Joint ICTP-IAEA School on Nuclear Energy Management

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World Energy Demand and Supply Recent Trends

H.H. Rogner

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World Energy Demand and Supply
Recent Trends

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Outline

1. Challenges and issues
2. Energy system
3. Current situation
4. Drivers of energy demand
5. Resources & technology
6. Future outlook
Challenges and issues

- Energy security
  - Eradicating energy poverty (energy for meeting MDGs)
  - Access and affordability
  - Reliability
- Economic competitiveness
  - Market structures
  - Subsidies
- Environment protection and climate change
- Resources & technology
- Demand growth
- Sustainability calls for energy system transformation
- Finance
Challenges for 21st Century Energy Supplies

- Energy is central to achieving sustainable development goals including the Millennium Development Goals (MDGs)
- Economic development translates into growing demand for energy services
- Demand is compounded by continued population growth
- Some 1.3 billion people without access to modern energy services
- Poverty eradication calls for affordable energy services
- Need to minimize of health and environmental impacts
- Energy security
- Sustainability calls for energy system transformation
Worrisome trends

- Economic concerns have focused attention on short-term energy security to the detriment of longer term sustainable development objectives.
- Post-Fukushima, a bumpy road ahead for nuclear.
- MENA turmoil raised questions about region’s investment plans.
- Some key trends are pointing in worrying directions:
  - $CO_2$ emissions rebounded to a record high (2012).
  - Energy efficiency of global economy worsened for 2\textsuperscript{nd} straight year (2011).
  - Spending on oil imports is near record highs.
  - Financial & economic crises.
Architecture of the Energy System

**Sources**
- coal
- oil
- natural gas
- sunlight
- uranium
- wind
- biomass

**Extraction Treatment**
- coal
- hydro
- oil cleaning
- separation
- benefication liquefaction
- gasification
- mine
- dam
- rig

**Conversion Technologies**
- hydro
- thermal power
- oil
- nuclear generating
- photovoltaic
- wind station
- plant
- refinery
- station
- cell
- converter

**Currencies (fuels)**
- electricity
- gasoline
- methanol
- methane
- hydrogen
- heat

**Distribution**
- electricity grid
- gas grid
- truck
- dewar
- railway
- district heat grid

**Service Technologies**
- automobile
- light telephone
- furnace
- microwave
- aircraft
- PC
- bulb
- oven

**Services**
- transportation
- communication
- keeping warm/cold
- food
- potable water
- health care
- security
- consumer goods

Primary energy
Secondary energy
Final energy
Energy services
First Law of Thermodynamics: Energy conservation

Energy

- 144 EJ Primary
- 22 EJ Conversion
- 161 EJ Secondary 352 EJ
- 169 EJ Distribution
- 496 EJ Refinery
- 169 EJ End use
- 330 EJ Final
- 161 EJ Useful
- 496 EJ Services
- 169 EJ Power Plant
- 161 EJ Light Bulb
- 496 EJ Light

Examples

- Crude Oil
- Gasoline
- Truck
- Car
- Passenger-km

- Coal
- Electricity
- Grid
- Energy
- Radiant

Waste heat and rejected energy
Shares of primary energy

- Biomass
- Coal
- Oil
- Gas
- Hydro
- Nuclear
- Renewables

Percent

1850 1875 1900 1925 1950 1975 2000

0 25 50 75 100
Global primary energy supply, 1970-2012

Average annual growth rate 1970-2012: 2.27%

Source: Adapted from OECD/IEA Statistics and BP
Total primary energy supply (TPES) in 2012: 13 310 Mtoe

- Coal: 28.1%
- Natural gas: 21.4%
- Oil: 32.0%
- Biomass & MSW: 9.7%
- Nuclear: 4.8%
- Hydro: 2.4%
- Solar/wind/other: 1.7%

Source: Adapted from OECD/IEA Statistics and BP
Coal won the energy race in the first decade of the 21st century

Average annual growth rate
2000-2010 2.5%

Coal accounted for nearly half of the increase in global energy use over the past decade, with the bulk of the growth coming from the power sector in emerging economies

Source: OECD/IEA - World Energy Outlook 2011
Historical carbon intensity of energy supplies

- All PE carriers and CO₂ emissions
- Without biomass CO₂ (but including biomass GJ)
- Biomass: 112 kg CO₂/GJ
- Coal: 94.6 kg CO₂/GJ
- Oil: 73.3 kg CO₂/GJ
- Gas: 56.1 kg CO₂/GJ
Total global primary energy in 2012: 13 310 Mtoe

