Coal–based IGCC Plants

- Recent Operating Experience and Lessons Learned

Neville Holt - EPRI

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IGCC Plant Information Sources/Contacts

- Tampa Electric – Mark Hornick, John McDaniel
- Wabash – Steve Vick (Global), Jack Stultz (Cinergy)
- Nuon – Marco Kanaar, Carlo Wolters
- ELCOGAS – Ignacio Mendez Vigo, Francisco Garcia Pena

Coal based IGCC Plants

Project/ Location	Combustion Turbine	Gasification Technology	Net Output MW	Start-Up Date
Wabash River, IN	GE 7 FA	E Gas (ConocoPhillips)	262	Oct 1995
Tampa Electric, FL	GE 7 FA	Texaco (GE Energy)	250	Sept 1996
Nuon (Formerly Demkolec) Buggenum Netherlands	Siemens V 94.2	Shell (Offered jointly with Krupp-Uhde)	253	Jan 1994
ELCOGAS Puertollano Spain	Siemens V 94.3	Prenflo (Offered jointly with Shell)	300	Dec 1997

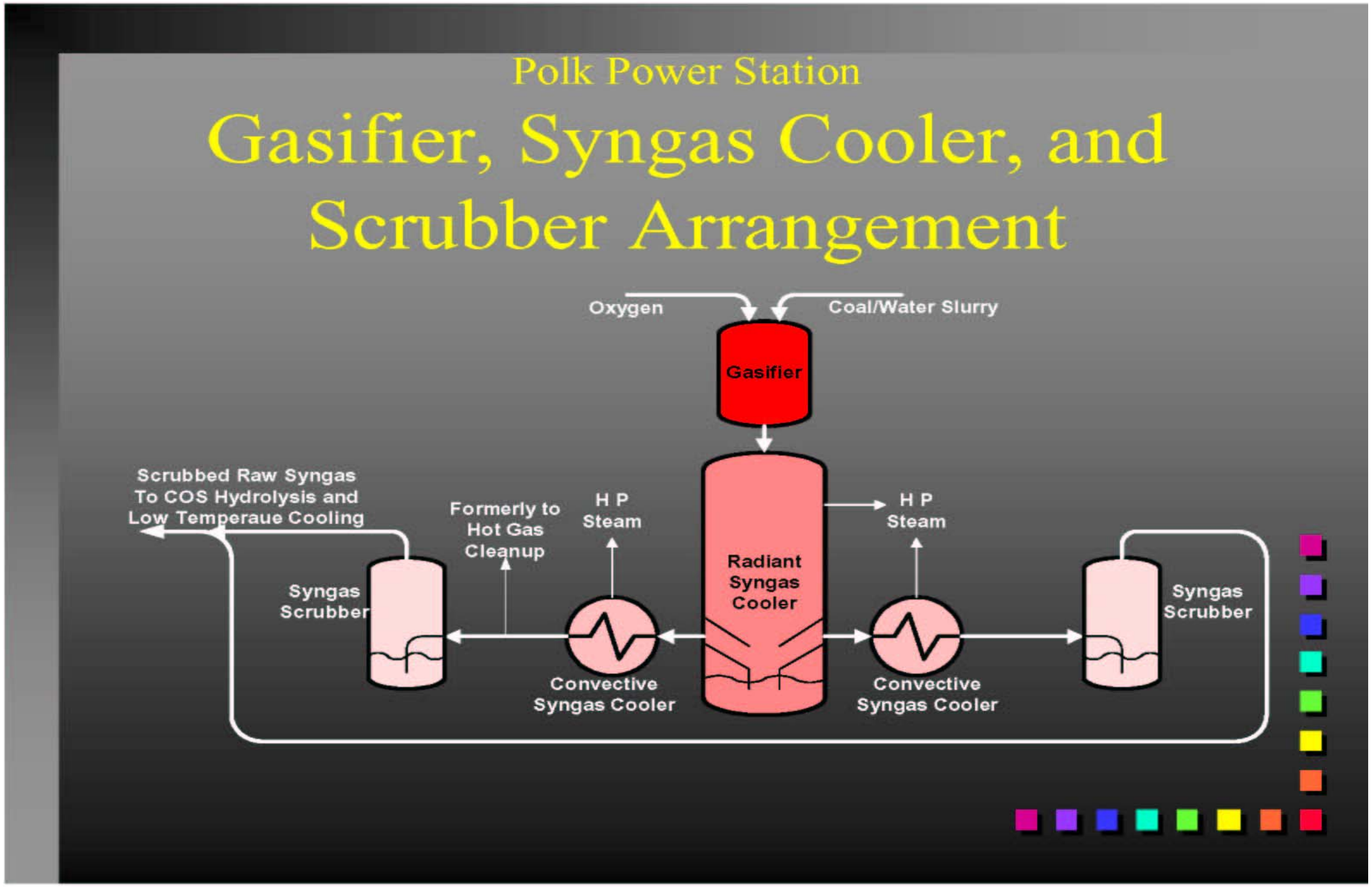
Salient Characteristics of Major Gasification Technologies

