Advanced Coal Workshop for EPA

IGCC – Status, Comparisons, and R&D
Other Advanced Coal Options
CO₂ Capture and Storage
Industry / EPRI Programs to Advance Deployment

Hank Courtright
Senior Vice President
June 19, 2006 Conference Call
Types of Coal Generation

• **Pulverized coal** (PC): Finely ground coal is burned to make steam and then flue gases are cleaned up; there are more than 1000 such “conventional coal” plants in the U.S.

• **Very high-temperature versions of PC** employ supercritical (SC) steam, and even higher use ultra-supercritical (USC)

• **Circulating fluidized-bed combustion** (CFBC or FBC): Larger coal pieces are “fluidized” by combustion air and entrained with a “sorbent” such as limestone to remove SO₂

• **Gasification** of coal involves reaction with oxygen and heat/steam to produce a “synthesis gas” containing CO, hydrogen, and (sometimes) methane. The gas is cleaned and then burned in gas turbine with the exhaust heat used to make steam; such plants are “integrated gasification combined cycle” (IGCC).
What Is “Clean Coal?”

• Even modern conventional coal plants are much cleaner than prior designs, but most people refer to designs meeting very stringent emission regulations as “clean coal”

• Coal-based IGCC plants have very low SO$_2$, NOx and mercury emissions and are almost as clean as natural gas plants

• Advanced PC combustion plants designs have improved efficiency and low emissions

• EPRI and the Coal Utilization Research Council have defined clean coal plant performance and emission goals for 2010 and 2020 (see Roadmap at www.coal.org). DOE has provided significant input into the Roadmap.
Regional U.S. Coal Differences Favor Multiple Advanced Coal Options

• IGCC with slurry feed economics are best with “high-rank” bituminous coals or low-rank (PRB) coal plus petroleum coke (economics currently do not favor IGCC, but emissions do)

• New IGCC designs may be better for low-rank coal – these are still in developmental

• Waste coals and biomass may be best in fluidized-bed combustion (FBC) units, but supercritical steam conditions are unproven

• Most announced new U.S. coal plants are for new “conventional” pulverized coal due to lower fuel costs; where fuel costs are high, ultra-supercritical (USC) designs are favored

• CO₂ can change the balance
IGCC With and Without CO₂ Removal

IGCC

H₂ & CO₂ (e.g., FutureGen, BP Carson on Coke)
Today - Existing Coal-based IGCCs

Puertollano (Spain)  Wabash (Indiana)  Polk (Florida)  Buggenum (Netherlands)
# Coal Based IGCC Plants

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

<table>
<thead>
<tr>
<th>Name/Owner</th>
<th>Location</th>
<th>MW</th>
<th>Technology</th>
<th>Other Products</th>
<th>Notes/Status</th>
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<tr>
<td>AEP</td>
<td>OH, W.Va, Ky</td>
<td>600</td>
<td>GE</td>
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<td>FEED w/GE</td>
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<td>Cinergy</td>
<td>IN</td>
<td>600</td>
<td>GE</td>
<td></td>
<td>FEED w/GE</td>
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<tr>
<td>Excelsior</td>
<td>Mesaba, MN</td>
<td>600</td>
<td>COP E-Gas</td>
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<td>CCPI 2</td>
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<td>Steelhead</td>
<td>Illinois</td>
<td>615</td>
<td>COP E-Gas</td>
<td>95 MSCFD SNG</td>
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<tr>
<td>Energy NorthWest</td>
<td>Washington</td>
<td>600</td>
<td></td>
<td></td>
<td>Study with COP E-Gas</td>
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<tr>
<td>WMPI</td>
<td>Pennsylvania</td>
<td>60</td>
<td>Shell</td>
<td>5000 bpd F-T Diesel</td>
<td>CCPI 1, Culm ( waste coal)</td>
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<tr>
<td>SoCo/Orlando</td>
<td>Florida</td>
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<td>Air-blown KBR</td>
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<td>CCPI 2, PRB</td>
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<tr>
<td>Royster Clark/Rentech</td>
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<td>550</td>
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<td>FEED Eastman</td>
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<td>BP/Edison Mission</td>
<td>California</td>
<td>500</td>
<td></td>
<td>Hydrogen. CO₂ for EOR</td>
<td>Pet Coke Announcement</td>
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<td>Global</td>
<td>Lima, OH</td>
<td>530</td>
<td>COP E-Gas</td>
<td></td>
<td>Earth moving</td>
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IGCC RD&D Implementation Path for Cost Reduction Case: Slurry-fed gasifier, Pittsburgh #8 coal, 90% availability, 90% CO₂ capture, 2Q 2005 dollars

