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## **Pushing Forward IGCC Technology at Siemens**

### **Abstract**

Saving primary energy sources in combination with more stringent emissions limitations, especially with regard to CO<sub>2</sub>, leverages advanced power plant technologies. IGCC (Integrated Gasification Combined Cycle) is one technology which can meet these requirements while avoiding the use of high cost fuels such as natural gas. Via gasification IGCC is capable of operating on a wide range of fuels and offers the ability to produce a range of products including power, heat, hydrogen and other valuable chemicals. Future applications of IGCC can be configured to remove carbon components with minimal efficiency losses when compared to today's technologies. However, these new advanced IGCC concepts require additional component development in the areas of integration and gas turbine combustion in order to keep IGCC technology competitive and reliable.

This induced Siemens and ELCOGAS to enter into several R&D programs which emphasize on syngas and hydrogen rich gas combustion and the development of advanced IGCC concepts with and without CO<sub>2</sub> capture. The projects are partly funded by the European Commission within the 5<sup>th</sup> EC Framework Program. They are carried out in close cooperation with various European utilities, industrial partners as well as research institutes.

Siemens through Siemens Westinghouse has also begun a program to develop ultra low NO<sub>x</sub> combustion technology for these advanced IGCC plant concepts in cooperation with the U.S. Department of Energy.

Enhancing efficiency and specific power output of future IGCC applications needs syngas burner technology which is applicable in high efficient gas turbines like Siemens Vx4.3A or W501F and W501G. In parallel, further burner improvements of the silo-type combustors for the V94.3 and V94.2(K) engines are required to increase plant availability to different types of fuels. Several years of operational experience at the ELCOGAS and ISAB facilities have proven that a more robust combustion system enhances the plant economics.

This report summarizes the status of Siemens' current activities on using low grade gases for power generation and the experience gained from recent modifications at Puertollano IGCC plant.

## 1 Introduction

There is a broad consensus about the capability of IGCC (Integrated Gasification Combined Cycle) technology for mitigating the environmental impact of power generation from fossil fuels: The high efficiency potential of approx. 52 % (net) aimed to be achieved within this decade is one precondition for saving primary energy and reducing CO<sub>2</sub> emissions [1]. Via gasification a wide range of feedstocks including biomass and low-grade opportunity fuels such as refinery residues or waste material can substitute valuable fossil fuels. As a result of the typical pressurized process high efficient gas cleaning systems are available leading to very low emissions of all relevant contaminants. IGCC is seen as the most promising technology when removal of CO<sub>2</sub> as the most important greenhouse gas would be obliged for power plants based on fossil fuels. IGCC could be also an economic option for new power generation schemes depending on the natural gas price tendency and if emission standards become more stringent.

This is the reason why power plant industries and research organizations worldwide are pushing this technology promoted by various national and international institutions such as the U.S. Department of Energy (DOE) or the European Commission (EC). Siemens and ELCOGAS have been active in IGCC development from the very first, in the first European IGCC demonstration plant at Puertollano/Spain as well as in various R&D projects.

## 2 IGCC Applications with Siemens Technology

### 2.1 Fuel-Flexible Siemens Gas Turbines

#### *Gas Turbine Fleet*

The Siemens gas turbine development for the use of low-BTU gases is based on the standard product range applied for natural gas or fuel oil (Figure 1, Table 1). For this application several modifications of the combustion system as a consequence of the clearly lower specific heat input and possibly of the compressor are necessary.

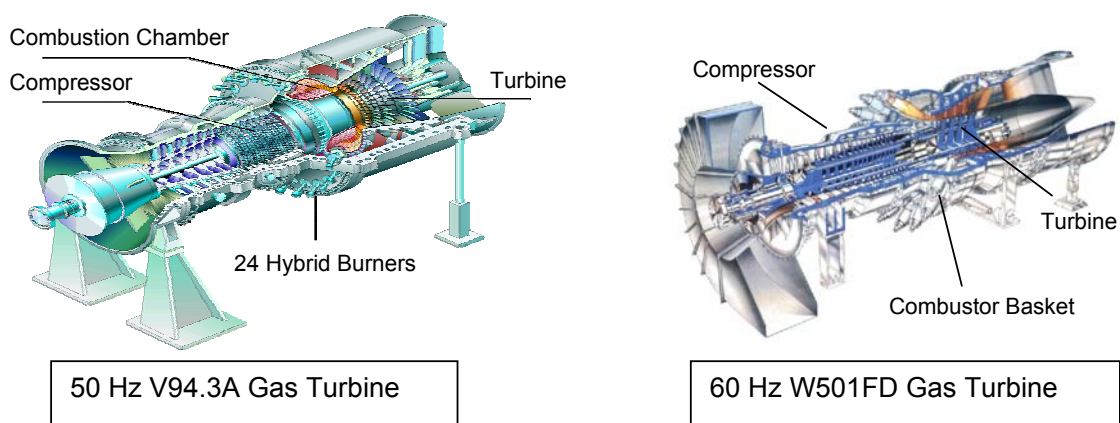


Figure 1: Siemens gas turbine series.

