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IGCC & Gasification for a Changing Marketplace

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Gasification Technologies Conference
Washington, DC

October 1-4, 2006

IGCC Standard Offerings 2004-5

- 2004-5 IGCC Offerings basically positioned to compete with PC plants in the US power market
- Gasifier operating pressure selected as the minimum required to get through gasification, heat recovery, gas clean up and gas turbine control valve
- GE emphasis on bituminous coals & Pet. coke
- COP full slurry quench design (~30% to 2nd stage) for Pet. Coke, bituminous and sub-bituminous (PRB) coals
- Shell for range of Pet. Coke, bituminous, sub-bituminous coals and lignite.
- GE, COP and Shell IGCC all with Syngas coolers to maximize efficiency to better compete with Supercritical PC and USC plants

The Changing Marketplace 2006 ff

(1 of 3)

- Emergence of CO₂ emissions as an issue in the selection of technology for the power industry. Carbon Capture and Storage/Sequestration (CCS) getting more serious consideration.
- Many Environmental groups supportive of IGCC over PC (re CCS) for its environmental attributes but without much understanding of the effects of design variations and coal types on the cost of CCS and a competitive Cost of Electricity (COE)
- In the power industry IGCC is generally perceived as not yet fully commercially proven, whereas capture of CO₂ from coal gasification derived syngas, via the shift reaction ($\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$) and subsequent CO₂ removal is commercially mature. In contrast PC plants are fully commercially proven but post combustion CO₂ capture from PC plants is not proven at the scale needed for deployment.
- Without consideration of capture the COE from currently offered IGCC with bituminous coals has mostly been evaluated as being 10-20% greater than the COE from PC plants. That margin is greater with low rank coals such as PRB and lignite. Both margins may be reduced with increased IGCC commercial deployment.

The Changing Marketplace 2006 ff

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- For CCS it has often been stated that IGCC + CCS is preferred over PC + CCS. However this is based on a number of studies using bituminous coals and the GE/Texaco Quench type gasifier, not the currently offered IGCC designs. With the added cost of the expensive syngas coolers the advantage over PC will be less.
- Given the 300 GW of PC coal in the US and the rapidly increasing PC base in China etc there is an enormous incentive to reduce the cost of post combustion capture and possibly to develop Oxyfuel combustion. Significant improvements can be anticipated.
- Western coals, particularly PRB, are increasingly selected for new coal plants. The currently offered IGCC designs for PRB are even less competitive with PC than for bituminous coals. Although the added cost of capture maybe less with IGCC the COE with CCS may be no better than PC + CCS for these coals
- *Unless lower cost IGCC Quench designs are developed and commercially offered soon IGCC may lose its perceived advantage over PC for CCS.*

The Changing Marketplace 2006 ff

(3 of 3)

- The high price of natural gas has made syngas from coal or petroleum residuals more attractive for chemical synthesis (Ammonia, Methanol, DME)
- The even higher price of crude oil has prompted serious consideration of gasification of low value fossil resources (remote gas GTL, Coal CTL) to provide syngas for the synthesis of liquid transportation fuels via the Fischer-Tropsch (F-T) technology. For CTL economies of scale are important and larger gasifiers to match the syngas requirements of large F-T reactors are highly desirable. F-T reactors of 10,000- 20,000 bbl/d size require gasification of 6,000-12,000 tons/day of typical bituminous coal.
- The emergence of a 50 Hz IGCC market in Europe and Asia based on low value feedstocks and fuels. Larger gasifiers (factor 1.4) will also be needed to match the larger size 50 Hz gas turbines. Even larger gas turbines (GE 9H, Siemens 6000G and 8000H) may require gasification capacity of 4000 tpd of bituminous coal

GE Energy Standard Design

(GE/Bechtel Papers at 2005 Gasification Technologies Conference and CoalGen)

- Two-train Radiant Cooler Only with 2 x 7 FB Gas turbines. Nominal 630 MW (net) output. Designed for a range of bituminous coals (up to 4% sulfur and 14% ash) with 38.5–40% efficiency. Deep sulfur removal to allow for SCR option. ~40% of ASU air extracted from CT compressors. No spare. Suggested scheduling of gasifier maintenance in Spring and Fall.
- CoalGen Paper showed 8845 Btu/kWh for Illinois coal (~38.6% efficiency HHV basis)