Regional TPES

North America 20.3%
China 22.1%
Europe 15.2%
Middle East 6.1%
Latin America 6.8%
Africa 3.2%
Pacific OECD 7.2%
ASEAN 4.1%
India 4.5%
CIS 8.3%
Other Asia 2.1%

Source: Adapted from OECD/IEA & BP Statistics
Structure of global final energy use, 2010

Total final energy: 8 677 Mtoe

- **Biomass**: 1,102 Mtoe (12.7%)
- **Gaseous**: 1,318 Mtoe (15.2%)
- **Electricity**: 1,536 Mtoe (17.7%)
- **Solids**: 853 Mtoe (9.8%)
- **Liquids**: 3,570 Mtoe (41.1%)
- **Heat**: 276 Mtoe (3.2%)

**Distributed renewables**: 22 Mtoe (0.3%)

Source: Adapted from OECD/IEA Statistics
Historical development of global electricity generation, 1970 - 2010

Source: Adapted from OECD/IEA Statistics
Structure of global electricity supply

Global electricity generation in 2010: 21 430 TWh

- Coal: 41.0%
- Natural gas: 22.2%
- Nuclear: 12.9%
- Oil: 4.6%
- Hydro: 16.0%
- Biomass: 1.5%
- Other Renewables: 2.1%

Nuclear capacity share: 7.1%

Source: Adapted from OECD/IEA Statistics
Structure of electricity supply – Developing countries

Total electricity generation in 2010: 8 880 TWh

- **Coal**: 51.2%
- **Gas**: 17.4%
- **Oil**: 7.5%
- **Nuclear**: 2.0%
- **Hydro**: 20.0%
- **Bioenergy**: 0.7%
- **Non-hydro renewables**: 1.3%

**Source**: Adapted from OECD/IEA Statistics
Energy intensities by regions

Energy intensities are converging: the ratio among the highest & lowest values has declined from a factor of nine in the 1980s to just under five currently

Source: IEA World Energy Outlook 2012
The drivers of carbon emissions

KAYA identity which finds its origin in IPAT or
Impact = population × affluence × technology

Total emissions = population × per capita income ×
energy intensity × carbon intensity

Total emissions = population × (GDP/population) ×
(energy/GDP) × (emissions/energy)

Total emissions = Pop × (GDP/pop) × (E/GDP) × (CO₂/E)

Total emissions = Pop × ($/pop) × (MJ/$) × (CO₂/MJ)
“Kaya Identity” components and their effect on total energy related CO₂ emissions levels

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Decadal change in emissions (in Gt of CO₂)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Carbon intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy intensity</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GDP per capita</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total Change</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Historical GHG emissions (Kyoto gases)

Global GHG emissions by major region – all six Kyoto gases

Global GHG emissions, major economic recessions and El-Ninos

CO₂ emissions – World and Annex I

Global

Industrialized countries

Gt CO₂


EIA
IEA
CDIAC
BP
EDGAR
ANNEX I (UNFCCC)
ANNEX I (EIA)
ANNEX I (IEA)
Emissions allocated on the basis of territory (solid lines) and final consumption (dotted lines)

**Total CO₂ emissions**

- Annex B
- Non-Annex B

**Per capita CO₂ emissions**

- Annex B
- Non-Annex B

**Allocation:**
- Territorial
- Consumption

**Net transfer/leakage:**
- Territorial
- Consumption
Drivers of future demand for energy services

- Demographic development
- Economic development
- Technology
- Environmental policy
Population by major country/region

Source: OECD/IEA - World Energy Outlook 2011/12
Global population – an important driver of energy needs – is projected to grow by 1% per year on average, from an estimated 6.8 billion in 2010 to 8.3 billion in 2030.

