The World Energy Model

Marco Baroni
Directorate of Global Energy Economics
International Energy Agency
Paris, 20 June 2013
A complex energy world requires a well integrated model to capture all the interactions among markets, sectors, fuels and countries.
Energy demand rises by over one-third in 2010-2035. In the New Policies Scenario, underpinned by rising living standards in China, India & the Middle East.
World Energy Model (WEM)

- Partial equilibrium model that allows scenario analysis
  - Detailed sectoral and regional energy demand balances
  - Regional supply of all fuels and trade matrixes
  - \( CO_2 \) emissions from fuel combustion
  - Investment needs in the supply and end-use technologies

- Time horizon to 2035, with annual data
  - Complete update every year (e.g. in WEO 2012 the last complete data set was 2010, but many data available for 2011 are integrated)

- Regional resolution: 25 regional models
  - Of which 12 country models, including US, China, India, Japan, Russia, Brazil...

- Three main modules
  - Final Energy Consumption – Industry, Transport, Residential, Services, Agriculture, Non-Energy Use
  - Energy Transformation – Power Generation, Heat Production, Refinery/Petrochemicals, Other Transformation
  - Supply and Trade – Coal, Oil, Gas and Biomass

http://www.worldenergyoutlook.org/weomodel/
Change in global primary energy demand by measure and by scenario

Energy savings in 2035

<table>
<thead>
<tr>
<th>Measure</th>
<th>CPS to NPS</th>
<th>NPS to 450</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency in end-uses</td>
<td>67%</td>
<td>66%</td>
</tr>
<tr>
<td>Efficiency in energy supply</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Fuel and technology switching</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Activity</td>
<td>16%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>Total (Mtoe)</strong></td>
<td><strong>1 479</strong></td>
<td><strong>2 404</strong></td>
</tr>
</tbody>
</table>

Note: CPS = Current Policies Scenario; NPS = New Policies Scenario; 450 = 450 Scenario.

Efficiency is the single largest contributor to energy savings in achieving the New Policies Scenario and in moving beyond it, reflecting its large economic potential.
Policy implications

- Impact of policies under consideration on global energy trends
- Role of emerging economies on global energy demand and supply
- Implications of technological developments of carbon-free technologies
- Exploitation of the economic energy efficiency potential, its costs and benefits
- Environmental impact of energy use and the effect of policies to limit it
- Competitiveness within the energy sector and among countries
Power sector modeling in the World Energy Model

Brent WANNER
International Energy Agency
Paris, 20 June 2013
World Energy Model (WEM) overview

Electricity and heat end-user prices
<table>
<thead>
<tr>
<th>Power generation sub-modules</th>
<th>Main driver(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generation</td>
<td></td>
</tr>
<tr>
<td>Thermal plants</td>
<td>Economics</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Political support, economics</td>
</tr>
<tr>
<td>CCS</td>
<td>CO₂ price, support, learning</td>
</tr>
<tr>
<td>Renewables</td>
<td>Support, learning, potentials</td>
</tr>
<tr>
<td>Distributed Generation</td>
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<tr>
<td>Electricity from CHP</td>
<td></td>
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<tr>
<td>Desalination</td>
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<tr>
<td>Transmission &amp; Distribution</td>
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<tr>
<td>Wholesale &amp; End-user prices</td>
<td></td>
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<tr>
<td>Heat Production</td>
<td></td>
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<tr>
<td>Heat Plants</td>
<td></td>
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<tr>
<td>Heat from CHP</td>
<td></td>
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</tbody>
</table>

**Electricity generation**

- **Thermal plants**
  - Economics
- **Nuclear**
  - Political support, economics
- **CCS**
  - CO₂ price, support, learning

**Renewables**

- Support, learning, potentials

**Distributed Generation**

- TFC fossil fuel demand and prices

**Electricity from CHP**

- Heat demand

**Desalination**

- Water demand

**Transmission & Distribution**

- Power demand, integration of renewables

**Wholesale & End-user prices**

- Market structure, power mix, fuel and CO₂ prices, investment
The module determines which plants are added and how they operate.

