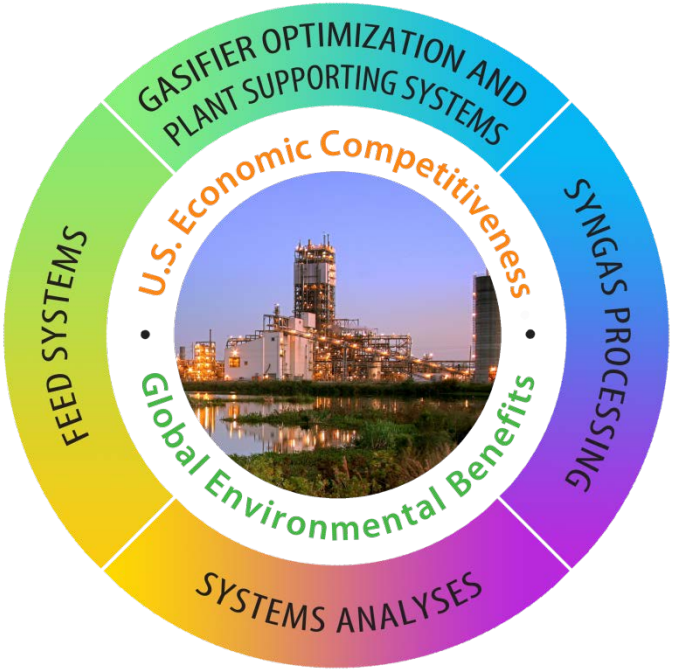

Gasification Systems Overview

Jenny B. Tennant

Technology Manager, Gasification

February 2015

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Gasification 101

Energy Outlook

Program Slides

Gasification Systems Projects

- Feed Systems
- Gasifier Optimization and Plant Supporting Systems
- Syngas Processing Systems

NETL In-House R&D (ORD)

DOE Supported Major Demonstration Gasification Projects

Systems Analysis

- On-going and Planned Gasification Studies
- Bituminous Baseline Cost Updates
- Bituminous IGCC Pathway Study
- Low Rank Coal Baseline Study: IGCC Cases

Conventional IGCC Compared to PC and NGCC

Commercial IGCC Plants

Closing

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Gasification 101

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What is Gasification?

Gasification converts any carbon-containing material into synthesis gas, composed primarily of carbon monoxide and hydrogen (referred to as syngas)

Syngas can be used as a fuel to generate electricity or steam, as a basic chemical building block for a large number of uses in the petrochemical and refining industries, and for the production of hydrogen

Gasification adds value to low- or negative-value feedstocks by converting them to marketable fuels and products

What Is Gasification?

Let's Start with Fire – where we only want to make Heat

COAL

AIR

Combustion with Oxygen

$C + O_2 \longrightarrow CO_2$

SMOKE

$H_2 + {}^1/_2\, O_2 \longrightarrow H_2O$

HEAT

And Ashes

What Is Gasification?

Converting cheap fuels into molecules that are able to be used to build more valuable products

Syngas
(depending on the gasifier and operation)
has about equal amounts of Carbon Monoxide and **Hydrogen**

Partial Combustion with Oxygen
*and reactions with water**

$C + O_2 \rightarrow CO$

$H_20 - {}^1/_2\, O_2 \rightarrow H_2$

Syngas

less HEAT

And Slag

Chemicals and Products from Gasification

Syngas →

- **Hydrogen**
- Methanol → Gasoline
- Fischer-Tropsch Process → Diesel
- Ammonia $\xrightarrow{+\,CO_2}$ Fertilizer (Urea)
- Plastics, Clothes, etc. (“almost anything”)

Why Hydrogen?

It's a genuinely clean fuel

$$2H_2 + O_2 \longrightarrow 2H_2O$$

If we burn Hydrogen in a turbine to make power, the only combustion product is Water

Water-Gas-Shift Reaction

Recall, Syngas contains a lot of CO

If Carbon Monoxide is burned it becomes Carbon Dioxide

We don't want that emission from a power plant

$$CO + O_2 \longrightarrow CO_2$$

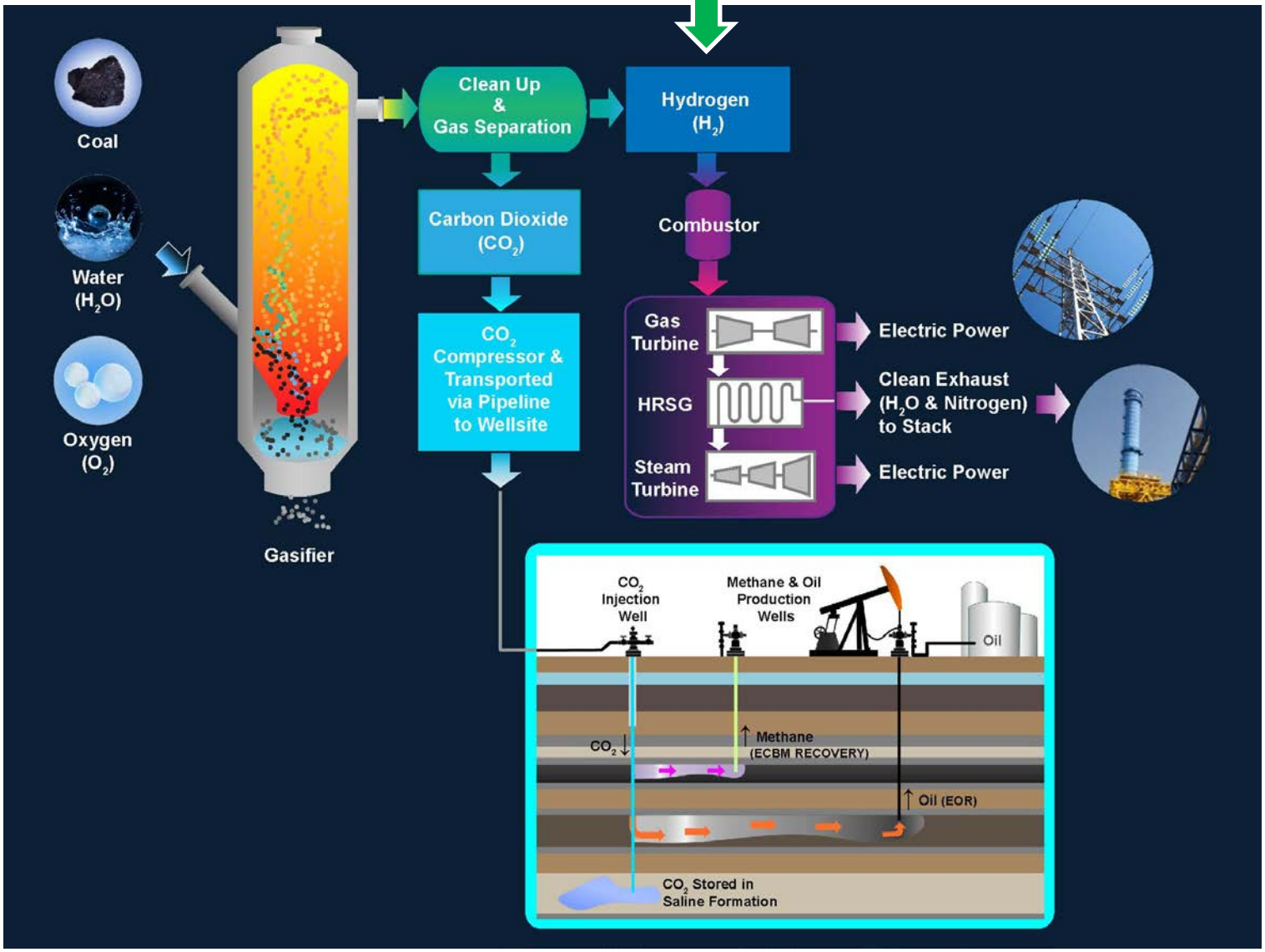
What if, instead, the CO is reacted with water?

$$CO + H_2O \longrightarrow CO_2 + H_2$$

The Water Gas Shift Reaction

DOE Vision of Gasification-based Clean Power

Hydrogen-based



DOE Vision for Gasification Systems

Coal In, Power (and Other Products) and Water Out

- **Ultra-clean coal conversion into syngas (H_2 & CO)**
- **Use water-gas shift to make more hydrogen**

$$H_2O + CO \rightarrow H_2 + CO_2$$

- **Separate <u>shifted</u> syngas (H_2 + CO_2)**

CO_2 → Sequester/Reuse

H_2 → Burn in turbine to make power; H_2O up the stack

- **CO_2, sulfur and slag turned into marketable products**

TECHNOLOGY EXISTS TO DO THIS NOW

NEED TO DEVELOP LOWER COST AND MORE EFFICIENT TECHNOLOGIES

Power

Integrated Gasification Combined Cycle (IGCC)

Syngas for power may use air or oxygen

- Air (79% nitrogen; 21% oxygen)
  - Nitrogen adds mass going through the turbine
  - No added cost for oxygen production
- Oxygen
  - More efficient gasification process
  - Less mass (no nitrogen) makes contaminant cleanup (sulfur, mercury, etc) and CO_2 sequestration less expensive

Integrated

- Designed to minimize heat /efficiency losses

Combined Cycle

- Both combustion & stream turbines for improved efficiency

Energy Outlook

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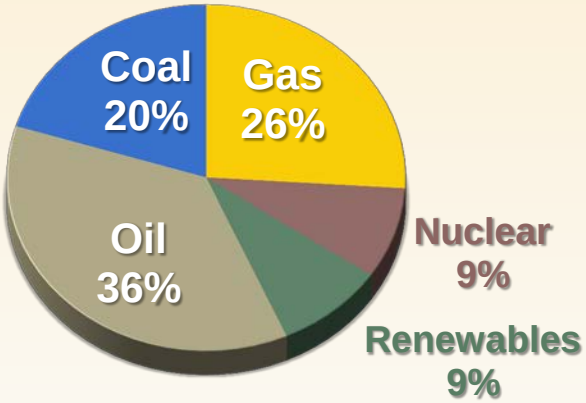
Energy Demand 2011

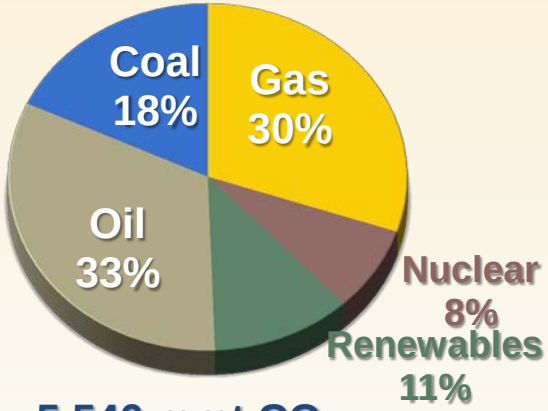
97 QBtu / Year
83% Fossil Energy



5,498 mmt CO_2

Energy Demand 2035

104 QBtu / Year
81% Fossil Energy

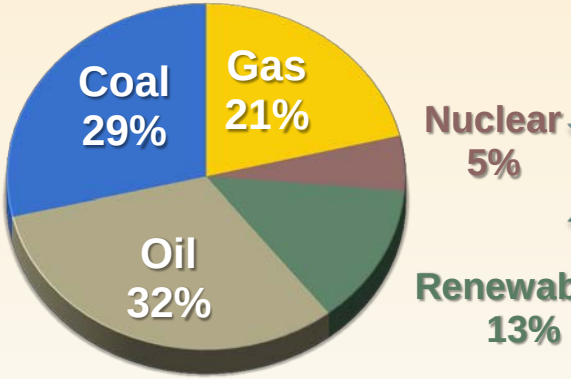


5,546 mmt CO_2

+ 7%

United States

519 QBtu / Year
82% Fossil Energy

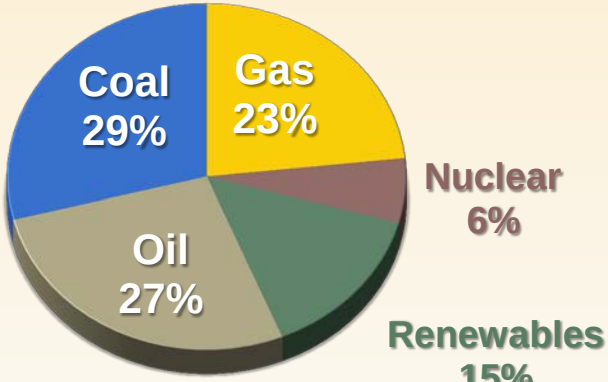


31,162 mmt CO_2

+ 43%

World

740 QBtu / Year
80% Fossil Energy

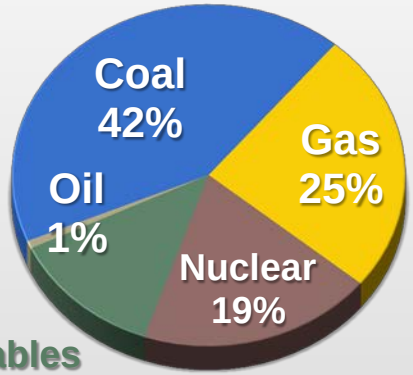


43,111 mmt CO_2

Sources: U.S. data from EIA, Annual Energy Outlook 2014: World data from IEA, World Energy Outlook 2013

Electricity Demand 2011

4,084 BkWh / Year
68% Fossil Energy

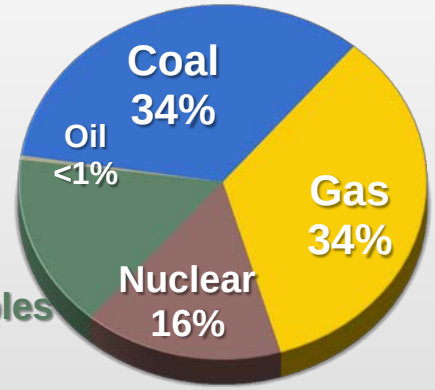


Renewables
13%

2,171 mmt CO_2

Electricity Demand 2035

4,980 BkWh / Year
68% Fossil Energy



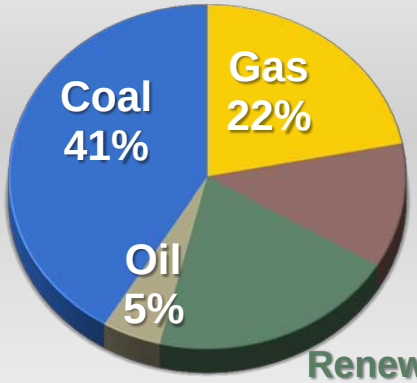
Renewables
16%

2,247 mmt CO_2

+ 22%

United States

22,113 BkWhr / Year
68% Fossil Energy



Nuclear
12%

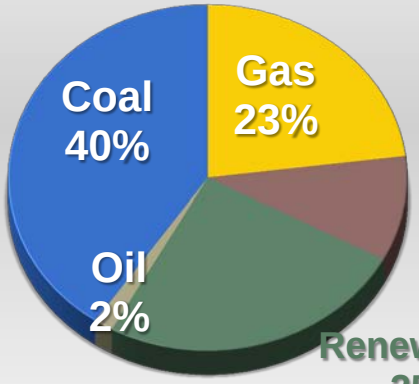
Renewables
20%

12,954 mmt CO_2

+ 80%

World

39,854 BkWh / Year
65% Fossil Energy



Nuclear
10%

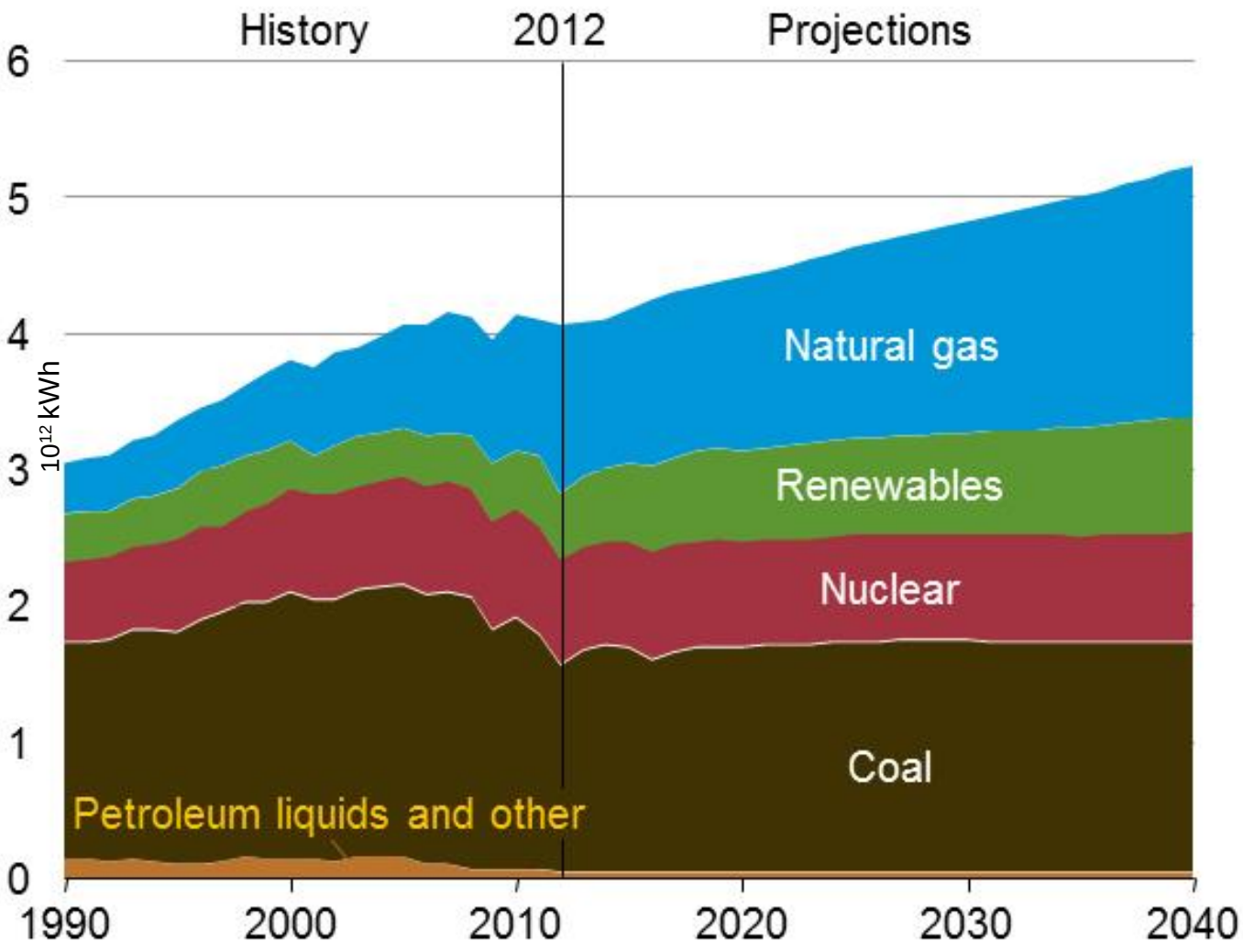
Renewables
25%

19,122 mmt CO_2

Sources: U.S. data from EIA, Annual Energy Outlook 2014; World data from IEA, World Energy Outlook 2013

Why Continued Interest in Coal?

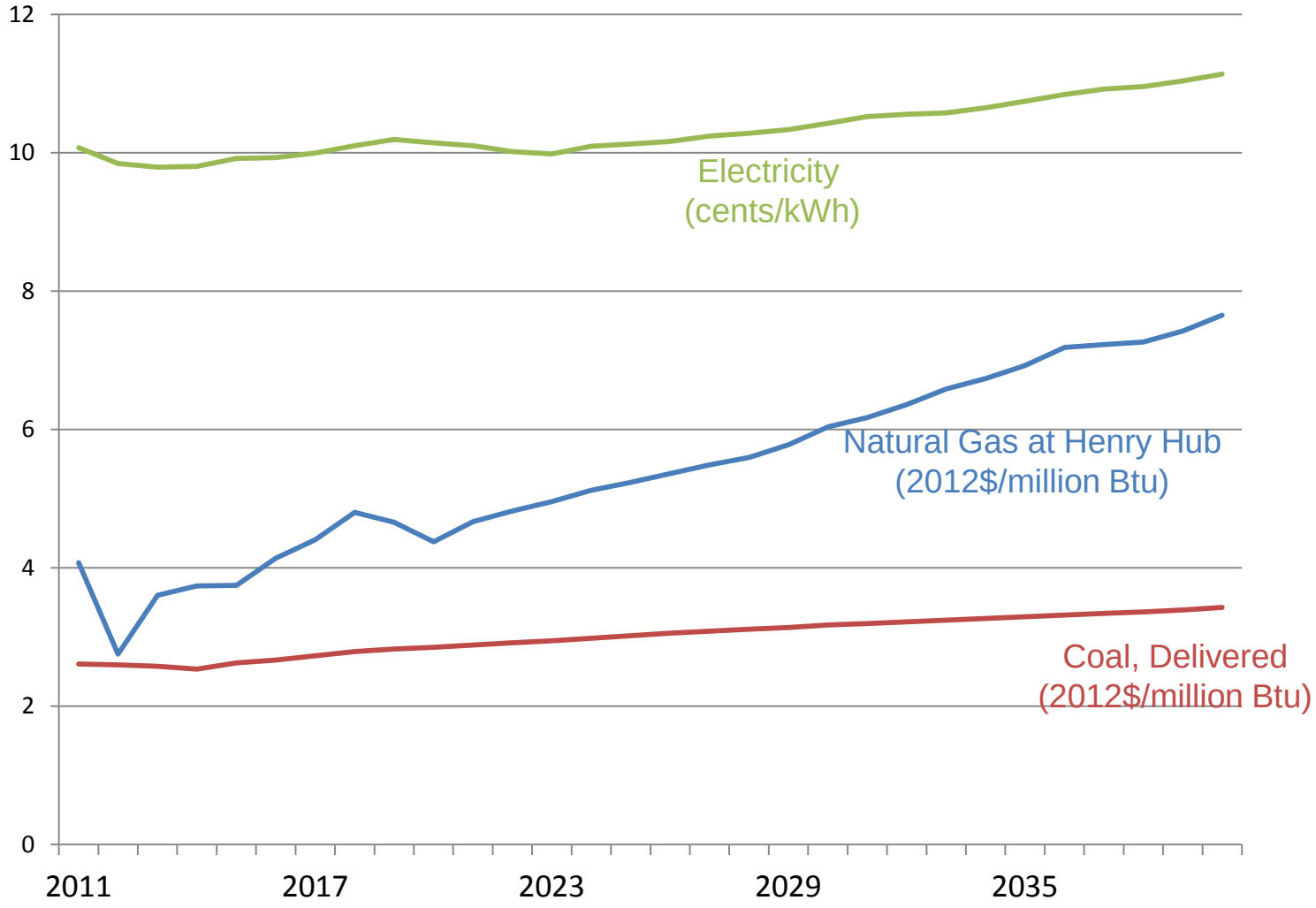
U.S. Electricity Generation by Fuel 1990-2040



Source: Electricity generation by Fuel in the Reference case, 1990-2040: Projections: AEO2014 National Energy Modeling System, run REF2014.D102413A.

Coal Prices *Still* More Stable than Natural Gas

U.S. Electricity and Fuel Prices 2011-2040



Source: Projections: AEO2014 National Energy Modeling System, Total Energy Supply, Disposition, and Price Summary, Reference case

Higher Natural Gas Prices Elsewhere may Drive Prices up in the U.S.

World LNG Estimated December 2014 Landed Prices

Source: *Waterborne Energy, Inc*. Data in $US/MMBtu

Note: Includes information and Data supplied by IHS Global Inc. and its affiliates ("IHS"); Copyright (publication year) all rights reserved.

Updated November 2014

Program Slides

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Why the Interest in Coal Gasification?

