Mathematical modeling of long-term energy sources mix dynamics

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Summary

• Why is very long term energy view needed?
• Modeling of energy supply chain
• Mathematical representation
• Case study
• Energy resources - reserves
• Present global energy trends
• Results
• Hypothesized global energy trends
• Role of nuclear energy
• Towards a sustainable energy era
Why is very long term energy view needed?

• To achieve a better consciousness of the criticality of a correct management of the energy problem for ensuring human species’ life development and survival

• It can help in evaluating the correct size and dynamics of energy crises, in spite of uncertainties

• To anticipate large and irreversible energy crises that could threaten survival of future generations
Why is very long term energy view needed?

• To forecast what will happen in the long term, in order to support decisions to make now: what seems good now, could be bad in the long term
• Return of infrastructures’ investments requires a long term view of energy supply chain dynamics
• Long term view allows to better absorb short term economy and energy prices fluctuations
• Moral duty to leave a sustainable world to future generations
Modeling of energy supply chain

• The energy supply chain can be schematized in a series of three major systems: production, logistics and final uses.
Simplyfication of energy supply chain model

• For the purpose of the present work the energy supply chain can be simplyfied, including the production system in the logistic system, thus leaving in input only the primary energy sources:

Primary Energy Sources → Logistics → Final uses
Scopes of the model

• Time dependent simulation and resources time duration estimation

• Individuation of logistic system critical behaviour: capacity overload; underload and utilization factor; need for expansion, reconfiguration, dismissal

• Analysis of time dependent logistics versus production mix or final energy uses variations

• Input to economical analysis of risk or profitability of existing or needed investments
Limits of the model

- No material flows: all flows are converted into energy flows
- Short-time logistic delays not considered because of the long term view
- Logistic system energy losses (consumption) can be incorporated into the final energy uses or in an overall logistic efficiency
Building blocks

\[ E_{stIN} \rightarrow \text{storage} \rightarrow E_{stOUT} \]
\[ E_{stIN} \rightarrow E_{stLOSS} \]

\[ E_{TIN} \rightarrow \text{Transport} \rightarrow E_{TOUT} \]
\[ E_{TIN} \rightarrow E_{TLOSS} \]

\[ E_{TRIN} \rightarrow \text{Transformation} \rightarrow E_{TROUT} \]
\[ E_{TRIN} \rightarrow E_{TRLOSS} \]
Mathematical representation

• Balance equations
• Reduction equations
• Matrix representation
• Matrix equations
• Constraints
• Primary resources equations
Balance Equations

- Balance equations of these types can be written for the aggregation of primary energy resources or final energy uses production rates, at different levels. For example at the region level of aggregation:

\[ R_{pi} = \sum_{k=1}^{N_R} R_{pik} \]

\[ R_{cj} = \sum_{k=1}^{N_R} R_{cjk} \]
Balance Equations

\[ R_{K1_{IN}} \]
\[ R_{K2_{IN}} \]
\[ R_{K3_{IN}} \]
\[ R_{K_{OUT}} \]
Reduction equations

\[ E_{st1_{IN}} \rightarrow \text{Storage 1} \rightarrow E_{st1_{OUT}} \]

\[ E_{st1_{LOSS}} \]

\[ E_{st2_{IN}} \rightarrow \text{Storage 2} \rightarrow E_{st2_{OUT}} \]

\[ E_{st2_{LOSS}} \]

\[ C_{st_{IN}} = C_{st1_{IN}} + C_{st2_{IN}} \]

\[ E_{st_{IN}} = E_{st1_{IN}} + E_{st2_{IN}} \rightarrow \text{Storage 1+ 2} \rightarrow E_{st_{OUT}} = E_{st1_{OUT}} + E_{st2_{OUT}} \]

\[ E_{st_{LOSS}} = E_{st1_{LOSS}} + E_{st2_{LOSS}} \]
Logistic matrix

- Element represents: energy repartition coefficient, energy flow rate, logistics efficiency, maximum capacity, time dependence
- Matrix can be divided into submatrices according to: primary energy source, final use, country, region, subregion, plant
Matrix Representation

