Nuclear Power Made in France

The Model?

Mycle Schneider

International Consultant on Energy and Nuclear Policy

NPEC, 15 September 2008
1. General Context
2. Electricity, Primary Energy, Final Energy and Oil Myth
2. Overcapacities and Peak Load Trap
3. Electricity Trade
4. Plutonium Glut
5. Public Opinion
## Nuclear Power in the World

*By Country*

(as of September 2008)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Operate</th>
<th>Average Age</th>
<th>Under Construction</th>
<th>Planned</th>
<th>Share of Electricity</th>
<th>Share of Commercial Primary Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2</td>
<td>30</td>
<td>1</td>
<td>1</td>
<td>7% (=)</td>
<td>3%</td>
</tr>
<tr>
<td>Armenia</td>
<td>1</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>43% (=)</td>
<td>?%</td>
</tr>
<tr>
<td>Belgium</td>
<td>7</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>54% (=)</td>
<td>15%</td>
</tr>
<tr>
<td>Brazil</td>
<td>2</td>
<td>17</td>
<td>0</td>
<td>1</td>
<td>3% (=)</td>
<td>1%</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>2</td>
<td>19</td>
<td>2</td>
<td>0</td>
<td>44% (=)</td>
<td>16%</td>
</tr>
<tr>
<td>Canada</td>
<td>18</td>
<td>24</td>
<td>0</td>
<td>3</td>
<td>15% (=)</td>
<td>7%</td>
</tr>
<tr>
<td>China</td>
<td>11</td>
<td>7</td>
<td>6</td>
<td>24</td>
<td>2% (=)</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>6</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>30% (=)</td>
<td>14%</td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>29</td>
<td>1</td>
<td>0</td>
<td>29% (=)</td>
<td>20%</td>
</tr>
<tr>
<td>France</td>
<td>59</td>
<td>24</td>
<td>1</td>
<td>0</td>
<td>77% (=)</td>
<td>39%</td>
</tr>
<tr>
<td>Germany</td>
<td>17</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>26% (=)</td>
<td>10%</td>
</tr>
<tr>
<td>Hungary</td>
<td>4</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>37% (=)</td>
<td>14%</td>
</tr>
<tr>
<td>India</td>
<td>17</td>
<td>17</td>
<td>6</td>
<td>10</td>
<td>3% (=)</td>
<td>1%</td>
</tr>
<tr>
<td>Iran</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0% (=)</td>
<td>0%</td>
</tr>
<tr>
<td>Japan</td>
<td>55</td>
<td>23</td>
<td>1</td>
<td>12</td>
<td>28% (=)</td>
<td>12%</td>
</tr>
<tr>
<td>Korea RO (South)</td>
<td>20</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>35% (=)</td>
<td>14%</td>
</tr>
<tr>
<td>Lithuania</td>
<td>1</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>64% (=)</td>
<td>25%</td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>5% (=)</td>
<td>2%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>4% (=)</td>
<td>1%</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2</td>
<td>23</td>
<td>1</td>
<td>2</td>
<td>2% (=)</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Romania</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>9% (=)</td>
<td>4%</td>
</tr>
<tr>
<td>Russia</td>
<td>31</td>
<td>26</td>
<td>7</td>
<td>10</td>
<td>16% (=)</td>
<td>5%</td>
</tr>
<tr>
<td>Slovakia</td>
<td>5</td>
<td>20</td>
<td>0</td>
<td>2</td>
<td>54% (=)</td>
<td>20%</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>40% (=)</td>
<td>7%</td>
</tr>
<tr>
<td>South Africa</td>
<td>2</td>
<td>24</td>
<td>0</td>
<td>1</td>
<td>5% (=)</td>
<td>2%</td>
</tr>
<tr>
<td>Spain</td>
<td>8</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>17% (=)</td>
<td>8%</td>
</tr>
<tr>
<td>Sweden</td>
<td>10</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>46% (=)</td>
<td>30%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>5</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td>40% (=)</td>
<td>22%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>6</td>
<td>27</td>
<td>2</td>
<td>0</td>
<td>19% (=)</td>
<td>8%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>15</td>
<td>20</td>
<td>2</td>
<td>0</td>
<td>48% (=)</td>
<td>15%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>19</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>15% (=)</td>
<td>7%</td>
</tr>
<tr>
<td>USA</td>
<td>104</td>
<td>29</td>
<td>1</td>
<td>12</td>
<td>19% (=)</td>
<td>8%</td>
</tr>
<tr>
<td>EU27</td>
<td>146</td>
<td>25</td>
<td>4</td>
<td>4</td>
<td>28% (=)</td>
<td>12%</td>
</tr>
<tr>
<td>Total</td>
<td>439</td>
<td>24</td>
<td>35</td>
<td>87</td>
<td>14% (=)</td>
<td>&lt;6%</td>
</tr>
</tbody>
</table>