Energy diversity/security

- The U.S. has a lot of coal
- Gasification can convert coal to power, or to products typically made from oil, or even into synthetic natural gas

Gasification can be used to make: hydrogen [H_2], fertilizer, chemicals (methanol, plastics, etc.) and transportation fuels

Can be the lowest cost option to make power with almost total carbon dioxide (CO_2) capture and storage

CO_2 is a global problem, and most of the world does not have cheap natural gas

DOE Gasification Systems Program R&D Goal

The goal of the Gasification Systems Program is to reduce the cost of electricity with carbon capture, while increasing power plant availability and efficiency, and maintaining the highest environmental standards

Gasification Program Overview

Benefits

- U.S. Economic security – keeping coal in the mix increases certainty of stable energy foundation
- Global greenhouse gas benefits

Focus

- To reduce the cost of electricity, while increasing power plant availability and efficiency, and maintaining the highest environmental standards

Economic Challenges & Opportunities

Gasification Systems

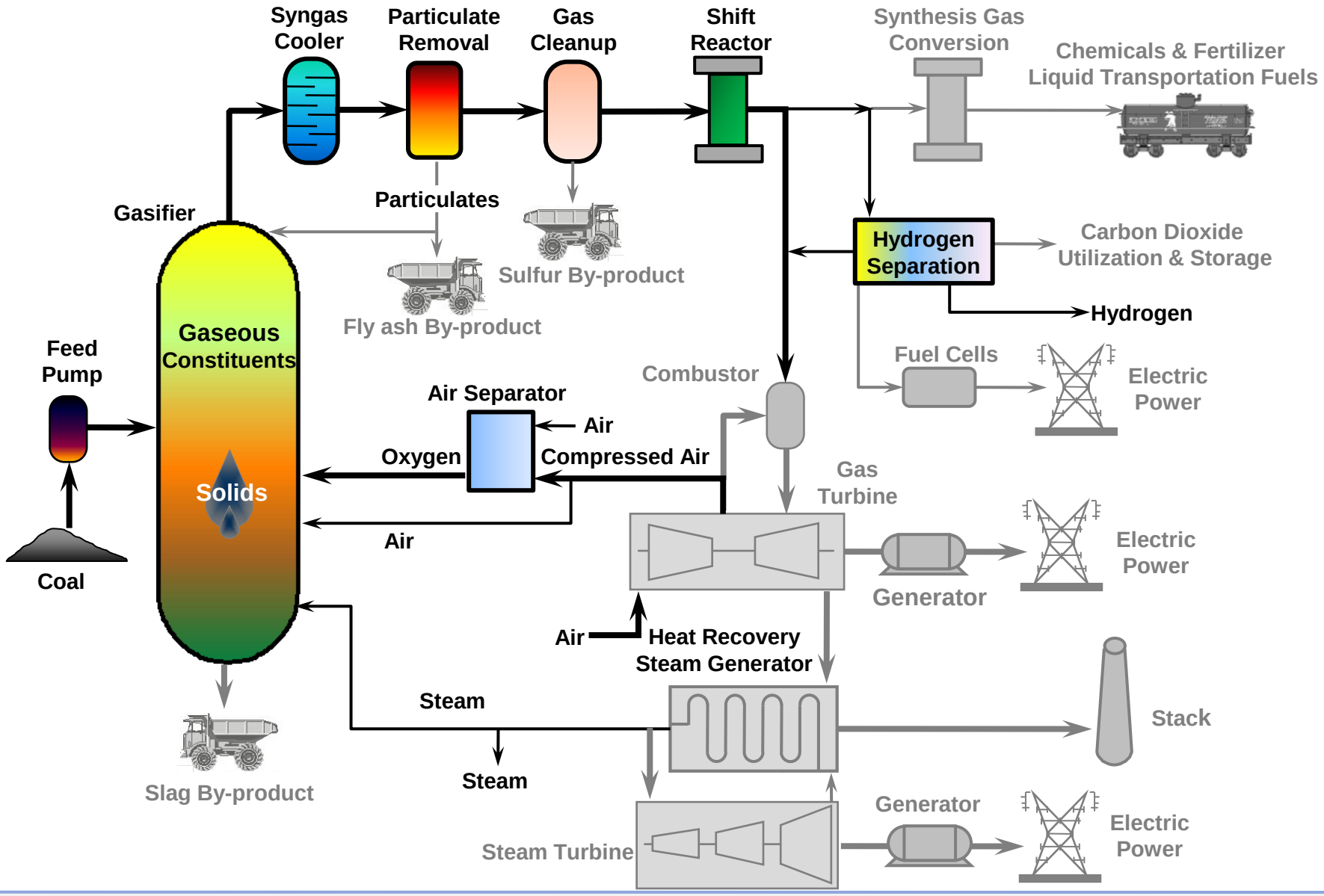
Challenges

- Low natural gas prices
- Lack of stringent Greenhouse Gas (GHG) control legislation: Gasification based power is expected to compete well in a high-carbon capture future

Opportunities

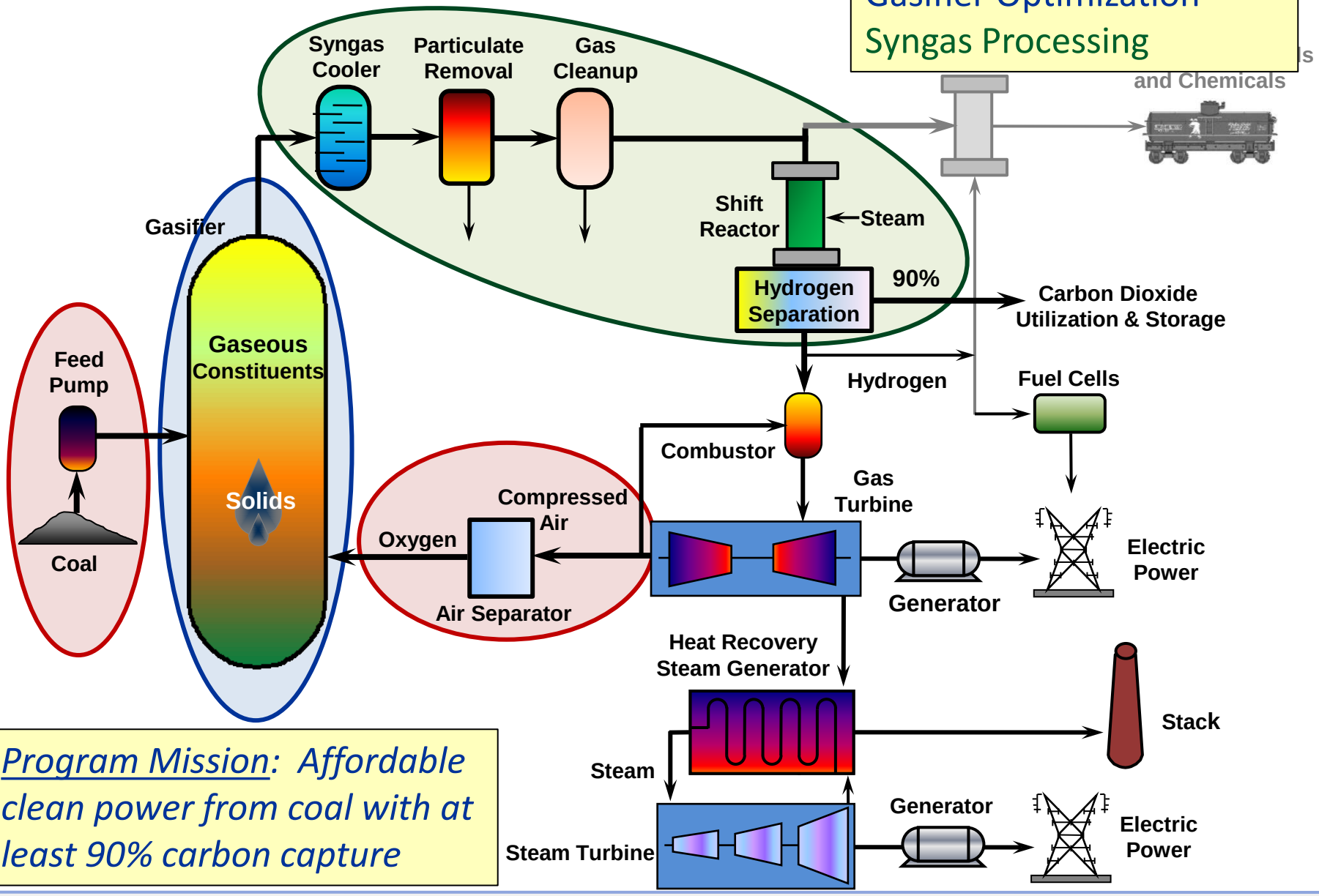
- Economic stability through diversified power sources
- Set stage for significant GHG control across globe through reduced cost of electricity with at least 90% CCS

Gasification Systems Program



Gasification Systems Program

Feed Systems
Gasifier Optimization
Syngas Processing



Program Mission: Affordable clean power from coal with at least 90% carbon capture

Gasification Systems Program

Key Technologies

Feed Systems

- Oxygen separation
- Expand fuel flexibility
- Increase efficiency and reliability, and improve economics

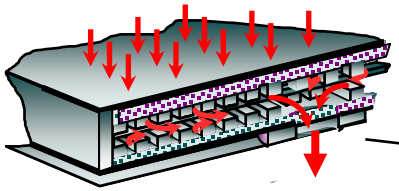
Gasifier Optimization and Plant Supporting Systems

- Improve reliability
- Increase efficiency and reliability, and improve economics

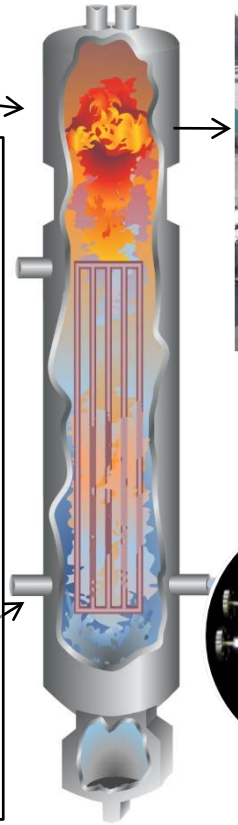
Syngas Supporting Systems

- Hydrogen and carbon dioxide separation
- Control multi-contaminants to extremely low levels
- Increase efficiency and reliability, and improve economics

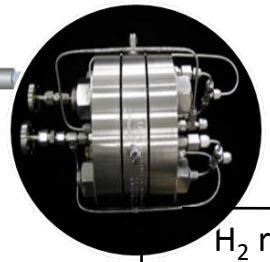
Gasification Systems Program Projects



Oxygen



Water Gas Shift



H_2 rich stream

CO_2

FEED SYSTEMS

Bench Scale

CMR O_2 Enriched Air Separation
GTI O_2 Production via Contactor
ITN Cost-Effective O_2 Separation
MIT Coal-CO_2 Slurry Feeding
TDA Air Separation Systems
WRI Sorbent-Based O_2 Production
USC O_2 Separation Fiber Membranes

Pilot Scale

2-APCI Ion Transport Membrane
NCCC Advanced Coal Feeder
AR Dry Coal Feed Pump

SYNGAS PROCESSING SYSTEMS

Bench Scale

APCI Advanced Acid Gas Separation
Alstom Chemical Looping
OSU Chemical Looping
SRI H_2 Rich Syngas
TDA Warm Gas Cleanup
TDA Advanced Reactor Design WGS
UK Chemical Looping
UW Catalytic Gasification
VPI Catalytic Gasification

Pilot Scale

NCCC WGS Optimization & Candle Filter
Praxair H_2/CO_2 Membrane
Praxair OTM Membrane
RTI Integration for H_2 Rich Syngas
RTI Warm Gas Cleanup
TDA Integrated CO_2 Removal & WGS
WPI H_2/CO_2 Membrane

GASIFIER OPTIMIZATION AND PLANT SUPPORTING SYSTEMS

Bench-scale

ORD Novel Design
ORD Improve Refractory
ORD Multiphase Modeling
MSU Opt. of Microbial Activity
U of Utah Ceramic Proppant
SIU Optimized Microbial
Physical Optics Oxygen Distiller

Pilot Scale

AR Adv. Gas. Water Gas Shift
REI Mitigation of Fouling
NCCC Refractory Durability

Gasification Systems Projects

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National Carbon Capture Center at the Power Systems Development Facility

Southern Company Services

Location: Wilsonville, AL

Cost Share Partners

American Electric Power

Arch Coal

Electric Power Research Institute

Luminant

NRG

Duke Energy

Cloud Peak Energy

Development and commercial scale-up of modular industrial scale gasification-based processes and components

National Carbon Capture Center

Southern Company Services

Goal

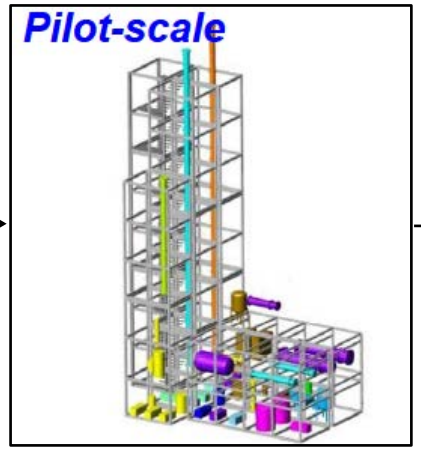
Accelerate path to cost-effective CO_2 capture technology for all 3 major areas of CO_2 Capture; post combustion, pre-combustion, oxy-combustion

Technology

Flexible testing facilities from bench to engineering-scale

Project tasks

Modifications underway to enhance and enlarge pre-combustion CO_2 capture testing infrastructure to enable testing of membranes, sorbents and solvents



National Carbon Capture Center (NCCC)

Advanced Gasification and Hydrogen/CO_2 Separation

Fuel flexibility, filter materials, sensor development

Two gasification tests in 2014 using Powder River Basin coal totaling ≥ 1600 hours

- Continued evaluating & improving new gasifier temperature control scheme
- Continued long-term evaluation of hot gas filter elements
- Conducted sensor development involving sapphire thermowell for gasifier service, coal-flow measurement device, vibration type level detector, and tunable diode laser
- Conducted oxygen-blown gasification testing with biomass co-feed
- Replaced gasifier standpipe (15 years of service life with dozens of thermal cycles)

Carbon capture

Enhancements and modifications to pre-combustion CO_2 capture testing infrastructure have enabled testing of membranes, sorbents, and solvents including

- Hydrogen and CO_2 membranes from four developers
- CO_2 capture with advanced solvents
- Water-gas shift catalyst performance
- CO_2 capture sorbents

National Carbon Capture Center (NCCC)

Advanced Gasification and Hydrogen/CO_2 Separation

Accomplishments include:

- 38 major gasification test campaigns
- Over 21,880 hours of gasification operation
- Successful engineering scale demonstration of advanced power systems technologies, including hot gas filtration and high-pressure solids handling systems
- Developed gasifier suitable for low-rank fuels use; modified gasifier to improve carbon conversion, gas/solids separation efficiency, and syngas heating value
- Extensive successful operation on a variety of coals including: lignite, subbituminous, and bituminous
- Identified suitable filter elements to achieve the long-term high collection efficiency required by commercial turbines (routinely operated filtration system with outlet solids concentrations in the syngas less than 0.1 ppmw)
- Identified failsafe devices that reliably seal off failed filter elements, thus enhancing reliability and protecting downstream components
- TRIG™ technology being used in CCPI demonstration, Kemper County, MS
- Supported DOE's SOFC development programs with fuel cell tests on syngas
- Conducted air- and oxygen- blown gasification testing with biomass/coal co-feed
- Demonstrated advanced syngas cleanup technologies such as mercury sorbents

Power Systems Development Facility (PSDF)

Project History - Accomplishments

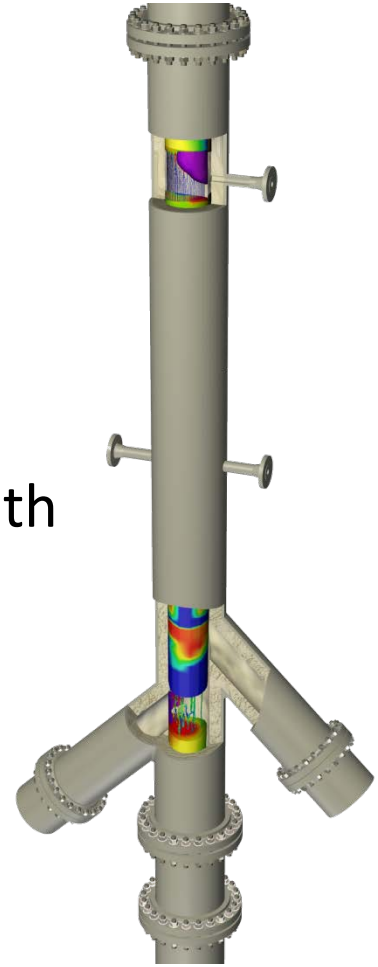
History - Established by DOE in early '90s

To accelerate development of more efficient advanced coal-based power plant technologies

Research centered around high-temperature, high-pressure filtration

Signed over 115 non-disclosure agreements (NDA)s with developers to support advancement of their technologies

Air-blown Transport Gasifier commenced operation in 1999



Feed Systems Projects

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Recovery Act: Development of Ion-Transport Membrane Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems

Air Products and Chemicals

Program Strategy

- Develop, scale-up, demonstrate a leading edge, non-cryogenic air separation technology for large-scale production of oxygen at costs that are step-change lower than conventional cryogenic plants

Benefits

- 25% oxygen plant capital cost reduction; 3% decrease in IGCC COE

Objective

- Use ITM ceramic membranes to selectively separate oxygen in air from nitrogen

Scope of Work

- 100 TPD test system and module manufacturing facility under test
- Current ARRA project will end with start-up of commercially-capable facility for module creation

Project Team

- Ceramatec Inc., GE (Texas), Pennsylvania State University – OSP, Concepts NREC , Siemens Westinghouse Power Corp., NovelEdge Technologies LLC, SOFCo-EFS Holdings LLC, Electric Power Research Institute

Project Duration

- 10/98 - 3/15

This technology may be used by other industries at smaller-scale, substantially reducing the risk and cost of initial IGCC deployment

R&D focus has been on high pressure oxygen production for IGCC but Advanced Oxygen Production will also reduce costs in Oxyfuel applications

Development of ITM Oxygen Technology for Low-cost and Low-emission Gasification and Other Industrial Applications

Air Products and Chemicals

Program Strategy

- Building upon the work of a previous DOE Cooperative Agreement FC26-98FT40343 to develop, scale-up, demonstrate a leading edge, non-cryogenic air separation technology for large-scale production of oxygen at costs that are step-change lower than conventional cryogenic plants

Benefits

- 25% oxygen plant capital cost reduction; 3% decrease in IGCC COE

Objective

- Perform additional engineering development and module fabrication to position the ion transport membrane (ITM) Oxygen technology and team to begin execution of the ITM Oxygen Development Facility, a nominal 2000 TPD demonstration-scale test unit

Scope of Work

- Develop materials to enhance membrane module reliability and performance, and improve ceramic processing and wafer/module architecture
- Engineering development of heat exchange and ITM vessel design specifically for large-scale applications, and contaminant mitigation to reduce process complexity and ensure long operating life for ITM modules

Project Team

- Ceramatec, Inc., Pennsylvania State University, WorleyParsons

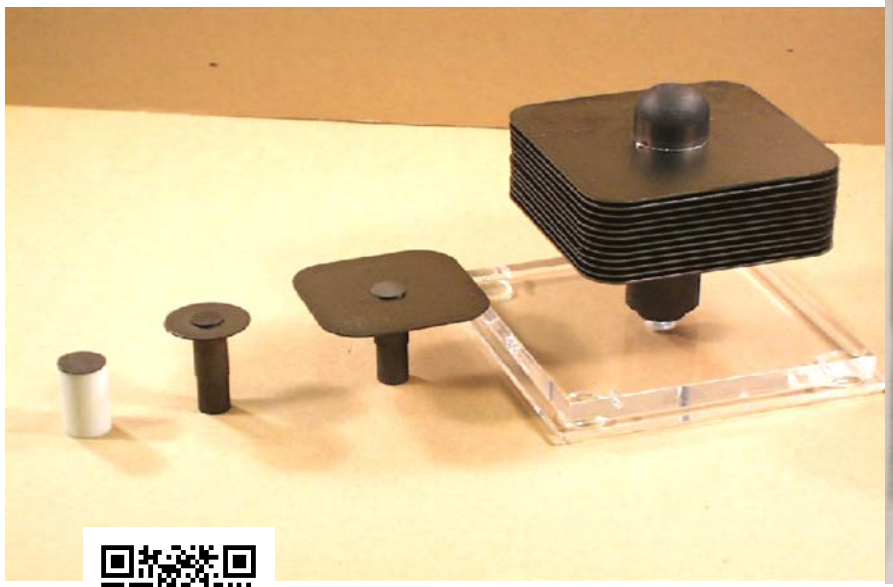
Project Duration

- 10/13 – 7/16

Ion Transport Membrane (ITM)

Development of ITM Oxygen Technology

Progression to commercial size wafers



0.5 TPD Stack

1.0 TPD Stack

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Ion Transport Membrane (ITM)

Air Products and Chemicals, Inc. (APCI)

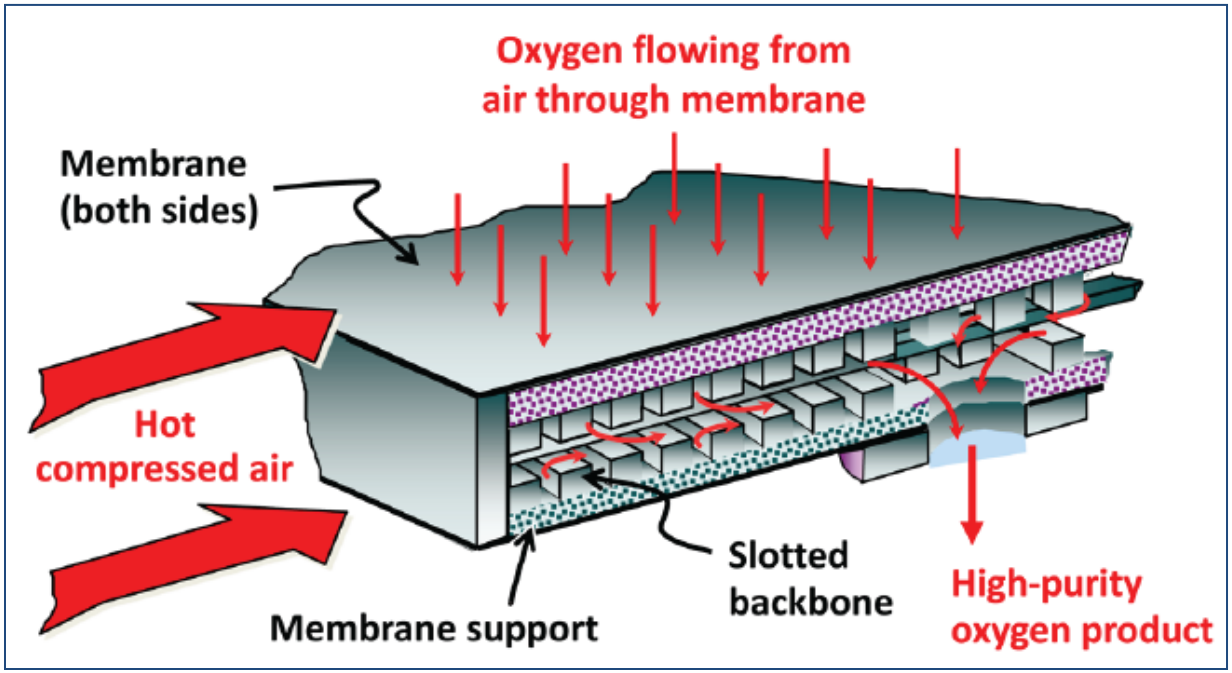
Ion Transport Membrane (ITM)

Supported thin-film, ceramic planar devices

Fast, solid state electrochemical transport of oxygen

Pressure-driven; compact

All the layers are composed of the same ceramic material



1.0 TPD Stack

Membrane Air Separation Advantages

Cryo-ASU vs. ITM in IGCC

IGCC Efficiency	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	0.8%	2.9%
With CCS	BASE	0.3%	2.2%

Improved Efficiency

Oxygen Plant Cost	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	-24.9%	-34.8%
With CCS	BASE	-24.5%	-36.3%

Better Economics

Cost of Electricity	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	-1.6%	-5.0%
With CCS	BASE	-3.0%	-4.9%

G-Class cases include full air-side integration of advanced gas turbine and oxygen plant

Source: Air Products and Chemicals, Inc.

Cost Effective Oxygen Separation System Based on an Open Gradient Magnetic Field by Polymer Beads

ITN Energy Systems

Program Strategy - *12% COE and $11-13/tonne Reduction in Cost of Capture*

- Small Business Innovation Research Project - Developing a low cost oxygen separation system, current cryogenic oxygen separation technology is cost and energy intensive

Benefits

- Reduced cost for integrated gasification combined cycle and oxy-combustion power plants, and other oxygen intensive industrial processes, (i.e. aluminum, glass, and steel)

Objective

- Achieve high purity ~99% oxygen production via air separation under magnetic gradients
- Determine technical and economic feasibility of novel system for oxygen production
- Reduce cost of producing power with CO_2 capture

Scope of Work

- Establish proof of concept of an oxygen production system employing polymer beads with an open gradient magnetic field
- Analyze lab sensor and software modeling results to determine optimum operating parameters and settings for airflow, field strength, bead chemistry, etc.
- Conduct comparative techno-economic analysis to validate system feasibility

Project Team

- ITN Energy Systems and Texas A & M University

Project Duration

- 6/13 - 7/16

Novel Magnetic Oxygen Distiller

Physical Optics Corporation

Program Strategy - *12% COE and $11-13/tonne Reduction in Cost of Capture*

- Small Business Innovation Research Project - Developing a low cost oxygen separation system, current cryogenic oxygen separation technology is cost and energy intensive

Benefits

- Reduced cost for integrated gasification combined cycle and oxy-combustion power plants, and other oxygen intensive industrial processes, (i.e. aluminum, glass, and steel)

Objective

- Achieve high purity oxygen production via air separation under magnetic gradients
- Determine technical and economic feasibility of novel system for oxygen production
- Reduce cost of producing power with CO_2 capture

Scope of Work

- Design, simulate, and analyze a small-scale Novel Magnetic Oxygen Distiller (NMOD) prototype
- Fabricate a small-scale NMOD prototype for separating oxygen from air
- Perform tests under differing operating conditions and parameters to determine technical and economic feasibility

Project Team

- Physical Optics Corporation

Project Duration

- 6/14 - 3/15

Low Cost Oxygen Enriched Air by Membrane Separation

Compact Membrane Systems

Program Strategy - *12% COE and $11-13/tonne Reduction in Cost of Capture*

- Small Business Innovation Research Project - Developing a low cost oxygen separation system, current cryogenic oxygen separation technology is cost and energy intensive

Benefits

- Reduced cost for integrated gasification combined cycle and oxy-combustion power plants, and other oxygen intensive industrial processes, (i.e. aluminum, glass, and steel). Provide highly concentrated CO_2 for use or safe storage

Objective

- Develop fouling resistant, highly stable, high flux, high separation factor, and good durability oxygen selective membranes
- Determine technical and economic feasibility of novel system for oxygen production
- Reduce cost of producing power with CO_2 capture

Scope of Work

- Fabricate compact membrane system for separating oxygen from air
- Test both single gas (O_2, N_2) performance followed by mixed gas performance
- Perform extensive engineering and economic evaluation to determine the cost of membrane process compared to conventional industrial processes

Project Team

- Compact Membrane Systems

Project Duration

- 6/14 - 3/15

OTM-Enhanced Coal Syngas for Carbon Capture Power Systems and Fuel Synthesis Applications

Praxair

Program Strategy

- Employ oxygen transport membrane (OTM) to reduce cost by building on work developed under DOE Cooperative Agreement DE-FC26-07NT43088

Benefits

- Enhanced syngas quality, reduced cryogenic-derived oxygen requirement, and allows for coal and natural gas integration

Objective

- Use OTM membranes to enhance oxygen separation

Scope of Work

- Develop a membrane with integrated catalyst that is robust under high pressure (225-425 psig)
- Integrate and test at a 50-100 tube scale, with syngas from the coal-fed gasifier at the National Carbon Capture Center (NCCC)
- Techno-economic analysis including cases with and without natural gas integration, and, production of Fisher-Tropsch liquids

Project Team

- Praxair Inc.