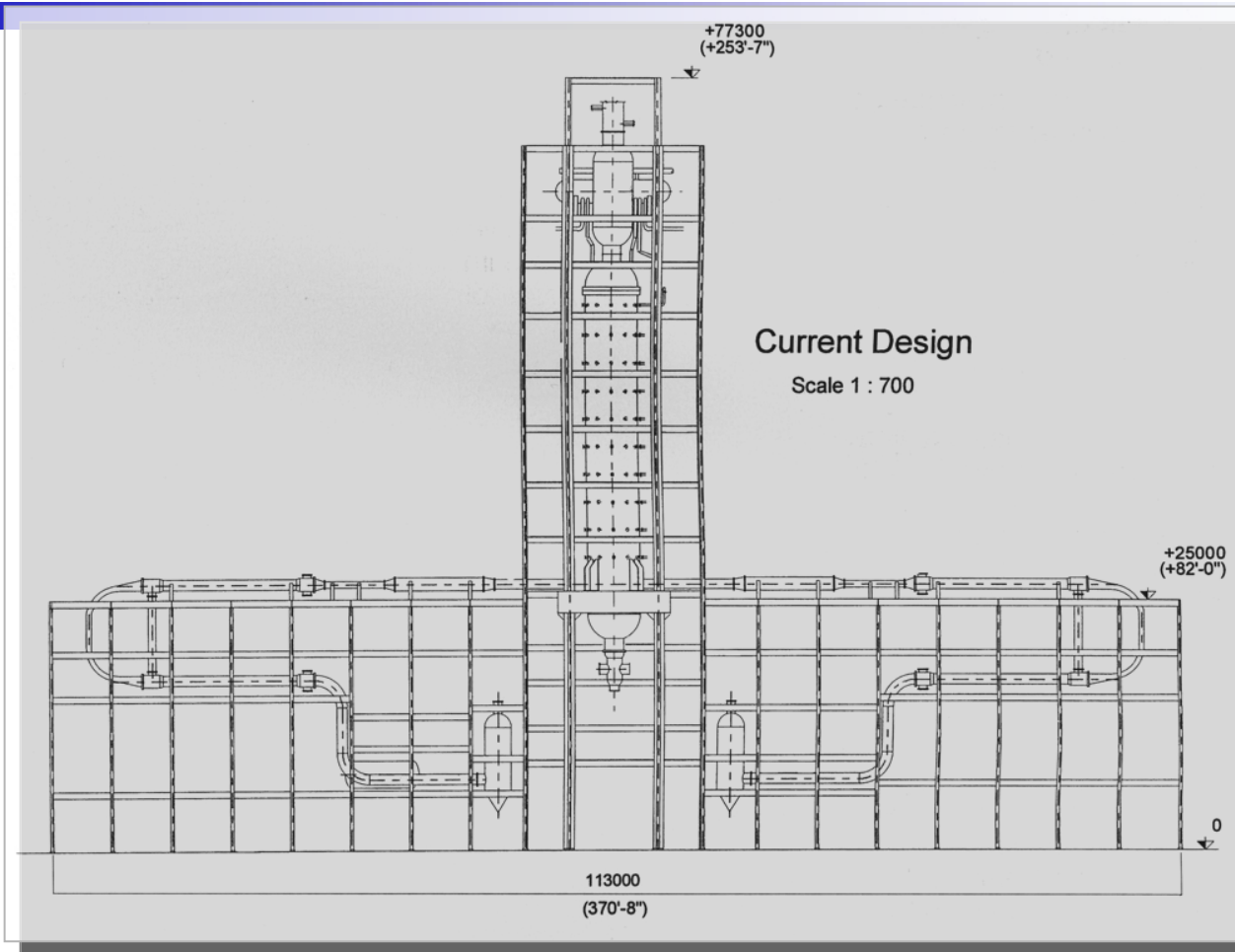
GE Energy Standard Design (cont'd)

(GE/Bechtel Papers at 2005 Gasification Technologies Conference and CoalGen)

- Compared Quench (Q), Radiant Only (R), and Radiant + Convective (R+C) IGCC designs without spare
- Q has 3x900 ft³ gasifiers whereas R and R+C have 2x1800 ft³ gasifiers? Why? The pressure was not stated but with no expansion turbines it was probably 500 psig. On this basis, Q and R were evaluated at the same \$/kW. R has 60 MW more output and HR 830 Btu/kWh lower than Q. R was assessed to have 1.5% better availability than Q or R+C. R has been selected for the Standard Design.
- This result differs from previous studies with a spare and with the same size gasifiers for all configurations.