Technology Name/Owner	Texaco/ GE Energy	E Gas/ ConocoPhillips	Shell/Shell
Feed	Coal in Water Slurry	Coal in Water Slurry	Dry coal
Configuration	Single Stage Downflow	Two Stage Upflow	Single Stage Upflow
Gasifier Wall	Refractory	Refractory	Membrane Wall
Pressure PSIG	500-1000	Up to 500	Up to 600
Notes	Offered as Quench or with Heat Recovery	Only offered with Heat Recovery	Only offered with Heat Recovery .

Gas Turbines at IGCC Plants

Plant	Wabash	Tampa	Nuon	Elcogas
Turbine Model	GE 7 FA	GE 7 FA	Siemens V 94.2	Siemens V 94.3
MW	192	192	155	200
Combustor Design	Can Annular	Can Annular	Twin Vertical Silos	Twin Horizontal Silos
NOx Control	Saturation + Steam	Nitrogen + Saturation	Nitrogen + Saturation	Nitrogen + Saturation
% ASU air from GT	0	0	100	100

Tampa Electric – Gasification Arrangement



Tampa Electric Polk Power Station IGCC 2003-2004 Operations

- Currently using 55/45 Petroleum Coke/Coal feed
- Lowest dispatch cost unit in TECO fleet
- Rewinding of both Generators and 7FA Gas turbine Rotor replacement in Fall 2003 adversely impacted 2003 availability (early fleet problem – not IGCC related)
- IGCC currently operating at 95% availability (with fuel back up) and 82% Gasifier availability
- New coarse slag screen produces slag of ~2% carbon sold for cement and enables full recycle of screen underflow to the feed rod mills. The previously accumulated slag pile is gone.
- New NOx permit limit of 15 ppmv at 15% oxygen achieved with addition of syngas saturator
- Use of ion exchange for elimination of HSS has reduced corrosion and improved the MDEA unit performance

