Nuclear Power in a Three Dimensional Energy World: Economy, Environment, Security

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Energy and the World Economy

- Energy = (Population) x (GDP/Population) x (Energy/GDP)
- World Population: projected to increase to 9 billion by 2050 and 10 billion by 2100
- World Per Capita Income is going up
- World Energy Demand in “Business as Usual” case must go up to match the economic requirements
IIASA Projection of Future Energy Demand Scenario A1 (High Growth)
Primary energy to nominal GDP ratio - World

Source: IMF, World Bank, Bloomberg, IEA, BP, BofAML Global Commodities Research
### Percentage of Total Primary Energy Supply (TPES) and World CO$_2$ Emissions by Fuel

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage of TPES</th>
<th>Percent of World CO$_2$ Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>34</td>
<td>40</td>
</tr>
<tr>
<td>Coal</td>
<td>26</td>
<td>40</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Combustibles</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Source - IEA 2007
## Coal Reserves and Consumption

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>271</td>
<td>1.1</td>
</tr>
<tr>
<td>Russia</td>
<td>173</td>
<td>0.26</td>
</tr>
<tr>
<td>China</td>
<td>126</td>
<td>2.3</td>
</tr>
<tr>
<td>Indonesia</td>
<td>102</td>
<td>0.51</td>
</tr>
<tr>
<td>Australia</td>
<td>87</td>
<td>0.15</td>
</tr>
<tr>
<td>South Africa</td>
<td>54</td>
<td>0.20</td>
</tr>
<tr>
<td>Rest of World</td>
<td>188</td>
<td>2.7</td>
</tr>
<tr>
<td>WORLD Total</td>
<td>1001</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Source: DOE Energy Information Agency
Oil Supply and Cost

Availability of oil resources as a function of economic price

Source: IEA (2005)
CO₂ emissions paths: BAU versus stabilizing CO₂ concentration to limit $\Delta T_{\text{avg}}$

Path for 50% chance of avoiding $\Delta T_{\text{avg}} > 2$ C (gold) is much more demanding than path for 50% chance of avoiding $>3$ C (green).
Reducing The Use Of Fossil Fuels

• Transportation – Efficiency + Electrification (50 mpg for gasoline; decarbonized electricity)

• Electricity – Efficiency + Fuel Switching (one GWe coal gives 8 million tonnes of CO₂ per year; gas gives 1/3 of coal; nuclear – hydro – wind – solar – geothermal give zero)

• Buildings – Efficiency + fuel switching

• Industry – Efficiency + fuel switching

• More on efficiency see http://www.aps.org/energyefficiencyreport/
California's Energy Future - The View to 2050

Goal: Emissions at 20% of 1990

Assumptions:
• Population 55 million
• Economy nearly twice as large
• Renewables at least 33%
• CCS at 90% effective
• Light vehicles electrified
• Heavy trucks and planes on biofuels
• 40% efficiency improvements

Conclusion
Cannot be done with renewables alone

The mix:
33% Wind and solar,
33% nuclear, 33% geo, hydro, biofuels etc,
An increasing nuclear electricity demand

Numbers are from Jan 2009. In October 2010 441 are operating and 58 are under construction.
Some of the New Nuclear Power Aspirants

A tentative list as examples
From GENIV International Forum

- UAE
- Saudi Arabia
- Yemen
- Egypt
- Jordan
- Morocco
- Tunisia
- Libya
- Algeria
- Italy
- Turkey
- Poland/Latvia/Lithuania
- Kazakhstan
- Vietnam
- Indonesia
- Philippines
- Thailand
- Ghana
- Chile
Pre-Fukushima Expectation

- Large expansion in Asia
- Expansion in EU and US
- 1600 operating by 2050
- Fraction of world electricity doubled to 32%
Levelized Cost Comparison for Electric Power Generation With $100 per Ton Tax on Carbon (2010 Fuel Prices)

Source: Energy Modeling Forum 2010
Fukushima Accident
Fukushima Tsunami
Nuclear Accidents

Three Mile Island (1979) — A Partial Core Meltdown
- LWRs have containment building
- Little Radiation Offsite

Chernobyl (1986) — World’s Worst
- Reactor type not used outside of old Soviet bloc (can become unstable)
- Lots of radiation offsite

Fukushima (2011)
- Midway between – probably about 10% of Chernobyl; still being evaluated
Risk: Perception vs. Reality

Transportation

Deaths per Billion –Passenger-Kilometers

- Air: 0.05
- Bus: 0.4
- Rail: 0.6
- Van: 1.2
- Water: 2.6
- Car: 3.1
- Bicycle: 44.6
- Foot: 54.2
- Motorcycle: 108.9

Source: http://en.m.wikipedia.org/wiki/Air_safety

Electricity

Years of Life Lost per TWh

- Wind: 2.7
- Nuclear: 25
- Gas: 42
- PV: 58
- Coal: 305
- Oil: 359

Fukushima Impact

• Fukushima was and still is a serious incident
• There will be a rethinking of reactor safety and the setting of “design basis” threats.
• Gen III+ & SMRs – Safety by design
• Regulators will be given more power (India)
• The actual impact of Fukushima compared to other conventional electricity sources will be small, but radiation is feared and it is too soon to see the impact on public perception.
• Personal opinion – world wide impact will be small
An Essential Safety Requirement

• Independence of Regulators
  – US did it in 1974
  – India did it 2 weeks after Fukushima
  – Japan is doing it now
  – China has not yet done so.
Spent Fuel Disposal

