Economic Analysis of the Modular Pebble Bed Reactor

These slides present the conclusions of a preliminary study based on existing cost data found in “Evaluation of the Gas Turbine Helium Reactor” - DOE-HTGR-90380 - Dec. 1993 and compared against an NEI report issued in 1992 on the economics of alternative options. The purpose was to evaluate on a relative scale whether the pebble bed could be competitive. For the purposes of this study the gas price in 1992 was assumed constant and did not increase. This study will be revised as better data is developed.

June 1998
Economic Analysis

• Group Goals
  – determine cost estimate for construction
  – compare cost estimate with that of existing technologies
  – examine financing options
  – examine economies of scale vs. productivity
MPBR Cost Estimate

- Capital cost
- O&M cost
- Fuel cost
- Decommissioning cost
Capital Cost

• Cost savings come from:
  – more factory fabrication, less site work
  – learning effect from 1st to 10th unit
  – natural safety features
  – shorter construction time

• Total capital cost for 1100 MWe plant
  $2,296 million
Plant Construction

- Construction Plan / Techniques
- Plant Physical layout
- Construction Model
Construction Plan / Techniques

• Factory Assembly
• Existing Technology
• Modular Construction Allows:
  – Parallel Construction
  – Ease of Shipment
  – Rapid Assembly
  – Streamlined Testing
Construction Flowpath for a Standard Unit
Unit Construction Flowpath

Graph for Instantaneous Work in Progress

Instantaneous Work in Progress: Most Likely Week
Construction Model

• Can it be done?
• Influence of external factors?
• What are vulnerabilities / areas for time and cost savings?
• What is the relationship between construction time and cash flow?
• Sensitivity analysis
The table presents the MPBR Plant Capital Cost Estimate in millions of January 1992 dollars without contingency. Here are the details:

<table>
<thead>
<tr>
<th>Account No.</th>
<th>Account Description</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>LAND &amp; LAND RIGHTS</td>
<td>2.5</td>
</tr>
<tr>
<td>21</td>
<td>STRUCTURES &amp; IMPROVEMENTS</td>
<td>192</td>
</tr>
<tr>
<td>22</td>
<td>REACTOR PLANT EQUIPMENT</td>
<td>628</td>
</tr>
<tr>
<td>23</td>
<td>TURBINE PLANT EQUIPMENT</td>
<td>316</td>
</tr>
<tr>
<td>24</td>
<td>ELECTRIC PLANT EQUIPMENT</td>
<td>64</td>
</tr>
<tr>
<td>25</td>
<td>MISCELLANEOUS PLANT EQUIPMENT</td>
<td>48</td>
</tr>
<tr>
<td>26</td>
<td>HEAT REJECT. SYSTEM</td>
<td>25</td>
</tr>
</tbody>
</table>

**TOTAL DIRECT COSTS**  
1,275

<table>
<thead>
<tr>
<th>Account No.</th>
<th>Account Description</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>CONSTRUCTION SERVICE</td>
<td>111</td>
</tr>
<tr>
<td>92</td>
<td>HOME OFFICE ENGR. &amp; SERVICE</td>
<td>63</td>
</tr>
<tr>
<td>93</td>
<td>FIELD OFFICE SUPV. &amp; SERVICE</td>
<td>54</td>
</tr>
<tr>
<td>94</td>
<td>OWNER’S COST</td>
<td>147</td>
</tr>
</tbody>
</table>

**TOTAL INDIRECT COST**  
375

**TOTAL BASE CONSTRUCTION COST**  
1,650

**CONTINGENCY (M$)**  
396

**TOTAL OVERNIGHT COST**  
2,046

**UNIT CAPITAL COST ($/KWe)**  
1,860

**AFUDC (M$)**  
250

**TOTAL CAPITAL COST**  
2296
O&M Cost

- Simpler design and more compact
- Least number of systems and components
- Small staff size: 150 personnel
- $31.5 million per year
Fuel Cost

