The possible role of fusion power in a future sustainable global energy system using the EFDA TIMES global energy model

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INTRODUCTION

The EFDA Times model (ETM) has been built in the framework of the European Fusion Development Agreement.

ETM background (2004): ORDECSYS, KanORS, HALOA and KUL\(^{[1]}\)

ETM participants are EURATOM Associations: CCFE (UK), CIEMAT (ES), ENEA (IT), IPP (GE), IST (PT), ÖAW (AU), RISO DTU (DK) and VTT (FI)

Special mention to GC Tosato who, while being the EFDA Socio-Economic Office leader, fostered the ETM construction

DESCRIPTION

The EFDA Times Model (ETM) is a multi-regional, global and long-term energy model of economic equilibrium, responsive to energy technology innovations, domestic and international trade energy policies, climate change mitigation and environment objectives.

\(^{[1]}\) Ordecsys, KanORS, HALOA and KUL. EFDA World TIMES Model. FINAL REPORT and Annexes (2004)
- 15 world regions: Africa, Australia-New Zealand, Canada, China, Central and South America, Eastern Europe, Former Soviet Union, India, Japan, Middle East, Mexico, Other Developing Asia, South Korea, United States, and Western Europe.
- Time horizon: 2100
- Six time slices: three seasons (winter, summer and intermediate) and two part of the day (day and night)
- Sectors in the RES: residential, commercial, agriculture, industrial, transportation, electricity production and upstream/downstream
- Demand scenario: energy demand driver projections from the general equilibrium model GEM-E3 [2]
- Trade: inter-regional exchange process (trade of commodities) among the different regions


**MAIN CHARACTERISTICS**

- 15 world regions: Africa, Australia-New Zealand, Canada, China, Central and South America, Eastern Europe, Former Soviet Union, India, Japan, Middle East, Mexico, Other Developing Asia, South Korea, United States, and Western Europe.
- Time horizon: 2100
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**MAIN ETM OBJECTIVE**

To develop consistent long-term energy scenarios containing fusion as an energy option and showing the potential benefits of fusion power as an emission free energy source

**FUSION TECHNOLOGIES IN THE MODEL**

<table>
<thead>
<tr>
<th></th>
<th>Start</th>
<th>Life</th>
<th>AF</th>
<th>INV (€/kW)</th>
<th>FIXOM (€/kW)</th>
<th>VAROM (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic plant</td>
<td>2050</td>
<td>40</td>
<td>85%</td>
<td>3940 (10th) 2950 (100th)</td>
<td>65.8</td>
<td>2.16 (10th) 1.64 (100th)</td>
</tr>
<tr>
<td>Advanced plant</td>
<td>2070</td>
<td>40</td>
<td>85%</td>
<td>2820 (10th) 2170 (100th)</td>
<td>65.3</td>
<td>2.14 (10th) 1.64 (100th)</td>
</tr>
</tbody>
</table>

Fusion power plants characterization: Power Plant Conceptual Study (PPCS) [3]

LAST ACTIVITIES

Some tasks carried out from 2004:
• Revision and update of the data included in the upstream, power generation, residential, commercial, industry and transportation sectors
• RES sector update
• Modelling of the natural gas markets of the model
• Prospects for fusion generation: sensitivity analysis and storylines
• Preliminary scoping studies of the role of fusion in the future energy market
• Analysis of global energy scenarios
• Resource potentials update

And also:
Continuous data checking and updating, scenario validation, model testing and assessment of results

SCENARIOS

➢ Base case scenario: there is no limit to CO₂ emissions
➢ 550ppm scenario: a limit of 550ppm in CO₂-eq concentrations is set by 2100

For the sensitivity analysis

➢ 650ppm scenario: a limit of 650ppm in CO₂-eq concentrations is set by 2100
➢ HFC scenario: 550ppm scenario + fusion costs 30% higher
➢ HUR scenario: 550ppm scenario + high uranium resources (x10)
➢ ULC scenario: 550ppm scenario + low uranium extraction costs (-50%)
RESULTS - Power Generation

Base case scenario

RESULTS - Primary Energy

Base case scenario

550 ppm scenario
SENSITIVITY ANALYSIS - CO₂ reductions

650 ppm scenario

Power Generation

550 ppm scenario

Biomass
CHP
Coal
Fission
Fusion
Gas
Geothermal
Hydro
Oil
CCS
Solar
Wind

SENSITIVITY ANALYSIS - High Fusion Costs (+30%)

HFC scenario
(+550ppm)

Power Generation

550 ppm scenario

Biomass
CHP
Coal
Fission
Fusion
Gas
Geothermal
Hydro
Oil
CCS
Solar
Wind
SENSITIVITY ANALYSIS - High Uranium Resources (x 10)