Project Duration

10/14 - 9/16

Projects Focused on Oxygen Production

Intermediate Temperature Nano-Structured Ceramic Hollow Fiber Membranes for Oxygen Separation

University of South Carolina

Project Objectives and Scope

Develop intermediate temperature nano-structured ceramic hollow fiber membranes for high-purity oxygen production from air

- Ceramic membrane materials synthesis and innovation
- Screening and identification of materials that have high bulk conductivities and/or surface exchange properties
- Fabrication of nanostructured composite ceramic hollow fiber membranes
- Characterization and oxygen separation performance and stability evaluations of the membranes

Project Team

- University of South Carolina

Sorbent-Based Oxygen Production for Energy Systems

Western Research Institute

Project Objectives and Scope

Develop advanced, cost effective O_2 production technology based on new mixed-conducting metal oxide ceramic sorbents

- Novel oxygen-selective sorbents
- Cost-effectively synthesize sorbents based on optimized sorbent chemistry of mixed-conducting metal oxide ceramic materials
- Characterize sorbent properties
- Evaluate oxygen sorption performance as a function of operational parameters
- Perform cyclic pressure swing adsorption (PSA) experiments to demonstrate oxygen production rate and purity

Project Team

- Western Research Institute, New Mexico State University, Arizona State University, LP Amina

Dry Solids Pump Coal Feed Technology

Aerojet Rocketdyne

Program Strategy

- Use of large U.S. low cost low-rank coals (LRC) reserves limited in IGCC due to coal feed systems; lock-hoppers have high capital and operating cost and are unreliable, slurry feed inefficient due to high moisture in LRC

Benefits

- Improve efficiency of feeding coal, petcoke, and/or biomass into high-pressure gasifiers
- Enables higher efficiency of gasification plants
  - Eliminates the need to form slurry, and the use of lock hoppers
- Reduction in feed system capital, maintenance and operating costs
- Expected to make low rank coals more commercially competitive

Objective

- Improve availability and efficiency of gasification-based power plants,
- Reduce plant capital and operations costs.

Scope of Work

- Commissioning of 400 tpd prototype underway
- Techno-economic analysis

Project Team

- Aerojet Rocketdyne, University of North Dakota Energy & Environmental Research Center

Project Duration

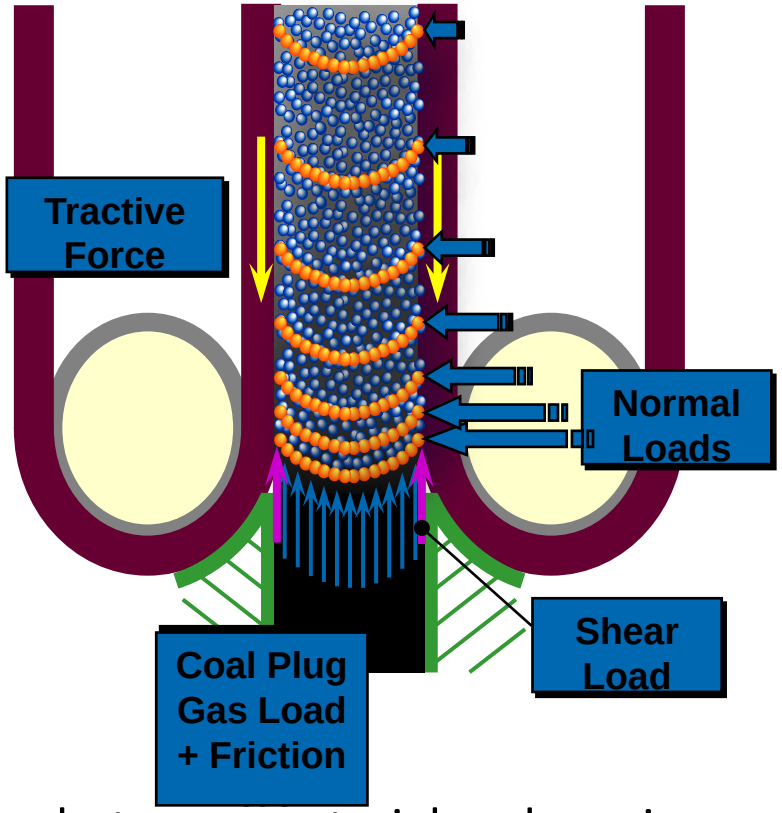
- 10/13 - 9/16

This project continues the work started in FC26-04NT42237
"Development of Technologies and Capabilities for Coal Energy Resources"

High Pressure Solids Pump

Aerojet Rocketdyne

- Pump operation relies on ability of bulk solids to form multiple stable "bridges" or arch between parallel wall structure, bridges can support very large loads
- Increasing load is transferred to sidewalls, making the bridge more stable, further increasing load will ultimately fail the sidewall
- Extrusion or "pumping" occurs when sidewalls are moved mechanically and material is released by separating the walls



In "lock-up" there is no "slip" or relative motion between material and moving walls, device exhibits "positive displacement" with a volumetric displacement of unity

Gasifier Optimization and Plant Supporting Systems Projects

Table of Contents

Advanced Gasifier and Water Gas Shift Technologies for Low Cost Coal Conversion to High Hydrogen Syngas

Aerojet Rocketdyne

Program Strategy
- Combine gasification and water gas shift technologies to generate low cost, high-hydrogen syngas from coal

Benefits
- Syngas synthesis with increased efficiency and availability, and with decreased capital cost (15-18%)
- Feedstock flexibility, and quick start-up and shut-down
- Commercially competitive production of power from IGCC with 90 percent carbon capture and/or fuels from CTL at petroleum-equivalent greenhouse gas emissions
- Broad utilization of U.S. coal resources, improvement of U.S. economic competitiveness, environmental benefits world-wide

Objective
- Develop an advanced pilot-scale gasifier for use in a first-of-a-kind, commercially relevant demonstration plant

Scope of Work
- Design and operate a AR compact gasifier at a pilot scale with RTI advanced water gas shift system
- GTI to test a range of coals, as well as a coal/natural gas hybrid, in the compact gasifier
- Nexant to prepare a techno-economic analysis of benefits of the technology for both integrated gasification combined cycle (IGCC) and coal-to-liquids (CTL) plants

Accomplishments
- Underway

Project Team
- Aerojet Rocketdyne (AR), RTI International (RTI), Gas Technology Institute (GTI), Coanda, Nexant

Project Duration
- 10/14 – 11/16

Hybrid Molten Bed (HMB) Gasifier for High-Hydrogen Syngas Production

Gas Technology Institute

Program Strategy

- 1 year scoping study; Produce syngas with hydrogen to carbon dioxide ratio (H_2/CO_2) ranging from 1 to greater than 6 using HMB, a dual coal-natural gas fueled process

Benefits

- Enables economic coal-based gasification electricity generation or transportation fuels production by
  - Reduced cost and increased performance of high hydrogen syngas production
  - Lower environmental emissions, including carbon dioxide

Objective

- Conduct HMB gasification process techno-economic analyses in two configurations to; (1) maximize IGCC power production (2) maximize Fischer-Tropsch (FT) diesel yield

Scope of Work

- Model the HMB gasifier and provide data for techno-economic analysis
- Conduct lab-scale HMB gasification tests to collect data and provide engineering input for techno-economic analysis and process scale up, start of the HMB gasification concept test imminent
- Conduct techno-economic analyses of the HMB gasification process in IGCC and FT diesel production configurations with comparisons against existing gasifiers

Project Team

- Gasification Technology Institute, Nexant, and Praxair

Project Duration

- 10/13 - 3/15

Mitigation of Syngas Cooler Plugging and Fouling

Reaction Engineering International

Program Strategy

- Improve cost competitiveness of gasification plants by improving plant economics, efficiency, and increasing plant availability

Benefits

- Operating cost reductions through the increase in availability of the unit operation syngas cooler
- Positive impact on the reliability, availability, and maintainability

Objective

- Develop a better understanding of ash deposition onto refractory and metal surfaces associated with syngas coolers (SC) in IGCC plants
- Evaluate plugging and fouling of syngas cooler designs
- Develop methods to mitigate syngas cooler plugging and fouling
- Define and validate means to implement mitigation methods

Scope of Work

- Perform laboratory scale experiments to evaluate the bond strength between deposits and metallic and refractory surfaces for a range of temperatures and fuels
- Modeling to assist in test design, data interpretation and Computational Fluid Dynamic (CFD) modeling to investigate deposition, plugging and fouling
- Evaluate alternative process conditions and equipment designs to mitigate plugging and fouling

Project Team

- Reaction Engineering International, University of Utah - Department of Chemical Engineering

Project Duration

- 10/11 - 6/15

Projects Focused on Microbial Coal to Methane Conversion

Optimized Microbial Conversion of Bituminous Coal to Methane for In Situ and Ex Situ Applications

Southern Illinois University

Project Objectives and Scope

- R&D to maximize methane productivity from bituminous coal in a dynamic system adopting parameters optimized at batch modes
- Determine effects of nutrient addition, coal particle size, temperature, pH, mixing, and addition of surfactants, solvents and electron donors in microcosm setups

Project Team

- Southern Illinois University, Illinois Clean Coal Institute

Increasing Rate and Extent of Microbial Coal to Methane Conversion through Optimization of Microbial Activity, Thermodynamics, and Reactive Transport

Montana State University

Project Objectives and Scope

- Determine chemical and biological parameters limiting methane production from coal
- Develop strategies for optimization of microbial enhanced coal bed methane technology based on thermodynamic and reactive transport considerations
- Scale up laboratory microcosms to optimize microbial coal-to-methane production in column flow reactors

Project Team

- Montana State University

Ceramic Proppant Design for In Situ Microbially Enhanced Methane Recovery

University of Utah

Project Objectives and Scope

- Develop new technology to enhance economic viability of in-situ microbial coal to methane conversion within unmineable fossil fuel resources
- Demonstrate new delivery method of microbes to reservoir and select bacterial consortium and nutrient combination to yield economical methane production rate
- Scale up laboratory microcosms to optimize microbial coal-to-methane production in column flow reactors

Project Team - University of Utah

Syngas Processing Systems Projects

Table of Contents

Warm Syngas Cleanup Technology

RTI International

Invention (2001)
- Proprietary RTI sorbent
- R&D 100 Award (2004)

Lab testing (2001-2003)
- RTI, NC
- Concept proven & modeled

Pilot testing (2006-2008)
- Eastman Chemical Co., TN
- 3000 hr, coal-derived syngas

Demonstration (2010-2015): Syngas cleanup/carbon capture
- Tampa Electric Co., Polk 1 IGCC Plant, FL
- 50 MW_e equivalent scale, coal/petcoke-derived syngas

From Lab to Large Scale Demonstration

Source: RTI International

Recovery Act: High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project

Research Triangle Institute

Program Strategy - Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- Mitigate technical risk associated with scale-up of high-temperature syngas cleanup and CCS technologies for coal gasification

Benefits (in combination with hydrogen membranes)

- 2.0% point increase in efficiency ; 4.0% decrease COE

Objective - Design, construct, commission, operate warm syngas cleaning demonstration system

- Establish relevant commercial operating experience
- Establish RAM (reliability, availability and maintenance) targets
- Mitigate design and scale up risk for commercial plant
- Demonstrate CO_2 capture using conventional capture technology (activated amine)
- Obtain up to 8,000 hours of operations
- Pre-commercial (50 MWe) scale demonstration testing underway

Scope of Work

- Demonstrate, at pre-commercial scale, RTI's warm syngas cleaning system integrated with an activated MDEA system, for CO_2 capture, using syngas generated from a commercial gasification system being operated with a mixture of petroleum coke and coal

Project Team

- RTI International, Tampa Electric Power Company, CH2M Hill, The Shaw Group, Inc., Sud Chemie, Inc., BASF Corporation, Eastman Chemical Company, AMEC, TECHNIP USA

Project Duration

- 7/09 - 9/15

Chemical-grade trace contaminant levels are expected to exceed current and future EPA requirements, enabling IGCC to be the cleanest option for turning coal into power. Project builds on progress made during field testing with real syngas from commercial gasifier under DOE Contract DE-AC26-99FT40675

Syngas Cleanup Technology Scale-Up and Demonstration

Research Triangle Institute

50 MW Demo Under Construction at Tampa Electric

Construction is complete

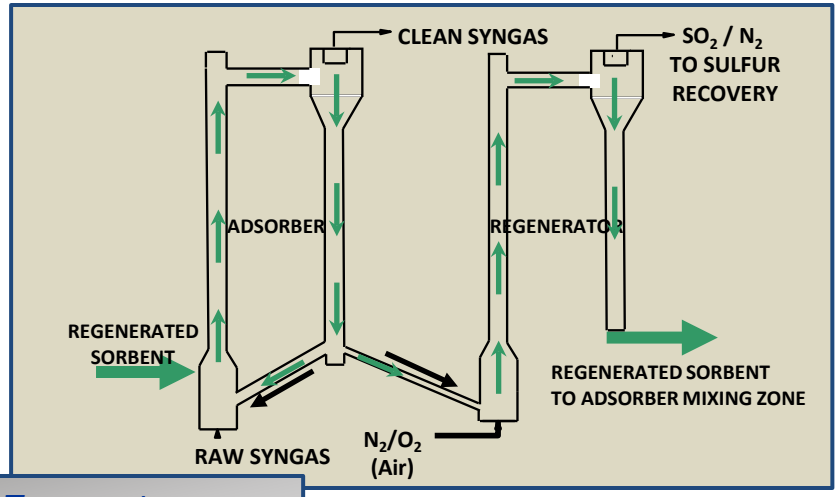
Testing has begun

Test unit has cleaned sulfur to below 5 parts per million

Attrition appears to be *less* than project target

The heart of the technology is a sorbent developed by RTI with DOE support

The sorbent is mixed with the raw syngas and adsorbs the sulfur out of the syngas – then it's regenerated



High Temperature Gas Desulfuration Process

Warm Gas Cleanup – RTI

Previous Testing at Eastman Chemical

RTI Warm Gas Cleanup Technologies

Cleans multi-contaminants from coal-derived syngas while creating pure sulfur product

High Temperature Desulfurization Process

> 99.9 % removal of both H_2S and COS (to < 5 ppmv levels)

> 3,000 hours of operation at 0.3 Mwe

Direct Sulfur Recovery Process

> 99.8 % SO_2 conversion to elemental sulfur

96 % ammonia removal

90 % mercury and arsenic removal

Pilot Plant Operation at Eastman's Gasification Facility, Kingsport, TN

High Hydrogen, Low Methane Syngas from Low-Rank Coals for Coal-to-Liquids Production

Southern Research Institute

Program Strategy Gasification, Syngas Cleanup, and Hydrogen Separation

- Increase H_2:CO ratio of the syngas and reduce down-stream fouling costs and efficiency losses

Benefits

- Reduce cost of coal-based gasification cleanup, reduce carbon emissions, and increase efficiency of low-rank coal gasification for electricity and coal-to-liquids production

Objective

- Reduce advanced gasification costs via process intensification and efficient gas cleanup
- Develop a high-temperature, sulfur-tolerant steam reforming catalytic process
- Increase the yield and H_2 to CO ratio of low-rank coal syngas

Scope of Work

- Develop, test, and optimize steam-reforming catalysts for converting tars, C_{2+} hydrocarbons, NH_3, and CH_4 in high-temperature and sulfur environments,
- Using top performing catalyst, design and analyze a modified advanced gasification platform for the conversion of low rank coals to syngas for CTL and IGCC applications, fabrication of the lab-scale microreactor system underway
- Conduct techno-economic analysis using feedstock-to-fuel and feedstock-to-electricity with carbon capture models to validate system feasibility

Project Team

- Nexant, ThermoChem Recovery International

Project Duration

- 10/13 - 3/15

Advanced Hydrogen Transport Membranes for Coal Gasification

Praxair

Program Strategy Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- Hydrogen transport membrane uses dense metal to separate H_2 from shifted syngas leaving CO_2 at high pressure produces ~100% hydrogen stream

Objective

- Develop and test separation module producing 50 lb per day of hydrogen

Scope of Work

- Membrane reactor module design will be scaled up to incorporate larger membrane tubes, assembly and fabrication of the Membrane Test Stand underway
- Design to incorporate improved gas mixing to improve flux and employ better metal/ceramic sealing techniques
- Develop improved alloys to maximize membrane performance in expected syngas environment
- Gasification testing at University of North Dakota Engineering and Environmental Research Center

Project Team

- Colorado School of Mines, University of North Dakota Energy & Environmental Research Center

Project Duration

- 10/10 - 9/12 Phase 1
- 10/12 - 9/15 Phase 2

Hydrogen membranes make chemical-grade hydrogen, useable in IGCC, chemical and liquids production and for polygeneration applications

Engineering Design of Advanced H_2 CO_2 PD and PD/Alloy Composite Membrane Separations & Process Intensification

Worcester Polytechnic Institute

Program Strategy Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- Hydrogen transport membrane uses dense metal to separate H_2 from shifted syngas leaving CO_2 at high pressure produces ~100% hydrogen stream

Benefits in combination with RTI high-temperature syngas cleanup

- 1.4% pt increase in efficiency; 2.3% decrease COE

Objective

- Develop and test a separation module producing 20 lb per day of hydrogen

Scope of Work

- Advance from single tube membrane to shell and tube module
- Develop procedures for commercial membrane production
- Combine Membraguard coating and pre-treatment of syngas with absorption beds to improve performance
- Gasification testing at National Carbon Capture Center (NCCC) in Wilsonville, AL

Project Team

- Johnson Matthey, Membrane Technology & Research, T3 Scientific LLC

Project Duration

- 10/10 - 9/12
- 10/12 - 9/15

Hydrogen membranes make chemical-grade hydrogen, useable in IGCC, chemical and liquids production and for polygeneration applications

Benefits of Integrating Aerojet Rocketdyne & RTI Advanced Gasification Technologies for Hydrogen-Rich Syngas

Research Triangle Institute

Program Strategy Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- 1 year scoping study; integration of RTI's warm gas clean up with novel water-gas shift technology, using Aerojet Rocketdyne (AR) Compact Gasification Technology (gasifier & feed pump), BASF aMDEA® CO_2 removal, and sulfur polishing

Benefits 12% COE reduction and $11-13/tonne reduction in cost of capture

Objective

- Assess potential for integrated advanced technologies to substantially reduce capital and production costs for hydrogen-rich syngas
- Attain near-zero emissions from coal gasification with CO_2 capture for power and for coal-to-liquids production
- Achieve production costs for syngas that is cost-competitive with other conversion technologies

Scope of Work

- Utilize costs and performance data from recent pilot plant and near-commercial demonstrations
- Complete preliminary conceptual designs and techno-economic analyses
- Include experimental work to evaluate the feasibility of an advanced hydrogen enrichment process

Project Team

- Aerojet Rocketdyne (AR) and Research Triangle Institute (RTI)

Project Duration

- 10/13 – 6/15

In separate projects;

- *WGCU is being integrated with BASF aMDEA® during 50 MWe tests at TECO*
- *RTI's experimental work on advanced water gas shift (AWGS) technology is being further investigated in a recent award to Aerojet Rocketdyne*

Advanced Reactor Design for Integrated WGS/Pre-combustion CO_2 Capture

TDA Research, Inc

Program Strategy – *Less than 12% in COE and $11-13/tonne Reduction in cost of carbon capture*

- 1 year scoping study; Combine warm gas CO_2 scrubber and water-gas shift (WGS) advanced technologies into a single integrated package

Benefits

- Expected net plant efficiency higher than plants using Selexol for CO_2 capture, reduce cost of carbon capture over current state-of-the art, reduce carbon emissions

Objective

- Develop a new high-hydrogen synthesis gas production technology
- Demonstrate techno-economic viability for integrated gasification combined cycle (IGCC) power plants and coal-to-liquids (CTL) plants that process low-rank coals and woody biomass

Scope of Work

- Design and fabricate a novel integrated CO_2 scrubber/WGS reactor system
- Test using synthesis gas slipstream generated at a to be determined field location
- Incorporating test results, conduct techno-economic analyses of novel system for both IGCC and CTL production

Project Team

- UCI and Pall Corporation

Project Duration

- 10/13 - 9/15

Integrated Water-Gas-Shift (WGS) / Pre-Combustion Carbon Capture Process

TDA Research, Inc

Program Strategy

- Develop a low cost, efficient CO_2 capture technology for IGCC and coal-to-liquid plants to run on a wide range of coals (bituminous to low-rank) and petcoke

Benefits

- High CO_2 capacity and removal efficiency (>90%) at temperatures above syngas dew point eliminates need to condense steam in gas and maximizes mass flow through gas turbine, increasing power cycle efficiency

Objective

- Develop an integrated water-gas shift pre-combustion CO_2 capture technology to eliminate CO_2 emissions from IGCC power plants

Scope of Work

- Design a gasification reactor using computational fluid dynamics and kinetic modeling to achieve optimum CO_2 removal and hydrogen recovery
- Design a fully equipped slipstream test unit with syngas treatment capacity to demonstrate the technology's viability
- Conduct field tests at National Carbon Capture Center (NCCC) the Wabash River IGCC plant

Project Team

- Gas Technology Institute, University of California, Irvine, Indigo Power Systems LLC, NCCC and CB&I/Lummus Technology

Project Duration

- 10/14 - 9/17

Warm Gas Multi-Contaminant Removal System

TDA Research, Inc

Program Strategy - Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- Unlike the commercially available gas clean-up technologies, the TDA multi-contaminant control system operates above the dew point of the synthesis gas (500 degrees Fahrenheit).

Benefits

- Synthesis gas would not have to be cooled in order to remove the contaminants, improving process thermal efficiency

Objective

- Develop low-cost, high capacity, sorbent for removal of ammonia, hydrogen cyanide, and trace metal contaminants (such as mercury, arsenic and selenium) from synthesis gas in a single process step that operates above the dew point of synthesis gas

Scope of Work

- Identify optimum chemical composition and structure for best sorbent performance
- Determine effect of operating parameters
- Conduct multiple-cycle experiments to test sorbent life for ammonia and mercury removal
- Prepare preliminary sorbent reactor design

Project Team

- TDA Research Inc.

Project Duration

- 6/12 - 8/15

Advanced Acid Gas Separation Technology for Clean Power and Syngas Applications

Air Products and Chemicals

Program Strategy Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- 1 year scoping study; novel processes to separate syngas into desired products; hydrogen and carbon monoxide, a sulfur stream (primarily hydrogen sulfide), and sequestration-ready CO_2

Benefits

- Reduce capital cost of CO_2 capture in high hydrogen syngas with >90% CO_2 capture
- Provide critical information for advancing technology toward commercialization

Objective

- Test performance of APCI's Advanced Acid Gas Separation Technology on real syngas slip stream produced from gasification of low rank coals
- Assess new process to reduce cost of capital for CO_2 capture in high hydrogen syngas with >90% CO_2 capture efficiency

Scope of Work

- Slip stream testing of 2 bed sour pressure swing absorption (PSA) using high hydrogen syngas produced from low-rank coals at NCCC
- Evaluation of pressure equalization cycles using multi-bed PSA process development unit
- Build techno-economic analysis of PSA utilization for methanol production

Project Team

- National Carbon Capture Center, Air Products and Chemicals, Inc.

Project Duration

- 10/13 - 6/15

Alstom's Limestone Chemical Looping Gasification Process for High Hydrogen Syngas Generation

Alstom Power

Program Strategy Gasification, Syngas Cleanup, and Hydrogen Separation

- Chemical Looping Gasification (CLG) – a system that uses coal or other fossil fuels to produce high hydrogen syngas nearly free of emissions, and a pure stream of sequestration-ready CO_2

Benefits

- Increase efficiency of conversion of coal into hydrogen rich syngas suitable for power or liquid fuel production with near zero CO_2 emissions

Objective

- Further develop Alstom's Limestone Chemical Looping - Gasification (LCL-G™) concept for conversion of coal to high-H_2 syngas for power generation and/or for liquid fuel production with >90% carbon capture

Scope of Work

- Cold and reacting flow experiments to evaluate and develop solids management
- Sequential testing of increasing complexity in a 3 MWth prototype chemical looping system
- Conduct techno-economic analysis of 550 MWe LCL-G system

Project Team

- NewCO2Fuels, Illinois Clean Coal Institute

Project Duration

- 10/14 - 3/17

Pilot Scale Operation and Testing of Syngas Chemical Looping for Hydrogen Production

Ohio State University

Program Strategy Gasification, Syngas Cleanup, and Hydrogen Separation

- Chemical Looping Gasification (CLG) – a system that uses coal or other fossil fuels to produce high hydrogen syngas nearly free of emissions, and a pure stream of sequestration-ready CO_2

Benefits

- Increase efficiency of conversion of coal into hydrogen rich syngas suitable for power or liquid fuel production with near zero CO_2 emissions

Objective

- Operate and test a pilot scale Syngas Chemical Looping (SCL) unit for reliable syngas conversion and H_2 generation in long-term operations.