Polk IGCC Plant Dimensions

(Divided flow from base of Radiant cooler will probably not be used in Future designs)



Tampa Radiant Syngas Cooler



GE Gasifier Sizes and Production Capacity

Plant/Location	Gasifier Type/ Pressure psig	Reactor Size ft ³	Tons/day Bituminous coal	Syngas Production MBtu/hr LHV
Eastman, TN	Quench/ 1000	450	1350	1000
Cool Water, CA	Radiant + Convective/ 450	900	1200	900
Tampa, FL	Radiant/ 450	1800	2200	1650
NPRC Negishi, Japan	Quench/ 1000	900	Equiv 3100 (2200 Asphalt)	2400

GE Gasifier for CO₂ Capture and Synthesis

- Quench design is least cost method of providing moisture to syngas for shift reaction.
- High pressure Quench as used at Eastman and Negishi advantageous for capture and synthesis.
- Currently 900 ft³ at 1000 psig can supply syngas to fully load MHI 701 F or ~ 2400 MBtu/hr LHV
- Larger gasifier of 1200 ft³ or 1800 ft³ (Tampa size) at 1000 psig could supply enough syngas for 50 Hz gas turbines and reduce the number of gasifiers needed to match the syngas requirements of large 10,000 -20,000 bbl/day F-T reactors thus providing considerable economies of scale.
- Potential improvements:
 - Water injection replacing quench ring (RAG/RCH)
 - More residence time (increase L/D) to increase conversion on scale up.
 - For capture IGCC consider Jacobs GEM configuration (with shift), particularly for the 50 Hz market. Better efficiency, more capture ready since ASU, gasification and gas clean up already sized for shift to fully load GT's.

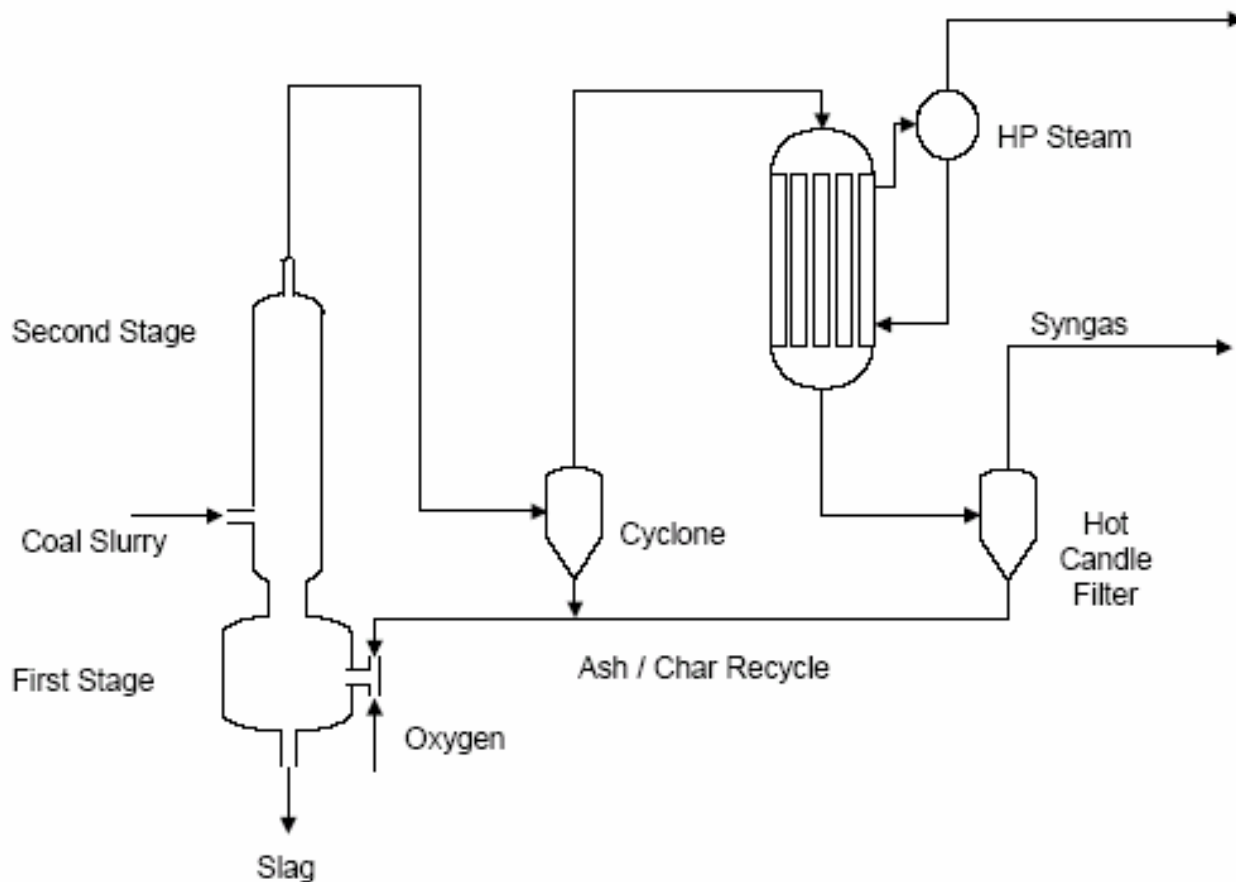
ConocoPhillips E-Gas – ESTR for Capture, Synthesis and LR Coals?

