European Energy Infrastructure

The Chalmers databases 2006

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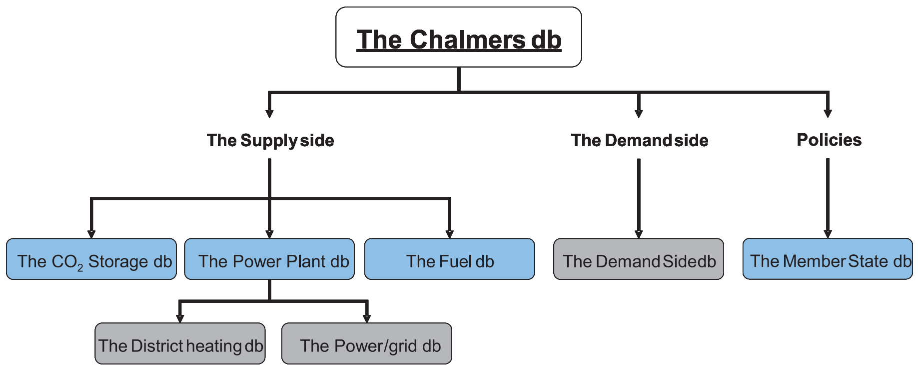

The structure of the Chalmers databases. The databases marked with blue colour are ready to use, while the grey colour indicates that the database is under construction

This report is a result from the project *Pathways to Sustainable European Energy Systems* – a five year project within The AGS Energy Pathways Flagship Program.

The project has the overall aim to evaluate and propose robust pathways towards a sustainable energy system with respect to environmental, technical, economic and social issues. Here the focus is on the stationary energy system (power and heat) in the European setting.

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PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS

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CHALMERS Chalmers University of Technology, was founded in 1829 following a donation, and became an independent foundation in 1994.Around 13,100 people work and study at the university. Chalmers offers Ph.D and Licentiate course programmes as well as MScEng, MArch, BScEng, BSc and nautical programmes.

Contact: Alexandra Priatna
Phone: +46 31 772 4959 Fax: +46 31 772 4958
E-mail: alexandra.priatna@ags.chalmers.se

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Contact: Peter Edwards
Phone: +41 44 632 4330 Fax: +41 44 632 1215
E-mail: peter.edwards@env.ethz.ch

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Contact: Karen Gibson
Phone: +1 617 258 6368 Fax: +1 617 258 6590
E-mail: kgibson@mit.edu

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Contact: Yuko Shimazaki
Phone: +81 3 5841 7937 Fax: +81 3 5841 2303
E-mail: shimazaki@ir3s.u-tokyo.ac.jp

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AGS Pathways report 2006:EU1

PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS
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Göteborg 2006

This report can be ordered from:
AGS Office at Chalmers
GMV, Chalmers
SE - 412 96 Göteborg
alexandra.priatna@chalmers.se

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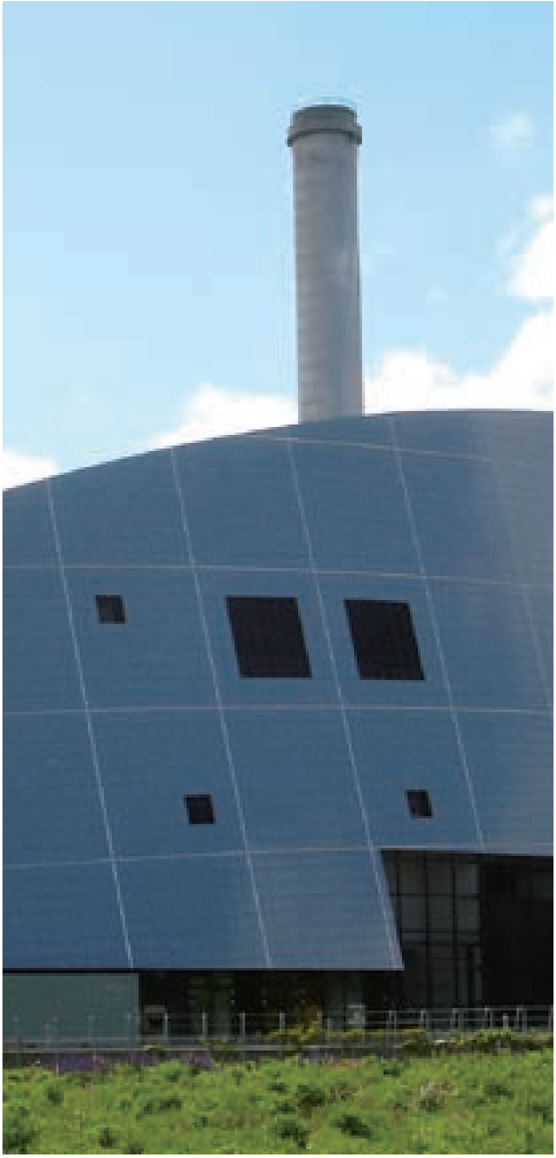
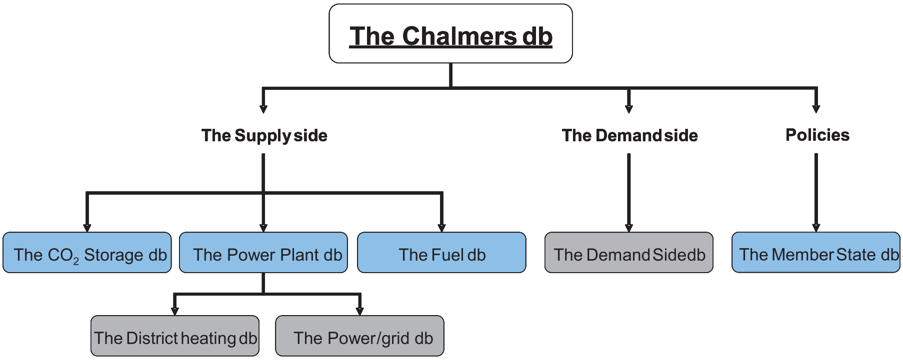
Content

The Chalmers databases 2006

Literature gives numerous studies on the development of global, national and regional energy systems with respect to CO_2 emissions for various scenarios. These are often based on techno-economic modeling with costs and emissions of specific technologies as inputs under various constraints. Such studies give valuable information on the options and costs for various scenarios of the energy-system development. Still, there is a lack of studies which are based on a detailed description of the current energy system with power plants together with other infrastructural limitations and possibilities. To be able to develop sustainable pathways to the future energy system, there is a need for these studies. For example, when considering CO_2 capture and storage, it is useful that the emission sources are matched with the location and the capacity of the sinks. In order to develop a method for such a detailed analysis, a group of comprehensive databases of the European energy supply system has been developed: The Chalmers databases.

This report starts by a brief description of the different databases produced at Chalmers. Thereafter, each database is described in detail containing the aim the database, its content and its current status. For each database, one or a few case studies are given that describe how the databases have been used in the research at Chalmers.





The structure of the Chalmers databases. The databases marked with blue colour are ready to use, while the grey colour indicates that the database is under construction

The Chalmers databases are separated into one Supply and one Demand side and one Policy part. The Supply side consists of three sub-databases designed to give a comprehensive description of the supply side of the stationary European Energy system. The Demand side database, which is not yet ready to use, will present a comprehensive and realistic view of the demand side of the stationary energy system. The Policy part contains current European energy policies.

The supply side

The supply side consists of the following databases:

- **The Power Plant database**
  which contains all power plants in the EU plus Norway and Switzerland with a capacity of at least 10 MWe. The database contains cross-border transmission capacity (the Power grid database) and thermal production (the District Heating database).
- **The Fuel database**
  which contains global field specific data on oil, gas and coal fields as well as data related to major transport facilities such as pipelines, Liquefied natural gas (LNG) and regasification terminals.
- **The CO_2 Storage database**
  which contains all identified CO_2 storage reservoirs in Europe with a storage potential of 1 Mt CO_2 or more, i.e. gas and oil fields and aquifers.

The Policy part

The database containing European energy policies is:

- **The Member State database**
  which contains historic trends of key indicators like GDP and power generation as well as key national energy documents like Climate Change Strategy and Energy Strategy in EU. Furthermore, the Member State database identifies and lists country-specific energy systems that should be included in the modeling process.

Why Chalmers has chosen to create its own databases

The Power Plant database

Several power plant databases exist in the public domain, like for instance IEA's global power plant database, the power plant database compiled by the Stockholm Environmental Institute (SEI) or the database established specifically to gather information on power plants burning solid fuels only and compiled by the Centre for Solid Fuels Technology and Applications (CSFTA) together with Technische Vereinigung der Grosskraftwerksbetreiber (VGB). However, these databases either lack detailed information down to block level, as the database from IEA or SEI or they refer to power plants with a specific technology, like the CSFTA/VGB database. One of the main features of the Chalmers Power Plant database is that data like age, fuel, capacity, installation of scrubbers and more, is collected down to block level. Furthermore, the Chalmers Power Plant database contains a section for planned power plants and is continuously being updated, a major advantage in the extremely dynamic power sector.

The Fuel database

The Fuel database consists of information regarding resources and infrastructure. The resources of interest here are gas, oil and coal fields while the infrastructure consists of pipelines, LNG plants and regasification units, gas storage sites and gas sales and purchase agreements. Although the resource part of the Chalmers Fuel database has global coverage it is important to stress that this part of the database makes no attempt to collect data on all coal, gas and oil fields worldwide. Firstly, such information is not available in the public domain and possibly not anywhere else either. Secondly, there exists a vast amount of oil and gas fields in the world and an attempt to register all fields would be too time consuming and still not provide all data required. Instead, the main objective of the database on coal, oil and gas fields is to derive future coal, gas and oil production capacity on a country specific level. To accomplish this we have chosen to register fields according to the following:

- Sufficient information of field specific production history within a country to derive a plausible growth rate or decline rate for existing fields. This however, still requires a large number of fields. For instance all oil fields with a production rate of 1 kbl/d or above as reported in the Oil and Gas Journal annual production survey dating back to 1994 has been included in the database.
- Information on all discoveries dating back to the year 2000 and all development projects as of January 1st, 2005.

With one exception, most data in the infrastructure part of the Chalmers Fuel database exist easily obtainable in the public domain. The exception is historic data on gas and sales agreements still in force, in many cases up to 2020-2030. Still, we have chosen to compile our own database for two obvious reasons; i) the ability to integrate the information with information in the other databases and ii) the ability to update the data over time and as such have control of the market dynamics.

The CO_2 Storage database

The first comprehensive study on CO_2 storage potential in subsurface reservoirs within Europe was conducted by Holloway (1996). However, as stated in Holloway's study, the reservoir specific storage potential was highly provisional and in order to derive an exact storage *capacity* a site specific investigation would have to be carried out for each reservoir. The Gestco project (Geological Storage of CO_2, 2004) was the second comprehensive study of the storage potential of European subsurface reservoirs.

The Gestco project did however only cover reservoirs in eight European countries and has so far published data only for a limited number of reservoirs. The decision to compile our own database on CO_2 storage sites was taken partly because existing data initially was limited but improving over time as more site specific studies were revealed, and partly because the obvious advantages this would offer when data from specific storage reservoirs was integrated with data from the Power Plant database.

Collection of information

The Power Plant database

A significant part of the data in the Power Plant database has been collected through direct contact with utilities and companies, in particular large energy groups like EON, Vattenfall, RWE, EDF, Fortum, Endesa, Enel, EdP Electrabel and others, have been helpful in providing input for the power plant database.

Direct contact has also been applied to gather information from smaller energy companies. In cases where direct contact has not been used, reports by responsible ministries and International Governmental Organizations (IGOs) have served as source.

The Fuel database

The information in the Chalmers Fuel database can be divided into two parts; the resource and the infrastructure part, respectively. The resource part, consisting of oil, gas and coal fields, has global coverage and is based on four main sources;

- Northern Europe: Responsible ministries for the oil and gas business within the country
- Middle East and North Africa (MENA): IEA WEO Insights 2005
- Oil and Gas Journal, in particular the annual production survey
- American Association of Petroleum Geologists (AAPG): Giant Oil and Gas Fields

Additionally, a large number of company reports and press releases have been scanned for field specific data. All discoveries back to the year 2000 and development projects as of January 1^{st}, 2005, that have been reported in the public domain are included. The main objective of this part of the database is to collect sufficient information of field specific production history within a country to derive a plausible growth rate or decline rate for existing fields to which development projects and discoveries may be added in order to derive future production capacity on a country level.

The infrastructure part, which also has global coverage, contains information on LNG and regasification terminals, pipelines, gas storage sites, sales and purchase agreements. The inclusion of the coal market infrastructure will be carried out during 2006. The information in the infrastructure part of the database is mainly based on data available in the public domain like company reports and reports from the Energy Information Administration (EIA), US, as well as from the International Energy Agency (IEA).

