Carbon Capture Technology Options and Costs

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Topics

CO₂ Capture Applied To……..

- **New Coal-fired Power Plants**
  - IGCC → Pre-combustion CO₂ Capture
  - PC → Post-combustion CO₂ Capture

- **Existing Pulverized Coal Power Plants**
  - Post-combustion CO₂ Capture
National Energy Technology Laboratory

- Only DOE national lab dedicated to fossil energy
  - Fossil fuels provide 85% of U.S. energy supply
- One lab, five locations, one management structure
- 1,200 Federal and support-contractor employees
- Research spans fundamental science to technology demonstrations

Alaska

Oklahoma
Oregon
Pennsylvania
West Virginia
Coal-fired Generation CO₂ Forecast
AEO’07 Reference Case

Large Proportion of Total Coal-fired CO₂ From Existing Plants

Existing units 90.1% of cumulative coal-fired CO₂ 2007-2030
(74.6% of year 2030 coal-fired CO₂)
CO₂ Capture Technology Options

- Post-combustion
- Pre-combustion
- Oxycombustion

Amine solvents
Physical solvents
Cryogenic oxygen

Advanced physical solvents
Advanced amine solvents
Ammonia

PBI membranes
Solid sorbents
Membrane systems
ITMs

Ionic liquids
MOFs
Enzymatic membranes
CAR process

Chemical looping
OTM boiler
Biological processes

Cost Reduction Benefit

Time to Commercialization

Present
5+ years
10+ years
15+ years
20+ years
Power Plant Cost Trends

• Power plant construction costs have risen at rates greater than that of inflation in past few years

• Why?
  – Global demand for electricity infrastructure-related items
  – High fuel and labor prices
  – High raw material prices

• Expected to worsen
CERA Power Capital Cost Index (PCCI)

> 80% Increase in Power Plant Capital Cost in past 8 years

Source: http://www.ihsindexes.com/

*Excludes Nuclear
New IGCC
With and Without CO$_2$ Capture
New IGCC Power Plant
No CO₂ Capture

Process Design¹:
Plant: 2 gasifiers, 2 Comb. Turbine, 1 Steam Turbine
Power: ~600 - 650 MW
Oxygen: 95% O₂ via cryogenic ASU
Turbines: Advanced F-Class Turbine
Steam: 1800psig/1050°F/1050°F

¹See Appendix for further design conditions: Coal type, Plant Location, Financial Criteria, etc.


TPD: Short Ton per Day
TPY: Short Ton per Year (at 80% Capacity Factor)
New IGCC Power Plant
With Selexol™ CO₂ Scrubbing

IGCC CO₂ Capture Advantages:
1. High \( P_{CO_2} \)
2. Low Volume Syngas Stream

Selexol™ CO₂ Capture Advantages:
1. Physical Liquid Sorbent
2. Highly selective for \( H_2S \) and \( CO_2 \)
3. \( CO_2 \) is produced at “some” pressure
4. 30+ years of commercial operation (55 worldwide plants)

1See Appendix for further design conditions: Coal type, Plant Location, Financial Criteria, etc.

New IGCC Efficiency

- **Without CO₂ Capture**
  - Existing PC: 25 - 35%
  - New IGCC: 39%

- **With CO₂ Capture**
  - 40% CO₂ Capture: 36%
  - 60% CO₂ Capture: 35%
  - 70% CO₂ Capture: 34%
  - 90% CO₂ Capture: 32%

CO₂ Capture ↓’s New IGCC net efficiency by 3 to 8% pts.