+ 5 countries (11 units)
= 15 countries stable
– 11 countries, incl. France (218 units or 50%)
Nuclear France

• 58 PWR
• 1 FBR
• ca. 260 Facilities with >1 SQs of Nuclear Material
Final Energy Consumption in France in 2007
73% fossil fuels, 16% nuclear

- Renewables + Waste (thermal) 7%
- Electricity 21% (of which 16% nuclear power)
- Coal 4%
- Oil 48%
- Gas 21%

### Adjusted Level of French Energy Independence in 2007

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Mtoe</th>
<th>Level of Energy Independence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Primary Energy Generation + other Primary Energies (Renewables, etc)</td>
<td>114.6</td>
<td>21.8</td>
</tr>
<tr>
<td>a) Electricity exports 56.8 TWh</td>
<td>- 4.9</td>
<td></td>
</tr>
<tr>
<td>b) Nuclear auto-consumption ca. 18 TWh</td>
<td>- 1.6</td>
<td></td>
</tr>
<tr>
<td>Primary Energy Generation/Independence</td>
<td>129.9</td>
<td>48.0%</td>
</tr>
<tr>
<td>c) Nuclear final energy contribution + Renewables + Coal, oil, gas</td>
<td>28.7</td>
<td>11.9</td>
</tr>
<tr>
<td>Final Energy Generation/Independence I</td>
<td>42.6</td>
<td>23.9%</td>
</tr>
<tr>
<td>d) - Uranium imports</td>
<td>- 28.7</td>
<td></td>
</tr>
<tr>
<td>e) + Plutonium &amp; reprocessed uranium credit</td>
<td>+1.3</td>
<td></td>
</tr>
<tr>
<td>Final Energy Generation/Independence II</td>
<td>15.2</td>
<td>8.5%</td>
</tr>
</tbody>
</table>

*Source: Mycle Schneider Consulting*
CO2 Emissions by Sector in France
from 1970 to 2004 (million tons of carbon)

Source: Observatoire de l’Energie, DGEMP, 2001; MIES 2004; CITEPA 2006
Electricity Consumption in France 1990-2007

- Total: 323 TWh
- Nuclear: 344 TWh (+43%)
- Fossil Fuels: 45 TWh (+24%)
- Hydro: 36 TWh
- Other Renewables: 240 TWh

Washington DC, September 2008
Load Demand on the French Electric Network, Annual Minima and Maxima per Day, 1978-

French Electricity Trade 2001-2007

RTE, Statistiques 2007, 2008
### EDF Restarts 30-Year Old Oil Fired Power Plants

<table>
<thead>
<tr>
<th>Oil Plant</th>
<th>Capacity</th>
<th>Original Start-up</th>
<th>Mothballed</th>
<th>Restart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcheville-1</td>
<td>600 MW</td>
<td>1968</td>
<td>1995</td>
<td>2008</td>
</tr>
<tr>
<td>Cordemais-3</td>
<td>700 MW</td>
<td>1976</td>
<td>?</td>
<td>2007</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2600 MW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EDF operates its oil fired power plants between 200 h et 1500 h per year.
AREVA’s Representation of the « Fuel Cycle »