The CO_2 storage database

The CO_2 Storage database contains all identified reservoirs within Europe that can store at least 1 Mt CO_2. CO_2 storage potential has been calculated for each specific reservoir by using the same method as applied in Holloway (1996) and Gestco/NGU (2002). Much of the data has been provided by the same sources as for gas and oil fields. Additionally, large amounts of storage related data have been collected from the Gestco-project (Geological Storage of CO_2, 2004), Norway's Geological Survey (NGU 2002), the Millenium Atlas (2003) published by the Geological Society of London, Holloway (1996) and, not at least, direct personal contact.

The Collection of information has undertaken the following policy:

1) Information is collected as close to the facility/field/contract as possible. Hence, the information will most likely come from owners of different facilities or from representative ministries.
2) Information from the owner of a facility always serves as main source
3) When other sources than above are being used the information must come from at least two different sources, else the facility will not be inserted into the databases

Current status of the Chalmers databases

The Chalmers databases are not just a limited work activity but a long-term project. The work started in 2003 with the ambition to continually develop new material and simultaneously update existing information. Today, a vast part of the databases are ready to use. However, all databases are continously being updated. Special focus during 2006 will be to implement coal infrastructure into the database where most of the European coal fields already are in place. The Member State database is renewed each time updated information is required. During 2006 the aim is also to finish the work on the Power Grid database. Current information about the status of each database can be received by contacting Chalmers University.

The use of the Chalmers databases

All information is gathered in Microsoft Access database software wherefrom linked Excel- and GIS-files are being created. This creates a stable environment where every single update of the Access database will result in changes in simulations etc made in Excel or GIS programs. Furthermore, all identified objects in the databases are geographically described by four parameters: coordinates, city/community level, national region, global region. The use of the same methodology for all databases enables an efficient way for combining information in the databases.

Output from the databases can be received in numerous ways, for example:

- As data files (usually Excel) containing parts of one or more databases
- As report files with formatted data, e.g. the largest coal plants in Germany or the total CO_2 storage potential in different regions
- As diagrams showing information from data files or formatted data in report files
- As maps showing for example position of utilities or routes for power grids and pipelines
- As input files for energy models

Today the scientists at Chalmers University use the databases in their studies when they need:

- Detailed information about the energy infrastructure in Europe as base for their scientific work
- Basic data for analysis of the development of the energy system and its effects on the environment
- Basic data for consequence analysis of political and strategic decisions in Europe and in specific countries
- Basic data for the construction of energy models, both for the structure of the models as well as for the description of pathways for the European energy system
- Detailed input to energy models constructed at Chalmers as well for externally generated (e.g. MARKAL) that are used in the scientific work at Chalmers
- To control and make quality checks of their own and others results

Case studies on how the databases have been used so far by Chalmers scientists will be shown in later chapters of this report.

More information

For more information about the Chalmers databases, and the use of them, please contact prof. Filip Johnsson, dept. of Energy and Environment, SE-412 96 Göteborg, Sweden. Phone: +46 31 772 1000.
E-mail: filip.johnsson@me.chalmers.se

The main features of

The Chalmers Power Plant database

Aim of the database

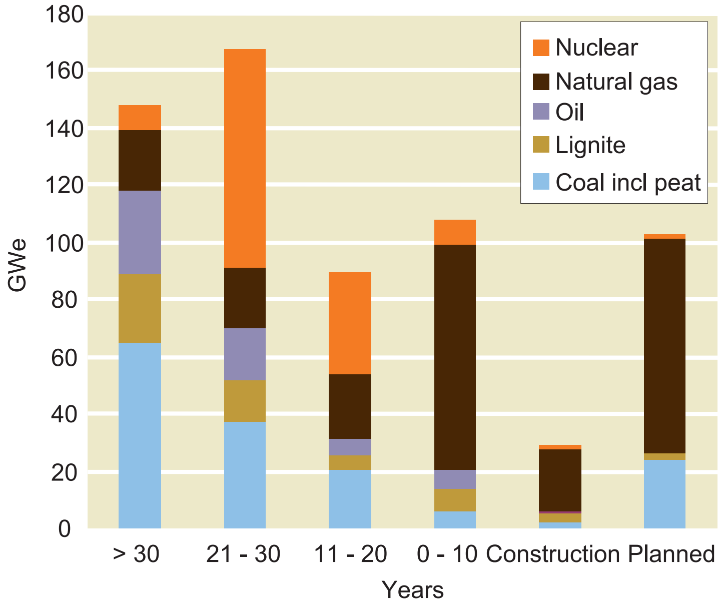
The aim of the Chalmers Power Plant database is to create a description of the EU power plant structure with a level of detail down to block level. This will create opportunities for the building of complex energy models which can be used in visualizing and analyzing future pathways for the European energy system.

Contents of the database

- Comprises EU, Norway and Switzerland
- Designed to fully describe the European power plant structure
- Covers all conventional technologies
- Contains all plants with a capacity ~ 10 MWe.
- Plants with a capacity below 10 MWe plus onshore wind farms are represented on an aggregated level on regional basis according to fuel/technology
- Contains all cross-border transmission lines
- All plants except wind farms are registered down to block level
- Generation and emissions in 2001 are provided for around 40% of all units.

Current status

The figure below presents the power plant structure in the EU as seen in the Chalmers Power Plant database. The figure clearly shows the transition of the energy system during the last four decades with a steady decrease of coal fired plants, a rapid expansion of Nuclear power in the 70ies and 80ies, and finally todays expansion of gas fired power plants.



EU Thermal power plants by fuel and age (biomass excluded)

Thermal power plants	Hydro plants	Wind
Age	Age	Age
Boiler type	Investment cost	Onshore and Offshore
Efficiency	Location	Investment cost
Emissions	Owner	Location
Flue gas cleaning technology	Power capacity	Owner
Fuel	Present status	Power capacity
Investment cost	Production	Present status
Location	Refurbishments	Production
Owner		
Power capacity		
Present status		
Production		
Repowering		
Technology		
Thermal capacity		
Turbine type		

The Contents of the Chalmers Power Plant database

All information in the Power Plant database is gathered in one main file. However, some figures considered to have greater importance are also found in subfiles. These are: total emissions and emission factors, production figures and load hours. The subfiles are connected to the main file so that updates in one file will also affect the substance of the other.

Compared to statistics from Eurostat with figures for power capacity on an aggregated level in EU, Chalmers Power Plant database today cover more than 90 % of all power capacity. For nuclear power this figure is 100 % and for thermal power plants the figure is around 95 %. More than 400 plants of various technology are currently (summer, 2006) identified as planned or under construction.

The databases have already been used in a number of projects carried out by Chalmers University. For example the co-firing potential of biomass with coal in Polish plants and the potential of district heating from Combined heat and power (CHP) in Bayern, germany have been analyzed in two master thesis. Furthermore, analysis of necessary investment patterns within the UK power generation sector in order to meet the goal of 60% CO_2 emission reduction by the year 2050 are currently being carried out in a PhD Thesis. The following pages will present results from these studies and give examples of information in The Power Plant database.

Country	Plant name	Owner	Status	Main fuel	Commissioning year	Block net power capacity MW	Plant net power capacity MW	Latitude
UK	Killingholme II	Eon UK Ltd	OPR	G	1992	450	0	
UK	Teeside IX	Teeside Power Ltd	OPR	G	1992	156,5	0	
UK	Teeside I	Teeside Power Ltd	OPR	G	1992	150	18	
UK	Teeside II	Teeside Power Ltd	OPR	G	1992	150		
UK	Teeside III	Teeside Power Ltd	OPR	G	1992	150		
UK	Rye-House	Scottish Power	OPR	G	1993			
UK	Peterborough	Centrica	OPR	G	1993			
UK	Drakemyre CHP	Roche Products Ltd	OPR	G				
UK	Killingholme I	Eon UK Ltd	OP					
UK	Fellside	Fellside heat &						
UK	Deesside II	Inte						
UK	Derwent							
UK	Killi							
UK								

View of the contents of
the Chalmers Power Plant database

The use of the Chalmers Power Plant database

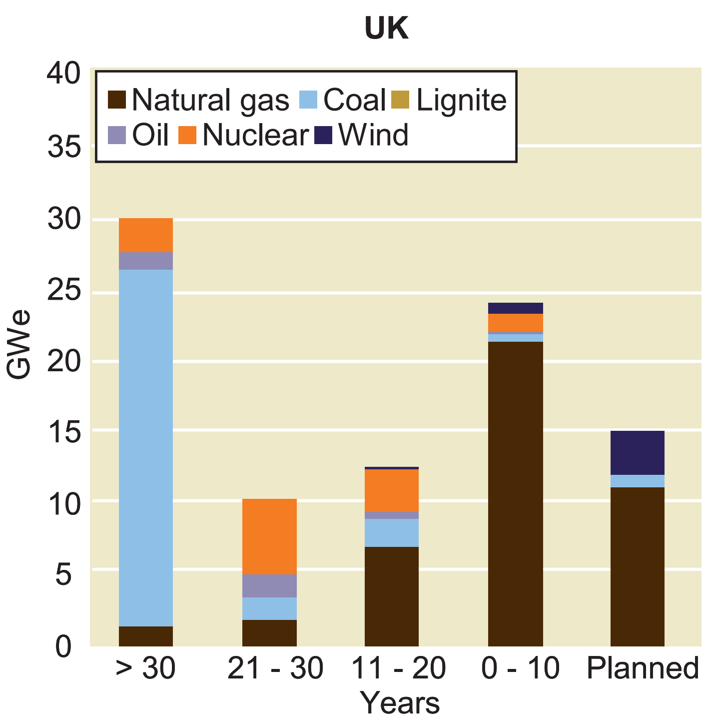
The following chapters will describe the practical use of the Chalmers Power Plant database with the following three case studies:

- Power plant structure in Germany and UK according to the Chalmers Power Plant database
- Biomass co-combustion potential for electricity production in Poland
- Modeling the power generation system - a case study of the UK

Case study 1:
Power Plant Structure in Germany and UK according to the Chalmers Power Plant database

The UK power generation system

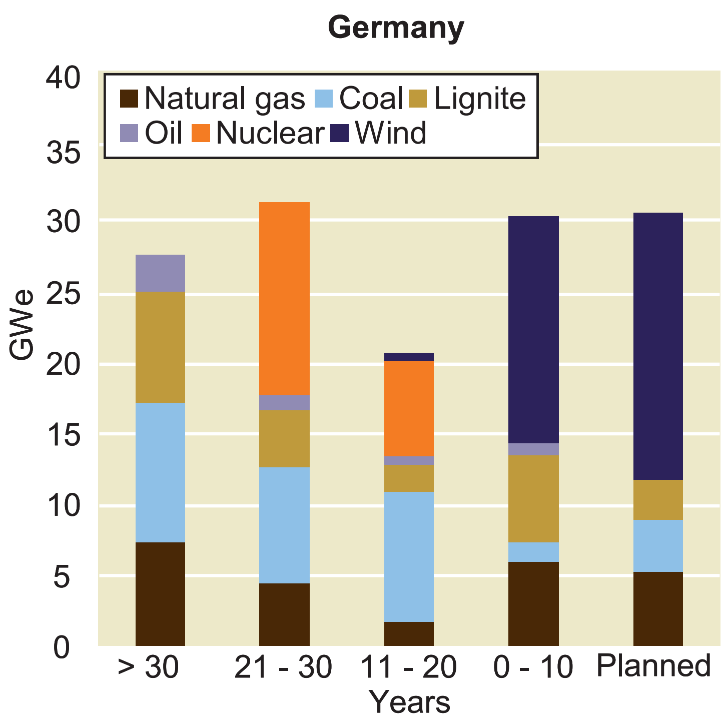
Installed capacity in the UK is divided into nearly 78% fossil, 14% nuclear and almost 8% renewables including pumped storage. Almost 40% of existing capacity is older than 30 years. The figure shows a clear switch to natural gas over the last two decades, as more than three quarters of all commissioned plants during this period are natural gas fuelled and current share of natural gas capacity is around 37%. The shift seems to continue as close to 80% of planned thermal plants are natural gas combined cycles (14.2 GW gas versus 17.8 GW in total net capacity) although the actual commissioning of some of these plants is highly uncertain. Moreover, 85% of all coal plants are older than 30 years, indicating that natural gas will



Capacity of power plants in UK by fuel and age as obtained from the Chalmers Power Plant database become even more dominant if the current trend remains. The figure also indicates that wind finally seems to be taking off in the UK. By mid 2005 UK had around 1.1 GW installed wind power, another 800 MW under construction while projects with an additional capacity of around 2.3 GW had been granted consent and were being planned.