References:
New IGCC Cost of Electricity

Without CO₂ Capture

To Match CA Proposed 1,100 lb/MWh

To Match New NGCC 800 lb/MWh

New IGCC with CO₂ Capture ↑’s Existing PC COE by ~ 5X

References:
New Pulverized Coal

*With and Without CO$_2$ Capture*
New Supercritical PC Power Plant
No CO$_2$ Capture

**Process Design:**
- **Steam:** 3500 psig/1110°F/1150°F
- **NOx:** LNB, OFA and SCR
- **SOx:** Wet limestone FGD
- **PM:** Baghouse

**CO$_2$ Capture Challenges:**
- **Low Pressure:** 14.8
- **Low Concentration:** 13% volume

**CO$_2$ Emissions:**
- 11,635 TPD
- 3,610,323 TPY

TPD: Short Ton per Day
TPY: Short Ton per Year

Reference: Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008
**New Supercritical PC Power Plant**

*Amine Scrubbing CO₂ Capture*

**Process Design:**
- **CO₂ Capture:** 30-90%, compressed to 2,215 psia
- **Balance of Plant:** Oversized to maintain 550 MW net

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**CO₂ Capture Process Flow Diagram in Appendix**

TPD: Short Ton per Day
TPY: Short Ton per Year

Reference: Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008
Alkanolamines for Acid Gas Removal

1. Developed in 1930
   - Triethanolamine (TEA), first commercially available, used in gas treating (H₂S and CO₂ removal)
   - TEA replaced by amine mixtures (MEA, DEA, MDEA) in the 1950’s

2. 2005—Various proprietary formulations offered by: Fluor Daniel, Dow Chemical, UOP/Union Carbide, Huntsman Corp., BASF, EXXON, MHI, Coastal and others.

### Advantages

1. Proven Technology → Remove CO₂ and H₂S from NG
2. Chemical solvent → High loadings at low CO₂ partial pressure
3. Relatively cheap chemical ($2-3/lb)
4. Small scale commercial experience

### Disadvantages

1. High heat of reaction → high regeneration energy required
2. Easily degraded by SOx, NOx, PM
3. Post-combustion capture (for food grade CO₂) is limited and currently at small scale (<200 TPD)
## Amine Scrubbing Experience

**Fluor Econamine FG℠ Commercial Plants (2004)**

<table>
<thead>
<tr>
<th>Owner</th>
<th>Location</th>
<th>Tonne/day</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Liquid Air Australia</td>
<td>Australia</td>
<td>60</td>
<td>Food Industry</td>
</tr>
<tr>
<td>2 Liquid Air Australia</td>
<td>Australia</td>
<td>60</td>
<td>Food Industry</td>
</tr>
<tr>
<td>3 Industrial de Gaseouses Cia. Ltda.</td>
<td>Ecuador</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>4 Pepsi Cola</td>
<td>Philippines</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>5 Pepsi Cola</td>
<td>Philippines</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>6 Cosmos Bottling Co.</td>
<td>Philippines</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>7 San Miguel Corporation</td>
<td>Philippines</td>
<td>40</td>
<td>Food Industry</td>
</tr>
<tr>
<td>8 Indo Gulf Fertilizer Co. (Feed)</td>
<td>India</td>
<td>150++</td>
<td>Urea Plant</td>
</tr>
<tr>
<td>9 Luzhou Natural Gas (Feed)</td>
<td>Sechuan Prov., PRC</td>
<td>160++</td>
<td>Urea Plant</td>
</tr>
<tr>
<td>10 Northeast Energy Associates</td>
<td>Mass., USA</td>
<td>320</td>
<td>Food Industry</td>
</tr>
<tr>
<td>11 Kansei Electric Power Co.</td>
<td>Japan</td>
<td>2</td>
<td>Pilot Plant</td>
</tr>
<tr>
<td>12 Tokyo Electric Power Co.</td>
<td>Japan</td>
<td>5</td>
<td>Pilot Plant</td>
</tr>
<tr>
<td>13 Sumitomo Chem/Nippon Oxygen</td>
<td>Japan</td>
<td>150++</td>
<td>Food Industry</td>
</tr>
<tr>
<td>14 Cervezaria Bavaria</td>
<td>Columbia</td>
<td>25</td>
<td>Food Industry</td>
</tr>
<tr>
<td>15 Prosint</td>
<td>Brazil</td>
<td>90 (2 units)++</td>
<td>Food Industry</td>
</tr>
<tr>
<td>16 Coca Cola</td>
<td>Egypt</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>17 Azucar Liquida SA</td>
<td>Dom. Republic</td>
<td>6</td>
<td>Food Industry</td>
</tr>
<tr>
<td>18 European Drinks Industry</td>
<td>Romania</td>
<td>36</td>
<td>Food Industry</td>
</tr>
<tr>
<td>19 Messer Greisheim do Brazil Ltda</td>
<td>Brazil</td>
<td>50</td>
<td>Food Industry</td>
</tr>
<tr>
<td>20 Messer Greisheim do Brazil/SPAL</td>
<td>Brazil</td>
<td>80</td>
<td>Food Industry</td>
</tr>
<tr>
<td>21 Grupo Walter</td>
<td>Spain</td>
<td>87</td>
<td>Food Industry</td>
</tr>
<tr>
<td>22 Air Products</td>
<td>Singapore</td>
<td>36</td>
<td>Food Industry</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>817</strong></td>
<td></td>
</tr>
</tbody>
</table>