Table 1: Siemens heavy duty gas turbine models.

	50 Hz				60 Hz		
	V94.3A	V94.3	V94.2	V64.3A	W501G	W501F	W501D5A
Gross power output [MW]	266	222	159	67	253	190	121
Gross efficiency [%]	38.6	36.2	34.3	34.9	39.0	37.1	34.7
Gross heat rate							
[kJ/kWh]	9323	9945	10495	10305	9240	9700	10380
[Btu/kWh]	8836	9426	9947	9767	8760	9190	9840
Pressure ratio	17.0	16.1	11.4	15.8	19.2	17.0	14.2

### Combustion Technology for Syngas Applications

By fuel gas conditioning, mainly humidifying or dilution with nitrogen, the emissions of NO<sub>x</sub> are excellent low. Even with high dilution sufficient burning velocity can be kept for stable flame. For stable burning conditions without blow-off or burner overheating swirl generators for both fuel gas and air are installed as well as specific blockages at the outlet of the syngas passage. The typical range of the fuel gas heating value is between about 4 (Nuon, ELCOGAS IGCC) to nearly 9 MJ/kg (ISAB) (see also Table 5). The syngas burner for the Siemens W series of gas turbines is a state-of-the-art burner based on the proven syngas burner used at the DOW Plaquemine IGCC Project (Figure 2). In the summer of 2002, first syngas combustion test campaign for the W501FD using the W501F syngas burner was successfully completed.

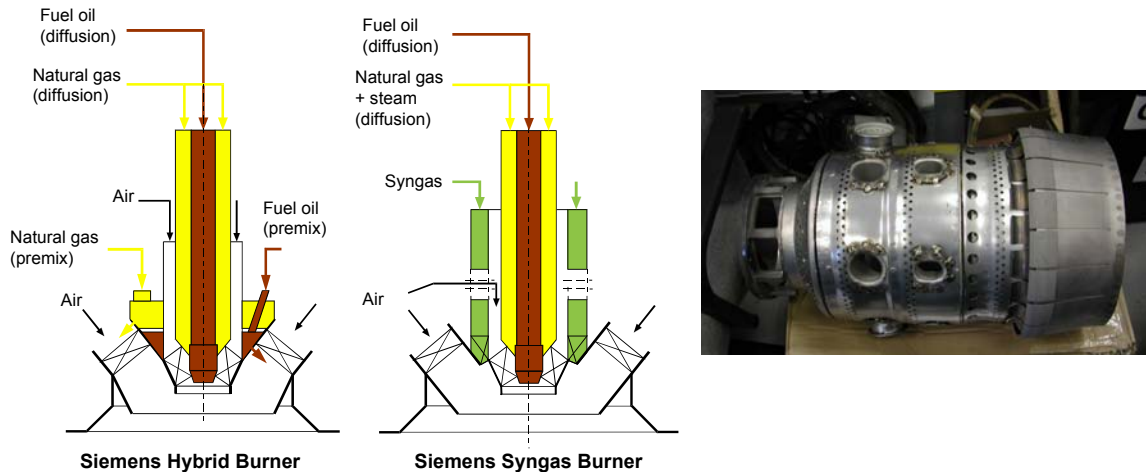


Figure 2: Siemens V94 series hybrid burner, syngas burner and W501 syngas combustor basket.

### The Well-proven V94.2/V94.2K

The V94.2K is a derivative from the well-proven V94.2 gas turbine. The main difference is one additional compressor stage. This modification was implemented to specifically meet the requirements of non or partially integrated IGCC plant concepts, as it is the case at the ISAB IGCC (non integration). The V94.2/2K gas turbines are proven with syngas produced from coal or refinery residues as well as with steel-mill recovery gas and allow extraction of process air for the air separation unit.

Beside gasification also steel-making processes are sources for low-BTU gases. For power augmentation and improving the flame stability the recovered BFG (blast furnace gas) and COG (coke oven gas) may to be conditioned before combustion. Different configurations are considerable. At Elettra GLT combined cycle power plant (Servola, Italy) natural gas is added for this purpose leading to a fuel gas heat content of about 7.5 MJ/kg. Table 2 shows the resulting upgraded fuel gas which is fed to one V94.2. Back-up fuel is natural gas.

Table 2: Design fuel gas for Elettra GLT combined cycle  
(Blast furnace gas + coke oven gas + natural gas)

Gas composition [% vol]						Lower heating value	H <sub>2</sub> /CO (vol)
H <sub>2</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> + others	CH <sub>4</sub>	H <sub>2</sub> O		
9.0	16.3	13.6	41.0	14.6	5.5	209 BTU/SCF 7.2 MJ/kg	0.55

Based on V94.2K the turnkey concept of a standardized IGCC plant for power production from refinery residues has been elaborated applying the Shell Gasification Process (SGP) [2]. The plant size was defined to a 500 MW class because detailed analyses of refinery locations have concluded that a 500 MW IGCC power block corresponds most advantageously to typical and accessible refinery sizes. Gasification and gas turbine are arranged as dual trains and for operational reasons a partial air side integration concept (50 %) has been assumed. Fuel oil is used as a secondary fuel for combined cycle operation and for start-up purpose.