The German power generation system

By the end of 2003 German power plant capacity consisted of 61% fossil, 17% nuclear and 22% renewables including pumped storage. Around a quarter of current thermal capacity is older than 30 years. In contrary to the UK, no switch to natural gas can be observed but commissioned coal and lignite capacity has decreased since 1970 with lowest values between 1995 and 2004, when only 7.5 GW were installed. 13.8 GW coal, 3.7 GW lignite and 11.2 GW gas fuelled capacity is currently under construction or being planned. The most striking feature in the German power plant structure is the significant growth of



Capacity of power plants in Germany by fuel and age as obtained from the Chalmers Power Plant database wind capacity during the last decade with an installed capacity of 18.4 GW by the end of 2005 and the growth seems to continue (see planned plants). However, onshore wind is close to saturation and it is expected that growth in onshore wind capacity mainly will come from upgrading of existing turbines. Thus, the bulk of incremental capacity should arise from offshore installations. According to the Federal Ministry of Environment (BMU) 29 applications covering several hundred wind farms have been handed in by January 2002.

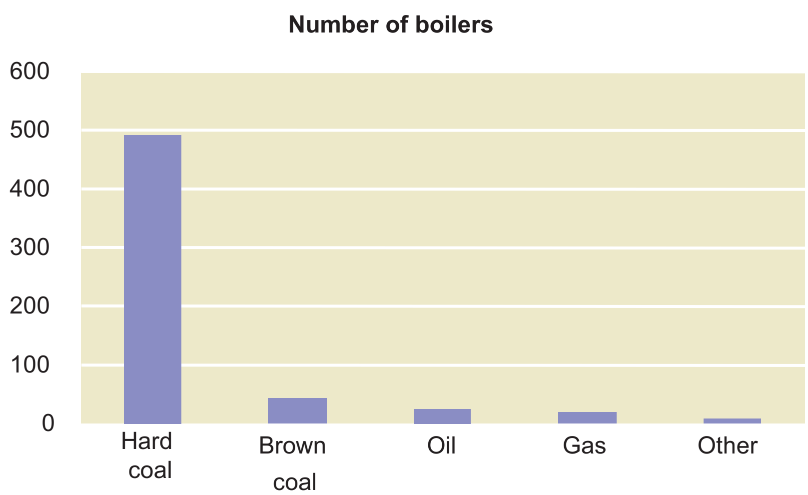
Case study 2:
Biomass co-combustion potential for electricity production in Poland

As part of the EU accession treaty, Poland set out a target to increase the share of renewable energy to 7.5% by 2010 (the share in 2002 was about 2%). Electricity produced from biomass is expected to contribute significantly to that increase. Co-combustion of biomass together with fossil fuels in existing plants has the potential to be implemented at a low cost and over a reasonably short period of time (compared with new installations of biofuelled plants).

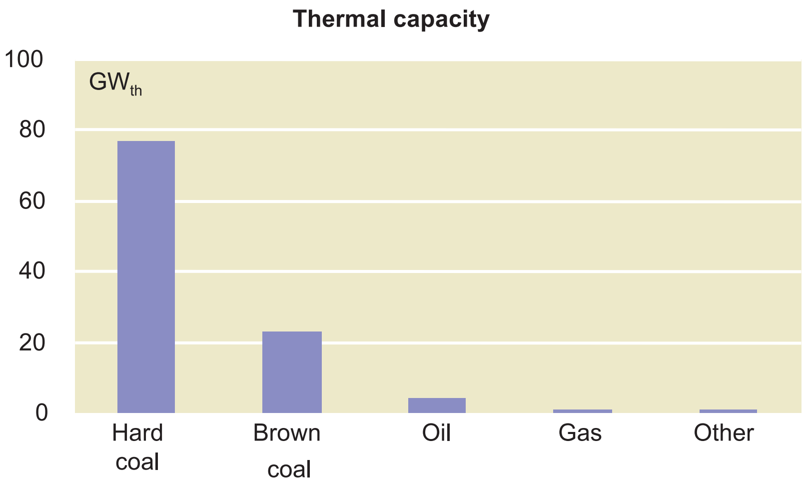
Polish power plant infrastructure

In order to determine the potential for co-combustion, the Polish power plant infrastructure has been investigated by using the Chalmers Power Plant database. The information in the database has also been expanded to comprise the boiler type, including pulverized coal combustion (PC), Grate boiler and Fluidized bed boiler (FB). The investigation clearly shows that the vast majority of the boilers used for electricity production in Poland are PC boilers, both in terms of number and installed capacity. Furthermore, 11 FB boilers and 178 Grate boilers (most of them small, <50 MW_{th}) have been installed.

The Chalmers Power Plant Database provides information about the main fuel used in each boiler. The figures below show the number of



The number of different types of boilers in Poland as obtained by the Chalmers Power Plant database plants using each fuel and the installed thermal capacity for each fuel in Poland. About 92% of the boilers and more than 95% of the installed capacity are fuelled with coal. There is a possibility of using co-combustion in natural gas-fired boilers but this involves gasification of the biomass, which is expensive. Experience from Sweden opens up the possibility of re-powering oil-fired plants for co-combustion of coal and biofuel. Although it is possible to use the oil and natural gas-fired boilers for co-combustion, they have not been considered to offer significant potential for biofuel combustion in this work. The high costs and relatively low installed capacity of these technologies indicate that the focus on implementing co-combustion is applicable mainly in coal-fired plants.



The thermal capacity of different types of boilers in Poland as obtained by the Chalmers Power Plant database

Calculating the technical potential for co-combustion

The term "technical potential" refers to available boiler capacity for burning biomass in co-combustion. From the inventory of the power plants in Poland it was concluded that 233 boilers were less than 30 years old and therefore considered to be economically suitable for co-combustion. To calculate the technical potential of these boilers, the possible shares of biomass in co-combustion have been estimated to the figures presented in the table below:

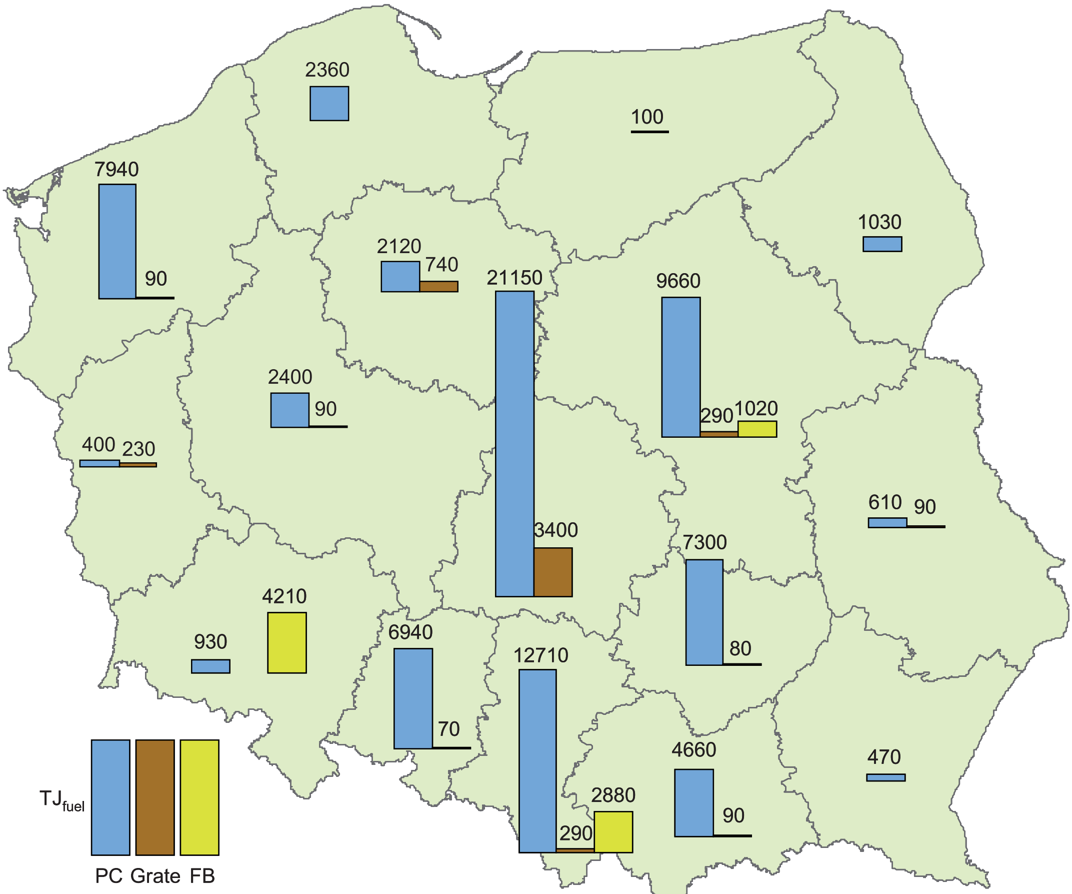
Assumed maximum share of biomass in co-combustion for different boilers as a percentage of biomass on an energy basis

Type of boiler	Wood fuel and energy crops (% on energy basis)	Straw (% on energy basis)
PC-boiler	10	-
Grate boiler	-	10
FB-boiler	15	-

In order to calculate the technical potential in terms of annual electricity generation and fuel use, an average operating time must be estimated. This has been done by using figures from the Central Statistical Office in Warsaw (2004) for installed electricity capacity and annual production in Poland. The average time was calculated at 4,451 hours/year from the 2002 data. This operating time has been used when estimating the production in all boilers. By applying the figures for the maximum share of biomass in co-combustion and the operation time to the 233 boilers, a technical potential for burning biomass is obtained for each region.

.

The result is shown in the figure below. The figure shows that the major capacity is in the central-southern part of Poland and consists mostly of PC boilers. The FB boilers are situated in three regions in south and central Poland. The figure also show that the potential for co-combustion in grate boilers is much lower compared with the PC and FB boilers.



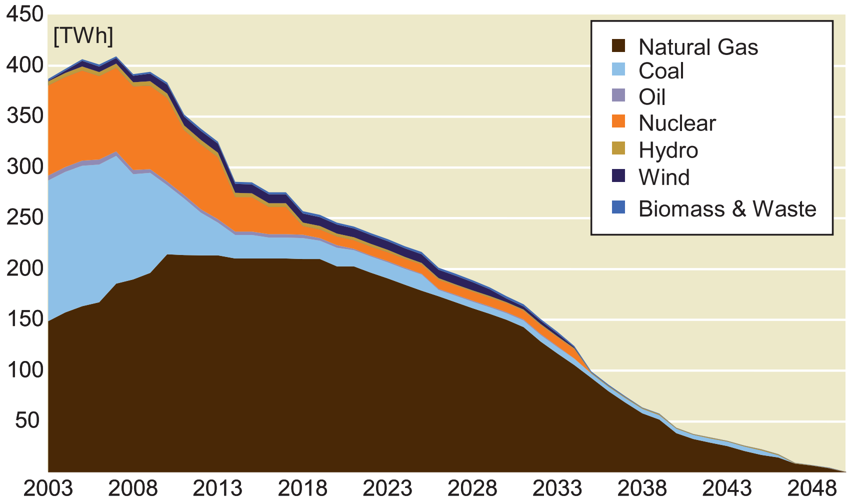
Calculated total boiler capacity for burning biomass in co-combustion with coal in Poland (TJ$_{fuel}$/year)

Case study 3:

A model of the UK power generation system

For the UK, a model has been developed at Chalmers, which determines the development of the power generation capacity based on the Chalmers Power Plant database and a specific scenario for renewable electricity, electricity demand and CO_2-emission reductions. The model gives power generation mix (depending on assumptions), CO_2 emissions and generation costs.

The calculations for the UK start by determining the power generation (GWh) from the existing system. This is done by assuming specific load factors combined with existing production capacities (MW) taken from the Chalmers Power Plant database. This means that for each year the model sums up available production capacity for each fuel type and power plant type defined in the Chalmers Power Plant database. The year of commission and the technical life time for the existing power plants yield the phase out profile of these as exemplified in the figure below.



