Objectives

• Background – Electricity demand in Shanghai
• Analysis of options for capacity expansion:
  1. Large coal plant
  2. Large natural gas plant
  3. Small natural gas plant + expansion option
• Tools used:
  – Decision analysis (NPV, cost-benefit)
  – Binomial lattice valuation of options
• Conclusion

Compared directly
Robust Demand Growth in Recent Decades

Total demand growth approximately 7.9% per year.
Requires rapid build-out of new capacity – how to meet demand?
How to encourage cleaner power production?
Options

Plan 1 – Large coal plant → “put-like” option to close
Plan 2 – Large natural gas plant
Plan 3 – Small natural gas plant → “call-like” option to expand

Analysis:
- Define assumptions (demand growth, feedstock price, regulation)
- Develop cost model
- Evaluate value of flexibility
  - Decision analysis
  - Binomial lattice valuation
## Cost Model: Assumptions

<table>
<thead>
<tr>
<th></th>
<th>1 – Large Coal</th>
<th>2 – Large NG</th>
<th>3 – Flex NG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>500MW</td>
<td>500MW</td>
<td>300MW</td>
</tr>
<tr>
<td><strong>Capital Cost</strong></td>
<td>$500m</td>
<td>$400m</td>
<td>$300m</td>
</tr>
<tr>
<td><strong>Expansion</strong></td>
<td>N.A.</td>
<td>N.A.</td>
<td>$180m</td>
</tr>
<tr>
<td><strong>Heat Rate</strong></td>
<td>10,900 BTU/kWh</td>
<td>5687 BTU/kWh</td>
<td>5687 BTU/kWh</td>
</tr>
<tr>
<td><strong>Feedstock Price</strong></td>
<td>$1.05/MMBTU</td>
<td>$6.05/MMBTU</td>
<td>$6.05/MMBTU</td>
</tr>
<tr>
<td></td>
<td>($7.05/MMBTU)</td>
<td>($7.05/MMBTU)</td>
<td></td>
</tr>
<tr>
<td><strong>O&amp;M Cost</strong></td>
<td>$10m</td>
<td>$10m</td>
<td>$6m (+ $6m)</td>
</tr>
<tr>
<td><strong>Max Output</strong></td>
<td>3,700m kWh</td>
<td>3,700m kWh</td>
<td>2,200m kWh</td>
</tr>
<tr>
<td></td>
<td>(+ 2,200m kWh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Period Length</strong></td>
<td>2 x 5 years</td>
<td>2 x 5 years</td>
<td>2 x 5 years</td>
</tr>
<tr>
<td><strong>Demand Growth</strong></td>
<td>350m kWh/yr</td>
<td>350m kWh/yr</td>
<td>350m kWh/yr</td>
</tr>
<tr>
<td></td>
<td>(450m kWh/yr)</td>
<td>(450m kWh/yr)</td>
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</tbody>
</table>
### Sample Cost Model: Flex Plant

**Used to determine net present value (NPV)**

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost ($ millions)</td>
<td>300.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>180.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Price of Gas ($/MMBTU)</td>
<td>6.05</td>
<td>6.05</td>
<td>6.05</td>
<td>6.05</td>
<td>6.05</td>
<td>6.05</td>
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</tr>
<tr>
<td>Fuel Cost ($ millions)</td>
<td>15.48</td>
<td>30.97</td>
<td>46.45</td>
<td>61.93</td>
<td>75.69</td>
<td>91.18</td>
<td>106.66</td>
<td>122.14</td>
<td>137.63</td>
<td>151.39</td>
<td></td>
</tr>
<tr>
<td>O&amp;M Cost ($ millions)</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
</tr>
<tr>
<td>Price of Electricity (cents/kWh)</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
<td>8.20</td>
</tr>
<tr>
<td>Demand (100 million kWh)</td>
<td>4.50</td>
<td>9.00</td>
<td>13.50</td>
<td>18.00</td>
<td>22.00</td>
<td>26.50</td>
<td>31.00</td>
<td>35.50</td>
<td>40.00</td>
<td>44.00</td>
<td></td>
</tr>
<tr>
<td>Revenues ($ millions)</td>
<td>36.90</td>
<td>73.80</td>
<td>110.70</td>
<td>147.60</td>
<td>180.40</td>
<td>217.30</td>
<td>254.20</td>
<td>291.10</td>
<td>328.00</td>
<td>360.80</td>
<td></td>
</tr>
</tbody>
</table>

- **Net Income, NI = R - C(Cap) - C(Fuel) - C(O&M)**
- **Discount Rate**
- **Discount Factor**
- **Annual Discounted Cash Flow**
- **NPV**

**Assumptions:** Start with 300MW capacity, demand high, price low, build new plant.
Decision Analysis

Probability of large losses if demand low, reg.

