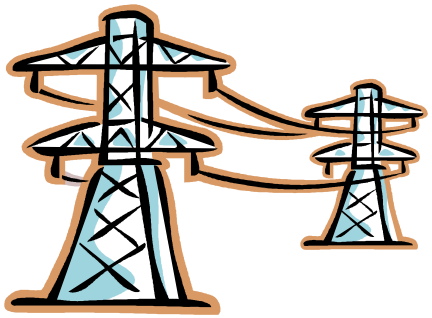
Electrical Power Generation Options

(With a Nuclear Bias)

17th March 2010

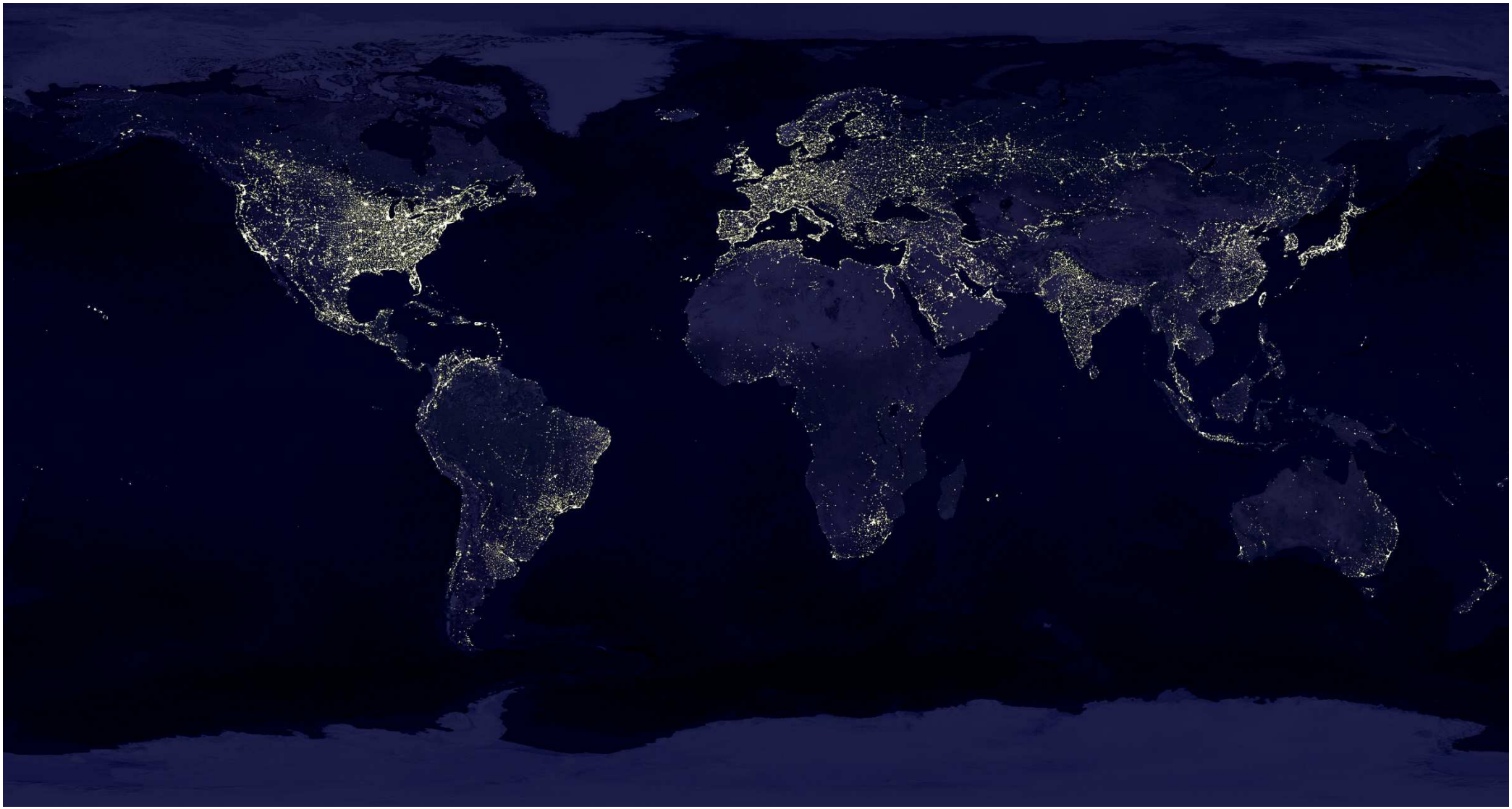
Erica Smyth



Electricity Supply Presentation Outline

- Global Context total energy
- Energy and CO2
- Electricity generation options
- Making the appropriate choice
- The GHG constrained world
- Ways forward