Scope of Work

- Maintenance, startup and operation of the SCL pilot unit in hydrogen generation mode for chemical production for up to four gasifier test campaigns at the National Carbon Capture Center
- Completion of a technical and economic evaluation of the technology based on knowledge gained from test campaigns

Project Team

- Babcock & Wilcox Company, Clear Skies Consulting

Project Duration

- 10/14 - 9/16

Projects Focused on Syngas Production

Advancing Coal Catalytic Gasification to Promote Optimum Syngas Production

Virginia Polytechnic Institute & State University

Project Objectives and Scope

Experiments, kinetic modeling, and computational fluid dynamics to advance catalytic gasification of coal and coal-biomass mixtures. Project will use red mud catalyst with sub-bituminous coal to effectively gasify coal and produce a cleaner syngas with elevated levels of hydrogen

Project Team - VPI, University of Delaware, Northeastern University, University of Utah

Catalytic PRB Coal-CO_2 Gasification for Fuels and Chemicals with Two Different Types of Syngas and Low CO_2 Emissions

University of Wyoming

Project Objectives and Scope

Develop a new catalytic gasification technology utilizing Powder River Basin subbituminous coal and catalysts to produce zero or near-zero methane syngas for the production of fuels and chemicals

Project Team - University of Wyoming

Application of Chemical Looping with Spouting Fluidized Bed for Hydrogen-Rich Syngas Production From Catalytic Coal Gasification

Center for Applied Energy Research University of Kentucky

Project Objectives and Scope

Develop catalytic coal gasification technology using chemical looping for in-situ separated oxygen for coal partial-combustion and gasification, central to the project are a catalytic oxygen carrier (OC) and a spouted bed gasifier

- Develop database of lifecycle performance of catalyst-oxygen carrier in reactivity, capacity, efficiency and agglomeration
- Determine the best catalyst-oxygen carrier formulation

Project Team - University of Kentucky College of Agriculture Research Foundation

Recently Completed Projects

Table of Contents

Prototype Commercial Gasifier Sensor

Gas Technology Institute

Program Strategy

- As gasifier injectors (which feed fuel into the gasifier) age and wear out, the flames they produce change, a sensor for monitoring the flame enables operators to more accurately predict when injectors should be changed, reducing gasifier maintenance costs

Benefits

- Improved flame sensors enable better control of gasifier operation, leading to increased efficiency and decreased downtime associated with gasifier maintenance

Objective

- Further develop and demonstrate flame sensor technology to enable real time delivery of gasifier temperature to operators

Scope of Work

- Modification of hardware and software to enable real time data acquisition and improve reliability
- Evaluation of sensor system for accuracy, durability, and commercial viability

Project Team

- Gas Technology Institute, Wabash River, CB&I, North Carolina State University

Project Duration

- 8/12 - 1/15

Follow on of previous project which developed and demonstrated technology; "Real Time Flame Monitoring of Gasifier Burner and Injectors" DE-FC26-02NT41585

Feasibility Studies to Improve Plant Availability and Reduce Total Installed Cost in IGCC Plants

General Electric Company

Program Strategy

- Reduce the time to technological maturity and enable IGCC plants to reach higher values of availability in a shorter period of time at a lower installed cost

Benefits

- Improve plant availability and reduce total installed cost in IGCC power plants

Objective

- Reduce total installed cost of an IGCC plant
- Conceptual ideas that can improve the availability of an IGCC plant toward the targeted 90 percent without increasing total installed cost;

Scope of Work

- Identification of system and component level requirements
- Development of designs and materials for technical evaluation of concepts, validation, and testing of components/subsystems
- Development of appropriate operating methodologies, simulations and controls philosophies

Project Team

- General Electric Company

Project Duration

- 10/11 - 12/14

Low Cost High-Hydrogen Syngas Production for Power and Liquid Fuels

Gas Technology Institute

Program Strategy Warm Syngas Cleanup (WGCU) and Hydrogen Separation

- 1 year scoping study; integration of GTI's hydrogen (metal-polymeric) membrane with Aerojet Rocketdyne (AR) Compact Gasification Technology (gasifier & feed pump), and GTI's novel multi-contaminant removal process (UCSRP-HP)

Benefits *Systems Analysis Projects*

- 12% COE reduction and $11-13/tonne reduction in Cost of Capture

Objective

- Determine technical and economic feasibility of a systems approach for producing high-hydrogen syngas from coal and coal co-fed with natural gas
- Reduce cost of producing power, hydrogen, or liquid fuels with CO_2 capture
- Reduce environmental impacts of gasification

Scope of Work

- Establish proof of concept of novel metal-polymeric membrane for H_2 separation
- Obtain critical design data for integrated multi-contaminant removal process
- Techno-economic analyses of coal co-fed with natural gas and integrated with AR Compact Gasification Technology (gasifier & feed pump)

Project Team

- Gas Technology Institute (GTI), SRI, and Aerojet Rocketdyne (AR)

Project Duration

- 10/13 - 1/15

Liquid CO_2 Slurry for Feeding Low Rank Coal Gasifiers

Electric Power Research Institute

Program Strategy

- Use a portion of the existing high-CO_2 product stream as the carrier fluid to feed low rank coal (LRC)

Benefits

- Potentially reduce cost and significantly increase the efficiency of IGCC power plants with carbon capture and storage

Objective

- Gain a greater understanding and confirm potential advantages of using low rank coal/liquid CO_2 (LRC/LCO2) slurry

Scope of Work

- Use laboratory tests to support the development and evaluation of mechanical engineering designs of low rank coal/liquid CO_2 (LRC/LCO2) slurry preparation systems, develop higher resolution IGCC plant performance and cost models

Accomplishments

- Developed a Technology Development Roadmap on novel technology designed to reduce the cost of low rank coal gasification
- Performed a plant-wide technical and economic analyses of low rank coals using both liquid CO_2 and water slurry feeds

Project Team

- Electric Power and Research Institute, Dooher Institute of Physics and Energy, WorleyParsons Group Inc., Columbia University, ATS Rheosystems/REOLOGICA

Project Duration

- 10/11 - 9/13

A Technology To Mitigate Syngas Cooler Fouling - Phase II

Reaction Engineering International

Program Strategy - *12% COE and $11-13/tonne Reduction*

- Reduce and better manage plugging and fouling to eliminate unscheduled outages and limit cleaning of the syngas cooler (SC) to scheduled (e.g., annual) shutdowns

Benefits

- Improvements in availability and reliability of the syngas cooler (SC) directly improves availability of the overall gasification-based plant, reducing cost of electricity in IGCC power plants, and other products from syngas

Objective

- Mitigate SC fouling and improve SC performance:
  - Periodic in-situ tube cleaning with targeted soot blowing
  - Surface coatings to inhibit buildup of deposits

Scope of Work

- Analyze fouling deposits and perform laboratory scale tests to understand SC particulate deposition and morphology
- Computational fluid dynamics modeling of generic SC and of soot blower configurations
- Predict impact of improvements on cost of electricity

Project Team

- Clyde Bergemann Power Group, KnightHawk Engineering, University of Utah

Project Duration

- 7/10 - 7/11 (Performance Period 1)
- 5/12 - 5/14 (Performance Period 2)

Chemical Looping Gasification for Hydrogen Enhanced Syngas Production with In-Situ CO_2 Capture

The Ohio State University

Program Strategy Gasification, Syngas Cleanup, and Hydrogen Separation

- Chemical Looping Gasification (CLG) – a system that uses coal or other fossil fuels to produce high hydrogen syngas nearly free of emissions, and a pure stream of sequestration-ready CO_2

Benefits

- Increase efficiency of conversion of coal into hydrogen rich syngas suitable for power or liquid fuel production with near zero CO_2 emissions

Objective

- Achieve high quality hydrogen and syngas production through improved oxygen carrier performance and > 98% coal conversion via bench (2.5 kWt) and sub-pilot scale (25 kWt) testing
- Ensure smooth gas and solids handling in sub-pilot scale reactor design and design scale-up of reactor through cold flow model studies

Scope of Work

- Demonstrate CLG process to generate high hydrogen gas with low methane, CO_2, and water
- Testing to improve oxygen carriers and identify the effects and fates of sulfur, nitrogen and other trace contaminants
- Conduct comparative techno-economic analysis to validate feasibility of CLG system

Project Team

- Worley Parsons,Clariant, and Clearskies Consulting

Project Duration

- 10/13 - 12/14

NETL In-House R&D (ORD)

Table of Contents

NETL Office of Research & Development

Gasification Systems Tasks

Development of Reacting Multiphase Models for Advanced Gasification Processes

- Development, validation, and application of reacting multiphase flow models
  - Enables cost-effective study of advanced gasification technologies
- Work based on NETL Multiphase Flow with Interphase eXchanges (MFIX) suite of open-source computational fluid dynamics models

Experimentation for Model Development and Validation

- Well-characterized laboratory-scale data will be generated to:
  - Aid in understanding physical processes for development of mathematical models and for use code validation
  - Provide development platforms for development and validation of novel measurement techniques

NETL Office of Research & Development cont.

Gasification Systems Tasks

New Concepts for Gasification and Fuel Conversion

- Exploring concepts for fuel conversion with non-thermal energy input including:
  - Microwave for coal conversion
  - Fuel processing in supercritical water
  - Using plasma for coal gasification
- Investigating thermo-catalytic conversion of fuels using two different catalytic systems:
  - Mixed-metal oxide for syngas conversion
  - Syngas and methane conversion to useful chemicals using soft oxidants

NETL Office of Research & Development cont.

Gasification Systems Tasks

Material Interactions During Gasification

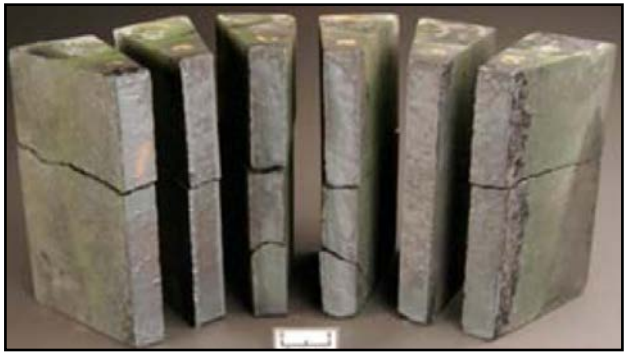
- Refractory Material Development
  - Developing improved performance refractory materials with focus on; high chrome oxide refractory with phosphate additions, and impregnated high chrome oxide refractory
- Sensor Development
  - Studying thermocouple sensor materials removed from commercial gasifiers to determine causes of refractory failure
- Ash/Slag Management
  - Developing a model to accurately predict slag viscosity in coal based carbon feedstock
- Vanadium Phase Studies
  - Enabling phase modeling of carbon feedstock containing petcoke by gathering data on high temperature vanadium phases existing in slags at low oxygen partial pressures that occur during gasification
- Agglomeration Studies
  - Targets preventing agglomeration in fluidized bed systems

Advanced Refractory For Gasifiers

Rotary Slag Test

New refractory chemistry

- Increases mechanical durability
- Reduces slag penetration

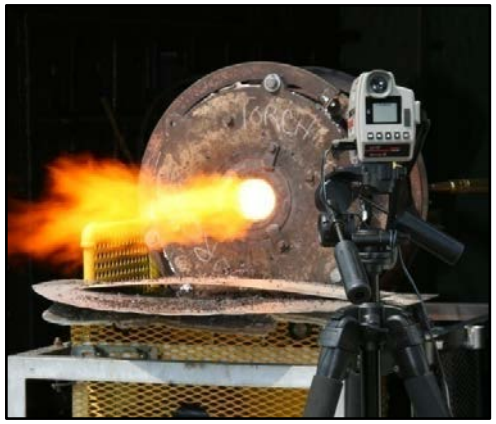


Conventional refractory after rotary slag testing

Phosphate modified high-chrome oxide refractory material

Advanced Refractories for Gasifiers

NETL Office of Research and Development



Current refractory goal is to refine/evaluate composition in commercial gasifiers

Cr^{+6} formation in high Cr_2O_3 refractories is thermodynamically predicted not to be an issue with current carbon feedstock

- Low oxygen partial pressure results in low Cr^{+6} formation
- Gasification environment has O_2 partial pressure about 10^{-8}

Conversion and Fouling

NETL Office of Research and Development

Modeling

- Evaluate and validate sub-models for particle-slag interaction, particle fragmentation, and mineral matter chemistry (sulfur release) and implement into CFD model
- Develop and evaluate reduced order model to predict mineral matter split between slag and fly ash for entrained-flow gasifier
- Convective Syngas Cooler Fouling
- Literature survey of deposition models
- Investigate gasifier ash deposits to determine problematic ash characteristics

Kinetics

- Effect of pressure on pyrolysis kinetics
- Preliminary gasification kinetics at high pressure

Slag Characterization

- Continue to characterize coal and petcoke blends, characterize ash and slag, begin studies of FeS and VOx behavior in slag

Control of Ash in IGCC

NETL Office of Research and Development

Goal: Solutions to IGCC Ash Management Problems

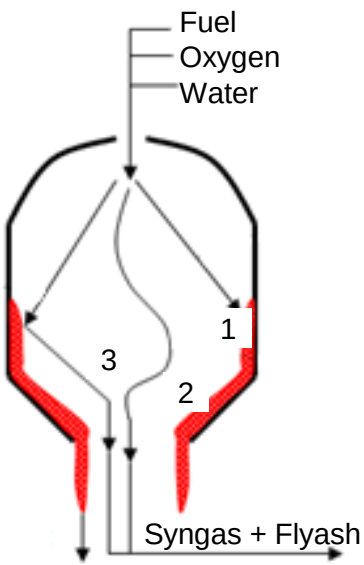
- Unconverted carbon in gasification flyash
- Syngas cooler fouling

Development of Models and Techniques to improve IGCC plant operations

- Inorganic transformations and char/slag interactions
- Particle trajectories and deposition modeling
- Gasification kinetics

Coordinate and leverage R&D at NETL and five nationally recognized, regional universities

- Carnegie Mellon University
- Pennsylvania State University
- University of Pittsburgh
- Virginia Polytechnic Institute and State University
- West Virginia University



1. Particles contact and coalesce with slag
2. Particles do not contact slag
3. Particles contact but do not coalesce with slag

Low Rank Coal Optimization

NETL Office of Research and Development

Kinetics

- Development of NETL's Carbonaceous Chemistry for Computational Modeling (C3M) software to bridge coal kinetics software (PCCL, CPD, etc) and available kinetic experiments with CFD software (MFIX, Fluent, Barracuda), other models
- Provide modelers and experimentalist with a virtual kinetic laboratory

Fuel Pretreatment

- Continued modeling and evaluation of feedstock grinding
- Correlate the NETL laboratory scale results with large scale grinding energies

Multiphase Models

- NETL's open source suite of multiphase solvers will be used to aid in the design and optimization of operating conditions and establishing performance trends in the NCCC/TRIG with uncertainty quantification
  - MFIX-DEM
  - MFIX continuum
  - MFIX-PIC and
  - Multiphase Reduced Order Models

Warm Syngas Cleanup

NETL Office of Research and Development

Elevated temperatures result in higher IGCC thermal efficiency

Palladium-based sorbents are currently among the most promising candidates for high-temperature capture of mercury, arsenic, selenium, phosphorus and the other trace elements

Progress:

2007 - License agreement between the NETL and sorbent manufacturer Johnson Matthey

2008 - Warm Syngas Cleanup received the R&D 100 award

2009 to 2013 - Over 99% removal of mercury, arsenic, and selenium from syngas slipstreams at 550°F over several weeks testing at the National Carbon Capture Center

Present - Identifying an optimum form of the palladium sorbent (loading, support, alloy)

DOE Supported Major Demonstration Gasification Projects

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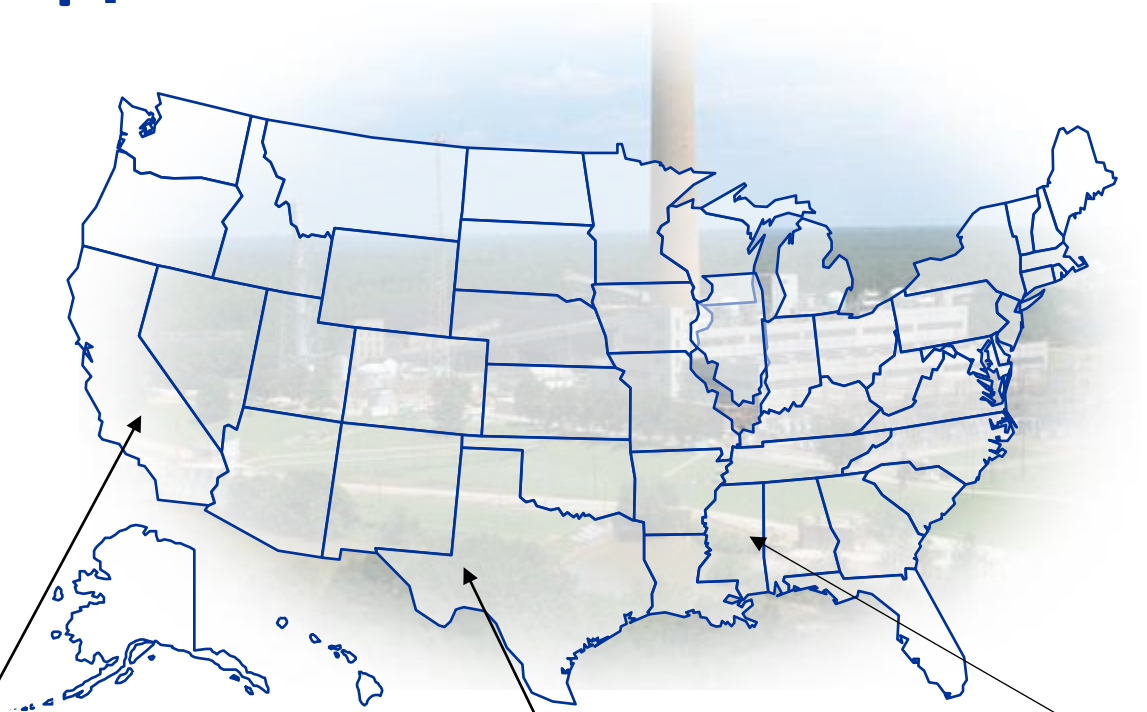
DOE Supported IGCC Demonstration Projects



SCS Energy
Hydrogen Energy California
Kern County, CA
Up to 300 MWe (net) & 1.0 MT/yr Urea
1- Mitsubishi Heavy Industries gasifier
90% Carbon capture
Fuel: Sub-bituminous coal/petcoke
EOR – ~2.6 MM TPY

- Construction: 2015
- Operation: 2019

Summit Power
Texas Clean Energy Project
Penwell, TX
200 MWe (net) & .7 MT/yr Urea
2 -Siemens SFG-500 gasifiers
90% Carbon Capture
Fuel: Sub-bituminous Powder River Basin
EOR – ~2.2 MMTPY

- Construction: 2015
- Operation: 2018

Southern Company
Kemper County Energy Facility
Kemper County, MS
582 MWe (net)
2 – KBR TRIG™ gasifiers
65% Carbon capture
Fuel: Mississippi lignite
EOR – ~3.0 MM TPY

- Construction: > 75% complete
- Operation: 2015

Southern Company Services, Inc.

Advanced IGCC with CO_2 Capture

- Kemper County, MS
- 582 MWe (net) with duct firing; 2 TRIG™ gasifiers, 2 Siemens combustion turbines, 1 Toshiba steam turbine
- Fuel: Mississippi lignite
- 67+% CO_2 capture (Selexol® process); 3,000,000 tons CO_2/year
- EOR: Denbury Onshore LLC, Treetop Midstream Services LLC
- Total DOE Project: $2.01 Billion; DOE Share: $270 Million (13%)
- Total estimated plant cost: ~$6.17 Billion

Key Dates

- Project Awarded: Jan 30, 2006
- Project moved to MS: Dec 5, 2008
- NEPA Record of Decision: Aug 19, 2010
- Initiate excavation work: Sept 27, 2010
- Operation: 2015

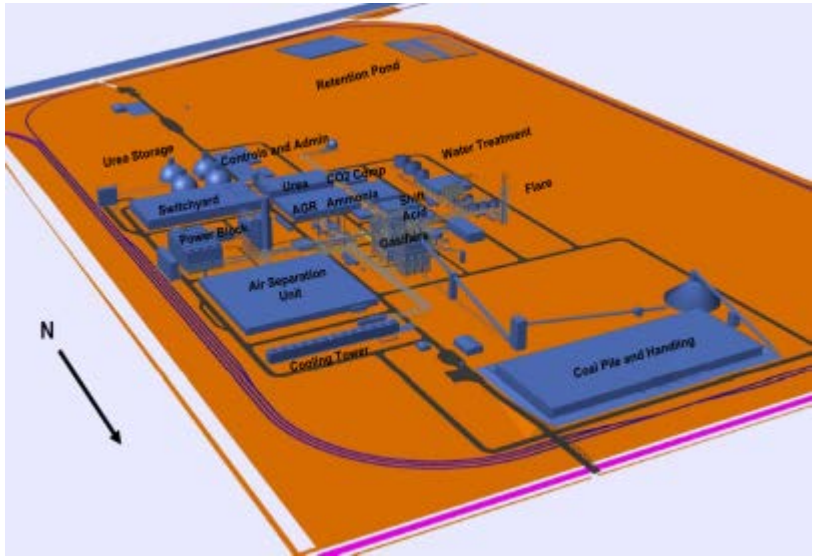
Status

- Plant construction >60% complete; >5,200 construction personnel on site
- CO_2 off-take agreements signed
- Lignite mine under development
- Subsystems (water treatment, cooling towers) to begin pre-commissioning
- First fire combustion turbine : Sept 2013
- Gasifier heat-up: Dec 2013

Summit Texas Clean Energy, LLC

Advanced IGCC-Polygen

- **Penwell, Ector County, TX**
- **200 MW (net), 0.7 MMT/yr Urea; greenfield IGCC with Siemens gasification & power Block**
  - SFG-500 gasifiers (2 x 50%)
  - High H_2 SGCC6-5000F combined cycle (1 x 1)
- **Fuel: PRB sub bituminous coal**
- **90% CO_2 capture – ~2,700,000 tons CO_2/year**
  - 2.2 MM tonnes EOR; 0.5 MM to Urea production
  - 2-stage Water Gas Shift, Linde Rectisol® AGR
- **EOR: Permian Basin oil fields**
- **Total DOE Project: $1.727 Billion**
  DOE Share: $450 Million (26%)
- **Total Plant Cost ~$2.6 Billion**



Key Dates

- **Project Awarded: Jan 2010**
- **Air Permit; Dec 2010**
- **NEPA Record of Decision: Sep 2011**
- **Financial Close: Jul 2013**
- **Construction: 3rd Q2013**
- **Operation: Nov 2017**

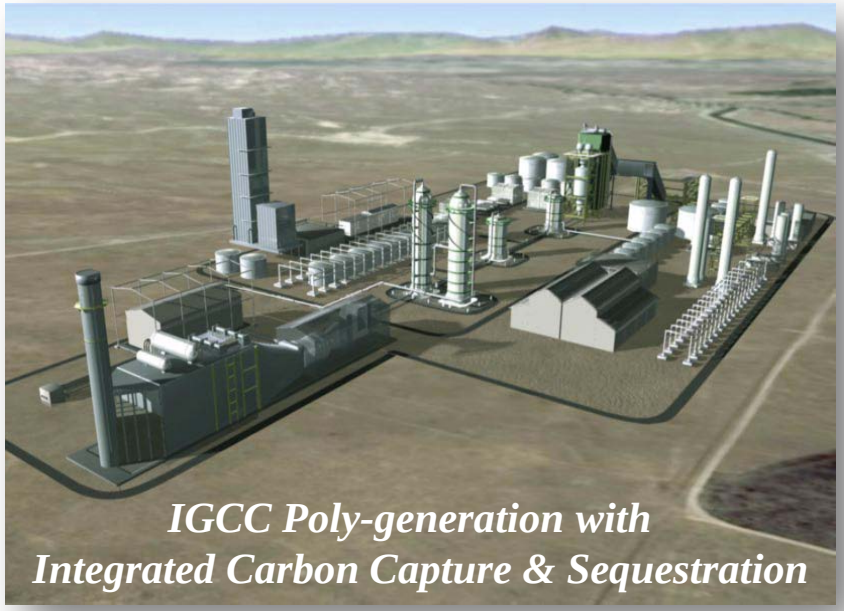
Status

- **Urea contract: Jan 2011**
- **CO_2 contract(s): Nov 2011**
- **Power off-take contract: Dec 2011**
- **Chexim signed for debt financing MOU: Sep 2012**
- **Sinopec signed EPC agreement: Dec 2012**

Hydrogen Energy California

Advanced IGCC-Polygen

- **Kern County, CA**
- **Up to 300 MWe (net) with load following; greenfield IGCC, 1.0 MT/yr Urea/UAN**
  - MHI oxygen-blown gasifier (1 x 100%)
  - MHI G-class air cooled combustion turbine (1)
- **Fuel: Sub-bituminous coal/petcoke**
- **90% CO_2 capture – 3,020,000 tonnes CO_2/year**
  - 2.57 MM tonnes EOR; 0.45 MM Urea production
  - 2-stage Water Gas Shift, Linde Rectisol® AGR
- **EOR: Elk Hills oil field**
- **Use of brackish water for power production; ZLD**
- **Total DOE Project: $4 Billion DOE - $408 Million (10%)**
- **Total Plant Cost: ~$5 Billion**



IGCC Poly-generation with Integrated Carbon Capture & Sequestration

Key Dates

- **Project Awarded: Sep 2009**
- **New Owner, SCS Energy: Sep 2011**
- **Financial Close: Jun 2014**
- **Start of Construction: Jan 2015**
- **Start of Operation: Jul 2019**

Status

- **NEPA public scoping meeting: Jul 2012**
- **Power/Fertilizer/CO_2/EPC discussions in progress**
- **FEED completion: 2013**
- **Draft PSA/EIS: Jun 2013**

Systems Analysis

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NETL's Program Analysis Support

On-going and Planned Gasification Studies

Advanced technology assessments

Studies for FY14 and FY15 Gasification awards which includes updated performance data of advanced technologies

- Pathway study updates
  - Using Bituminous coal in IGCC processes with carbon capture
  - Using low rank coals and preforming pressure sensitivity analysis
- Evaluation of process intensification
  - combination of WGS and carbon capture technologies
  - Integration of other advanced energy processes into gasification
- Evaluation of warm gas clean up technologies coupled with various carbon capture technologies

Baseline Technology Assessments

Update of Cost and Performance Baseline for Fossil Energy Plants

- Addition of zero liquid discharge requirements for IGCC process water
- Updates to the Selexol and WGS economics

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Bituminous Baseline

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General Objective of NETL Baseline Studies

What - Determine cost and performance estimates of near-term commercial offerings

- Consistent design basis
- Consistent performance and capital cost estimates
- Technologies built now and deployed in the near term