Source: www.areva.com
Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium $\text{UF}_6$
- Enriched Uranium $\text{UO}_2$
- Uranium Fuel $\text{UOX}$
- Spent Uranium Fuel
- Depleted Uranium $\text{U}_3\text{O}_8$
- Uranium Tailings
- Storage Disposal

Categories:
- VLLW
- LLW
- HLW
Wastes and Materials Generated in the Fuel Chain

**Uranium Fuel Chain**

- **Fuel fabrication**
  - Mining
  - Milling
  - Conversion
  - Enrichment
- **Reactor use**
- **Reprocessing**
  - Storage
  - Disposal
- **Wastes and Materials**
  - Uranium Ore
  - Natural Uranium $\text{UF}_6$
  - Enriched Uranium $\text{UO}_2$
  - Uranium Fuel $\text{UOX}$
  - Depleted Uranium $\text{U}_3\text{O}_8$
  - Spent Uranium Fuel
- **Wastes**
  - Uranium Tailings $\sim\text{VLLW}$
  - Depleted Uranium $\sim\text{LLW}$
  - Spent Uranium Fuel $\text{HLW}$

**AREVA NC La Hague**

- 750 acres
- 6,000 people

Washington DC, September 2008
Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium $\text{UF}_6$
- Enriched Uranium $\text{UO}_2$
- Uranium Fuel $\text{UO}_x$
- Spent Uranium Fuel
- Depleted Uranium $\text{U}_3\text{O}_8$
- Uranium Tailings
- Reprocessing
- Spent Uranium Fuel
- Vitrified Waste
- Structure Waste
- Process Waste
- Storage/Disposal
- ~VLLW
- ~LLW
- HLW
- HLW
- ILW
- ILW
- Uranium Fuel Chain
- Reprocessing
Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium UF₆
- Enriched Uranium UO₂
- Uranium Fuel UOX
- Depleted Uranium UO₂
- MOX Fuel
- Separated Plutonium PuO₂
- Vitrified Waste
- Structure Waste
- Process Waste
- MOX Scrap
- Spent MOX
- Spent Uranium Fuel
- Vapours and Gases
- Uranium Tailings
- Depleted Uranium U₃O₈
- Separated Plutonium PuO₂

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Mycle Schneider Consulting
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Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium UF₆
- Enriched Uranium UO₂
- Uranium Fuel UOX
- Reprocessed Uranium UF₆
- Depleted Uranium UO₂
- MOX Fuel
- Separated Plutonium PuO₂
- Spent MOX
- Spent RE-RepU Fuel
- Depleted RE-RepU U₃O₈
- Reprocessed Uranium U₃O₈
- Depleted U₃O₈
- Separated Plutonium

Flow paths:
- Uranium Fuel Chain
- Reprocessing
- Plutonium Re-use
- Uranium Re-use
Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium $U\text{F}_6$
- Enriched Uranium $UO_2$
- Uranium Fuel $UO_X$
- Spent Uranium Fuel
- Depleted Uranium $U_3O_8$
- Vitrified Waste
- Structure Waste
- Process Waste
- Separated Plutonium $PuO_2$
- MOX Scrap
- MOX Fuel
- Spent MOX
- Depleted RE-RepU $U_3O_8$
- Reprocessed Uranium $U_3O_8$
- Depleted RE-RepU $U_2O_8$
- Depleted RE-RepU Fuel
- Spent RE-RepU Fuel
- Operational Waste
- ILW
- LLW
- HLW

- Uranium Fuel Chain
- Reprocessing
- Plutonium Re-use
- Uranium Re-use
- Operation
Wastes and Materials Generated in the Fuel Chain

- Uranium Ore
- Natural Uranium UF₆
- Enriched Uranium UO₂
- Uranium Fuel UOX
- Reprocessed Uranium U Oxide
- Separated Plutonium PuO₂
- MOX Fuel
- Spent MOX
- Spent Uranyl Oxide
- Depleted Uranium U₃O₈
- Reprocessed Uranium U Oxide
- Re-RepU Fuel
- Depleted RE-RepU Fuel
- Spent RE-RepU Fuel
- Re-RepU U Oxide
- Decommissioning Waste
- Operational Waste