• Assumptions:
  – One fuel pebble will cost $20.00 (‘92$)
  – One third of the fuel pebble bed is replaced annually (120,000 per unit per year)
  – 1.0 mill/kWh for spent fuel disposal and radioactive waste management

• Cost: $32.7 million / year
Decommissioning Cost

- $211 million
- Remove all radioactive wastes from site and all construction material to a level of 3ft below grade.
- Less than 1 mill/kWh levelized busbar cost
## MPBR Busbar Generation Costs (‘92$)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Thermal Power (MWt)</td>
<td>10 x 250</td>
</tr>
<tr>
<td>Net Efficiency (%)</td>
<td>45.3%</td>
</tr>
<tr>
<td>Net Electrical Rating (Mwe)</td>
<td>1100</td>
</tr>
<tr>
<td>Capacity Factor (%)</td>
<td>90</td>
</tr>
<tr>
<td>Total Overnight Cost (M$)</td>
<td>2,046</td>
</tr>
<tr>
<td>Levelized Capital Cost ($/kWe)</td>
<td>1,860</td>
</tr>
<tr>
<td>Total Capital Cost (M$)</td>
<td>2,296</td>
</tr>
<tr>
<td>Fixed Charge Rate (%)</td>
<td>9.47</td>
</tr>
<tr>
<td>30 Year Level Cost (M$/yr):</td>
<td></td>
</tr>
<tr>
<td>Levelized Capital Cost</td>
<td>217</td>
</tr>
<tr>
<td>Annual O&amp;M Cost</td>
<td>31.5</td>
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<tr>
<td>Level Fuel Cycle Cost</td>
<td>32.7</td>
</tr>
<tr>
<td>Level Decommissioning Cost</td>
<td>5.4</td>
</tr>
<tr>
<td>Revenue Requirement</td>
<td>286.6</td>
</tr>
</tbody>
</table>

### Busbar Cost (mill/kWhr):

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (mill/kWhr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>25.0</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>3.6</td>
</tr>
<tr>
<td>Fuel</td>
<td>3.8</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>0.6</td>
</tr>
<tr>
<td>Total</td>
<td>33.0</td>
</tr>
</tbody>
</table>
Financing Construction

• Cost of capital
  – debt-to-equity ratio
  – distribution of risk

• Consortium approach
  – share risk
  – lower return on investment
Amortization of debt

• Determine annual revenue requirements
  – debt-to-equity ratio
  – return on preferred equity
  – return on common equity
  – income taxes
Debt Service Coverage

• Ratio of total revenue generated to annual revenue required
  – depends on amortization length
  – distribution of risk

• Consortium approach best
Competitive With Gas?

- Natural Gas: 3.4 Cents/kwhr
- AP 600: 3.62 Cents/kwhr
- ALWR: 3.8 Cents/kwhr
- MPBR: 3.3 Cents/kwhr

Levelized Costs (1992 $ Based on NEI Study)
Group Findings

• Low levelized cost
  – low fuel cost
  – low O&M cost

• High unit capital cost
  – low capacity design
  – high contingency factor (24%)
Future Work

• Determine optimal capital structure
• Adjust cost estimate to design changes
• Create detailed cash flow statement
Major MPBR Conclusions

• Naturally Safe (Regulatory / Safety Implications)
  – Constrained by Fuel Particle failure above 1600ºC
    • Core power density chosen as 3.54 MW/m³
    • Fuel pebble manufacturing defects are the most significant source of fission product release

• Economically Competitive
  – 3.3 cents/kWhr (natural gas = 3.4 cents/kWhr)
    • Producing revenue within 3 years (rapid construction)
    • Low staffing and O&M costs
    • Factory Assembly

• Societal Acceptance
  – Proliferation Resistance -- promising, but future work needed
  – Waste Disposal -- promising, but future work needed