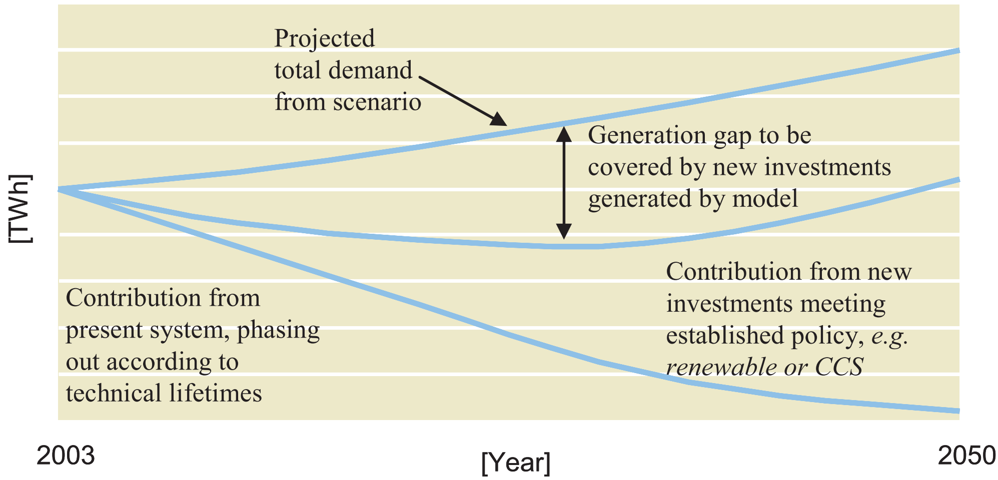
Phase out pattern of present UK electricity generation system (including planned and approved facilities) under influence of assumed technical lifetimes and annual average full load hours

Model description

To determine fuel specific values on equivalent full load hours corresponding to the power plant structure of the Chalmers Power Plant database, generation figures reported to the IEA statistics are divided with the capacity listed in the Chalmers Power Plant database. This method also serves as a calibration of the model in cases of small capacity variations between the Chalmers Power Plant database capacity and the actual capacity. When the available production capacity is known the power generation (TWh) can be determined from estimated full-load hours for each fuel-type category resulting in power generation trends as exemplified in the figure. The existing (Chalmers Power Plant database) and new power generation is divided into the following fuel type categories:

- Fossil-fuel based generation
  - Lignite
  - Hard coal
  - Natural gas
  - Oil
  - Peat
  - Other fossil
- Nuclear generation
- Renewable generation
  - Biomass & waste
  - Wind onshore
  - Wind offshore
  - Run off river
  - Pumped storage
  - Other renewable

The figure below briefly outlines the structure of the model.



Schematic description of the principle of the analysis

A scenario with quantified targets has been constructed for the UK by using the Chalmers Member State database. In short the scenario consists of the following assumptions:

- The target for CO_2-reductions in the UK was first set out by The Royal Commission on Environmental Pollution (RCEP) and later adopted by the UK government. The goal is to reduce the emissions of CO_2 by 60 % in 2050.

- The growth rate in demand is today 0.8 % per year, which is assumed to be the growth rate in total generation until the year 2020. Thereafter the total demand side is reduced to reach 1998 levels by 2050, which is in line with the outset target by RCEP.

- Long term targets on renewable energy supply (RES) are based on potentials in accordance with the projections made by the RCEP

- Targets on gas technologies are based on assumptions from the RCEP prescribing gas technologies will become the choice for backup and peak generation with 88 GW installed capacity generating about 82 TWh of electricity in 2050. Near term targets comprise planned facilities until 2010 taken from The Chalmers Power Plant database. In addition, gas technologies are believed to cover possible shortages between supply and demand until 2050. However, any shortage in 2050 must be covered with carbon free technologies to not offset the cap to be met by the electricity generation sector.

- Nuclear technologies are phased out according the technical lifetimes as given by operating permissions issued by the UK government. New nuclear power is assumed to be the choice of technology to cover possible generation shortage in 2050 to comply with the CO_2-taget.

- It is assumed that no new investments are made in coal- and oil-based technologies.

Modeling results

The outputs from the model are:

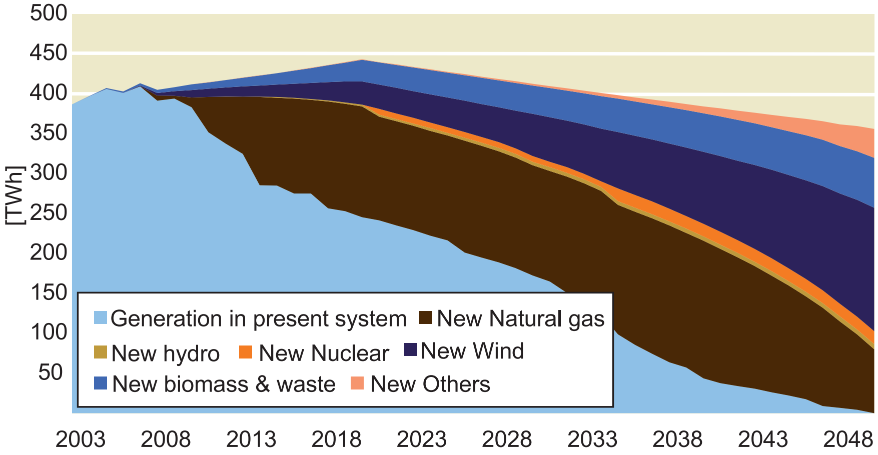
- Power plant mix for each of the UK supply system over thenext 50 year period
- Cost data, e.g. electricity generation cost, system cost and/or CO_2 avoidance cost compared to reference scenario
- CO_2 emissions.

Thus, these outputs will be used to analyze cost effective solutions for CO_2 free electricity production with respect to present and future power plant structure, CO_2 storage and transport infrastructures. Projections and estimates over the period after the year 2020 are associated with great uncertainties. At the same time it is not likely that CO_2 capture will play a significant role in the overall EU power generation prior to 2020. Therefore, the analysis should be of principal nature investigating implications of large scale introduction of CO_2 capture and storage technologies (with special focus on pre-combustion capture technologies).

The modeling results when using the scenario for the UK as described above show that not all of the electricity generation can be covered by RES and gas power during the period including the final target year. However, for this scenario all CO_2 emissions by 2050 come from gas technologies used for backup and peak production. Additional emissions on top of prescribed emissions from gas technologies would offset the target of 60 % CO_2 emission reduction within the overall national energy system by 2050. Hence, to investigate a possible system structure the nuclear facilities are assumed to continue the scheduled phase

out. But also a long term reinvestment target is set to cover the final generation shortage of 16 TWh, *i.e.* nuclear capacities will be reinvested after 2020 to reach and stabilize output of 16 TWh during the last 30 year period. Remaining shortages are covered with gas technologies resulting in a system able to meet both demand and emission targets. The final fuel mix of a system following the outlined scenario and handling shortages as described above is given in the figure below. It can be noted that this pathway gives an increased dependency on gas technologies culminating around 2020 by 75 % of generation coming from gas. This may become difficult to synchronize with policy targets for security of supply.

The same calculations will be performed for each EU member state and then aggregated to an EU level. Thereby, sustainable pathways for the European power generation system can be outlined.



UK electricity generation according to set targets and supply shortage handling with nuclear and gas technologies

The main features of

The Chalmers Fuel database

Aim of the database

The aim of the Chalmers Fuel database is to track future global production capacity for oil, gas and coal, current and future capacity of the transport infrastructure as well as contracted transport flows, i.e. according to committed gas sales and purchase agreements.

Contents of the database

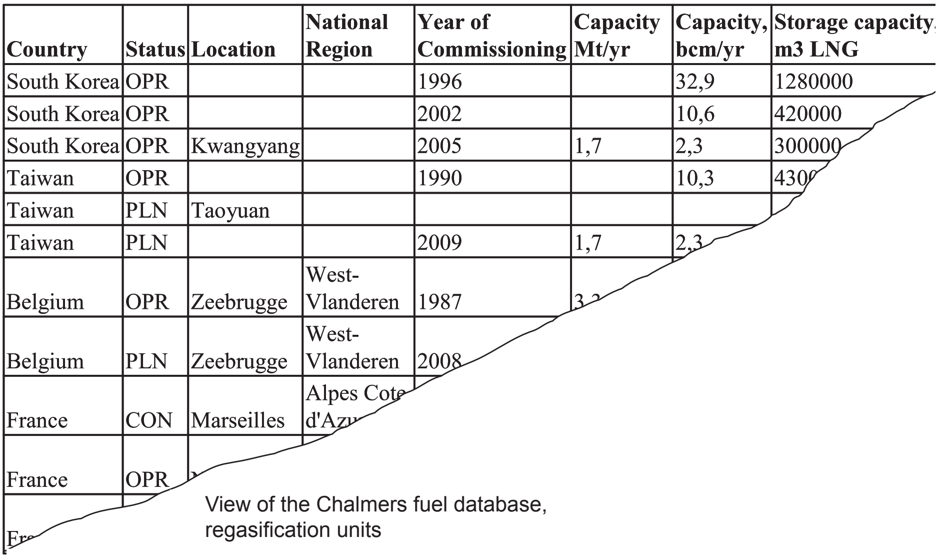
- Global coverage
- Is designed to describe future oil and gas production capacity as well as gas transport capacity including LNG
- Contains gas fields producing at least 100 mmcf/d and oil fields producing at least 1 kbl/d
- Contains production history, remaining and ultimately recoverable reserves, OOIP and GIIP
- Contains most gas and oil discoveries back to year 2000 and tracks the field throughout their lifetime
- Contains all LNG plants and regasification terminals including capacity along with current operating status
- Contains major global and national European pipelines
- Contains gas sales and purchase agreements
- Contains all coal fields within the EU
- Diversifies between onshore, shallow water, deep water and ultra-deep water fields
- Separates OPEC countries from other oil-producing countries
- Includes country specific oil and gas production, consumption and reserves history as quoted by O&GJ and BP annual statistics

Gas and oil fields	Coal fields	Pipelines	LNG plants and regasification terminals	Gas storage facilities	Gas sales and purchase agreements
Status	Status	Commissioning year	Status	Status	LNG SPA's Global coverage
Location, 4 different levels	Location, 4 different levels	Exit and entry point	Location, 4 different levels	Location, 4 different levels	Pipe SPA's European and FSU coverage
Production	Production	Flow rates	Capacity	Total storage capacity	EU external and internal agreements
Water depth	Type of coal	Diameter and length	Commissioning year	Working gas capacity	Length of agreement
Economic and geologic reserves	Economic and geologic reserves	Buying/ Dispatching Country/ Global Region	Connection between LNG plants and re-gasification terminals	Injection capacity	Buying /Dispatching Country/ Global region
Production capacity	Coal heating value	Operator/ owner	Storage capacity	Withdrawal capacity	Start and end year of agreement
Cumulative production	Operator				Contract price
Field classification					Take or Pay (ToP) level
Subsurface depth					Volume
Discovery year					
Production start-up year					
Operator					
Degree API					

The contents of the Chalmers Fuel database

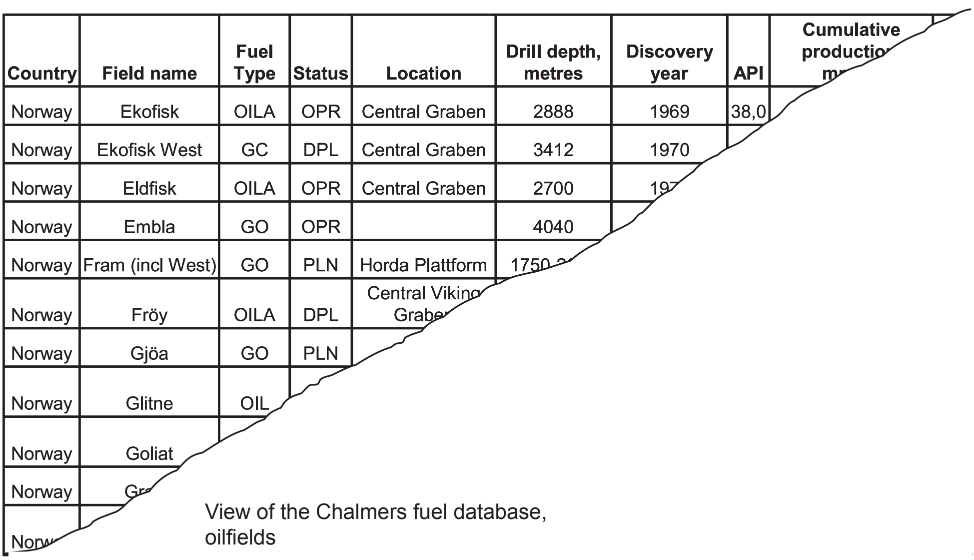
Current status

The Chalmers Fuel database is today ready to use with a global coverage of all vital gas and oil fields, LNG plants and regasification terminals. Current work is focused on integrating coal fields and coal supply infrastructure as well as gas storage sites with the database. Samples of the database can be seen below.



