SUSTAINABLE GAS ENTERS THE EUROPEAN GAS DISTRIBUTION SYSTEM

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1. INTRODUCTION

Biomass is one of the most important sources of renewable energy. The European Commission depicts in its 1997 White Paper "Energy for the Future - renewable sources of energy" (Ref 3) a strategy and action plan for the enhanced use of renewable energy sources. Table 1summarises some data from this White Paper.

		1995	**2010**
Total utilised renewable energy sources	PJ	3100	7600
Biomass for energy	PJ	1870	5650
Contribution of biomass to total use of renewable energy sources	%	60	74
Heat from biomass	PJ	1590	3140
Biomass for electricity production	PJ	280	2510
Electricity from biomass	PJ	83	830
Electric conversion efficiency	%	29	33

Table 1 EC’s White Paper data on the growth of utilisation of the energy from biomass

Biomass is the most important contributor to the growth in renewable energy sources. Between 1995 and 2010 3780 PJ of biomass capacity will be installed. The cost efficiency for using energy from biomass equals that of hydro and wind power but is better compared to other sources of renewable energy as photovoltaic or geothermal by a factor three to ten.

The worldwide production of biomass on the land surface exceeds the energy consumption by a factor 100 (Ref 1). Only a part of this biomass is, by its remote location and dispersed nature, available for energy production. Even from the biomass available for energy production currently only a small part is utilised. The present level of conversion efficiency from biomass to useful energy is normally also quite low. Notwithstanding this sub-optimal utilisation, biomass already in 1990 contributed to 13% of all primary energy (Ref 2). It is estimated that in 2050 nearly 40% of the direct fuel use and 17% of the power production will be provided from biomass.

Renewables have traditionally normally been used to produce heat via combustion but in some countries and applications have also been converted to gas in biogas plants. Gas can be used for local production of heat and electricity but can also be distributed if a suitable network exists.

2. TECHNOLOGIES FOR MANUFACTURE AND DISTRIBUTION OF SUSTAINABLE GASES

Sustainable gas is in this paper defined as a gas obtained from biomass which is upgraded to a quality similar to natural gas. Sustainable gas can be manufactured through two main processes; anaerobic digestion of organic (normally moist) material or thermal gasification of organic (normally dry) material. In both cases the gas from primary production has to be upgraded in a secondary step to produce a gas that is suitable for injection into the gas grid.

2.1 Gas from anaerobic digestion

In the anaerobic conversion of biomass and waste, organic materials are microbiologically converted to methane, carbon dioxide and water. The rate of the anaerobic digestion is determined by the composition of the reaction mixture and the temperature. The rate of reaction increases with higher temperatures. This increase of the reaction rate is limited by the stability of the microbiological agents in this process. Temperatures to about 55°C are however feasible.

Examples of anaerobic conversion processes for the production of biogas are:

- **Sewage treatment plants:** Many sewage treatment plants produce methane rich gases in the sludge fermentation stage. Utilisation of methane from sewage plants is used on a large scale in many countries. Optimised process conditions can enhance the production and collection of these gases.
- **Landfills**: All landfills produce methane rich gases. Collection and utilisation of the gases is quite widely applied. Improved collection, processing and utilisation of landfill gases will be an important tool to increase the importance of landfill gas.
- **Cleaning of organic industrial waste streams:** Anaerobic digestion processes are often successfully applied to clean the waste streams of agricultural processing industry. The methane rich gases are mainly utilised to produce electricity.
- **Mesofilic and thermophilic digestion of organic waste:** Compact installations convert at higher temperatures organic waste to methane rich gases. The main difference between the two methods is the digestion temperature (35°C in the mesofilic process and 55°C in the thermofilic process.

Biogas plants utilising anaerobic digestion make a valuable contribution to the solution of a range of problems concerning agricultural, environmental and energy interests. It is therefore relevant to regard biogas technology as a promising element in the chain of organic waste recycling. The biogas concept offers a total appropriate system for treatment, sanitation, redistribution and nutrient utilisation from livestock slurry and organic waste (Ref 6).

Anaerobic digestion is the common denominator for a wide range of microbiological processes where biomass is converted to biogas. In some applications the biogas is converted to heat. This is mainly done for landfill gases where abundant, low cost, biogas is used to provide heat in local industrial applications.