HUR scenario
(+550ppm)

Power Generation

550 ppm scenario

Biomass
CHP
Coal
Fission
Fusion
Gas
Geothermal
Hydro
Oil
CCS
Solar
Wind

SENSITIVITY ANALYSIS - Uranium Low extraction Costs (-50%)

ULC scenario
(+550ppm)

Power Generation

550 ppm scenario

Biomass
CHP
Coal
Fission
Fusion
Gas
Geothermal
Hydro
Oil
CCS
Solar
Wind
POSSIBLE NEXT STEPS

- Re-aggregation of regions
- Re-calibration to a new base-year
- Introducing new TIMES options to the EFDA model
- Enhancement of model in nuclear power sector
- Review of technologies such as CCS, central solar power, road transport or storage technologies
- Review of resources such as uranium resources
- Review of demand drivers

CONCLUSIONS

- In the Base Case scenario, fusion does not enter the power system, while in the 550ppm one it is responsible of almost half of the global electricity production in 2100
- Also in primary energy, coal is displaced from a relevant position in 2100 by fusion and RES when limiting the CO₂ emissions
- Fusion penetration in the global power system is bigger and anticipates when the restrictions on the CO₂ emissions are stricter
- Fusion penetration is quite robust under cost increase
- In an utopian scenario with unlimited Uranium resource, fission technologies dominate the system from 2040
- Uranium costs reductions do not influence fusion development

Fusion has a chance in the low carbon energy systems
THANK YOU FOR YOUR ATTENTION!

ANNEXES
<table>
<thead>
<tr>
<th>Parameter (plasma physics)</th>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
<th>Model D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Size (GW)</td>
<td>1.55</td>
<td>1.33</td>
<td>1.45</td>
<td>1.53</td>
</tr>
<tr>
<td>Fusion Power (GW)</td>
<td>5.00</td>
<td>3.00</td>
<td>4.00</td>
<td>2.53</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Elongation (95% flux)</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
<td>1.9</td>
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<tr>
<td>Triangularity (95% flux)</td>
<td>0.33</td>
<td>0.25</td>
<td>0.24</td>
<td>0.47</td>
</tr>
<tr>
<td>Major Radius (m)</td>
<td>9.25</td>
<td>8.6</td>
<td>7.5</td>
<td>6.1</td>
</tr>
<tr>
<td>Divertor (T)</td>
<td>7.6</td>
<td>6.9</td>
<td>6.0</td>
<td>5.1</td>
</tr>
<tr>
<td>Plasma Current (MA)</td>
<td>20.5</td>
<td>20.0</td>
<td>20.1</td>
<td>14.1</td>
</tr>
<tr>
<td>First-wall, total</td>
<td>2.8, 3.5</td>
<td>2.7, 3.4</td>
<td>3.4, 4.0</td>
<td>3.7, 4.5</td>
</tr>
<tr>
<td>Breeding Fraction</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.76</td>
</tr>
<tr>
<td>P_{out} (MW)</td>
<td>246</td>
<td>270</td>
<td>132</td>
<td>71</td>
</tr>
<tr>
<td>ltd/9.5</td>
<td>1.2</td>
<td>1.2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter (engineering)</th>
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</thead>
<tbody>
<tr>
<td>Average neutron wall load</td>
<td>3.2</td>
<td>2.0</td>
<td>2.2</td>
<td>2.4</td>
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<tr>
<td>Divertor Peak load (kW/m²)</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>5</td>
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<tr>
<td>HACD Efficiency</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
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<tr>
<td>Plant Efficiency</td>
<td>0.35</td>
<td>0.35</td>
<td>0.42</td>
<td>0.6</td>
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<tr>
<td>Coolant blanket T_{av}</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Water</td>
<td>285/325</td>
<td>300/300</td>
<td>400/700</td>
<td>700/1100</td>
</tr>
<tr>
<td>Helium</td>
<td>300/300</td>
<td>400/700</td>
<td>700/1100</td>
<td>300/600</td>
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<tr>
<td>LHe</td>
<td>300/300</td>
<td>400/700</td>
<td>700/1100</td>
<td>300/600</td>
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<tr>
<td>Coolant divertor T_{av}</td>
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<td></td>
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<tr>
<td>Water</td>
<td>150/367</td>
<td>540/720</td>
<td>540/720</td>
<td>600/900</td>
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<tr>
<td>Helium</td>
<td>300/300</td>
<td>400/700</td>
<td>700/1100</td>
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<tr>
<td>LHe</td>
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<td>400/700</td>
<td>700/1100</td>
<td>300/600</td>
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<tr>
<td>Power conversion</td>
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<td>Rankine</td>
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</table>

Table 1: Main parameters of the PPCS models.

* the plant efficiency is the ratio between the unit size and the fusion power.