Source: OECD/IEA - World Energy Outlook 2011/12
GDP development 2010 – 2030

OECD
Non-OECD
Asia
European Union
Africa
Middle East
Latin America
E. Europe/Eurasia
United States
China
Japan
India
Russia
Brazil

World GDP Trillion US$$_{ppp}$ at 2010 prices and exchange rates

2010: 70.8
2030: 151.1

Source: OECD/IEA - World Energy Outlook 2011
### Per-capita income by selected regions

<table>
<thead>
<tr>
<th>Region</th>
<th>2009 CAAGR</th>
<th>2030 CAAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>2.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>OECD</td>
<td>1.7%</td>
<td></td>
</tr>
<tr>
<td>Non-OECD</td>
<td>4.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Asia</td>
<td>5.1%</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>4.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Russia</td>
<td>2.2%</td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Latin America</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>2.5%</td>
<td>1.7%</td>
</tr>
<tr>
<td>India</td>
<td>5.5%</td>
<td>1.7%</td>
</tr>
<tr>
<td>European Union</td>
<td>5.5%</td>
<td>1.7%</td>
</tr>
<tr>
<td>E. Europe/Eurasia</td>
<td>3.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>China</td>
<td>6.0%</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>3.1%</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>1.5%</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Adapted from OECD/IEA - World Energy Outlook 2011

China is assumed to experience the fastest rate of growth in per-capita incomes, but the income gap with OECD countries remains wide in 2030.
Efficiency improvements industrial processes

- 

- Efficiency index

- Production volume share

- 10-30%
Technology: Example of energy demand reduction through retrofitting

Before retrofitting

Retrofitting according to the passive house principle

over 150 kWh/(m²a)  -90%  15 kWh/(m²a)

Technology & structural change

TPES without efficiency improvements & structural change

Million tonnes of oil equivalent

1990 2007
World

OECD+

EU

OME

OC

1990 2007

-21%
Innovation: Nuclear power generation

**Generation I**
- Early prototype reactors
  - Shippingport
  - Dresden, Fermi I
  - Magnox

**Generation II**
- Commercial power reactors
  - LWR-PWR, BWR
  - CANDU
  - VVER/RBMK

**Generation III**
- Advanced LWRs & HWRs
  - AP1000, ABWR, System 80+
  - ACR
  - EPR

**Generation III+**
- Evolutionary designs with improved economics and safety for near-term deployment

**Generation IV**
- Highly economical
- Enhanced safety
- Minimal waste
- Proliferation resistant

Timeline:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030
Brazil – Ethanol Learning Curve

Source: IIASA

Data: Goldenberg, 1996
Innovation: Wind turbines

Source: German Wind Energy Institute (DEWI), 2004.
CO₂ capture and storage system

Fuels

Processes

Storage options
Capture of CO$_2$

- **Industrial separation**
  - Industrial process
  - CO$_2$ separation
  - Compression
  - CO$_2$
  - Product
  - Heat & electricity

- **Post-combustion**
  - Combustion
  - CO$_2$ separation
  - Compression
  - CO$_2$
  - Heat & electricity

- **Pre-combustion**
  - Combustion
  - H$_2$ + CO$_2$ separation
  - Compression
  - CO$_2$
  - H$_2$
  - Heat & electricity
  - Other products

- **Oxyfuel**
  - Combustion
  - O$_2$ separation
  - Compression
  - CO$_2$
  - O$_2$
  - Heat & electricity
  - Other products
Difference between CO$_2$ captured and CO$_2$ emissions avoided

- Additional fuel use of 10 - 40% (for same output)
- Capture efficiency: 85 - 95%
- Net CO2 reduction: 80 - 90%
- Assuming safe storage

**Graph:**

- Red: Emitted
- Blue: Captured

**Key:**

- CO$_2$ avoided
- CO$_2$ captured

**Plant with CCS:**

- CO$_2$ produced (g/kWh)
Economists maintain: There are no exhaustible resources really.

Reserve/resource assessments are efforts of estimating the economic portion of an unknown total.

What exists in the Earth’s crust is “neutral stuff”.

Demand for a resource “creates” it - without demand the resource remains “neutral stuff”.

If production costs become too expensive, alternative solutions will be sought.

Innovation and advancements of knowledge push the resource frontier of “exhaustible” resources.
### Resource Classification: The McKelvey Box

<table>
<thead>
<tr>
<th>Identified Reserves</th>
<th>Undiscovered Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrated</td>
<td>Probability range (or)</td>
</tr>
<tr>
<td>Measured</td>
<td>Hypothetical</td>
</tr>
<tr>
<td>Indicated</td>
<td>Speculative</td>
</tr>
<tr>
<td>Inferred</td>
<td></td>
</tr>
</tbody>
</table>

- **Economic**
- **Subeconomic**
- **Not economic**

**Unconventional and low-grade occurrences**

**Reserves**

- Increasing degree of economic feasibility
- Increasing degree of geological assurance
A Primer on Exhaustible Resources

