

**IGCC experience and further
developments to meet CCS
market needs**

Juergen Karg

**Siemens AG
Energy Sector
Fossil Power Generation Division**

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Answers for energy.

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Abstract	3
Market requirements and CCS options	4
Market environment	4
CCS options	5
Available experience with IGCC	7
Key components and integration	8
Integration	8
Gas Turbine	10
Gasification	15
Challenges for IGCC commercialization, improvement potential	17
Summary, conclusions	19

Abstract

The knowledge about current market requirements is the decision basis for further development and improvements of products in the energy sector. An important requirement is to meet the world's growing need for energy which demands for clean and efficient solutions in power generation, transmission and distribution.

Coal is readily available all over the world and has risen only moderately in price compared with gas. As a result, coal-fired power plants are a fundamental element of the world's energy supply. Accordingly, technologies have to be employed to lower the carbon dioxide emissions of these plants.

Two promising methods for the capture of carbon dioxide are post-combustion and pre-combustion technologies. Siemens is developing solutions for both technology paths. This paper will focus on pre-combustion capture, i.e. IGCC.

The identified market requirements and the available broad operational experience from existing IGCC plants form the basis for the further IGCC development. This includes the results of recent studies and the analysis of lessons learned for future robust plant designs.

An update on key IGCC components is given, covering gas turbine and gasification. However a special focus will be on system integration aspects and their relevance to current market requirements. Examples are (air/nitrogen) integration alternatives for the air separation unit (ASU) or the gasifier concept.

The view on customer requirements on one hand and technology development on the other hand has to be combined with an evaluation of the challenges for IGCC commercialization under the current market conditions.

Market requirements and CCS options

Market environment

By approximations of the UN, the world's population will grow by 1.1 billion to reach 7.5 billion people by 2020. This growth will be accompanied by a trend towards further growth and industrialization of transitional countries. In combination with an additional increase in urbanization, this will lead to a rapidly increasing demand for energy.

Electrical power is the primary most suitable energy carrier that can meet the challenges of the future. The highest efficiencies in generation and utilization, as well as the inclusion of renewable sources, represent indispensable advantages in the struggle against climate change. While fossil fuels, and especially coal, will continue to play a central role in power generation, the future, more than ever, calls for a diversified energy mix. Therefore, more efficient use of fossil fuels has to be combined with an intensified reliance on renewable energy sources (Fig. 1).

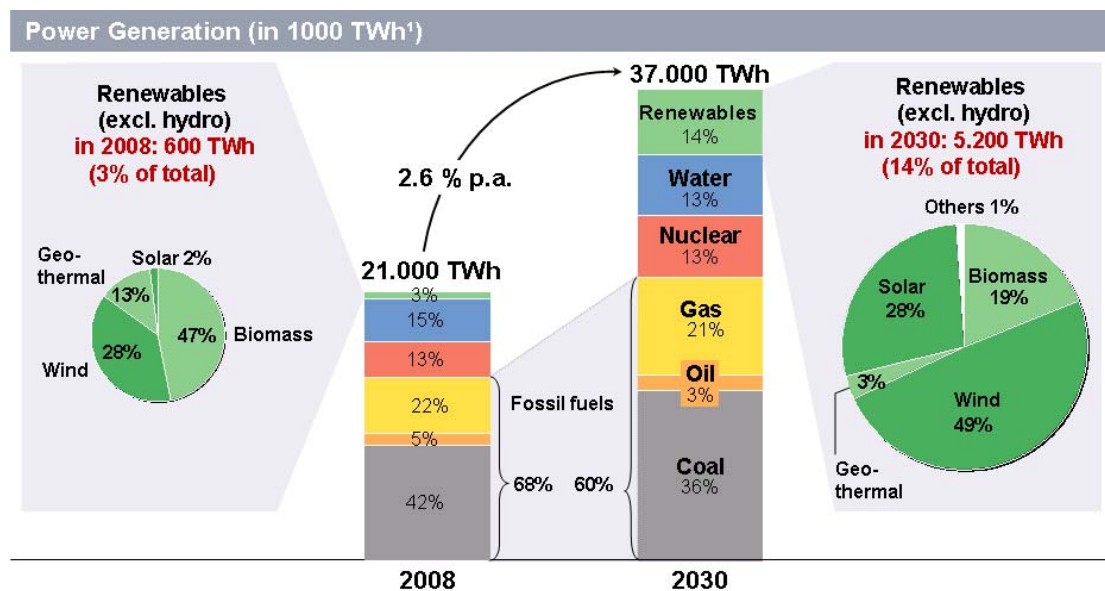


Fig. 1: Renewables are gaining in importance – fossil fuels will continue to be the mainstay