- Current design pressure (600 psig?) and throughput limitations 4400 tpd PRB coal or 1950 MBtu/hr LHV syngas
- Standard IGCC design features “Full slurry quench” with ~ 30% coal fed to 2nd stage with consequent higher methane content that inevitably limits carbon capture capability and suitability for most synthesis applications.
- Proposed improved ESTR currently envisaged as tall cylindrical design (maybe two diameters) with 100% coal to upper stage and recycled char to bottom stage. Lower gasifier outlet temperature gives higher gasifier efficiency with higher methane content but increased risk of tar survival. Higher pressure enables gasifier to process larger feed rates of low rank coals including lignite.
- To achieve larger sizes, higher pressures and economies of scale the ESTR tall cylinder could be run as at Wabash (~10-15% to 2nd stage). This gas would be much more suitable for higher carbon capture and synthesis applications. Size would also then be suitable for the 50 Hz market.

ConocoPhillips

- Proposed New Reactor Configuration

Entrained Slagging Transport Reactor (ESTR)



Advantages

- Dry feed to 1st Stage
- Lower Oxygen usage
- High efficiency
- Slagging gasifier
- High pressure operation
- Extends to more effective performance with LR coals

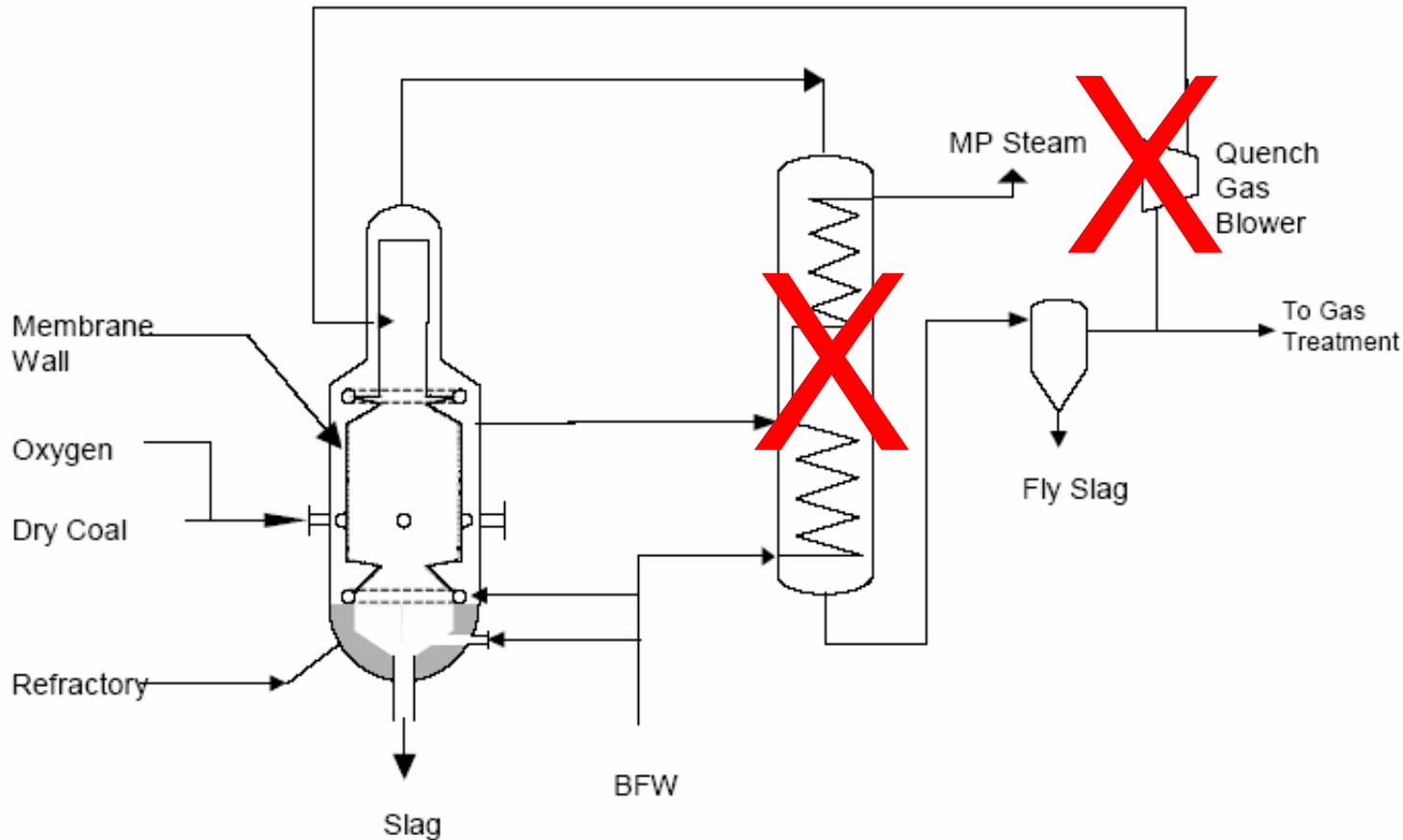
Disadvantages

- Refractory lined
- Higher methane content
(could limit CO₂ recovery)
- Water quench only at low temperature

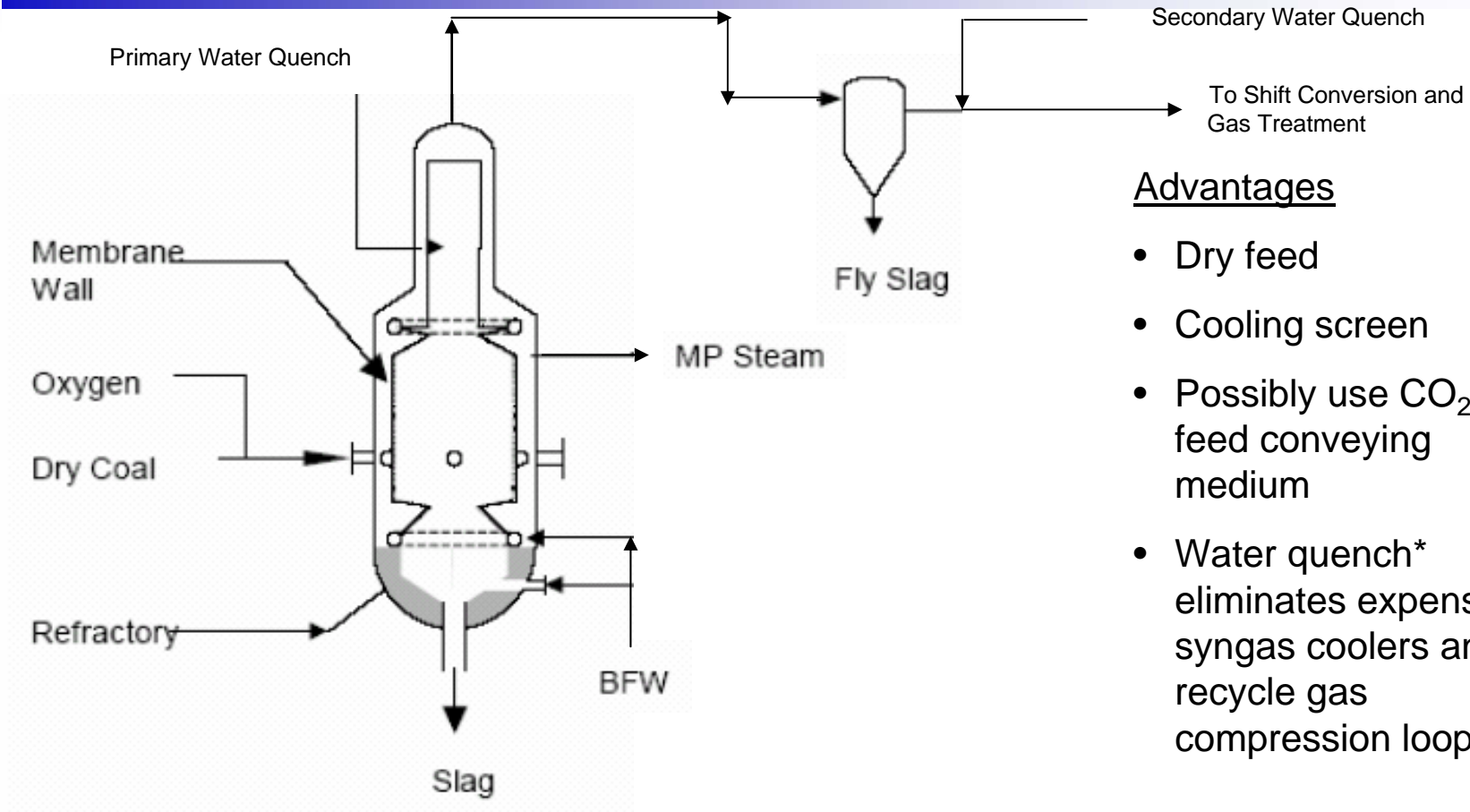
Shell – Quench design for Capture, Synthesis, High output and all coals?