Country	Status	Location	National Region	Year of Commissioning	Capacity Mt/yr	Capacity, bcm/yr	Storage capacity, m3 LNG
South Korea	OPR			1996		32,9	1280000
South Korea	OPR			2002		10,6	420000
South Korea	OPR	Kwangyang		2005	1,7	2,3	300000
Taiwan	OPR			1990		10,3	430
Taiwan	PLN	Taoyuan					
Taiwan	PLN			2009	1,7	2,3	
Belgium	OPR	Zeebrugge	West-Vlanderen	1987	3,		
Belgium	PLN	Zeebrugge	West-Vlanderen	2008			
France	CON	Marseilles	Alpes Cote d'Azu				
France	OPR						
Fr							

View of the Chalmers fuel database, regasification units



Country	Field name	Fuel Type	Status	Location	Drill depth, metres	Discovery year	API	Cumulative productio
Norway	Ekofisk	OILA	OPR	Central Graben	2888	1969	38,0	
Norway	Ekofisk West	GC	DPL	Central Graben	3412	1970		
Norway	Eldfisk	OILA	OPR	Central Graben	2700	197		
Norway	Embla	GO	OPR		4040			
Norway	Fram (incl West)	GO	PLN	Horda Plattform	1750			
Norway	Fröy	OILA	DPL	Central Viking Grabe				
Norway	Gjöa	GO	PLN					
Norway	Glitne	OIL						
Norway	Goliat							
Norway	Gr							
Norw								

View of the Chalmers fuel database, oilfields

The use of the Chalmers Fuel database

Case study: The European Gas Market

Literature gives various reports and papers related to the development of the natural gas market globally and within Europe. Still, there is a lack of studies based on a detailed description of the current and planned natural gas infrastructure combined with an analyze of the energy system with infrastructural limitations and possibilities. In order to understand the prospects of increased use of natural gas in the EU and to evaluate various pathways for the EU energy system, the global gas market must be understood with respect to development of the power generation sector, where the main growth is expected to occur, infrastructural constraints, financing and future price of natural gas. This analysis has been made successfully by the use of the Chalmers Power Plant and Fuel databases.

Name	Dispatch country	Receiving country	Status	Capacity, bcm/yr	Diameter, inch	Length, km	Lifetime	Inv
Franpipe	Norway	France	OPR	19.0	42	840		
Frigg transport	Norway	UK	OPR	13.9				
Europipe 1	Norway	Germany	OPR					
Europipe 2	Norway	G						
Norpipe								

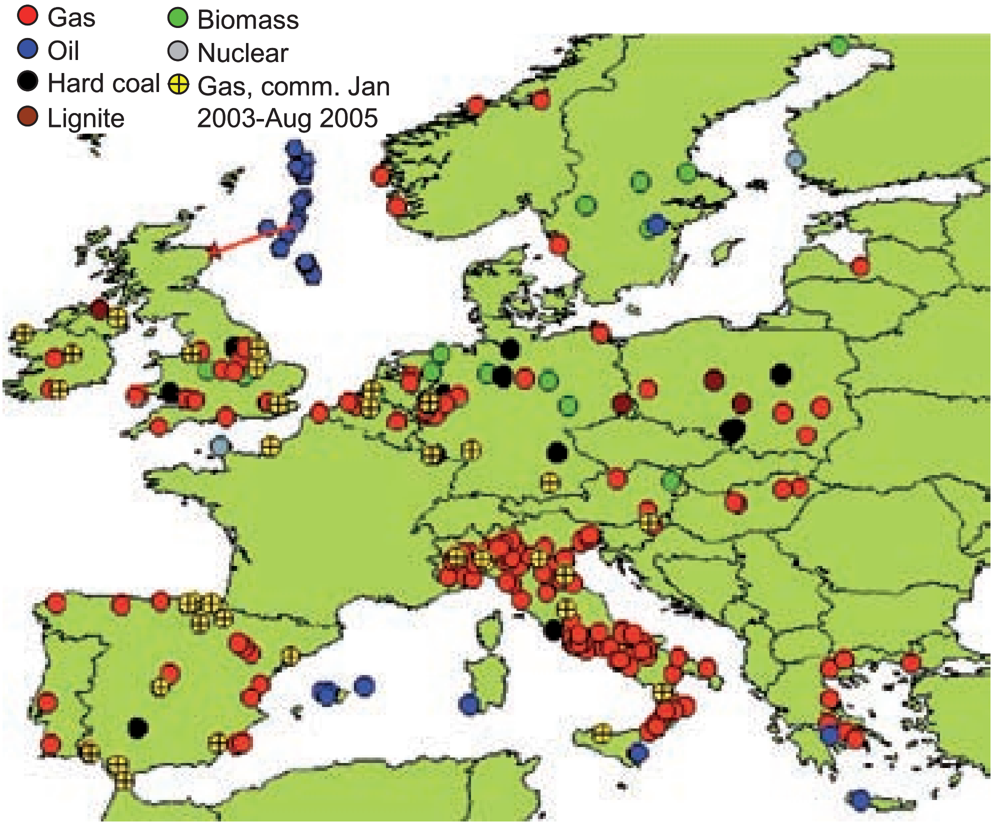
View of the Chalmers fuel database, pipelines

The Power Generation Sector

The increased use of gas as a fuel in the power generation sector over the last decade can be observed from the capacity of existing and planned thermal power plants (a figure is shown in chapter “The Chalmers Power Plant database”). The data for this study is taken from The Chalmers Power Plant database, which shows that there are currently 129 GW fossil fuelled power plants either under construction or planned within the EU, of which 97 GW will be fuelled by natural gas. However, for some regions in the EU, a number of large gas plants have been planned for several years, but without any indication of actual implementation (e.g. the 1.2 GW Lubmin Combined Cycle Gas Turbine (CCGT) in Germany and the 1 GW Fleetwood CCGT in the UK).

Some additional projects will probably emerge from now and up to 2010, adding another few GW gas capacity but at the same time around 5 GW will have reached 40 years lifetime indicating that they will be decommissioned in the near future. Thus, it seems as if only 40 to 45 GW net gas capacity will be added up to between 2005 and 2010.

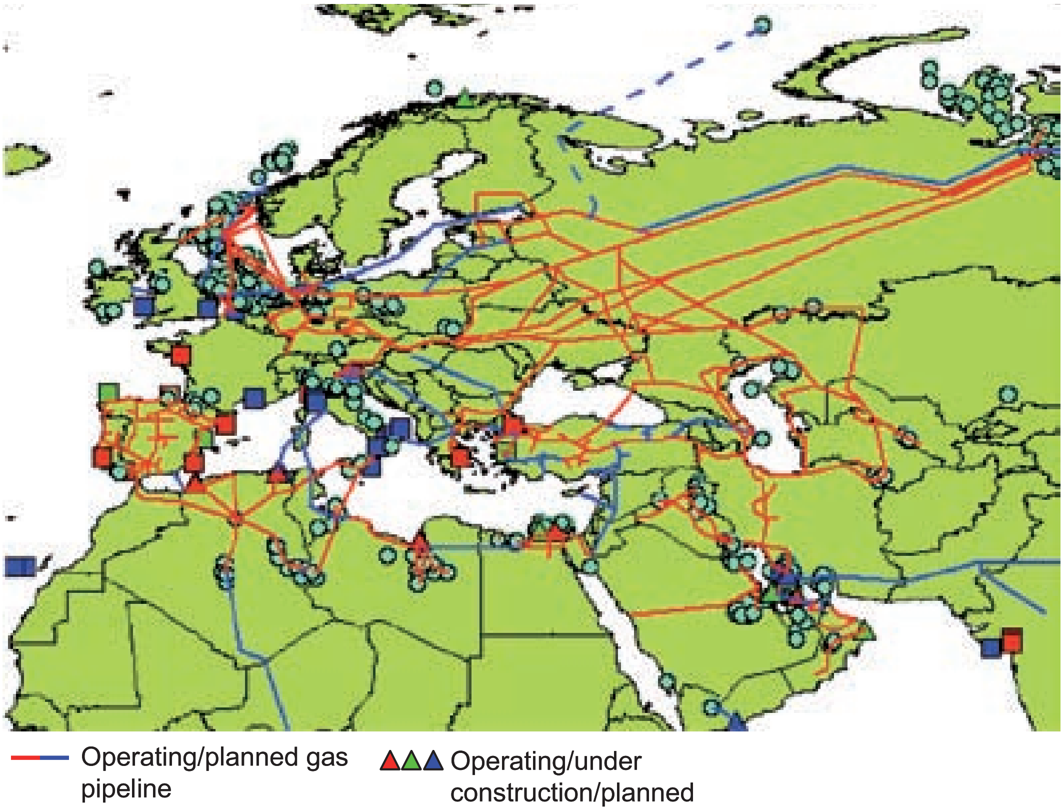
The map on next page shows planned power plants in Europe distributed by fuel as well as commissioned gas fuelled plants between January 2003 and August 2005. Also shown is an imaginary CO_2 pipeline for injection into the Miller oil field.



Capacity distributed by fuel for planned thermal plants in the EU-25 as obtained from the Chalmers Power Plant database (Kjärstad and Johnsson, 2004). The red arrow illustrates a proposed CO_2 pipeline.

The structure of the gas market

The Fuel database gives information about gas pipelines, LNG plants and regasification units in the world. The map on the next page shows existing and planned gas pipelines into the EU as well as planned pipelines that will affect the EU supply, like the Mediterranean ring along the coast of North Africa, the proposed NIGAL pipeline from Nigeria to Algeria connecting to the existing Algerian network at In Salah and the Iran-Pakistan-India pipeline. Also shown are the European regasification terminals (squares), LNG plants (triangles) as well as main gas fields for the EU supply (light blue circles). Red illustrates operating units, green corresponds to units under construction while dark blue illustrates planned units. Note that the map does not show exact pipeline routes for Russian pipelines entering into Ukraine.



Gas pipelines, LNG units and regasification terminals together with major gas fields for the EU supply. From Chalmers Fuel database

Year 2003, the annual (technical) EU import capacity was around 360 bcm, which relative to 2002/03 imports gives an import capacity-to-import ratio of 1.5. In order to maintain the ratio at 1.5 relative to the supply gap as projected by IEA, the EU will need an import capacity of around 510 bcm by 2010 followed by the requirement to add another 22 bcm *annually* in average between 2010 and 2030. The table on next page shows existing and planned import projects that are expected to enter into operation by 2011. Pipeline capacity is shown by dispatch country while LNG capacity is shown according to exit country. Only three of the proposed Italian re-gasification terminals have been included under the assumption that these terminals are the terminals most likely to have been commercialized by 2011. These are: the Brindisi terminal and the GNL Adriatico terminal *two* of the three proposed terminals by Shell and Gas Natural. The Galsi, Nabucco, and NEGP 1 pipelines from Algeria, Turkey/Iran, and Russia respectively have all been included.

Existing and planned pipeline/gasification capacity (technical) into the EU-25, bcm/yr (from Chalmers Fuel Database)

Entry points pipe:	Existing	Under construction	Planned	Total
Algeria	35.3	8.0	14.5	57.8
Libya	8.0	-	0.0	8.0
Norway	108.2	35,5	0.0	143.7
Russia*	183.00	27.5	19.0	229.5
Turkey	-	3.5	28.0	31.5
Total Pipes	**334.5**	**74.5**	**61.5**	**470.5**
Exit points LNG:				
Belgium	4.6	-	4.6	9.2
France	15.5	8.2	-	23.7
Greece	1.9	-	3.4	5.3
Italy**	3.7	16.0	16.2	35.9
Netherlands	-	-	20.1	20.1
Portugal	4.1	-	-	4.1
Spain	26.7	10.4	3.6	40.7
UK***	4.4	16.9	24.4	45.7
Total LNG	**60.9**	**51.5**	**72.3**	**184.7**
Total Pipes +LNG	**395.4**	**126.0**	**133.8**	**655.2**

Note: The table includes only those projects that have been considered likely to enter into operation by 2011
Planned Pipelines Algeria: Includes expansions on existing pipes plus Galsi
Pipelines under construction Norway: Langeled and Tampen Link
Planned Pipelines Russia: New pipeline through Ukraine
Planned Pipelines Turkey: The Turkey-Greece-Italy IC plus Nabucco supplying 20 bcmpy to Austria
Planned LNG Italy: Includes the Brindisi, Taranto and Augusta LNG terminals
Planned LNG Spain: Includes two smaller terminals on Canary Islands
* There is large uncertainties related to real Russian transport capacity into EU, according to IEA “Security of gas supply in open markets” the system through Ukraine has a theoretical capacity of 170 bcm of which 135 bcm is dedicated to central and western Europé. In addition the Yamal pipeline has a capacity of 33 bcm while it has been estimated that the pipelines into Finland, Latvia, Estonia and Lithuania can carry around 15 bcm annually
** There is currently at least 10 terminals with a combined capacity of 70 bcmpy under planning in Italy
*** Even UK has a number of additional LNG terminals under planning but capacity and timing is not yet clear

From the table above it can be concluded that the EU import capacity probably will exceed 510 bcm with good margin by 2011. However, provided all projects in the table enter into operation by 2011, another 80 bcm import capacity will still have to be added to the 655 bcm between 2010 and 2020 and a further 220 bcm during the following decade in order to maintain the capacity ratio at 1.5.

Conclusions

It can be concluded that the EU gas demand is expected to increase rapidly up to 2010 driven foremost by the power sector in Southern Europe. At the same time the EU gas-import needs will increase at a faster rate than the demand due to declining production in Northern Europe, most notably in the UK. The evolvement of gas demand in the power sector after 2010 will to a large extent depend on the level of further CO_2 emission restrictions after 2012, the future of nuclear power, and the possibility of storing carbon dioxide in subsurface reservoirs. It seems that these factors together with barriers to rapid deployment of renewable technologies force the EU member states into a high dependency on natural gas, counteracting security of supply, both with respect to increased dependency on imported gas and on increased dependency on gas as fuel for power generation.