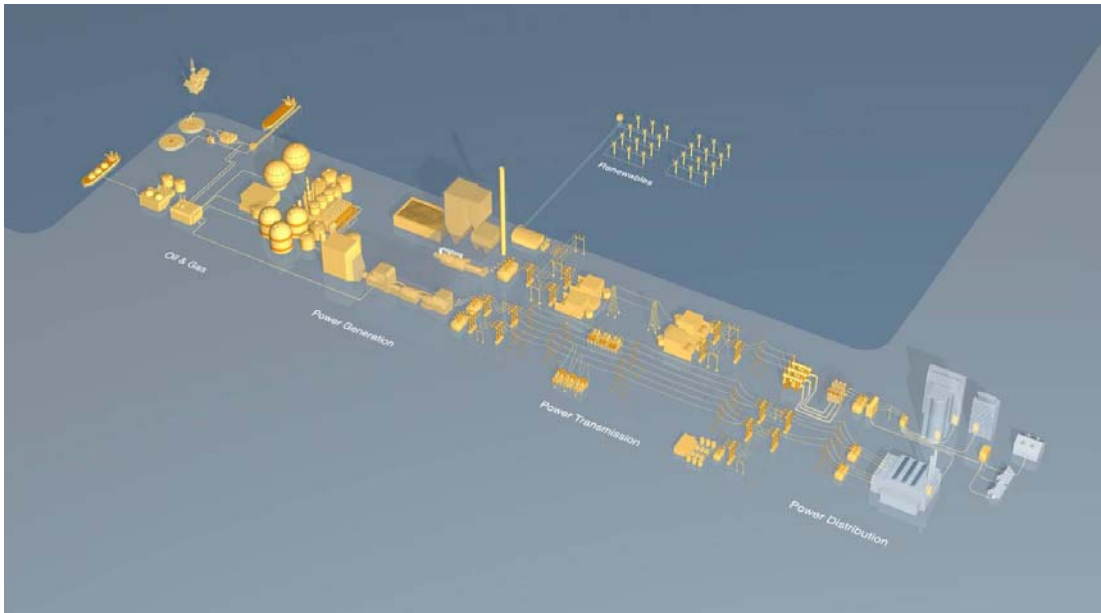


Fig. 2: From primary energy to power distribution – CO₂ reduction in the whole process chain

In general the necessity for more efficient use of primary energies in combination with more stringent environmental regulations for fossil-fuelled power plants will push concepts with increased efficiencies and reduced CO₂ emissions. This is valid for the whole process chain starting with primary energy and ending with power distribution to the consumers (Fig. 2).

Against this background development of new and improved technologies for future applications is a permanent challenge. Among these technologies there are highly efficient gas turbines for CCPP or IGCC applications and the supercritical steam technology for power generation. Further innovations include highly efficient transformers as well as ultra-high-power transmission and gas-insulated underground power lines for low-loss transmission of vast power quantities into metropolitan areas.

CCS options

As far as the power generation part is concerned, increasing efficiencies is one of the levers for reduction of CO₂ emissions. Especially for coal as a fuel with high carbon content also solutions with CCS (Carbon Capture Sequestration) have to be considered to make coal-fired power plants carbon-neutral and to achieve the CO₂ emission reduction targets (Fig. 3).

Integrated Gasification Combined Cycle (IGCC) technology with CCS is one of the promising options which need to be considered for future power generation. These future IGCC applications with CCS can take advantage from the experience and lessons learned from IGCC plants without CCS as they are in operation e.g. in Buggenum/The Netherlands or in Puertollano/Spain.

In addition to the experience with IGCC plants on a large-scale there is also significant experience available with CO₂ capture from syngases in the chemical industry. According to information from the Gasification Technologies Council more than 80 percent of the global industrial gasification capacity is already capturing CO₂ as part of the manufacturing process, but not for sequestration.

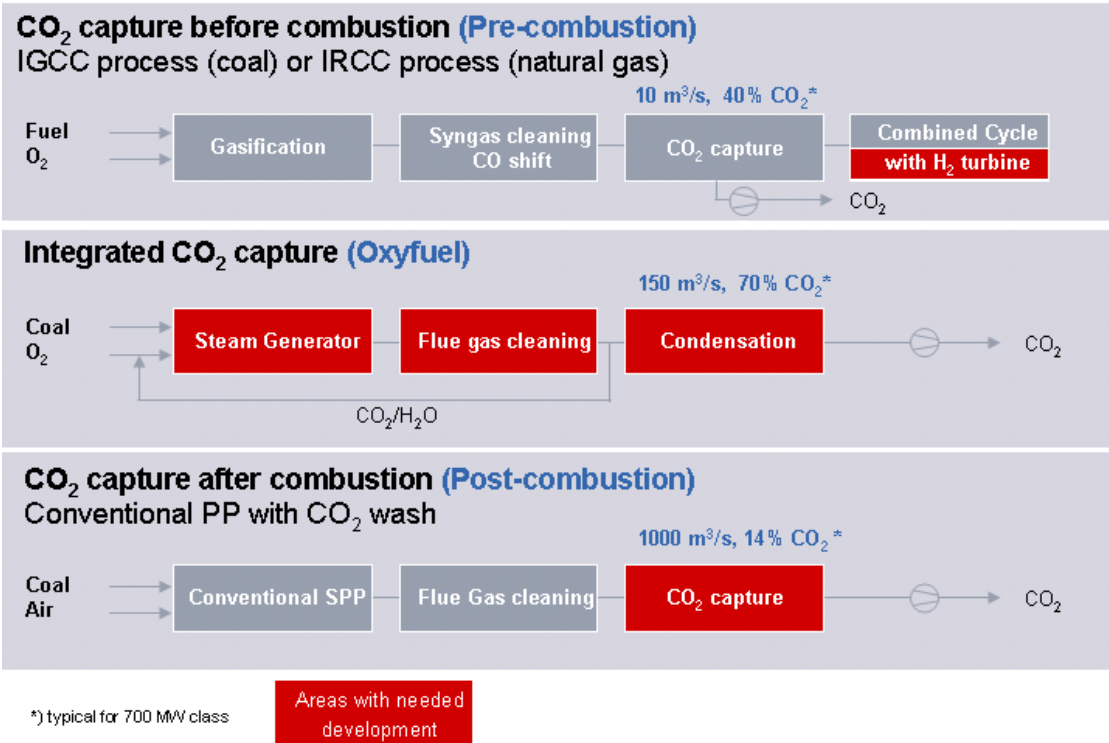


Fig. 3: Process options for CO₂ capture

The second option toward carbon-free, fossil-based power generation pursued by Siemens is the post-combustion capture technology (Fig. 4).