New PC Efficiency

CO₂ Capture ↓’s New PC net efficiency by 4 to 12% pts.

References: Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008
Integrated Environmental Control Model 2008
New PC Cost of Electricity

Without CO₂ Capture

With CO₂ Capture

To Match New NGCC 800 lb/MWh ~ 65% Capture

To Match CA Proposed 1,100 lb/MWh

CO₂ Capture ↑’s Existing COE by ~ 4 — 5X

References:
Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008
Integrated Environmental Control Model 2008
Existing Pulverized Coal
With CO₂ Capture
Key Challenges to PC CO₂ Retrofits

1. Space limitations — acres needed for current scrubbing
2. Major equipment modifications
3. Regeneration steam availability — can steam turbine operate at part load using current scrubbing technology?
4. Sulfur — additional deep sulfur removal required using current CO₂ scrubbing technology
5. Make-up power — satisfy need to maintain baseload output
6. *Water availability
7. *Local storage availability (saline formation, EOR)
8. *Scheduling outages for CO₂ retrofits
9. *Post-retrofit dispatch implications due to increase in COE
10. *Retrofit triggering New Source Review
11. *Proposed legislation

*Analyses on these topics is currently in progress at NETL, beyond the scope of today’s presentation
Case Study: AEP Conesville Unit #5

- Total 6 units = 2,080 MWe
- Unit #5:
  - Subcritical steam cycle (2400psia/1005°F/1005°F)*
  - Constructed in 1976
  - 463 MW gross (~430 MW net)
  - ESP and Wet lime FGD (95% removal efficiency, 104 ppmv)

Mid-western bituminous coal

<table>
<thead>
<tr>
<th>Ultimate Analysis (wt.%)</th>
<th>As Rec'd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>10.1</td>
</tr>
<tr>
<td>Carbon</td>
<td>63.2</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.3</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>2.7</td>
</tr>
<tr>
<td>Ash</td>
<td>11.3</td>
</tr>
<tr>
<td>Oxygen</td>
<td>7.1</td>
</tr>
<tr>
<td>HHV (Btu/lb)</td>
<td>11,293</td>
</tr>
</tbody>
</table>

Existing PC Plant CO₂ Capture Modifications

Conesville Unit #5

**Existing PC Efficiency**

*Same trend as “New Plant”*

<table>
<thead>
<tr>
<th>CO₂ Capture (%)</th>
<th>Net Efficiency (% HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>29%</td>
</tr>
<tr>
<td>50%</td>
<td>27%</td>
</tr>
<tr>
<td>70%</td>
<td>24%</td>
</tr>
<tr>
<td>90%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Without CO₂ Capture: 35%

