Objective & Focus of the Study

- **Objective**
  - Evaluate Impacts of Adding a CO₂ Capture Plant on Existing Site-Specific Power Plants
    - Plant Performance, Economics, and Physical Impacts

- **Focus**
  - Impacts on Coal Fired and Natural Gas Fired Combined Cycle Power Plants
Performance and Economic Impacts

- **Performance Impacts On:**
  - Plant Net Output
  - Net Plant Efficiency
  - Additional Cooling Water Consumption

- **Economic Impact**
  - Additional Capital Expenditure
  - Additional O&M Expenditure
  - Increased Cost of Electricity ($/MWh)
    - With and w/o Replacement of Lost Power

- **Physical Impact on Site**
  - Additional Land Requirement

Approach and Methodology

- **Site Selection**
  - EPRI Identified a Coal Plant Site Within WestCarb Region
  - Plant Operator Agreed to participate
    - Provide Required Plant Data
    - Review Study Results
    - **Stay Anonymous**

- **Evaluate Plant Performance**
  - Preliminary Design of Capture Process
  - Estimate Interfaces with the Existing Plant
  - Integrate the Systems
Approach and Methodology  
(Cont’d)

- **CO₂ Capture Process Design**
  - Assume Mono-Ethanol-Amine (MEA) Capture
  - Use ASPEN Code to Design the Process Plant
  - Use GateCycle Code to Evaluate Overall Performance (Systems Integration)

- **Develop Plant Arrangement**
  - Develop Capture plant Layout including New Cooling Tower
  - Integrate with the Power Plant Layout

Approach and Methodology  
(Cont’d)

- **Develop Cost Estimate**
  - Use Nexant Internal Cost Code for Capture plant Cost
  - Plant Modifications Cost – Extrapolate from Earlier Studies (Nexant/Bechtel)
  - Estimated Costs
    - Additional Capital Cost
    - Additional Operational and Maintenance Costs
    - Incremental Cost of Electricity (COE)
  - Sensitivity Analysis – Effect of Varying (on COE)
    - Capacity Factor, Capital Cost, Financing Cost, Replacement Power Cost
Existing Plant Features

- Located in One of the Seven WestCarb States
- Sub-Critical Pulverized Coal Fired
  - 2,400 psig/1,000°F/1,000°F
  - Gross Generation – 431 Mwe
  - Net Generation – 372 Mwe
  - Net Plant Efficiency – 33.9%
- Coal – Bituminous
- Cooling System – Wet Cooling Tower
- Flue Gas Cleanup – Low Nox Burners, SCR, ESP, FGD
- Flue Gas: SO₂ – 20 ppm; CO₂ – 10.4%

Capture Plant Design Criteria

- Maximum SO₂ in Flue Gas - <10 ppmv
- CO₂ Removal from Flue Gas – 90%
- CO₂ Concentration at Plant Discharge – Min. 99%
- CO₂ Pressure at Plant Discharge – 2,200 psig.
Existing Plant – Process Flow

Retrofit Plant – Process Flow
Existing Plant – Flue Gas Process Flow

Integrated Plant Process Flow

• Major Interfaces:
  - Large Ducting @ Inlet & Outlet of Capture Plant
  - Low Pressure Steam Supply – Additional Steam Turbine
  - Condensate Return
Capture Plant Process Flow

Integrated Plant Site Plan
### Integrated Plant Performance

<table>
<thead>
<tr>
<th>Plant Performance</th>
<th>Existing Plant No CO&lt;sub&gt;2&lt;/sub&gt; Capture</th>
<th>Retrofit Plant W/CO&lt;sub&gt;2&lt;/sub&gt; Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross plant output, kWe</td>
<td>430,685</td>
<td>382,816</td>
</tr>
<tr>
<td>Plant auxiliary power, kWe</td>
<td>58,900</td>
<td>111,185</td>
</tr>
<tr>
<td>Net plant output, kWe</td>
<td>371,785</td>
<td>271,631</td>
</tr>
<tr>
<td>Net plant efficiency</td>
<td>33.9%</td>
<td>24.8%</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; production, tons/yr</td>
<td>3,357,637</td>
<td>3,357,637</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; removal, tons/yr</td>
<td>0</td>
<td>3,023,083</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; emission, tons/yr</td>
<td>3,357,637</td>
<td>334,554</td>
</tr>
</tbody>
</table>