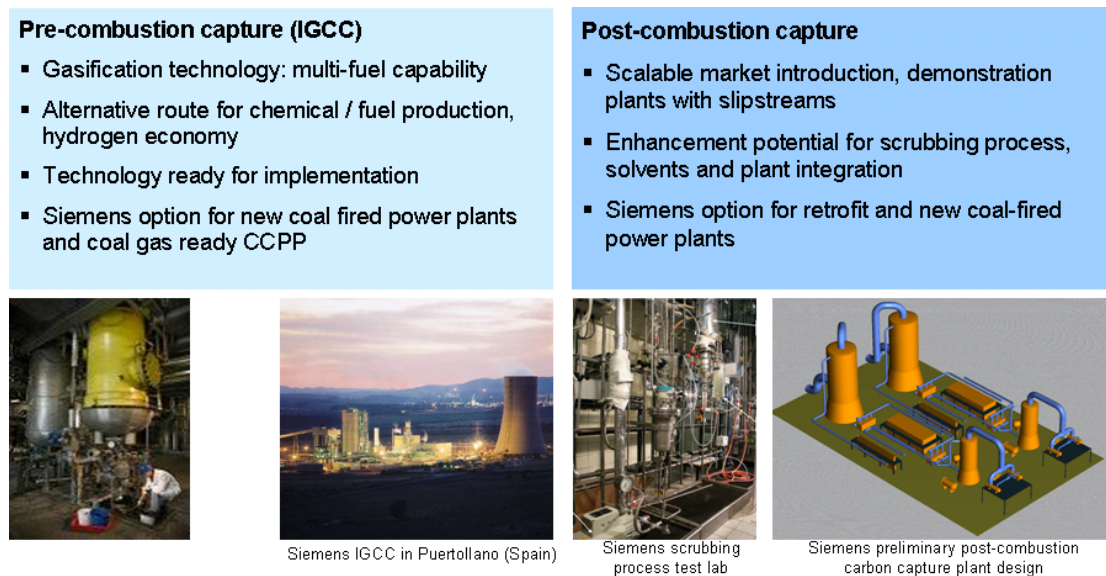


Fig. 4: Siemens preferred solutions for CO₂ capture

Available experience with IGCC

The development and demonstration efforts related with Integrated Gasification Combined Cycle technology were originally focussed on improved concepts for coal-based plants and thus on an alternative to conventional steam plants. The experience with the demonstration plants in Europe, in the United States, and now also in Japan, and the parallel development efforts for improved steam power plants resulted in a situation where coal-based IGCC is on the one hand today to be considered as a commercially available technology which on the other hand still needs further improvement of economics to be fully competitive.

Next generation plants of larger size, where the lessons learned from the operational plants are implemented and co-firing of low-cost fuels, wastes or biomass is foreseen for reduction of fuel costs and/or to produce green electricity, could pave the way for a commercial breakthrough. This is primarily expected for IGCC applications with CCS.

	Total MW _{el}	Total Operational MW _{el}	Operational Coal/petcoke IGCC	Operational Oil/ heavy residues IGCC
<u>Europe</u>	4,170	2,620	35 %	65 %
<u>Asia/Australia</u>	1,400	1,120	29 %	71 %
<u>Americas</u> USA, Canada	2,020	960	83 %	17 %
Total	7,590	4,700	43 %	57 %

Table 1: IGCC power plants built, in operation, under design, construction or commissioning

The situation is different for refinery residues where, depending on the individual site conditions, IGCC can already today be considered as a commercially attractive solution for power generation, co-generation or co-production of power and hydrogen for refinery-internal purposes. The introduction of IGCC for refinery applications was supported by the experience gained with the technology from the coal-based plants.

From the 7,600 MW of global IGCC power plants which have been built, or are under design, construction and commissioning, 4,700 MW are in operation. About 55 % of this operational capacity is installed in Europe (Table 1).

Key components and integration

Integration

IGCC power plants are not simply combined cycle power plants (CCPP) where the standard pipeline fuel natural gas is replaced by syngas. When integrating a gasification plant and a gas island, respectively, with a CCPP, several specific aspects have to be considered. The most important one is related with the gas turbine and the application of syngases with moderate or, in case of plant concepts with CCS, high hydrogen content, which must be handled by the combustion system.

The gas turbine is also affected by the optional interaction with the air separation unit (ASU). This is valid for the supply of dilution nitrogen from the ASU for NO_x and reactivity control, but also with regard to an optional (limited) process air supply from the gas turbine compressor for the ASU.

On the other hand also the sensible heat from the different process steps in the gas island needs to be properly integrated with the water/steam cycle of the CCPP unit and the overall IGCC, respectively.

The coal-based IGCC power plants which have been built in Europe were designed targeting maximum overall net plant efficiency under the given fuel and site conditions with the gas turbine technology available at the time of decision-making. This resulted in the selection of plant concepts with full air-side and nitrogen-side integration between gas turbine and ASU. The experience has shown that this type of plants can be operated successfully. On the other hand the lessons learned from plant operation indicate that reduced integration and the availability of a separate air compressor, which can at least cover the needs of an independent ASU start-up, can contribute to increased operational flexibility and robustness. As a consequence plant concepts with no or only partial air-side integration are preferred for future new IGCC plants without and with CCS (Fig. 5).