**CO₂ Capture** ↓’s net efficiency by 3 to 11% pts.

Existing PC Base Load Output Impact

Post CO₂ Retrofit Losses to Grid

<table>
<thead>
<tr>
<th>Unit</th>
<th>Net Output (MW)</th>
<th>CO₂ Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conesville Unit #5</td>
<td>434 MW</td>
<td>Without CO₂ Capture</td>
</tr>
<tr>
<td></td>
<td>392 MW</td>
<td>30% Capture</td>
</tr>
<tr>
<td></td>
<td>363 MW</td>
<td>50% Capture</td>
</tr>
<tr>
<td></td>
<td>333 MW</td>
<td>70% Capture</td>
</tr>
<tr>
<td></td>
<td>303 MW</td>
<td>90% Capture</td>
</tr>
<tr>
<td></td>
<td>42 MW</td>
<td>10% Loss</td>
</tr>
<tr>
<td></td>
<td>71 MW</td>
<td>16% Loss</td>
</tr>
<tr>
<td></td>
<td>101 MW</td>
<td>23% Loss</td>
</tr>
<tr>
<td></td>
<td>131 MW</td>
<td>30% Loss</td>
</tr>
</tbody>
</table>

**Existing PC Cost of Electricity**

**Existing Fleet Retrofit Advantage!**

Retrofit an *Existing* PC Plant up to ~40% CO₂ capture will have **lower** COE than *New PC* Plant w/o Capture

References:  Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008

Integrated Environmental Control Model 2008

<table>
<thead>
<tr>
<th>Cost of Electricity (cents/kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

**No Capture**

- **Conesville Unit #5**
- **New PC**
- **30% CO₂ Capture**
- **50% CO₂ Capture**
- **70% CO₂ Capture**
- **90% CO₂ Capture**

- Make-up power = 6.5 cents/kWh
- Make-up power = 12 cents/kWh
Summary Results Comparison
Power Plant Efficiency Summary

With 90% CO₂ Capture

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>90% CO₂ Capture</th>
<th>No CO₂ Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Efficiency (% HHV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing PC</td>
<td>25-35%</td>
<td></td>
</tr>
<tr>
<td>New SCPC</td>
<td>39%</td>
<td>39%</td>
</tr>
<tr>
<td>New IGCC</td>
<td>39%</td>
<td></td>
</tr>
<tr>
<td>Existing Plant</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>New SCPC</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>New IGCC</td>
<td>32%</td>
<td></td>
</tr>
</tbody>
</table>
Cost of Electricity Summary

With 90% CO₂ Capture

No CO₂ Capture

90% CO₂ Capture

Cost of Electricity (cents/kWh)

Existing PC
New PC
New IGCC
Existing PC
New SCPC
New IGCC

↑’s Existing COE by ~ 3 — 4X

↑’s Existing COE by ~ 5X
CO₂ Capture Summary

1. New Integrated Gasification Combined Cycle
   - For a 600 MW plant, @90% Capture 13,000 TPD or 3.6MM TPY removed
   - One current state-of-the-art technology option is Selexol™
   - CO₂ Capture “Parasitic Load” ↓’s net efficiency by 3 - 8% points
   - Cost of electricity 4 - 5X Existing average pulverized coal fleet cost

2. New Pulverized Coal
   - For a 600 MW plant, @90% Capture 15,000 TPD or 4.3MM TPY removed
   - Current SOA technology is amine-based scrubbing (Econamine, KS-1)
   - CO₂ Capture “Parasitic Load” ↓’s net efficiency by 4 - 12% points
   - Cost of electricity 4 - 5X Existing average pulverized coal fleet cost

3. Existing Pulverized Coal
   - NETL Existing PC Study Concluded that major no technical barriers exist with retrofitting with amine-based CO₂ capture from 30% to 90% removal
   - CO₂ Capture “Parasitic Load” ↓ net efficiency by 3 - 11% points
   - Existing PC plant will lose ~120 MW to grid! (532 MWe Æ 413 MWe)

4. Water usage
   - Existing PC ↑ by 40%
   - New PC >> IGCC

*Depending on the cost of Make-up-power
Appendix
### Design Basis: Bituminous Coal Type