• This is a Political Problem, Not a Technical One
• 1987 – Congress Forced Repository on Nevada (Texas and Washington have more political muscle)
• Other Counties have used a Consent Based System (Sweden, Finland, France)
• Blue Ribbon Commission Recommends Consent Based System
• We have one in New Mexico - WIPP
Summary

• Population increase and economic development will increase demand for energy by a large factor by 2100
• In business as usual scenarios global temperatures will increase creating serious environmental challenges, fossil fuels will get ever more costly, and security of supply will become a big issue
• Should move away from fossil fuels for reasons in all 3 dimensions - China has as much to gain as the US
• Efficiency, gas for coal, and nuclear are easy to implement in the shorter term – do it
• Wind and solar are limited to less than about 20-30% of electricity until better storage solutions are available
• International agreements should be modeled on Montreal Ozone Hole protocol rather than Kyoto
Back Up
Richter’s Laws of Government

Inaction

• 1st Law: The future is hard to predict because it hasn’t happened yet.

• 2nd Law: No matter how good a solution is, some will demand we wait for a better one.

• 3rd Law: Short-term pain is a deterrent to action no matter how much good that action will do in the long-term.

• 4th Law: The largest subsidies go to the least effective technologies.
Two International Climate Treaties

  - Signed by Reagan, Thatcher and many others
  - Origin in Vienna convention of 1985
  - Worked, economic impact small, everyone agreed

- Kyoto – Climate change (1997)
  - Divided world into two classes those who did nothing (developing), and those who did something Annex B (industrialized)
  - All missed targets EU, Canada, Japan, Russia etc plus US (nonsigner)
## Top 15 Emitters Represent 82% of World Emission

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (millions)</th>
<th>CO₂ Emissions (millions of tonne)</th>
<th>CO₂ Emission per Capita (kg per person)</th>
<th>CO₂ Emission per Dollar of GDP (2000 Dollars, market rates)</th>
<th>CO₂ Emission per Dollar (2000 Dollars, PPP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>People's Rep. of China</td>
<td>1,325.64</td>
<td>6,508.24</td>
<td>4.91</td>
<td>2.50</td>
<td>0.60</td>
</tr>
<tr>
<td>United States</td>
<td>304.56</td>
<td>5,595.92</td>
<td>18.38</td>
<td>0.48</td>
<td>0.48</td>
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<tr>
<td>European Union</td>
<td>498.92</td>
<td>3,849.53</td>
<td>7.72</td>
<td>0.32</td>
<td>0.31</td>
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<tr>
<td>Russian Federation</td>
<td>141.79</td>
<td>1,593.83</td>
<td>11.24</td>
<td>3.71</td>
<td>0.97</td>
</tr>
<tr>
<td>India</td>
<td>1,139.97</td>
<td>1,427.64</td>
<td>1.25</td>
<td>1.73</td>
<td>0.33</td>
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<tr>
<td>Japan</td>
<td>127.69</td>
<td>1,151.14</td>
<td>9.02</td>
<td>0.22</td>
<td>0.32</td>
</tr>
<tr>
<td>Canada</td>
<td>33.33</td>
<td>550.91</td>
<td>16.53</td>
<td>0.63</td>
<td>0.52</td>
</tr>
<tr>
<td>Islamic Rep. of Iran</td>
<td>71.96</td>
<td>505.01</td>
<td>7.02</td>
<td>3.15</td>
<td>0.86</td>
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<tr>
<td>Korea</td>
<td>48.61</td>
<td>501.27</td>
<td>10.31</td>
<td>0.67</td>
<td>0.44</td>
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<tr>
<td>Mexico</td>
<td>106.57</td>
<td>408.30</td>
<td>3.83</td>
<td>0.53</td>
<td>0.34</td>
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<tr>
<td>Australia</td>
<td>21.51</td>
<td>397.54</td>
<td>18.48</td>
<td>0.77</td>
<td>0.59</td>
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<tr>
<td>Saudi Arabia</td>
<td>24.65</td>
<td>389.16</td>
<td>15.79</td>
<td>1.54</td>
<td>1.04</td>
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<tr>
<td>Indonesia</td>
<td>228.25</td>
<td>385.38</td>
<td>1.69</td>
<td>1.56</td>
<td>0.43</td>
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<tr>
<td>Brazil</td>
<td>191.97</td>
<td>364.61</td>
<td>1.90</td>
<td>0.43</td>
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<tr>
<td>South Africa</td>
<td>48.69</td>
<td>337.42</td>
<td>6.93</td>
<td>1.84</td>
<td>0.63</td>
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<tr>
<td><strong>World</strong></td>
<td><strong>6,688.00</strong></td>
<td><strong>29,381.00</strong></td>
<td><strong>4.39</strong></td>
<td><strong>0.73</strong></td>
<td><strong>0.46</strong></td>
</tr>
</tbody>
</table>

International Energy Agency Key World Energy Statistics 2010
Wind Variability in Germany

Percentage of Electrical Demand Delivered by all the Wind Turbines of E.ON Energie during the year 2007. Averaged over the year, wind power delivered 18% of installed capacity. Figure courtesy of E.ON Energie.
A Common Local Problem

Water in Summer months comes from melting snow

- California – Sierra Nevada Mountains
- China – Tibetan Highlands
- Iran – Northern Mountains

Higher temperature means less snow and more rain in winter resulting in less water in the summer - an economic and security concern as well as an environmental one.
Other Renewables

- Big Hydro – not in favor by environmentalists
- Small Hydro – not a large source
- Hydrogen for Transportation – not ready
- Geothermal – good where there are sites
- Enhanced Geothermal – a failure so far
- Ocean systems – a good way to lose money
- Biofuels – corn ethanol is a farm subsidy; 2nd generation biofuels not ready for large scale use