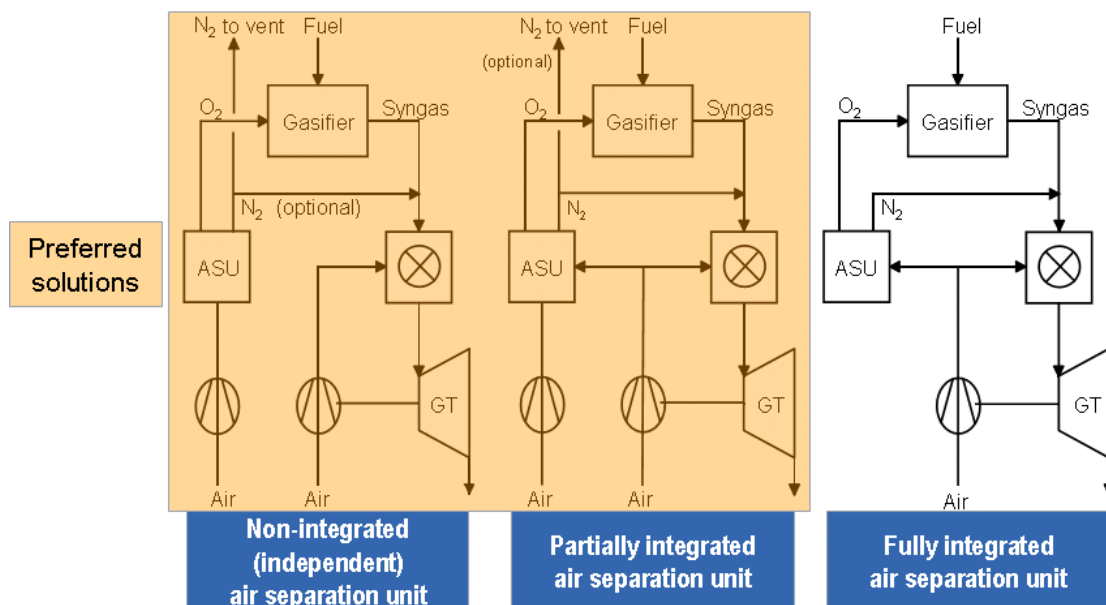


Fig. 5: Integration options for IGCC power plants

Considering on one hand operational flexibility and robustness as a must for new IGCC power plants and on the other hand the need for high efficiencies, special attention has to be given to an optimised integration. Plant concepts with full nitrogen integration but no or only partial air-integration typically result in reduced overall net efficiencies compared with a fully air and nitrogen integrated concept. Against this background modified concepts have to be implemented which can at least partly compensate the losses at lower air integration. One contribution to the performance improvement can come out of a combination of reduced nitrogen integration and optimised saturation of the syngas using preferably low-temperature level heat from the overall process (Fig. 6).

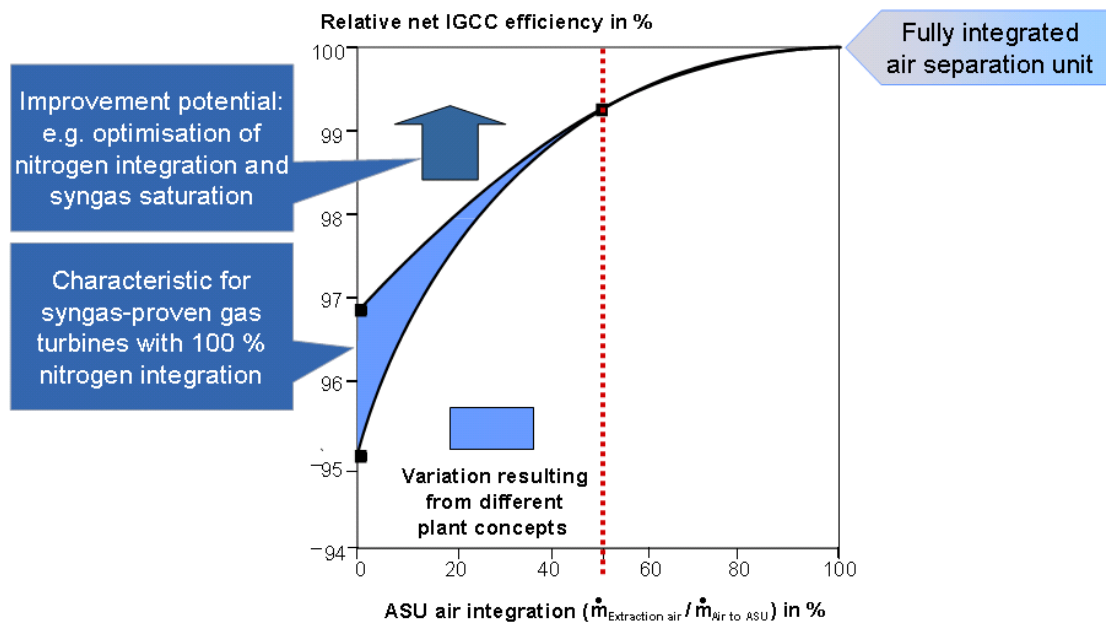


Fig. 6: Effect of ASU integration on net IGCC plant efficiency

Gas Turbine

For achieving high efficiencies with CCPP and IGCC power plants the gas turbine plays a major role. The Siemens heavy-duty gas turbine portfolio is designed to support high CCPP efficiencies. The most advanced engine, which is the new SGT5-8000H, is designed to achieve more than 60 % efficiency in combined cycle mode (Fig. 7 and Fig. 8).