#### Illinois #6 Coal Ultimate Analysis (weight %)

<table>
<thead>
<tr>
<th></th>
<th>As Rec’d</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>11.12</td>
<td>0</td>
</tr>
<tr>
<td>Carbon</td>
<td>63.75</td>
<td>71.72</td>
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<tr>
<td>Hydrogen</td>
<td>4.50</td>
<td>5.06</td>
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<tr>
<td>Nitrogen</td>
<td>1.25</td>
<td>1.41</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.29</td>
<td>0.33</td>
</tr>
<tr>
<td>Sulfur</td>
<td>2.51</td>
<td>2.82</td>
</tr>
<tr>
<td>Ash</td>
<td>9.70</td>
<td>10.91</td>
</tr>
<tr>
<td>Oxygen (by difference)</td>
<td>6.88</td>
<td>7.75</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>HHV (Btu/lb)</td>
<td>11,666</td>
<td>13,126</td>
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</table>
IGCC Environmental Targets

Based on EPRI’s CoalFleet for Tomorrow Initiative design basis

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Environmental Target</th>
<th>NSPS Limit¹</th>
<th>Control Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>15 ppmv (dry) @15% O₂</td>
<td>1.0 lb/MWh</td>
<td>LNB and syngas nitrogen dilution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.117 lb/MMBtu)</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>0.0128 lb/MMBtu</td>
<td>1.4 lb/MWh</td>
<td>Sulfinol (NC) Selexol (CC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.163 lb/MMBtu)</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>0.0071 lb/MMBtu</td>
<td>0.015 lb/MMBtu</td>
<td>Quench, water scrubber</td>
</tr>
<tr>
<td>Hg</td>
<td>&gt;90% Removal</td>
<td>20×10⁻⁶ lb/MWh (2.3 lb/TBtu)</td>
<td>Carbon Bed</td>
</tr>
</tbody>
</table>

NSPS: New Source Performance Standards
NC: No CO₂ Capture
CC: CO₂ Capture Case

¹Value in parenthesis is calculated based on a heat rate of 8,570 Btu/kWh from the non-capture IGCC case.
# New Pulverized Coal Environmental Targets

Based on BACT analysis, exceeding new NSPS requirements

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Environmental Target</th>
<th>NSPS Limit</th>
<th>Control Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.07 lb/MMBtu</td>
<td>1.0 lb/MWh (0.111 lb/MMBtu)</td>
<td>LNB, OFA, SCR</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>0.119 lb/MMBtu</td>
<td>1.4 lb/MWh (0.156 lb/MMBtu)</td>
<td>Wet Limestone Scrubber</td>
</tr>
<tr>
<td>PM</td>
<td>0.015 lb/MMBtu</td>
<td>0.015 lb/MMBtu</td>
<td>Fabric Filter</td>
</tr>
<tr>
<td>Hg</td>
<td>0.70 lb/TBtu</td>
<td>20\times10^{-6} lb/MWh (2.2 lb/TBtu)</td>
<td>Co-benefit capture</td>
</tr>
</tbody>
</table>

**NSPS**: New Source Performance Standards  
**LNB**: Low NOx Burners  
**OFA**: Over-fired air  
**SCR**: Selective Catalytic Reduction
Total Plant Cost

**Includes**
- Equipment
  - Initial chemicals and catalyst loadings
- Materials
- Labor
  - Direct and Indirect
- Engineering and Construction Management
- Project and Process Contingencies

**Excludes**
- Owner’s costs
  - Land, licensing and permitting, AFUDC
- Escalation to period of performance
- Taxes (except payroll)
- Site specific considerations
- Labor incentives in excess of 5 day/10 hour work week
- EPC premiums
New PC Capital Cost

CO₂ Capture ↑’s TPC by ~$1,300/kW

Reference: Pulverized Coal Oxycombustion Power Plants—Volume 1 Bituminous Coal to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, Revision 2 Final Report, August 2008
IGCC Total Plant Cost Summary

Without CO₂ Capture

- GE: $1,813/kW
- E-Gas: $1,733/kW
- Shell: $1,977/kW

With CO₂ Capture

- GE: $2,390/kW
- E-Gas: $2,431/kW
- Shell: $2,668/kW

CO₂ Capture ↑’s TPC by ~$580-690/kW

Note: See Appendix for Total Plant Cost Line Items Included and Excluded
## Economic Assumptions
### Financial Structure