Table 3 summarizes the design conditions and performance data. With the given conditions and visbreaker residue as feedstock a gross output of about 560 MW is achieved. The internal power consumption of the plant is dominated by the ASU compressors which contribute more than 70 % to the total auxiliary power demand. The resulting net plant output of about 485 MW corresponds with a net efficiency close to 43 %.

Table 3: Performance data of the standardized refinery residues based IGCC power plant

Feedstock (Visbreaker residue with 5 % sulfur)	1131.9 MJ/s
Gross power output	
Gas turbine (2 x V94.2K)	2 x 166.6 MW
Steam turbine	219.5 MW
Expander	6.9 MW
Total	559.6 MW
Gross efficiency (LHV)	49.4 %
Power demand	
Gas island	3.2 MW
Air separatoin unit	55.6 MW
Power island	15.9 MW
Total	74.7 MW
Net power output	484.9 MW
Net efficiency	42.8 %
ISO conditions (1.013 bar, 15 °C, rel. humiditiy 60 %), elevation 8 m, condenser pressure at design 0.055 bar, NO <sub>x</sub> emission 25 ppmv	

### **Experience with Low-BTU Gas Applications**

Siemens' IGCC experience originates from long time operating gas turbines for syngases from gasification as well as for other low-BTU gases, e.g. blast-furnace gas (Table 4).

Table 4: Application of Siemens gas turbine technology for utilization of syngas and steel making recovery gas.

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	VM5	Blast-furnace-gas-fired, gas turbine as compressor drive	1960/ 2000
U. S. Steel Corp. (Chicago, USA)	20 MW	CW201	Blast-furnace-gas-fired gas turbine	1960
STEAG/Kellermann (Lünen, Germany)	163 MW	V93	First CC plant in the world with integrated LURGI coal gasification (hard coal)	1972
DOW Chemicals (Plaquemine, USA)	208 MW <sup>1)</sup>	2 x W501D5	CC plant with integrated DOW coal gasification	1987
Nuon Power Buggenum (Buggenum, Netherlands)	253 MW	V94.2	CC plant with integrated SHELL coal gasification (hard coal and biomass blend)	1993 <sup>2)</sup> 1994/95
ELCOGAS (Puertollano, Spain)	300 MW	V94.3	CC plant with integrated PRENFLO coal gasification (coal and petroleum coke blend)	1996 <sup>2)</sup> 1997/98
ISAB Energy (Priolo Gargallo, Italy)	521 MW	2 x V94.2K	CC plant with integrated TEXACO heavy-oil gasification (asphalt)	1998 <sup>3)</sup> 1999
ELETTRA GLT (Servola, Italy)	180 MW	V94.2K	CC plant with steel-making recovery gas	2000
EniPower (Sannazzaro, Italy)	250 MW	V94.2K	CC plant with integrated SHELL heavy-oil gasification	2005
1) 160 MW from syngas and 48 MW from natural gas 2) Natural gas firing 3) Oil firing				

## 2.2 The European Large-Scale IGCC Plants

Main data and features are listed in Table 5 for the DOW Plaquemine plant, that has been operated on syngas for a number of years, and the three European large-scale IGCC plants, Nuon Power Buggenum, ELCOGAS/Puertollano and ISAB Energy/Priolo, which have been successfully operating over last few years. The Shell coal gasification based Nuon plant is now in its eighth year of syngas operation. Due to changing market conditions and power supply requirements several modifications have been implemented or are under consideration [3]: Co-gasification or even co-firing of biomass feedstock aim at increasing fuel flexibility and at partly producing CO<sub>2</sub> neutral power. By adding natural gas to the syngas the load changing capability had been improved.

The two V94.2K gas turbines applied at ISAB Energy IGCC plant are in satisfying operation for about three years now. After the first year deposits on the burner outlet cropped up caused by unstable nickel carbonyl impurities. These deposits may modify the aerodynamics and finally result in burner overheating and damages. CFD analyses and tests done by Siemens' licensee Ansaldo Energia led to a modified, more robust burner design and to improved operational behavior [4].

Table 5: Main data of IGCC power plants applying Siemens gas turbine technology.