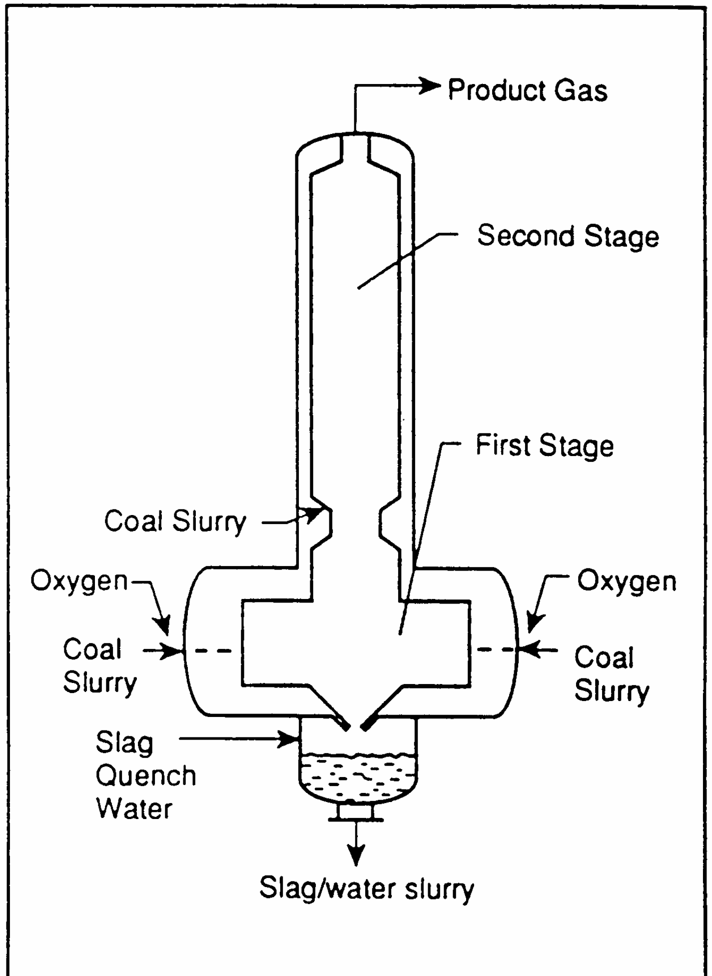
TECO Polk IGCC – Technical Issues

- Carbon Conversion lower than design. Exacerbated by use of Petroleum coke. Adversely affects efficiency and oxygen consumption. Additional oxygen supply under consideration.
- Slag/Fines handling & corrosion /erosion in black & gray water circuits
- Convective Syngas Cooler fouling. Significant progress with tubesheet fouling eliminated. Upstream agglomeration persists – soot blowing installed.
- Distillate oil back-up Fuel Reliability. Coking of fuel in lines.

TECO Polk IGCC – Possible Improvements/Innovations

- Seeking permit to run up to 100% Pet. Coke
- Some Biomass – up to 5% feed (Florida DEP)
- Possible partial air extraction from the gas turbine compressor to augment the supply from the ASU main air compressor
- Potential host site for DOE project of a syngas slip stream pilot test of Nexant/Simteche CO_2 Hydrate process (DOE) for CO_2 removal

E-Gas Gasifier – As used at Wabash IGCC (Technology now owned by ConocoPhillips)



Wabash River IGCC Repowering - Status 2004

- Global Energy owns the Gasification plant with a services agreement with ConocoPhillips (COP)

  - 15 COP personnel (Tech. & Mgmt.) at Wabash

  - Access agreement for technology advances/DOE projects, slipstream testing, operator training .
- Initial operation 1995-2000 under DOE CCT Demonstration program. Operation with 100% petroleum coke since completion of DOE contract.
- COP/DOE NETL test programs 2003-5 at site include two fuel cell modules (MCFC from Fuel Cell Energy), corrosion resistant coatings, gasifier temperature measurement, cyclone and candle filters, warm gas clean-up, and hydrogen selective membranes
- Not currently in operation for business reasons