\[
R_p(t) = \begin{bmatrix}
R_{p1}(t) \\
\vdots \\
R_{pi}(t) \\
\vdots \\
R_{pN_s}(t)
\end{bmatrix}
\]

\[
R_c(t) = \begin{bmatrix}
R_{c1}(t) \\
\vdots \\
R_{cl}(t) \\
\vdots \\
R_{cN_{FE}}(t)
\end{bmatrix}
\]

\[
M = \begin{bmatrix}
m_{11} & \cdots & m_{1N_{FE}} \\
\vdots & \ddots & \vdots \\
m_{N_s1} & \cdots & m_{N_sN_{FE}}
\end{bmatrix}
\]
Matrix Equations

\[ R_p(t) = M \cdot R_c(t) \]

\[ R_{pi}(t) = \sum_{l=1}^{N_{FE}} m_{il} \cdot R_{cl}(t) \]
Constraints

• Capacity constraints are taken into account for each block or aggregate of the logistic system:

\[ m_{il} \cdot R_{cl}(t') \leq C_{il}(t) \]

\[ m_{il} = \text{PARTITION COEFFICIENT} \]
Primary resources equations

- Resource i discovery rate
  \[ R_{d_i}(t) \]

- Discovered amount of resource i
  \[ S_i(t) = \int_0^t R_{d_i}(t) dt \]
Primary resources equations

• Resource $i$ production rate

\[ R_{pi}(t) \]

• Remaining amount of resource $i$

\[ S_i(t) = \int_0^t R_{di}(t)\,dt - \int_0^t R_{pi}(t)\,dt \]
Primary resources equations

- Ultimate available amount of resource $i$

$$S_{i\infty}(t) = \int_0^{\infty} R_{d_i}(t) dt$$
Energy balance of supply chain

• The energy supply chain satisfies the following macro energy balance equation:
  Primary energy production = Logistics energy loss + Final energy uses
Case study

- Aggregation at world level
- Final energy trend imposed
- Primary energy rate (net/gross) as output
- Logistics system evolution, assuming no time change of the logistic system structure, but only proportional capacity increase
- Time evolution of specific elements of the logistic system
## Oil & Gas Reserves and Resources

### World Ultimately Recoverable Conventional Oil and NGL Resources, end 2007 (WEO 2008) (billion barrels)

<table>
<thead>
<tr>
<th>Remaining Reserves</th>
<th>Remaining Recoverable Resources</th>
<th>Current average daily production (mb/d)</th>
<th>Current year production (mb/y)</th>
<th>Remaining Reserves Time Duration (y)</th>
<th>Remaining Recoverable Resources Time Duration (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1241</td>
<td>2449</td>
<td>84.3</td>
<td>30769.5</td>
<td>40.33</td>
<td>79.59</td>
</tr>
</tbody>
</table>

### World Ultimately Recoverable Conventional Natural Gas Resources, end 2007 (WEO 2008) (tcm)

<table>
<thead>
<tr>
<th>Remaining Reserves</th>
<th>Remaining Recoverable Resources</th>
<th>Current average daily production (bcm/d)</th>
<th>Current year production (bcm/y)</th>
<th>Remaining Reserves Time Duration (y)</th>
<th>Remaining Recoverable Resources Time Duration (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>178.8</td>
<td>380</td>
<td>7.9</td>
<td>2916</td>
<td>61.32</td>
<td>130.32</td>
</tr>
</tbody>
</table>
# Coal Reserves

<table>
<thead>
<tr>
<th>Ultimately Recoverable Resources</th>
<th>Remaining Reserves</th>
<th>Remaining Recoverable Resources</th>
<th>Current production (MTCE/y)</th>
<th>Remaining Reserves Time Duration (y)</th>
<th>Remaining Recoverable Resources Time Duration (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>736</td>
<td></td>
<td>4396</td>
<td>167.62</td>
<td></td>
</tr>
</tbody>
</table>
# Uranium Identified Resources