Data from CoalFleet for Tomorrow®

- **Mid-Term**
  - ITM Oxygen
  - G-Class to H-class CTs
  - Supercritical HRSG
  - CO₂-Coal Slurry
  - Dry Ultra-low-NOₓ combustors

- **Long-Term**
  - Membrane separation
  - Warm gas cleanup

- **Longest-Term**
  - Fuel cell hybrids

...plus efficiency also improves from 30–45%
Ultrasupercritical PC Plants

- European and Japanese USC PC Experience Base
  - 600°C (1112°F) high availability, good load following
  - Baseline S-O-A for a new coal-fired plant

- In Development:
  - European Advanced 700°C PC (1292°F)
  - DOE EIO/EPRI 760°C (1400°F) boiler materials program
Comparative Costs of 2010 Generating Options

Levelized Cost of Electricity, $/MWh

[Graph showing cost of electricity versus cost of carbon dioxide, with labels for NGCC @$6 and PC w/o CO2 capture]

EPRI 2004 projections for Midwest site and Pittsburgh #8 Bituminous coal @ 80% CF
Pulverized Coal w/o Capture

Levelized Cost of Electricity, $/MWh

PC w/o capture 2010
PC w/o capture 2020

EPRI 2004 projections for Midwest site and Pittsburgh #8 Bituminous coal
IGCC w/o Capture

Levelized Cost of Electricity, $/MWh

Cost of CO₂, $/metric ton

IGCC w/o capture 2010

IGCC, w/o capture 2020

EPRI 2004 projections for Midwest site and Pittsburgh #8 Bituminous coal
PC vs. IGCC with Improvements

1. More efficient, but higher cost IGCC
2. Eliminate spare gasifier
3. Larger, more efficient gas turbine

Levelized Cost of Electricity, $/MWh

Cost of CO₂, $/metric ton

Base IGCC COE
Base PC COE
Remaining gap between COE for IGCC and PC
What About CO₂?

• Higher efficiency designs inherently produce less CO₂ per kWh

• Neither IGCC nor pulverized coal inherently captures CO₂ and it takes additional energy and cost to capture and store CO₂

• US and world efforts are aimed at developing better options for high efficiency generation and understanding how to economically capture and safely store CO₂

• CO₂ storage viability is key
PC with capture/transport/storage

Levelized Cost of Electricity, $/MWh

Cost of CO₂, $/metric ton

EPRI 2004 projections for Midwest site and Pittsburgh #8 Bituminous coal

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IGCC with capture/transport/storage

Levelized Cost of Electricity, $/MWh

Cost of CO₂, $/metric ton

IGCC, w/o cap 2020

IGCC w/cap/t/s 2020

EPRI 2004 projections for Midwest site and Pittsburgh #8 Bituminous coal
Comparison of IGCC and PC (2020)

Reducing Cost of PC CO2 capture is a key technology challenge

Levelized Cost of Electricity, $/MWh

Cost of CO2, $/metric ton

PC with MEA capture

IGCC w/o cap

Cost Gap

PC w/o cap

IGCC w/cap

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Overview of Advanced Coal R&D Programs

