibility of existing/new pipelines | 🟡 | 🟡🟢 | 🟢 |
| | Availability of H2 end-use equipment | 🟡🔴 | 🟡 | 🟢 |
| Mix bio-gas into natural gas grid | Price incentives for use of renewables | 🟡 | 🟢 | 🟢 |
| | Availability of bio-gas | 🟡 | 🟡🟢 | 🟡🟢 |
| Renewables in gas industry operations (e.g. hydropower) | Price diff. hydro vs gas (incl. CO2-price) | 🔴 | 🟡🟢 | 🟡🟢 |
| | Availability of renewable energy for specific plant locations | 🟡🔴 | 🟡🔴 | 🟡🔴 |
| CCS for already captured CO2 (e.g. LNG, high CO2 NG) | Lack of long-term CO2-regime & -price | 🟡🔴 | 🟢 | 🟢 |
| | Long term storage liability | 🔴 | 🟡🟢 | 🟢 |
| CCS from flue gases in gas industry | Lack of long-term CO2-regime & -price | 🟡🔴 | 🟡🟢 | 🟡🟢 |
| | Lower cost technologies and more tech.suppliers | 🟡 | 🟡🟢 | 🟢 |
| Sell CO2 for use in enhanced oil recovery projects | Distance between sufficiently low cost CO2-sources and EOR locations | 🟡 | 🟡 | 🟡 |
| | Oil price high enough to defend EOR-costs? | 🟢 | 🟢 | 🟢 |
| Gas companies as CO2-transp/-storage service providers | See as interesting new business sector? | 🟡 | 🟢 | 🟢 |
| | Lack of regulatory framework for cross-border transportation and storage sites | 🔴 | 🟢 | 🟢 |
| Limit gas industry flaring, venting, fugitive emissions | Lack of long-term GHG regime & -price | 🟡🟢 | 🟢 | 🟢 |
| | Long turnover time for equipment, pipelines, compressors etc. | 🟡 | 🟢 | 🟢 |
| Assist oil industry in reducing flaring | Lack of long-term GHG -regime & -price (CDM, JI [7]) | 🟡🟢 | 🟢 | 🟢 |
| | Gas prices high enough to defend costs | 🟡🟢 | 🟡🟢 | 🟡🟢 |

**Table 7.1** Barriers and enablers to climate change mitigation in the natural gas industry and with natural gas customers.

The green, yellow and red lights in table 7.1 - while discouraging in the short term to 2015 - gives rise to considerable optimism in the medium (to 2025) to longer term. Much is already happening that may remove barriers for the most relevant mitigation efforts both within governments and within the natural gas industry itself and with our present and future gas customers.

One of the more significant barriers against energy efficiency in the gas industry itself is the long turn-over time for equipment. An industry-wide expectations of relatively high gas prices as well as ready availability of capital will on the other hand offer incentives for efficiency measures.

Energy efficiency among the customers of the natural gas industry is more affected by government regulations (e.g. standards), the attitudes of individuals as well as the availability of natural gas to potential future customers. When perhaps as few as 10% of humanity has access to natural gas, this means that as many as 90% of the global population are likely to choose less clean forms of energy.

Fuel switching in power generation and industry (e.g. coal to natural gas) depends to a large extent on the price difference between the various fuels ("spark-spread"), in particular between coal and gas.

Since the power and industry sectors are heavily regulated by governments, political factors traditionally play important roles in moulding national fuel mixes. Fuel switching in other energy intensive industries (e.g. iron and steel) is mainly dependent on price difference between coal, heavy oil and natural gas.

Increasingly the expected future costs of emitting $CO_2$ to the atmosphere are becoming part of the equation for energy intensive branches of industry. Efficiency and climate motivated technology development will in the medium to long run be an important driver for switching to natural gas in many energy intensive industries.

Fuel switching from oil products to natural gas in buses, trucks, cars and even ships have happened for some time, but are still low on the development curve. Both price differentials between fuels, environmental concerns and government actions have in the past been important for promoting natural gas in these end-use sectors.

Some parts of the gas industry are very active in the transportation sector, others may up to now have underestimated their own roles in furthering a sector important for both local pollution and climate.

Hydrogen as an energy carrier made from natural gas with $CO_2$-storage can in a deep $CO_2$-reduction perspective turn out to be an important supplement to electricity. Barriers such as lack of a transport and distribution grid and commercial availability of end-use equipment will, however, take a long time to overcome. Building from an almost non-existing base will stretch over many decades.

Mixing biogas into natural gas grids is happening to an increasing extent. The barriers are to be found in the magnitude of the biogas resource close to gas grids as well as in government incentives for renewable energy sources.

The use of renewables in the internal operations of the gas industry will be limited by the availability of such resources close to the gas operations. For the gas industry this seems likely to be niche applications particular to a few regions, but still an important way of furthering the introduction of more renewables.

Capture and –storage (CCS) of $CO_2$ captured from natural gas is already happening and the gas industry is pioneering this technology. Increasingly, however, the uptake of this technology is hampered by political and market uncertainty of the future price of emitting $CO_2$ to atmosphere. One of these barriers is the present lack of acceptance of CCS under the CDM regime. Another barrier in most countries is the long term liability of the $CO_2$ stored underground. The industrial view is that this long term perspective must be the responsibility of governments.

