Technical Assistance Consultant's Report

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People's Republic of China: Capacity Strengthening in Planning and Implementation of Integrated Gasification Combined Cycle Plant

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For Greengen Company Ltd

Asian Development Bank

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Executing Agency:

GREENGEN GREENGEN CO.,LTD.

REPORT OF CONSULTANT

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ELCOGAS

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Asian Development Bank

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Summary

Assessment of the project is that technical risks are according to the status of IGCC technology.

IGCC technology has been proved as feasible, and after three generations of demonstration commercial scale plants is prepared for deployment but is not yet deployed.

Tianjin project is framed in the most feasible tendencies for power generation under future environment regulations and warranty of supply considering national conditions and resources.

Main challenge of Tianjin IGCC project is the construction of a plant first of its kind, without a reference of identical plant. Tianjin project management knows and is facing all the aspects to deal that kind of projects as international good practices do advise.

The major risk, that is the associated risks to the first gasifier of TPRI design at the scale of the project, is minimised since the gasifier has been developed in several years of tests at minor scales and it is based on concepts that have been probed in existing gasifiers, taking their advantages and improving their weaknesses.

Therefore the general assessment from consultant is that the technical risks of the project are minimal; in spite of it can have a character of demonstration of technology.

Considering that with this kind of projects, the experience is an important point to have success on performance, schedule and budget; in chapter 3 some commentaries are described, based on the experience of consultant.

Those comments have been selected as comments that can help to achieve the ultimate goal in a more direct way and they are not presented as a criticism. Some of them are based in the construction and operation experience of Puertollano IGCC and others existing projects, without being possible to compare with Tianjin project since it is yet in the status of design.

GreenGen knows and understands the relevancy of those commentaries, which are coming from the experience in the kind of projects, and current organisation management has expressed clear intention to consider measures to reduce the described risks.

1. Introduction

Asian Development Bank has contracted the services of Francisco García Peña to the firm ELCOGAS S.A. to perform the activities that are defined in Terms of Reference of the contract S16811which confirmation of acceptance was signed on December 1st, 2008.

The contracted service, in summary, consists on Technical Assistance, as international Integrated Gasification Combined Cycle (IGCC) Plant Expert, to analyse the project that GreenGen Co. is developing to install a 250 MWe IGCC plant in Tianjin (PRC).

The assistance is focused in analysing specifically the technical aspects in comparison with existing IGCC plants around the world, considering the current status of art of the related technologies. Main target is to disseminate lessons learned in others existing IGCC plants, to identify potential technical risks of GreenGen IGCC project, and to propose recommendations to mitigate these risks.

The work was scheduled to be done in 30 intermittent days between January 14th, and April 30th of year 2009, with the following steps:

a) Study of technical information that GreenGen deliver to consultant under petition.

b) Meetings in Beijing, GreenGen offices, between consultant and GreenGen Tianjin IGCC project staff to analyse information and to disseminate main lessons learned in the IGCC of ELCOGAS in Puertollano (Spain). Meeting in Beijing with National Consultant Prof. Yao Quiang.

c) Elaboration of a report draft to be commented by ADB.

d) Issue, presentation, and discussion with GreenGen staff of final report and recommendations.

2. International background

Coal

Electricity largely is produced from fossil fuels, and coal is the predominant fuel choice all around the world. Coal-fired power plants supply more than half of the electricity consumed in developed countries. Coal has become the primary fuel for affordable and reliable electric power production because it is relatively easy to transport and use and because it is social-geographic-political diversified, with indigenous coal resources in many countries.

In exploiting the benefits of electricity generated from coal and other fossil fuels, societies face many environmental quality challenges. During the last few decades, producers of coal-based electricity in developed countries have successfully responded to ever-more-stringent regulations to control emissions from coal plants (particulates, sulfur oxides, nitrogen oxides, and, more recently, mercury). Now, additionally, CO_2 concentrations in the atmosphere that could result in global climate change pose a new challenge. As the widest and most recognised scientific community is claiming, the need to limit anthropogenic emissions of CO_2 and other GreenHouseGases is in the agenda of energy stakeholders and it has become a familiar topic among policymakers and the public.

Climate Change

About CO_2 emission reduction all relevant reports (IPCC, IEA, EPRI, European Technology Platforms, …) are pointing to three clear actions as required to mitigate climate change:

a) Improvement of efficiency.

b) Increasing use of renewable energy sources.

c) Developing CO_2 capture and storage. CCS.

As power industry knows very well no one technology can be the winner. Diversification is a requirement to warranty sustainable supply. Therefore to achieve some success is necessary, at least, to work in the three former areas.

IGCC and GHG

Among all range of technologies, power production by Integrated Gasification with Combined Cycle (IGCC) is, a priori, the most promising technology:

a) **Efficiency**. Since it uses a combined cycle to generate electricity with the synthetic gas produced by gasification of almost any carbon primary fuel, the net efficiency is between 3 and 10 % higher than any other demonstrated technology using the same primary fuel (i.e. coal). What represents directly a reduction up to 20% of CO_2 emissions.

b) **Renewable**. IGCC technology permits the easiest cogasification of a wide range of biomass with coal, or other fossil fuels. Without relevant reduction in net efficiency, large amounts of biomass can be used as it is demonstrated mainly in Buggenum and in Puertollano IGCCs (up to 600 and 250 t/d of biomass in cogasification at 30% and 10% rates respectively). That can represent another 10-30% CO_2 emission reduction in power generation.

c) **CCS**. Currently, when the industry requires to produce CO_2 it is produced by gasification of solid-liquid fuels, or steam reforming of gas fuels. That means that the industry status of art to separate CO_2 in the use of fossil fuels (CO_2 capture) is by gasification (reforming is a kind of gasification too), obtaining as energy carrier a synthetic gas with a high concentration in H_2. Therefore IGCC requires only adapting the design to separate CO_2 from syngas by integrating the developed technology for H_2 and chemicals with the electricity generation. While other technologies require drastic changes, and R&D to decrease high costs.

But, additionally IGCC has the following advantages from the point of view of GHG emission reduction:

- Carbon Capture with IGCC technology implies to obtain a syngas with high H_2 concentrations that can be used as fuel in fuel cells, or to obtain liquid fuels as substitute of gasoline with less carbon intensity. That means it is the only carbon capture system in the use of fossil fuels or biomass that permit to decrease emissions too in the transport sector.
- The syngas obtained from gasification is cleaned to levels that permit to use it as fuel in a gas turbine instead of natural gas. That means, additionally to the above CO_2 considerations, that the emissions of other GHG or contaminants (SOx, NOx, particulates, or mercury) is similar or better than the emissions of a combined cycle with natural gas, very far of the best available technologies to use coal. And with the best potential to improve since the cleaning is done on site, before combustion, and it permits easier adaptations to more stringent requirements.

On the other hand, as disadvantages when it is compared with other technologies, the experience of demonstration projects is pointing to:

a) Technology requires adaptation to the power production. Power industry requires developing plants to learn the problematic of the technology and the integration of "chemical plants" (gasification and syngas purification) in power plants (combined cycle). Demonstration projects are required at commercial scales.

b) Since the plant is more complex than other power technology, the investment uses to be higher too. That aspect, in the world economic situation of last years has been the main burden to disseminate its use and to improve life quality from environment point of view.

IGCC demonstration plants

Gasification of solid fuels to obtain a synthesis gas as energy carrier or intermediate material to obtain chemical products or liquid fuels has been used since more than a century around the world.

The concept of generating electricity by gasifying coal and using the synthesis gas as fuel in a gas turbine was suggested since 1950.

The first three plants to put this idea into it practice at a commercial scale were Lünen (Germany), Cool Water (CA-USA), and Plaquemine (LA-USA) between 1969 and 1987.

These three plants can be classified as prototypes and the experience gained with them was the basis for the next generation 0f 250-300 MWe plants which were all put into service in the 1990's.

Most relevant of them, due to the clear character of demonstration plants, are:

Nuon Power, Buggenum, The Netherlands

Nuon Power's 253 MWe (net) IGCC power plant in Buggenum, The Netherlands, was taken into service as a demonstration facility in 1994. The plant was built by Demkolec, a consortium of Dutch power producers, next to an existing coal fired power station on the River Maas.

The gasifier is a single dry-feed Shell SCGP unit with experience in chemical industry. And the Combined cycle is based on a Siemens V94.2 Gas Turbine.