<table>
<thead>
<tr>
<th>Type of Security</th>
<th>% of Total</th>
<th>Current (Nominal) Dollar Cost</th>
<th>Weighted Current (Nominal) Cost</th>
<th>After Tax Weighted Cost of Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Risk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>50</td>
<td>9%</td>
<td>4.5%</td>
<td>2.79%</td>
</tr>
<tr>
<td>Equity</td>
<td>50</td>
<td>12%</td>
<td>6%</td>
<td>6%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>11%</td>
<td>8.79%</td>
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<td><strong>High Risk</strong></td>
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<td></td>
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<tr>
<td>Debt</td>
<td>45</td>
<td>11%</td>
<td>4.95%</td>
<td>3.07%</td>
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<tr>
<td>Equity</td>
<td>55</td>
<td>12%</td>
<td>6.6%</td>
<td>6.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.55%</td>
<td>9.67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>High Risk</th>
<th>Low Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Charge Factor</td>
<td>0.175</td>
<td>0.164</td>
</tr>
<tr>
<td>Coal Levilization Factor</td>
<td>1.1439</td>
<td>1.1485</td>
</tr>
<tr>
<td>General O&amp;M Levelization Factor</td>
<td>1.1607</td>
<td>1.1660</td>
</tr>
</tbody>
</table>
## Economic Assumptions

### Parameter Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Tax Rate</td>
<td>38% Effective (34% Federal, 6% State less 1% Property and 1% Insurance)</td>
</tr>
<tr>
<td>Repayment Term of Debt</td>
<td>15 years</td>
</tr>
<tr>
<td>Grace Period on Debt Repayment</td>
<td>0 years</td>
</tr>
<tr>
<td>Debt Reserve Fund</td>
<td>None</td>
</tr>
<tr>
<td>Depreciation</td>
<td>20 years, 150% Declining Balance</td>
</tr>
<tr>
<td>Working Capital</td>
<td>Zero for all parameters</td>
</tr>
<tr>
<td>Plant Economic Life</td>
<td>30 years</td>
</tr>
<tr>
<td>Investment Tax Credit</td>
<td>0%</td>
</tr>
<tr>
<td>Tax Holiday</td>
<td>0 years</td>
</tr>
<tr>
<td>Start-up Costs (% EPC)</td>
<td>2%</td>
</tr>
<tr>
<td>All other additional costs ($)</td>
<td>0</td>
</tr>
<tr>
<td>EPC escalation</td>
<td>0%</td>
</tr>
<tr>
<td>Duration of Construction</td>
<td>3 years</td>
</tr>
</tbody>
</table>
**CO₂ Mitigation Costs**

**CO₂ Avoided**
\[
\frac{(\text{COE}_{\text{capture}} - \text{COE}_{\text{base}})}{(\text{Emissions}_{\text{base}} - \text{Emissions}_{\text{capture}})}
\]

**CO₂ Captured**
\[
\frac{(\text{COE}_{\text{capture}} - \text{COE}_{\text{base}})}{\text{(CO₂ Removed)}}
\]
CO_2 Capture Process
Selexol™ Scrubbing

Fuel Gas
6 MMscfd
95°F/495 psia

Stage 1
H₂S Absorber
(2 Columns)

Stage 2
CO₂ Absorber
(4 Columns)

Lean Selexol
10,000 gpm

Semi-Lean Selexol
50,000 gpm

H₂S Absorber
10,000 gpm

CO₂ Rich
Selexol

Fuel Gas
To Turbine

Lean Selexol
10,000 gpm

Semi-Lean Selexol
50,000 gpm

Makeup
60 gpd

13% total CO₂
78 Mol% CO₂

17% total CO₂
97 Mol % CO₂

35% total CO₂
99 Mol % CO₂

CO₂ Rich

Shifted Syngas
100°F/500 psia

H₂S/CO₂ Rich

H₂S Concentrator

N₂ Purge

H₂S/CO₂ Rich

H₂S/CO₂ Acid
Gas Stripper

To Claus
H₂S/CO₂

120 MMBtu/hr

Steam

MP Flash

HP Flash

LP Flash

300 psia

160 psia

50 psia

400 psia

35% total CO₂
78 Mol % CO₂