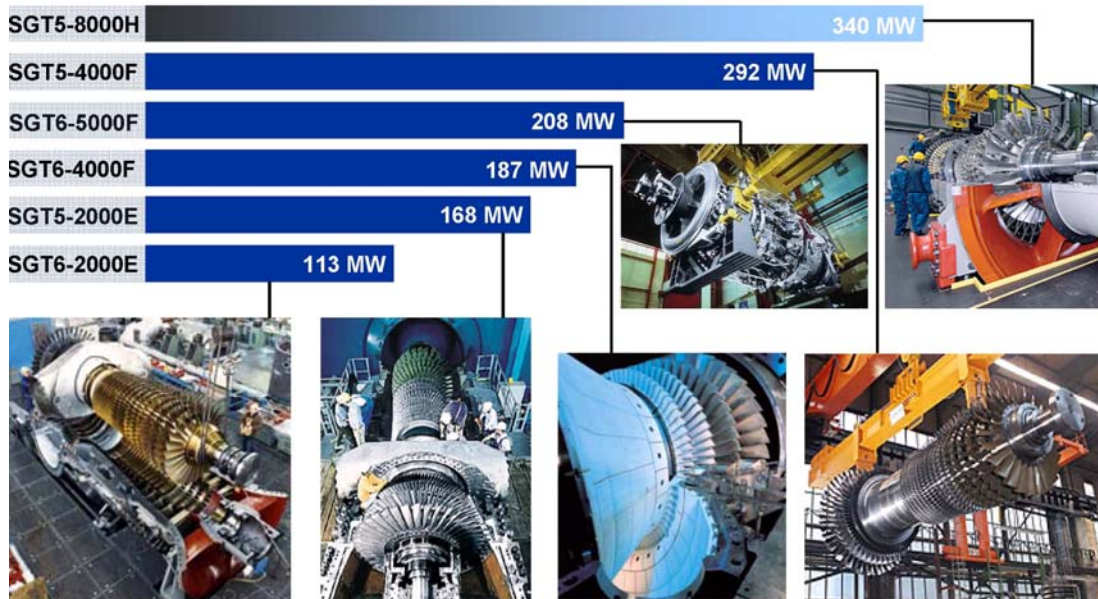


Fig. 7: Siemens heavy-duty gas turbine portfolio

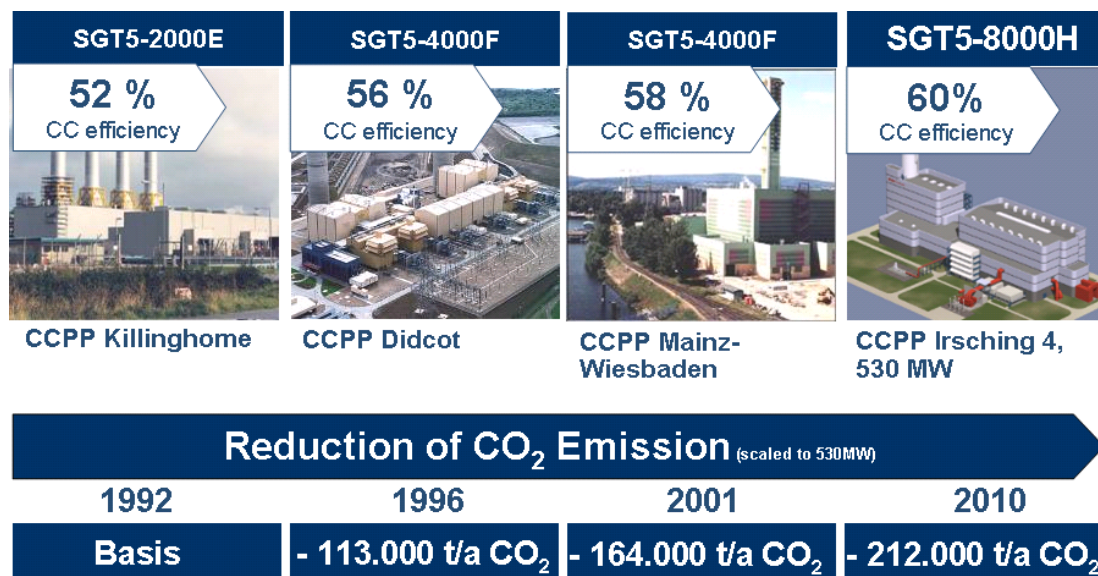


Fig. 8: Evolution of Siemens combined cycle efficiency

Continuous development efforts have contributed to significantly increase CCPP efficiencies over the last two decades up to the high level achievable today, which also contributes to a significant reduction of CO₂ emissions (Fig. 8). In parallel to the improvements implemented for natural gas-based gas turbines, developments were made to enable syngas as a fuel and thus integration of gas turbines in IGCC plants.

As a consequence Siemens has been involved in all of the European coal-based IGCC demonstration plants, including the world’s first IGCC built in Germany. All of these European demonstration plants included the largest syngas-capable 50-Hz gas turbines available at the time of decision-making for these projects. Compared with other coal-based IGCC plants built in the 1980ies and 1990ies in the United States, and also after 2000 in Japan, the European plants achieved significantly higher efficiencies as a result of the selected technologies and the gas and water/steam-side integration philosophy (Fig. 9).

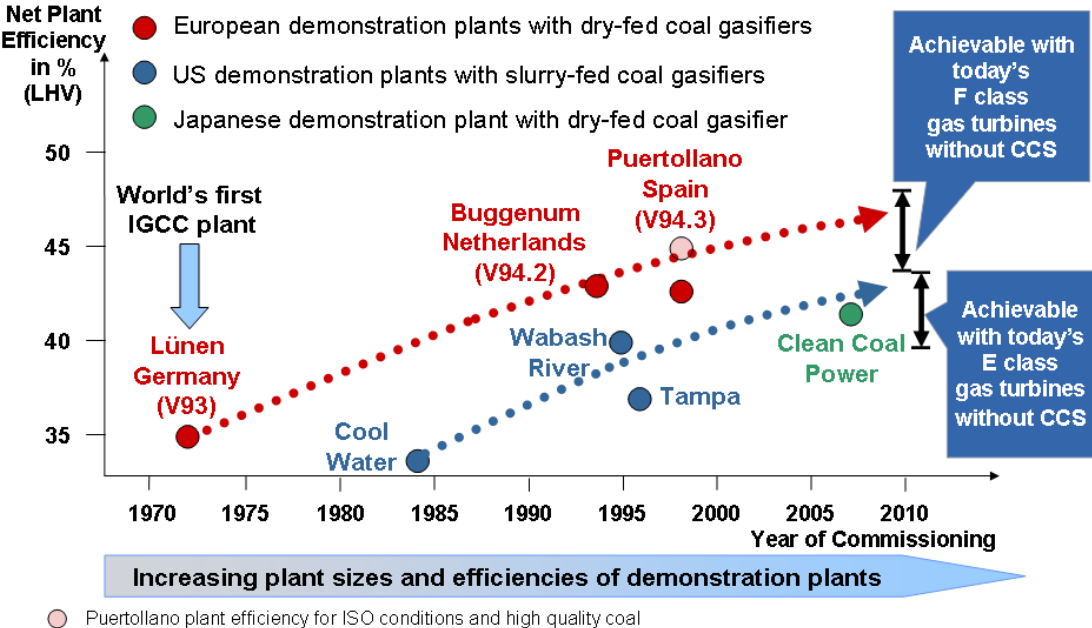


Fig. 9: Development of IGCC net plant efficiencies for coal-based plants without CCS

Today, broad experience is available within Siemens which covers a wide range of IGCC application alternatives (Table 2) concerning plant integration, gasifier fuels and resulting syngas compositions. Currently, the total syngas/ IGCC experience sums up to more than 650,000 operating hours, including steel-mill recovery gas applications.