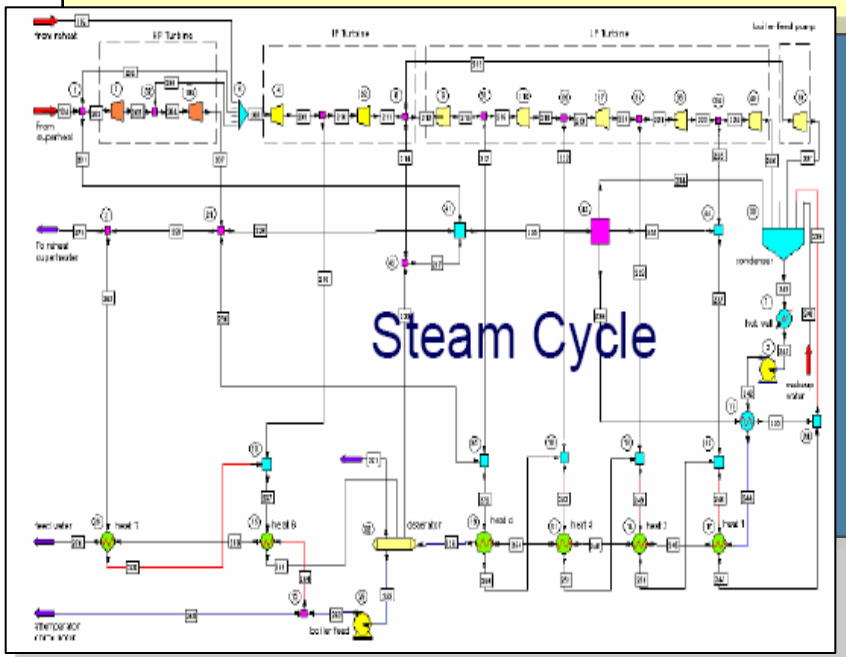
Why - Provide baseline costs and performance to:

- Compare existing technologies
- Provide basis for sensitivity analyses
- Provide basis for screening studies on advanced technology undergoing R&D
- Provide starting point for pathway studies incorporating multiple advanced technologies and identifying R&D needs for significant improvement in plant cost and performance

Technical Approach

1. Extensive Process Simulation (ASPEN)

- All major chemical processes and equipment are simulated
- Detailed mass and energy balances
- Performance calculations (auxiliary power, gross/net power output)



2. Cost Estimation

- **Inputs from process simulation** (Flow Rates/Gas Composition/Pressure/Temp.)
- **Sources for cost estimation**
  - WorleyParsons
  - Vendor sources where available
- **Follow DOE Analysis Guidelines**

Study Matrix

Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/ Boiler	Acid Gas Removal/ CO_2 Separation / Sulfur Recovery	CO_2 Cap
IGCC	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)	F Class	GEE	Selexol / - / Claus	
				Selexol / Selexol / Claus	90%
			CB&I E-Gas	MDEA / - / Claus	
				Selexol / Selexol / Claus	90%
			Shell	Sulfinol-M / - / Claus	
				Selexol / Selexol / Claus	90%
PC	2400/1050/1050		Subcritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
	3500/1100/1100		Supercritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
NGCC	2400/1050/1050	F Class	HRSG		
				- / Econamine / -	90%

GEE – GE Energy
CoP – Conoco Phillips (now CB&I)

Cost Basis and Select Assumptions

Cost estimate basis

- -15%/+30% accuracy
- Generic location, excluding site-specific costs
- Nth-of-a-kind costs, excluding cost premiums associated with first-of-a-kind plants
- Greatest value of costs lies in comparison between cases as opposed to absolute accuracy of cost estimates for the individual cases

Capacity factor assumed to equal availability

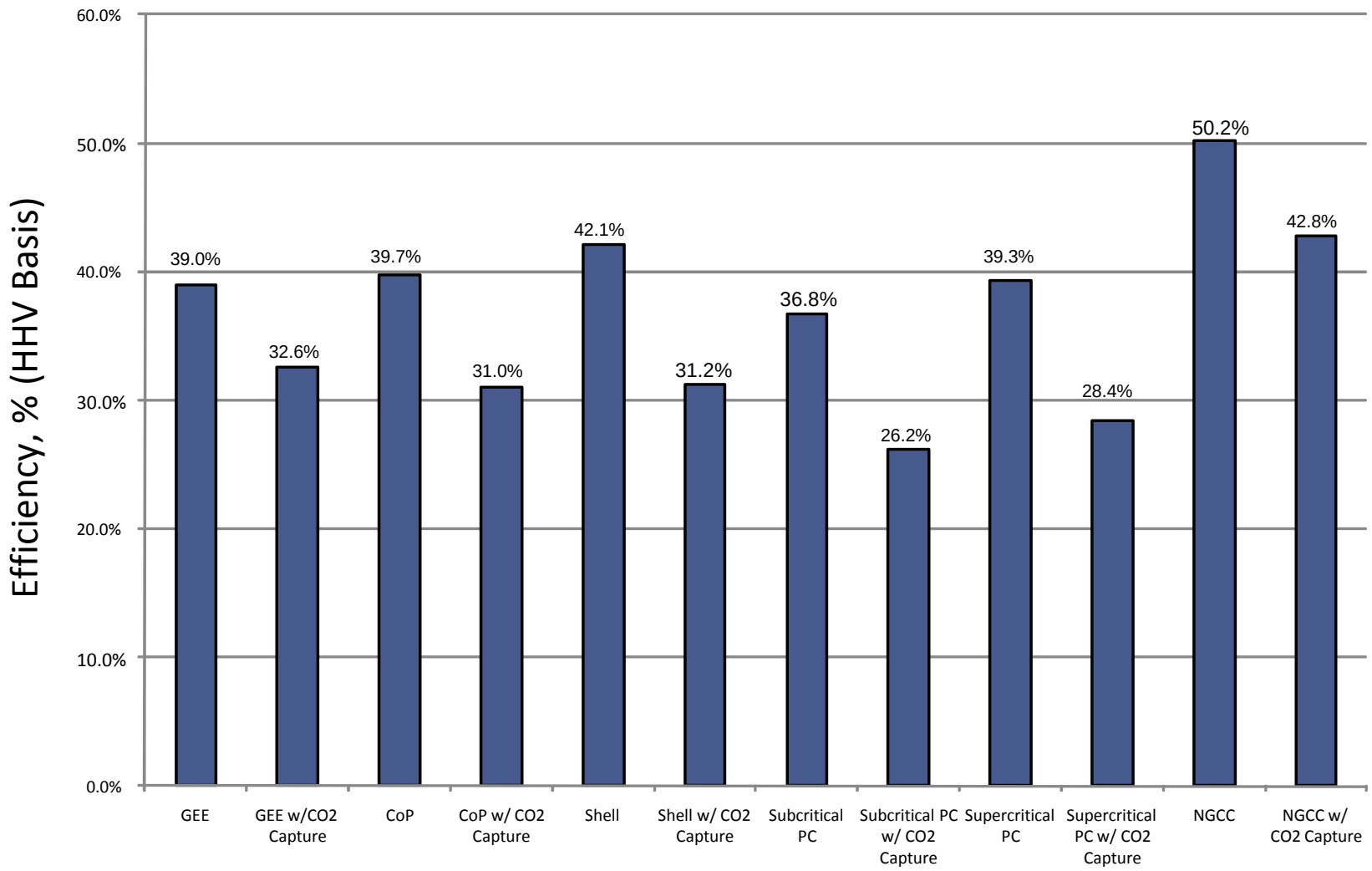
- IGCC capacity factor = 80% w/ no spare gasifier
- PC and NGCC capacity factor = 85%

Investor owned utility finance structure

- 12% IRROE
- 4.5-5.5% interest rate
- 45-50% debt

In CO_2 capture cases, CO_2 compressed to 2200 psig, transported 100 km (62 miles) and stored in a saline aquifer

Plant Efficiency



Performance Highlights

Coal-based plants using today's technology are efficient and clean

- IGCC & PC: 39%, HHV (without capture on bituminous coal)
- Today's capture technology can remove 90% of CO_2, but at significant increase in COE
- Meet or exceed current environmental requirements (the study plant designs are currently being updated to achieve recently imposed EPA regulations)

Capital Cost Highlights

Total Overnight Cost without Capture: IGCC ~25% higher than PC

- NGCC: $891/kW
- PC: $2,420/kW
- IGCC: $2,969/kW

Total Overnight Cost with Capture: PC ~10% higher than IGCC

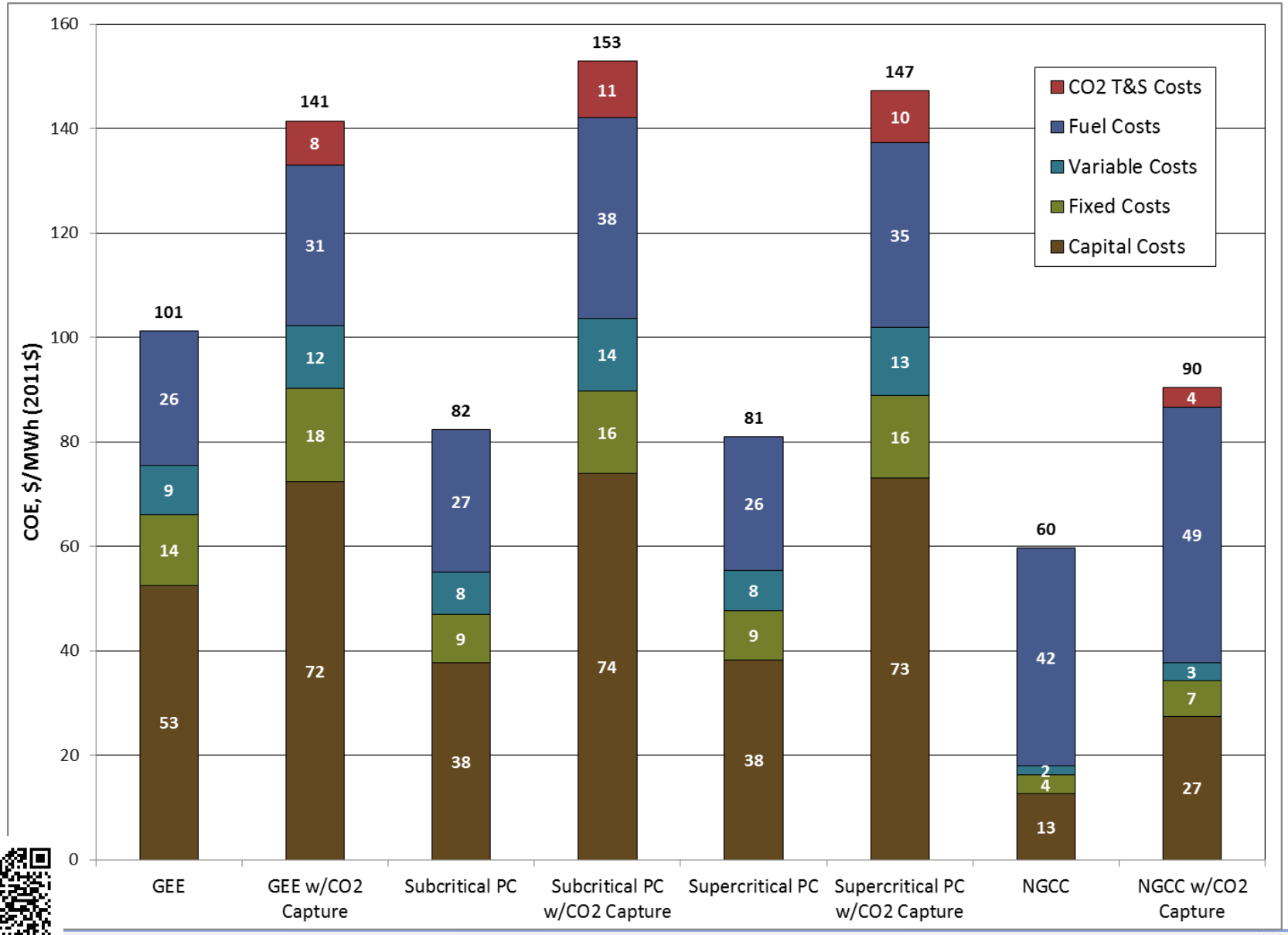
- NGCC: $1,842/kW
- PC: $4,438/kW
- IGCC: $4,086/kW

CO_2 Transport and Storage (T&S) Costs

Determine region-specific costs using "CO_2 Transport and Storage Costs in NETL Studies"

Plant Location	Basin	Transport over 100 km (2011$/tonne)	Storage (2011$/tonne)	Total T&S (2011$/tonne)	T&S Value for System Studies (2011$/tonne)	*Range for 2007 studies (2007$/tonne)*
Midwest	Illinois	3.65	5.75	9.40	10	*Coal plants: 5 – 7* *NG plants: 8 – 9*
Texas	East Texas		6.06	9.71	10	
North Dakota	Williston		10.96	14.61	15	
Montana	Powder River		17.86	21.51	22	

COE Breakdown by Cost Component



Cost of Electricity Highlights

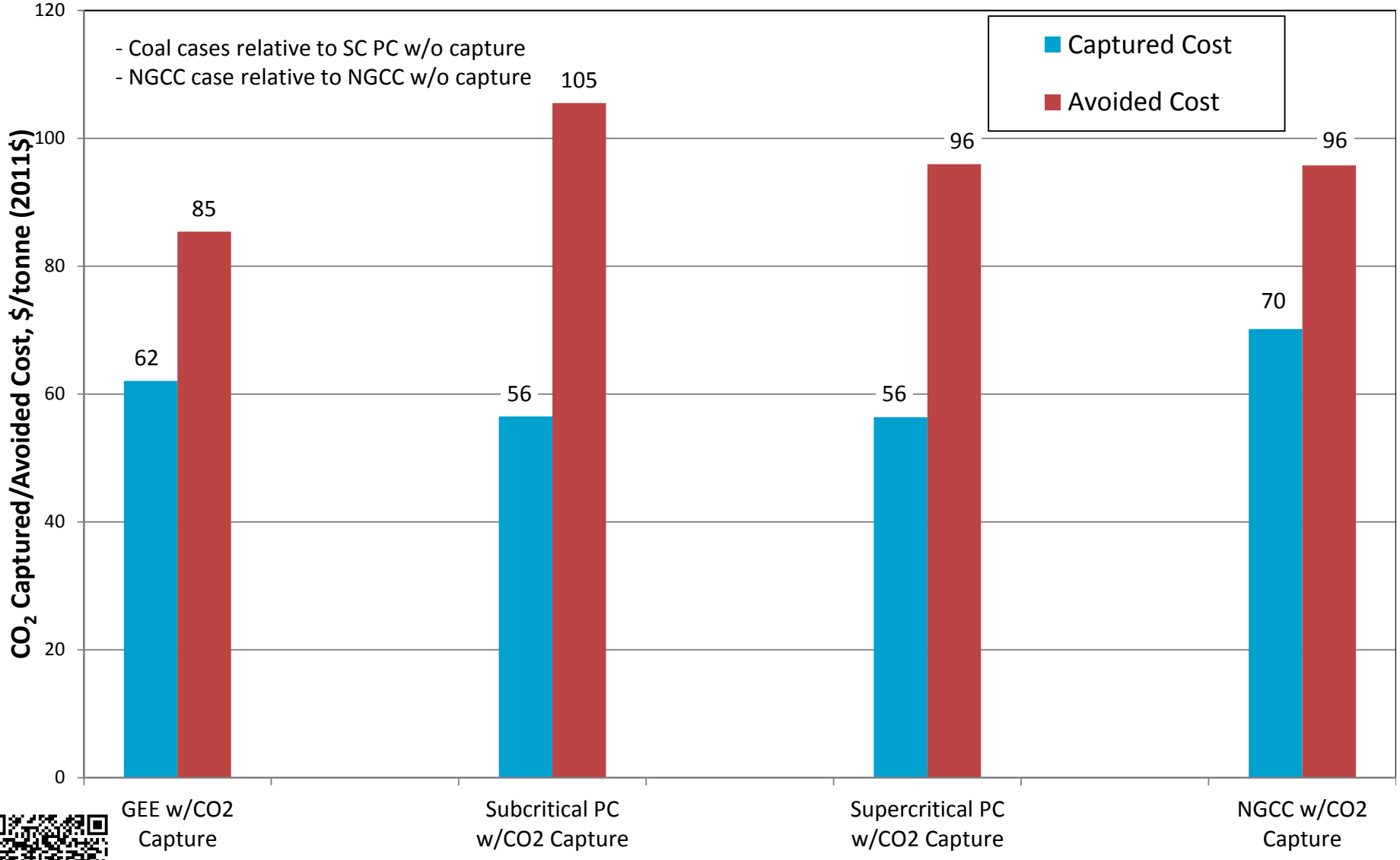
COE: NGCC & PC lowest cost generators

- NGCC: 60 $/MWh
- PC: 82 $/MWh (average)
- IGCC: 101 $/MWh

With CCS: PC lowest coal-based option

- NGCC: 90 $/MWh
- PC: 150 $/MWh (average)
- IGCC: 141 $/MWh

CO_2 Capture and Avoided Costs



Results

Case	TOC, $/kW	COE (w/o T&S), $/MWh	COE (w/T&S), $/MWh	CO_2 Capture Cost (w/o T&S), $/tonne*	CO_2 Avoided Cost (w/T&S), $/tonne*
June 2011 Cost Basis					
IGCC	2,969	101	N/A	N/A	N/A
IGCC w/capture	4,086	133	141	62	85
SubC PC	2,420	82	N/A	N/A	N/A
SubC PC w/capture	4,438	142	153	56	106
SC PC	2,452	81	N/A	N/A	N/A
SC PC w/capture	4,391	137	147	56	96
NGCC	891	60	N/A	N/A	N/A
NGCC w/capture	1,842	87	90	70	96
IGCC	2,447	76	N/A	N/A	N/A
IGCC w/capture	3,334	100	106		
SubC PC	1,996	59	N/A	N/A	N/A
SubC PC w/capture	3,610	104	110		
SC PC	2,024	59	N/A	N/A	N/A

* Coal cases relative to SC PC w/o capture
* NGCC cases relative to NGCC w/o capture

NETL Baseline References

- Energy Analysis – Cost and Performance Baselines for Fossil Energy Plants (Home Page) - http://www.netl.doe.gov/research/energy-analysis/energy-baseline-studies
- "Cost and Performance Baseline for Fossil Energy Plants: Volume 1 – Bituminous Coal and Natural Gas to Electricity" - http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/OE/BitBase_FinRep_Rev2a-3_20130919_1.pdf
- "Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases" - http://netl.doe.gov/research/energy-analysis/publications/details?pub=c89c9846-7a6a-44b5-99a8-46ac8bb4e011
- Energy Analysis – Quality Guidelines for Energy System Studies for Fossil Energy Plants (Home Page) - http://www.netl.doe.gov/research/energy-analysis/quality-guidelines-qgess
- "Carbon Dioxide Transport and Storage Costs in NETL Studies – Quality Guidelines for Energy System Studies" - http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/QGESS_CO2T-S_Rev3_20140514.pdf

Bituminous IGCC Pathway Study

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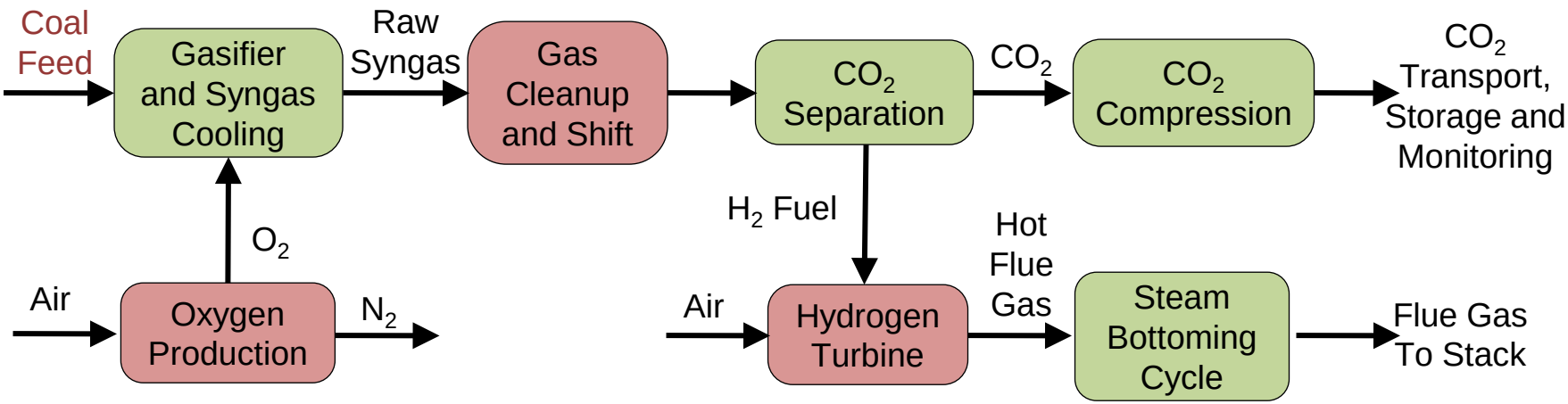
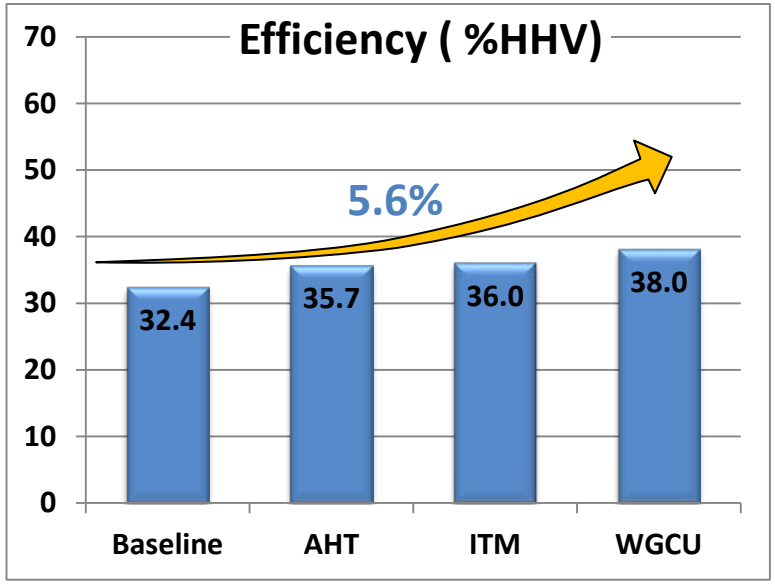
Ref: Current and Future Technologies for Gasification-Based Power Generation Volume 2: A Pathway Study Focused on Carbon Capture Advanced Power Systems R&D Using Bituminous Coal, Revision 2, 2013 DRAFT, DOE/NETL-2009/1389

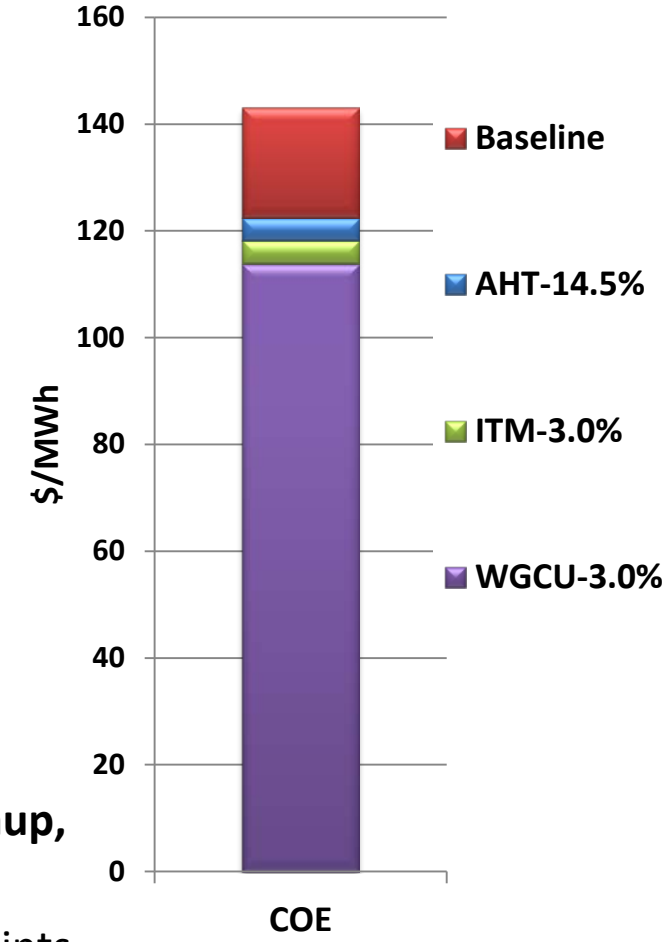
IGCC 2nd Generation Technology Assessments



Case	Case Title	Gas Turbine	Oxygen Production	Gas Clean Up	CO_2 Separation
1	Baseline	Advanced F-frame Turbine	Cryogenic ASU	2-Stage Selexol	
2	Advanced H_2 Turbine (AHT)	AHT			
3	Ion Transport Membrane (ITM)		ITM		
4	Warm Gas Cleanup (WGCU)			WGCU	1-Stage Selexol

2nd Generation IGCC Systems





Advances in hydrogen turbines, warm gas cleanup, and oxygen production show potential for:

- Efficiency improvements of 5.6 percentage points
- Cost of electricity (COE) reduction of 20.5%

Low Rank Coal Baseline Study: IGCC Cases

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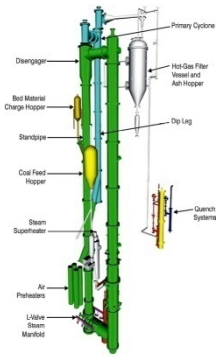
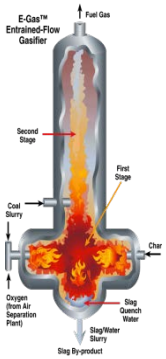
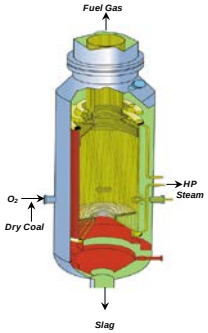
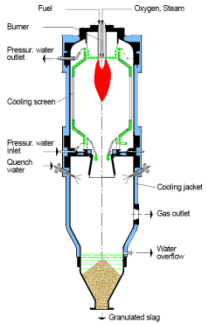
IGCC Cases: Technical Design Basis