The plant was designed for a wide range of imported, internationally traded coals. In the meantime the plant operates with a substantial component of biomass (up to 30%-mass tested).

Wabash River Energy, Terre Haute. USA

The 250 MWe (net) “Wabash River“ Project went on stream in October 1995 as the first of the USA-DOE supported IGCC power plants.

The project was developed jointly by Destec, at the time the owner of the gasification technology, which is today owned by ConocoPhillips and marketed as E-Gas and which had originally been developed by Dow Chemical, and PSI, owner of the existing conventional coal-fired Wabash River power station in Indiana and a subsidiary of Cinergy Corp.

The Combined Cycle Unit is based on a GE 7FA gas turbine.

Tampa Electric Company, Polk Power Station. USA

The 250 MWe (net) Polk Power Station in Florida was the second of the USA-DOE supported IGCC power plants to go on stream (September 1996). The plant has been continuously under the ownership of Tampa Electric Company. The plant design concept was largely based on up scaling the Cool Water 100 MWe demonstration plant in California.

The gasifier is a single-stage; slurry feed GEE Radiant Cooler design with subsequent fire-tube boiler. And the Combined Cycle Unit is based on a GE 7FA gas turbine.

Elcogas, Puertollano

The 295 MWe (net) Puertollano IGCC power plant in Spain went into operation in March 1998. The project was supported by the European Union’s Thermie program. Seven European power producers as well as a number of key component suppliers joined together to form the operating company ELCOGAS.

Gasifier is a PRENFLO license from Uhde, similar to Shell and Koppers gasifiers with dry feeding. The combined cycle is based on Siemens V94.3 Gas Turbine.

Those four plants were projects developed from Power industry.

Other IGCC, with similar innovative designs were installed by Chemical industry, with more experience in gasification and oriented to refinery sub products use in electricity production:

Valero, Delaware City

The plant was built by Motiva Enterprises at the Delaware City Refinery to gasify the coke produced in the refinery. The plant was taken into service on 2000.

The gasifiers (2) are GEE quench type, and combined cycle is based on two GE 6FA Gas Turbines.

Shell, Pernis

The plant serves to gasify refinery residues in the Shell refinery in Rotterdam-Pernis manufacturing hydrogen for use in the refinery and simultaneously producing about 130 MWe (gross) electric power.

The gasification plant uses 3 x 1/3 gasifiers. The gas turbine is built for syngas and natural gas operation (two GE MS 6541 B gas turbines).

ISAB, Priolo, Sicily

The nominal 512 MWe IGCC power plant which gasifies asphalt from the ISAB refinery in Priolo, Sicily was the first of three IGCCs to be built in Italian oil refineries at the end of the 1990s. The plant went into commercial operation in April of 2000.

The project was implemented by ISAB Energy, a joint venture of ERG Petroli and Mission Energy (USA), with two GEE quench gasifiers and a combined cycle based on two V94.2K Siemens gas turbines.

Sarlux, Sarroch, Sardinia

The nominal 550 MWe IGCC (gross) power plant gasifies refinery residues from the Saras refinery in Sardinia, with 3 gasifiers GEE water quenched, and a combined cycle based on three GE 9E gas turbines. In addition to the power produced the plant also supplies about 40000 Nm^3/h hydrogen and 185 t/h steam for process use in the refinery.

The project was implemented by Sarlux SpA, a joint venture between Saras S.a.r.l. and Enron (USA). The plant went into commercial operation in January 2001.

api Energia, Falconara, Italy

The nominal 250 MWe IGCC power plant which gasifies refinery residues at the api refinery in Falconara has installed two 50% GEE oil gasifiers with integrated water quench, and the Combined cycle unit is based on one Alstom (formerly ABB) 13E2A gas turbine.

The plant supplies 65 t/h process steam to the refinery, but does not supply any hydrogen. The project was implemented by api Energia, a joint venture of api, ABB and Texaco. The plant went into commercial operation in 2000.

Nippon Oil, Negishi, Japan

The 350 MWe IGCC plant which gasifies refinery residues from the NOC refinery in Negishi (Yokohama) was taken over into commercial operation in June 2003.

It has installed two 50% GEE oil gasifiers with integrated water quench, and the Combined cycle unit is based on a Mitsubishi 701F gas turbine.

IGCC projects now

All those projects have settled the basis for the following generations of IGCC plants as the clear option for current and future environment requirements with sustainable and economical fuels.

In that sense, along last years and all around the world a wide spread of IGCC announcements has been produced (for electricity, for chemicals and polygeneration, with and without carbon capture, for H_2 economy, with lower SOx and NOx emissions, to capture mercury, with coal, with pet-coke and other refinery wastes, municipal wastes, biomass, …).

Due, mainly, to the financial constrains and to the uncertainty of environment legislation differences between countries, unfortunately, the number of projects cancelled has been higher than the number of projects built up to now, but that situation requires only some time to change, what represents an opportunity for the industry of countries or companies that can afford it before.

To support that idea, only to point that at February 2009, the total of IGCC projects for power generation existing in the world, in the scale of more than 100 MWe, is 47. They are largely based on coal use, some of them even already commissioned, and the regional distribution is:

USA & Canada	24
China	10
European Union	4
Australia	3
India	2
Japan	2
South Africa	1
South Korea	1
Russia	1

The list of existing IGCC projects, out of China is shown in the following table, which is sorted by feedstock type.

OWNER	Place	Feedstock	Gasification	Turbine
Peabody Homeland Energy Solutions	USA	NR	EPIC	
Summit Pwr/TX Clean Energy	Texas	NR	Siemens	
First Energy/Consol	OH	NR		
Mohave Station	CA	NR		
Mountain Island Energy	Twin Falls, ID	NR		
Otter Creek	MT	NR		
Future Power PA Inc	Schuylkill, PA	Anthracite		
HRL/ Harbin Power	HRL/Harbin Victoria, Australia	Brown Coal	HRL Fluid Bed	
EPCOR Demo	Genesee Station, Alberta Can	Coal	1 x 500 MWh Siemens	
APGENCO/ BHEL/NTPC	Vijaywada, India	Coal	BHEL Fluid Bed	
Finland	Finland	Coal	Carbona	Existing 6B
J-Power/ Chugoku-Eagle	Hiroshima, Japan	Coal	Eagle	
Carbon Energy	Australia	Coal	Ergo/Exergy (UCG)	
Eskom	Majuba, S. Africa	Coal	Ergo/Exergy (UCG)	
Duke Energy Indiana	Edwardsport, IN	Coal	GEE Rad Quench	2 x GE 7FB
Clean Power CCPR&D	Nakoso, Japan	Coal	MHI Air Blown	MHI 701 DA
Powerfuel Pwr	Hatfield, UK	Coal	Shell Partial Quench	2 x 9FA+e
ZeroGen Stanwell	Queensland, Australia	Coal	Shell Partial Quench	GE 9FB size
Korea Western Power/Kepco	Taean, South Korea	Coal	Shell SCGP & SGTT	
Buffalo Energy Partners	Glenrock, Wyoming	Coal		
Midwest Generation/Edison	Illinois	Coal		
Sierra Pacific	Ely, Nevada	Coal		
Southern Cal Edison	Utah	Coal		
Global Energy	Lima, OH	Coal/Pet Coke		
Nizhnekansk Refinery	Russia	Heavy Oil	GEE	
Sokolovska uhelna	Czech Republic	Heavy Oil	Siemens	GEE 9Es
Mississippi Power Southern	Miss. USA	Lignite	KBR	
RWE	Germany	Lignite	Shell, Siemens or HTW	
St Lucie County/Geoplasma	Florida	MSW	Plasma Arc Gasification	
ENMAX	Calgary, Canada	NG/Coal	TBD	
Hydrogen Energy	Bakersfield, CA	Pet Coke	GEE 2 x 57 % Quench	GEE
Sask Power, et al	Canada	Pet Coke	TBD	TBD
Calpine	Gulf Coast	Pet Coke		
Hindustan PCL-Mittal	Punjab, India	Pet Coke		
Luminant	Texas	PRB		
Excelsior Energy - Mesaba	Holman, MN	PRB/Pet Coke	3 x 50 CoP E-Gas	SGT65000F
Luminant	Texas	Texas Lignite		

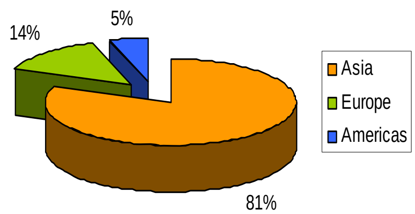
Gasification and IGCC in China

Looking at gasification plants, not only at IGCC applications, on a worldwide basis the main coal gasification activity is centred in China as can be seen in following figure (Gasification Technology Council).