Customer/Plant (Location)	Electrical Output (net)	Gas Turbine	Main Features	Start- up
Hörde Steelworks (Dortmund, Germany) Handan Iron & Steel (Handan, P.R. China)	8 MW	1 x VM5	Blast-furnace-gas-fired, gas turbine as compressor drive	1960/ 2000
U. S. Steel Corp. (Chicago, USA)	20 MW	1 x CW201	Blast-furnace-gas-fired gas turbine	1960
STEAG/Kellermann (Lünen, Germany)	163 MW	1 x V93	First CC plant in the world with integrated LURGI coal gasification (hard coal)	1972
DOW Chemicals (Plaquemine, USA)	208 MW ¹⁾	2 x W501D5	CC plant with integrated DOW coal gasification	1987
Nuon Power Buggenum (Buggenum, Netherlands)	253 MW	1 x V94.2	CC plant with integrated SHELL coal gasification (hard coal and biomass blend)	1993 ²⁾ 1994/ 95
HRL (Morwell, Australia)	10 MW	1 x Typhoon	CC plant with integrated drying gasification process (lignite)	1996
Sydkraft (Värnamo, Sweden)	6 MW	1 x Typhoon	First CC plant in the world with integrated biomass gasification	1996
ELCOGAS (Puertollano, Spain)	300 MW	1 x V94.3	CC plant with integrated PRENFLO coal gasification (coal and petroleum coke blend)	1996 ²⁾ 1997/ 98
ISAB Energy (Priolo Gargallo, Italy)	521 MW	2 x V94.2K	CC plant with integrated TEXACO heavy- oil gasification (asphalt)	1998 ³⁾ 1999
ELETTRA GLT (Servola, Italy)	180 MW	1 x V94.2K	CC plant with steel-making recovery gas	2000
ARBRE (Eggborough, UK)	8 MW	1 x Typhoon	CC plant with integrated biomass gasification	2002
EniPower (Sannazzaro, Italy)	250 MW	1 x V94.2K	CC plant fuelled with syngas from SHELL heavy-oil gasification	2006
Huaneng Tianjin IGCC Green Coal Power (Tianjin, China)	250 MW	1 x SGT5- 2000E(LC)	CC plant with integrated TPRI gasification (coal)	2011
1) 160 MW from syngas and 48 MW from natural gas; 2) Natural gas firing; 3) Oil firing; SGT5-2000E = V94.2 (old naming); SGT5-2000E(LC) = V94.2K (old naming) => engine with modified compressor				

Table 2: Syngas/IGCC experience

Siemens participated in the 1990ies in both of the European coal-based IGCC demonstration plants which are today running as commercial plants with coal/biomass (Buggenum) or coal/petroleum coke mixtures (Puertollano). Presently, there are activities underway to install at both plants, Buggenum and Puertollano, small-scale demonstration facilities for separation of CO₂ from syngas.

Siemens was already involved in world's first IGCC plant which was started up in 1972 at Steag's Lünen site in Germany. In 1987 a further plant was started up at Plaquemine in the United States where syngas from coal gasification was used in gas turbines.

Based on the experience gained from the large coal-based IGCC applications in Europe and in the United States IGCC technology was then also selected for clean

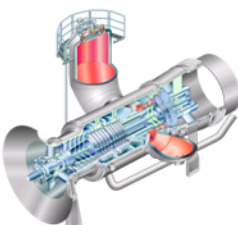
use of refinery residues. Several such commercial plants are running today in Italy, and the plant at Priolo Gargallo has two gas turbines with Siemens technology which are operated successfully since the end of the 1990ies. A further residues-based plant is in operation at Sannazzaro. The latest syngas reference is a gas turbine application within a coal-based IGCC plant at Tianjin which is part of China's GreenGen Programme.

Based on the experience from the operational plants, syngas solutions for already syngas-proven and commercially offered 50-Hz E class gas turbines have been further improved. The syngas-capable F class gas turbine for 50-Hz markets is under development and ready for bid in short term. For this engine the special focus is on CCS applications and syngas fuels with high hydrogen content. E and F class gas turbines for syngas applications in 50-Hz markets are specifically designed to meet the requirements of IGCC plant concepts without or with only limited air integration with the ASU. As a consequence both engines, designed for low calorific fuels, have one additional compressor stage (Fig. 10).

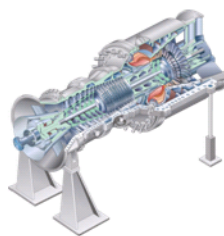
A modular syngas fuel conditioning and optional air extraction system enables conditioning of the syngas with nitrogen and water vapor according to the emission reduction and reactivity control requirements of the gas turbines. The modular fuel system is also integral part of the overall plant performance optimization efforts.

Syngas-specific features of "LC" (Low Calorific Gas) gas turbines

- Additional compressor stage to meet the requirements of no or only partial air integration
- New syngas burners and piping systems for syngas supply to individual burners
- Openings for optional air extraction and piping systems for extracted air
- Modular syngas fuel conditioning and air extraction system
- New / additional controls



E Class: References available
Gross GT output: 173 MW^{*)}



F Class: Development underway
Gross GT output: > 300 MW^{*)}

*) Assumption: Syngas operation in a non air- integrated IGCC plant concept

Fig. 10: 50-Hz gas turbine modifications for IGCC application

Gasification

For IGCC applications another key component is the gasification technology. Oxygen-blown entrained-flow gasification technology with dry fuel feeding has been demonstrated to be the most suitable and fuel-flexible solution for IGCC applications, resulting in higher overall plant efficiencies compared with other gasification principles. The Siemens Fuel Gasification (SFG) technology is of this type.