<table>
<thead>
<tr>
<th>Resource category</th>
<th>2005</th>
<th>2007</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identified (Total)</td>
<td>4743</td>
<td>5469</td>
<td>726</td>
</tr>
<tr>
<td>&lt;USD 130/kgU</td>
<td>3804</td>
<td>4456</td>
<td>652</td>
</tr>
<tr>
<td>&lt;USD 80/kgU</td>
<td>&gt; 2746</td>
<td>2970</td>
<td>224</td>
</tr>
<tr>
<td>RAR</td>
<td>3297</td>
<td>3338</td>
<td>41</td>
</tr>
<tr>
<td>&lt;USD 130/kgU</td>
<td>2643</td>
<td>2598</td>
<td>-45</td>
</tr>
<tr>
<td>&lt;USD 80/kgU</td>
<td>&gt; 1947</td>
<td>1766</td>
<td>-181</td>
</tr>
<tr>
<td>Inferred Resources</td>
<td>1446</td>
<td>2130</td>
<td>684</td>
</tr>
<tr>
<td>&lt;USD 130/kgU</td>
<td>1161</td>
<td>1858</td>
<td>697</td>
</tr>
<tr>
<td>&lt;USD 40/kgU</td>
<td>&gt; 799</td>
<td>1204</td>
<td>40</td>
</tr>
</tbody>
</table>
# Uranium Undiscovered Resources

<table>
<thead>
<tr>
<th>Undiscovered Resources (1000 tU)</th>
<th>2005</th>
<th>2007</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource category</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10015</td>
<td>10539</td>
<td>485</td>
</tr>
<tr>
<td>Prognosticated Resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;USD 130/kgU</td>
<td></td>
<td>2769</td>
<td></td>
</tr>
<tr>
<td>&lt;USD 80/kgU</td>
<td></td>
<td>1946</td>
<td></td>
</tr>
<tr>
<td>Speculative Resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost range unassigned</td>
<td></td>
<td>2973</td>
<td></td>
</tr>
<tr>
<td>&lt;USD 130/kgU</td>
<td></td>
<td>4797</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7770</td>
<td></td>
</tr>
<tr>
<td>Conventional Resources (Identified + Undiscovered)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (1000 t U)</td>
<td></td>
<td>16008</td>
<td></td>
</tr>
</tbody>
</table>
# Uranium Unconventional Resources

<table>
<thead>
<tr>
<th>Resource category</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uranium Phosphates</strong></td>
<td>22000</td>
</tr>
<tr>
<td><strong>Rocks</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Seawater</strong></td>
<td>4200000</td>
</tr>
</tbody>
</table>
# Uranium Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Pre-2004</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>Total to 2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2112349</td>
<td>40188</td>
<td>41943</td>
<td>39603</td>
<td>2234083</td>
<td>43328</td>
</tr>
</tbody>
</table>
Present Global Energy Trends

• Population
• Demand
• Production
• Growth rates
• Energy Era Indicators
• Remaining Resources Duration
• Climate
Population Growth Distribution

Source: IEA 2008
Results of case study

Starting from input final energy uses trend, the following results are obtained:

- output net primary energy
- output gross primary energy
- capacity changes required on specific elements of the logistic system
- energy era indicators
Input final energy uses trend

![World final energy trend 2007-2030](image)
Output net primary energy

World net primary energy demand 2007-2030

- MTOE
- Year
- coal
- oil
- gas
- hydro
- nuclear
- elect
- biofuel
- other
- total

- 2005
- 2010
- 2015
- 2020
- 2025
- 2030
- 2035

- 8.083
- 9.557
- 11.403

- 0
- 2000
- 4000
- 6000
- 8000
- 10000
- 12000

- coal
- oil
- gas
- hydro
- nuclear
- elect
- biofuel
- other
- total
Output gross primary energy