The future availability of ‘exhaustible resources’ must be set in the context of:

- Anticipated demand;
- Market prices;
- Alternative fuel cycle options;
- Knowledge; and
- Technology change/innovation.
Peak oil: Discovery matters

![Chart showing the relationship between oil discovery and production. The x-axis represents years from 1930 to 2000, and the y-axis represents Gbbl/year. The chart illustrates the increase in production compared to discovery.](image-url)
Peak oil: Boundaries matter

- McKelvey Box
- Economic frontier (demand, technology, prices)
- Static vs dynamic approach
- Conventional vs unconventional oil
- Environmental frontiers
- Social preferences
Global long-term oil-supply cost curve

-8,000 -4,000 0 4,000 8,000 12,000 16,000 20,000 24,000 28,000 32,000 36,000
Reserves and Resources (EJ)

-20 0 40 60 80 100
Production cost (2005 $ per bbl)

-8,000 -4,000 0 4,000 8,000 12,000 16,000 20,000 24,000 28,000 32,000 36,000
Reserves and Resources (EJ)

-20 0 40 60 80 100
Production cost (2005 $ per bbl)

Source: adapted from Farrell, 2008.
The total recoverable oil-resource base is estimated at 6.5 trillion barrels of which we have so far produced 1.1 Tb.
Recoverable oil resources and production by region and type in the New Policies Scenario

Source: OECD/IEA - World Energy Outlook 2011
Peak oil or undulating plateau?

![Graph showing oil production and reserves](image)

- **Conventional oil Past production**
  - ∑ 1.15 trillion barrels

- **Conventional oil URR**
  - ∑ 2.3 trillion barrels

- **Undulating plateau**

- **Unconventional oil**

- **NGLs**

---

IAEA

0

20

40

60

80

100

120

Million barrels per day (Mbbl/d)


Million barrels per day (Mbbl/d)
Shale gas – another player on the scene?

- Existence known for quite some time but no technology solution for economic extraction
- Hydraulic fracturing key to mobilizing the methane
- Major impact on the NA gas market
- Analogies sought elsewhere
- Low carbon contents
Map of 48 major shale gas basins in 32 countries

Source: USDOE EIA, 2011
Issues & challenges

- Most regions outside NA with limited or no resources (not to speak of reserve) assessments and poor understanding of production costs
- Share of economically producible quantities (recovery rates) yet to be determined
  - Initially reserves are a small sub-set of resources but are dynamically changing
  - Reserves take years of development drilling and lots of $ before turning into supplies
  - Known reserves may never be developed
- Traps versus ‘continuous‘ basins’
- Current prices in the US are not sustainable unless cost reductions through technology progress
- Prices elsewhere should be a stimulus
Interregional gas price gaps

Source: Alboran Research
Natural gas production by type in the IEA GAS Scenario

Source: Are we entering a golden age of gas? IEA, 2011
## Estimates of conventional natural gas reserves

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Europe</td>
<td>172</td>
<td>176</td>
<td>193</td>
<td>154</td>
<td>185</td>
<td>220</td>
<td>274</td>
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<tr>
<td>CIS</td>
<td>2,015</td>
<td>2,137</td>
<td>1,939</td>
<td>2,074</td>
<td>2,244</td>
<td>2,052</td>
<td>1,657</td>
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<tr>
<td>Africa</td>
<td>490</td>
<td>501</td>
<td>522</td>
<td>521</td>
<td>521</td>
<td>513</td>
<td>338</td>
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<tr>
<td>Middle East</td>
<td>2,549</td>
<td>2,555</td>
<td>2,654</td>
<td>2,688</td>
<td>2,661</td>
<td>2,597</td>
<td>1,604</td>
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<tr>
<td>Asia</td>
<td>415</td>
<td>498</td>
<td>535</td>
<td>574</td>
<td>569</td>
<td>536</td>
<td>409</td>
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<tr>
<td>North America</td>
<td>283</td>
<td>287</td>
<td>335</td>
<td>307</td>
<td>329</td>
<td>283</td>
<td>222</td>
</tr>
<tr>
<td>Latin America</td>
<td>262</td>
<td>242</td>
<td>264</td>
<td>301</td>
<td>268</td>
<td>266</td>
<td>255</td>
</tr>
<tr>
<td>World</td>
<td>6,186</td>
<td>6,395</td>
<td>6,441</td>
<td>6,618</td>
<td>6,776</td>
<td>6,468</td>
<td>4,759</td>
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</tbody>
</table>
Risked gas in-place and technically recoverable shale gas resources