GASIFICATION GROWTH

2004	2007
117 operative plants	138 operative plants
385 gasifiers	417 gasifiers
Capacity~45.000MWth	Capacity~56.000MWth
Feed: Coal 49% Residual petcoke 36%	Feed: Coal 55% Residual petcoke 32%
Products: Chemicals 37% F-T 36% Power 19%	Products: Chemicals 44% F-T 30% Power 18%

Shares of growth in world gasification capacity 2004-2010



Source: 2007 World Gasification Survey, Gasification Technologies Council

Growth of gasification in the world is clearly leaded by Asia industry.

Both imported and national developed technologies are being widely deployed in China.

GE has over 40 licenses with over 20 plants in operation, and Shell has 18 licenses with 11 plants in operation. Lurgi dry ash technology is used in 6 plants. Siemens, BGL and SES also have orders for their gasifiers.

It is known that China is developing several different gasification technologies. The most extended of which has been up to now the ECUST OMB process using slurry fed refractory lined gasifiers. There are 13 plants using 33 gasifiers in operation or planned in the next two years.

Dry coal-feed gasifiers with membrane wall design have also been developed and are in construction (i.e. TPRI gasifiers).

Currently, 31 new gasification projects out of a total of 143 existing in the world are being planned or built in China. 10 of them are based on IGCC technology for power generation with at least 3 based on national developed gasification technology.

One of those 3 Chinese IGCC projects is the 250 MW IGCC of Tianjin.

From an international perspective it is expected to see Chinese industry to offer its gasification technologies in the wider market place abroad.

Main conclusion of this introduction is that Tianjin IGCC project is coherent with main tendencies in new plants for power generation considering:

- Warranty of supply: China has one of the largest reserves of coal in the world (100 to 200 years).
- Increasing of electricity demand: As newly industrialised country, forecast for electricity demand is the highest increase in short and medium term.
- Environment protection demand and international agreements: Climate change. Kyoto. International trading threats and opportunities.
- Status of the art in power generation technologies: IGCC would be in 3rd or 4th generation of deployment which warranties enough optimisation of the technology about required investment and reliability.

3. Project analysis. GreenGen IGCC in Tianjin

3.1.Information and references

The information that has been used by consultant to perform the work is attached in annexes I to X of the report and it is described in the following:

Annex I. Tianjin IGCC project presentation

General presentation of the project done by North West Electric Power Design Institute (Nwepdi) in September 2008.

It includes description of the plant, main features of project islands and a cost analysis.

Annex II. Tianjin Construction Schedule

Schedule, enough detailed, of the construction, commissioning and some design activities, of the plant, where it is planned to start construction in December 2008 with cooling tower foundation.

Annex III. Tianjin organisation diagram

Organisation diagram of main companies or entities that are participating in the project.

Annex IV. Q&A about Heating Value limitations to gas turbine

Specific question that was answered by e-mail first, and during Beijing meetings, it was discussed with more detail.

Annex V. Presentation of Consultant about Puertollano IGCC experience

The presentation was used along Beijing meetings to explain main aspects of Elcogas-Puertollano experience about, company and project organisation, schedule, operation and maintenance focused in availability, other lessons learned, and R&D plan.

Annex VI. Question list from Tianjin project answered and discussed along Beijing meetings February 16th to 20th

Question list was followed as agenda in Beijing meetings with staff of Tianjin project. It describes the kind of technical aspects that were discussed in the meetings.

Annex VII. Start up sequence in Puertollano IGCC

The chart was used in Beijing meetings to explain the sequence of start up of the unit in Puertollano plant. The chart shows, with real time operation parameters, a full hot restart of the unit, with description of steps and main problematic of each one.

Annex VIII. Gasification temperature supervision in Puertollano IGCC

The chart was used to explain how is supervised the gasification reaction operating conditions at Puertollano plant. It shows used parameters and functions with real time data.

Annex IX. Nitrogen consumption in Puertollano IGCC

It is a real record of the procedure that is followed at Puertollano plant to supervise and to optimise the consumption of pure Nitrogen in the Puertollano plant. It shows by services and headers the design and real consumptions in an operative period of plant.

Annex X. Question of consultant and answers of Tianjin project

That list of questions was delivered by consultant to GreenGen representative, once those Beijing meetings, with Tianjin project staff, were finished.

It was done with the target of filling consultant gaps of information or to complete it in the points the consultant consider necessary to develop this report.

A data sheet, in excel file, was delivered too to be filled by GreenGen staff with the current status of detailed engineering and fabrication status.

In the annex, the answers and data, together with some solicited documents, are included.

3.2. Beijing meetings February 16th to 20th

Between 16th and 18th, meetings were developed in about 8 hours per day, between consultant and 25 to 30 persons of Tianjin project GreenGen staff, including the persons that are already working at site in preparation of construction and as future O&M personnel.

General dealing of that part was: Consultant started with a presentation and discussion of Puertollano IGCC experience centred in lessons learned. Then, the list of Tianjin staff questions was discussed point by point.

After those meetings, consultant prepared the list of questions and forms for status of attachments X, and last day, 20th, was dedicated to finish some aspects of the Tianjin staff questionnaire, and a general meeting with high management of GreenGen Co.

Additionally, a meeting with National Consultant Prof. Yao Quiang was maintained on 17th. In that meeting we can share our general point of views about the project in a national and international context.

3.3. Assessment of the project

Assessment of the project is that technical risks are according to the status of IGCC technology.

IGCC technology has been proved as feasible, and after 3 generations of demonstration commercial scale plants is prepared for deployment but is not yet deployed.

Main challenge of Tianjin IGCC project is the construction of a plant first of its kind, that is, without a reference of identical plant. And, as far as the consultant has been able to know, all the aspects to deal that kind of projects are being known and faced for the organisation of the project as good practices do advise.

The major risk, that is the associated risks to the first gasifier of TPRI design at the scale of the project, is minimised since it has being developed in several years of tests at minor scales and it is based on concepts that have been probed, and they are working, in existing gasifiers, taking their advantages and improving their weaknesses.

Therefore it is important to say, first at all, that the general assessment from consultant is that the technical risks of the project are minimal.

Considering that in this kind of projects, the experience is an important point to have success on performance, schedule and budget; in the following chapters some commentaries are described, based on the experience of consultant.

GreenGen knows and understands the relevancy of those commentaries and current organisation management has expressed a clear interest on them and a firm intention to consider measures to reduce the possible associated risks.

The following comments do not represent a criticism but as comments that can help achieve the ultimate goal in a more direct way. And some of them are based in the construction and operation experience of Puertollano IGCC and others existing projects, without being possible to compare with Tianjin project since it is yet in the status of design.

They have been selected from the point of view of what can be observed as a technical risk, together with the recommended actions to face it.

It is considered only the first phase of the project, 250 MWe IGCC, since it is the centre of the project in progress and it is the current subject of ADB's support.

3.3.1. General

Main aspect to consider is the general structure of the project. Combined cycle, Air Separation Unit and auxiliary systems and units are based on proved technology that is adapted to the particularity of the plant, as any other plant.

Gasification Island is the challenge of the project since it is based on a gasifier design that has been proved only at smaller scales than the commercial scale of the project.

That "new" design has the following strengths:

- It has been developed in a R&D program of Thermal Power Research Institute in several years of theoretical and practical studies.
- Experience of other gasifier designs applied to power production through IGCC concept has been available and considered.
- IGCC technology applied to clean coal uses is in a point near to extended deployment, after two or three generations of optimisation and preparation for a new step in contaminants control associated to power generation.

The weaknesses is that the gap between performance of equipment, like the gasifier, at laboratory or small scales and performance at commercial scale, integrated in an operational plant, is a large gap with a risk in costs mainly, what at the end is conditioning the technical solutions to the found problems, that anyone can be sure are being "discovered".