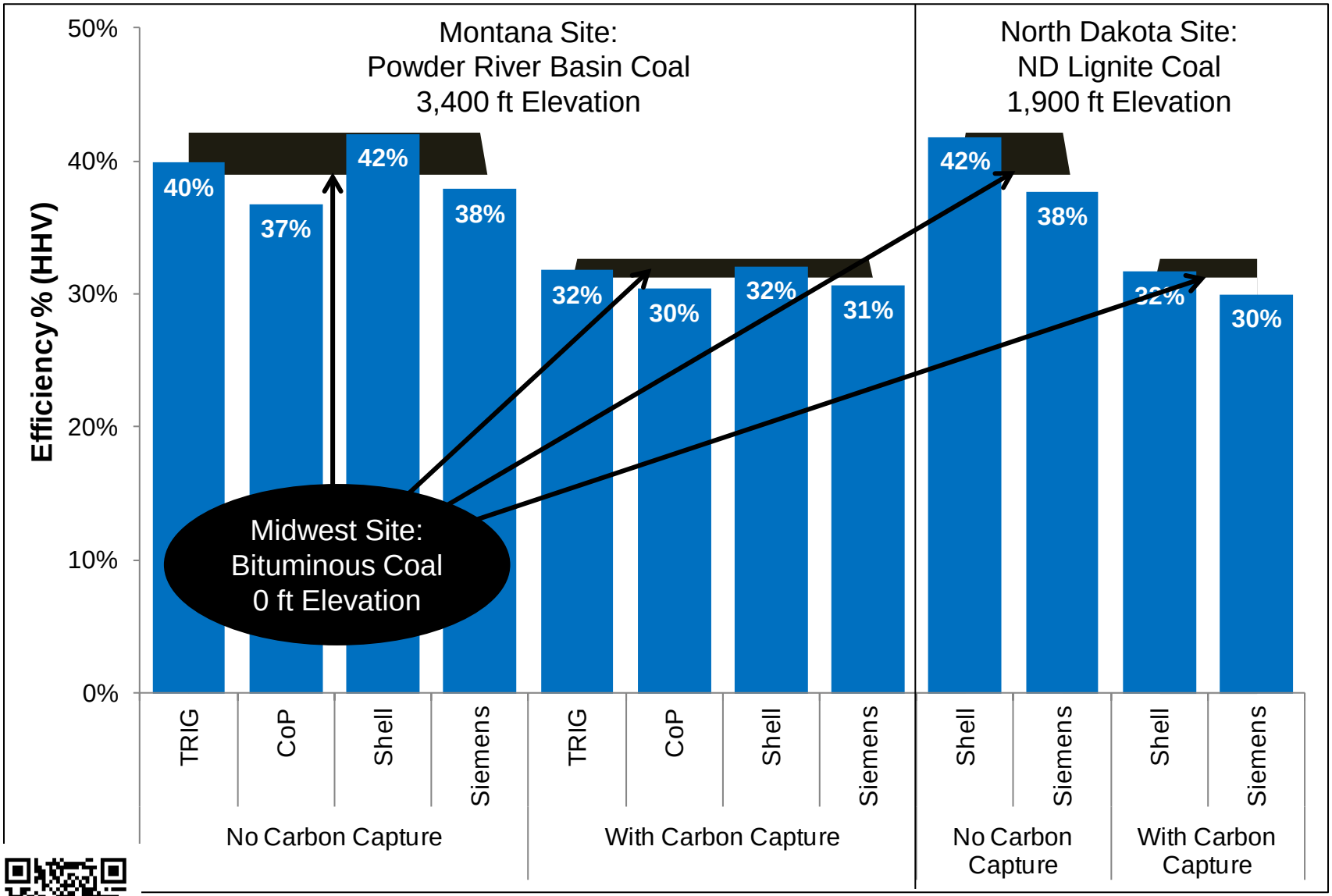




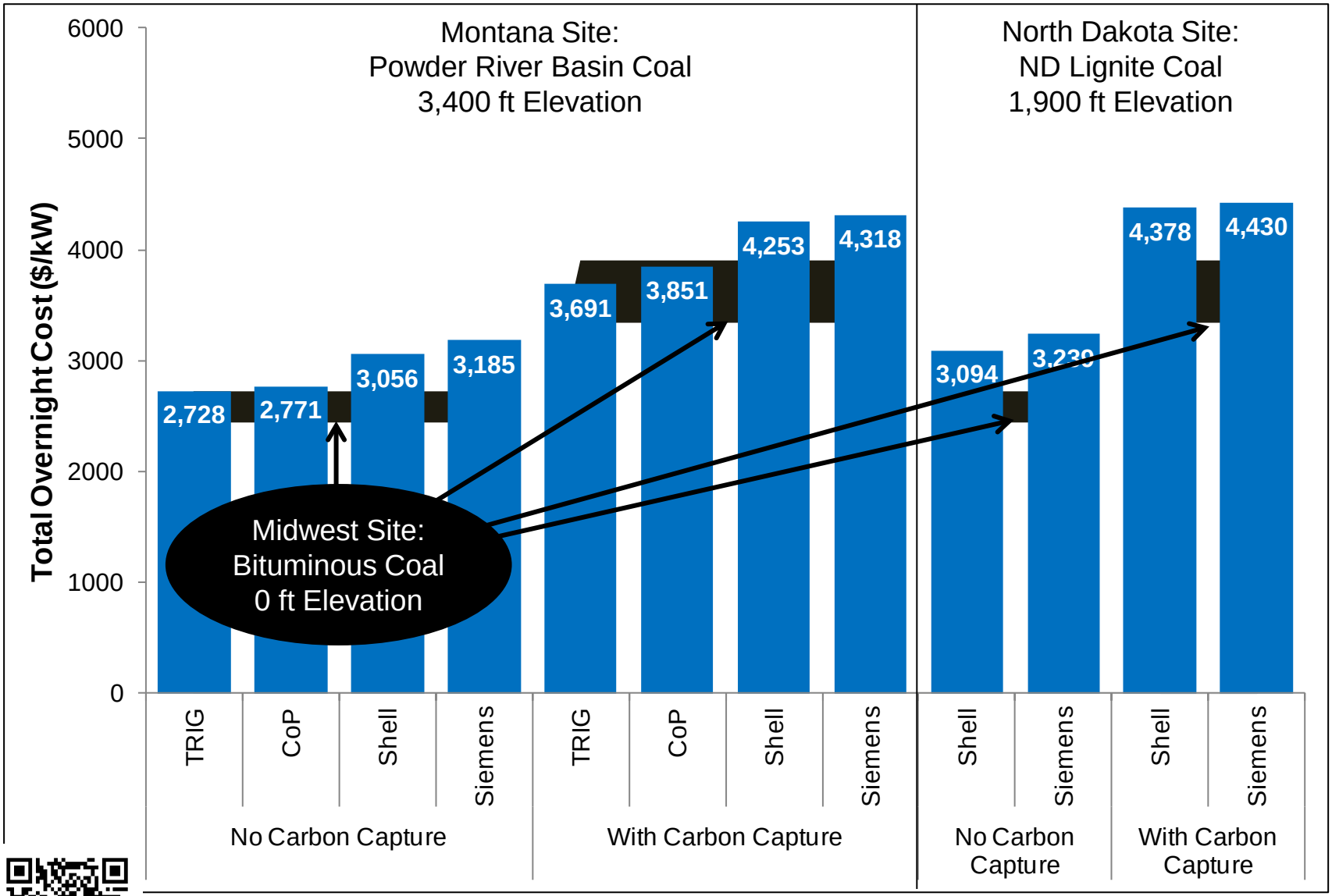


	Southern Company TRIG	CB&I E-Gas	Shell SCGP	Siemens (GSP/Noell)
Gasifier	Transport	Slurry; entrained	Dry-fed entrained	
Coal Type	PRB		PRB & ND Lignite	
Location/Elevation	Montana/3400 ft		PRB: Montana/3400 ft Lignite: ND/1900 ft	
Coal Drying	Indirectly heated fluidized bed	NA	WTA process	
Oxidant	Oxygen			
AGR for CO2 capture plants	2-Stage Selexol			
Gas Turbine	Advanced F-class (Nitrogen dilution and air integration maximized)			
Steam Cycle (psig/F/F)	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)			
Carbon Capture	83%	90%		
Availability	80%			

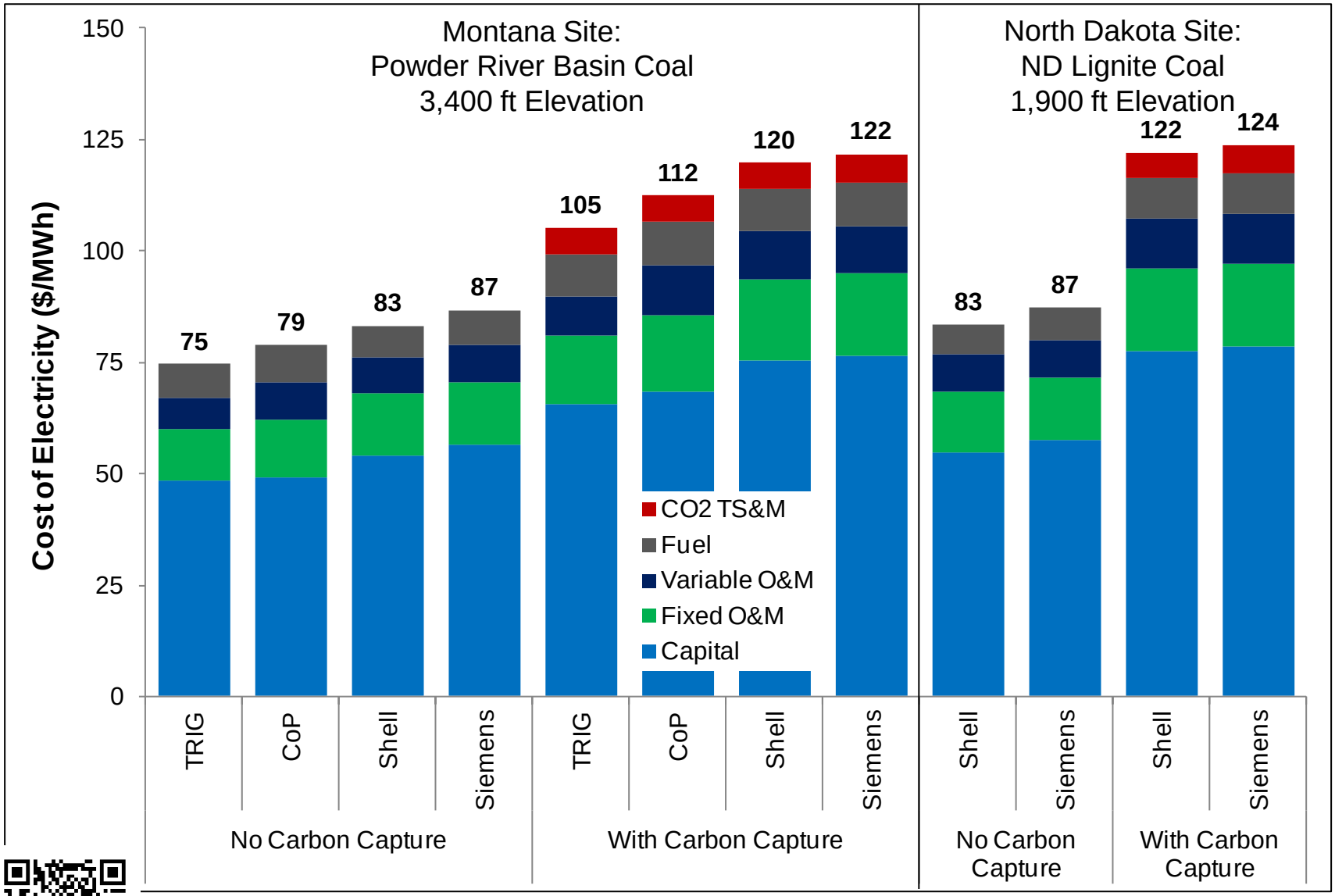
IGCC Efficiency: Bituminous Coal Comparison



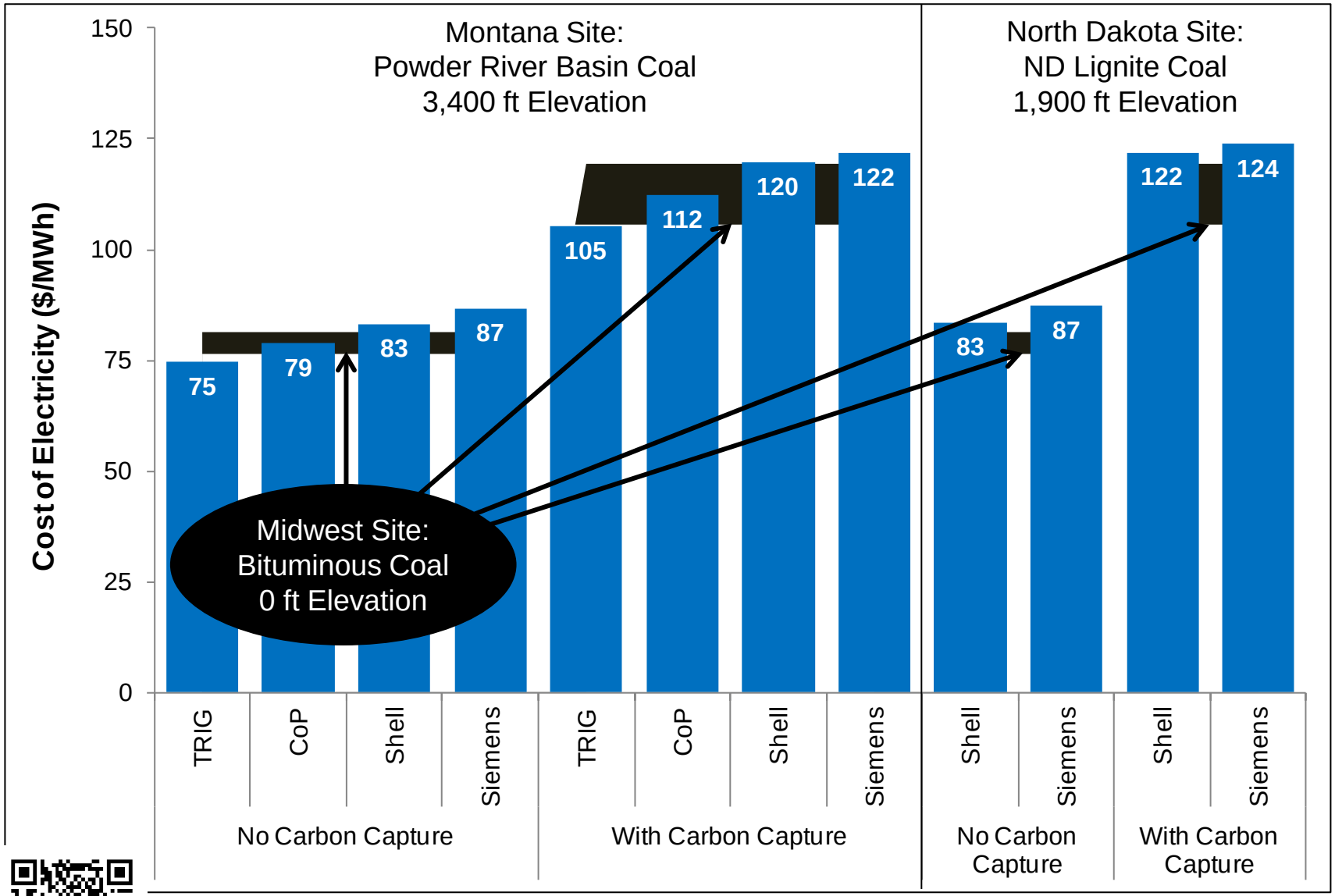
IGCC Plant Cost: Bituminous Coal Comparison



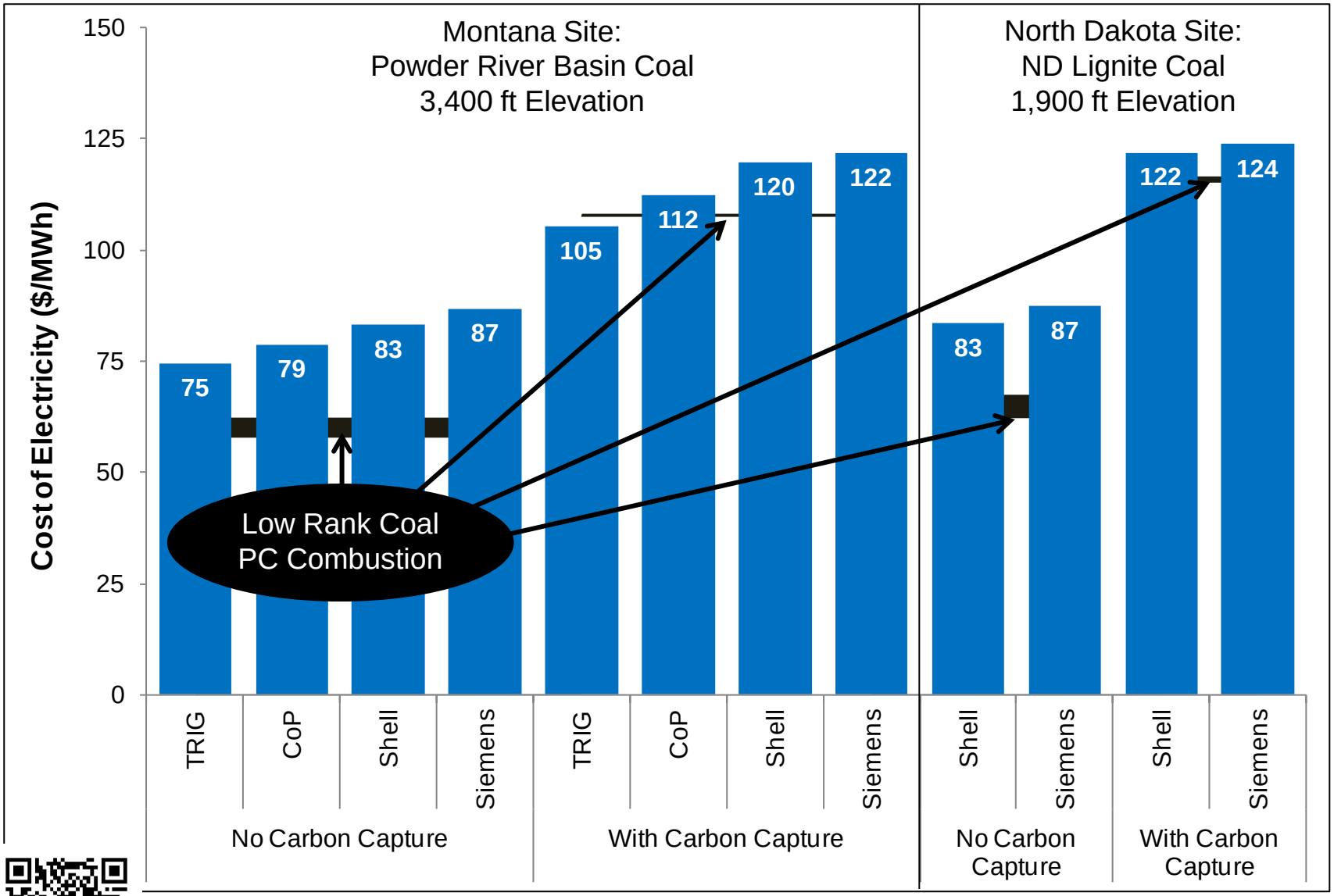
Conventional IGCC: COE



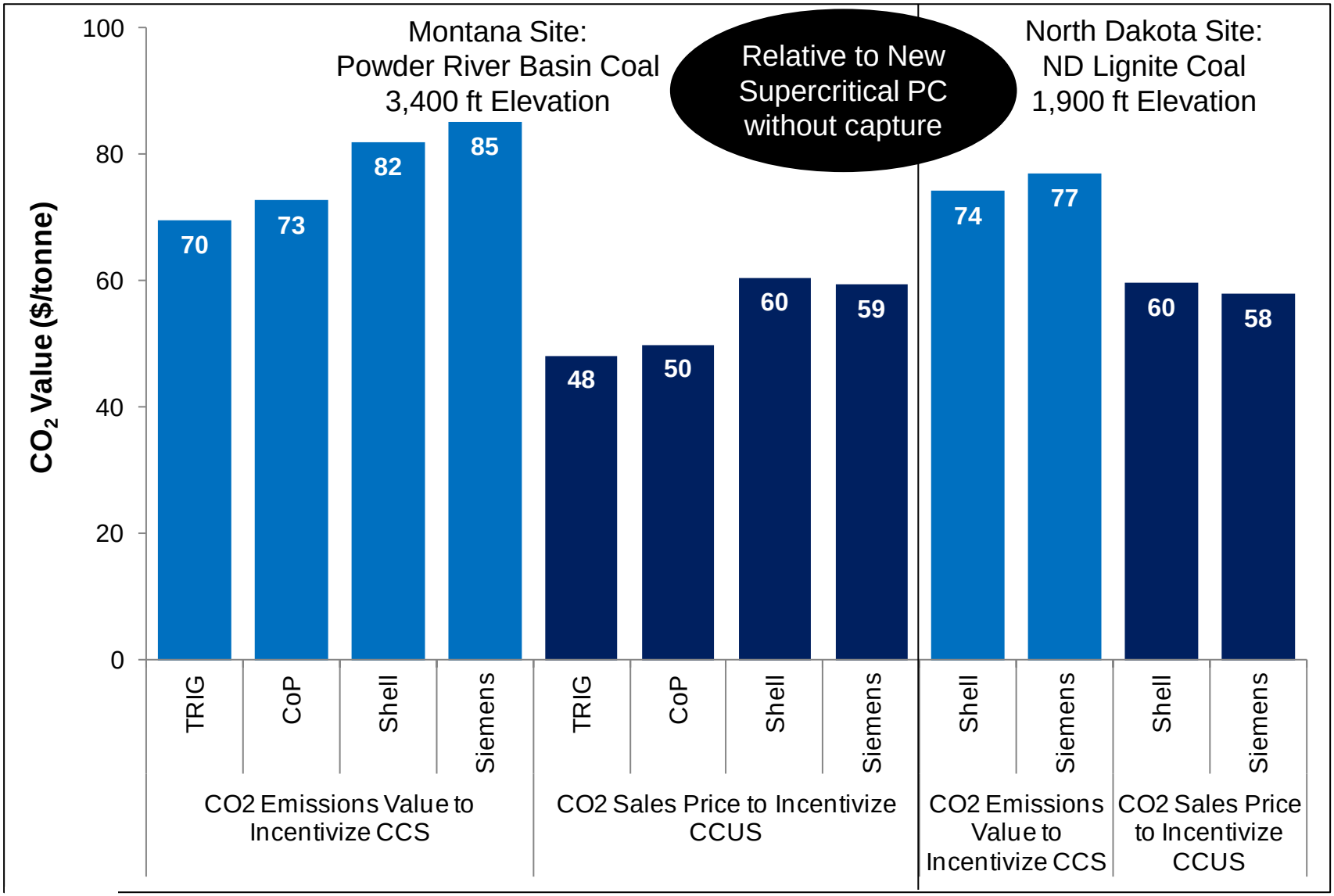
IGCC COE: Bituminous Coal Comparison



IGCC COE: Comparison to PC Plants



Conventional IGCC: CO_2 Capture Cost



CCUS = Carbon capture, utilization and storage

Key Findings & Next Steps

- **Transport gasifier provides low cost IGCC power**
- **Slurry-fed gasification still competitive for high-moisture PRB coal**
- **Western location/low rank coal gasification COE on par with midwest/bituminous coal gasification**
- **IGCC with carbon capture COE essentially equivalent to PC PRB**
- **All coal systems, with and without carbon capture, face challenges competing in today's U.S. market**
  - No carbon policy
  - Current natural gas prices
- **Opportunities for IGCC**
  - State-of-the-Art: Co-production, CO_2 utilization via enhanced oil recovery
  - 2nd Gen: R&D and demonstration for advanced technologies