- Can handle all coals but current design with syngas cooler and gas recycle is expensive
- For capture and synthesis a quench (or partial quench) design would be much lower cost and would provide the moisture for shift in the most cost effective manner.
- For capture and synthesis applications recovered CO₂ can be used as the feed conveying gas rather than nitrogen. CO₂ is a reactant whereas nitrogen is an inert just taking up expensive space in downstream processing and the synthesis loops
- Shell gasifier has capability for higher throughput by addition of more fuel injectors. Should be a good match for large F-T synthesis reactors and for large advanced 50 Hz gas turbines (Siemens G&H?, GE 9 FB?)

Shell Coal Gasification Process (SCGP)



Shell Coal Gasification Process (SCGP) With New Quench System

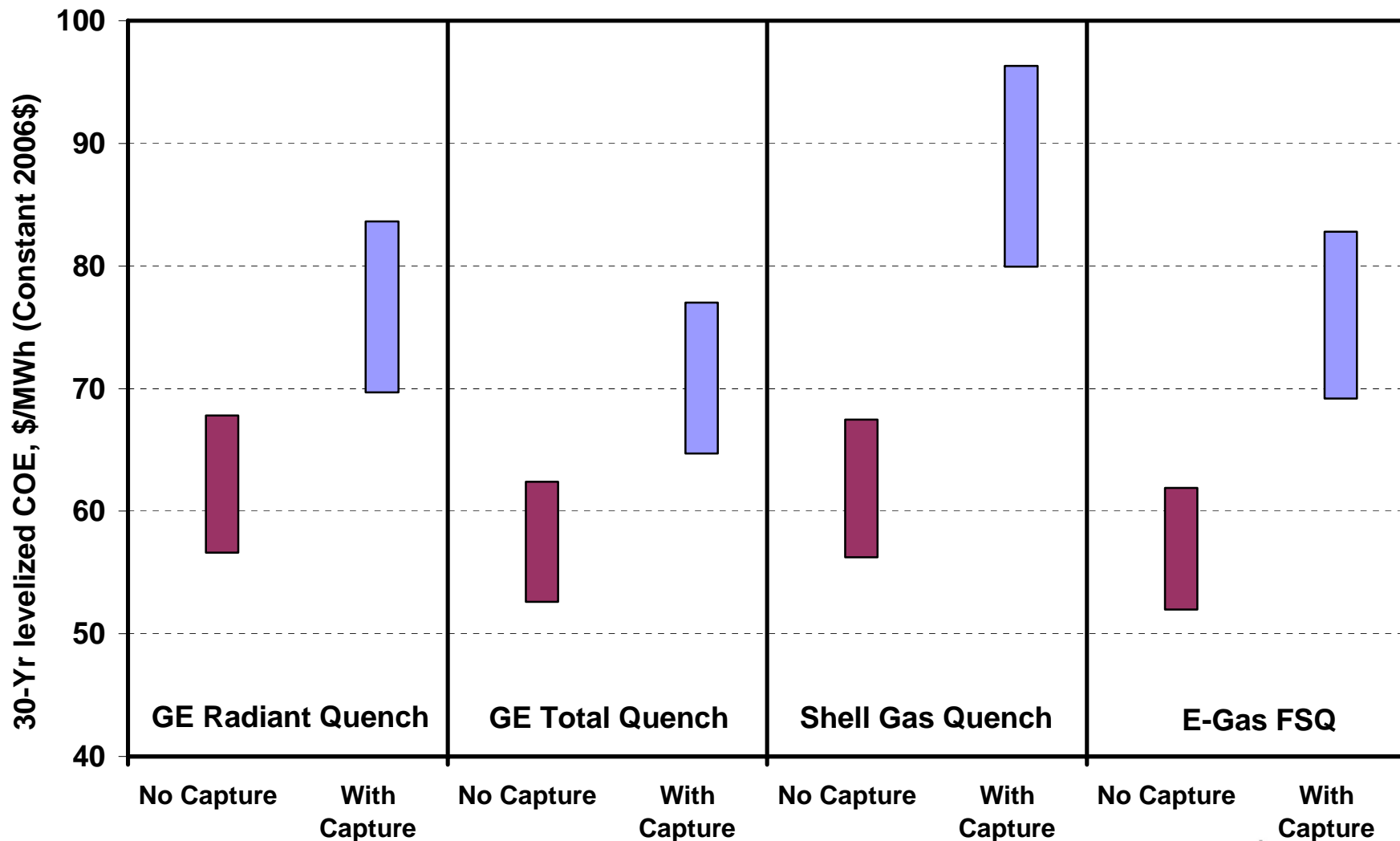


Advantages

- Dry feed
- Cooling screen
- Possibly use CO₂ for feed conveying medium
- Water quench* eliminates expensive syngas coolers and recycle gas compression loop