<table>
<thead>
<tr>
<th>Continent</th>
<th>Risked Gas In-Place (Tcf)</th>
<th>Risked Technically Recoverable (Tcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>3,760</td>
<td>940</td>
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<tr>
<td>Other North America</td>
<td>3,856</td>
<td>1,069</td>
</tr>
<tr>
<td>South America</td>
<td>4,569</td>
<td>1,225</td>
</tr>
<tr>
<td>Europe</td>
<td>2,587</td>
<td>624</td>
</tr>
<tr>
<td>Africa</td>
<td>3,962</td>
<td>1,042</td>
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<tr>
<td>Asia</td>
<td>5,661</td>
<td>1,404</td>
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<tr>
<td>Australia</td>
<td>1,381</td>
<td>396</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25,776</strong></td>
<td><strong>6,700</strong></td>
</tr>
</tbody>
</table>

Global Energy Assessment (GEA) Rogner 1997

Resource Potential
14,900 EJ or 14,100 Tcf
16,100 Tcf

Reserves
6,300 EJ or 5,970 Tcf
Success/Risk Factors

- The resource values for each basin have been risked for:
  - the probability that the shale gas formation will (or will not) have sufficiently attractive gas flow rates to become developed; and
  - an expectation of how much of the prospective area will be developed in the foreseeable future
Shale gas impact on natural gas prices

Unconventional gas (particularly the higher quality gas shales) is today the low cost portion of the natural gas price/supply curve.

Prior Perception

New Understanding
Magnitude of gas hydrate potential by type of deposit

- Arctic Sands near Infrastructure
- Arctic Sands away from Infrastructure
- Marine Sands
- Other Marine Deposits
- Massive Mounds
- Dispersed in Shale or Filling Veins and Fractures

~ 2,7000,000 EJ
### Fossil and uranium occurrences

<table>
<thead>
<tr>
<th></th>
<th>TPES in 2010: ~500 EJ</th>
<th>Historical production through 2010</th>
<th>Production 2010</th>
<th>Reserves</th>
<th>Resources</th>
<th>Additional occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional oil</td>
<td>6 788</td>
<td>141.2</td>
<td>4 900 - 7 610</td>
<td>4 170 - 6 150</td>
<td></td>
<td>&gt; 40 000</td>
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<tr>
<td>Unconventional oil</td>
<td>629</td>
<td>22.7</td>
<td>3 750 - 5 600</td>
<td>11 280 - 21 000</td>
<td>&gt; 40 000</td>
<td></td>
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<tr>
<td>Conventional gas</td>
<td>3 572</td>
<td>105.5</td>
<td>5 000 - 7 100</td>
<td>7 200 - 10 650</td>
<td></td>
<td>&gt; 1 000 000</td>
</tr>
<tr>
<td>Unconventional gas</td>
<td>173</td>
<td>15.1</td>
<td>20 100 - 67 100</td>
<td>40 200 - 121 900</td>
<td></td>
<td>&gt; 1 000 000</td>
</tr>
<tr>
<td>Coal</td>
<td>7 426</td>
<td>156.2</td>
<td>17 300 - 21 000</td>
<td>291 000 - 435 000</td>
<td></td>
<td>&gt; 1 000 000</td>
</tr>
<tr>
<td>Conventional uranium</td>
<td>1,484</td>
<td>31.6</td>
<td>2 400</td>
<td>7 400</td>
<td></td>
<td>&gt; 2 600 000</td>
</tr>
<tr>
<td>Unconventional uranium</td>
<td>34</td>
<td></td>
<td></td>
<td>7 100</td>
<td></td>
<td>&gt; 2 600 000</td>
</tr>
</tbody>
</table>

|                      | Conventional oil (Gbbl) | 1 188 | 24.7 | 860 - 1 333 | 730 - 1 080 |           |
|                      | Unconventional oil (Gbbl) | 110   | 4.0  | 660 - 980   | 1 970 - 3 690 | > 7 000  |
|                      | Conventional gas (Tcm)   | 96    | 2.8  | 134 - 190   | 193 - 287   |           |
|                      | Unconventional gas (Tcm) | 5     | 0.4  | 540 - 1 800 | 1 080 - 3 200 | > 25 000 |
|                      | Coal (Gtce)             | 253   | 5.3  | 590 - 720   | 9 930 - 14 800 |           |
|                      | Conventional uranium (ktU) | 2 519 | 54   | 4,076       | 12,645      |           |
|                      | Unconventional uranium (ktU) | 58    |      |             | 12,016      | 4,500,000 |
Renewable energy flows