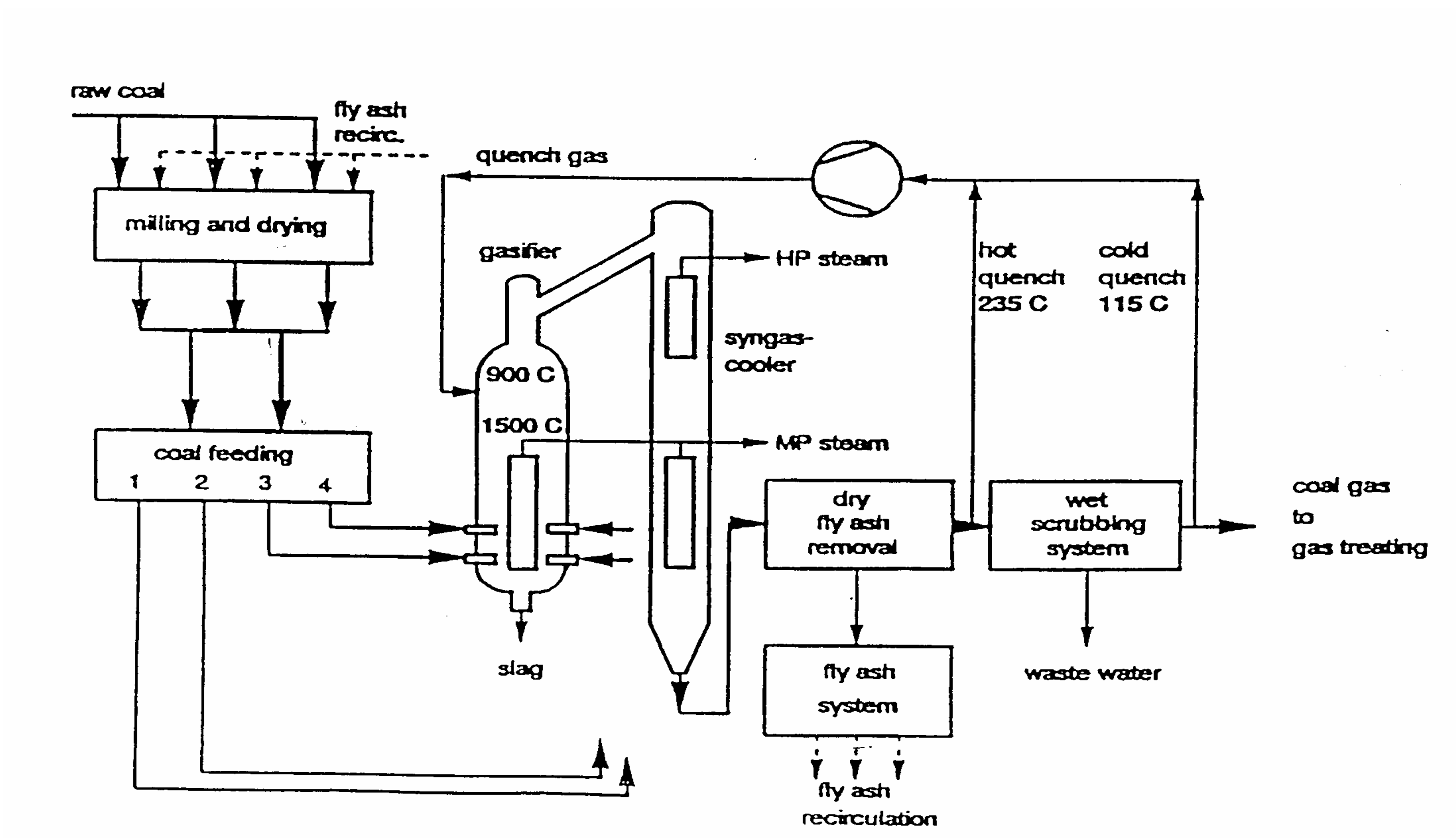
Wabash IGCC – Plant improvements

- Over 4200 hours on gasifier fuel injectors (mixers)
- Hot gas flow path modifications at fire tube SynGas Cooler (SGC) inlet to correct ash deposition on tubesheet. Development of mechanical cleaning of tubes in situ.
- Replacement of ceramic by metallic elements in the hot gas filter
- Addition of wet scrubber to remove chlorides prior to COS hydrolysis
- Additional waste water treatment results in zero liquid discharge from gasification island.
- Ion exchange system for removal of heat stable salts (HSS) from MDEA circulation

Wabash IGCC- PSI Energy Power Block Experience with GE 7FA

- Stable operation on syngas (better than oil). Syngas saturation and steam injection meet NOx permit requirements of <25 ppmv at 15% Oxygen. No environmental violations for water or air in any year.
- Early (1996) replacement and redesign for syngas expansion bellows, solenoid valves and fuel nozzles. In 1999 compressor rotor was replaced - a fleet problem not related to syngas application.
- Power block availability adversely affected by persistent leaks in HRSG and some problems associated with the 2001 changeover to add natural gas capability.
- In 2002 and 2003 the hours on syngas were 4692 and 5220 with reliability 77% and 87% respectively. In 2004 ~1000 hours of operation on syngas thru' June.