	<b>DOW Plaquemine (USA)</b>	<b>Nuon Power Buggenum (NL)</b>	<b>Elcogas Puertollano (E)</b>	<b>ISAB Energy Priolo Gargallo (I)</b>
Feedstock	Coal	Coal (recently mixed with biomass)	Coal/petroleum coke	Asphalt
Gasification	DOW (predecessor of ConocoPhillips' E-Gas)	Shell	Prenflo	Texaco
Fuel gas temperature	149 °C/ 300 °F	300 °C/ 572 °F	302 °C/ 576 °F	195 °C/ 383 °F
Fuel gas compositions	% vol	% vol	% vol	% vol
H <sub>2</sub>	41.4	12.3	10.7	31.3
CO	38.5	24.8	29.2	28.5
CO <sub>2</sub>	18.5	0.8	1.9	3.2
N <sub>2</sub>	1.5	42.0	53.1	-
CH <sub>4</sub>	0.1	-	0.01	-
Ar	-	0.6	0.6	-
H <sub>2</sub> O	-	19.1	4.2	36.9
O <sub>2</sub>	-	0.4	0.3	-
H <sub>2</sub> /CO ratio (vol)	1.07	0.50	0.36	1.10
Lower heating value (LHV)	239 BTU/SCF 10.4 MJ/kg	113 BTU/SCF 4.3 MJ/kg	123 BTU/SCF 4.3 MJ/kg	174 BTU/SCF 9.1 MJ/kg
Secondary fuel	Natural gas	Natural gas	Natural gas	Fuel oil
Gas turbine	2 X W501D5	1 x V94.2	1 x V94.3	2 x V94.2K
Air extraction from GT of ASU input	0 %	100 %	100 %	0 %
of GT compr. flow	0 %	16 %	18 %	0 %
Nitrogen integration	0 %	100 %	100 %	0 %
Net power output	208 MW	253 MW	300 MW	521 MW
Net efficiency (LHV)	Not available	43.2 %	45.0 %*)	< 40.0 %

\*) ISO conditions and use of high quality hard coal

### 3 The ELCOGAS IGCC Plant

#### 3.1 Status

ELCOGAS' power plant has been operated as NGCC since 1996 and as IGCC since 1998. The plant has been operating in 2001 and 2002 more than 5,100 hours/year as IGCC and more than 7,000 hours/year as total operating time (syngas plus natural gas), demonstrating its competitiveness in the Spanish liberalized electricity market. (Figure 3)

Availability of gasification island has been increasing in that time, which can be considered as the learning required time due to the adaptations of auxiliary systems mainly: Handling of solids (fuel, slag and fly ash) and raw gas cleaning (filtering, washing and desulfurization) systems.

Gas turbine (V94.3) performance is yet requiring preventive inspections of combustion chambers, mainly due to the observed impairment of ceramic tiles and depending on the findings and operating parameters.

Present year, after 50,000 EOH overhaul, gas turbine burners have been changed to a new model, in symmetric configuration, looking for better combustion conditions with syngas, and a new control concept has been installed, too, to optimize transients response, looking for a more stable operation to extend life of components. Good results are expected to be confirmed after enough operating hours.

The experience that has been accumulated is a very appreciable basis to be considered in the development of following generation of IGCC power plants to get an optimal design of main equipment, and specifically in aspects related to process integration.

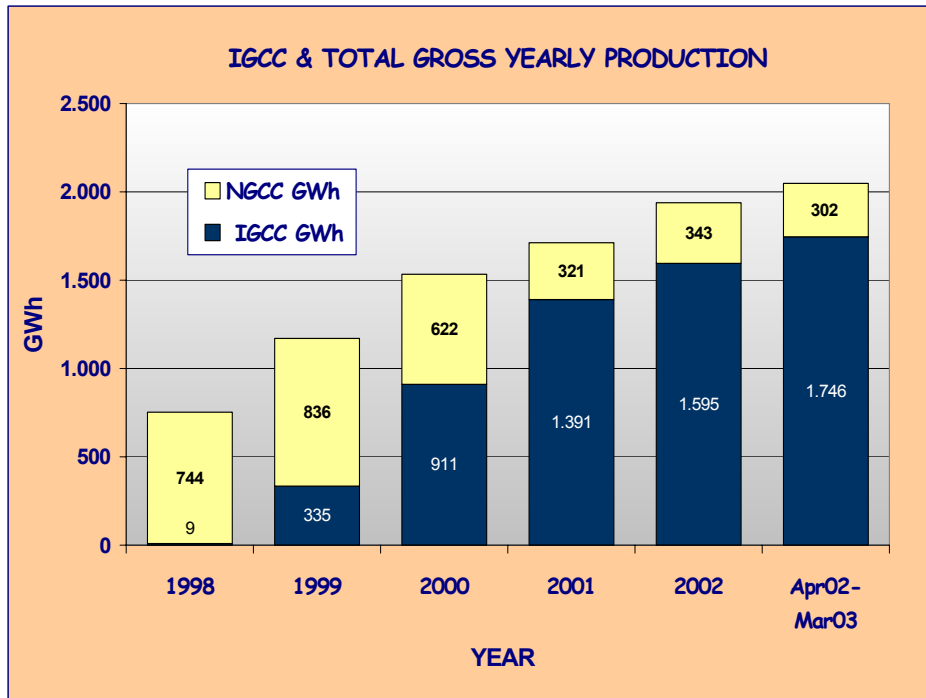


Figure 3: Operation experience at ELCOGAS IGCC power plant.

