Technology Innovation and Development — The Process of Achieving a Sustainable Energy Future

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Why Hydrogen?
It’s abundant, clean, efficient, and can be derived from diverse domestic resources.
Drivers of Technology Development

- Acid Rain
  - Clean Air Act
  - Joint Report of Special Envoys
  - Clean Air Act Amendments
  - Prevention of Significant Deterioration Regulations (PSD)

- Clean Hydrogen/Dirty Hydrogen
  - Energy Security
  - Economy
  - Environment
    - Clear Skies Initiative
    - Global Climate Change Initiative
    - FreedomCAR

Clean Coal Technology

Hydrogen Fuel Initiative/FutureGen
Eliminating Acid Rain

- Clean Air Act Amendments (CAAA) require major reduction in SO$_2$, near elimination in 21$^{st}$ century
- Advanced systems redefined state-of-the-art in scrubber technology. These systems can:
  - Cut capital and operating costs nearly in half
  - Produce valuable by-products
  - Mitigate plant efficiency losses
  - Capture multiple air pollutants
- A portfolio of technologies available:
  - Advanced scrubbers
  - Low capital cost sorbent injection systems
  - Clean high energy density fuels
Eliminating Acid Rain

- **Investment:**
  - Between 1979 and 2000, over $223 million invested

- **Return:**
  - FGD technology costs one-third of what it did in the 1970s
  - More than 400 commercial deployments of FGD systems
  - SO\(_2\) emissions at utilities declined from 4.4 pounds per million Btu coal burned in 1970 to 1.1 pounds per million Btu coal burned in 1977 – a 75% reduction
  - Combined direct economic benefit from lower cost FGD technology and resulting environmental improvement estimated at over $50 billion through 2005

- **Result** – acid rain no longer a barrier to coal use
Taking On Smog

- Prior to clean coal technologies, nitrogen oxide control systems not proven in U.S. economy
- Portfolio of cost-effective regulatory options now exists for full range of boiler types that have:
  - Provided real time data for formulating regulations
  - Formed foundation for meeting emission limits into the 21st century
  - Positioned U.S. industry to export NO\textsubscript{x} control technology
- Clean coal technologies include:
  - Low-NO\textsubscript{x} burners
  - Reburning systems
  - Selective catalytic reduction
  - Selective non-catalytic reduction
  - Artificial intelligence controls
Taking On Smog

- **Investment:**
  - Between 1987-1999 nearly $100 million invested — 44% DOE and 56% private

- **Return:**
  - 75% of existing coal fired units have or are currently being retrofit with low-NO\textsubscript{x} burners
  - SCR technology now costs half of what it did in 1980, 30% of U.S. coal fired capacity with or about to have SCR units
  - A projected 60 million ton reduction in U.S. NO\textsubscript{x} emissions from 1970 through 2005
  - Combined direct economic benefit (both lower cost and environmental improvement) estimated at $25 billion through 2025
Pollution Reduction at Coal-Fired Power Plants

**Successes to date:** pollutant emissions per unit of coal burned have decreased significantly.

**Challenges for the future:** increased coal use has brought pressure to reduce emissions further (e.g., Clear Skies Initiative).

**Average rate of pollutant emissions from U.S. coal-fired power plants:**
- PM: 0.5 lb/MM Btu coal burned (1970), 0.03 lb/MM Btu coal burned (1997), 0 lb/MM Btu coal burned (2005)

**Coal use for power generation in the U.S.:**
- 1970: 7.2 Q EJyr
- 1997: 18.8 Q EJyr
- 2005 (projected): 22.1 Q EJyr
Tampa Electric (TECO) Clean Coal Project
A New Path to Clean Air

TECO’s coal-to-gas plant in Polk County, Florida, is the pioneer of a new type of clean coal plant.

- **SO₂**
  - Older Coal Plant: 2.07
  - Fleet Avg.: 1.2
  - TECO CCT Plant: 0.1
  - Older Coal Plant: 0.6 to 1.2

- **NOₓ**
  - Older Coal Plant: 0.47
  - Fleet Avg.: 0.07 (15 ppm)
  - TECO CCT Plant: 0.07
Wabash River Clean Coal Project
A Case Study for Cleaner Air

The Wabash River Plant in Terre Haute, Indiana, was repowered with gasification technology.