That means that based on previous tests at smaller scales, theoretical studies, and other gasifiers experience, the confidence on good performance at higher scales can be enough high to commit the high investment that any technology development at commercial scale requires. But the company has to be prepared for:

- New findings in the gasifier itself coming from unveiled aspects that can only be confirmed or studied in the scale. Such as velocities, reaction equilibrium, fuel grain size effect, volumes, temperature distribution, local effects, and other fabrication details that are very robust in small scales but that can not be so robust in larger scales.
- Mistakes in the development of the detailed engineering of the project since there is no reference plant. Any "well known" conventional process system or equipment requires adaptation to its integration with "new" equipment, systems or processes. That adaptation requires some

part of trial and error because to consider all possible aspects is not the best way of project engineering development with reasonable costs.

To face those expectable facts with success it is required, and enough, to provide a team to work specifically with those aspects that are not required in other projects that are based on proved and referenced plants.

That team has to count with personnel that has participated in the development of the new equipment, the gasifier, and with experimented professional people in the managing and development of detailed engineering for power and chemical industry.

That specific task requirement is relevant since the design and construction, but very much relevant during commissioning and first years of operation (1 to 3 years). After that, and progressively, the required resources can decrease significantly, up to reach an asymptotic level to deal the kind of aspects that long term operation unveils and to settle and consider the lessons that have been developed.

Participation of companies or persons with experience in IGCC projects and O&M is very convenient since it will decrease the number of mistakes and it will conduct to quicker solutions of findings. But what is basic is the participation of the people with the gasifier development knowledge, together with project plants engineering professionals.

Additionally, complementary to former general recommendation, sharing of information with other companies that are IGCC operators is always very much convenient.

In that sense to associate GrenGen to international existing user association, like Gasifier User Association, can improve the knowledge, international reference, and technical support.

To create some kind of similar association or collaboration agreement at national level, including IGCC plants of chemical industry, to coordinate activities and even to share spare parts and services, would be a clear benefit for users.

3.3.2. Design

Herein the commentaries that are related to engineering design aspects are described.

3.3.2.1. General Arrangement

General arrangement of the plant is rather extended in such a manner that some equipments of the plant are separated more than what processes efficiency would advise.

That has some clear advantages like possibilities of working in parallel in all areas during construction, an easier large equipment maintenance works, possibilities of increasing or modification of equipments, or a better and clear final appearance, but other inconveniences like:

- Looses in transport of materials and process fluids between islands and between equipments. Energy looses in steam transport between Gasification Island and combined cycle, and between Heat Recovery Steam Generator and Steam turbine, can be higher than usual and will require a specific work about insulation efficiency.
- Larger area to be covered by maintenance services. More difficulties to concentrate field supervision, which will require more personnel and a good communication system.

3.3.2.2. Heat & Mass balances

In the status of design it is indicated that H&M balances are in preliminary status. According to GreenGen staff that is due to few non-core figures that can have minor revision.

Since to go ahead with fabrication and detailed engineering, to have H&M balances in frozen status is basic reference for design and warranty tests, it would be very convenient to fix those details in order to permit the tightest schedule for the remaining detailed engineering and equipment supply.

3.3.2.3. Gasification

Main technical risks have been described before in general commentaries. Herein some particular aspects are commented accordingly to revised documents of annexes.

Carbon conversion rate.

It is expected greater than 99% in design conditions and with recirculation of fly ash to burners.

Probably it can be achieved in optimum conditions, but the average of a long period of operations, like a year, can be less than design conditions figures. The reasons are that in long term commercial operation there are transients or special operation modes where optimum reaction adjustments can not be maintained. E.g. start up, shut down, low load operations, changes of load, equipment incidences, etc.

Therefore is necessary to foreseen that the amount of unburned material can be higher than 1% along some considerable periods. For unburned material in fly ash a recycling system is foreseen, but major part of ash in the fuel is leaving the gasifier as slag, and unburned material in slag is a contaminant that is necessary to separate.

One of the values of the high temperature gasification is that most of the ash is leaving the process as crystallised slag where major part of heavy metals are bind and the waste can be handled as subproduct like no leachable slag. Unburned fuel in slag is a contaminant since it is a leachable material. In normal, optimum, operating conditions the unburned material is separated from slag by keeping the slag water clean of particulates through some kind of filtration where unburned particulates are separated like "slag fines". The amount of that material can be between 0,5% and 2,5 % of total fuel dust feeding and its heating value is high enough to design some system to recycle it like fuel.

To install a system to recycle those slag fines is a method to assure that the expected efficiency of the plant can be achieved or improved, and to assure the best environment performance with subproducts.

An area for mixing / recycling some products can help to handle overproduction of slag fines and to future programs of alternative fuels cogasification.

Syngas cooler inlet temperature.

It seems that the inlet temperature of raw gas to syngas cooler would be controlled with some cold gas recycling to keep it around 900ºC. This temperature can be too high.

900ºC can be enough to assure that fly ash will be in solid state. But it can not be enough to solidify other compounds that can be carried with the fly ash (metal compounds of sulphur e.g.). These kind of low melting temperature compounds would solidify in the first “cold” surface that they find, creating a lay of sticky material and promoting the grow up of deposits up to reach the blockage of the flow path, besides of impairing in heat transfer during normal operation.

In that case, industry tendency will be to install some kind of cleaning device as soot blowers that are used in conventional boilers to clean heat transfer surfaces. But that solution has new difficulties like the pressure of the gasifier since current soot blowers are developed to work into vessels without pressure.

A more clear solution is to foreseen a larger capacity of recirculation of filtered and cold “quench” syngas to reduce inlet temperature so far as reasonable to avoid too much penalisation in auxiliary consumptions and in piping and components sizing. The reduction of inlet temperature will be compensated by higher heat transfer coefficient at higher velocities.

In any case there will be compounds which melting point is too low to freeze enough to avoid the phenomena of sticky lay in cold surfaces. That means that as a regular preventive maintenance activity around syngas cooler must be to open and clean. The periodicity of that activity has to be determined during first operations.

Fly ash recirculation.

It is expected in Tianjin design that unburned material carried with fly ash can be too high to dispose fly ash out of the plant. In that case fly ash would be recycled as fuel. Design is considering a recirculation from fly ash filters directly to coal burners.

That system of recycling has following inconveniences:

- For recycling from downstream of gasifier to burners (upstream), to increase pressure at the fly ash outlet of filters is required. The best way to do that with high density solids transport is by another system of lock hoppers and feed been exclusively for fly ash. That implies more high cost pressure vessels and components.
- Proper regular feeding to burners is required to keep gasification reactions under control. To add another feeding system in parallel to coal dust feeding is an additional difficulty that will require tests and a quite good job of control tuning and maintenance.

A way for easier design, procurement, construction and commissioning, lower cost in equipment, and with very much less technical risks is to recycle fly ash, when it is necessary, to the outlet of grinding and drying systems.

Fuel dust feeding system.

In the system of sluicing and feeding of fuel to gasifier burners there are some aspects that can become critical:

- Since gasifier operating pressure is over 30 bar the required pressure of lock hoppers and feed bin will be between 35 and 40 bars. For dry feeding to gasifier it is necessary to transport the fuel dust in high density (400 to 600 Kg/m^3) and the difficulties to keep fuel fluidised enough to permit the controlled flow to burners are higher with higher pressures. Therefore a flexible and oversized system for fluidisation of vessels and pipes would be recommendable in order to mitigate required tuning and adjustment during commissioning and operation.
- Flow control of fuel dust feeding will require a flow measurement as feedback of the control loop. Existing commercial devices are not enough optimised for dust measurement in high density near to bulk density as dry feeding gasifiers require. To mitigate that uncertainty is necessary to install enough redundancies in operation, and in stock like spare parts. Sharing of information and parts with other dry-feeding operating IGCC plants will help and reduce risks.

Water-Steam Gasifier systems.

To cool syngas up to 340 ºC and to keep gasifier equipment and reaction chamber cooled there is a system with boiler feed water pumps, heat transfer surfaces, recirculation pumps, and drum to separate steam that is exported to steam uses and to the Combined Cycle.

These components, in the gasifier, with gas temperatures between 1.500 and 340 ºC, are working like they would in a large thermal power boiler, but its design is done mainly conditioned by gasification processes.

All the learning that is automatically incorporated in high power conventional boilers design is usually skipped in the “boiler” gasifier design.