Biogas is in many cases converted by a generator to produce electricity. This conversion has, due to its small scale, a modest efficiency between 20 - 35%. Biogas can be the feedstock to produce pipeline quality gas. After cleaning the biogas can be distributed in a medium calorific gas grid. After cleaning and upgrading to sufficient methane content the biogas can be fed to a natural gas grid. Depending on the raw material and the digestion process, the composition of the gas produced will vary. The energy content of the gas is linked to the methane component, which may come as high as 80% in case of industrial sewage.

Carbon dioxide and nitrogen, are inert gases that reduce the heating value of the biogas. Carbon dioxide is always present in gas from anaerobic digestion whereas nitrogen only is present in landfill gas or in gas from anaerobic reactors with air leakage.

Upgrading of biogas by removal of nitrogen is still expensive, whereas several techniques are available for removal of carbon dioxide at low costs. Biogas containing larger amounts of nitrogen can however be added to the grid distributing pipeline quality gas with a low heating value (L-gas). Hydrogen sulphide is poisonous and highly corrosive, the content being dependent on the raw material. Even in small-scale installations this component is normally removed to a level of less than 3 ppm.

Component		Biogas plant	Sewage plant	Landfill
Methane	%	60 - 70	55 - 65	45 - 55
Carbon dioxide	%	30 - 40	balance	30 - 40
Nitrogen	%	< 1	< 1	5 - 15
Hydrogen sulphide	ppm	10 – 2000	10 - 40	50 - 300

Table 2**:** Typical raw (untreated) biogas compositions at the different plants

In order to obtain pipeline quality gas the biogas must pass two major processes:

1. A cleaning process, in which trace components harmful to the natural gas grid, appliances or end-users are removed.
2. An upgrading process, in which the calorific value, Wobbe index and other parameters are adjusted in order to meet the pipeline specifications.

Furthermore, the gas must be odorised before it is added to the natural gas grid.

Carbon dioxide in biogas is easily absorbed in water or other solvent at elevated pressure and this has made the use of water scrubbing for CO_2-removal a widely used process. Other possibilities are PSA (Pressure Swing Adsorption) or membrane separation.

2.1.1 Water absorption

Two types of water absorption processes are commonly used for upgrading of gas from anaerobic digestion, single pass absorption and regenerative absorption. The major difference between the two processes is that the water in the single pass process is used only once. A typical installation is at a sewage water treatment plant. Water can also be recycled and in this case a stripper collumn has to be integrated in the process (regenerative absorption). The singel pass process is described below.
Cleaned sewage water is of sufficient quality for use in the absorption column. After the flash tank the water is depressurised by a regulator valve and returned to the sewage water treatment system.

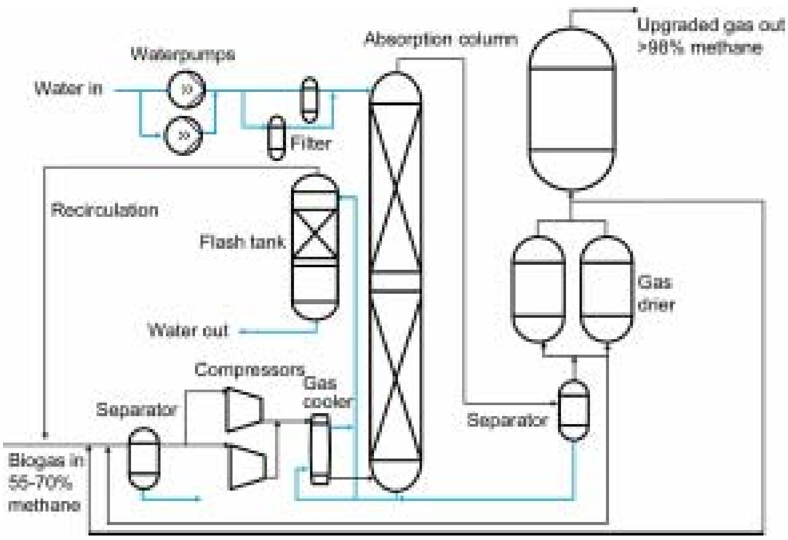

Figure 1: Removal of carbon dioxide using water wash without regeneration

2.1.2 Membrane separation

The principle of membrane separation is that some components of the raw gas are transported through a thin membrane while others are retained. The permeability is a direct function of the chemical solubility of the target component in the membrane. Solid membranes can be constructed as e.g. hollow fibre modules, which give a large membrane surface per volume and thus very compact units. Typical operating pressures are in the range of 25 - 40 bar.