EPRI 600 MW (net) Cost of Electricity (COE) Estimates

(Illinois #6 Coal \$1.50/MBtu; with and without CO₂ capture, No spare gasifiers)



Pre-Investment Options for CO₂ Capture

- **Partial Capture (60%)** – Where NGCC CO₂ levels are desired
 - Single-stage shift reactor – Normal Syngas Combustors
 - Lower cost of electricity than Maximum Capture option
- **Maximum Capture (90%)**
 - Multi-stage shift reactor – Hydrogen Combustors
 - Higher cost of electricity

Standard Provisions

- Space for additional equipment, BOP, and site access at later date
- Significant net power capacity, efficiency and cost and penalty upon conversion to capture

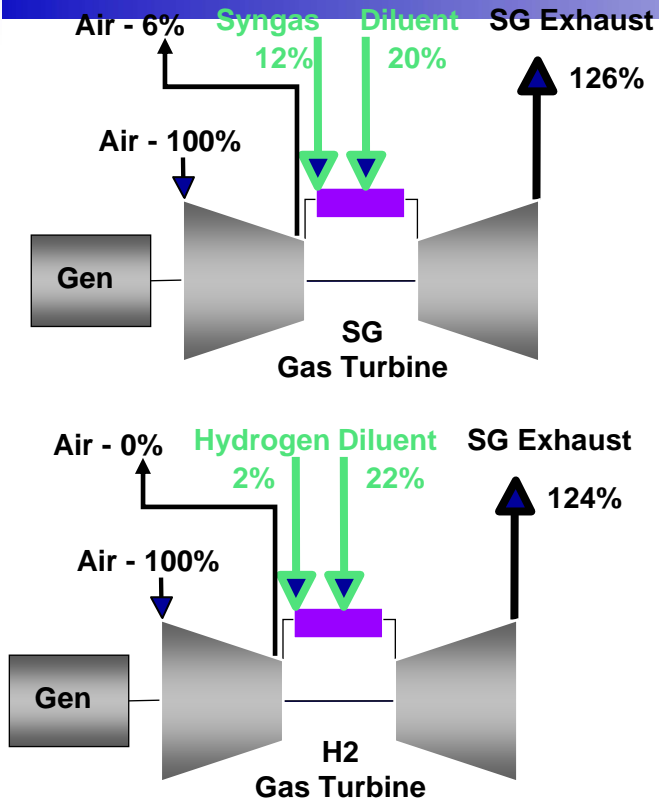
Moderate Provisions

- Includes oversizing of major components: gasification block, ASU, etc.
- Mitigate the cost and efficiency penalty by fully loading the combustion turbines after C&S
- Excess syngas production capacity could be used for poly-generation or supplemental firing