Conventional IGCC Compared to PC and NGCC

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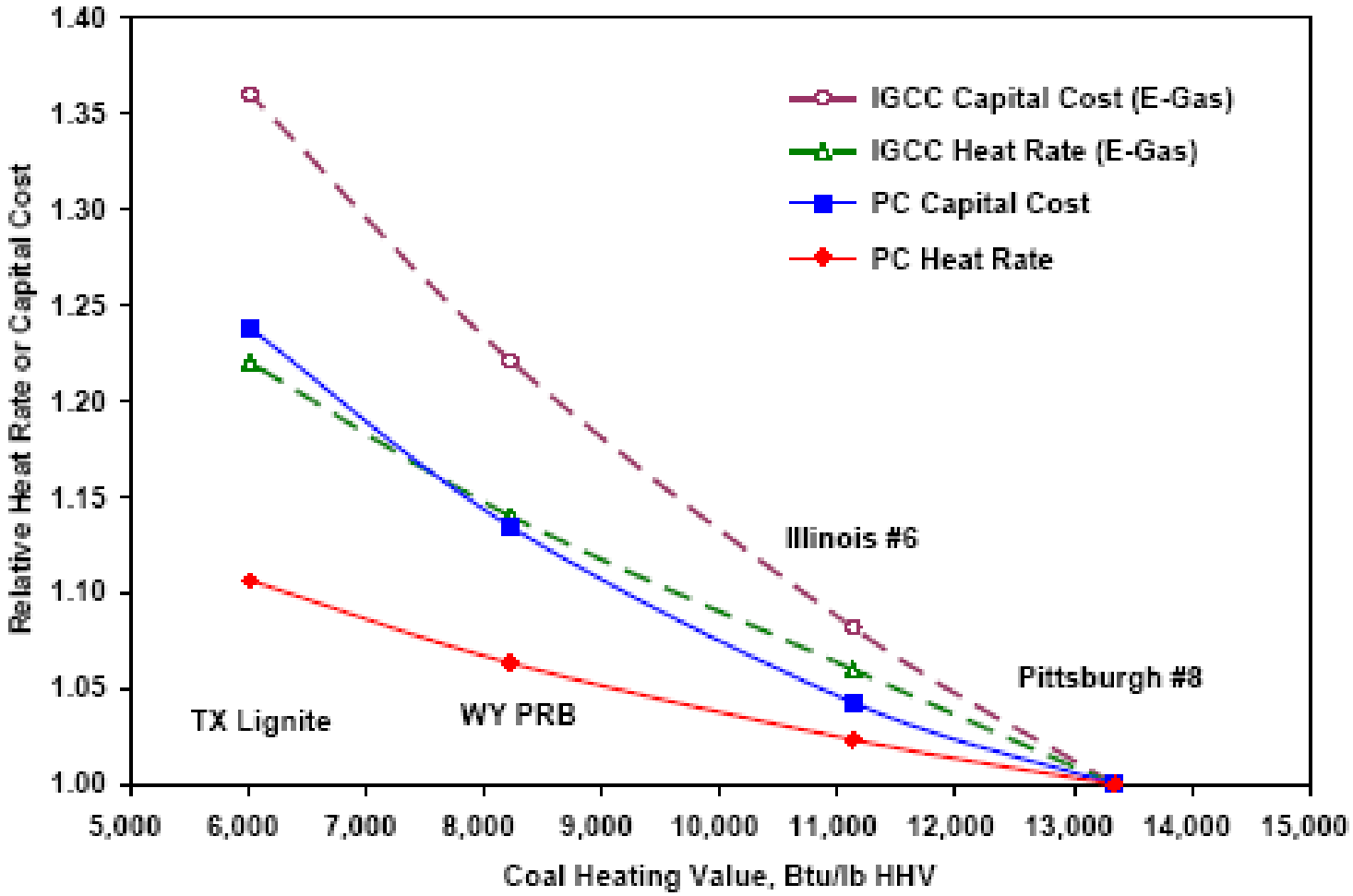
Fundamental Comparison of IGCC with Advanced PC-Fired Plant

	IGCC	PC
Operating Principles	Partial Oxidation	Full Oxidation
Fuel Oxidant	Oxygen	Air
Temperature	≤ 3000 °F	≤ 3200 °F
Pressure	415-1000 psia	Atmospheric
Sulfur Control	Concentrate Gas	Dilute Gas
Nitrogen Control Combustion	Not Needed	Pre/Post
Ash Control	Low Vol. Slag	Fly/Bottom Ash
Trace Elements	Slag Capture	ESP/Stack
Wastes/By-products	Several Markets	Limited Markets
Efficiency (HHV)	39-42%	37-40%

Comparison of Air Emission Controls: PC vs. IGCC

	Sulfur	NO_x	PM	Mercury
PC Post Combustion	FGD system	Low-NO_x burners and SCR	ESP or baghouse	Inject activated carbon
IGCC Pre Combustion	Chemical and/or physical solvents	Syngas saturation and N_2 diluent for GT and SCR	Wet scrubber, high temperature cyclone, barrier filter	Pre-sulfided activated carbon bed

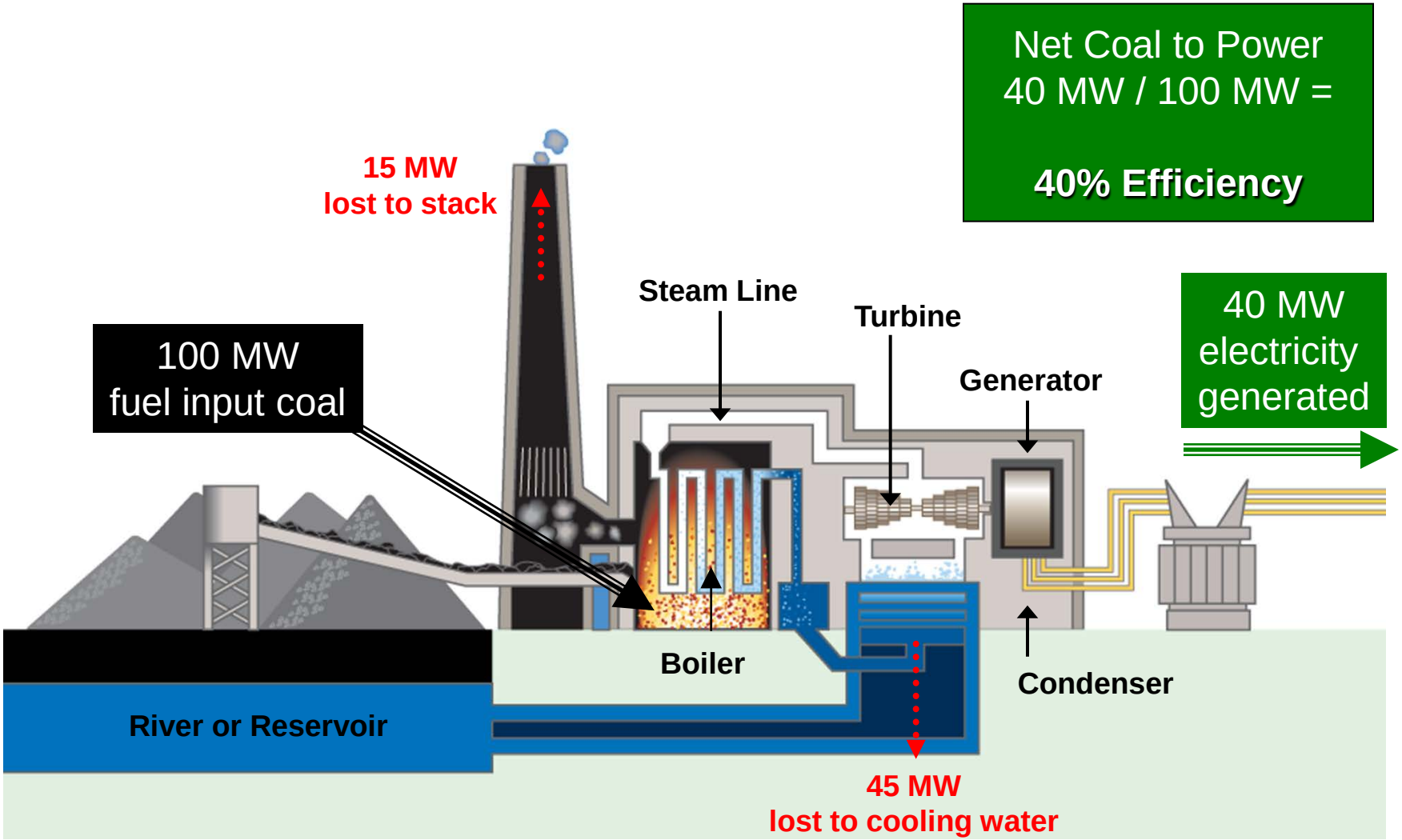
Effect of Coal Quality on PC and IGCC Plant Heat Rates and Capital Costs



Source: EPRI (Booras and Holt), "Pulverized Coal and IGCC Plant Cost and Performance Estimates", GTC Conference, October 2004

Conventional Coal Plant

(Illustration only)



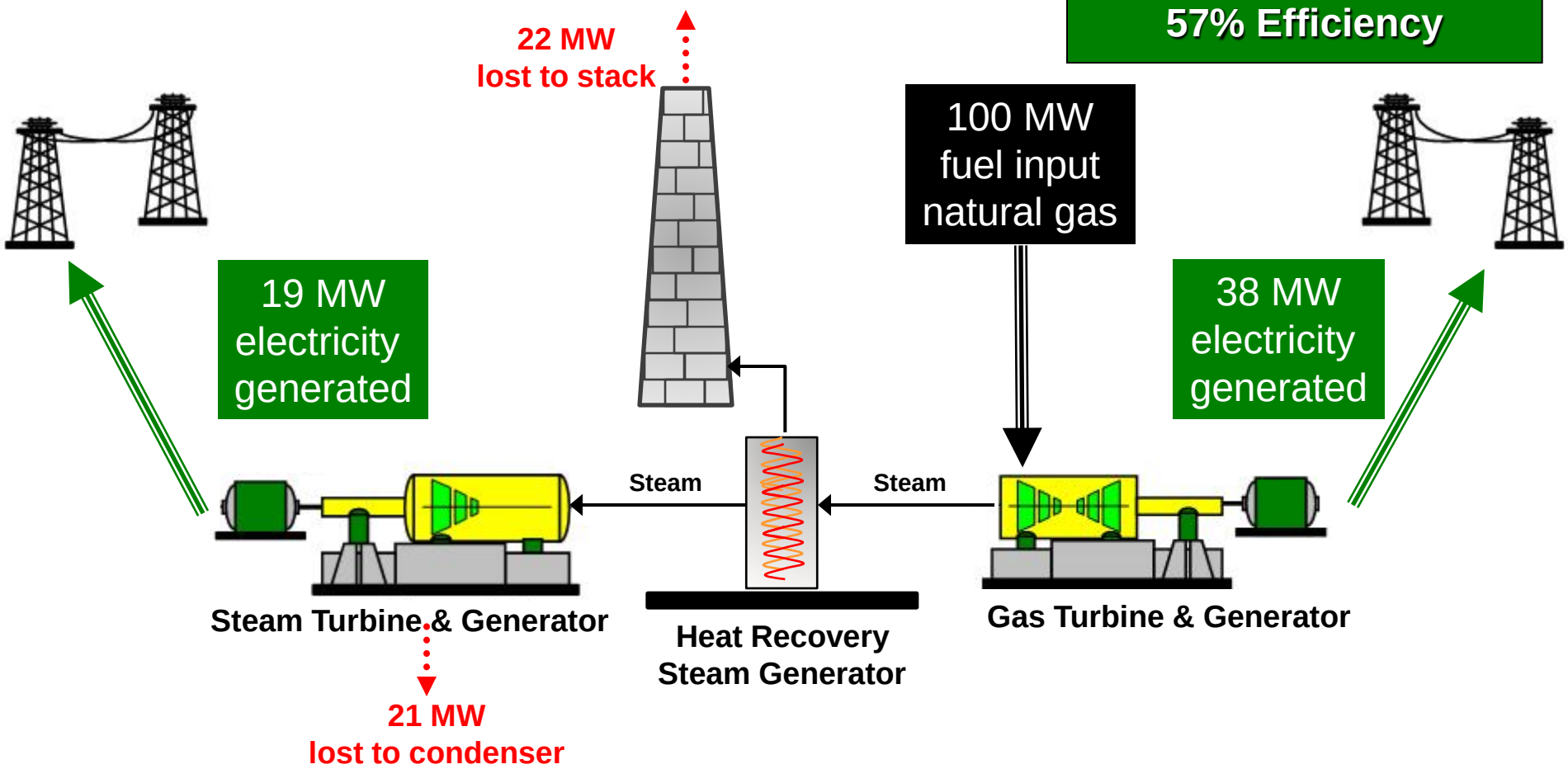
Source: EPRI

Natural Gas Combined Cycle

(Illustration only)

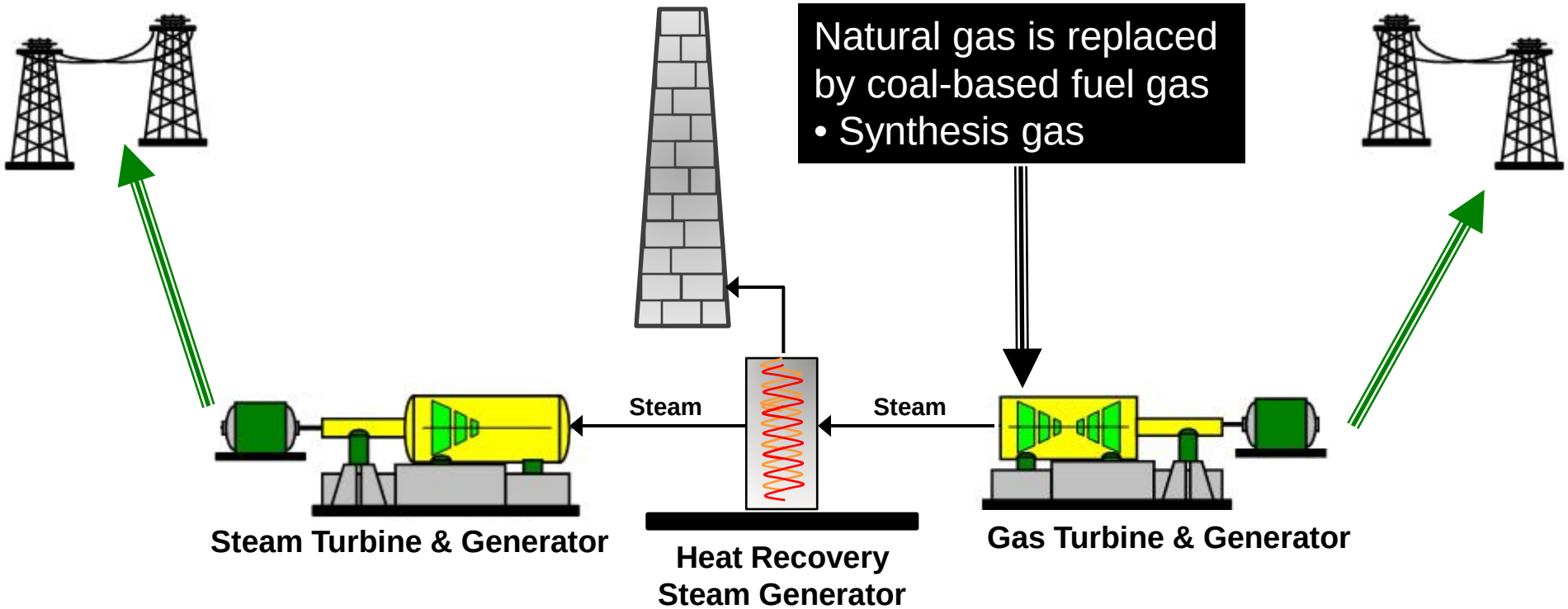
Net Natural Gas to Power
(19 +38) MW / 100 MW =

57% Efficiency

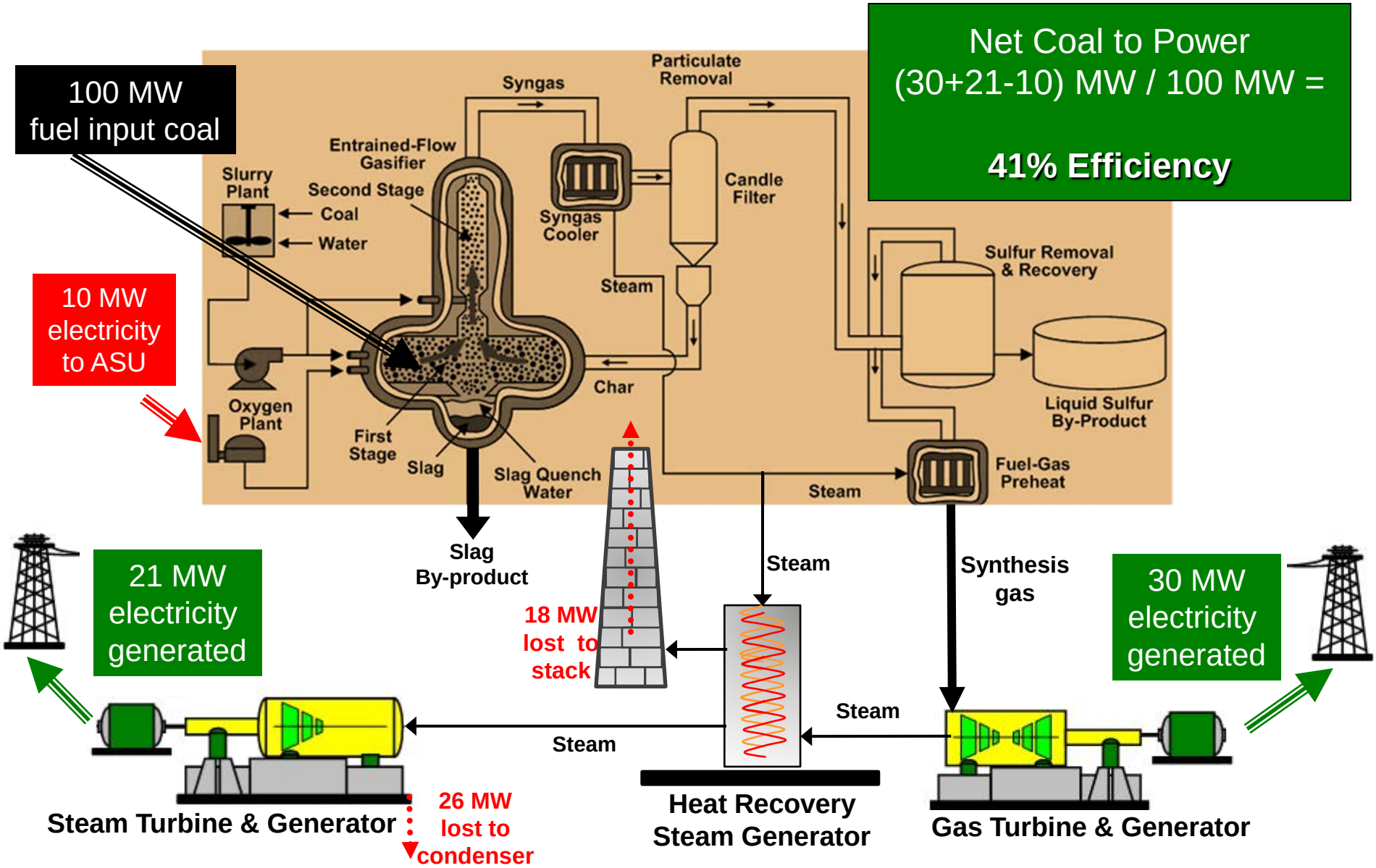


Coal-Based IGCC Power Plant

Gasification Island
- Converts coal to synthesis gas
- Cleans & conditions synthesis gas



Coal-Based IGCC Power Plant



Gasification-Based Energy Conversion Systems

RESOURCES

- Air/Oxygen
- Coal
- Biomass
- Petroleum Coke
- Heavy Oil
- Refinery Wastes
- MSW
- Orimulsion
- Other Wastes

GASIFIERS

OXYGEN-BLOWN

Entrained Flow
- GE Energy, E-Gas, Shell, Prenflo, Noell, Huaneng CERI, OMB

Fluidized Bed
- HT Winkler, U-Gas

Moving Bed
- British Gas Lurgi (BGL)
- Lurgi (Dry Ash)

Transport Reactor
- KBR

AIR-BLOWN

Fluidized Bed
- HT Winkler, GTI U-Gas, KRW

Sprouting Bed
- British Coal, Foster Wheeler

Entrained Flow
- Mitsubishi

Transport Reactor
- KBR

ENVIRONMENTAL CONTROL

Particulate Removal and Recycle
- Filtration, Water Scrubbing

Chloride and Alkali Removal
- Water Scrubbing

Acid Gas Removal
- Amine Processes
- Rectisol, Selexol

COS Hydrolysis

Sulfur Recovery
- Claus Process
- SCOT Process
- Sulfuric Acid Plant

Water Treatment
- Process Water, BFW

Tail Gas Treating

Turbine NOx Control
- Nitrogen/Steam Dilution
- SCR

Syngas Mercury Capture

Syngas CO_2 Capture

ENERGY CONVERSION

- Gas Turbine
- Heat Recovery Steam Generator (HRSG)
- Steam Turbine
- Boiler
- Syngas Conversion to Fuels & Chemicals
- Catalytic Conversion
- Shift Conversion
- Fischer-Tropsch
- Fuel Cell
- H_2 Turbine

PRODUCTS

- Steam
- Electric Power
- Liquid Fuels
- Chemicals
- Methanol
- SNG
- Hydrogen
- Ammonia/ Fertilizers
- Slag
- Sulfur/ Sulfuric Acid

Commercial IGCC Plants

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Commercial IGCC Plants in the U.S.

Active and Under Construction

Wabash River Coal Gasification Repowering Project

262 MWe coal/petcoke (1995 - present)

Tampa Electric Polk Power Station

250 MWe coal/petcoke (1996 - present)

Duke Energy's Edwardsport Integrated Gasification Combined Cycle Station

618 MWe coal (2013 - present)

Mississippi Power's Kemper County Energy Facility

582 MWe Mississippi lignite (2015 - in service)

Wabash River IGCC

SG Solutions – West Terre Haute, Indiana

Plant startup July 1995

E-Gas gasifier
CB&I

2,500 tons/day coal or petcoke

Bituminous coal
1995 thru August 2000

Petcoke
2000 thru Present

DOE CCT Round IV
Repowering project

Power generation

Combustion turbine:	192 MWe
Steam turbine:	105 MWe
Internal load:	-35 MWe
Net output:	**262 MWe**

Wabash River IGCC Plant Aerial Photo

Polk Power Station Unit 1

Tampa Electric Co. – Mulberry, FL

GE Gasifier
Oxygen blown
Slurry fed
Entrained flow
Refractory lined
Feedstock 2,200 tons/day
Coal and petcoke blend
CT is GE 7F
Single train configuration
One gasifier supplying one CT
Acid gas removal via
MDEA and COS hydrolysis
DOE Clean Coal Technology Program
Plant startup July 1996

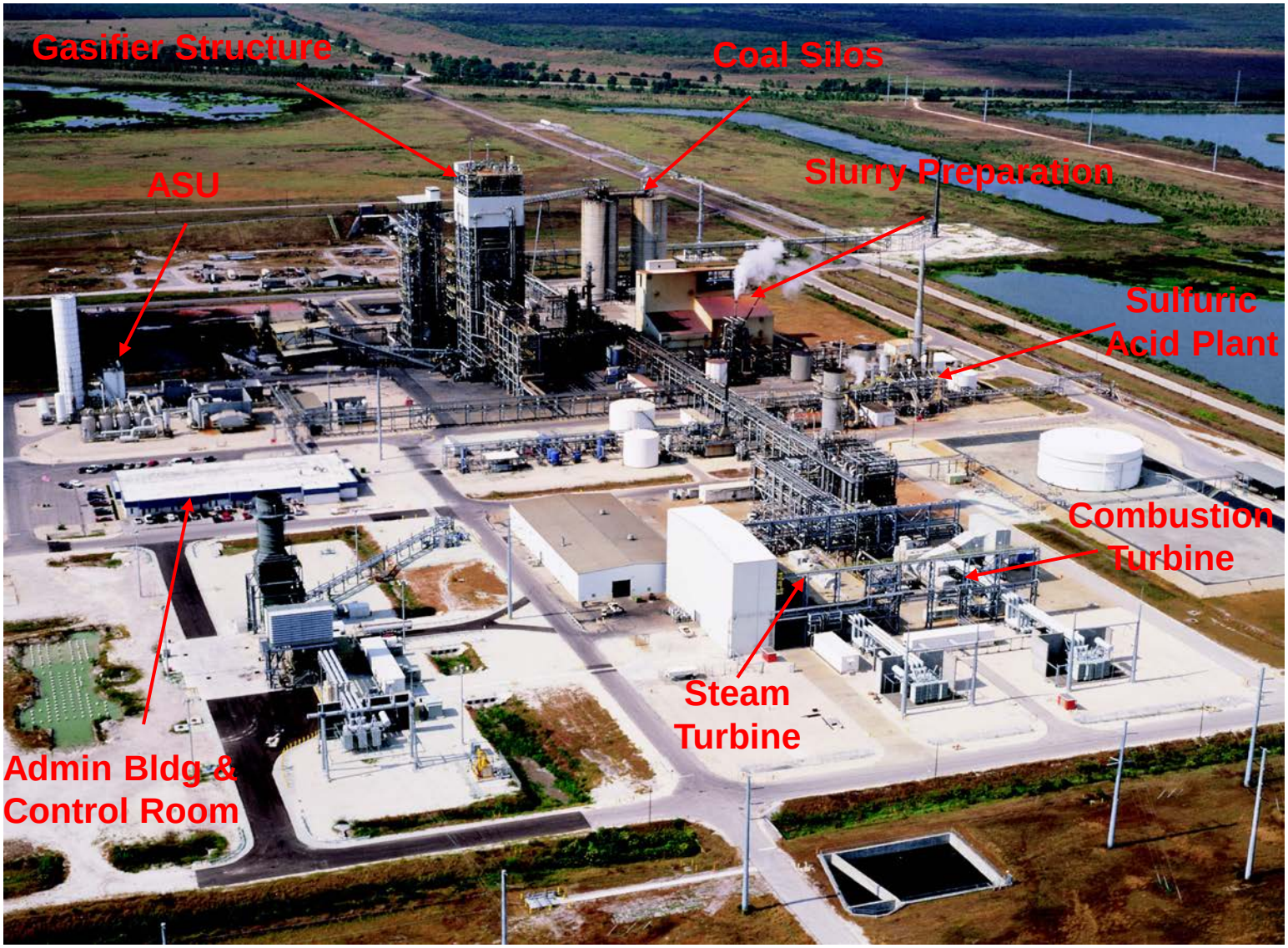
Polk Power Station, Unit

Power generation

Combustion turbine:	192 MWe
Steam turbine:	123 MWe
Internal load:	- 55 MWe
Other auxiliaries:	- 10 MWe
Net output	**250 MWe**

Courtesy: Tampa Electric Co.