Recommended actions to mitigate those risks are:

- To install a specific chemical control system for the boiler water of gasifier drum. In spite that boiler feed water to gasifier is coming from

Combined Cycle feed water tank, and there a chemical control system is installed; this system is designed to fit the requirement of combined cycle HRSG. That can condition the chemical treatment of gasifier boiler water, and in any case the physical separation between HRSG and gasifier boilers determine that a good feedback for chemical control in combined cycle can not be a good feedback for chemical control in gasifier boiler water.

- To design gasifier boilers (heat transfer surfaces and drum) with enough operational, and start up & shutdown, drains to remove particles from the low points and from low velocity headers of the circuits.
- To design gasifier boilers (heat transfer surfaces specifically) without flow restrictions where particles can accumulate increasing restriction.

Syngas cooler outlet temperature.

Syngas cooler is cooling raw gas up to 340 ºC. That level of temperature can develop following risks:

- Fly ash is removed from raw syngas by ceramic filters type Boer-Schumacher. Expected temperature of 340 ºC is higher than operating temperature in existing ceramic filters of IGCC plants. That can introduce risks about performance of some components of the filters, like gaskets and other no fixed components subject to expansion cycles.
- Cold gas recycle is done by a compressor or blower. This equipment will be critical since it has to work with raw syngas at high temperature. Specific materials, sealing, and wearing parts, are required to assure availability and performance.

Clear warranties about operating life and maintenance requirements must be solicited to equipment designers and suppliers.

Materials.

A general statement about used materials in Tianjin project is that in general carbon steel and stainless steel will be used and special material when hydrogen corrosion resistant material is necessary. The risks of no reference plant are to select materials accordingly to process design fluid, but without the experience of incidents in long term operative plants.

In that sense is remarkable to consider down time corrosion during maintenance and unexpected shutdowns, plus the real operating conditions of piping. E.g.: components that can accumulate particles of fly ash in contact with humidity of atmospheric conditions can corrode carbon steel even after inertisation process. Or nitrogen piping fabricated in carbon steel can become corroded by gas condensates when the piping in normal operation has no flow and it is in contact with pressure boundary of syngas.

A program to check periodically thickness of piping and components in selected points of systems is necessary since construction to have proper references and to manage a particular predictive maintenance program.

Vessel size for sluicing of solid materials.

In sluicing of materials (fuel dust, fly ash and slag), to the normal difficulties inherent to solid transport, the difficulty of change of pressure, high differential pressure, have to be added.

The process to transport in those cases is by lock hoppers system, where vessels are working as collectors and once they are full, they are isolated from the source of material, and, isolated, pressure of the vessel is changed to the pressure of the receiving equipment to connect them and permit a discharge. That is, they are operating in batch. Therefore there is a time during which the vessel is not receiving, and material is accumulated in the source. This time is critical because any problem in instrument, valve or auxiliary system can extend the time without equipment to receive material, and it can provoke a reduction of load or even stop of gasifier to wait to recover lock hopper system.

In that sense, 5 minutes between discharges for slag removal system for instance, is too short. No operational problem can be solved in 5 minutes. Some corrective action is necessary to avoid that any single fault of simple component around lock hopper system is promoting a gasifier stop.

To mitigate the risk of unavailability several actions can be taken: a) Install several parallel, redundant, vessels. b) Install bigger and "comfortable" collector vessels.

3.3.2.4. Syngas purification systems

Liquid effluents.

A green plant has to take special care about emissions and effluents. In an IGCC gaseous emissions are relatively easy to control from proper design of main equipment and it is one of the clear advantages of IGCC plants. But with liquids effluents is more difficult because effluent permit is depending more on local legislation and specific operation permits.

Therefore each plant has to develop its proper process with liquid effluents. The experience of existing IGCC is that is a matter of time to install the best possible system to minimise effluents (zero emissions concept).

In an IGCC, to the usual obligations of any coal plant with cooling water blow down, or run offs coming from fuel storage or solids handling systems, the blow down of closed circuit to wash raw syngas has to be added.

According to information Tianjin project is being designed by collecting grey water of solids handling systems with blow down of syngas washing system, and directing to treatment plant from where the water is recycled and pollutants are separated as a cake.

To deal with both streams in the same system could require too large and expensive equipment (e.g. how to separate raining water of grey water and run offs of solids handling and storage areas?). Since grey water can require a softer treatment than scrubber blow down, to design separated treatment systems can be advisable in order to avoid the risks coming from upset situations of the plant and effluents treatment limitations.

Sour gases from scrubber blow down.

Closed circuit of water scrubber to wash raw syngas requires a blow down to remove sour components from syngas. That blow down has a high level of contaminants (cyanides, halogens, ammonia, sulphur compounds …) and it requires a dedicated treatment.

Usual treatment consist on stripping of water separating most sour gases, by applying heat in the stripper, before sending water to effluents treatment plant.

Those sour gases can be directed to some kind of incinerator when operating emissions limits are permitting it, but progressively is more often avoided the solution of incinerator and it is directed to the sulphur recovery unit where is mixed with the claus gas coming from syngas desulphurisation unit.

In that case, sulphur recovery unit has to be designed considering it since corrosion by sour gases can be higher than corrosion by claus gases depending on used materials and selected process to recover sulphur.

Gas condensates at MDEA column inlet.

According to general H&M balance for Tianjin project, raw gas, before entering MDEA column is cooled up to 60 ºC to separate gas condensates, warm up to COS hydrolysis catalytic reaction (where more water is obtained), and then cooled again up to 45 ºC.

In order to avoid risks of equipment plugging and corrosion, to install drains, after cooling at the outlet of COS catalytic reaction that has to be collected as gas condensates, is necessary.

Carbonyls and other pollutants.

Between MDEA column and gas turbine there is not any other system where syngas is cleaned and pollutants can be separated. Pollutants in syngas fuel can become critical in the stability of gas turbine burners flames and impairing of gas turbine hot path components (burners, ceramic tiles and blades & vanes).

The kinds of pollutants that can be created after washing with MDEA solution at 45 ºC are mainly:

- Corrosion particulates produced from metallic components (piping) as normal corrosion of steel in operation and down time. When distances are so long as they can be in an IGCC (more than 100 m of piping between MDEA system and gas turbine), normal corrosion can produce accumulation of metallic particulates that can be creating deposits at burners or cooled blades of gas turbine.
- Iron and Nickel carbonyls. Carbon monoxide is the major component of syngas. This gas attacks equipments with iron and nickel producing iron or nickel carbonyls. These compounds are stable in gas phase in a range of temperatures approximately between 50 and 200 ºC at the levels of pressure that an IGCC works. At higher temperatures carbonyls are not stable and can produce deposits of metal oxide in burners or ceramic tiles. The problem, like with other particulates, is that corrosion level can be acceptable for the expected life of piping and vessels, but with long distances the accumulation of deposits in hot gas path of gas turbine can not be tolerated after some weeks or months of operation.

The problem of deposits at burners can be managed by adjusting syngas tip of burners in order to avoid low velocities that can help to grow up deposits, but it is a complex solution that requires trial and error with all the plant and long term tests. And, what is worse, gas turbine supplier can argue those deposits as the cause of non stable flame or other problems in gas turbine, while other supplier tasks, like required adjustment of syngas flames, are hidden behind the deposits topic.

To avoid those risks it is advisable to install equipment and piping from MDEA column up to gas turbine burners in stainless steel in such a way that the contamination of gas turbine fuel is minimised.

Syngas final temperature.

In Tianjin project is foreseen a temperature of syngas fuel to gas turbine of 200 ºC. This temperature is important to get better efficiency in the combustion at gas turbine burners. So near to the temperature of compressed air for the combustion (300 to 400 ºC) so better efficiency of gas turbine.

Since the warming of syngas up to 200 ºC is achieved by a heat exchanger, it can be advisable to install a better heat exchanger in order to get temperatures near 300 ºC. That can be an improvement in efficiency.

3.3.2.5. Air Separation Unit

The unit considered for Tianjin project is a conventional industrial plant to produce oxygen for gasifier and some pure nitrogen for safety and fuel dust transport. Therefore technical risks are of two kinds: The same than any Air Separation Unit that is operating in any industrial complex, and the risks associated to the integration with gasification and combined cycle units.

Main risks of **standard** ASU can be summarised in:

- **Availability of critical single equipment**. Most important is the air compressor. Not only from the point of view of availability but from the point of view of performance efficiency too. Since it is large rotating machinery, a specific maintenance program should be planned. Including its auxiliary systems (filters, lubrication, sealing, vibration, IGVs, etc.), spare parts, expert supervision, and predictive maintenance procedures based on performance.