### 3.2 Modifications of the Overall Control System

IGCC power plant economics and reliability strongly depend on the automation concept optimized for the selected air and nitrogen integration between air separation unit and gas turbine. Each integration approach leads to a different level of operational and control complexity growing from non air-side integration to fully integration with nitrogen return for syngas dilution. While operational complexity increases with the degree of integration, fully integrated concepts do have advantages with respect to plant investment (e.g. no additional air compressor necessary) and to improved efficiency.

Hence the IGCC Puertollano was designed as a fully integrated concept and appropriate unit control features were elaborated to meet fully integrated requirements. After several years of operation the concept has been proven and valuable information is available now to further improve the fully integrated approach. Based on those data and experience, pressure control on the extracted air side over the full gas turbine load range has been installed in order to operate the extracted air flow as smoothly as possible and to minimize even minor gas turbine temperature fluctuations. It is expected that this improvement will contribute to extending the operational periods between gas turbine inspections and to reduce operator activities during start-up and load changes. At the air separation unit the integrated control concept consists of oxygen and nitrogen flow control and at the gas turbine side pressure control which provides stable conditions at air separation inlet. The gas turbine exhaust gas temperature is controlled by the fuel control valves and the compressor end pressure by the inlet guide vanes. Load following mode requested by the load dispatcher is controlled by gas turbine inlet guide vane. [5]

### 3.3 Robust Combustion Technology Applied

At ELCOGAS IGCC one Siemens V94.3 is in operation burning syngas from coal and petcoke gasification since 1998. The gas turbine has proven a good performance on syngas. However, inspections of combustion chambers have shown deposits on burners and first row vanes and indications of partial overheating traces on the burners as well as tile deterioration.

For further improving operational availability a new syngas burner nozzle design has been developed and introduced in July 2003, derived from the ISAB modifications which resulted in less sensitivity against deposit formation. This new design has three advantages for Puertollano plant: (1) Shape of flame is more elongated. (2) Axial swirlers are less sensible against overheating traces. (3) Deposit formations that could provoke flame instability are prevented.

The initially installed burner design with segments is a very proven design and has demonstrated its reliability at the Nuon plant. This design is the most favorite one because of its excellent mixing behavior, which finally leads to very low  $\text{NO}_x$  emissions. But when a more stable design is required, the new advanced nozzle is preferred because of its robustness against deposit formations and less aggressiveness to tiles (Figure 4). In ELCOGAS case,  $\text{NO}_x$  emissions are in the same range than burners with segments, due to the particular treatment and preparation of syngas before it is fed to the burners (water saturation and high nitrogen dilution).

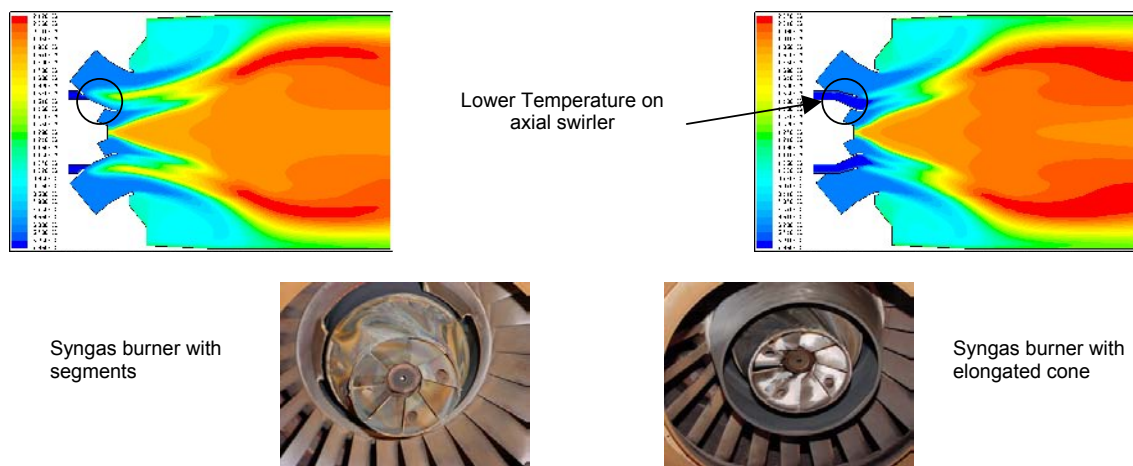


Figure 4: Siemens syngas burner nozzle designs.

## 4 IGCC Development Activities

New market conditions, the adaptation to the progress made in current gas turbine technology and novel application fields are the incitements for further development work on IGCC technology. In the past, Siemens with ELCOGAS and others have been involved in various IGCC R&D programs initiated by the EC and the U.S. DOE. This year new



projects have been announced, mostly aiming at improved gas turbine technology for syngas and new plant concepts. They are carried out in close cooperation with utilities, industrial partners as well as research institutes in Europe and the United States. Siemens and ELCOGAS are involved in two of the projects in Europe. In the United States, Siemens Westinghouse is engaged in a DOE co-funded catalytic combustion program which is focusing at achieving single digit  $\text{NO}_x$  values for future syngas application.