World gross primary energy demand 2007-2030

Year
MTOE
coal
oil
gas
hydro
nuclear
elect
biofuel
other	totale

2005  2010  2015  2020  2025  2030  2035

11.729
14.120
17.012

17.012
Specific logistic capacity change

Oil in transport

Year

MTOE

2005 2010 2015 2020 2025 2030 2035

0 500 1000 1500 2000 2500 3000 3500

oil
Specific logistic capacity change

Nuclear in industry

MTOE

Year

2000 2010 2020 2030 2040

0 50 100 150 200 250 300 350

nuclear
Specific logistic capacity change

Gas in residential

MTOE

Year

2005 2010 2015 2020 2025 2030 2035

Gas in residential
Energy Era Indicators

- Population
- Population growth rate
- GDP per capita and GDP growth rate
- Primary Energy per capita
- Resources Consumption rate/Formation rate
- Spent/Remaining resources
- Time to resources final exhaust
- Resource substitution potential
**End of the Easy Energy Era**

**Scenario A**

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2030</th>
<th>2050</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population growth rate (%)</td>
<td>1,3000</td>
<td>1,0000</td>
<td>0,0000</td>
<td>0,0000</td>
</tr>
<tr>
<td>Population (billion)</td>
<td>6,7000</td>
<td>8,9019</td>
<td>10,8620</td>
<td>10,8620</td>
</tr>
<tr>
<td>GDP Growth Rate (%)</td>
<td>1,1000</td>
<td>1,1000</td>
<td>1,0000</td>
<td>1,0000</td>
</tr>
<tr>
<td>GDP per capita ($ 2007)</td>
<td>6716</td>
<td>6430</td>
<td>6559</td>
<td>8003</td>
</tr>
<tr>
<td>Primary Energy Demand Growth Rate (%)</td>
<td>1,6415</td>
<td>1,6000</td>
<td>1,6000</td>
<td></td>
</tr>
<tr>
<td>Primary Energy Demand (MTOE)</td>
<td>11700</td>
<td>17014</td>
<td>23745</td>
<td>33140</td>
</tr>
<tr>
<td>Primary energy per capita (TOE)</td>
<td>1,74</td>
<td>1,91</td>
<td>2,18</td>
<td>3,05</td>
</tr>
<tr>
<td>Primary Energy Sources Formation Rate Growth (%)</td>
<td>-1,0000</td>
<td>-1,0000</td>
<td>-2,0000</td>
<td></td>
</tr>
<tr>
<td>Remaining Resources (GTOE)</td>
<td>908,40</td>
<td>787,15</td>
<td>506,03</td>
<td>37,85</td>
</tr>
<tr>
<td>Time to final exhaust (y)</td>
<td>77,64</td>
<td>46,26</td>
<td>21,31</td>
<td>1,14</td>
</tr>
<tr>
<td>Resources substitution potential</td>
<td>1,0000</td>
<td>0,5959</td>
<td>0,2745</td>
<td>0,0147</td>
</tr>
</tbody>
</table>
## End of the Easy Energy Era

### Scenario B

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2030</th>
<th>2050</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population growth rate (%)</td>
<td>1,3000</td>
<td>0,5000</td>
<td>0,0000</td>
<td>1,0000</td>
</tr>
<tr>
<td>Population (billion)</td>
<td>6,7000</td>
<td>8,9019</td>
<td>9,8357</td>
<td>9,8357</td>
</tr>
<tr>
<td>GDP Growth Rate (%)</td>
<td>1,1000</td>
<td>1,1000</td>
<td>1,0000</td>
<td>1,0000</td>
</tr>
<tr>
<td>GDP per capita ($ 2007)</td>
<td>6716,4179</td>
<td>6430,6569</td>
<td>7243,6459</td>
<td>8838,6246</td>
</tr>
<tr>
<td>Primary Energy Demand Growth Rate (%)</td>
<td>1,6415</td>
<td>1,0000</td>
<td>0,1000</td>
<td></td>
</tr>
<tr>
<td>Primary Energy Demand (MTOE)</td>
<td>11700</td>
<td>17014</td>
<td>20968</td>
<td>21413</td>
</tr>
<tr>
<td>Primary energy per capita (TOE)</td>
<td>1,74</td>
<td>1,91</td>
<td>2,13</td>
<td>2,17</td>
</tr>
<tr>
<td>Primary Energy Sources Formation Rate Growth (%)</td>
<td>-2,0000</td>
<td>-4,0000</td>
<td>-4,0000</td>
<td></td>
</tr>
<tr>
<td>Remaining Resources (GTOE)</td>
<td>908,40</td>
<td>808,31</td>
<td>539,76</td>
<td>115,37</td>
</tr>
<tr>
<td>Time to final exhaust (y)</td>
<td>77,64</td>
<td>47,50</td>
<td>25,74</td>
<td>5,38</td>
</tr>
<tr>
<td>Resources substitution potential</td>
<td>1,0000</td>
<td>0,6119</td>
<td>0,3315</td>
<td>0,0694</td>
</tr>
</tbody>
</table>
Swenson Curve