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<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>53.5</td>
<td>2 400</td>
<td>800</td>
<td>44 - 130</td>
</tr>
<tr>
<td>Geothermal</td>
<td>2.5</td>
<td>1 500</td>
<td>720</td>
<td>75</td>
</tr>
<tr>
<td>Hydro</td>
<td>13.7</td>
<td>504 000</td>
<td>160</td>
<td>30 - 47</td>
</tr>
<tr>
<td>Solar</td>
<td>0.6</td>
<td>3 900 000</td>
<td>280 000</td>
<td>40 – 200</td>
</tr>
<tr>
<td>Wind</td>
<td>1.5</td>
<td>110 000</td>
<td>1 700</td>
<td>72 - 350</td>
</tr>
<tr>
<td>Crop residues, MSW, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Primary energy intensity and energy per capita (selected regions and countries) - NPS

Source: OECD/IEA - World Energy Outlook 2012
Electricity Demand Annual Growth Rates

Source: OECD/IEA - World Energy Outlook 2011
Per-capita electricity use in non-OECD countries doubles by 2030, reaching 2,400 kWh, but remains well below even the current OECD average of 7,640 kWh.

Source: OECD/IEA - World Energy Outlook 2011
Trends in energy & CO\textsubscript{2} intensity, historical & by scenario

Renewables subsidies, carbon pricing & coal to gas switching in the power sector underpin a decline in carbon intensity of 0.4% per year in the New Policies Scenario

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

Source: OECD/IEA - World Energy Outlook 2012
Total primary energy demand – New Policy Scenario (NPS)

![Energy Demand Chart]

Source: OECD/IEA - World Energy Outlook 2012
Fossil fuels account for 60% of the overall increase in demand, remaining the principal sources of energy worldwide.

Source: OECD/IEA - World Energy Outlook 2012
Emerging economies steer energy markets

Share of global energy demand

Global energy demand rises by over one-third in the period to 2035, underpinned by rising living standards in China, India & the Middle East
Change in global primary energy demand by measure & by scenario

Energy demand reduction in 2035 to NPS to 450

- Efficiency in end-uses: 67% to 66%
- Efficiency in energy supply: 5% to 8%
- Fuel & technology switching: 12% to 12%
- Activity: 16% to 14%
- Total (Mtoe): 1,479 to 2,404

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 & in moving beyond it, reflecting its large economic potential.
Energy-related CO₂ emissions by scenario & abatement measures

CO₂ emissions in the Efficient World Scenario peak before 2020 & then decline to 30.5 Gt in 2035. Emissions are 6.5 Gt lower than in the New Policies Scenario in 2035.
Despite fuel mix differences, trend of greater diversity is common to OECD & non-OECD countries. Policies drive renewables up & coal down in OECD countries.

Source: OECD/IEA - World Energy Outlook 2012
Global final energy demand by fuel

Source: OECD/IEA - World Energy Outlook 2012
Structure of global electricity supply, 2030
Source: IEA 2012 World Energy Outlook (New Policies Scenario)

Global electricity generation in 2035: 36 640 TWh

- Coal: 32.5%
- Oil: 1.5%
- Gas: 23.1%
- Nuclear: 11.9%
- Hydro: 15.5%
- Wind: 7.3%
- Other renewable: 4.1%
- Biomass and waste: 4.1%

2010 Structure:
- Coal: 40.6%
- Oil: 4.7%
- Gas: 22.2%
- Nuclear: 12.9%
- Hydro: 16.0%
- Biomass: 1.5%
- Wind: 1.4%
- Other Ren: 2.1%
Structure of global electricity supply, 2030
Source: IEA 2012 World Energy Outlook (450 ppm Scenario)

Global electricity generation in 2035: 31 750 TWh

- Gas: 18.2%
- Nuclear: 18.8%
- Hydro: 19.7%
- Other renewable: 13.7%
- Biomass and waste: 6.4%
- Coal: 13.5%
- Oil: 1.0%

2010 Structure:
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Avoidance of CO2 emissions in a 450 ppm scenario

2030 (NP) 2035 (450 ppm)