Still, there will be ample supplies of natural gas in the foreseeable future. Although Algeria, Norway, and Russia will continue to be main suppliers in the short-term a number of countries will substantially increase gas exports to EU, both in the short- and medium-term. The increased competition, signs indicating that the EU gas market may be oversupplied between around 2007 and 2012, the competitiveness of Algerian and Norwegian gas on the main growth markets as well as a number of problems in the Russian gas industry will possibly lead to a situation where Russia looses market shares at least in the short-and medium-term. In the longer-term, i.e. after 2020, it is expected that Qatar and Iran will emerge as major suppliers together with Russia.

The main features of

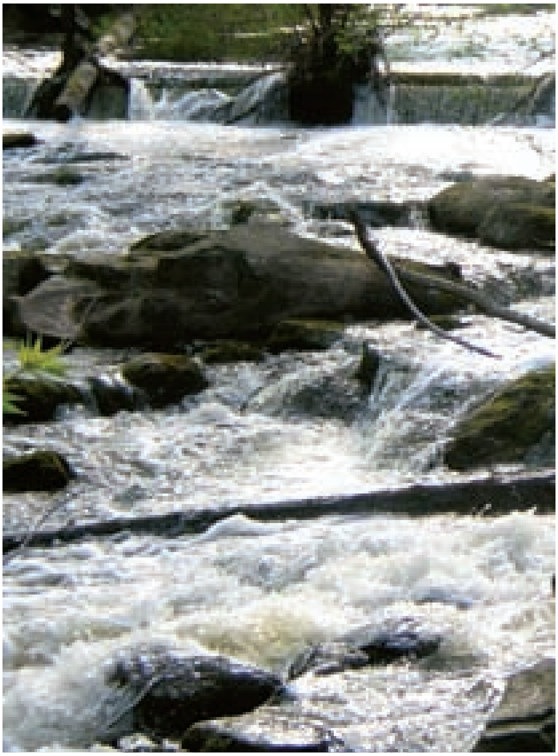
The Chalmers CO_2 Storage database

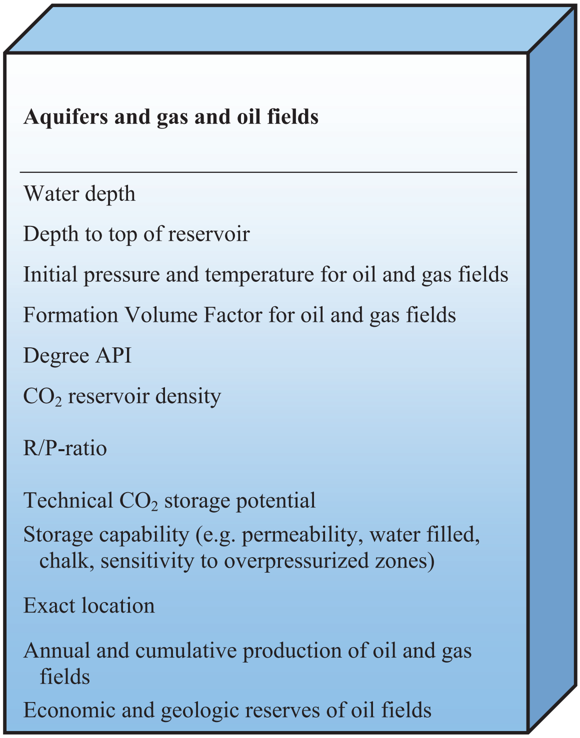
Aim of the database

The aim of the Chalmers CO_2 Storage database is to describe all potential CO_2 storage reservoirs in order to integrate these data with the Power Plant database. This enables modeling of Carbon Capture and Storage (CCS) as a bridging technology towards a sustainable European power generation system.

Contents of the database

- Comprises the EU, Norway and Switzerland
- Contains aquifers and gas and oil fields
- Includes a large number of site specific storage parameters
- Includes exact location and, if available, annual and cumulative production and economic and geologic reserves.





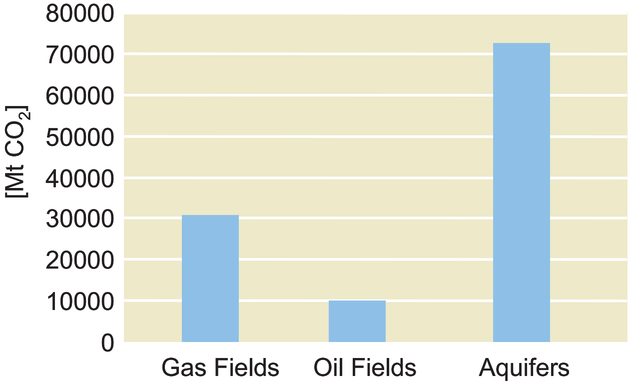
The contents of the Chalmers CO_2 storage database

Current status

The Chalmers Storage database currently contains 852 aquifers, gas and oil fields, which represent currently identified sites with a potential of at least 1 million tonne CO_2 in EU and Norway. The quality of the data in the database is high for reservoirs located in and around the North Sea area but deteriorates as we move southwards due to lack of data.

There has been attempts to collect data on reservoirs in the 10 new member states (Latvia, Lithuania, Poland, Slovakia, Cyprus, Czech Republic, Slovenia, Malta, Estonia and Hungary), which has proven to be a difficult task as little has been done in these countries with respect to mapping of potential subsurface CO_2 storage sites.

The figure and table on next page summarize the technical storage potential presently available in the Chalmers Storage database. The figure gives the technical storage potential in gas and oil fields and in aquifers in EU and Norway south of 76^{o}N while the table shows the same storage potential divided into onshore and offshore storage distributed by country.



Known trapped storage potential in EU and Norway south of 76ºN distributed by reservoir type

Known trapped storage potential in EU and Norway south of 76ºN by country

	Onshore (Mt CO_2)	Offshore (Mt CO_2)
Austria	89	0
Belgium	100	0
Denmark	13153	4854
France	1849	0
Germany	25814	65
Greece	859	1369
Ireland	0	407
Italy	1438	979
Netherlands	10699	
Norway	0	21672
Poland	300	0
Spain	1466	73
Sweden	0	1610
UK	312	30041

The methodology to calculate storage potential

For oil and gas fields it is assumed that the volume of oil and gas produced under primary, secondary and tertiary recovery can be entirely replaced by CO_2. The formation volume factor is used to calculate the volume occupied by oil and gas under reservoir conditions while initial pressure and temperature of the reservoir is used to calculate CO_2 reservoir density.

For aquifers the storage potential and the methodology adapted will depend on whether the aquifer is completely closed or open. First however, the aquifers total volume is calculated by multiplying surface area with an assumed average internal height of the aquifer. Secondly, the volume occupied by porous rocks is calculated by multiplying the entire aquifer volume by the so called Net/Gross ratio and thirdly, the pore volume is calculated by multiplying the volume occupied by porous rocks with the porosity. None of these parameters are usually known, apart from regions where intensive oil and gas prospecting has been conducted. Neither are the distribution of these parameters known for the largest aquifers. Details concerning the distribution of permeability within the aquifer or whether the aquifer is regionally compartmentalised are other parameters that are not known at the present.

Further calculations are needed to calculate the storage potential once the pore volume has been derived. If the aquifer is closed the storage capacity of the entire aquifer is calculated based on a storage efficiency of 2% or, if it is open, a storage efficiency of 6%. This means that 2% or 6% of the pore volume in open or closed reservoirs respectively can be filled with CO_2. The trapped storage potential is calculated by assuming that 4% of the pore volume can be filled with CO_2 and that 3% of the aquifer volume is in a trap.

Hence, a critical parameter for the derived storage potential is the asssumptions made on storage efficiency and additionally, for trapped storage potential, the assumptions made on trapped pore volume.

Uncertainities in the calculations

Difference in estimates of most of the above mentioned parameters has led to that the storage potential in Norwegian aquifers south of 62ºN today has been reduced by nearly 75% relative to earlier studies, from 476 billion tons to 123 billion tons assuming storage to take place in the entire aquifer, i.e. not trapped.

Other factors that may affect storage potential for all types of reservoirs are the depth of the reservoir, whether they are chalk reservoirs, if they are already water filled and if they have sufficient permeability. In the case of the North Sea, the distribution of extremely high pressure close to the fracture pressure in deeper strata (Jurassic and Triassic) may further affect the storage potential.

View of the database

The figure below gives a view of the Chalmers CO_2 Storage database. In all, the database contains more than 40 columns of information regarding the storage potential in aquifers and oil and gas fields. The information is gathered in an accessible database wherefrom information is being exported to other models for simulations etc.

Reservoir Classifi-cation	Field name	Status	Country	Location	Reservoir Age	CO2 density	Trapped storage potential Mt	Aquifer volume km3
AQF	Bunter Sandstone 1/41		UK	TEXT	Triassic	100,7	48,7	
GAS	Amethyst East, West	OPR	UK	Southern Gas Basin	Rotliegend	692	51,1	
GAS	Ann	OPR	UK	Southern Gas Basin	Rotliegend	674,2		
OIL	Angus	OPR	UK	Central Graben	Upper Jurassic	800		
GAS	Annabel	PLN	UK	Southern Gas Basin				
GAS	Alison, Alison KX	OPR	UK	Southern Gas Basin	Perm			
GAS	Anglia	OPR	UK	Southern Gas Basin				
OIL	Andrew	OPR	UK	M				
AQF	Beatrice		UK					
AQF	Brae							
AQF	Brent UK							
AQF	Bri							
OI								

View of the content of the Chalmers CO_2 storage database

The use of the Chalmers CO_2 Storage database

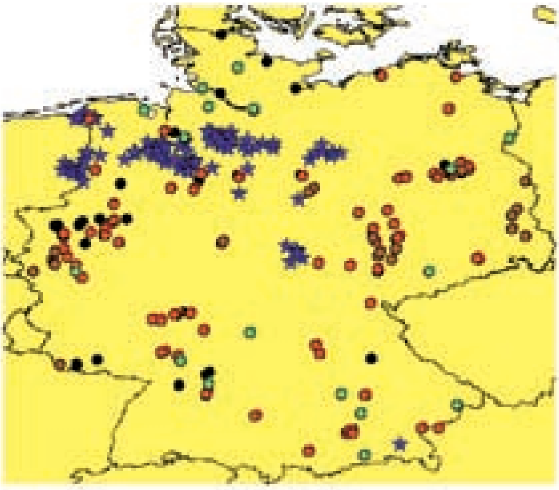
The chapter below will describe how the Chalmers CO_2 Storage database can be used together with the Chalmers Power Plant database in order to analyze possible regions where CO_2 capture and storage can present a realistic option to reduce CO_2 emissions from power production.

Case study: Storage of Carbon Dioxide

It should be underlined that storage potential is different from the actual storage capacity. As our knowledge of individual reservoirs improves, the storage potential may decrease. Storage potential in UK aquifers may decrease significantly compared to previous estimates as large parts of the potential are based on storage in chalk reservoirs and as large areas of the North Sea have significant overpressure in reservoirs below upper cretaceous, close to the fracture pressure. The same reductions but for other reasons may be observed for gas and oil fields like it has been observed in Forties, Hewett, Gullfaks and Frigg.

Germany

The German offshore storage potential is not known. Only one offshore oil field exists, the Mittelplatte field, which may store around 30 Mt CO_2 based on recoverable reserves of 36 million m^3 oil, a formation volume factor of 1.1 and a CO_2 reservoir density of 710 kg/m^3. Similarly, CO_2 storage in onshore oil fields will be limited due to the modest size of German oil fields. A recent estimate of storage potential in onshore aquifers based on regional studies gives the range of 10 to 40 Gt in closed (trapped) structures. The estimate is associated with a large range of uncertainties, and as with North Sea aquifers, it is based on estimated average values for a large range of parameters including for instance a storage efficiency of 40%. Storage in gas fields has one large advantage compared to storage in aquifers: the integrity of the seal has been intact for millions of years. In addition, it may create an opportunity to carry out the world's first attempt on CO_2 Enhanced Gas Recovery (EGR). A total of 95 German gas fields are registered in the Chalmers Storage database, with a total gross storage potential of 2.6 Gt based on cumulative production figures. However, at least 24 of the gas fields are located at depths of 3500 meters or more. Furthermore, some of the fields are tight gas fields with very



German onshore gas fields (blue stars) and fossil plants (dots). Source: Chalmers Power Plant and Fuel databases

low permeability, like the Söhlingen field located at a depth of 4800 metres with an estimated storage potential of 114 Mt CO_2.