#### **4.1 Burner Systems for Syngas Application in Vx4.3A's Annular Combustion Chamber**

The application of the latest gas turbine technology in IGCC power plants is a vital next step in improving IGCC economics. This way, IGCC technology can profit from the enhanced efficiency resulting from higher turbine inlet temperature. Together with the higher unit power output this would lead to lower specific investment and improve IGCC's competitiveness to conventional steam power plants.

One of the main difference between the standard combustion system of the existing, low firing temperature gas turbines and the current more advanced engines is the design of the combustion chamber. The compact design results in low residence time and thus decreased  $\text{NO}_x$  formation. On the other side, for ensuring complete burnout of the different fuels (syngas, natural gas, fuel oil) combustor length has to be considered.

For the development of advanced burner technology for V94.3A's annular combustion chamber a strong consortium has been formed. The three-year project, titled "High efficient gas turbine for syngas application" (HEGSA), is promoted by the EC under the 5<sup>th</sup> Framework Program (FP 5). Beside the coordinator Siemens and its licensee Ansaldo Energia several European research institutes and Utilities bring in their knowledge and experience (Figure 5).

In the first phase, all operational and market driven requirements are specified, for example the range of fuels to be considered or the load changing characteristics. The combustor design work starts from the proven silo-type. Modifications necessary for the integration into the advanced Vx4.3A as well as for  $\text{NO}_x$  emissions reduction and improved operational/fuel flexibility lead to a prototype design. This phase is supported by computational fluid dynamics (CFD) simulations. The calculation model will be adjusted especially to the specific combustion conditions of syngas. Thermo-acoustic aspects of syngas combustion, which are of high priority in terms of operational behavior and availability, are the further objectives. This is supported by small scale generic thermo-acoustic tests. Based on the design and simulation work, a prototype of the advanced combustor is tested in an adapted single burner test rig under atmospheric and pressurized conditions.

EC project NNE5/644/2001 (HEGSA)

### **High Efficient Gas Turbine with Syngas Application**

#### **Targets**

- Increasing theoretical and technological knowledge of syngas combustion
- Improving the flexibility of current gas turbine syngas combustion systems
- Developing an advanced combustion system for annular burner technology operating at higher pressure and temperature using low-BTU syngases

#### **Scope**

Specification of requirements - adjusted CFD simulations including generic burner experiments - thermo-acoustic investigations - design studies - prototype design - atmospheric and pressure combustion tests

#### **Partners**

- Siemens AG PG (Coordinator, D)
- ANSALDO ENERGIA Spa (I)
- Universiteit Twente (NL)
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (D)
- Enel Produzione SpA (I)
- NV NUON Energy Trade & Wholesale (NL)

#### **Duration**

01/2003 – 12/2005

Figure 5: Essentials of EC FP5 project HEGSA.

## **4.2 Ultra Low-NO<sub>x</sub> Combustion Technology**

Under the sponsorship of the U.S. DOE's National Energy Technology Laboratory, a team of organizations led by Siemens Westinghouse Power Corporation have just begun a three-year research and development program focusing on catalytic combustor for fuel flexible turbines. In this program, the team will develop and demonstrate a cost effective catalytic-based turbine combustor that will achieve the aggressive target of less than 2 parts per million NO<sub>x</sub> emissions at the turbine exhaust without the need for expensive back-end after treatment systems currently employed in gas turbine combined cycle generating plants.

The catalytic combustor will be suitable both for retrofit into the installed base of operating turbines and also for deployment in the latest generation of advanced, high firing-temperature turbines, while achieving the low emissions objective at even the high firing temperatures of advanced turbines. The combustor will support fuel-flexible power generating facilities, with equal performance capabilities when operating on either conventional natural gas fuels or on synthetic fuels derived from coal, petcoke, or residual oil. The program culminates in the demonstration of the combustor on syngas at the Power Systems Development Facility in Wilsonville, AL.

## **4.3 Next Generation IGCC Power Plant**

In 1992 the IGCC plant at Puertollano was launched as a EC THERMIE Targeted Project to demonstrate the feasibility of European IGCC technology. Operating and improving the first generation IGCC plants which are in commercial operation for long time revealed potential for cost reduction and weak points necessary to address for a second plant generation. With the knowledge gained and considering technical progress achieved in the meantime, it is possible to define plant concepts with enhanced efficiency and environmental behavior, as well as with lower plant cost, thus obtaining a technology ready for the today's market.

Therefore, ELCOGAS initiated and coordinates a R&D project under EC's CARNOT program (Figure 6). In contrast to FP 5 this Energy Framework Programme is focusing on the two last stages of technology maturity namely commercialization and market success. The project has been finally contracted in July 2003.