  Other critical equipments are cryogenic pumps for liquid oxygen and for liquid nitrogen. But criticality is far of air compressor due to possible application of redundancies, and limited waiting time to get spare parts or repair services.

- **Safety.** Special risks are the associated to cryogenic conditions, under oxygenated (nitrogen), and over oxygenated (oxygen) conditions. These can be avoided easily by applying good operation & maintenance procedures and practices.

  More potentially dangerous are the incidents coming from oxygen processes. Any contact of high concentration of oxygen with hydrocarbons or oils has to be avoided. Therefore, special procedures since erection of components and special areas for oxygen-service components maintenance are required. Additionally specific procedures for hydrocarbons in the inlet air and liquid oxygen periodic blow down are required too.

Technical risks associated to **integration** in IGCC are:

Liquid nitrogen storage capacity. The peak of nitrogen consumption is during start up and after shut down of gasifier. Precisely the periods where liquid nitrogen has just started to be produced or when has just stopped the production. Besides, during maintenance outages is frequent to require nitrogen for inertisation of vessels with some materials (e.g. coal dust vessels). Those are the reasons to consider specifically the storage capacity for liquid nitrogen, together with a good contract for external supply. In the contrary the risks are higher costs and delays of outages.

External supply of nitrogen becomes critical during commissioning of ASU and Gasification Island.

Control integration. Air separation unit control is based on demand set point for oxygen gas and for nitrogen gas production. Those set points are defined from gasifier requirement and basically they are determining the amount of required air at the ASU inlet and the amount of waste nitrogen.

Since Gasification demand is defined according mainly to fuel dust flow and it is quite far of stable (density changes in transport), and the inertia of the air distillation column and cold box are big, it is difficult to match ASU production with gasifier consumption. This situation requires venting or recirculation of nitrogen and oxygen during normal operation to assure the minimum required pressure in the delivery. What is producing an impairment of theoretical global efficiency of the plant.

Good design of control and accurate tuning, maintenance and operating supervision are required to minimise that risk.

3.3.2.6. Combined cycle

Siemens model for gas turbine SGT5-2000E is the most experimented Siemens turbine to work with low heating value gas as fuel. It is operating by thousands of hours with different “syngas” or waste gases qualities: Buggenun, ISAB, Servola, etc. That is a guaranty of final success in the performance of the gas turbine with syngas.

However some technical requirements are a risk for the budget and for the achievement of commissioning and first operations of IGCC that can be mitigated, or even overridden, facing them with the knowledge and experience of existing plants.

In the following are described the most relevant that can apply to Tianjin project.

Adjustments for syngas operation.

Gas turbines are very sensitive to the quality of feeding fuel. When that fuel is some standard fuel, like LFO or natural gas, gas turbine can be delivered with all final adjustment and design details prepared for quick commissioning and operation. But when the design fuel is syngas, the quality of syngas depends on the process for its production.

Existing IGCC plants are each one, with few exceptions by the moment, designed as the first of its kind or specifically adapted to the characteristic of specific fuels. That means that gas turbine requires special adjustment and “optimisations” during commissioning and first operations to get expected warranties with the design fuel.

Those tests are heavy since they are requiring syngas operations at different loads and different settings (Output temperature, heating value, air inlet temperature, IGV position, pressure drop at fuel valves, any parameter in the operating window for syngas condition, …) to browse all possible and permitted operating conditions and to obtain limits and alarms values to be applied during gas turbine operation. To check the validity of each adjustment an inspection of gas turbine hot gas path is required. If findings, then corrective actions are required too. Like change of damaged parts, adjustment of syngas burners tip, or repetition of the tests, besides of waiting time for the analysis and definition of the solution from engineering headquarters.

To mitigate the potential delays of those tests it is advisable the following:

- To define a clear and detailed commissioning program with supplier. To better achievement of it, it is very helpful to count with direct information from IGCC operators of real tests that were done in the commissioning and first operation of their units. Once that program is agreed, to foresee resources, spare parts, and technical support with commitment is easier.
- To get from Siemens several sets, with different alternative design, of removable syngas burners tips in order to easy change and short time to obtain the optimum performance.
- To agree and to install commissioning devices like TV cameras, control tools for quick and safe analysis of parameters, and other specific instrumentation that can help to short the period of tests, trial and error.
- To obtain from gas turbine supplier a clear and concrete list of no permitted contaminants in syngas and in auxiliary fuel, and to foreseen agreed procedures to check it under warranty conditions. In the contrary, first answer of gas turbine supplier to findings in gas turbine during commissioning and first operations will be questioning the quality, and pollutants, of syngas due to gasification processes and materials.

Heating value control.

Heating value of syngas to feed gas turbine is an important parameter for the stability and performance of the gas turbine.

Since syngas is produced on site and “on line” without a specific buffer equipment, transients in gasification operation are affecting permanently to the quality of syngas and its heating value. To mitigate that, gas turbine supplier defines restrictive limits in the parameters at scope of supply boundaries that can condition very much commissioning and operation, by impairing the availability of the plant.

An advisable measure would be to install around syngas saturator some kind of heating value control. It can be based on “on line” analysers plus control actions on steam and nitrogen addition to the syngas.

Integration of gas turbine control.

Due to the difficulties to coordinate different engineering and procurement suppliers there is a tendency to work isolated in each scope.

The efforts are concentrated in clear definition of conditions at battery limits.

But integration is a basic concept for the success of any IGCC design.

Project coordinators have to get from gas turbine suppliers specific adaptations of gas turbine, and balance of combined cycle, to the design of the whole plant, mainly gasification island, in order to help to the availability of the plant (to avoid unnecessary trips).

Those adaptations must consider main expectable transients with origin out of combined cycle scope. E.g.:

- Transitory low pressure in syngas.
- Transitory low flow in exported steam from gasifier.
- Gasifier single burner trip.

Coordinated control.

General coordinated control in power plants is based on the definition by operator, or remote, of the required power to delivery to the grid. Then the controls of each unit is taken that set point as the reference of load target of each unit by a theoretical conversion between produced power to the grid and load of required product of each unit.

Those theoretical conversions factors are adjusted by operator according to experience, or according to change of fuels or other operating parameters.

Experience of existing IGCC plants is that those kinds of controls are producing normal flaring of syngas, and oxygen and nitrogen, to the atmosphere during normal operation, impairing whole efficiency of the plant. The reason is that, in spite of how good the correlation factors can be, a real plant is never operating in the theoretical possible conditions but around them.

Best coordination of controls between units is to install a coordinated control like above described only for the combined cycle. To dedicate master control of gasification island to control pressure of syngas, and to design master control of ASU to attend the instant demand of gasifier.

With that strategy the flaring will be produced only in the ASU products, and efforts to minimise it can be concentrated in optimisation of control integration between gasifier and ASU.

Gasification and combined cycle coupling.

Start up general process at Tianjin plant would be:

1st. Starting up ASU up to oxygen quality and capacity is available. That can take between few hours and few days, depending on the cryogenic status of ASU equipment.

2nd. Starting up of gasifier up to pressure, flow and syngas quality are suitable to fuel gas turbine. That can take some hours due to the criticality of gasifier pressure increasing ramp with the lock hopper system feeding burners. Lock hoppers have to operate changing pressure to load and unload when the gasifier reference pressure is changing.

Combined cycle should start up with auxiliary fuel in some moment before gasification island is ready to delivery syngas in the required conditions to do in the gas turbine the switch over from auxiliary fuel to syngas as fuel.

In that general sequence ASU and gasification are operating like a unit and the combined cycle is operating like another unit in parallel. They both are preparing to couple. Two aspects of coupling have to be considered:

Syngas coupling (switch over):

According to project information the capacity of storage of auxiliary fuel is enough to start up the combined cycle, and it is based on the data from supplier that combined cycle is able to start up in only 26 minutes to reach full load with auxiliary fuel.

May be that timing is theoretical possible, but in practice it seems too short due mainly to:

- Metal temperature ramp limitation of Heat Recovery Steam Generator components.
- Steam pressure ramp in drums of HRSG. When changing pressure, level control of drum is being very affected and it has to be done with a sophisticated control plus a careful increasing ramp.
- Warming up of steam piping and steam turbine valves and casings, in order to avoid stress by differential temperature, to avoid condensates in the steam path, and to assure pollutants of steam below limit conditions, requires time.
- Usual incidents during start up, like instrument or valve faults that are not critical to stop the unit but that require some maintenance intervention, need some waiting time.