Shell Gasification as used at the Buggenum 250 MW IGCC



Nuon 250 MW IGCC at Buggenum

- Fully integrated IGCC with all the air for the ASU extracted from the GT compressor
- Shell gasifier could handle greater than design coal flow.
- Fuel injectors have demonstrated >20,000 hours of life
- Large variety of coals gasified with >99% carbon conversion
- Syngas Cooler fouling not a major cause of outage and is largely controlled by rappers.
- Fly slag captured in the ceramic filter at ~250°C is very low carbon and is sold (not recycled). Most of coal mercury appears in the fly slag. Ceramic elements have >20,000 hours life.
- H_2S content of cleaned syngas is <10 ppmv.

Nuon 250 MW IGCC at Buggenum

- Operated in daily load following mode 2002-3. Ramp speed 1.5 MW/minute in gasifier load following. By adding natural gas the ramp can be increased to 3.5 MW/minute over a limited load range.
- In 2004 returned to base load operation.
- For period Aug 2003-May 2004 Power block 89.9% on stream, 6.6% Planned outage, 0.6% Unplanned outage and Gasification unit 81.8 % on stream, 7.4% Planned outage, 9.4% Unplanned outage.
- Dutch Coal Covenant requires CO_2 Emissions reduction of 200,000 mt/yr at Buggenum. This is equivalent to ~35 MWe from Biomass or ~ 30% by weight of biomass in the feed. Low cost secondary fuels are being sought and test runs have been conducted with Sewage sludge solids and Wood waste.

Nuon IGCC – Forced Outages 2002-4

- Syngas Cooler Pipe leaks largely due to construction defects. Improved flexible repair and control of vibrations.
- Claus sour gas condenser tube sheet leaks. New design of tube sheet.
- Slag bath circulation. Better quality piping installed.
- ASU drain blockages, valve and LOX quality. Improved operations and mol sieves.
- Nitrogen quality trips. Improved ASU control and addition of IP steam as replacement for NOx control.
- Modifications to gas turbine burners and Integrated control system (as described in the 2002 paper) have reduced the vibrations to a low level.

Nuon IGCC- Biomass Co-gasification

- Test program conducted 2001-4. Sewage sludge, Chicken litter, Wood, Paper pulp and Coffee.
- Paper by M.Kanaar at Brighton discusses the Biomass Fuel flexibility issues in depth by plant section. Fuel preparation, fouling and corrosion, by product quality, syngas quality are all important considerations.
- Test run with 4-5% Sewage sludge showed Syngas Cooler (SGC) fouling (Iron species rich in Sulfur and Phosphorus). Possible solutions are blending and SGC cleaning modifications.
- Plant has demonstrated good fuel flexibility. Main restrictions are feed system (nitrogen), Syngas CO_2 content for AGR, permitted emissions and byproduct quality.
- Ability to control Mercury (from e.g. sewage sludge and Demolition Wood dust) may be a unique niche advantage
- Future Green credits and CO_2 emissions allocations are uncertain.

ELCOGAS 300 MW IGCC at Puertollano, Spain

- European Consortium led by Endesa and EDF.
- Dry coal fed entrained Prenflo (now Shell) gasifier
- Full integration with all the air for the ASU extracted from the GT compressor
- Operating on 50/50 Petroleum coke/local Spanish coal (~40% ash)
- Fly slag from filter is low carbon and is not recycled
- H_2S + COS ~12ppmv in syngas ex MDEA unit
- First IGCC operation in 1998. 3 month shutdown in mid 2003 to revamp GT.
- IGCC currently operating at 93% availability (with fuel backup) and 76% gasifier availability (82% if start-up included)
- Slip stream CO_2 capture and Hydrogen production project planned for submittal to EU and for potential CLSF support.