Ability to take advantage of upside limited.

Can exercise option to take greater advantage of upside if demand high.

Values in millions of dollars
Value at Risk and Gain

Based on probabilities in decision analysis:

Staged natural gas plant allows plant operators to take advantage of upside, minimize downside risks.

Coal plant has large potential upside but also large potential downside.
Choosing Best Design

Upside potential → Coal (Plan 1)
Downside minimized → Staged NG (Plan 3)
NPV → Staged NG (Plan 3)

Cost-Benefit Ratio → Staged NG (Plan 3)
(C-B better than NPV for ranking)

<table>
<thead>
<tr>
<th>Project</th>
<th>Expected NPV</th>
<th>NPV of Cap Ex</th>
<th>Benefit-Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan 1 – Large Coal (500 MW)</td>
<td>$ 77.16</td>
<td>$ 500</td>
<td>0.1543</td>
</tr>
<tr>
<td>Plan 2 – Large Gas (500 MW)</td>
<td>$ 60.20</td>
<td>$ 400</td>
<td>0.1505</td>
</tr>
<tr>
<td>Plan 3 – Phased Gas (300 MW or 600 MW)</td>
<td>$ 98.88</td>
<td>$ 300 (+$ 112*0.5) E = $ 356</td>
<td>0.2778</td>
</tr>
</tbody>
</table>

E = probability weighted capital expenditures for phased gas plant based on decision analysis. All values in millions.
Annual Localized Demand Growth

- Goal: Meet localized demand
- Demand is growing year-on-year
- Used to estimate year-on-year demand growth in lattice model, summed to obtain cumulative growth in lattice
- Start value assumed is average of 3.0 100 million kWh
- Evolution described by lattice of probabilities

\[ y = 0.3577e^{0.1862x} \]
Binomial Lattice Analysis

Evolution of probabilities every year through 2020. Used to model evolution of demand.

Upstate probability = 0.71
Downstate probability = 0.29
Assumed growth* = 18.62 %
Volatility = 44.12 %
Start value = 3.0 100 million kWh

* Based on annual localized incremental demand growth
“Call” Option in Natural Gas Plant

Value of Option:

- Decision analysis compared to single large plant:
  $98.88m - $60.20m = $38.68m

- Binomial lattice valuation
  Base case (500 MW) – $144.49m
  Flex case, not expand – $128.52m
  Flex case, forced expand – $146.42m
  Flex case, with option – $205.97m

Optimal Decision in Fifth Year

<table>
<thead>
<tr>
<th>Probability</th>
<th>Demand</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>70.94</td>
<td>EXPAND</td>
</tr>
<tr>
<td>0.37</td>
<td>31.11</td>
<td>EXPAND</td>
</tr>
<tr>
<td>0.30</td>
<td>15.76</td>
<td>EXPAND</td>
</tr>
<tr>
<td>0.12</td>
<td>10.14</td>
<td>NO CHANGE</td>
</tr>
<tr>
<td>0.02</td>
<td>8.28</td>
<td>NO CHANGE</td>
</tr>
<tr>
<td>0.00</td>
<td>7.81</td>
<td>NO CHANGE</td>
</tr>
</tbody>
</table>
“Put” Option on Coal Plant

Value of option to close – dynamic programming.

Cost of closing plant: $ 4.5 million

Value of option to close = $ 3.45m

NPV with flexibility = $ 523.86m
NPV with no flexibility = $ 520.41m

Decision strategy
Conclusions

• Ability to adjust capacity as demand is valuable.
  $ 38.68m more value than single large plant (decision analysis)
  $ 77.45m more value than small plant, no expansion (lattice valuation)

• Ability to close coal plant in the event of low demand, regulations has value.
  $ 3.45m more value than without option to close

• Given high degree of uncertainty, flexibility can play an important role in construction of new infrastructure in Shanghai.

  ➔ On many measures (cost-benefit, expected NPV, minimize downside), staged natural gas plant (Plan 3) is superior.

  ➔ Option to close has small benefit for coal plant (Plan 1).