Normal time to reach stable conditions in the combined cycle enough to do the switch over of gas turbine fuels can be between 30 minutes (hot start) and 2 to 4 hours (cold start).

Additionally to those facts, incidents in the balance of plant during normal IGCC operation have to be considered. It is relatively frequent that some incidents that require switch back gas turbine to auxiliary fuel can happen. Like instrument, analyser, fault, blockage in solids transport, or any other cause of lack of fuel dust to gasifier, etc. In that situation, when the origin of the fault can be solved in few hours it is advisable to keep the combined cycle working with auxiliary fuel in order to a quicker return to syngas operation.

Commissioning period has to be considered too. During commissioning or syngas tests in gas turbine, switch over and switch back between auxiliary fuel and syngas is required to do with a very much higher frequency than during normal operation after "learning curve". In that situation the availability of auxiliary fuel can critically condition the schedule, number of starts and shutdowns (equivalent operating hours of machines), and the costs.

Considering above reasons, a very minimum auxiliary storage capacity of around 6 hours would be advisable. And a reposition capacity of less than 24 hours or similar should be considered too.

Auxiliary fuel availability has another advantage. It would permit to operate the combined cycle in peak requirements of the grid when gasification is not available for any reason.

Steam coupling:

Boiler feed water to the gasifier, and its auxiliary systems, is delivered from combined cycle.

Therefore some combined cycle equipment is required to start up gasifier. Mainly feed water tank, condensate system, condenser, and demineralised water make up to condenser.

Part of the boiler feed water supply to gasification is expected to return to the combined cycle as steam, or condensate, to be recirculated in the cycle through the steam turbine condenser.

During start up of gasifier there is a period of time when gasification is receiving boiler feed water but this water is not returning to combined cycle up to steam and condensates production of gasification is coupled to combined cycle condenser.

During that time a higher amount of demineralised water make up to the condenser is necessary, and that amount is not required in normal operation, after coupling. Besides of the extra consumption of demineralised water, chemical control of boiler feed water is difficult to maintain, mainly oxygen content in condensate water.

The risks are to delay start up due to short availability of demineralised water, and shorting life of water steam components due to poor chemical quality of boiler water. In addition to the higher consumption of water in the plant.

Therefore is very important to design systems in such a manner that coupling of steam and condensates can be done as soon as possible, and before gasifier load is relevant.

Stack flue gases temperature.

According to information the expected temperature of flue gases at combined cycle stack outlet is 70 ºC.

That value is a good figure for the general efficiency of combined cycle. It uses to be determined by the sulphur compounds condensation at the coldest components of HRSG that are the last exchangers before stack. Condensation of gas sulphur compounds over cold surfaces depends on the concentration of those compounds in the flue gas. That is, it depends on the amount of sulphur in the gas turbine fuel.

So low figure suggests that it has been determined according to expected normal performance of syngas purification systems.

But during operation has to be considered that desulphurisation systems of gasification island are not working at optimum parameters from time to time. E.g. sudden or progressive deactivation of COS catalyst, wearing of MDEA solution, flow transients in MDEA circulation. And in those cases sulphur compounds condensates will increase in exchanging surfaces of HRSG.

The risks of those condensations are:

- Deposits growing up in the surfaces that are obstructing flue gas path can increase exhaust pressure of gas turbine, with a relevant decreasing of efficiency and power.
- External corrosion of coldest surfaces of HRSG will be accelerated.

To mitigate those risks is necessary to consider a variable temperature control of flue gas at the stack outlet that can permit transient operations with more sulphur in syngas than in design conditions, and to foresee a procedure to clean up periodically HRSG cooling surfaces from external side.

3.3.2.7. Auxiliary systems

Storage capacity of products and fuels.

Besides of the commented required capacity for gas turbine auxiliary fuel storage and supply, the following capacities have been considered in Tianjin project:

- 2 hours of buffer capacity for fuel dust. It can be short since incidents in solids handling, grinding and drying plant, are relatively frequent. Enough time to fix and repair easy mechanical problems, like blockages, should be foreseen.
- 25 h of storage of slag and 120 of fly ash. The figures are adequate to support normal incidents. But since removal from the site will depend on an external company or entity it is convenient to foreseen emergencies, with some additional yard for storage or with diversification of removal contracts.
- Water supply for cooling, demineralised water, and raw water is coming from an external plant or company. It would require adequate storage capacity to independent operation of other company. The figure in the information is 2000 m^3 of storage capacity of water when the consumption is 326 m^3/h. Supply has to be assured permanently or storage capacity should increase to permit 12 to 24 hours of operation without water supply.

Concentration cycles in cooling towers.

It is expected only 1,5 cycles of concentration in cooling towers. The figure seems low since currently, with proper and easy chemical treatment of cooling water, concentration cycles over 3 and 5 are commonly used.

That is important to decrease water consumption and to mitigate risk of water supply since main consumption of water is the evaporated in cooling towers.

Grinding and drying.

In the presentation of Tianjin project is stated that 2 trains of 100 % capacity each are considered. But in questionnaire from consultant it is stated 3 trains of 50 t/h each.

The proper solution is the solution with 3 trains. Only 2 trains, 100% redundant, would introduce more operating problems since, when managing solid materials, so larger are the system and equipments so more complicated to solve are the operation and maintenance incidents.

Antiicing.

It is not mentioned in general description of the project any system for icing, freezing, protection. It is supposed that it is foreseen since there are many systems managing water with piping.

Special attention has to be pointed to systems that are managing water in the slag lock hoppers. In spite that temperature of water processes is usually high enough to avoid freezing in operation, those systems are working in batch, with some periods in stationary mode. Low temperature can freeze small piping and instruments tubing easily in short time without circulating flow.

Gas leakage. Safety.

Gas leakage to the atmosphere can provoke the most severe accident in the plant. So as the potential ignition and fire or explosion, as the potential toxic bubbles that can move to areas were workers can be or must be to operate the plant, must be considered.

A proper system of gas leakages detection is necessary to protect personnel and equipment. In the case of HVAC systems for control room to install toxic gas detection in the air intake is necessary in order to alarm and to isolate external air intake to permit operators keep their operation position enough time as emergency actuation plans can require.

3.3.2.8. Control system

Integration.

Engineering of integration of controls between units is in the scope of GreenGen as owner and coordinator of the project. As it has been explained before this task is very important and it will affect in a relevant manner to commissioning success and final efficiency of the whole plant.

It is advisable to create a specific task force with the participation of process or operation experts of each unit together with engineering I&C experts. Part of these persons should participate in the commissioning of the plant.

Alarms.

Complexity of the plant and the nowadays available control systems are the reasons to get a very high number of signals available in the control systems.

A consequence is that the number of existing alarms is too big and there is a clear risk of overriding by operators.

To avoid it is necessary to perform a specific work about alarm engineering, in order to permit that operators can use in a friendly manner the high level of information that is available in the control system.

Configuration management.

Control of modifications and proper use of documentation is a must in any complex industrial project. In the contrary, the number of mistakes, incidents, and man power to revise and update documents can be exacerbated.

That control is specially complicated when the modification is physically done in software, because to do a modification of logic controls by software is very easy and its consequence can be more important than hardware modifications.

The number of software modifications is extremely high during commissioning, when to apply a configuration control is more difficult. But it is absolutely necessary to define a good procedure for software modifications with the proper level of authorised persons and enough flexible to avoid obstruction of works.

Control room design.

To avoid operation mistakes, with heavy consequences sometimes, control room has to be designed according to some standard rules for the purpose. Quite area, all information should be available in the scope of operator easy action, enough isolated to avoid distraction and disturbances, good communications, easy assistance of other working groups, and basic ergonomic rules considered to help operators to feel comfortable. If windows are designed they must be oriented to have a general overview of the operating units.

The picture of control room that is showed in Tianjin general presentation should be modified consequently.