CARNOT project 4.1004/D/02-002/2002	
<b>Pre-Engineering Studies for a New IGCC Plant Based on Puertollano ELCOGAS Plant Experience</b>	
<b>Targets</b>	
<ul style="list-style-type: none"> <li>➤ Definition of a Second Generation IGCC plant concept</li> <li>➤ Assessment of an optional pre-combustion CO<sub>2</sub> removal</li> <li>➤ Dissemination of IGCC technology capability for clean and efficient power generation</li> </ul>	
<b>Scope</b>	
Compilation of relevant plant operation data - definition of the potential of improvement - evaluation of technical, environmental and other general boundary conditions – definition of main process units – assessment of CO <sub>2</sub> capture and H <sub>2</sub> co-production – design – market potential emphasizing Russia - dissemination	
<b>Partners</b>	<b>Duration</b>
<ul style="list-style-type: none"> <li>• ELCOGAS S.A. (Coordinator, E)</li> <li>• UHDE GmbH (D)</li> <li>• Siemens AG PG (D)</li> </ul>	08/2003 – 01/2005

Figure 6: Essentials of ELCOGAS' CARNOT project.

One essential component intended for the concept is the V94.3A which allows to increase efficiency and specific power output. In a further step CO<sub>2</sub> capture will be considered as a means to mitigate global warming problem, as accorded in the Kyoto Protocol. Already the existing plant has a strong relation to refinery operation via the petroleum coke feedstock. Next IGCC plants may have interfaces also on the product side, mainly by supplying hydrogen or steam to the refinery. These will be considered in detail in the project MIGREYD (see chapter 4.4)

#### 4.4 Concepts for Future Gasification-Based Energy Plants

IGCC applications will be increasingly limited not only to power generation but will extend to CHP (combined heat and power) or even to co- or polygeneration [6]. The amounts of syngas used for power generation or converted to fuels and chemicals will depend on market demands. The goal of co-production is to fully utilize the feedstock and maximize revenue streams. Gasification and power generation could operate independently to a certain extent and this could lead to an economical optimum.

One essential application field for cogeneration, especially hydrogen production including CHP, is the refinery industry. There is an increasing tendency towards light hydrogen-enriched chemicals simultaneously resulting in a rising amount of heavy residues which would have to be disposed off. From the existing refineries about 300 Mt/a of liquid residues accrues, which corresponds to a total IGCC potential of about 170 GW<sub>el</sub>. Due to various restrictions, e.g. minimum refinery capacity, 90 GW<sub>el</sub> are estimated to be used. The worldwide refining industry added a significant amount of capacity last year which reverses a downward trend during the last two years. Through 2010 an additional IGCC

potential of 30 GW<sub>el</sub> may result from new capacity additions which are expected based on recent oil consumption projections by IEA. This ends up in a total IGCC potential of 120 GW<sub>el</sub> worldwide.

Under coordination of University Duisburg-Essen (Germany) and together with other European institutions Siemens and ELCOGAS have recently started the FP 5 project "Modular IGCC concepts for in-refinery energy and hydrogen supply" (MIGREYD) [7]. Project target is the development of concepts for optimally combining power generation and co-production within a refinery's structure. The concepts should be flexible in terms of feedstock, e.g. co-gasification of biomass and residues, and of products. Synergetic effects lead to saving primary resources as well as to sustainable pollution control including a significant decrease of the total plant's CO<sub>2</sub> emission ("green refinery") (Figure 7).

EC project NNE5-2001-670 (MIGREYD)	
<b>Modular IGCC Concepts for In-Refinery Energy and Hydrogen Supply</b>	
<b>Targets</b>	
<ul style="list-style-type: none"> <li>➤ Developing the concept of a "green refinery": Reduction of CO<sub>2</sub> emissions by integrating IGCC power plants into refineries</li> <li>➤ Preparation of optimized modular plant structures aiming at standardisation and cost reduction</li> <li>➤ Sustainable pollution control and substitution of high-grade fossil fuels</li> </ul>	
<b>Scope</b>	
Market research of refinery residues, H <sub>2</sub> - definition of project data basis - generation of the modular plant structure including process routes for H <sub>2</sub> production and power generation - thermodynamic optimization - evaluation of environmental benefits - co-gasification of biomass - integration of fuel cell topping cycle - economical evaluation - dissemination	
<b>Partners</b>	<b>Duration</b>
<ul style="list-style-type: none"> <li>• University of Essen (Coordinator, D)</li> <li>• Siemens AG PG (D)</li> <li>• Continental Engineers (NL)</li> <li>• Energy Research Centre of the Netherlands (NL)</li> </ul>	07/2003 – 06/2006  <ul style="list-style-type: none"> <li>• ELCOGAS S.A. (E)</li> <li>• Instituto Superior Técnico (P)</li> </ul>

Figure 7: Essentials of EC FP5 project MIGREYD.