• DOE Gasification and CO2 programs - extensive R&D&D

• FutureGen Alliance (DOE/Industry)
  • A “living laboratory” for advancing IGCC technology and associated CO₂ capture technology and hydrogen co-production
  • Demonstration of large-scale storage of “gasification power plant” CO₂

• EPRI CoalFleet Program
  • Focused on accelerating the deployment of advanced coal technologies
    – IGCC
    – Ultra-supercritical PC
    – Supercritical Circulating Fluidized-Bed
  • Development of IGCC CO₂ capture capability/convertibility

• EPRI CO₂ Capture Initiative
  • Focused on developing advanced post-combustion CO₂ capture technology for PC plants
  • Understanding issues and demonstrating storage of CO₂ from combustion

Coordinated Plan Avoids Duplication and Gaps
CoalFleet for Tomorrow® an EPRI Program

• An Industry Initiative to Accelerate the Deployment of Advanced Coal-Based Power Plants
• Billion Dollar Plus Investments in an Emission-Limited World
• Risks and questions IGCC & USCPC and other technology
  – Is it reliable?
  – What designs are best?
  – How can it be licensed (permits)?
  – How much will the new technology cost?
  – How can it be financed?
  – How can it be made CO₂ capture ready?

Summer 2005 EPRI Journal article available at www.EPRI.COM
CoalFleet Leverages U.S. DOE/Industry Programs to Accelerate Deployment of Advanced Coal Plants

Economics and CO₂ Capture Options

Plant Design and Permitting Guidelines

Augmented RD&D Plan Implementation

DOE R&D
CCPI Demonstrations

FutureGen

Early Deployment Units

IGCC
USC PC/FBC

Near-term RD&D

Long-term RD&D (e.g., CO₂ Capture Capable IGCC & USC PC)

Next-Generation Units

Next-Generation Units

Next-Generation Units

Next-Generation Units

Next-Generation Units

2005 2010 2015 2020
Conclusions

• IGCC is a promising technology with very low emissions, excellent promised efficiency. IGCC has potential for capturing CO₂ with additional cost and some loss of efficiency – right now it is more expensive (10-15%) than pulverized coal without capture.

• EPRI believes with western coals both IGCC and pulverized coal with CO₂ capture may be in competition regarding cost, emissions in 2015-2020.

• Major programs such as the DOE Regional Carbon Sequestration Partnerships promise CO₂ storage assurance.

• FutureGen Program aimed at providing hydrogen firing plus CO₂ capture and storage – a living laboratory.

• CoalFleet for Tomorrow® is aimed at deployment of the best designs using global lessons learned with CO₂ options for capture.
CO₂ Capture & Storage

An Overview

Hank Courtright
Senior Vice President
Worldwide CO$_2$ Storage Potential

Source: IPCC
CO₂ Storage Related Activities Underway or Proposed
Sleipner Project, North Sea

- 1996 to present
- 1 Mt CO$_2$ injection/yr
- Seismic monitoring

Picture compliments of *Statoil and LBNL*
Weyburn CO$_2$-EOR and Storage Project

- 2000 to present
- 2.7 Mt/year CO$_2$ injection
- CO$_2$ from the Dakota Gasification Plant in the U.S.

Photo’s and map courtesy of PTRC, Encana, and LBNL.
In Salah Gas Project

Salah Gas Project
- Krechba, Algeria
Gas Purification
- Amine Extraction
1 Mt/year CO₂ Injection
Operations Commence
- June, 2004

Slide courtesy of BP and LBNL
Risk Management

• Leakage
• Environmental Impacts
• Permitting
• Legal Issues
Understanding the Risk
Storage Failure Mechanisms

- Leakage through poor quality or aging injection well completions
- Leakage up abandoned wells
- Leakage due to inadequate caprock characterization
- Inconsistent or inadequate monitoring
Well Bore Integrity

- In lab CO$_2$ reacts with Portland cement rapidly
- Not experienced in field, but 30 years of service shows some increased corrosion
- Develop a project to evaluate a CO$_2$ Injection well
Theoretical and experimental studies are needed to confirm this hypothesis.

