Coal-fired power plant technologies

Rankine-cycle (a.k.a. "conventional", "pulverized coal", "PC" or "steam" technology)
- Subcritical PC - Mature commercial
- **Supercritical PC - Emerging technology of choice**
- Ultra-supercritical PC - Early commercial
- Any of the above w/ fluidized bed combustion - Commercial in smaller sizes
- CO2 separation and sequestration (CSS) for any of the above - Not commercial and likely very expensive

Gasification
- **Integrated coal gasification combined-cycle (IGCC) - Very early commercial**
- IGCC w/CSS - Components are commercial, complete plant not.

 Alternatives to be characterized in detail for the portfolio analysis
Rankine-cycle coal-fired power plant considerations I

Investment risk:
- Moderately high capital cost (currently $3000 - 4000/kW)
- Moderately long development and construction lead time
- Proven ability to construct a completed plant on time
- Moderately-high fixed costs

Fuel price risk
- Abundant and low-cost fuel supply
- Exposure to transportation fuel price risk for locations requiring rail haul

Operational characteristics and risks:
- Mature, reliable technology (~90% availability)
- Inherent sustained peaking capability
- Limited regulation and load-following capability

Rankine-cycle coal-fired power plant considerations II

Environmental risks and Catch-22
- Criteria air pollutants (SOx, NOx, particulates, etc.) controlled to "best available control technology" (BACT) levels with established technology.
- ~ 40% Hg control inherent w/wet FGD + SCR CAPcontrol, reduction to 90% possible at moderate cost using commercial activated C injection technology.
- Substantial CO2 production unless equipped with CO2 separation equipment and an accessible sequestration facility.
- WA, OR & MT state policies effectively prohibits utilities (IOUs in Montana) from executing long-term contracts for coal plants w/o CSS.
- Post-combustion CO2 separation technology in very early pilot stage.
- Proven sequestration limited to enhanced oil recovery.

Public perception:
- Recent Northwest proposals have been controversial
- Issues, here and elsewhere have been air emissions and CO2 risk
Coal price forecast

Why Supercritical Technology?

3500 psig/1050 F vs 2400/1000F psig steam conditions
Results in higher efficiency - 9000 vs 9800 Btu/kWh (38% vs 35%)
Proportionally lower (~ 8%):
- Fuel consumption
- Fuel cost
- Criteria air emissions
- CO2 production

Early reliability problems discouraged use of technology in U.S
Established technology in Europe and Japan (higher fuel costs)
Technology shift appears underway in North America, beginning with Genesee 3 in Alberta (completed in 2005)
Emerging strategy is new supercritical plant + biomass co-firing + BACT retrofit to adjacent existing project(s)
Capital cost estimate: Supercritical PC coal plant (no CSS)

- Generic Supercritical w/o CSS
- Rankine Projects
- Supercritical 6th Plan Draft

Proposed 2008 (for 2012 service) estimate $3500/kW

Fifth Plan Estimate $1450/kW

Forecast supercritical PC coal plant construction costs

- Costs flatten in 2008 - 2009
- 2015 > Costs constant in real $
- General decline in construction costs
- Historical cost estimates
Supercritical PC coal-fired power plant assumptions

Configuration:
• Single unit; 450 MW supercritical (>3500+ psig) steam cycle
• 90% availability; 85% capacity factor (for levelized cost of energy estimates)
• Heat rate 8900 - 9000 Btu/kWh (Use 9000; 38%)

Development and construction cost (overnight):
• $3500/kW (2008 cost, 2011 service)

Operating costs:
• Fixed O&M - $60.00/kW/yr
• Variable O&M - $2.75/MWh
• System Integration - None (Fully dispatchable)

Schedule and cash flow
• Development - 36 mo; 3% of total plant cost
• Optional construction - 8 mo; 27% of total plant cost
• Committed construction - 27 mo; 70% of total plant cost

Earliest service for new project available to the Northwest ~ 2015

Supercritical PC plant cost elements

December 9, 2008
### Impact of steam conditions and CO2 capture on power plant cost and performance

<table>
<thead>
<tr>
<th>Steam Conditions (typical)</th>
<th>Total Plant Cost</th>
<th>Operation &amp; Maintenance Cost</th>
<th>Heat Rate</th>
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<td>Ultrasupercritical PC w/Amine CS 113°F</td>
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<td>213</td>
<td>113</td>
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</tbody>
</table>

1) 90% CO2 separation and compression; excluding transportation, injection & monitoring. From MIT *The Future of Coal* (2007)

### Technology variants scaled to supercritical PC assumptions

<table>
<thead>
<tr>
<th></th>
<th>Total Plant Cost ($/kW)</th>
<th>Fixed O&amp;M ($/kW/yr)</th>
<th>Variable O&amp;M ($/MWh)</th>
<th>Heat Rate (Btu/kWh)</th>
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</tbody>
</table>

December 9, 2008
Comparison of technology variants

Levelized lifecycle cost ($/MWh)

- CO2 (Bingaman-Spector cap)
- Transmission & Losses
- System Integration
- Variable Fuel
- Variable O&M
- Fixed Fuel*
- Fixed O&M
- Capital

IOU financing
2020 service
85% CF
Estimates exclude the cost of CO2 transportation, injection and monitoring

Resource options, early 2020s

Levelized lifecycle cost ($/MWh)

- Emission (CO2) cost
- Transmission & Losses
- System Integration
- Plant costs

Transmission cost & losses to point of LSE wholesale delivery
No federal investment or production tax credits
Baseline operation (CO2: 85%CF, Nuc: 87.5% CF, SCPC: 85%)
Medium NG and coal price forecast (Proposed 6th Plan)
Bingaman/Specter safety valve CO2 cost

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