Key Results:
- Effective Capacity Factors
- Total installed capacity by plant
- Early retirements
- Effective Capacity Factors
- Wholesale price
- End-user prices
- Fuel consumption by plant
- CO₂ by plant type

Additions of new plants:
- Investment assumptions
- Retrofits
- Retirements of existing plants
- Refurbishments

Merit Order Dispatch:
- Load curve
- Fuel and CO₂ prices
- Efficiencies
- Historical capacity by plant
- Max Capacity Factors
- Electricity demand

Generation by plant:
- Plant Investment needs
- T&D Investment needs
- Renewables support
The module determines which plants are added and how they operate.

Additions of new plants

Key Results
- Investment assumptions
- Retrofits
- Refurbishments

Plants
- Load curve
- Fuel and CO₂ prices
- Efficiencies
- Historical capacity by plant
- Total installed capacity by plant
- Early retirements
- Effective Capacity Factors
- Merit Order Dispatch
- Wholesale price
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- Fuel consumption by plant
- CO₂ by plant type

Generation by plant
- Electricity demand

Plant Investment needs
- T&D Investment needs
- Renewables support

Retirements of existing plants
- Refurbishments

Max Capacity Factors
Capacity additions mechanism

- Installed capacity is greater than peak demand to allow system to cope with maintenance and unexpected outages ⇒ Capacity Margin
- Plants are added each year based on demand growth, maintaining the capacity margin, replacement of retiring plants

- Annual data is not enough
  - Need for greater granularity in the year
  - Split the load duration curve (hourly demand ordered from biggest to smallest) in 4 blocks
    - Peak load
    - Mid load 1 and 2
    - Base load
Plants are added on a least-cost basis, with a portfolio approach.

Competition depends on several factors (fuel prices, CO$_2$ prices, efficiency, investment cost, construction time, WACC, economic lifetime) and is very much time-dependent.

\[ LRMC = \frac{\text{fuel cost} + \text{CO}_2 \text{ price} \times \text{emission factor} + \text{VOM}}{\text{efficiency}} + \frac{\text{Inv. cost} \times \text{prepayment coefficient}}{\left( \sum_{t=1}^{n} \frac{1}{(1+i)^t} \right)} + \frac{\text{FOM}}{\text{capacity factor} \times \frac{8760}{1000}} \]
How much each plant generates in a year is determined by the merit order.
How much each plant generates in a year is determined by the merit order.

Fuel cost, efficiency, and CO₂ prices determine a plant’s position in the merit order.
The power generation mix is set to change

Global electricity generation by source, 2010-2035

Renewables electricity generation overtakes natural gas by 2015 & almost coal by 2035; growth in coal generation in emerging economies outweighs a fall in the OECD
The bulk of the gross capacity additions projected to 2035 comes from coal- and gas-fired power plants and wind power.
Components of the end-user price of electricity

<table>
<thead>
<tr>
<th>Wholesale electricity generation cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost of power plants</td>
</tr>
<tr>
<td>Fuel cost</td>
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<tr>
<td>CO₂ cost</td>
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<td>Operation and maintenance cost</td>
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<table>
<thead>
<tr>
<th>System operation cost</th>
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<tr>
<td>Balancing cost</td>
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<td>Adequacy cost</td>
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<thead>
<tr>
<th>Transmission and distribution cost</th>
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<tbody>
<tr>
<td>Capital cost of network infrastructure</td>
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<tr>
<td>Operation and maintenance cost</td>
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<tr>
<td>Cost of network losses</td>
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</table>

<table>
<thead>
<tr>
<th>Supply cost</th>
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<tbody>
<tr>
<td>Metering</td>
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<tr>
<td>Billing and payment recovery</td>
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<tr>
<td>Other commercial costs</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Taxes and subsidies</th>
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<tbody>
<tr>
<td>Value-added taxes</td>
</tr>
<tr>
<td>Renewables subsidies</td>
</tr>
<tr>
<td>Other taxes and subsidies</td>
</tr>
</tbody>
</table>
Wide variations in the price of power