Temporal Evolution of Trapping Mechanisms

Storage security should increase with time at an effective storage site.
22 Geologic Injection Tests
   – 8 Enhanced Oil Recovery /Saline
   – 6 Saline Reservoirs
   – 8 Enhanced Coal Bed Methane / Enhanced Gas Recovery
   – Test injections are between 1,000-450,000 tons of CO\textsubscript{2}
EPRI CO₂ Capture Initiative

A multi-phase testing program to develop cost-effective and practical PC CO₂ capture technologies

**Phase 1**
- 5 MW Chilled Ammonia Pilot with Alstom
- Testing of other solvents or technologies
- Test materials to be used for compression, transport and injection of flue-gas CO₂

**Phase 2**
- Larger CO₂ Test Center (possibly up to 100 MW)
- Capture and store CO₂ at substantial scale and real operating environments
- Future phases – larger demos to scale-up to full plant

Focused on closing the PC CO₂ capture cost gap
Phase 1 5MW Project Schedule

2006
- Funding
- Design/Construct

2007
- Capture Test Ready
- Testing

2008
- Testing

2009
- Potential Storage Test

Targeting Test Results in 2008
Closing the Capture Cost Gap

**Levelized Cost of Electricity, $/MWh**

- **PC with Capture**
- **IGCC with capture**

-Chilled Ammonia shows potential to close the cost gap

Cost of CO$_2$, $/metric ton
Transport Issues

• The technology is relatively straightforward but there are some questions
  – What impurities are allowable?
  – Must it meet current commercial pipeline specifications?
  – What will permitting be like if the pipeline is not in rural areas?
Public Awareness

• Surveys in Europe and North America indicate public awareness of CO2 Storage is limited
  – But, awareness of impacts of climate change is extensive
• After explanation of technology the public surveyed were not against technology
• Need to build public awareness of need for and benefits of CO2 Storage
• Public need to be engaged early in an open and transparent process
ADDITIONAL REFERENCE SLIDES IF NEEDED FOR DISCUSSION SESSION
U.S. Capacity Additions 1999-2014

Ref.: EPRI P67 Newsletter on New Power Plants, September 2005

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Coal Plants 2005-2014
Coal is Under Development

Newest IGCC proposed sites
Added to graphic –
see P 67 newsletter P66 annual report

IGCC Status, Markets and Vendors

- 4 Single train coal-based IGCC 250-300 MW on coal/coke operating
- AEP, and Duke (previously Cinergy) plan ~600 MW coal plants. Several others in development including co-production (ammonia, synthetic natural gas, liquids).
- Technology needs improvement in economics for low-rank coals (e.g., Powder River Basin).
- Petroleum Residuals (8 worldwide) - Energy Northwest and BP & EMG plan ~ 600-500 MW coke fueled (BP & EMG make hydrogen).
Polk Gasification Arrangement (Texaco – now GE)
Polk Gasifier Texaco (now GE)

- Water slurry fed design
- Issues on Powder River Basin Coal –
  - Reduced efficiency with PRB.
  - GE working on improved performance with PRB.
E-Gas Gasifier—As Used at Wabash River (Technology Now Owned by ConocoPhillips)

- Water slurry fed
- PRB Issues
  - Reduced efficiency with PRB.
  - Latest High Pressure design offers some improvement for PRB.
  - Can blend with Pet. Coke if available (as planned at Excelsior and ENW)
- Multi-stage design in development
Shell Gasifier Cutaway

- Uses Dry Feed (better on Powder River Basin Coal)
- Water walls (less maintenance and outage than with refractory)
- Current offering has high Syngas Cooler (SGC) cost.
- Lower cost partial quench design being developed