The principle of membrane separation constitutes a conflict between high methane purity in the upgraded gas and high methane yield. The purity of the upgraded gas can be improved by increasing the size or number of the membrane modules, but a larger amount of the methane will permeate through the membranes and is therefore lost, see Figure 2.

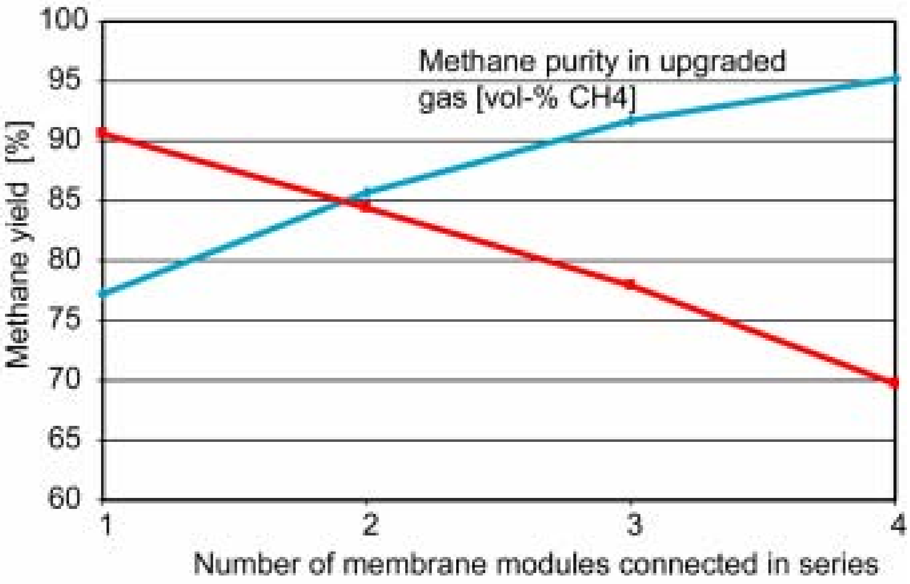

Figure 2*:* Relation between methane purity in upgraded gas and methane yield with membrane modules connected in series (no recycling)

2.1.3 Pressure Swing Adsorption

Pressure Swing Adsorption, or PSA, is a method for the separation of carbon dioxide from methane by adsorption/desorption of carbon dioxide on zeolites or activated carbon at different pressure levels. The adsorption material adsorbs hydrogen sulphide irreversibly and is thus poisoned by hydrogen sulphide. For this reason a hydrogen sulphide removing step is often included in the PSA process.

The upgrading system consists of four adsorber vessels filled with adsorption material. During normal operation each adsorber operates in an alternating cycle of adsorption, regeneration and pressure build-up. During the adsorption phase biogas enters from the bottom into one of the adsorbers. When passing the adsorber vessel, carbon dioxide, oxygen and nitrogen are adsorbed on the adsorbent material surface. The gas leaving the top of the adsorber vessel contains > 97% methane.

Before the adsorbent material is completely saturated with the adsorbed feed gas components, the adsorption phase is stopped and another adsorber vessel that has been regenerated is switched into adsorption mode to achieve continuous operation.

Regeneration of the saturated adsorbent material is performed by a stepwise depressurisation of the adsorber vessel to atmospheric pressure and finally to near vacuum conditions. Initially the pressure is reduced by a pressure balance with an already regenerated adsorber vessel. This is followed by a second depressurisation step to almost atmospheric pressure. The gas leaving the vessel during this step contains significant amounts of methane and is recycled to the gas inlet. Before the adsorption phase starts again, the adsorber vessel is repressurised stepwise to the final adsorption pressure. After a pressure balance with an adsorber that has been in adsorption mode before, the final pressure build-up is achieved with feed gas.