The SFG technology is applicable for a wide range of feedstocks. Especially depending on the fuel ash content either a reactor with cooling screen or with refractory lining is available (Fig. 11). The latter is also applicable for liquid feedstock as for example refinery residues.

Siemens has acquired the gasification technology in 2006. Since that time significant successes have been achieved for introduction of commercial-size gasifiers to the market. Present focus is on applications in the chemical industry, but the technology has also been selected for IGCC projects (Table 3).

For coals typically the reactor with cooling screen and pneumatic dense flow feeding system is the preferred and robust design, resulting in high conversion efficiencies. In combination with a downstream water quench instead of a syngas cooler this system is also an ideal fit for CCS solutions where steam is required for the conversion reaction in the CO-shift.

For IGCC applications without CCS a syngas cooler downstream of the gasifier is beneficial for improved heat recovery to produce for example high pressure steam which can be integrated effectively with the water/steam process of the CCPP and thus increases overall plant efficiency significantly. All of the existing coal-based IGCC power plants are based on gasifiers with syngas coolers for this purpose.

For IGCC plants with CCS the situation is different as a – at least partial – water quench has advantages in conjunction with the CO-shift which is needed in this case as a pre-condition for the CO₂ removal. As a consequence the advantage in efficiency of a syngas cooler concept compared with a full water quench becomes smaller (Fig. 12). Against this background solutions are under investigation, which

enable an optimized and economic heat recovery considering the specific requirements of applications with CCS.

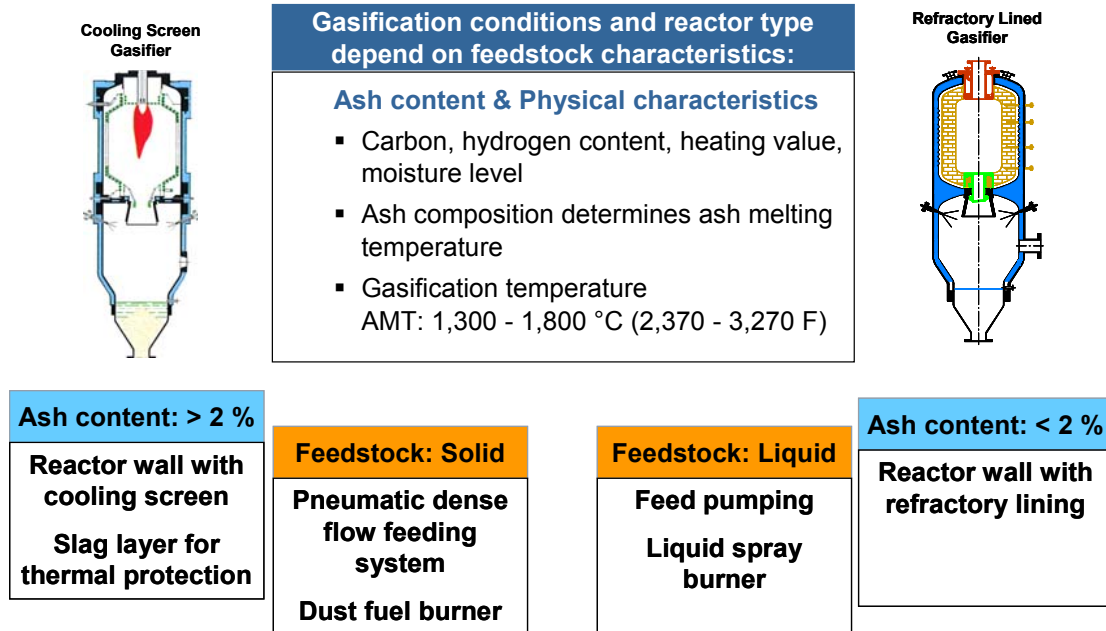


Fig. 11: Gasification product design for different feedstocks

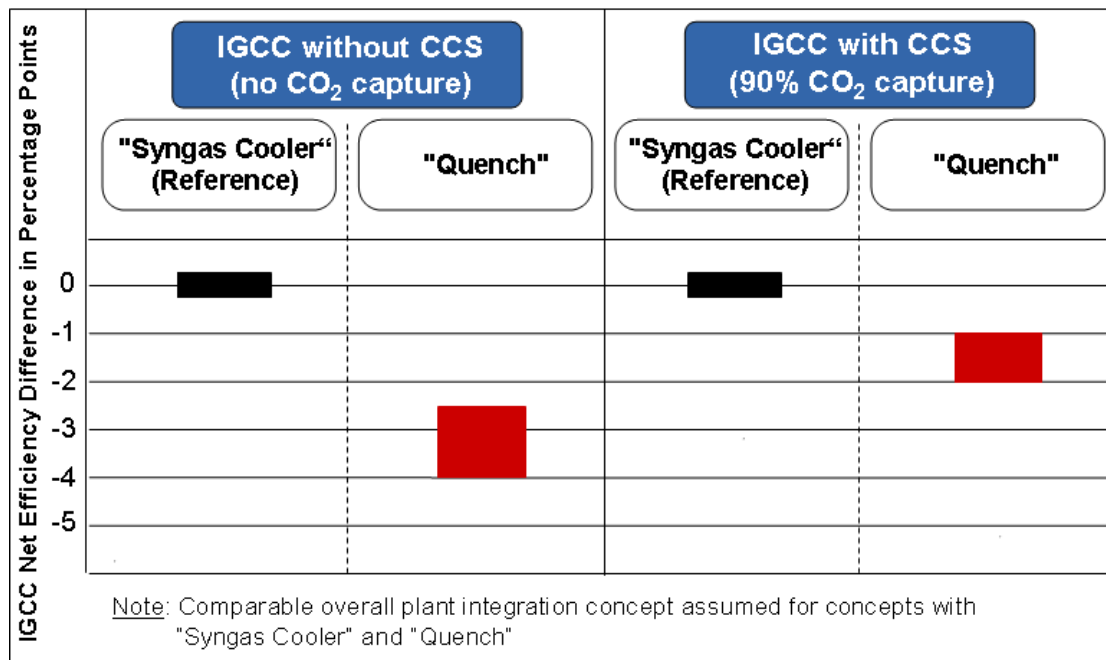


Fig. 12: Influence of gasifier syngas heat recovery concept on IGCC net efficiency