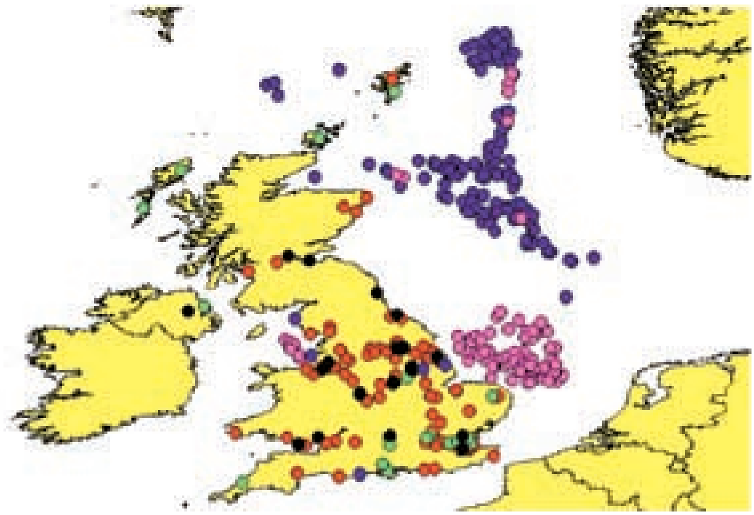
The feasibility of EGR has been examined in the Altmark gas reservoirs as a part of the EC-funded CO_2STORE project. The Altmark fields consist of 9 "soon to be depleted" gas fields with an estimated storage potential of 660 Mt based on cumulative production figures. Storage in aquifers in the North German basin combined with capture at the 1.6 GW (gross) Schwarze Pumpe lignite power plant is also investigated in the CO_2STORE project.

The bulk of German gas fields are located in the North German basin, relatively close to the bulk of German coal and lignite power stations. For instance in the north eastern parts of Germany there is around 12 GW net baseload capacity located between 200 and 300 km from the Altmark gas fields. Estimated annual emissions from these power plants are between 85 and 95 Mt CO_2. Similarly, in the north western parts of Germany, west of the Weser river in Niedersachsen, there are more than 30 gas fields with a total storage potential of around 1100 Mt. These are all located within 200 to 300 km from around 13 GW coal and 11 GW lignite-fuelled baseload power plants in Nordrhein-Westfalen with estimated annual emissions between 170 and 190 Mt CO_2. Trunk pipelines collecting emissions from the power plants in these two regions for storage in gas fields and aquifers may provide a substanXXX CO_2 reduction potential for Germany. This does not necessarily mean that we believe that capture primarily will take place at existing plants but rather that we believe that future plants to a large extent will be located on existing plant sites. However, it should be noted that public acceptance may present a barrier to onshore storage of CO_2.

UK

UK has a large storage potential in subsurface reservoirs although recent papers reveal that the UK storage capacity may decrease over time. The technical offshore storage potential in the UK is estimated to around 6 Gt in gas fields, 4 Gt in oil fields and 20 Gt trapped within aquifers, of which 14.3 Gt in 29 structures within the Bunter sandstone just off the coast in the Southern North Sea basin. Given that the entire aquifer volume can be utilized, the CO_2 storage potential in the UK has been estimated to 240 Gt (Joule II, 1996). The most promising near-term storage option in the UK may be Enhanced Oil recovery (EOR). The Department of Trade and Industry (DTI) estimates a storage potential through CO_2 EOR of around 700 Mt CO_2 over 20 years. There are, however, a number of factors that may complicate EOR in the North Sea.

Firstly CO_2 is corrosive when dissolved in water. Most existing facilities are not designed to handle that, and re-designing is not always feasible. Secondly, EOR needs to be implemented on a large number of fields, with different sizes and which are distributed over a large area. The CO_2 demand profile will depend on time of depletion for each field and, for some fields, decrease over time caused by reinjection of CO_2 (Water Alternating Gas-schemes). Since pipeline flow rates influence transport costs, logistics will be essential for the economics of EOR in the North Sea. The most cost-effective solution will probably be a trunk pipeline to a large field like Forties which then will be divided into several smaller pipelines serving smaller surrounding fields. Any surplus gas could be injected into nearby aquifers.



UK fossil plants and offshore gas (purple dots) and oil fileds (blue dots).
Source: Chalmers Power Plant and Fuel databases

The main features of

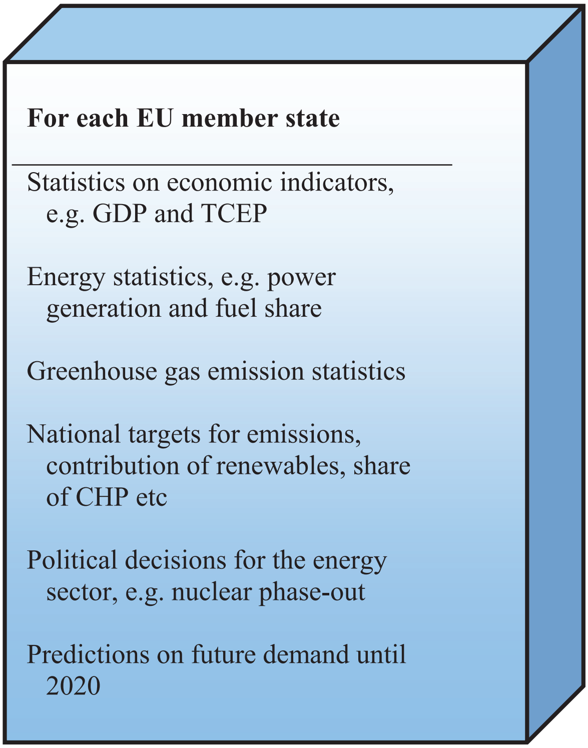
The Chalmers Member State database

Aim of the database

The aim of the Chalmers Member State database is to identify and evaluate political decisions and targets for the energy sector within the EU. The Member State database also integrates data from the supply side databases (the Chalmers Power Plant, CO_2 Storage and Fuel databases) and presents a projection of future fuel distribution within the power sector.

Contents of the database:

- Comprises the EU
- Designed to project a realistic future fuel distribution within the power sector down to a national level
- Compiles and evaluates major energy related political decisions, both on a national and EU level, e.g. the nuclear phase-out announced by some member states and the LCP directive
- Identifies and evaluates major energy related development paths
- Identifies and evaluates major energy related infrastructural constraints, e.g. that western parts of Denmark are experiencing balancing problems due to a large contribution from wind power and decentralized generation
- Contains key energy related statistics such as power generation and fuel mix
- Projects a ”realistic” future fuel distribution within the power sector down to a national level based on the aforementioned input



The contents of the Chalmers Member state database

Current status

Today the Chalmers Member State database contains information regarding each member of the EU. However, as political decisions and targets will always be renewed, the database needs to be constantly updated. These updates will preferably occur whenever the scientists at the Chalmers University need current information about a certain country.

The data in the Member State database has been compiled from national statistics along with data from utilities, transmission system operators in the gas and power sector, and gas transport/ distribution companies.

The information in the database is divided into two parts, where the first contains policies, aims and statements made by the national governments and the second part contains figures for power generation, emissions etc.

For example, the headings in the Member state database for the UK are the following:

Policies, aims and statements	Statistical figures

• Basic indicators
• Electricity
• Emissions
• Plants structures
• Interconnectors
• Politically designed scenarios and political framework
• Renewables
    • Wind power
    • Biomass
    • Hydro
    • Emerging technologies
• CO_2 storage
• Defined main uncertainities
• Recommended action
	• Historical primary energy consumption
	• Historical national green house gas emissions
	• Historical green house gas emissions from power stations
	• National production capacity
	• Historical power generation from renewables
	• Yearly targets for renewable energy production
	• Historical energy production
	• Historical energy import and export
	• Scenarios for green house gas emission reductions
	• Scenarios for future energy production
	• Projected future energy demand
	• Projected future fuel share in energy production

The use of the Chalmers Member State database

The scientists at Chalmers have used the Chalmers Member State database in their work to develop future scenarios for the power generation sector in different countries. By first using the information in the Chalmers Power Plant database to construct the current energy system, the scenarios can then be used for evaluating the development of the system. An example of this method was described in the chapter "The use of the Chalmers Power Plant database – A model of the UK power generation system". Below another example will be given that begins with the description of today's German and UK power generation system previously described in the chapter "The use of the Chalmers Power Plant database – Power plant structure in German and UK according to the Chalmers Power Plant database".

Case study:

The future power generation system in Germany and UK

The Chalmers Power Plant and Member State databases are applied in simulating development of the German and the UK power generation systems with respect to phasing out of existing generation capacity, fuel mix, fuel dependency, CO_2 emissions and the role of CO_2 storage under stringent CO_2 emission constraints up to 2050.

Long-term development of energy demand is difficult to forecast and the approach here is therefore to use previously developed forecasts of growth rates in power production. These growth rates are in line with those used for global and regional energy forecasts by IIASA/WEC energy scenarios and IEA WEO 2004. The analysis is based on the following four scenario assumptions:

- Moderate (MOD) with an average annual growth rate between 2003 and 2050 of 0.1%.
- Moderate Coal (MOD Coal) with the same growth rate as above.
- Medium (MED) with an average annual growth rate between 2003 and 2050 of 0.6%.
- Business as usual (BAU) with an average annual growth rate between 2003 and 2050 of 1.0%

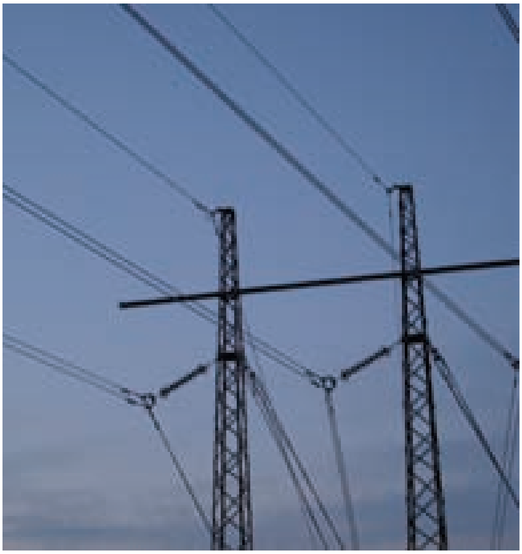
Further important assumptions are:
A maximum realistic penetration level of renewables based on national targets and strategic national reviews (denoted ”realistic maximum”). All targets are relative to the LOW-scenario.

- For Germany this implies:
  - 12.5% of generation by 2010 as stated by the Federal Government, 20% by 2020 and 50% by 2050 as proposed by BMU.

- For the UK this implies:
  - 10% of generation by 2010, 15% by 2015 as proposed by the UK Government and 20% by 2020 as suggested by the Performance and Innovation Unit (PIU). The further deployment of renewables in the UK up to 2050 is based on the 60% CO2 reduction target set out by the AEA Technology in “Options for a low carbon future”.

Decommissioning of current generation of existing thermal plants is made by applying calculated average load factors for each fuel type based on 2004/05 capacity and production figures and according to:

- Fossil plants commissioned 1967 or earlier are decommissioned in 2008.
- Fossil plants commissioned 1968 or later have been decommissioned in their 41st year.
- Coal and oil plants in the UK:
  - 12.3 GW net capacity is assumed to operate under the ELV regime with a prolonged lifetime to 2025.
  - 8 GW is assumed to choose the opt-out option generating 20000 hours between 2008 and 2012 expecting higher carbon penalties after 2012.
  - Remaining coal based capacity operating under the NERP regime plus all oil plants are assumed to be shut down in their 41st year, beginning in 2008.
- Nuclear plants in Germany:
  - According to remaining residual generation for each plant divided by plant specific average annual generation between 2000 and 2004.
- Nuclear plants in the UK:
  - Phased out according to announcements made by the utilities. Dungeness B is decommissioned in 2019 in accordance with statements from British Energy of a ten year lifetime extension,



- Coal and lignite plants currently listed as planned in the Chalmers PP db and considered as likely to enter into operation have been added to the generation stock. In Germany 12.5 GW coal and 2.8 GW lignite capacity generating in total 81 TWh annually was added between 2010 and 2012 while 1.5 GW coal generating nearly 7 TWh annually was added to the UK plant stock in 2010.

Based on assumed growth rates, deployment of renewables and phase-out of thermal units the remaining gap between supply and demand has been filled with 100% natural gas based generation in the LOW-, MED-, and BAU scenarios or by a 50% split between coal and natural gas in the LOW Coal-scenario.