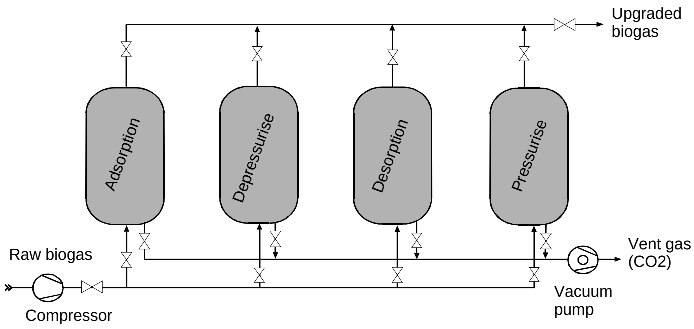

Figure 3 Biogas upgrading system with PSA technology

LPG addition can be used as a supplementary method that can be combined with other upgrading methods. Following the main upgrading process, propane addition can be used to regulate the gas quality towards pipeline quality, and thereby compensate for variations in the composition of the upgraded biogas. The major advantage of supplementary propane addition is that the main upgrading process can operate with lower outlet methane concentrations. For some upgrading processes, e.g. membrane separation, this means that higher efficiencies/methane yields can be obtained. The required amount of LPG addition depends on the main upgrading process, the pipeline specifications, the biogas quality etc.

2.1.4 Case descriptions

A number of plants for biogas distribution in natural gas grids or in separate grids exist in Europe and some of them (from Sweden, Denmark and the Netherlands) are described below.

Revninge - Denmark

The biogas plant at Revninge started operating in 1990, and supplies biogas in a medium BTU gas network to 67 households in Revninge. For back up or for adjustment of the gas quality a mixture of natural gas and air can also supply the small network that is isolated from the natural gas network. An evaluation of the domestic boilers in Revninge in 1994 showed some minor corrosion problems, but the concept is in general promising. Instead of biogas upgrading and supply of biogas to the natural gas network, the Revninge concept could be a model for smaller parts of the natural gas network. For safety reasons only minor variations of the Wobbe index can be accepted when supplying households. For separate biogas networks backup supply from natural gas or propane/butane is recommended.

Gothenburg - Sweden

In Gothenburg, Sweden, another solution has been chosen. Gothenburg has an old distribution system for town gas and a mixture of natural gas and air is now being distributed on this grid. The mixture is 47% natural gas and 53% air, resulting in a product with a Wobbe number similar to the old town gas that was manufactured from reforming of butane. The maximum load on this system is around 3000 m^3/h. Biogas in Gothenburg is produced in the local treatment plant for sewage water and is presently being used for the combined production of heat and power in a number of gas engines at the water treatment plant. Part of the biogas is compressed, cooled and transferred to the old town gas plant, where now the mixture of natural gas and air is introduced in the town gas grid. In 2002 11% of the energy demand on the town gas grid (total supply 90,6 GWh/year) was covered by biogas.

The biogas system has a maximum capacity of 300 m^3/h and the maximum amount of biogas that is introduced into the grid is limited to 30%, a figure based on tests performed with different kind of gas equipment presently used in the town gas system. Appropriate quality of the gas on the town gas system is maintained by a control system where first natural gas and air is mixed to a specified Wobbe number and then the resulting mixture is blended with a biogas that has been adjusted to a specified heating value. This procedure maintains a stable gas quality on the town gas system and thereby ascertains a safe and stable operation of the equipment connected to the grid.

Laholm - Sweden

The Laholm plant in Sweden will in 2003 have a capacity to feed 500 m^3/h upgraded biogas into the local low pressure distribution grid. The activities in the Laholm biogas plant is described in detail in Ref 7.

Stockholm - Sweden

The new residential district in Stockholm, Hammarby sjöstad combines modern architecture with new technologies. Hammarby Sjöstad (the Hammarby Nautical Village) is a newly developed area in Stockholm that is being built in an old harbour and industrial area in the southern parts of Stockholm.The total number of apartments will be 8000 for a total of 15- 20 000 inhabitants. It is the largest civil engineering project in Sweden for the moment. One objective with the area is to demonstrate sustainable systems, a good environment and low energy use. A normal Swedish building uses around 200 kWh/m^2,year and one of the targets in the area is to reach an energy consumption of less than 60 kWh/m^2,year. One way of reducing the electricity consumption is to replace the electric stoves in the apartments by gas stoves and this has been done in more than 1000 of the apartments in the area. The gas to these stoves is supplied from the sewage water treatment plant that handles the waste water from the area. The gas is upgraded from 60-70% methane content to a quality that corresponds to Swedish standard for biogas as vehicle fuel (>97% methane) and is then distributed in the area in a gas distribution system that is built according to Swedish standard for natural gas distribution systems. The availability of upgraded biogas in the area also provides the possibility to supply gas to a NGV filling station in the area and discussions are also under way about the use of biogas as fuel for the ferry connecting the area to central parts of Stockholm.