### Capture Plant Capital Cost

- **Net Plant Output, kWe-retrofit**: 271,631
- **Net Plant Output, kWe-existing**: 371,785

**Summary Plant Cost**
- Capture & Recovery Equipment, $K: 44,866
- Compression Plant Equipment, $K: 16,706
- Total Commodities, $K: 72,666
- Balance-of-Plant Adjustment, $K: 55,427
- Indirect Costs, $K: 87,550
- Project Contingency, $K: 56,485
- Process Contingency, $K: 40,669
- Total Plant Cost (TPC), $K: 374,569

<table>
<thead>
<tr>
<th>Total CO&lt;sub&gt;2&lt;/sub&gt; Plant Cost/kW</th>
<th>$0</th>
<th>$200</th>
<th>$400</th>
<th>$600</th>
<th>$800</th>
<th>$1,000</th>
<th>$1,200</th>
<th>$1,400</th>
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<tbody>
<tr>
<td>Retrofit Plant Output Basis</td>
<td>$1,379</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Existing Plant Output Basis</td>
<td>$1,007</td>
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<td></td>
</tr>
</tbody>
</table>

| $/kWe-retrofit                  | $1,379 |       |       |       |       |        |        |        |
| $/kWe-existing                  | $1,007 |       |       |       |       |        |        |        |
Incremental Costs
Electricity; CO₂ Removal; CO₂ Avoidance

Sensitivity Assessment – Financing Cost
### Sensitivity Assessment

**Cost of Replacement Power**

![Chart showing cost of replacement power](chart.png)

### Comparison with Other Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Present Plant</th>
<th>AEP Connesville Unit #5*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Plant Output (Base Plant)</td>
<td>MWe</td>
<td>371</td>
<td>434</td>
</tr>
<tr>
<td>Net Plant Output (Retrofit Plant)</td>
<td>MWe</td>
<td>271</td>
<td>303</td>
</tr>
<tr>
<td>Net Plant Efficiency-HHV (Base Plant)</td>
<td>%</td>
<td>34.0%</td>
<td>35.0%</td>
</tr>
<tr>
<td>Net Plant Efficiency-HHV (Retrofit Plant)</td>
<td>%</td>
<td>24.9%</td>
<td>24.5%</td>
</tr>
<tr>
<td>CO₂ Capture, Percent of Total Production</td>
<td>%</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Incremental Capital Cost</td>
<td>$/kWe</td>
<td>1,379</td>
<td>1,464</td>
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<tr>
<td>Incremental Levelized Cost of Electricity</td>
<td>$/MWh</td>
<td>55</td>
<td>54</td>
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<tr>
<td>Cost of CO₂ Avoided</td>
<td>$/ton</td>
<td>54</td>
<td>57</td>
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<tr>
<td>Cost of CO₂ Removed</td>
<td>$/ton</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td>Power Penalty</td>
<td>%</td>
<td>27%</td>
<td>30%</td>
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<tr>
<td>Efficiency Penalty</td>
<td>%</td>
<td>27%</td>
<td>30%</td>
</tr>
<tr>
<td>Energy Penalty</td>
<td>%</td>
<td>112%</td>
<td>241%</td>
</tr>
</tbody>
</table>

*Conesville plant incremental capital cost and LCOE are escalated to 4Q 2008 level.
Summary and Conclusion

- **Summary**
  - Efficiency and Power Penalty – Approx. 27%
  - Replacement Power @ $51/MWh - Adds 0% to COE
  - Replacement Power @ $95/MWh - Adds 23.5% to COE
  - Additional Water Consumption - Approx. 1,915 GPM (65% Increase)
  - Additional Land Requirement – Approx. 330,000 Ft²

- **Conclusion**
  - Difficult for Water-Constrained Sites
  - Land – Difficult for Urban-Sited Plants
  - Availability of Large Replacement Power May Be a Site Limitation