3.3.3. Fabrication of main equipment

General

With the exceptions of singular equipment (Gas turbine, steam turbine HRSG, gasifier, gasifier cooler and drum), and ASU main equipment, all suppliers are not yet determined. Some of those equipments can have a delivery time of one year or more since orders have been fixed (heat exchangers, control valves, pressure vessels, Control system, main transformers, etc.). If the time to complete design data sheets, supply specifications, proposals elaboration and evaluation of offers, is added, then there is a high probability that the construction can not finish before middle of 2011 if the project would receive the go ahead in next second trimester of 2009 by instance.

To mitigate that delay in construction it would be necessary to elaborate a schedule of the project that would concentrate efforts and resources in the engineering activities to define documentation for procurement of equipment and a strategy in evaluation of offers oriented to select manufacturers with shortest delivery time.

Gasifier

A specific risk of Tianjin project is the risk that is derived of gasifier fabrication. It is the first gasifier manufactured of TPRI design at the selected scale.

Manufacturer learning about fabrication and construction in the scale is required and it is being done in the project. That can rise up some mistakes with construction details, new fabrication procedures and tools, etc.

To mitigate that risk is advisable:

- Technology developer (TPRI) should perform a wide supervision of, and collaboration with, manufacturer.
- During commissioning, manufacturer representatives with high level of gasifier knowledge should supervise the operation and first inspections of gasifier under a conscientious program for preventive inspections, in order to obtain the best interpretation of potential findings, and therefore their solutions.

3.3.4. Construction and Commissioning Schedule

Following commentaries are done in the understanding that the schedule that GreenGen delivery to consultant (annex II) is a summary of main construction and commissioning activities sorted by units or group of systems. And that is not updated waiting for the decision of going ahead that should have been taken at the last quarter of 2008.

Comments try to point out main schedule considerations and other minor details that are in the version consultant received.

- Gas turbine requires a specific schedule for syngas combustion test and adjustment of parameters. Additionally, the activity of blowing syngas lines and equipment near gas turbine is a relevant activity that probably will be required by gas turbine manufacturer.
- HRSG. Erection of piping, instrument and cabling are not in schedule. If it is considered with steam turbine, it is in parallel to insulation and painting and that can not be possible.
- Steam turbine start up can not be done before blowing of HRSG.
- Most part of cabling is scheduled only in second semester of 2010 (with the exceptions of ASU and Coal yard equipment). Considering that the plant will have between 800 and 1.200 Km of cabling, considered period of time is too short (good erection average is between 100 and 150 Km / month in the platform, with 1 or 2 months of ramp to reach it and another ramp to finish). To get good erection monthly average and shorter time, a high quality, on time, detailed cabling engineering is required.
- ASU equipment erection finishes before electrical and control building finished. It is not possible since all equipment must have cabling between electrical and control building and equipment.
- Acceptance test for ASU is missing. It is important to agree it, not only for the verification of ASU warranties, but to avoid problems with the verification of warranties of other units or equipments.
- A specific and coordinated schedule is necessary for mechanical equipment, piping, electrical equipment, instruments and cabling. That sequence is defining the real schedule of plant construction with optimum costs and time.
- Considered time for commissioning of purification systems is too short. It is a more considerable activity since there are many instruments, control valves and equipments.

3.3.5. Organisation

Pointing only to the aspects that can represent a risk for the project development and the operational period the remarkable items are:

Scopes split.

Several engineering entities are participating: Combined cycle and service systems (Nwepdi), Combined Cycle supplier (Siemens), ASU supplier, Gasification island (SINOPEC), and TPRI for gasification basic design and integration between main systems or islands.

The unavoidable tendency will be to get a clear definition of interfaces at battery limits of each one since starting the work.

Since the plant will be the first of a kind it is not possible to define those interfaces in the finally required way.

Moreover the tendency of each one will be to define conditions that are comfortable for its scope without considering how easy or difficult is for the other side to fulfil it. And moreover, in case of doubt or conflict what is easier for a contracted company is to claim that is not in the scope.

The rising risks from that situation are a difficult, extended, and delayed detailed engineering specifically in definition of piping and in the definition of cabling. The same happens with software (control diagrams and logic control definition), that is not affecting to construction but very hardly to commissioning and start up of the plant, doing it more extended than expected and than what is possible.

The only action to mitigate those risks is that the team that is in charge of coordination of the project has experience in development of industrial complex projects. The persons or companies that are the technology developers are not the best to coordinate and to conduct an industrial complex project (with the exception of technology companies that have developed a specialised and experimented department to manage construction and start up). Technology developers should act as technology advisors, and may be as controllers, of the team that is managing the project, engineering coordination, its schedule and budget.

Training.

This kind of projects, first of a kind, has no reference enough detailed to permit that the personnel that will be working in Operation and Maintenance can be trained without direct participation in the design, construction, and commissioning.

That is, the best training for these cases, is “training on the job”. Their participation, no like observers but with tasks and responsibilities, during construction and, specially, during commissioning is critical for the following first O&M years.

Additionally, when possible, training at existing IGCC operated by companies into the group of users or with collaboration agreements is required.

3.3.6. Operation & Maintenance

From the received documentation and meetings only following general commentaries:

Gas turbine spare parts.

Main maintenance costs of any combined cycle plant, and an IGCC is it, are the spare parts for gas turbine.

Due to intellectual property rights, and usually cutting edge technologies for design and fabrication, dependency and costs are high.

Delivery time use to be long or very much expensive in case shorter time is required.

Therefore some specific strategy has to be defined and followed for that topic in order to avoid risks of downtime waiting for some required spare part or repair, and risks of maintenance budgets deviation.

Easiest strategy is to reach some kind of long term agreement with supplier where prices are fixed and negotiated for several maintenance cycles in order to low prices.

In that agreement is important to consider strategic spare parts (burners, ceramic tiles, blades and vanes for gas turbine and for compressor, together with other minor wearing parts) for commissioning uncertainties.

Management control system.

In the received documentation it is mentioned that a system for integrated management control will be used for operation and maintenance (MIS), and that it will be applied too since and during construction phase.

That is the best option to manage control of budgets, schedules, works, warehouses, purchasing and delivery of supplies, invoices, documentation, modifications, and maintenance predictive, preventive and corrective activities.

The risk of using it since construction is that during construction main concerns are schedule, budget, supply and services contracts…, while during operation the dealing of the plant will be around maintenance activities. That can become in a development of management control system focused for construction activities that can condition its use for maintenance and operation activities.

It is very important to get that since construction the system can be oriented to O&M activities too, by loading all workflows and maintenance data bases. That can be achieved integrating future O&M personnel in the team that is using MIS during construction, with the task to assure the compatibility of information and processes for both phases.

Participation of Maintenance experts in that team would be an excellent decision too.

3.3.7. R&D program

Since the project has a clear character of demonstration plant into the field of clean coal technologies development and climate change mitigation, etc., R&D associated program is a clear driver to help the project and to push it forward.

The concept is that IGCC technology is not yet generally deployed as commercial, competitive, technology, but only in some particular cases depending on availability of particular fuels. But it can be an extended competitive technology under environment, and warranty of supply, restrictions. After two or three generations of demonstration plants at commercial scales, technology is very near and it requires only to strength its weak points: Investment costs, learning and reference plants for the industry, considering that its best strength is the easiest adaptation to new environment requirements and fuel flexibility.

In that sense a R&D program should be defined and applied to demonstrate and optimise those concepts in order to improve the required technical and financial support.

The project counts with some R&D associated activities like the Carbon Capture and Storage (CCS) program that is based on a pilot plant of approximately 10 KW. That size is the size of a pilot plant in the scale of laboratory. It could not be required a demonstration plant of 250 MWe to perform that kind of pilot plants.

The risk is that without a clear and solid R&D program the project can be judged only under commercial and competition aspects of power generation with the consequent lack of support, in the public and private field, when it could be required, like any investment for the future requires.

Annexes

I. Tianjin IGCC project presentation
II. Tianjin Construction Schedule
III. Tianjin organisation diagram
IV. Q&A about Heating Value limitations to gas turbine
V. Presentation of Consultant about Puertollano IGCC experience
VI. Question list from Tianjin project answered and discussed along Beijing meetings February 16th to 20th
VII. Start up sequence in Puertollano IGCC
VIII. Gasification temperature supervision in Puertollano IGCC
IX. Nitrogen consumption in Puertollano IGCC
X. Question of consultant and answers of Tianjin project
    a. Draft balance of Plot Diagram—Tianjin IGCC
    b. Status of detailed engineering
    c. Status of equipment fabrication