Growth in Demand

Conservation

Lifestyle Change

Substitution

Deprivation?
Hypothesized Future Global Energy Trends

- Population growth continues at decreasing rate
- Increasing GDP and primary energy per capita
- Increasing energy consumption by non-OECD countries
- Rapid consumption of fossil energy resources and final exhaust
- Substitution of fossil fuels in a relatively short term
- Increasing importance of mix of renewables and nuclear energy
Role of nuclear energy

- Mitigating the fossil fuels depletion consequences
- Improving environmental conditions (contributing to climate change control)
- Coping with a variety of applications (heat, process, electricity, fuels and hydrogen production, water desalination)
- Giving a very long term response to the planet’s energy needs?
## World Uranium Demand

<table>
<thead>
<tr>
<th>World Uranium Demand (t U)</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of reactors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>439</td>
</tr>
<tr>
<td>In construction</td>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>41</td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Connected to the grid</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Electric Power (Gwe)</td>
<td></td>
<td></td>
<td></td>
<td>370.23</td>
<td>372.2</td>
</tr>
<tr>
<td>Global Electric Energy (TWh)</td>
<td>2524</td>
<td>2638</td>
<td>2630</td>
<td>2675</td>
<td></td>
</tr>
<tr>
<td>Annual Uranium requirements (t U)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66500</td>
</tr>
</tbody>
</table>
World Uranium Supply

<table>
<thead>
<tr>
<th>Source</th>
<th>Amount (t U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Sources of Uranium Supply in 2006</td>
<td>39603</td>
</tr>
<tr>
<td>Secondary Sources of Uranium Supply</td>
<td></td>
</tr>
<tr>
<td>Stock and inventories on natural and enriched Uranium</td>
<td>26897</td>
</tr>
<tr>
<td>Reprocessing of spent fuel and surplus of military Pu</td>
<td></td>
</tr>
<tr>
<td>Re-enrichment of depleted Uranium tails</td>
<td></td>
</tr>
<tr>
<td>Total (t U)</td>
<td>66500</td>
</tr>
</tbody>
</table>
## Uranium Resources Duration at present consumption rates

<table>
<thead>
<tr>
<th>Resource category</th>
<th>2007 Resources duration (y) with Global Reactor Consumption in 2006 (t U)</th>
<th>2030 total</th>
<th>2030 primary</th>
<th>2030 low case</th>
<th>2030 high case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Reactor Consumption (t U)</td>
<td>66500</td>
<td>39603</td>
<td>93775</td>
<td>121995</td>
<td></td>
</tr>
<tr>
<td>Identified (Total) &lt;USD 130/kgU</td>
<td>5469</td>
<td>82</td>
<td>138</td>
<td>58</td>
<td>44</td>
</tr>
<tr>
<td>Undiscovered Resources (1000 tU)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10539</td>
<td>158</td>
<td>266</td>
<td>112</td>
<td>86</td>
</tr>
<tr>
<td>Conventional Resources (Identified + Undiscovered) Total (1000 tU)</td>
<td>16008</td>
<td>240</td>
<td>404</td>
<td>170</td>
<td>131</td>
</tr>
<tr>
<td>Unconventional Resources (1000 tU)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranium Phosphates Rocks</td>
<td>22000</td>
<td>330</td>
<td>555</td>
<td>234</td>
<td>180</td>
</tr>
<tr>
<td>Seawater</td>
<td>4200000</td>
<td>63157</td>
<td>106052</td>
<td>44788</td>
<td>34427</td>
</tr>
</tbody>
</table>
## Uranium Resources Duration with Fossil Fuels Substitution