The already captured $CO_2$ from the gas industry may be sold to the oil industry to enhance oil recovery in aging fields. This offers the possibility of several win-wins. One being the better utilisation of oil reserves from already developed oil fields.

Another being the opportunity for the gas industry to earn money and a third opportunity is to build a $CO_2$-pipeline infrastructure that can be used to transport and store $CO_2$ once the oil fields are depleted. The gas companies may also see $CO_2$- infrastructure as a business opportunity both for own use as well as providers of services for customers.

Capturing and storing $CO_2$ from combustion related flue gases in the gas industry has the same barriers as for already captured sources of $CO_2$, but in addition even much more of an economic barrier given the high costs of capture from dilute flue gas sources.

The limitation or elimination of flaring, venting and fugitive emissions of methane from the oil industry is one important area where the gas industry can assist another branch of industry in climate change mitigation.

The barriers against this happening are to a large part economic. This economic uncertainty includes the level of future price of the recovered natural gas as well as the costs of emitting $CO_2$ or methane to the atmosphere in different countries and regions.

Another barrier to fast implementation is the long replacement time for large capital equipment as well as the remoteness of much of the flaring and venting locations.

Barrier removal success story 1;

**CCS and the OSPAR and London Conventions**

In those cases where $CO_2$ storage activities take place offshore, several international instruments comes into play in order to protect the marine environment. The primary international marine environment protection treaties are the Law of the Sea, the London Convention (and London Protocol), and the OSPAR (Oslo-Paris) Convention and other regional treaties.

Neither of these treaties had provisions for the relatively new topic of $CO_2$-capture and –storage, something that was realised by institutions such as the IEA Greenhouse Gas R&D Programme and some national governments in the 1990's. Under the leadership of governmental delegates, educational efforts were put in place about CCS for those involved.

Over a period of many years this resulted in amendments and monitoring guidance coming into place for both London and OSPAR. These legal developments must be monitored and considered as governments and industry attempt to harmonise international approaches to $CO_2$ storage monitoring and verification. In 2007, an amendment went into force under the London Protocol which allows the storage of $CO_2$ if:

1. The disposal is into a sub-seabed geological formation; and
2. Stored streams consist overwhelmingly of carbon dioxide; and
3. No waste is added for the purpose of disposal.

This amendment provided for the first time a basis in international environmental law to regulate $CO_2$ sequestration in sub-seabed geological formations. In June 2007 the OSPAR Commission followed a similar approach and adopted amendments to allow for the offshore geological storage of $CO_2$, if completed under an authorised permit from a responsible national government.

Barrier removal success story 2:

**How natural gas flaring in the oil industry came on the global agenda**

In 2002 the World Bank and its partners launched the Global Gas Flaring Reduction partnership (GGFR) at the World Summit on Sustainable Development in Johannesburg. The Partnership was preceded by an initiative between the Bank and the Norwegian Government to assess global gas flaring.

During the first international conference on gas flaring reduction in Oslo in 2002 it was agreed that a Global Public-Private Partnership was the way forward for it had the potential of making greater contributions to gas flaring reduction, in spite of the huge challenges faced back then and somehow still faced today. By now there is a much better understanding of the barriers that we need to overcome for reducing flaring, including the lack of reliable data to gauge the magnitude of the practice.

The actors are also more conscious of the need for countries to have not only effective regulations but also clear policies with the right incentives for operating companies so that the necessary infrastructure is put in place and markets for gas utilization are developed. Gas flaring reduction has been most successful where there is country buy-in, high-level support and an effective local partnership between government and industry.

There is no longer doubt that governments and private sector need to work as real partners if tangible results are to be achieved. There has also been developed a keener awareness of the critical role that leadership and commitment play in both the public and private sectors in order to sustain progress over the long term. GGFR's main role is that of a catalyst that brings key stakeholders around the table, facilitates the establishment of a common ground with clear targets, and does not allow them to give up or get distracted from the ultimate objective.

In summary the most important barrier-breakers are removal of institutional (mostly government and international treaty) barriers, deployment of better technologies as well as expectations of increasing costs of emissions of greenhouse gases to the atmosphere over the next decades. Expectations of future high energy prices will also work in the direction of an efficient energy system both in the industrialised and in the industrialising countries of the world.

The natural gas industry can – and does - clean up its own operations. This report has illustrated the many facets of this work around the world. The main contribution of natural gas to mitigation of global warming lies, however, in making it possible for our customers to reduce their greenhouse gas emissions. The report has shown how this can be done by switching from higher-carbon fuels, including mixing biogas (or even pure hydrogen) into natural gas as well as replacing oil products in vehicles and ships. By the nature of the fuel, natural gas enables energy efficiency in most applications. The gas industry is already helping the oil industry to reduce flaring and can in the future take a role as transporters and underground storage providers for $CO_2$ (CCS) on behalf of gas customers as well as in own operations.