- **SO₂**: Before CCT - 3.1, After CCT - 0.1
- **NOₓ**: Before CCT - 0.8, After CCT - 0.15
Vision for Energy Plants of the Future

- Remove environmental concerns associated with the use of fossil fuels for production of electricity, transportation fuels, and chemicals through technology

- Characteristics of future energy plants
  - “Near-zero” emissions (coal as clean as gas)
  - CO₂ sequestration-ready
  - Flexible (feed stocks, co-products, siting)
  - Highly energy efficient
  - Affordable (competitive with other energy options)
  - Industrial Ecology (waste into by-products)
  - Reduced water requirements
  - Timely deployment of new technology
  - Sustainable

Electricity
Hydrogen
Chemicals
FutureGen

- Produce electricity and hydrogen from coal using advanced technology
- Emit virtually no air pollutants
- Capture and permanently sequester CO₂

Addresses three Presidential initiatives:
- Hydrogen
- Clear Skies
- Climate Change
Why FutureGen is Needed

- FutureGen is a key step to creating a zero-emissions coal energy option
- FutureGen will enable us to:
  - Meet our growing energy needs with zero-emissions coal
  - Secure this country’s economic and energy future through the clean use of coal, our most abundant, strategic, domestic energy resource
  - Remove all environmental concerns over coal’s use, including climate change concerns, by sequestering carbon dioxide emissions from coal power plants
  - Produce clean low-cost hydrogen with zero emissions for power generation or for transportation
- Integration of concepts and components is the key to proving the technical and operational viability
FutureGen Project Concept

- **Coal Gasification-Based Power**
  - **Geological Sequestration**
  - **Enhanced Oil Recovery**

- **Electricity**
- **Hydrogen Pipeline**
- **CO₂ Pipeline**

- **Oil Pipeline**
- **Refinery**
Key Goals of FutureGen

- Verify effectiveness, safety, and permanence of carbon sequestration
- Establish standardized technologies and protocols for CO$_2$ measuring, monitoring, and verification
- Gain domestic and global acceptance for FutureGen concept
- Validate engineering, economic, and environmental viability of coal-based, near-zero emission technologies that, by 2020, will —
  - Produce electricity with < 10% increase in cost compared to non-sequestered systems
  - Produce H$_2$ at $4/\text{MMBtu}$ wholesale price ($0.48 /\text{gal} \text{ gasoline eq.}$) compared to today’s price of $0.70/\text{gal} \text{ gasoline eq.}$
Features of the Project

- Coal-fueled gasification process that produces electricity and hydrogen – 275 MWe [net equivalent output]
- Commercial scale of 1 million tons per year of CO$_2$ captured and sequestered
- Total project cost estimated at $1 billion
- Cost-shared by U. S. Department of Energy [maximum 80%] and industry [minimum 20%]
- Open to international participation through the Carbon Sequestration Leadership Forum
FutureGen Systems

Oxygen Separation

Gasification

Gas Cleaning

Fuels and Chemicals

Coal

By-Products Utilization

H₂/CO₂ Separation

CO₂ Sequestration

Transportation (fuel cell vehicles)

CO₂

Power

Fuel Cell

High Efficiency Turbine

Electricity

Coal Seams

Saline Reservoir

Enhanced Oil Recovery

O₂

e⁻
Boosting Power Plant Efficiencies
First Step Toward Reducing GHG Emissions

- Today’s Coal Plant
- Initial Plant
- Adding Fuel Cell/Turbine
- Adding Co-Product Production