ELCOGAS IGCC Technical Issues

- Vibration, tile impairment and hot spots in the silo combustors of the Siemens V 94.3 gas turbine. Flange deformation found at 50,000 hour overhaul April 2003. New burners and control system installed during 3 month outage. New burners have much improved operation. Control of natural gas/syngas switchover needs optimization.
- In the gasification area the main outage causes have been in fuel mixing and grinding, slag removal and corrosion in the colder areas of syngas clean up. The gas filter operating life is shorter than expected.
- Replacement of COS hydrolysis Alumina catalyst by Titania increased catalyst life and reduced formate production (lower HSS in MDEA and less MDEA usage). Fouling of COS preheater tubes by salts limits reactor temperature during long runs resulting in increased COS in syngas. A parallel preheater has been installed.

Elcogas IGCC Availability Statistics August 2003 – July 2004

% Time	IGCC	Gasifier	Power Block	ASU
On- stream	**65.8**	**69.2**	**90.7**	**79.7**
Planned Outages	**9.6**	**8.1**	**3.3**	**4.8**
Unplanned Outages	**24.6**	**15.2**	**4.1**	**3.3**
Product Not required	**0.01**	**7.5**	**2.0**	**12.2**

IGCC - Lessons Learned

- Very low SO_2, NOx, and Particulate Emissions below recent PC plants permit limits
- Global E Gas, Texaco, Shell and Prenflo gasifiers have been successfully demonstrated at commercial size
- Existing single train IGCC coal plants have not yet achieved their yearly availability targets of 85%– although on a quarterly basis the targets have been achieved. Commercial multi-train plants with spare gasifiers will achieve >90% availability.
- The high degree of Integration used in the European IGCC plants is not recommended for new IGCC plant designs.
- IGCC is currently being commercially used in many plants worldwide based on the gasification of petroleum residuals providing power, steam and hydrogen to refineries. These plants provide additional operating experience on key components and unit operations.

IGCC Design Studies – Notes on Sparing of Gasifiers

- Texaco and E-Gas refractory lined gasifiers need planned outage of 25-30 days for refractory replacement every 2-3 years. If a 90% Overall IGCC equivalent availability is required then, based on experience and lessons learned at the commercial demonstration plants, a spare gasifier would be required. The spare reduces the Scheduled Outage time and some of the Forced Outage time.
- Shell gasifiers do not need such extended outages and have experienced a higher availability. However Shell would also need a spare if 90% availability was required.
- E-Gas paper at 2002 conference made a case for no spare for those instances where Spring and Fall power demand is lower so that planned outages could be taken at such times.
- Careful consideration of the needed IGCC plant Equivalent Availability and annual power demand profile should be made to decide on sparing.

IGCC Gas Turbine Experience & Integration

- Full integration of GT and ASU not recommended. Most new designs compromise at 25-50% of ASU air supply extracted from the GT compressor with the optimum determined by the specific GT compressor characteristics
- Siemens GT's (silo combustors) in the European IGCC plants experienced vibration and hot spots. In future plants Siemens V 94.3A or 501 F/G with can annular combustors are more likely choice.
- The US IGCC's with GE can annular combustors have not experienced significant vibration problems.
- GE recommends reduction of firing temperature based on flue gas moisture to retain LTSA guarantees. N_2 dilution preferred over steam injection.

Next Generation IGCC Plant Designs 500-800 MW

- For 500-550 MW plants the basic configuration is two (possibly one) ASU's, two operating gasifiers, two GT's and a single ST. For 800-850 MW two ASU's, three operating gasifiers, three GT's, a single ST.
- For 90% Equivalent Availability add spare Gasification train
- Many new designs are for very low (~3ppmv at 15% O_2) SO_2, NOx, CO and particulates. If SCR is to be included to meet ultra low NOx GE recommends a flue gas SO_2 content of <2 ppmv (equivalent to <15 ppmv S in syngas) in order to avoid fouling and corrosion of the HRSG downstream of the SCR by Ammonium Bisulfate. These low emission levels are usually achievable with Selexol or Sulfinol M
- If CO_2 removal or Hydrogen production is required high pressure Quench gasifiers have a distinct advantage