Polk Power Station Aerial Photo



Edwardsport 618 MW IGCC Project

Duke Energy

2 x GE Gasifier

2 x GE 7 FB combustion turbines

232 MWe each

GE steam turbine

320 MWe

1.5 million tons of coal per year

Total project cost:

$ 3.5 billion

$133.5 million Federal investment tax credit award

$460 million in local, state and federal tax incentives

Start up /Commercial Operation: June 2013

Gasifier being installed at Duke Energy's Edwardsport Station

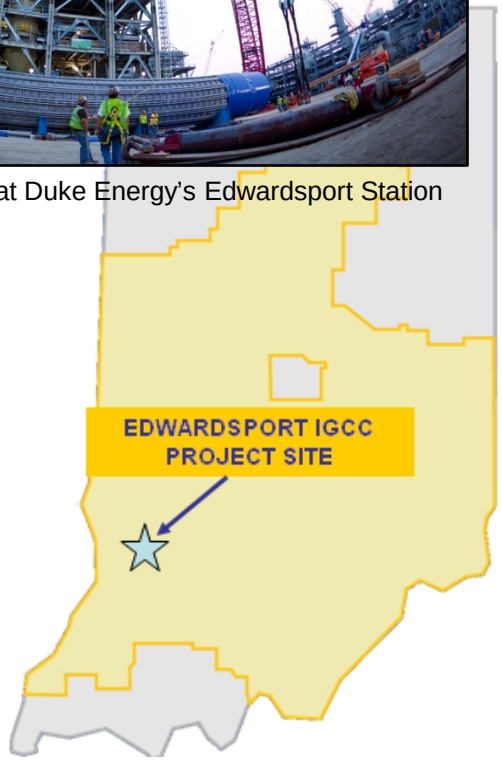


Image courtesy of Duke Energy Indiana

ELCOGAS

Puertollano, Spain

IGCC Plant Puertollano, Spain

PRENFLO gasifier

Pressurized entrained flow
gasifier now offered by Uhde

Oxygen blown

2,600 tons/day coal and petcoke

Commercial operation began in 1996 with natural gas

In 1998 began operating on 50/50 petcoke / local Spanish coal (~ 40% ash)

Siemens V94.3 gas turbine

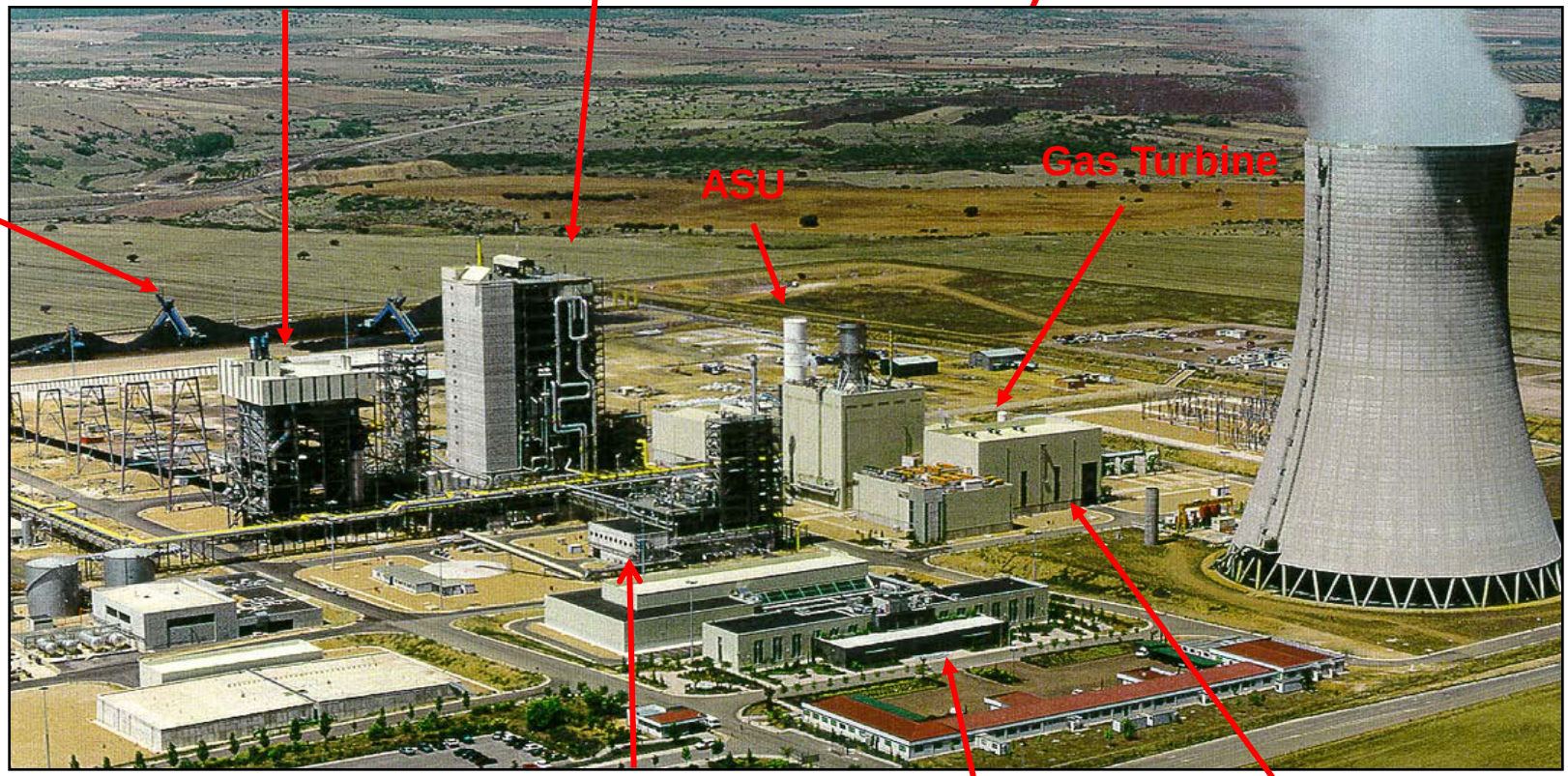
Independent power project without a power purchase agreement (PPA)

Power generation

Combustion turbine	182.3 MWe
Steam turbine	135.4 MWe
Internal load	- 35.0 MWe
Net output	282.7 MWe

Source: "Integrated gasification combined cycle technology: IGCC – Its actual application in Spain: ELCOGAS, Puertollanl" Manuel Treviño Coca
Image Source: www.elcogas.es/shared/enter_img2_r1_c1.jpg

ELCOGAS Plant Aerial Photo



Vresova IGCC Power Plant

Vřesová, Czech Republic

1970 Town Gas Production

1996 Converted to IGCC

26 Lurgi Gasifiers

Entrained flow

Dry coal feed - Lignite

1 Siemens SFG-200

Entrained

Added 2007

Oxygen blown – Full quench

Feedstock: Phenols, tars, petrol, etc. created during gasification

2 GE Combustion turbines

FRAME 9 E (9171 E)

ABB ES Steam turbine

Vřesová IGCC Plant, Czech Republic

Power generation

Combustion turbine:	309 MWe
Steam turbine:	114 MWe
Internal load:	- 25 MWe
Net output:	398 MWe

http://www.gasification.org/Docs/2005_Papers/05CHHO.pdf

Nuon Power Buggenum (Willem Alexander Centrale)

Buggenum, The Netherlands

Shell Gasification

Offered jointly with Krupp Uhde

Gas turbine: Siemens V94.2

2,000 tons/day feedstock

Bituminous coal

Biomass

Plant operated 1993

Power generation

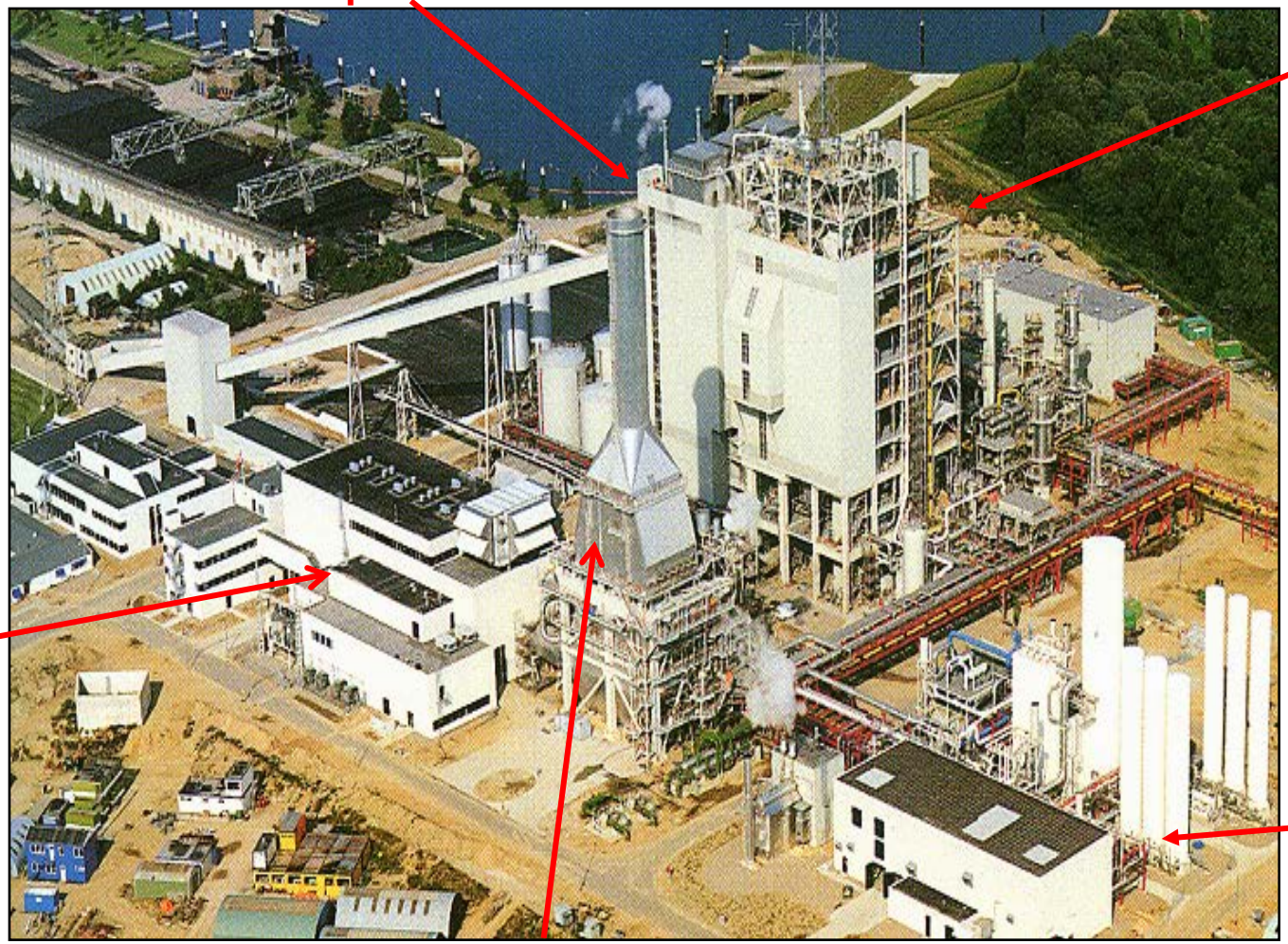
Combustion turbine:	155 MWe
Steam turbine:	128 MWe
Internal load:	- 30 MWe
Net output:	253 MWe

Buggenum IGCC Plant

Plant shut down April 2013 for economic reasons

http://www.gasification.org/Docs/2005_Papers/05CHHO.pdf

Nuon Plant Aerial Photo



Note: Sulfur Removal & Recovery (out of view)

Courtesy: Nuon

Clean Coal Power R&D IGCC Demonstration Plant

Nakoso, Japan

Mitsubishi Gasifier

- 250 MWe
- Air-blown
- Entrained flow
- Dry coal feed

1,700 tons/day coal

- Suited to wide range of coals

Water wall structure

Gas clean-up

- MDEA chemical absorption

Plant startup September 2007

Clean Coal Power R&D

Joint project of

- Mitsubishi Heavy Industries,
- Ministry of Economy, Trade and Industry, and
- Several EPC companies

Clean Coal Power R&D IGCC Demonstration Plant

Aerial Photo

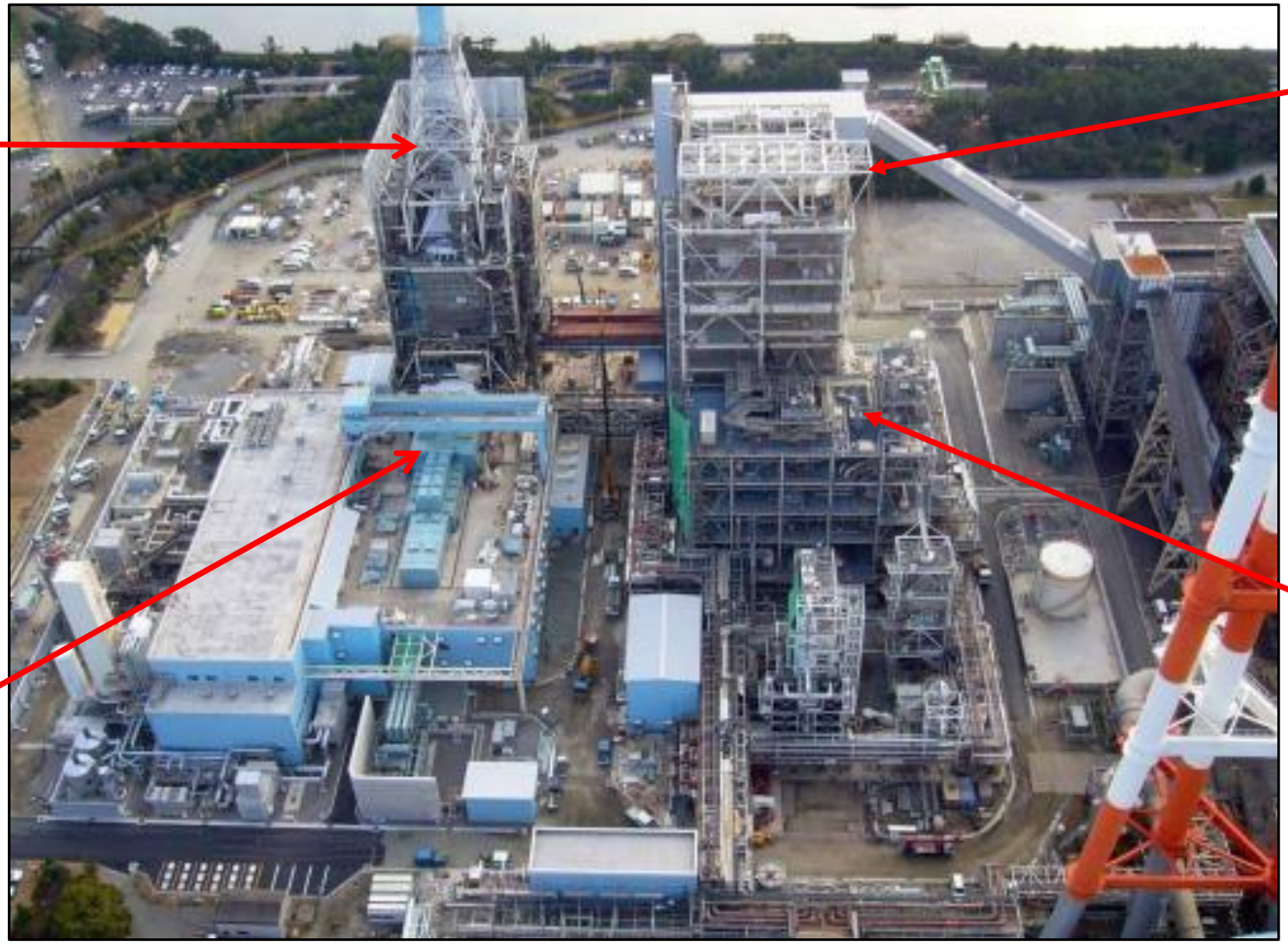


Photo: BLOOMBERG NEWS

Huaneng GreenGen Advanced IGCC

Tianjin, China

Phase I *(Complete) - Design, construct, and, operate IGCC power station*

250 MW IGCC

Gasifier: China Huaneng

Gas Turbine: SIEMENS

Steam Turbine: Shanghai Electric

Fuel: coal dry feed, 2000 tonnes/day

Net efficiency: 41%

SO_X: < 1.4 mg/Nm^3

NO_X: < 80 mg/Nm^3

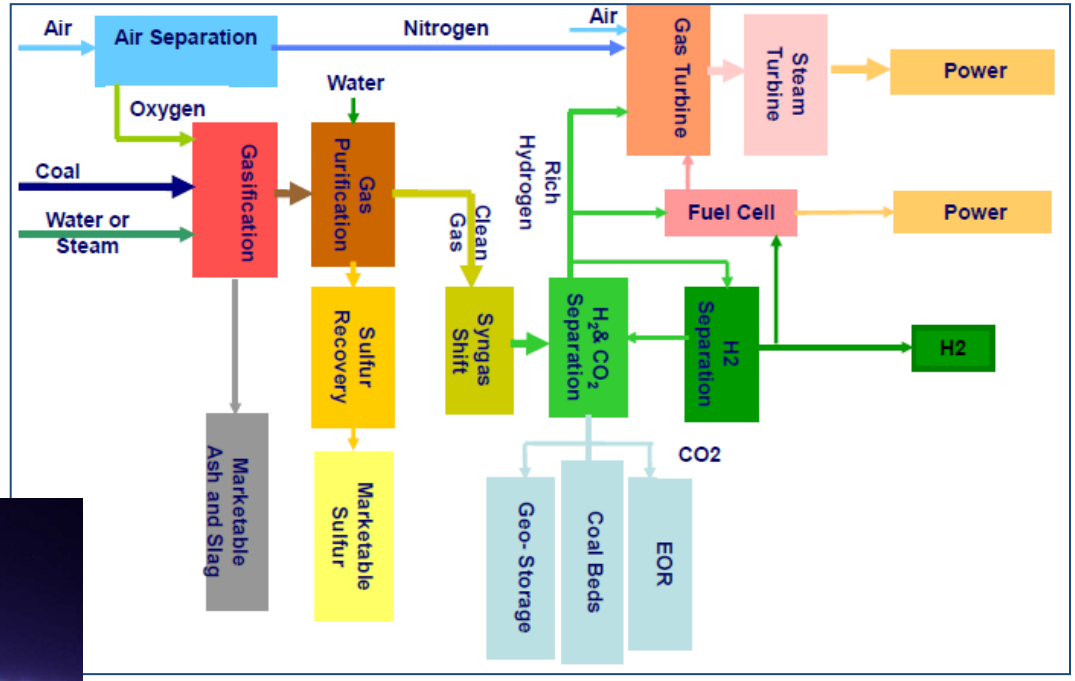
PM: < 1.0 mg/Nm^3

Phase II *(2013-2017) Slipstream demonstration*

Carbon capture facility, 10,000 tonnes/yr

Fuel cell power system, 100-200kW

Hydrogen separation membrane system, 200 m^3/hr



Phase III *(2018-2025) - 400MW with H_2 production, fuel cell power generation, H_2 turbine combined cycle and carbon capture for EOR and storage*

IGCC Plants in the U.S.

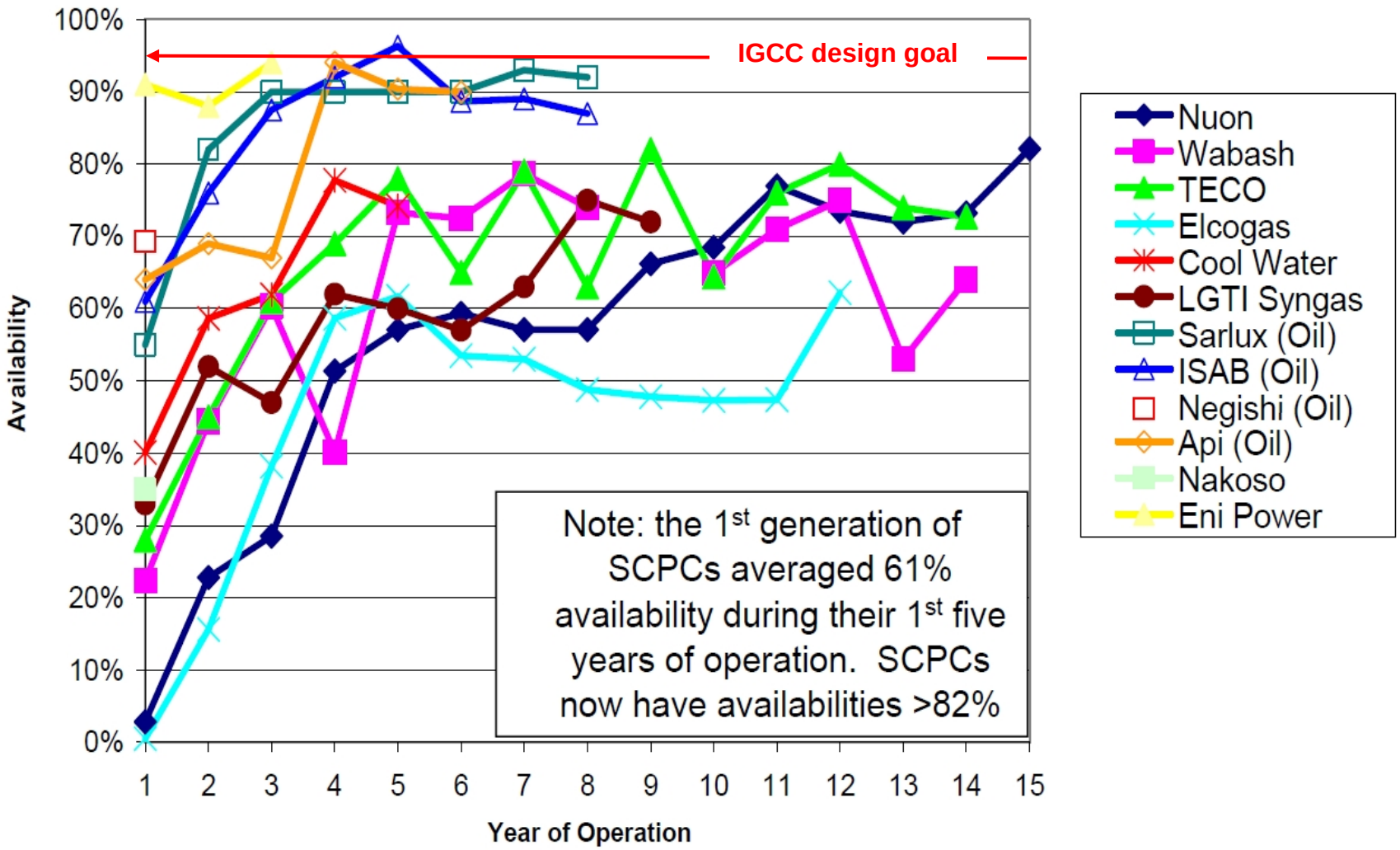
No Longer Operating

Southern California Edison's Cool Water Coal Gasification Plant
100 MWe coal (1984-1988)

Dow Chemical's Louisiana Gasification Technology Inc (LGTI) Project
160 MWe coal (1987-1995**)**

Valero Delaware City Refinery's Delaware Clean Energy Cogeneration Project
160 MWe (& steam) petcoke (2002 – 2009)

IGCC Availability History



Excludes impact of operation on back-up fuel

Source: Dr. Jeff Phillips Sr. Program Manager, Advanced Coal, EPRI
http://www.gasification.org/uploads/downloads/Workshops/2010/02phillips%20-%20IGCC%20101e.pdf

Closing

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Benefits of Gasification Technology

Feedstock flexibility

Wide range of coals, petcoke, liquids, wastes, biomass can be utilized

Product flexibility

Syngas can be converted to high valued products: electricity, steam, hydrogen, liquid transportation fuels, chemicals, SNG

Environmental superiority

Pollutants (SO_2, NO_X, CO, Hg, etc.) can be economically controlled to extremely low levels

Reduced water consumption

Potential solid wastes can be utilized or easily managed

High efficiency / low CO_2 production

CO_2 can be easily captured for sale or geologic storage (sequestration)

… the Benefits

GASIFICATION

Stable, affordable, high-efficiency energy supply with a minimal environmental impact

Feedstock Flexibility/Product Flexibility

Flexible applications for new power generation, as well as for repowering older coal-fired plants

BIG PICTURE

Energy Security -- Maintain coal as a significant component in U.S. energy mix

A Cleaner Environment (reduced emissions of pollutants)

The most economical technology for CO_2 capture

Ultra-clean Liquids from Coal -- Early Source of Hydrogen

Gasifipedia

For more information on gasification projects supported by the U.S. Department of Energy: Search the internet for "Gasifipedia"

It should be your first hit

Visit NETL Gasification Website

http://www.netl.doe.gov/research/coal/energy-systems/gasification

COAL GASIFICATION SYSTEMS

Research > Coal > Energy Systems

- News
- Gasifipedia
- Gasifier Optimization
- Feed Systems
- Syngas Processing
- Systems Analyses
- Gasification Plant Databases
- International Activity
- Program Plan
- Project Portfolio
- Project Information
- Publications
- Coal Gasification Magazine
- Solicitations
- Conferences and Workshops
- MFIX
- FAQs

Coal Gasification is a process that can turn coal into clean power, chemicals, hydrogen and transportation fuels, and can be used to capture the carbon from the coal for storage or for enhanced oil recovery. To better understand the basic concepts behind Gasification, watch this short video: What is Gasification? The Gasification Systems Program is developing advanced technologies to reduce the cost and increase the efficiency of producing coal syngas. **Click on the Graphic** for more information on key research and development areas, on how systems analysis supports the program, and for information on the benefits of gasification.

Other Gasification Systems Program Activities: Gasification Systems Program coordinates and works with other DOE programs, national laboratories, and private organizations to ensure that gasification R&D dovetails well with other R&D efforts, and to ensure efficient technology development with minimum cost to the taxpayer. Other program activities include; educating the public about gasification and ongoing contacts and discussions with the public and industry concerning what the future of gasification should be.

Your Comments: We hope the information provided in these Web pages proves of value. We welcome any comments, suggestions, or questions you might have. Click to contact us with Comments, Suggestions, or Questions.

- Program Presentations
- Closely Aligned Carbon Capture & Storage and Power Systems Programs
- Major Partner Test Sites
- Major Gasification Projects