Zero Emission Carbon (ZEC)
Hydrogen and Carbon Dioxide Production Concepts
# ZEC Potential – Why the technology is so interesting.

<table>
<thead>
<tr>
<th>Items</th>
<th>Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency, HHV %</td>
<td>68.9</td>
</tr>
<tr>
<td>Total Plant Cost, $/kWe</td>
<td>1,518</td>
</tr>
<tr>
<td>Cost of Electricity (COE), $/kWh</td>
<td>0.0432</td>
</tr>
<tr>
<td>Tons of CO$_2$ Sequestered per Year per MWe</td>
<td>4,090</td>
</tr>
<tr>
<td>COE, $/kWh with Sequestration at $20/ton of CO$_2$</td>
<td>0.054</td>
</tr>
</tbody>
</table>

600 MWe Conceptual Power Plant with High Temperature Fuel Cells

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ZEC Power Generation Concept

Enhanced Oil Recovery
Coal Bed Methane
Saline aquifers

Mineral Sequestration

Gasification

Carbonation

Calcination

Fuel Cell

Coal

H₂O (steam)

H₂O (steam)

CaCO₃

CaO

CO₂

CO₂ disposal

Gas Cleanup, Particulates, SOₓ

H₂O (Used as control)

CH₄, H₂O

Polishing Step (as needed)

H₂

H₂

H₂

N₂

Air

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Hydrogasification

\[ \text{C} + 2\text{H}_2 \rightarrow \text{CH}_4 \uparrow + \text{heat} \]

\[ \text{H}_2 \text{ Production, CO}_2 \text{ removal} \]

\[ \text{CH}_4 + 2\text{H}_2\text{O} + \text{CaO} \rightarrow \text{CaCO}_3 \downarrow + 4\text{H}_2 \]

Reforming Energy from

\[ \text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3 \]

Power Production

\[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{heat} + \text{electricity} \]

Pure CO\(_2\) regeneration

\[ \text{CaCO}_3 + \text{heat} \rightarrow \text{CaO} + \text{CO}_2 \uparrow \]
The Hydrogen Screening Study

Concept 1, the ZECA hydrogasification process is used to produce a synthesis gas, hydrogen and \( \text{CO}_2 \) from the oil sand coke in the presence of calcium oxide (lime).

Concept 2, a partial oxidation gasification process (Texaco, Shell, or Global Energy types) is used to produce the synthesis gas. The synthesis gas is then chemically shifted to form \( \text{H}_2 \) and \( \text{CO}_2 \). The gas treatment and hydrogen separation are conventional commercial technologies.

Concept 3, the ZECA hydrogasification process is used to produce a methane-rich synthesis gas, which is converted to hydrogen via commercial steam reforming techniques.
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Summary of Results

• ZEC Technology Hydrogen Costs About 30% Less Than For Traditional Gasification With Hydrogen Production. Both Concepts Include CO₂ Separation.

• ZEC Technology is Competitive With Traditional Steam Methane Reforming at a Natural Gas Feed Price of US$4.50 per MMBtu or Less.

• ZEC Technology is Less Mature Than Traditional Gasification and Requires Significant Test and Development. Neither Version Has Been Demonstrated for CO₂ removal and Hydrogen Production.
Concept 1, ZEC Hydrogen Production with Lime CO₂ Capture
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Concept 3, Hydrogasification With Water-Gas Shift

FEEDSTOCK STORAGE AND PREPARATION

PARTICULATE REMOVAL

RAW SYNTHESIS GAS

RAW SYNGAS WATER-GAS SHIFT

CO₂ REMOVAL (SELEXOL)

CO₂ Compression & Drying

CLAUSS/SCOT PLANT AND TAIL GAS TREATMENT

PRESSURE SWING ADSORPTION (PSA)

POWER GENERATION

PRODUCT HYDROGEN

PLANT & EXPORT POWER

STEAM

H₂S

SULFUR/ H₂SO₄

POWER GENERATION

WATER/ STEAM

TIL GÁS

PSA

SLAG/ASH REMOVAL

HYDROGASIFIER

GASIFIER FEED

P1--
Zero Emission Carbon (ZEC)
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Concept Criteria