Figure 8 gives a rough overview on the plant structure including alternative variants for the individual units. The most promising concepts will be conceptually engineered taking site-specific conditions into account. Environmental benefits such as co-gasification of biomass to the largest possible extent and even CO<sub>2</sub> mitigation strategies will be evaluated. Such concepts where hydrogen is produced not only for refining purposes are the pathways for future fuel cells applications. Depending on an available infrastructure this would open the traffic sector as well as distributed power generation for low-grade feedstock. For central applications high temperature fuel cells could be integrated as topping cycle to IGCC and thus be a highly efficient and elegant option for CO<sub>2</sub> control. This finally means bridging between conventional fossil fuel and further hydrogen-based power supply. However, such gasification-based energy plants are complex and thus operationally challenging.

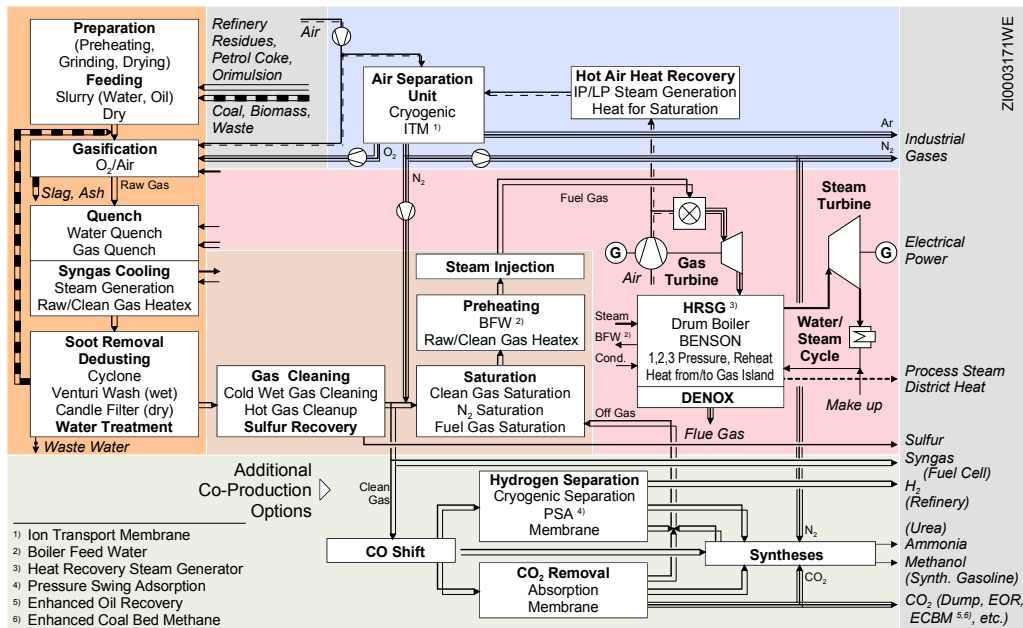


Figure 8: IGCC as center of advanced energy complexes.

## 5 Outlook

The problem of climate change has initiated big endeavors for efficiency increase as well as techniques for CO<sub>2</sub> capture. IGCC technology has a high efficiency potential and is open for effective pre-combustion CO<sub>2</sub> removal: Processes for CO<sub>2</sub> separation from the pressurized fuel gas are state-of-the-art and lead to an only moderate efficiency decrease of typically 5 to 7 % points (product CO<sub>2</sub> at gaseous state) [8]. An additional clear efficiency enhancement is expected from novel air separation technology via ceramic, highly selective membranes. Applying these ion transport membranes (ITM) instead of cryogenic processes should also decrease costs [9]. Because being operated at high temperature, ITM technology is ideally suited for integration with IGCC. Also future oxyfuel based processes where CO<sub>2</sub> is separated from the flue gas by simply condensing the water content will profit.

The development of ITM technology is pushed worldwide, also as a research target of the Department of Energy's (DOE) Vision 21 program. Siemens Westinghouse recently entered a project which is led by Air Products for evaluation of integrating ITM technology into IGCC plants based on the advanced W501G.

Under the leadership of the Swedish utility Vattenfall AB an Integrated Project dealing with the different aspects of CO<sub>2</sub>-capture from power plants has been proposed under EC's 6<sup>th</sup> Framework Program to be started in 2004. The project, called "Enhanced Capture of CO<sub>2</sub>" (ENCAP), brings together over 30 European industrial and research organizations as well as utilities. Siemens is mainly dealing with pre-combustion decarbonization technologies with an emphasize on developing combustion system for hydrogen-rich gases. Other subjects are principle concept finding and the a.m. oxygen production via membranes.

Within the scope of ENCAP Siemens will investigate the fundamentals of hydrogen combustion for V-engine technology. In this context the major challenges are the high reactivity of H<sub>2</sub> compared to typical syngas or natural gas and the higher adiabatic flame temperatures which will increase the NO<sub>x</sub> emissions.

The companies' commitments to the various projects as well as the support by national and international organizations bear out the strong interest in further developing IGCC technology. As a result of these programs, IGCC's inherent features of feedstock and product flexibility as well as its efficiency and environmental advantages, will be improved and will lead to improved market opportunities.

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