Fuel fabrication:
- U3O8
- MOX
- Scrape
- Separated Plutonium PuO₂
- Process Waste
- Vitriified Waste
- Spent Uranium Fuel
- Depleted Uranium U3O8
- Spent Uranium Oxide
- Uranium Tailings
- Vitrified Waste
- Structure Waste
- Mining Milling

Conversion Enrichment:
- Uranium Ore
- Natural Uranium UF₆
- Enriched Uranium UO₂

Reprocessing:
- Uranium Fuel UOX
- Reprocessed Uranium U Oxide
- Separated Plutonium PuO₂
- MOX Fuel
- Spent MOX
- Spent Uranyl Oxide
- Depleted Uranium U₃O₈
- Reprocessed Uranium U Oxide
- Re-RepU Fuel
- Depleted RE-RepU Fuel
- Spent RE-RepU Fuel
- Re-RepU U Oxide

Decommissioning:
- Decommissioning Waste
- Operational Waste

Operation:
- Uranium Fuel Chain
- Reprocessing
- Plutonium Re-use
- Uranium Re-use

Storage Disposal:
- Uranium Tailings
- Depleted Uranium U₃O₈
- Spent Uranium Fuel
- Vitrified Waste
- Structure Waste
- Process Waste
- Spent MOX
- Depleted RE-RepU U₃O₈
- Vitrified Waste
- HLW
- LLW
- ILW

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Mycle Schneider Consulting
Washington DC, September 2008
Separated Plutonium Shipments in France

Source: WISE-Paris
Fresh MOX Shipments in France

Source: WISE-Paris
Foreign Spent Fuel Stored at La Hague
as of 31 December 2007, in kilograms (!)

<table>
<thead>
<tr>
<th>Pays</th>
<th>Entreposés (kg ML)</th>
<th>Traitements prévus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allemagne</td>
<td>63</td>
<td>2008</td>
</tr>
<tr>
<td>Australie</td>
<td>140</td>
<td>jusqu’en 2010</td>
</tr>
<tr>
<td>Belgique</td>
<td>440</td>
<td>jusqu’en 2012</td>
</tr>
<tr>
<td>Suisse</td>
<td>5 273</td>
<td>2008</td>
</tr>
</tbody>
</table>

Note: Total quantity stored: 8,849 tons (!), 99.8% French.  

Source: AREVA NC, March 2008
Number of « Moxed » Reactors in France 1987 - 2007
Growth of French Separated Plutonium Stock

Metric Tons

- **Estimated Data**
- **Official Data**

- 1988
- 1989
- 1990
- 1991
- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005

Washington DC, September 2008
Public Opinion on Nuclear Power in the EU

- The share of nuclear energy should be increased, as it does not contribute to climate change and global warming.
- The share of nuclear energy should be decreased, as it poses safety problems like nuclear waste, or the danger of accidents.

Q9. One third of EU electricity comes from nuclear energy. Regarding nuclear energy there are two fundamental approaches, which one do you tend to agree more with? %, Base: all respondents, by country.
“The European public is still strongly opposed to the use of nuclear power; those who are worried about climate change are even more fiercely opposed.”

Conclusions

• Nuclear power covers 77% of electricity, <40% of primary energy; only 16% of final energy (oil still covers about half);
• France consumes more oil per capita than Germany, the UK, Italy or the EU on average and EDF reactivates 2,600 MW of 30- to 40-year old oil fired power plants;
• France accumulates a record foreign trade deficit of over $70 billion in 2007, Germany hits a record trade surplus of over $300 billion;
• EPR construction in Finland: after three years construction, two years behind schedule and 50% or $2.2 billion over budget; similar problems at the French Flamanville site; safety authorities halted concreting for almost two months because of significant quality control issues;
• France has piled up >50 tons of plutonium, which has no book value;
• Negligible new foreign reprocessing (Italy, 250t) and EDF did not sign up for a new long term contract yet because of increasing cost pressure.
• French public is as skeptical as in the rest of Europe.