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>ZEC Hydrogen Production, Concept 1</th>
<th>Partial Oxidation Gasification, Concept 2</th>
<th>Hydrogasification with Water-Gas Shift, Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Production, TPD</td>
<td>418</td>
<td>418</td>
<td>418</td>
</tr>
<tr>
<td>Hydrogen Production, MMSCF/D</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Coke Input, T/D</td>
<td>2,821</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Operating Capacity</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>
## Summary of Economic Results

### Economic/Financial Conditions
- Cost of Money = 11%
- Investment Duration = 15 years
- Cost of Coke = $5 per ton

### Cost of Hydrogen, $ per MMBtu

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<tr>
<td>$ 4.56</td>
<td>$ 5.81</td>
<td>$ 4.54</td>
<td></td>
</tr>
</tbody>
</table>

| Comparative Cost Ratio       | 0.78                              | 1.00                                     | 0.78                                          |

- Cost of Money = 11%
- Investment Duration = 15 years
- Cost of Coke = $0 per ton

| Comparative Cost Ratio       | 0.77                              | 1.00                                     | 0.77                                          |
Comparison of ZEC and SMR Hydrogen Costs

Cost of SMR Hydrogen Production Versus Natural Gas Feedstock Price Graph

Advantage ZEC

Advantage SMR

ZEC at $4.56 per MMBtu

SMR Natural Gas Cost, $ per MMBtu

Hydrogen, $ per MMBtu

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Future Tests, Development and Engineering

- **Hydrogasification**
  - Reactivity and Carbon Utilization
  - Methanation
  - Heat and Material Balance

- **Reforming and Carbonation**
  - Catalyst Requirements, Availability or Development
  - Reforming Reactions with Coke, Water and Limestone
  - Carbonation Under ZEC Environment

- **Calcination Operation**
  - Heat Transfer Issues
  - Limestone Makeup Requirements

- **Process Design Systems Integration**
  - Hydrogen Recycle and Water/Steam
  - Thermal Energy Source for Calcining
  - Synthesis Gas Cleaning (Hg, S, ?) and Product Gases Treatment
  - Power Generation/Compression Work
  - High Temperature Materials Handling, and other HT Issues
Future Tests and Development

- Hydrogasification
- Reforming and Carbonation
- Calcination Operations

• Laboratory Tests and Equipment Designs
• Modification of Existing Equipment
• Pilot Bench Scale Tests

OBJECTIVES

1. Design Data Specific to Oil Sand Coke, Bitumen, Ores
2. Data for Scale-up to Larger Pilot Plant
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Engineering and Design

- Hydrogasification
- Reforming and Carbonation
- Calcination Operations

- Coordinate Lab Work and Design Requirements
- Integrate Lab Results With Oil Sands Hydrogen Designs, Costs, and Economics
- Communications and Data Collection Re Catalyst and Equipment Suppliers

OBJECTIVES

1. Engineering and Cost for Pilot Plant
2. Engineering Design, Costs and Economics for Commercial Plant

DOE Power Systems Development Facility, Wilsonville

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Other Zero Carbon Information


Other Zero Carbon Information

Anaerobic Hydrogen Production, Precursor to Zero Emission Coal, LA-UR-00-1850, Hans-J. Ziock, Klaus S. Lackner, Douglas P. Harrison.


The work of the project and ZECA Corporation was recognized in the December 2003 issue of Scientific American magazine as the Business Leader in Environment. The work was chosen as one of the SCIENTIFIC AMERICAN 50, which "recognizes the singular accomplishments of those who have contributed to the advancement and technology in the realms of science, engineering, commerce and public policy."

For additional information please visit the ZECA, Los Alamos National Laboratory, Columbia University and Nexant web sites:

http://www.zeca.org/
http://www.lanl.gov/energy/est/zeca/ZECA_Factsheet.pdf
www.nexant.com/services/AdvancedTech/clean-fossil/zero.html
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QUESTIONS, DISCUSSION; The Path Forward