Martin Densing, Hal Turton, Evangelos Panos, Kathrin Volkart
Paul Scherrer Institute, Switzerland

Global Energy Scenarios 2050
of the World Energy Council

IEW 2013, Paris
• Why another global energy-system scenario-study?

• Regional disaggregation of the PSI/WEC model

• Model structure, scenario assumptions, and results focusing on transport sector sub-model

[PSI/WEC Global Mobility 2050]

→ Global results of whole energy system are launched at World Energy Congress in Daegu, South Korea, Oct. 2013
Features and Benefits of WEC’s Energy Scenarios

- Broad view of academics and of practitioners; hands-on experience by: Siemens, Tokyo Gas, Eletrobas, Petrobras, EdF, GDF Suez, Saudi Aramco, RWE, Eskom etc.

- **Coherent scenario storylines** of social, political and economical drivers (developed in regional workshops over the last 2 years) addressing emerging energy issues:
  - **Shale gas:** 32% of global gas resources [EIA 2013]
  - **PV uptake:** 2008 → 2010 → 2012: 15 → 38 → 97 GW [IEA, PVPS 2012]
  - **CCS vs. renewables:** CSS cost-effective at 50$/tCO₂? [IEA; PSI]
  - **Nuclear (after Fukushima):** capacity extension in USA, Europe, Japan?
  - **Poverty, Access:** 20% of people have no electricity [WEO 2011]
  - **Efficiency:** in primary energy –or– conversion –or– consumption?

**Approach:**

- 2 scenarios (not a sensitivity analysis by varying a single parameter of the energy system)
- **Energy system model GMM** (Global Multi-regional MARKAL) [Gü 2007; Densing&Turton 2012]
  - Cost-optimization of the energy system; bottom-up model with a detailed representation of resources, technologies, energy flows, and technological change
  - **Non-cost** and behavioural assumptions are modelled with side-constraints
  - Optional: Endogenous technology learning [Barreto 2001]
Regional partition: 15 Regions (final version)

Why a regional model? →
Regional partition: Diversity of TPES and of trade

Domestic production of primary energy (year 2010)

Net import (% of total primary energy supply)


BRAZIL: Bio -0.4%, Oil: 0.1%, CHINAREG: Gas 0.5%, INDIA: Gas 1.5%, LAC: Bio -0.4%; EU31: Bio: 0.3%
Regional partition: Developing vs. developed world

- Reference projections based on IPCC-SRES B2-scenario ("middle-of-the-road", "dynamics-as-usual")
- 66% of world GDP (MER) in
  - year 2010: EU + USA + China + Japan,
  - year 2050 (reference): EU + USA + China + India + Brazil + Japan + Indonesia.

→ traditional partitions by OECD and non-OECD countries no longer adequate, but difference in income between developed and some developing regions may persist.
Reference Energy System (Flow of Energy Carriers)

Resources
- Oil
- Natural Gas
- Biomass
- Other Renewables
- Uranium
- Coal

Conversion Processes
- Refinery
- T&D
- Heat Plants
- Methanol from Natural Gas
- Biofuels Production
- Power Plants
- Hydrogen Production

End-Use
- Residential/Commercial Thermal
- Residential/Commercial Specific
- Industry Thermal
- Industry Specific
- Personal Transport
- Aviation
- Other Transport

GMM has approx. 400 technologies per region

T&D: Transport and Distribution
Personal Transport Sector

- **Drivetrains**: Internal Combustion Engine Vehicle (ICEV), Advanced ICEV, Hybrid Electric (HEV), Plug-in (PHEV), Battery Electric (BEV), Hydrogen Fuel Cell with hybridisation (HFCV)

- **Fuels**: conventional liquid (gasoline, diesel); alternatives fuels: natural gas, electricity, hydrogen, different biofuels; fuel blending (e.g. maximal 10% (Bio-)Methanol into gasoline)

---

**Diagram**

- Gasoline
- Ethanol (Bio)
- Bio-Methanol
- Methanol
- Diesel
- Biodiesel (FT)
- Bio-Syngas
- Natural Gas
- T&D
- blend

- Gasoline Retail Station
- Gasoline ICEV
- Gas. Adv. ICEV
- Electricity (ELC)
- Gasoline HEV
- PHEV
- BEV
- Diesel ICEV
- Diesel Advanced ICEV
- Diesel HEV
- Hydrogen Hybrid
- Hydrogen Retail
- HFCV
- Compression
- CNG ICEV
- CNG HEV

**Blending Constraints**

**Short-Range Car Version**

Actual drive range: ~100 km

*WEO/PSI (2011): Global Transport Scenarios 2050*
Other Surface Transport and Aviation Sector

- Trucks, buses, other commercial road vehicles, 2-wheel, rail, ships: aggregated by fuel option
- Aviation: current + future technology

Other Surface Transport Sector

- Technologies categorized by
  - fuelling option, and
  - engine type

Aviation Sector

Blending Constraints
**Scenario Storyline (focused on transport)**

**Freeway:**
- More market driven
- Large demand growth in all transport sectors
- \(\text{CO}_2\) markets establish slowly
- Alternative fuels, technologies, and infrastructure are promoted only if cost-effective (in short term)
- Cost-effective efficiency measures
- Developing world is tending to developed world

**Tollway:**
- More policy driven (e.g. by energy security)
- Moderate demand growth in car transport; other sectors with considerable growth (depends on regions)
- \(\text{CO}_2\) tax increases (lagging in developing regions); promotion of renewables
- Alternative fuels are promoted (2\text{nd} gen biofuels)
- Promotion of BEV & HFCV in EU, Japan, USA
- Mandated efficiency measures
- Developed world is tending to developing world