Upgrading plants in Holland

At four sites in the Netherlands, landfill gas is upgraded to natural gas quality. The sulphur in the landfill gas is removed and the CO_2 is removed by water wash or by Pressure Swing Absorption (PSA). At all sites, the gas is injected in the 8 bar grid.
Quality control takes place by a continuous measurement of the Wobbe number.

In Table 3, the existing plants are outlined

Location Operator	**Feedstock and technology**	**Capacity** **m^3/h output**	**Status**
Tilburg	landfill gas: input 1400 m^3/h		on line 1986
	gas from biomass: input 560 m^3/h		on line 1994
	sewage gas: input 40 m^3/h		also used for electricity generation
	carbon dioxide removal with water wash	1200	on line 1986
Nuenen	landfill gas: carbon dioxide removal with pressure swing absorption	3000	in production since 1986
Wijster	landfill gas: carbon dioxide removal with pressure swing absorption	4000	in production since 1986
Wolvega	landfill gas: carbon dioxide removal with membrane separation	1800	Producing since 1993

Table 3*:* Survey of the locations in the Netherlands where biogas is added to the grid

Upgrading in other European countries

European upgrading plants for injection of biogas into the natural gas grid are at present in operation in Switzerland (2 plants), in the Netherlands (see Table 3) and in Sweden. Plants have been erected in France but has been temporarily been taken out of operation. Upgrading plants for production of vehicle fuel from biogas are in operation in the Czech Republic.

2.2 Sustainable gas from gasification and hydrogasification

The following steps can be distinguished in the SNG process:

- The collection and pre-treatment of biomass
- Gasification of the biomass
- Cleaning of the syn gas
- Methanisation of the syn gas
- CO_2 removal and odorisation
- Injection into the gas grid at a gas receiving station
- Supply to consumers

Gasification with air is not appropriate since the bulk of nitrogen in air will lead to a methanation reactor with large dimensions and extra costs for removal of nitrogen from the product. Steam gasification as well as gasification with oxygen can both be applied. However, steam gasification seems the most attractive gasification technique because of the lower costs.

The SNG process is very attractive since:

- a lot of customers can supplied with renewable energy by the gas grid
- During transport, the energy losses are negligible
- The gas grid is capable of transporting large energy streams
- The overall efficiency of the process from LHV biomass to LHV SNG is 58 % and very high

A consortium of Gastec Technology and the Dutch utilities REMU and Eneco have performed a pre-engineering study for a 20 MWth plant (Ref 4). The gas produced is L-gas with a Wobbe-number of 44 MJ/Nm^3 and a net calorific value of 31.7 MJ/Nm^3.

The key data from this study were:

- Production price of SNG of 20 €ct/ Nm^3
- Production rate of 9.8*10^6 Nm^3/year
- Tariff for CO_2 reduction of 38 €/ton CO_2

A variation on this process was reported by ECN (Ref 5)They evaluated the SNG production by means of hydrogasification. In the hydrogasification process, hydrogen is fed together with biomass to an autothermal gasifier at 30 bars. The hydrogen is to be supplied by industrial rest streams. The energy input of the incoming hydrogen is about the same as the thermal input of the biomass.
For a 50 MW plant a production price of 22 €ct/ Nm^3 was calculated.

3. POTENTIAL FOR SUSTAINABLE GAS IN EUROPE

There are today more than 3000 biogas plants in Europe and biogas is also used from a large number of landfill sites. The two countries that account for the largest biogas production in Europe are Germany and England. The total European biogas production was in 2002 estimated to 92 PJ/year and the total European potential is estimated to 770 PJ/year in 2020 (Ref 8). The countries with the highest biogas production per capita are the UK, Sweden, Denmark, Switzerland and the Netherlands. The potential production of SNG from dry biofuels (waste wood etc.) via gasification and hydrogasification is larger (in the magnitude of 2000 PJ/year). In the short term the main potential for biogas production is in the treatment of wet wastes like sewage water sludge, manure and waste from different kinds of food industries. In the long-term perspective the main source for biogas will be different kinds of agricultural products.