Average household electricity prices, 2035

Electricity prices are set to increase with the highest prices persisting in the European Union & Japan, well above those in China & the United States
Policy implications

- Evolution of the power generation mix in the (currently) highest CO2 emitting sector
- Impact of fossil fuel prices, CO₂ pricing and support policies to change the power mix
- Overall investment needs and revenues for power plants
- Impact of supported capacity on the power market structure
- Household spending on electricity bills
- Competitiveness of energy-intensive industries
Thanks!

weo@iea.org
Modelling the surge of LTO within the IEA WEM

C. Besson, J. Corben, P. Olejarnik
Supply shock from North American oil rippling through global markets

US EIA data

IEA Mid-Term OMR

US Oil Production

- Other Crude & Cond.
- Other Liquids
- NGPLs
- Gulf of Mexico
- Light Tight Oil

Forecast:
- Eagle Ford
- Bakken
- Granite Wash
- Bonespring
- Monterey
- Woodford
- Niobrara-Codell
- Spraberry
- Austin Chalk

*Includes additives and oxygenates. Does not include biofuels.
Iterations of smooth price trajectory until long term supply can match demand
Supply model splits demand by country and category

<table>
<thead>
<tr>
<th></th>
<th>New Policies</th>
<th></th>
<th>Current Policies</th>
<th></th>
<th>450 Scenario</th>
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<tr>
<td>Crude oil</td>
<td>23.9</td>
<td>35.7</td>
<td>38.5</td>
<td>46.1</td>
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<tr>
<td>Natural gas liquids</td>
<td>2.0</td>
<td>5.7</td>
<td>7.0</td>
<td>9.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconventional</td>
<td>0.0</td>
<td>0.7</td>
<td>1.8</td>
<td>2.1</td>
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<tr>
<td>Non-OPEC</td>
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<td></td>
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<td>51.8</td>
<td>53.2</td>
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<tr>
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<td>48.8</td>
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<tr>
<td>Natural gas liquids</td>
<td>3.7</td>
<td>6.4</td>
<td>8.2</td>
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<tr>
<td>Unconventional</td>
<td>0.4</td>
<td>3.2</td>
<td>8.0</td>
<td>10.4</td>
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<tr>
<td>World oil production</td>
<td>65.7</td>
<td>84.5</td>
<td>91.8</td>
<td>96.1</td>
<td></td>
<td></td>
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<tr>
<td>Crude oil</td>
<td>59.6</td>
<td>68.5</td>
<td>66.9</td>
<td>65.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas liquids</td>
<td>5.7</td>
<td>12.0</td>
<td>15.2</td>
<td>18.2</td>
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<td></td>
</tr>
<tr>
<td>Unconventional</td>
<td>0.4</td>
<td>3.9</td>
<td>9.7</td>
<td>13.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing gains</td>
<td>1.3</td>
<td>2.1</td>
<td>2.5</td>
<td>2.1</td>
<td></td>
<td></td>
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<tr>
<td>World oil supply*</td>
<td>67.0</td>
<td>86.6</td>
<td>94.2</td>
<td>99.2</td>
<td></td>
<td></td>
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<tr>
<td>World biofuels supply**</td>
<td>0.1</td>
<td>1.3</td>
<td>2.4</td>
<td>4.1</td>
<td></td>
<td></td>
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<tr>
<td>World total liquids supply</td>
<td>67.1</td>
<td>87.9</td>
<td>96.6</td>
<td>104.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| OECD               |      |      |      |      |      |      |      |      |      |      |      |
| Americas           |      |      |      |      |      |      |      |      |      |      |      |
| Canada             |      |      |      |      |      |      |      |      |      |      |      |
| Mexico             |      |      |      |      |      |      |      |      |      |      |      |
| United States      |      |      |      |      |      |      |      |      |      |      |      |
| Europe             |      |      |      |      |      |      |      |      |      |      |      |
| Asia Oceania       |      |      |      |      |      |      |      |      |      |      |      |
| Non-OECD           |      |      |      |      |      |      |      |      |      |      |      |
| E. Europe/Eurasia  |      |      |      |      |      |      |      |      |      |      |      |
| Kazakhstan         |      |      |      |      |      |      |      |      |      |      |      |
| Russia             |      |      |      |      |      |      |      |      |      |      |      |
| Asia               |      |      |      |      |      |      |      |      |      |      |      |
| China              |      |      |      |      |      |      |      |      |      |      |      |
| India              |      |      |      |      |      |      |      |      |      |      |      |
| Middle East        |      |      |      |      |      |      |      |      |      |      |      |
| Africa             |      |      |      |      |      |      |      |      |      |      |      |
| Latin America      |      |      |      |      |      |      |      |      |      |      |      |
| Brazil             |      |      |      |      |      |      |      |      |      |      |      |
Current production declines, so there is a gap with demand (here of conventional and unconventional crude)
Countries and types compete based on NPV each year to develop « tranches » of resources.
And then produce according to a standard profile
Light Tight Oil: a working definition