Natural gas is the youngest of the fossil fuels in terms of coming later to the market than coal or oil. Gas has for that reason yet to show its full potential in most countries and regions of the world. The global warming issue will be one of the keys to unlocking this potential in the first decades of the 21st century.

**Useful web-sites for this chapter:**
- International Gas Union (IGU): http://www.igu.org/
- Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch/
- London Convention: http://www.imo.org/home.asp?topic_id=1488
- Ospar Commission: http://www.ospar.org/
- Clean Development Mechanism (CDM): http://cdm.unfccc.int/index.html

**Abbreviations:**

| | |
|---|---|
| AC: | Alternating Current |
| ACEEE: | American Council for an energy Efficient Economy |
| BAT: | Best Available technology |
| Bcm: | Billion cubic metres |
| BP SRWE: | BP Statistical Review of World Energy (yearly statistics) |
| CCS: | $CO_2$-capture and -storage or carbon capture and -storage, alternatively carbon capture and -sequestration |
| CDM: | Clean Development Mechanism (one of the Kyoto Mechanisms) |
| CFLC: | Ceramic Fuel Cells Limited |
| $CH_4$: | Methane, a molecule consisting of one carbon atom and four hydrogen atoms |
| CHP: | Combined Heat and Power. Production of electricity + heat simultaneously |
| CNG: | Compressed natural gas |
| $CO_2$: | Carbon dioxide |
| $CO_{2eq}$: | Carbon dioxide equivalent |
| DnV: | Det norske Veritas (ship classification society) |
| DoE: | US Department of Energy |
| e.g.: | For example (Latin phrase : exempli gratia) |
| EIA: | US Energy Information Administration |
| EOR: | Enhanced oil recovery |
| GGFR: | World Bank Global Gas Flaring Project |
| $GSm^3$: | Giga standard cubic meters |
| GTL: | Gas to Liquids |
| GWP: | Global Warming Potential |
| $H_2S$: | Hydrogen Sulphide |
| HHV: | Higher heating value (or gross calorific value – GCV) |
| HVDC: | High Voltage Direct Current |
| IANGV: | International Association of Natural Gas vehicles |
| IEA: | International Energy Agency |
| IEA GHG: | IEA Greenhouse Gas R&D Programme |
| IGU: | International Gas Union |
| IIASA: | International Institute for Applied Systems Analysis (Austria) |
| IMO: | International Maritime Organisation |
| IPCC: | Intergovernmental Panel on Climate Change |
| IPCC SRCCS: | IPCC Special Report on $CO_2$-capture and –storage, 2005 |
| IPCC WG3: | IPCC Working Group 3 |
| JI: | Joint Implementation (one of the Kyoto Mechanisms) |
| kPa: | Kilo Pascal (unit of pressure) |
| LCA: | Life cycle analysis |
| LDV: | Light duty vehicle |
| LHV: | Lower heating value |
| LNG: | Liquefied Natural Gas; liquid at atmospheric pressure and -161 oC |
| LPG: | Liquefied Petroleum Gases (mostly propane, butane) |
| Mtoe: | Million tons of oil equivalent |
| MWhe: | megawatt hours electric |
| N.A.: | Not Applicable |
| NGV: | Natural gas vehicle |

| | |
|---|---|
| NETL: | National Energy Technology Laboratory (USA) |
| $Nm^3$: | Normal cubic metre |
| OECD: | Organisation for Economic Co-operation and Development |
| OSPAR: | Ospar Commission |
| R&D: | Research and Development |
| SCR: | Selective catalytic Reduction of NOx from combustion |
| $Sm^3$: | Standard cubic meter |
| SOFC: | Solid Oxide Fuel Cell |
| Tcm: | Trillion cubic metres |
| TJ: | Tera Joule |
| UK: | United Kingdom |
| UNECE: | United Nations Economic Commission for Europe |
| US: | Short for United States |
| US EPA: | US Environmental Protection Agency |
| USGS: | US Geological Survey |
| WEO: | World Energy Outlook report (IEA) |
| WRI: | World Resources Institute |
| Wrt.: | With respect to |
| Yr.: | Short for year |

## Conversion factors

| | | |
|---|---|---|
| 1 PJ (HHV) | = 25,6 million $m_3$ natural gas | |
| 1 $m^3$ of natural gas | = 39 mega joules (MJ - HHV) | = 10,8 kWh |
| 1 Mtoe | = 1 million tons of oil equivalent | = 41,89 PJ |
| 1000 $m^3$ of nat. gas | = 0,9 ton of oil equivalent (toe – crude oil) | |
| 1 Bcm | = 1 billion cubic metres | |
| 1 Tcm | = 1 trillion cubic metres (or 1000 Bcm) | |
| 1 cubic metre | = 35,315 cubic feet (cf) | |

Net Calorific Value (NCV or LHV) = 0,9 Gross Calorific Value (GCV or HHV)

| | |
|---|---|
| 1 megajoule (MJ) | = $10^6$ joules |
| 1 gigajoule (GJ) | = $10^9$ joules |
| 1 terajoule (TJ) | = $10^{12}$ joules |
| 1 petajoule (PJ) | = $10^{15}$ joules |

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INTERNATIONAL GAS UNION

www.igu.org/