- Emissions
- CCS
- Nuclear
- Biofuels
- Renewables
- Fuel switching
- Activity
- Efficiency

Source: Adapted from IEA WEO 2012
Global energy-related CO$_2$ emissions by scenario

CO$_2$ emissions rise to 44.1 Gt in CPS & 37 Gt in NPS and 22.1 Gt in 450 ppm by 2035

Source: OECD/IEA - World Energy Outlook 2012
Investment in new power plants: New Policies Scenario, 2011-2035

OECD: 4,336 billion
Non-OECD: 5,456 billion

Source: OECD/IEA - World Energy Outlook 2011
Electricity investment focuses on low-carbon technologies

Renewables supply 25% of additional generation but account for 50% of investment

Source: OECD/IEA - World Energy Outlook 2011
Renaissance of interest before 11 March 2011

- Continued strong growth in global energy demand
- Price volatility of fossil fuels along a rising trajectory
- Draining export revenues
- Energy security concerns
- Environment protection and climate change
- Renewables progressing but still too costly
- Need for stable and reliable base-load electricity
- U resources plentiful
The renaissance in interest – NP related factors

- Dramatic improvement in operating performance has transformed economics between 1990 and 2005
- Higher capacity factors
- Power up-rates
- Licence extensions
- Excellent safety record
- Market in “used” reactors
- Money printing machines
- Previous “hopes/fears” that NPPs would be victims of electricity liberalization have not materialized!
Annual **Incremental** Nuclear Capacity Additions and **Total** Nuclear Electricity Generation

- **Incremental nuclear power capacity additions in GWe**
- **Total nuclear electricity generation in TWh**

- **1965 to 2010**
Load factor: Global fleet of nuclear reactors

Equivalent to the construction of 34 NPPs of 1,000 MW each
Construction starts until 11 March 2013
# Fukushima impact to date

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium, Germany, Switzerland</td>
<td>Nuclear phase out – no new build</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Nuclear phased out intentions announced but new plant construction continues</td>
</tr>
<tr>
<td>Japan</td>
<td>All construction suspended, decommissioning of Fukushima 1-4, remaining 50 plants successively shut down by 5 May 2012. Two restarts in July 2012. Phase out intentions by late 2030s</td>
</tr>
<tr>
<td>China</td>
<td>Initially new construction licenses suspended – lifted in October 2012</td>
</tr>
<tr>
<td>Belarus, Turkey</td>
<td>First plants ordered</td>
</tr>
<tr>
<td>UAE, USA</td>
<td>Construction starts: UAE - 2 plants; USA - First new nuclear build in more than 30 yrs</td>
</tr>
<tr>
<td>Chile, Indonesia, Malaysia, Morrocco, Thailand, Saudi Arabia</td>
<td>Active preparation continues with final decision delayed or no final decision</td>
</tr>
<tr>
<td>Bangladesh, Vietnam, Egypt, Jordan, Nigeria, Poland</td>
<td>Continue preparing infrastructure</td>
</tr>
<tr>
<td>Italy, Kuwait, Senegal, Venezuela</td>
<td>Plans of introducing NP cancelled</td>
</tr>
<tr>
<td>Many Member States</td>
<td>Many Member States carried out national safety assessment reviews in 2011 and commitments were made to implement necessary corrective action</td>
</tr>
</tbody>
</table>
Drivers for nuclear power

- Global energy demand is set to grow

*Nuclear power expands supply options*
Electricity demand

History Projection – IEA NP

TWh

Developing countries
CIS
OECD

Some 1.260 million people have no access to electricity

Over 95% of those without electricity are in developing Asia or sub-Saharan Africa & nearly two-thirds are in just ten countries
Link between poverty and electricity access

Drivers for nuclear power

- Global energy demand is set to grow
  *Nuclear power expands supply options*

- Environmental pressures are rising
  *Nuclear power has low life-cycle GHG emissions*
Mitigation – Role of nuclear power

Life cycle GHG emissions of different electricity generating options

Nuclear power: Very low lifetime GHG emissions make the technology a potent climate change mitigation option
Drivers for nuclear power

- Global energy demand is set to grow
  *Nuclear power expands supply options*

- Environmental pressures are rising
  *Nuclear power has low life-cycle GHG emissions*

- Energy supply security back on the political agenda
  *Nuclear power contributes to energy security*
Nuclear power and energy security

- Small fuel volumes
- Long refueling cycles
- Resource a small share in generating costs
- Resource are plentiful
- Base load technology