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2030</th>
<th>2050</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population growth rate (%)</td>
<td>1,3000</td>
<td>0,5000</td>
<td>0,0000</td>
<td>1,0000</td>
</tr>
<tr>
<td>Population (billion)</td>
<td>6,7000</td>
<td>8,9019</td>
<td>9,8357</td>
<td>9,8357</td>
</tr>
<tr>
<td>Primary Energy Demand Growth Rate (%)</td>
<td>1,64</td>
<td>1,00</td>
<td>0,10</td>
<td>0,00</td>
</tr>
<tr>
<td>Primary Energy Demand (MTOE)</td>
<td>11700</td>
<td>17014</td>
<td>20968</td>
<td>21413</td>
</tr>
<tr>
<td>Primary Energy Demand (1000 GWh)</td>
<td>52466</td>
<td>76298</td>
<td>94029</td>
<td>96024</td>
</tr>
<tr>
<td>Number of operating reactors (LWR 1GW)</td>
<td>6558</td>
<td>9537</td>
<td>11754</td>
<td>12003</td>
</tr>
<tr>
<td>Nuclear Fuel (U) consumption rate (tU)</td>
<td>1003419</td>
<td>1459207</td>
<td>1798315</td>
<td>1836459</td>
</tr>
<tr>
<td>Remaining Uranium considering Conventional Resources (1000 tU)</td>
<td>16008</td>
<td>-11985</td>
<td>-18072</td>
<td>-22155</td>
</tr>
<tr>
<td>Time to final Uranium Exhaust (y)</td>
<td>15,95</td>
<td>-8,21</td>
<td>-10,04</td>
<td>-12,06</td>
</tr>
<tr>
<td>Remaining Uranium considering Conventional+ Phosphates Resources (1000 tU)</td>
<td>38008</td>
<td>10014</td>
<td>3927</td>
<td>-1557</td>
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<tr>
<td>Time to final Uranium Exhaust (y)</td>
<td>37,87</td>
<td>6,86</td>
<td>2,18</td>
<td>-0,08</td>
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<tr>
<td>Remaining Uranium considering unconventional resources (1000 tU)</td>
<td>4238008</td>
<td>4210014</td>
<td>4203927</td>
<td>4199844</td>
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<tr>
<td>Time to final Uranium Exhaust (y)</td>
<td>4223</td>
<td>2885</td>
<td>2337</td>
<td>2286</td>
</tr>
</tbody>
</table>
Towards a Sustainable Energy Era

• In order to cope with the depletion and final exhaust of fossil primary energy sources, a variety of choices should be exploited: energy efficiency improvement, use of nuclear energy and CFC Fast Breeder Reactors, combined with all renewables seems to be the most promising mix.

• Based upon the simulations presented there is evidence of huge energy needs that could not be satisfied with any of the energy sources we are using or we know at present, unless a drastic reduction of final energy consumption is achieved in all sectors.

• A Global Nuclear Fuel Cycle infrastructure should be developed to match the needs of the energy production system within a planetary energy governance agreement in order to cope with the very difficult decisions to tackle.
Thank You very much for your patient attention and for your questions!

Спасибо за внимание
Primary Energy Demand 1980-2030
Forecast WEO 2008

- **Oil**
- **Gas**
- **Coal**
- **Nuclear**
- **Hydro**
- **Biomass and Waste**
- **Other Renewables**
- **Total**

- **Mtoe**: 7224, 10032, 11730, 14122, 17014

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**Graph Details**
- **Primary Energy Demand**
- **Graph Title**: Primary Energy Demand 1980-2030
- **Forecast WEO 2008**
- **X-axis**: Year (1980-2030)
- **Y-axis**: Mtoe
- **Data Points**: 1980 (7224 Mtoe), 1990 (10032 Mtoe), 2000 (11730 Mtoe), 2010 (14122 Mtoe), 2020 (17014 Mtoe)
- **Legend**: Oil, Gas, Coal, Nuclear, Hydro, Biomass and Waste, Other Renewables, Total
Primary Energy Demand and GDP

Source IEA 2002