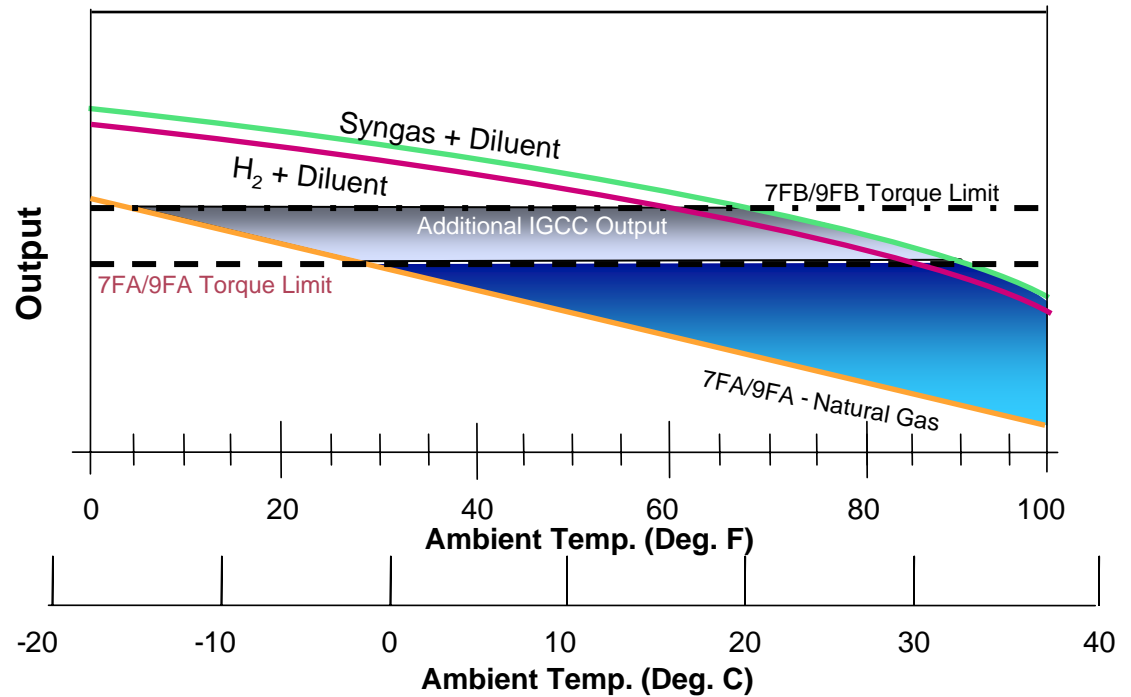
Extensive Provisions

- Total design for conversion-shift reactors, oversized components, no CO₂ compressors
- No need for a shutdown to complete the conversion to CO₂ capture

H₂ Output Impact – Source General Electric



Gas Turbine Output vs. Ambient Temperature



Gas Turbines – Syngas and Hydrogen

- GE 7 FB designed for 232 MW with Syngas at ISO conditions and ability for air extraction. However at higher ambient temperatures and elevations the ability to extract is constrained. So the ASU Main Air Compressor (MAC) may have to be designed for full air flow for plant operation at high ambients.
- In some cases could consider inlet air chilling to maximize output over a wider range.
- The Good News & Bad News (Trade Offs & Ironies).
 - Plant can be operated with extraction at lower ambients (if designed in) with better efficiency (less auxiliary power).
 - Capital cost is higher with full air flow MAC
 - Net output lower at higher ambients (more MAC MW).
 - Since apparently no air extraction is allowable when firing Hydrogen, then when adding capture the MAC is already sized more appropriately.
- Do the Siemens 5000F and 6000G gas turbines have similar limitations?

IGCC Design Issues for Capture

- Additional ASU, Gasification and gas clean-up is needed to fully load the GT's when Shift is added. If this oversizing is included in the initial IGCC investment the capacity can be used for supplemental firing or co-production. This version of "capture ready" would then permit full GT output with Hydrogen (at ISO) when capture is added.
- Addition of Sour Shift increases gas flow to the AGR particularly for the dry coal fed gasifiers with high CO content (next slide). Unlikely that the AGR would be able to take the extra flow unless there was pre-investment oversizing. May need to add a parallel absorber or replace the entire AGR plant (with a new two column absorption system) if capture is to be added to an existing IGCC designed without capture.
- Alternatively the original AGR (focused on H₂S Removal) could be retained and a Sweet shift added after the AGR with a simpler bulk CO₂ removal AGR (ADIP, MDEA, Selexol) added after shift. This would minimize intrusion into existing plant. This trade off of Sour versus Sweet Shift needs to be examined and may differ among the Gasification Technologies. Sweet Shift may incur additional efficiency and output penalties. Quench gasifiers would probably favor Sour Shift.

Gas Compositions and Flows before and after Shift

(Mol % Clean Dry Basis – Typical Bituminous Coal)

Gasifier	GE no Shift	GE with Shift	COP no Shift	COP with Shift	Shell no Shift	Shell with Shift
Pressure psig	500-1000	500-1000	600	600	600	600
H ₂	37	81	30	76	28	88
CO	47	3	49	3	64	4
CH ₄	<0.1	<0.1	6	6	<0.1	<0.1
CO ₂	14	58	12	58	2	62
N ₂ + A	2	2	3	3	6	6
Total Flow Mols	100	144	100	146	100	160

IGCC/Gasification and the Changing Marketplace – Conclusions/Needs

- Need Gas Turbines that enable air extraction across the ambient range and with Hydrogen firing
- GE larger HP Quench. New feed/design for LR coals
- COP HP tall Cylinder, higher throughput for LR coals
- Shell larger Quench (with water) design, CO₂ transport of feed for capture and synthesis, lower cost drying or new feeder for LR coals
- Need larger, higher pressure, lower cost Quench gasifiers for Capture, synthesis and 50 Hz markets otherwise IGCC may lose its perceived advantage over PC for CCS.