- Very low permeability formations

- Produced with multistage hydraulic fracturing in horizontal wells

- Produced from basin center, continuous, source rock
  - oil is trapped by nature of rock not by geometrical arrangements of layers
Rapid well decline

Does that invalidate the approach?

Typical (good) Bakken well and typical (good) offshore well
But not rapid play decline

North Dakota DMR projection for the Bakken made in 2012
Drilling a series of wells (with time) leads to a profile not unlike that of conventional.

Result of a typical drilling program

- **LTO**
- **Conv**
So can apply the same methodology of « resources tranche » development to a new type of oil.

With 2012 resources, predicts peak, because of effect of depletion on costs.
And you will read more in WEO2013!

Focus on oil

- Resources
- Production
- Demand
- Refining
- Implications (price, trade, investment...)

November 12th
Modelling the potential for industrial energy efficiency in IEA’s WEO

Dr Fabian Kesicki
International Energy Agency

International Energy Workshop, Paris, 20 June 2013
Global industrial energy demand increases by almost 40% up to 2035.
Today's industrial energy demand

Energy flows in the industry sector, 2010

Energy intensive sectors represent around 60% of industrial energy demand
Industry accounts for more than a third of final energy consumption, but modelling faces difficulties:

- No dominating sub-sector, many different production processes
- Energy savings can impact on product quality and thus limit deployment
- Data problems as energy consumption can evolve quickly and autoproduction can distort energy consumption
### WEM industry model structure

**Sub-sectors in industry**

<table>
<thead>
<tr>
<th>Sub-sector</th>
<th>Activity variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td>Crude Steel</td>
</tr>
<tr>
<td>Chemical and petrochemical</td>
<td>Ethylene</td>
</tr>
<tr>
<td></td>
<td>Propylene</td>
</tr>
<tr>
<td></td>
<td>Aromatics</td>
</tr>
<tr>
<td></td>
<td>Methanol</td>
</tr>
<tr>
<td></td>
<td>Ammonia</td>
</tr>
<tr>
<td>Cement</td>
<td>Cement</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>Paper</td>
</tr>
<tr>
<td>Other industries</td>
<td>Value-added in industry</td>
</tr>
</tbody>
</table>
Description of industry model

- Activity projection
  - Econometric projection based on value added, price and pop.
- Energy intensity
  - Process changes (e.g. primary vs secondary steel-making)
  - Technical energy savings
  - Systems optimisation
  - Operational efficiency
- Fuel shares
  - Multiple logit model, electricity and fuel treated separately
Industry modelling in WEM accounts for process changes in the various sub-sectors
How to model energy efficiency policies?