<table>
<thead>
<tr>
<th>Country</th>
<th>Income growth</th>
<th>Population growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa, Asia, Brazil, China, India, LAM, MENA, Mexico</td>
<td>Freeway &gt; B2, IMF, WB, Tollway ≈ B2, IMF, WB</td>
<td>Freeway &lt; UNDP, Tollway ≈ UNDP</td>
</tr>
<tr>
<td>Canada, Europe, FSU, OECD Pacific, Russia, USA</td>
<td>Freeway ≈ B2, IMF, WB, Tollway &lt; B2, IMF, WB</td>
<td>Freeway ≈ UNDP, Tollway &gt; UNDP</td>
</tr>
</tbody>
</table>

Input: Transport Demands

- **Passenger car demand** = motorization rate $\times$ population $\times$ km-driven/car/y

- **Other surface demand**: 45% (50%) of GDP growth rate

- **Aviation demand**: 85% (100%) of GDP growth rate
Policy measures (examples): gCO₂/km, biofuels

- **EU**: Directive 443/2009, European standard for new passenger cars (130g/km in 2015+, 120g/km with other contribution)
- **USA**: Energy Independence and Security Act 2007 (e.g., 35mpg in 2020+)
- **In-use emissions** = +17% of full target (based on car sample average) → fleet-average

- **EU**: Directive 2009/28/EC
- **USA**: Energy Independence and Security Act (EISA): Renewable Fuels Standard (RFS)
- etc.
## Fuel cost assumptions (excl. CO₂-costs)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Reference</th>
<th>Tollway assumptions</th>
<th>Freeway assumptions</th>
<th>regional adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels</td>
<td>EIA</td>
<td>↓ ‾ ↓ (short / mid / long-term)</td>
<td>↓ _ _</td>
<td>↓ AFRICA, BRAZIL, LAM, ASIA</td>
</tr>
<tr>
<td>(Bio-Diesel, EtOH, MeOH, Syngas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>EIA</td>
<td>↑ _ ↓</td>
<td>↓ ↑ ↑</td>
<td>↓ MENA</td>
</tr>
<tr>
<td>Gasoline</td>
<td>EIA</td>
<td>↑ _ ↓</td>
<td>↓ ↑ ↑</td>
<td>↓ MENA</td>
</tr>
<tr>
<td>MeOH</td>
<td>IEA</td>
<td></td>
<td></td>
<td>↓ CHINA</td>
</tr>
<tr>
<td>H₂</td>
<td>DoE</td>
<td>_ ↓ ↓</td>
<td>↓ _ _</td>
<td>↓ CHINA, RUSSIA, FSU, USA, INDIA, ASIA, AFRICA</td>
</tr>
<tr>
<td>Coal</td>
<td>EIA</td>
<td>_ _ _</td>
<td>_ _ _</td>
<td>_ _ _</td>
</tr>
<tr>
<td>CNG</td>
<td>EIA</td>
<td>↑ ↑ _</td>
<td>_ _ ↑</td>
<td>↓ MENA, RUSSIA, FSU</td>
</tr>
<tr>
<td>Electricity</td>
<td>EIA</td>
<td>↑ ↓ _</td>
<td>↓ _ _</td>
<td>↓ _ _</td>
</tr>
</tbody>
</table>

**Sources:** Annual Energy Outlook (EIA, 2011); Clean Cities - Alternative Fuel Price Report (US DoE, 2011); IEA, Automotive Fuels for the Future (1999)
### Freeway:
- **Market driven** (market power)
- Large demand growth in all transport sectors
- CO$_2$ price is very slowly developing
- Alternative fuels, technologies, and infrastructure are promoted only if they are short-term cost-effective

### Tollway:
- More regulative power of citizen/voter
- Moderate demand growth in car transport; other sectors with considerable growth (depends on regions)
- CO$_2$ price increases (lagging in developing regions)
- Alternative fuels are promoted: 2$^{nd}$ generation biofuels (larger targets), lower-carbon electricity
- Promotion of BEV and HFCV in EU, Japan, and USA

### Personal Cars:
- **Liquid Fuel ICEV**
- **Liquid Fuel Hybrid**
- **Liquid Fuel Plug-in**
- **Gas Fuel ICEV**
- **Gas Fuel Hybrid**
- **Hydrogen Hybrid**
- **Hydrogen Fuel Cell**
- **Electric Vehicle**

WEC/PSI: Global Transport Scenarios 2050
• Efficiency increase is cost-effective (hybridisation, electric motor, learning) → fuel demand decreases
• CNG is attractive (fossil gas is more abundant / less emissions than fossil oil)
• Biofuels (1st & 2nd generation) promoted by targets and by increasing fossil fuel costs

• Other surface & aviation: biofuels are not cost-effective, efficiency improvements limited → emissions increase
• Developing world: increase in car-emissions (due to large increase in demand) is partially offset by mid- and long-term efficiency improvements
Efficiency: 2.8 litre/100 km in year 2050 (gasoline equivalent, fleet, in-use)
Tollway: Personal Cars in Latin America (excl. Brazil)

- Energy Security → Gas

- Efficiency: 3.6 litre/100 km in year 2050 (gasoline equivalent, fleet, in-use)
Conclusion

• Demand growth especially in **aviation** and **personal cars in developing regions**

• **Gas in transport** is a cost-effective option: low CO₂-emissions, gas resources are still abundant

• Alternative drivetrains enter gradually: HEV → PHEV → BEV

• Commercial surface transport:
  • Existing engines are relatively efficient (e.g. only few start-stop cycles disfavour electric motors)

• Aviation: Biofuels, Synfuels?

**Outlook:**

• Launch of study for full energy system in Oct. 2013 in Daegu

• Model Extensions: LCA integration,…
Thank you!