Cost components in total generating costs at a 10% discount rate

Doubling of resource costs

Adapted from IEA/NEA 2010 and NEA 2003
Post Fukushima: Unchanged drivers behind the renaissance in the interest in nuclear power

- Global energy demand is set to grow
  *Nuclear power expands supply options*

- Environmental pressures are rising
  *Nuclear power has low life-cycle GHG emissions*

- Energy supply security back on the political agenda
  *Nuclear power contributes to energy security*

- Reliable base load electricity at predictable and affordable costs for meeting MDGs
  *Nuclear power offers stable and predictable generation costs based on low resource costs*
Range of levelized generating costs of new electricity generating capacities

- Geothermal
- Biomass
- Hydro - small scale
- Hydro - large scale
- Solar Thermal
- Solar PV - stand alone
- Solar PV
- Wind (offshore)
- Wind (onshore)
- Gas
- Coal (CCS)
- Coal
- Nuclear

Source: NEA/IEA, 2010
Externalities of different electricity generating options

- Biomass technologies
- Nuclear power
- Wind
- Natural gas technologies
- Existing coal technologies
  - no gas cleaning
- New coal technologies

Air pollution (PM$_{10}$) and other impacts vs. Greenhouse gas impacts

Source: EU-EUR 20198, 2003
Impact of carbon prices

![Graph showing the impact of carbon prices on different energy sources. The graph compares the costs of Coal, Coal CCS, and Gas CCGT under various carbon prices (30$, 20$, and 10$ per ton of CO2) against baseline costs. The graph indicates that higher carbon prices increase the cost of electricity production, with nuclear power being relatively less sensitive to carbon pricing.]
Status global nuclear power today

Units in Operation: 434
370.5 GWe

- Far East: 22.0%
- North America: 30.7%
- Western Europe: 30.7%
- Asia: 1.4%
- Eastern Europe/CIS: 13.1%
- South East Asia: 0.8%
- Africa: 0.5%
- Middle East: 0.2%

Units under construction: 69
65.3 GWe

- Far East: 58.2%
- Latin America: 3.0%
- North America: 5.2%
- Western Europe: 4.9%
- Eastern Europe/CIS: 18.3%
- South East Asia: 8.4%
- Middle East: 2.1%
Nuclear power generating capacity
(as 31 May 2013)
IAEA nuclear power projections (RDS-1)

- Projections of future role of nuclear power are presented as LOW and HIGH estimates.
- Projections are NOT predictions.
- The RDS-1 estimates should be viewed as very general growth trends whose validity must be constantly subjected to critical review.
  - Economic growth and structural economic change
  - Energy intensity
  - Technology performance and costs
  - Energy resource availability and future fuel prices
  - Energy policy and physical, environmental and economic constraints.
Predictions are difficult, especially about the future (Niels Bohr)

- Projections of future role of nuclear power are presented as LOW and HIGH estimates
- Projections are NOT predictions
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  - Energy intensity
  - Technology performance and costs
  - Energy resource availability and future fuel prices
  - Energy policy and physical, environmental and economic constraints.
Key assumptions

- **LOW** reflects a continuation current trends and changes in policies affecting nuclear power other than those already in the pipeline.

- **HIGH** is much more optimistic, but still plausible and technically feasible and assumes that:
  - the Fukushima Daiichi accident does not lead to a long-term retraction of nuclear power programmes globally.
  - the current financial and economic crises will be overcome in the not so distant future.
  - past rates of economic growth and electricity demand, especially in the Far East, would essentially resume.
  - the implementation of stringent policies globally targeted at mitigating climate change.
IAEA – LOW projection

Capacity in 2030: 456 GW versus 546 GW in 2010

Nuclear generation share in 2030: 10.4% versus 13.8% in 2010 projection
IAEA – HIGH projection

Capacity in 2030: 740 GW versus 803 GW in 2010

Nuclear generation share in 2030: 13.6% versus 16.6% in 2010 projection
Concluding remarks

- Rising incomes & population will accelerate the demand for energy services
- Oil supply diversity is diminishing, while new options are opening up for natural gas
- Globally, energy resources are plentiful and pose no limiting constraint – but timely investment required
- Less nuclear would lead to higher CO₂ emissions, increased energy prices and growing energy import bills
- Energy conversion technologies will become increasingly capital intensive
- Despite steps in the right direction, the door to 2°C is closing