Energy savings as a function of the payback period

Acceptable payback periods and technology penetration vary with the scenario and the corresponding policy assumptions
While growth will significantly slow down for iron & steel and cement, other industry sectors see continued growth, particularly in non-OECD countries.
Energy demand will increase in all sub-sectors as rapid growth in industrial production outpaces energy efficiency improvements.
Trends by subsector

Global final energy consumption by industrial subsector

- Iron and steel
- Chemicals and petrochemicals
- Cement
- Pulp and paper

Energy efficiency can cut industrial energy demand growth by around 30%
Policies to overcome existing barriers

- Numerous barriers impede the implementation of energy efficiency: short payback periods, lack of awareness, distraction from core business, production interruption

- Efficiency policies
  - Funding of research
  - Requirements for energy audits and management systems
  - Training and capacity building
  - Performance requirements
  - Financing mechanisms
Conclusions

- Industry is a driving factor behind energy demand growth in the future
- Energy efficiency can slow down this growth by around 30%
- Recent data and solid characterisation of production process are crucial for industrial energy modelling
- Future research needs to shed more light on the black box ‘non-energy-intensive’ industries
Modelling oil demand from road freight transport using WEM

Timur Gül
International Energy Agency
Paris, 20 June 2013
More than 50% of global oil demand today is concentrated in the transport sector, and most of it in road transport.

Road transport is central to global oil demand growth, with the main options to reduce demand growth including:

- Pursuing energy efficiency policy
- Substituting oil-based fuels by other options
- Modal shift

Curtailing oil demand growth from passenger cars has been at focus of policy-making, but attention to freight trucks was limited.
The transport module in WEM encompasses a detailed representation of the transport sector, with a high number of technology choices.
The transport module in WEM deploys many technology options for the assessment of technology evolution.

### Road transport

- **PLDV and LCVs (<3.5 t)**
  - ICEVs: Tyres, low friction design and materials, lightweighting components, aerodynamics, thermodynamic cycle, downsizing, thermal management, reduced driveline friction, auxiliary systems, weight reduction, variable valve actuation and lift, dual clutch transmission, hybridisation.

- **Trucks (3.5-16 t)**
  - ICEVs: Tyres, transmission, weight, engine, hybridisation.

- **Heavy trucks (>16 t)**
  - ICEVs: Tyres, management, transmission, idle reduction, engine, aerodynamics, weight, hybridisation.

- **Buses**
  - ICEVs: Tyres, transmission, engine, weight, hybridisation.

- **Two/three wheelers**
  - ICEVs: Tyres, transmission, engine, weight, hybridisation.

### Non-road transport

- **Aviation**
  - Aeroplanes: Engine retrofit, efficient gas turbines, composite structures, new engine systems, hybrid wing bodies, air traffic management, operational improvements.

- **Other**
  - Navigation
  - Rail
  - Pipeline

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Note: PLDV = passenger light-duty vehicles; LCV = light commercial vehicle; ICEV = internal combustion engine vehicle; t = tonnes
Distinguishes three classes of freight transport:

- *Light commercial vehicles* (< 3.5 t)
- *Medium freight trucks* (3.5 – 16 t)
- *Heavy freight trucks* (>16 t)

Efficiency improvements are exogenous (where policies exist) or endogenous (elsewhere) based on payback periods.

Fuel substitution occurs either policy-driven or based on cost using a Weibull function at n=4.
Deploying more efficient trucks in WEM

Efficiency choices for trucks in WEM are based on undiscounted payback periods with minimum payback periods of one to three years.
Oil demand from passenger light-duty is central to global oil demand growth, but freight transport is catching up.
Demand for freight service grows particularly fast in non-OECD countries, albeit from a low base.
World freight truck oil demand in the New Policies Scenario

Cost-effective efficiency improvements will be instrumental to reducing oil demand growth from freight trucks
Regions with fuel economy standards for trucks like the United States see the largest improvement in fuel economy than other regions.
Natural gas sees the highest growth in alternative fuels for road freight transport, but is constrained by the need to build up a refuelling infrastructure.
Policy implications

- Policy attention on improving fuel economy from passenger cars helps curbing future oil demand growth
- Road freight transport oil demand is set to grow strongly as oil substitutes are facing obstacles and efficiency-policy still lacks
- Policy can help realise efficiency potential for trucks, which is a market with many small operators that require low payback periods for efficiency investments