CO_2 emissions have been calculated by applying emission factors taken from IPCC and by:

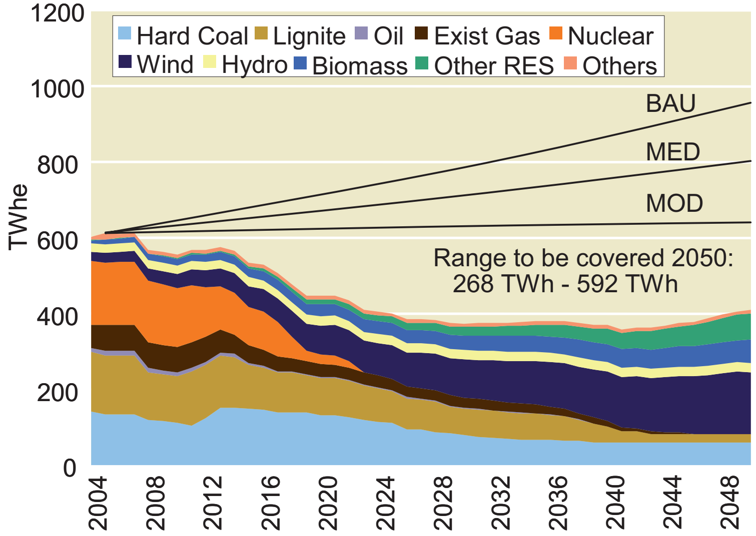
- Applying average specific fuel conversion efficiencies based on national statistics on the existing power generation system.

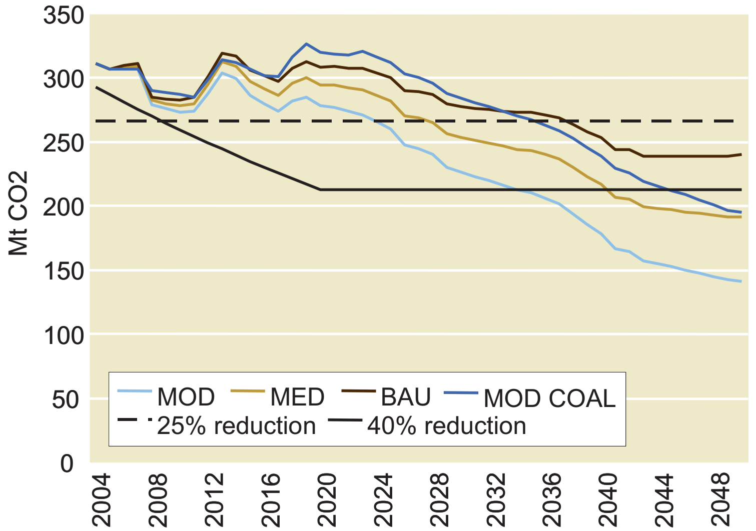
- Conversion efficiency of combined cycles has been set to 60% for new plants between 2009 and 2020, to 65% between 2021 and 2040 and to 70% between 2041 and 2050.

- Conversion efficiency for new coal plants has been set to 45% between 2009 and 2020, to 50% between 2021 and 2040, and to 55% between 2041 and 2050.

Scenario results: Germany

The figure on next page shows the power generation and corresponding CO_2 emissions for Germany applying the four scenarios up to the year 2050 and relative to specified targets. The patterned fields represent phasing out of the present generation capacity and increase in renewable generation according to the above description. The black lines represent the generation that has to be covered by fossil fuels under the various scenarios. The dotted target line illustrates 25% reduction while the solid line corresponds to a linear decrease to reach 40% reduction by 2020. The target lines are based on calculated emissions for total power production assuming 13.8% emission reduction in 2002 relative to 1990.





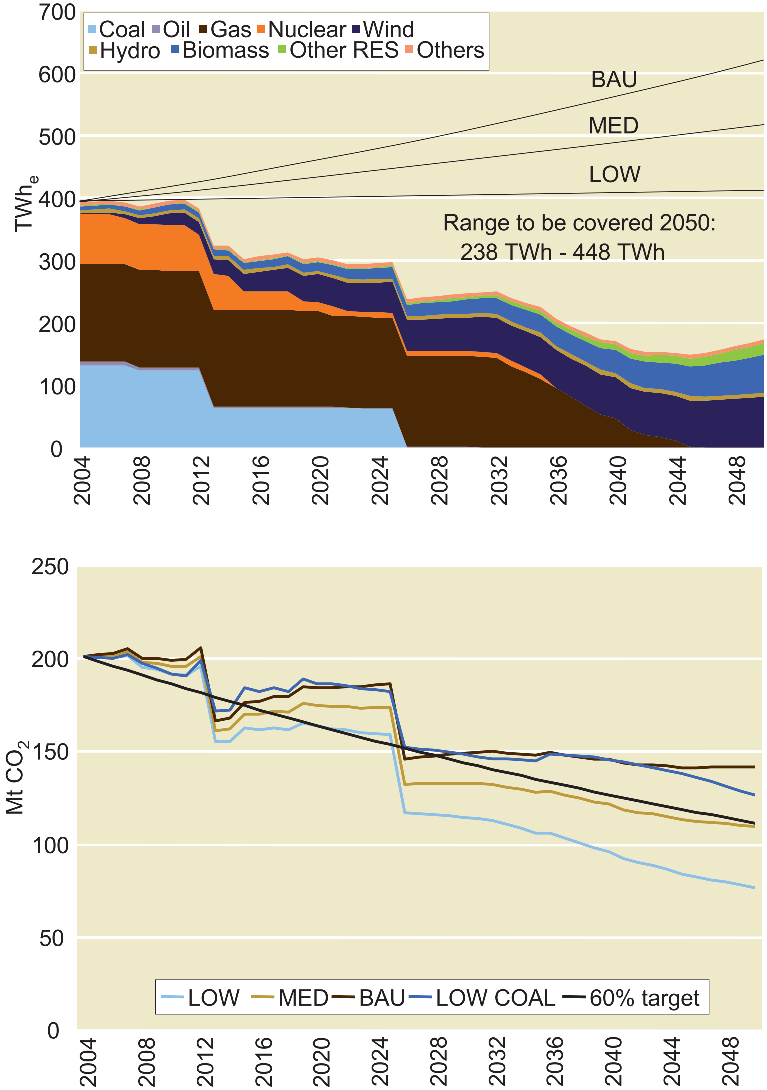
German phase-out of fossil and nuclear units according to technical lifetime and penetration of renewables based on "realistic maximum", and Corresponding CO_2 emissions under the various scenarios assuming 100% replacement of decommissioned units by gas CCGT or 50/50 gas/coal

Approximately 140 TWh coal and lignite based generation from existing plants is phased out up to 2020 and partly being replaced with 81 TWh generated in new coal and lignite plants. Most of the nuclear generation is phased out between 2010 and 2020, decreasing from 157 TWh (2010) to 26 TWh (2020). Total wind based generation in 2050 amounts to 165 TWh, biomass 60 TWh, geothermal and solar (Others) 71 TWh and hydro 25 TWh (BMU 2005). Natural gas based generation in 2050 ranges from 230 to 548 TWh in the three gas scenarios while lignite based generation peaks at 202 TWh in 2026 in the MOD Coal scenario.

Emissions decline in 2008 when 8 GW old coal plants are being phased out but increase from 2010 as new coal plants are being commissioned. Neither of the scenarios will reach the 25% reduction target (266 Mt) by 2005 nor by 2010. Emissions in the three gas scenarios are all peaking in 2013 because of the installation of new coal plants and reaches the 25% target in 2024 (MOD), 2028 (MED) and 2038 (BAU), respectively. The MOD-coal scenario reaches the target in 2036 with cumulative excess emissions between 2010 and 2035 amounting to 880 Mt. Relative to the 40% abatement target emissions in the BAU-scenario never meets the target. This, since there is almost 550 TWh gas based and 80 TWh coal based generation. Cumulative emissions exceeding the target from 2010 onwards will amount to between 970 Mt (MOD) and 2.4 Gt (BAU) with the various scenarios meeting the target in 2035 (MOD), 2041 (MED) and 2045 (MOD coal).

Scenario results: UK

The figure below shows in a similar way power generation and the CO_2 emissions in the UK. It is assumed the target for CO_2 emissions are reduced linearly during the model period to reach 60% by the year 2050.



UK phase-out of fossil and nuclear units according to technical lifetime and penetration of renewables based on a “realistic maximum”, and Corresponding CO_2 emissions under the various scenarios assuming 100% replacement of decommissioned units by gas CCGT or 50/50 gas/coal

According to the assumptions for decommissioning of coal plants in the UK around 8 GW coal is phased out in 2013 and another 12 GW in 2026, leading to that coal based generation accounts for around 18% of total generation relative to the MOD-scenario in 2020 and less than 5% in 2026. Nuclear generation decreases from 74 TWh in 2010 to only 8 TWh in 2024. Approximately 12 GW gas fired plants are commissioned between 2010 and 2020 in the MOD-scenario and gas accounts for 55% of total generation in 2020 (in the MOD-scenario). Renewable generation in 2050 amounts to 81 TWh wind, 61 TWh biomass, 14.4 TWh wave/tidal, 4.4 TWh solar photovoltaics and 7 TWh hydro. Parts of the intermittent capacity could instead be covered with baseload nuclear generation without affecting emissions or, under the MOD-scenario, with additional combined cycles still meeting the emission target.

As a consequence of the above mentioned phase out of coal in 2013 and 2026 emissions are reduced by 20 million tons (Mt) in 2013 and by almost a further 40 Mt in 2026 in the three gas scenarios leading to that both the MOD and MED scenarios comply with the emissions in 2026 as outlined by the 60% target line. However, emissions from both the BAU and MOD coal scenarios exceed emissions as specified by the target line throughout the period up to 2050. Under the MOD coal scenario coal based generation amounts to 122 TWh in 2050 leading to 90 Mt of CO_2 emissions from coal based generation alone and 126 Mt in overall emissions while total gas based generation in the BAU scenario amounts to 441 TWh in 2050 with overall emissions estimated to 144 Mt CO_2. Cumulative emissions between 2010 and 2050 in the two scenarios exceed cumulative emissions as specified by the target line by between 550 to 740 Mt CO_2.

Also in the MOD and MED scenarios emissions exceed targeted emissions periodically but as the second phase-out of coal plants occurs in 2026, emissions from both scenarios decline below the targeted emissions although emissions in the MED scenario exceed the emission limit marginally in 2050 as gas based generation increases. Total emissions in 2050 amounts to 79 (MOD) and 112 (MED) Mt CO_2.

Pathways to sustainable European energy systems

The European pathways project is a five year project with the overall aim to evaluate and propose robust pathways towards a sustainable energy system with respect to environmental, technical, economic and social issues. The focus is on the stationary energy system (power and heat) in the European setting. Evaluations will be based on a detailed description of the present energy system and follow how this can be developed into the future under a range of environmental, economic and infrastructure constraints. The proposed project is a response to the need for a large and long-term research project on European energy pathways, which can produce independent results to support decision makers in industry and in governmental organizations. Stakeholders for this project are: the European utility industry and other energy related industries, the European Commission, EU-Member State governments and their energy related boards and oil and gas companies. The overall question to be answered by the project is:

How can pathways to a sustainable energy system be characterized and visualized and what are the consequences of these pathways with respect to the characteristics of the energy system as such (types of technologies, technical and economic barriers) and for society in general (security of supply, competitiveness and required policies)?

This question is addressed on three levels; by means of energy systems analysis (technology assessment and technical-economic analysis), a multi-disciplinary analysis and an extended multi-disciplinary policy analysis. From a dialogue with stakeholders, the above question has been divided into sub-questions such as:

- What is the critical timing for decisions to ensure that a pathway to a sustainable energy system can be followed?

- What are ”key” technologies and systems for the identified ”pathways” - including identification of uncertainties and risks for technology lock-in effects?

- What requirements and consequences are imposed on the energy system in case of a high penetration of renewables?

- What are the consequences of a strong increase in the use of natural gas?

- What if efforts to develop CO2 capture and storage fail?

- Where should the biomass be used – in the transportation sector or in the stationary energy system?

- Are the deregulated energy markets suitable to facilitate a development towards a sustainable energy system?

- Will energy efficiency be achieved through free market forces or regulatory action?

- What are the requirements of financing the energy infrastructure for the different pathways identified?

In order to address the sub-questions in an efficient and focussed way the project is structured into 10 work packages addressing topics such as description of the energy infrastructure, energy systems modelling, technology assessment of best available and future technologies and international fuel markets. In planning of the project significant efforts have been put into ensuring that the project should not only be strong in research but also in management, communication and fundraising.

The global dimension will be ensured through integration with the other three regional AGS pathway projects in the Americas, East Asia, and India and Africa.

More information at Pathways website:
www.ags.chalmers.se/pathways

The Alliance for Global Sustainability

The Alliance for Global Sustainability (AGS) brings together four of the world's leading technical universities – the Massachusetts Institute of Technology, The University of Tokyo, Chalmers University of Technology and the Swiss Federal Institute of Technology – to conduct research in collaboration with government and industry on some of society´s greatest challenges.

The AGS represent a new synthesis of multidisciplinary and multi-geographical research that draws on the diverse and complementary skills of the AGS partners. In addition to academic collaborations each of the universities has extensive experience in working with stakeholders, particularly a growing number of visionary leaders from industry who recognise their fundamental role in achieving sustainable development.

More information at AGS website:
globalsustainability.org