Thorium Economics: A Few Perspectives

Paul Friley
Brookhaven National Laboratory
pfriley@bnl.gov
MARKAL Framework

- **Well established tool for energy systems analysis.**
  - 30 years of development under the auspices of the International Energy Agency.
  - Approximately 100 user institutions in more than 50 countries.

- **Bottom-up analysis with explicit technology representation.**
  - Includes physical description of energy technologies.
  - Allows for “well-to-wheel” comparison of technologies and technological pathways.
  - Studies the impact of technological change/progress on energy markets.
  - Provides a technology-rich basis for estimating energy dynamics over a multi-period horizon.

- **BNL is currently working with five MARKAL variants:**
  - Single Region U.S. Model
  - 10-Region U.S. Model
  - 15-Region ETP Global Model
  - New York City Model
  - Multi-Region Long Island Model (under development)
Clean Electricity Standard (CES)

- Requires retail electricity suppliers to meet a certain percentage of their sales with electricity generated from “clean” resources, like wind, biomass, solar, and geothermal. The requirement begins at 40% in 2015 and rises to 80% by 2035 and 95% by 2050.
  - All renewable and nuclear generation receive full credits
  - Natural gas combined-cycles get 0.50 credit and natural gas combined-cycles with CCS get 0.95 credit per kWh generated.
  - Coal with CCS gets 0.90 credit per kWh generated.
- Banking and trading of credits is permitted.
- For this analysis, our 10-region U.S. MARKAL model was calibrated to EIA’s 2011 AEO. We did not use any DOE R&D assumptions.
Reference Case Central Electric Generation

Total Central Electric Generation
Reference Case

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Combined Cycle</th>
<th>Combined Cycle w/cc</th>
<th>Nuclear</th>
<th>Other Steam &amp; CTs</th>
<th>Solar</th>
<th>Wind</th>
<th>Geothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2025</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2030</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2035</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2040</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2045</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2050</td>
<td>2500</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
With the CES, we see a sharp decrease in steam coal and increases in coal and gas with CCS, nuclear and renewable generation.
Impact on Power Sector CO2 Emissions

Power Sector CO2 Emissions

- Reference Case
- CES Case
Comparison of CES Without New Nuclear Generation Capacity

- In order to demonstrate the value of nuclear generation under a Clean Energy Standard, we ran a sensitivity case where no new nuclear power plants were allowed to be built.

- In this scenario, credit prices were 25% higher in 2050 and there were significant differences in inter-regional trade in credits. In real terms, annual inter-regional trade in CES credits increased from $19 billion to $38 billion in 2050.

<table>
<thead>
<tr>
<th>Net Sales of Credits from the South Atlantic Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
</tr>
<tr>
<td>CES</td>
</tr>
<tr>
<td>CES NN.</td>
</tr>
</tbody>
</table>
Clean Electricity Credit Balances Without New Nuclear Capacity
2050 [TWh]

- **Pacific**:
  - Gen: 207
  - Req’t: 337
  - Sell: 68

- **Mountain**:
  - Gen: 321
  - Req’t: 324
  - Buy: 3

- **West North Central**:
  - Gen: 285
  - Req’t: 312
  - Buy: 27

- **East North Central**:
  - Gen: 497
  - Req’t: 605
  - Buy: 108

- **New England**:
  - Gen: 97
  - Req’t: 122
  - Buy: 25

- **Mid Atlantic**:
  - Gen: 281
  - Req’t: 312
  - Buy: 32

- **South Atlantic**:
  - Gen: 660
  - Req’t: 883
  - Buy: 224

- **West South Central**:
  - Gen: 779
  - Req’t: 558
  - Sell: 221

- **East South Central**:
  - Gen: 292
  - Req’t: 228
  - Sell: 64
Fuel Cycle Economics

- Fuel cycle economics can be modeled in MARKAL, but the cost assumptions are quite speculative.
- Thorium fuel cycles have not been explicitly modeled for the U.S.
- However, the impacts of different fuel cycles on reducing repository needs is not. With current U.S. nuclear generation capacity and a once-through fuel cycle, we would need 4 YMe of repository space by 2100. If nuclear generation capacity was increased to maintain current market share (about 20%) we would need 8 to 10 YMe of repository space.
India needs to sustain a 9% economic growth rate for 20 years to eradicate poverty and meet it’s human development goals.

At this growth rate, under baseline improvements in end-use and generation efficiency, power sector CO2 emissions would almost triple by 2020 and coal consumption would increase by 2 ½ times.

The impacts of the potential increase in coal consumption could be quite dramatic, with significant environmental and public health impacts. There are also significant economic impacts. While India is currently the world's 3rd largest coal producer, it is also the 4th largest importer of coal. The 2006 Integrated Energy Plan estimated that imports would comprise between 35 and 57% of 2030 coal supply. This implies that significant investments are required for coal import terminals and rail infrastructure. Furthermore, there will be significant impacts on India’s balance of payments and the growing import dependence raises energy security issues.
While coal may be the answer in the shorter term, the Indian Government has identified that in the longer term, thorium reactors and solar generation are two key domestic resources that can reduce energy imports and enhance energy security.

Summary

- R&D, market conditions and energy/environmental policy matter.
  - Under many circumstances, advanced technologies may not enter the market. However, the technology R&D may provide “option benefits” if future market conditions or energy policy change.

- Advanced technologies are not limited to developed economies.
  - Ex. cell phones vs. land lines
  - In developed countries, market penetration is constrained by low energy demand growth, existing infrastructure, capital stock turnover and energy policy.
  - In developing countries, energy markets are growing rapidly, but each country is different and technology deployment will depend on local conditions.
Thorium Economics: A Few Perspectives

Paul Friley
Brookhaven National Laboratory
pfriley@bnl.gov