FutureGen Plant

2015
RD&D to Meet Technology Challenges

<table>
<thead>
<tr>
<th>Traditional Advanced Technology</th>
<th>Research Inventions</th>
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<tbody>
<tr>
<td>Cryogenic Separation</td>
<td>O₂ Membranes</td>
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<td>Amine Scrubbers</td>
<td>Hydrogen Membranes</td>
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<tr>
<td>Amine Scrubbers</td>
<td>“Clathrate” CO₂ Separation</td>
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<tr>
<td>Gas Stream Cleanup</td>
<td>“Dirty” Shift Reactor</td>
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<tr>
<td>Syngas Turbine</td>
<td>Hydrogen Turbine</td>
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<tr>
<td>Fuel Cell ($4,000/kW)</td>
<td>SECA Fuel Cell ($400/kW design)</td>
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<tr>
<td>EOR-based</td>
<td>Sequestration Technology (including <em>in situ</em> CO₂ monitoring)</td>
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<td>Existing Gasifier</td>
<td>Advanced Transport Reactor</td>
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<tr>
<td>System Integration</td>
<td>“First-of-a-Kind” System Integration</td>
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<tr>
<td>Plant Controls</td>
<td>“Smart” Dynamic Plant Controls &amp; CO₂ Management Systems</td>
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Why Coal?

- Abundant reserves
- Low and stable prices
- Technology improvements
  - Could enable near-zero emissions of air pollutants/GHGs

U.S. Fossil Fuel Reserves/Production Ratio

- Coal: 246 years
- Oil: 11.7 years
- Natural Gas: 9.2 years

Sources:
- EIA-U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves: 2001 Annual Report, November 2002;
The Hydrogen from Coal Program

FutureGen

Gasification
Fuel Cells

Production

Shifting
• Catalysts
• Reactors

Synthesis Gas-Derived Hydrogen-Rich Liquid Fuels
• Fuels Reforming
Catalysts/Reactors

Separations
• Advanced Hydrogen Separation
• Advanced CO₂ Separation
• Absorption/Solvent Systems

Polishing Filters (for ultra-clean hydrogen production)

Advanced Concept
• Combined WGS and H₂ separation with gas cleanup

Delivery

Hydrogen & Natural Gas Mixtures
• Define feasible, low-cost delivery routes

Storage

Carbon Nanotubes

Other Storage

Utilization

Engines
• Hydrogen/Natural Gas Mix

Polishing Filters (for ultra-clean hydrogen production)

Computational Science and Modeling – Supporting Sciences
Hydrogen from Coal

A. Gasifier Optimization
   • Gasifier modification for hydrogen

B. Hydrogen Production
   • Shift reactors for hydrogen
   • Low-cost conversion
   • Gas polishing

C. Hydrogen Separation
   • Impurity-tolerant membranes
   • Advanced separations

D. Hydrogen Quality & Utilization
   • Hydrogen cleanup and tailoring as needed to meet market requirements
   • High-quality hydrogen for fuel cells and pipelines
   • Advanced high density, safe storage, and transport
   • Technology/Systems
Hydrogen from Coal Program
Components and Product Areas

Coal (CH) → Gasification

Synthesis Gas: CO, CO₂, H₂, H₂O, SO₂

Ash/Slag → Gas Cleaning

Sulfur Particulates

Depleted Air → HRSG/ST Power

H₂O → SOFC

H₂O

CO/H₂ → Water Gas Shift & Membrane Separation

CO₂ → Syngas Conversion

F-T CH₃OH

Air → Combustion Turbine

HRSG/ST Power → CO₂ Sequestration

H₂ → Reforming

H₂ Storage

CO₂ Sequestration

Key:

Gasification
IEP/Coal Utilization By-Products
Fuel Cells ATS
CO₂ Sequestration
Coal Fuels & Hydrogen
Climate Change —
Why is Sequestration Important?

- May be only option that removes enough carbon to stabilize CO₂ concentrations in atmosphere
- Only approach that doesn’t require countries to overhaul energy infrastructures
- May prove to be lowest cost carbon management option

The FutureGen plant will be a first-of-its-kind project by the U.S. electric power industry to prove that large-scale sequestration is safe and practicable
CO₂ Capture and Storage
Develop Technology Options for GHG Management Team

- Technologies must be safe and environmentally acceptable
- They should result in:
  - <10% increase in cost of energy services (<$10/ton CO₂ avoided) for capture, transport, and storage
  - Measurement, Monitoring, & Verification protocols for assurance of permanent storage
- Support the Global Climate Change Initiative
  - Contributes to reducing carbon intensity by 18% by 2012
  - Provides portfolio of commercially ready technologies for 2012 assessment