Plant Name/Owner	Country	Start up / Project Status	Feedstock	Units and Size	Final Product
SVZ Schwarze Pumpe	Germany	COD 1984 (shut-down 2006)	Lignite, natural gas, tar oils, liquid waste	200 MW _{th}	Methanol and power
Sokolovská uhelná a.s.	Czech Republic	COD 2008	Generator tar and other fixed-bed gasifier by-products	175 MW _{th}	Power (IGCC)
Shenhua Ningxia Coal Industry Group Co., Ltd.	China	PDP engineering completed, 5 SFG-500 gasifier shipped and erected COD in 2010	Bituminous coal	5 x 500 MW _{th}	Polypropylene
Shanxi Lanhua Coal Chemical Comp., Jincheng	China	PDP engineering completed, 2 SFG-500 gasifier manufactured COD in 2012	Anthracite	2 x 500 MW _{th}	Ammonia/ fertilizers
Secure Energy, Inc. Decature, Illinois	USA	BEDP engineering completed, 2 SFG-500 gasifiers shipped, COD in 2011	IL bituminous coal	2 x 500 MW _{th}	SNG
Summit Power, Inc.	USA	SFGT Technology selected COD in 2014	Lignite	3 x 500 MW _{th}	Power (IGCC)
Epcor Power Inc. Genesee	CAN	License, Engineering and Hardware Agreements signed, Basic Eng. in progr. COD in 2015	Sub-bituminous coal	1 x 500 MW _{th}	Power (IGCC)
AEC Australian Energy Company	Australia	SFG technology selected, FEED to start mid 2009 COD in 2013	Lignite	2 x 500 MW _{th}	Ammonia/ urea

Table 3: Siemens gasification experience and current projects

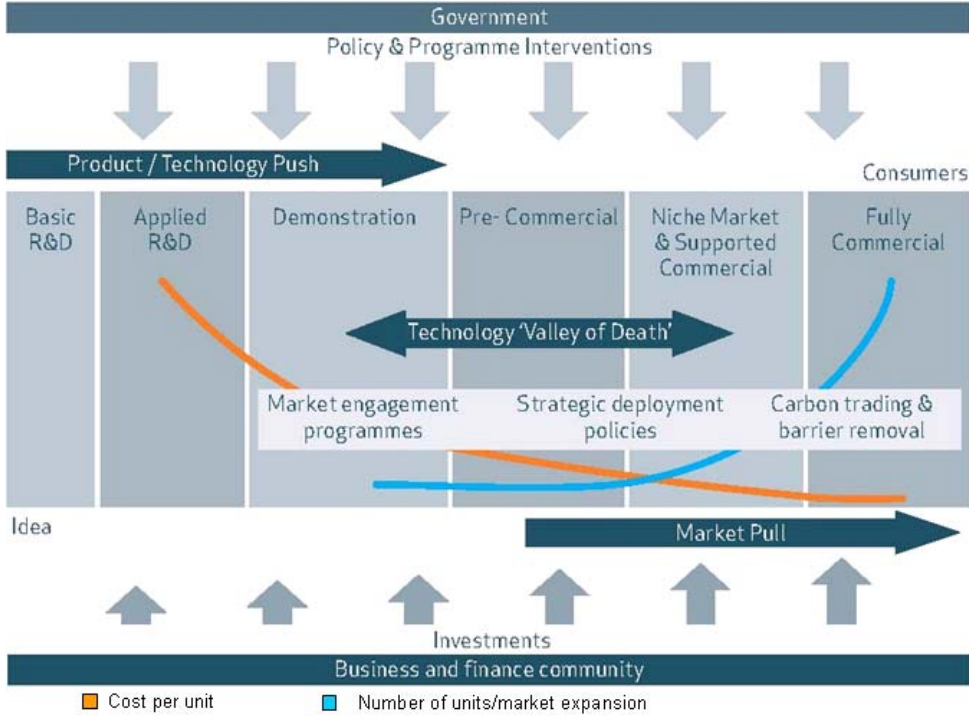
Challenges for IGCC commercialization, improvement potential

IGCC has today reached a status where experience is available from 1st generation and 2nd generation plants, built in the 1970ies/1980ies and in the 1990ies, respectively. These plants have been built as commercial-scale demonstrators for coal-based applications. Lessons learned from these plants will help to technically and commercially improve the next generation.

Today, further developed steam power plant technology is still the benchmark for gasification-based power plants. As IGCC is still to be considered as a relatively young technology with limited number of more or less tailor-made plants, it has significant improvement potential by implementation of the lessons learned for a more robust plant design, and by standardization.

As for every new technology the most important step for market introduction is to bridge the gap between funded large-scale demonstration units and fully commercial applications. This requires market pull instead of product and technology push. For IGCC applications with CCS, government policies and incentives, as they are for example intended within the EU Flagship Programme, could first create a niche

market for supported commercial projects. If these projects can be successfully implemented, this could pave the way for a commercial breakthrough of the technology (Fig. 13).



Source: World Coal Institute, "Coal Meeting the Climate Challenge", September 2007

Fig. 13: Actions needed for technology commercialization

Summary, conclusions

IGCC can be considered today as a technology which is available on a commercial scale. Further reduction of specific investment costs is required to improve commercial attractiveness and competitiveness with other power generation technologies.

IGCC with CCS is a promising technology to satisfy the market needs in a carbon-constrained environment, but a robust regulatory framework and clear investment incentives are required for a full commercialization.

Siemens has contributed significantly to the development of IGCC technology over the last decades and has gained experience back from the operational plants for the key components. This experience is used for further continuous improvement and development activities related with gas turbines for syngas/hydrogen-rich fuels, gasifiers and overall plant integration aspects.

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