4. OBSTACLES FOR AN INTRODUCTION OF SUSTAINABLE GAS INTO THE EUROPEAN GAS SYSTEM

The main obstacle for feeding upgraded biogas into the natural gas grid is normally the upgrading cost for the biogas. Upgrading costs of approx. 15 €ct/ Nm^3 SNG were estimated (average plant) by DGC in 2001. Costs for upgraded biogas between 17 and 50 €ct/ Nm^3 have been reported from the Swedish Biogas Association. The cost for the raw biogas is normally set on an alternative basis and can in some cases (where biogas usage is limited) be as low as 10 -11 €ct/ Nm^3. Upgraded gas can then be obtained at a price level of around 20 €ct/ Nm^3.
Another obstacle for the injection of biogas is the lack of standards concerning gas quality requirements, measurement procedures and regulations concerning the injection of biogas into the natural gas grid. In order to promote investments in biogas upgrading plants there is a need to establish clear guidelines and regulations for the rights and obligations for the involved organisations, including the owners of the upgrading plants, grid owners, customers (who buy the upgraded gas) etc. These measures can be regarded as parallel to the similar regulation for introduction of "green" electricity to the power grid.

5. APPLICATIONS FOR SUSTAINABLE GAS - INCENTIVES

The main reason for introducing sustainable gas into the natural gas grid is to gradually reach a larger in independance of fossile fuels in an economically feasible way. The infrastructure for distribution is in most European countries well developed and can be a feasible system for the distribution of sustainable energy in the same way as the electricity grid is used to supply "green" electricity.

The access of fuel gases to the European market is regulated in the 1998 EU directive "Common rules for the internal market in natural gas" (Ref 12). This directive sets the right of any producer to sell his fuel gas to any client in Europe. This directive is not necessarily limited to natural gas. Liquefied natural gas (LNG) and gases from natural gas storages are explicitly included in this directive. Gases from biomass, organic waste, coal or oil are not explicitly mentioned. It is left to the Member States to impose public-service obligations to the natural gas undertakings for security, security of supply, regularity, quality, price of supplies and environmental protection. From this directive it may be expected that all gas from biomass that meets the requirements of a natural gas may be added to the grid.

An interconnection can also provide the producer of biogas with possibilities of expanding his market without expanding his production capacity. A major problem in this respect is that increased production or purification capacity in a biogas production plant often requires large investments and these investments cannot be made before the market for the gas is established. By connecting the biogas plant to the natural gas grid, market development may be done without increasing the own production capacity (using gas from the grid) and investments may be postponed until the market for gas is established.

In a number of countries (e g Sweden, Denmark, the Netherlands, Switzerland) there is a tax difference between biogas and natural gas. Biogas normally has a zero tax. This difference (if large enough) can be an incentive for the natural gas distributor to trade tax free biogas instead of taxed natural gas.

6. SUMMARY AND CONCLUSIONS

Biogas upgrading and injection into the natural gas grid is a new way to increase the use of sustainable energy.

Discussion about how to support the use of biogas in the internal market has just begun at EU level and within the EU member countries. The development of the possibility to distribute biogas on the natural gas grids has to a large extent been facilitated by the opening up of the European gas market which (at least in theory) makes it possible for any producer of biogas to supply gas to the grid. Certain demands concerning gas quality, reliability of supply etc. in this case has to be fulfilled. Upgrading of biogas can be a feasible way to substantially increase the efficiency in the utilisation of biogas. Biogas is in most European countries used for electricity production due to different national subsidies. Subsidies up to 10 €c/kWh exist for production of "green" electricity for the electricity grid but no similar subsidies exist for injection into the natural gas grid

Upgraded biogas, however, may play an important role as primary energy to overcome such problems of obvious energy wastage.

Examples in Sweden, the Netherlands, Switzerland and other European countries (Ref 13) may provide sufficient basis to develop some kind of technical and legislative framework for injection of upgraded biogas or SNG from biomass similar to the framework for green electric energy in Europe. This is an important market incentive measure. For the time being some barriers need to be removed to treat renewable energies equally at the two internal markets of energy/international energy grids, the electricity market and the gas market.

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