### Cost Performance Goals

<table>
<thead>
<tr>
<th>Year</th>
<th>COE Penalty IGCC Plants (% Increase)</th>
<th>COE Penalty PC Plants (% Increase)</th>
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<tr>
<td>2002</td>
<td>30</td>
<td>80</td>
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<td>2007</td>
<td>20</td>
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<td>2012</td>
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U.S. Carbon Sequestration Program

Core R&D
- Capture CO₂
- Measurement Monitoring & Verification
- Non-CO₂ GHG Mitigation
- Breakthrough Concepts

Integration
- FutureGen
  Integrated Sequestration, Hydrogen and Energy Research Initiative

Infrastructure
- Regional Partnerships
  - Engage regional, state, local government entities
  - Determine benefits of sequestration to region
  - Baseline region for sources and sinks
  - Establish monitoring and verification protocols
  - Address regulatory, environmental, & outreach issues
  - Test sequestration technology at small scale
Carbon Sequestration Roadmap

Regulatory Approval and Compliance, Acceptance in GHG Trading Context

MMV R&D
- Ecosystem health
- Soil carbon measurement
- Subsurface transport, monitoring and modeling
- Surface leak detection

Regional Partnerships
- Baseline
- Infrastructure
- Stakeholders

Sequestration Field Tests

Capture R&D
- CO₂ storage optimization
- Site assessment capability
- Storage permanence
- Untested formation types

Sequestration R&D
- Chemical sorbents
- Physical sorbents
- Electrochemical pumps
- Membranes

Pilot-scale CO₂ Capture Tests

Integration of CO₂ Capture and Storage

Breakthrough Concepts
- Advanced capture
- Subsurface conversion
- Niche opportunities

Commercially Ready Sequestration Systems

Integration of CO₂ Capture with SOₓ, NOₓ, and Hg Control
Carbon Sequestration Program

A. Sequestration R&D
- CO₂ storage optimization
- Site assessment and best practices
- Storage permanence
- Untested formation types

B. Capture R&D
- Chemical & physical sorbents
- Membranes
- Oxyfuel combustion
- Chemical looping

C. Measurement, Monitoring, & Verification
- Ecosystem health
- Soil carbon measurement
- Subsurface transport, monitor/model
- Surface leak detection

D. Breakthrough Concepts
- Advanced capture/conversion
- Niche opportunities

E. Regional Partnerships
- Baseline/Infrastructure/Outreach
- Technology validation & deployment
Seven Regional Carbon Sequestration Partnerships
Carbon Sequestration Leadership Forum

- Forum for planning international multi-lateral sequestration projects including FutureGen
- Ministerial-level representatives
- Other nations invited to first meeting, June 2003 in Washington, DC

**Benefits of international involvement in FutureGen**
- Enrich intellectual talent pool
- Maximize global applicability and acceptance
- Leverage funds
- Help build consensus on climate change
International Partnership for the Hydrogen Economy (IPHE)

Secretary Abraham – Paris, France, April 28, 2003

“So, tonight, I would like to propose an International Partnership for the Hydrogen Economy”

The Partnership would:

- Develop common codes and standards for hydrogen fuel utilization
- Establish cooperative efforts to advance the research, development, and deployment of hydrogen production, storage, transport, and end-use technologies
- Strengthen exchanges of pre-competitive information necessary to build the kind of common hydrogen infrastructures necessary to allow this transformation to take place
- Formalize joint cooperation on hydrogen R&D to enable sharing of information necessary to develop hydrogen-fueling infrastructure
“The vision of the International Partnership for the Hydrogen Economy is that a participating country’s consumers will have the practical option of purchasing a competitively priced hydrogen power vehicle, and be able to refuel it near their homes and places of work, by 2020.”

Secretary of Energy Spencer Abraham
April 28, 2003
### International Partnership for Hydrogen Economy

#### The Partners

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**IPHE Partners’ Economy:**
- Over $35 trillion in GDP, 85% of world GDP
- Nearly 3.5 billion people
- Over 75% of electricity used worldwide
- Greater than two-thirds of CO₂ emissions and energy consumption
Conclusion

Clean Hydrogen From Coal
via Technology Innovation
and/or Development
Is a Reality