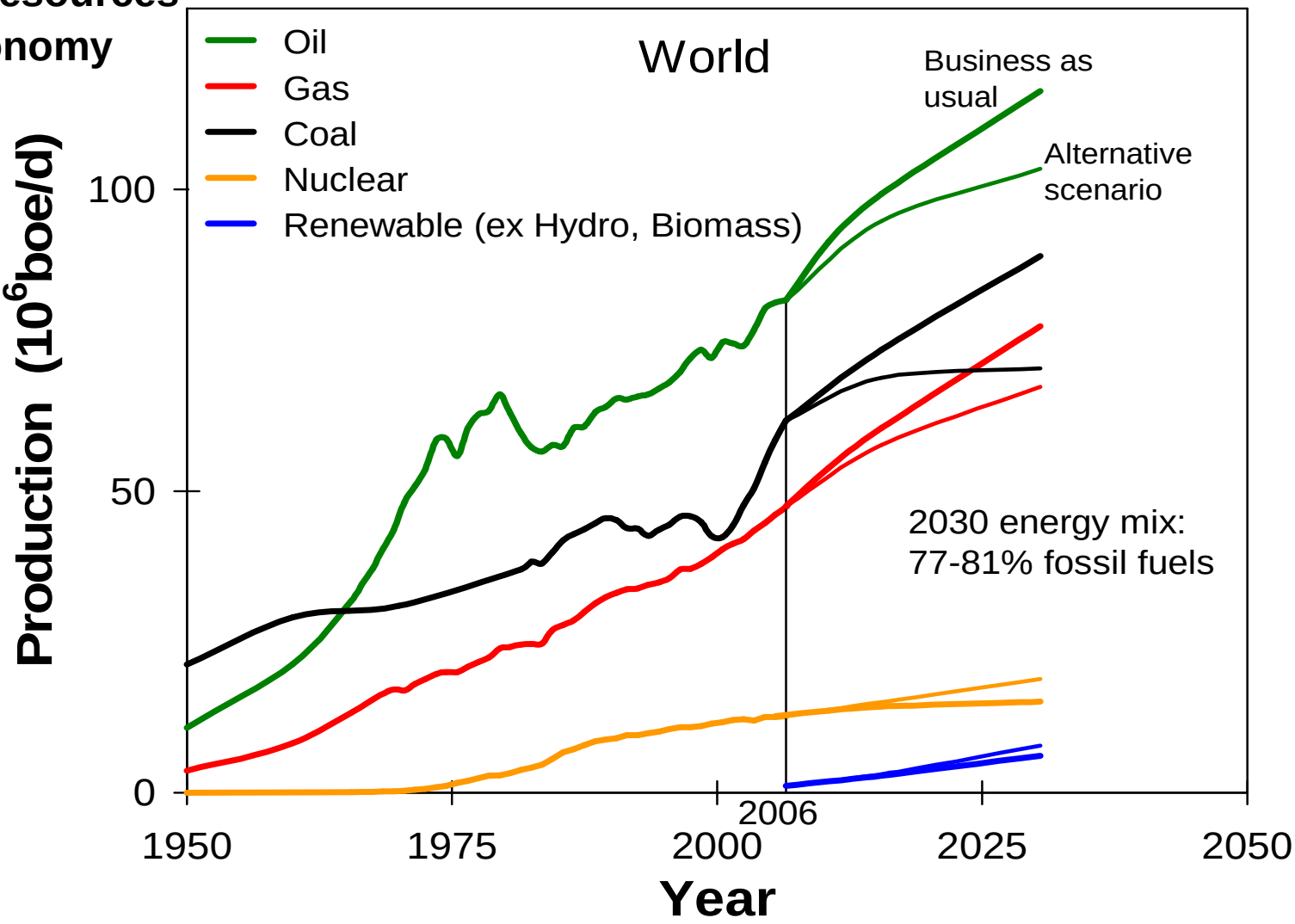
Global Context



Sources of the world's energy – Fossil Fuel Dominated

The world runs on fossil energy

- **Historically cheap**
- **Readily available resources**
- **Underpins our economy**



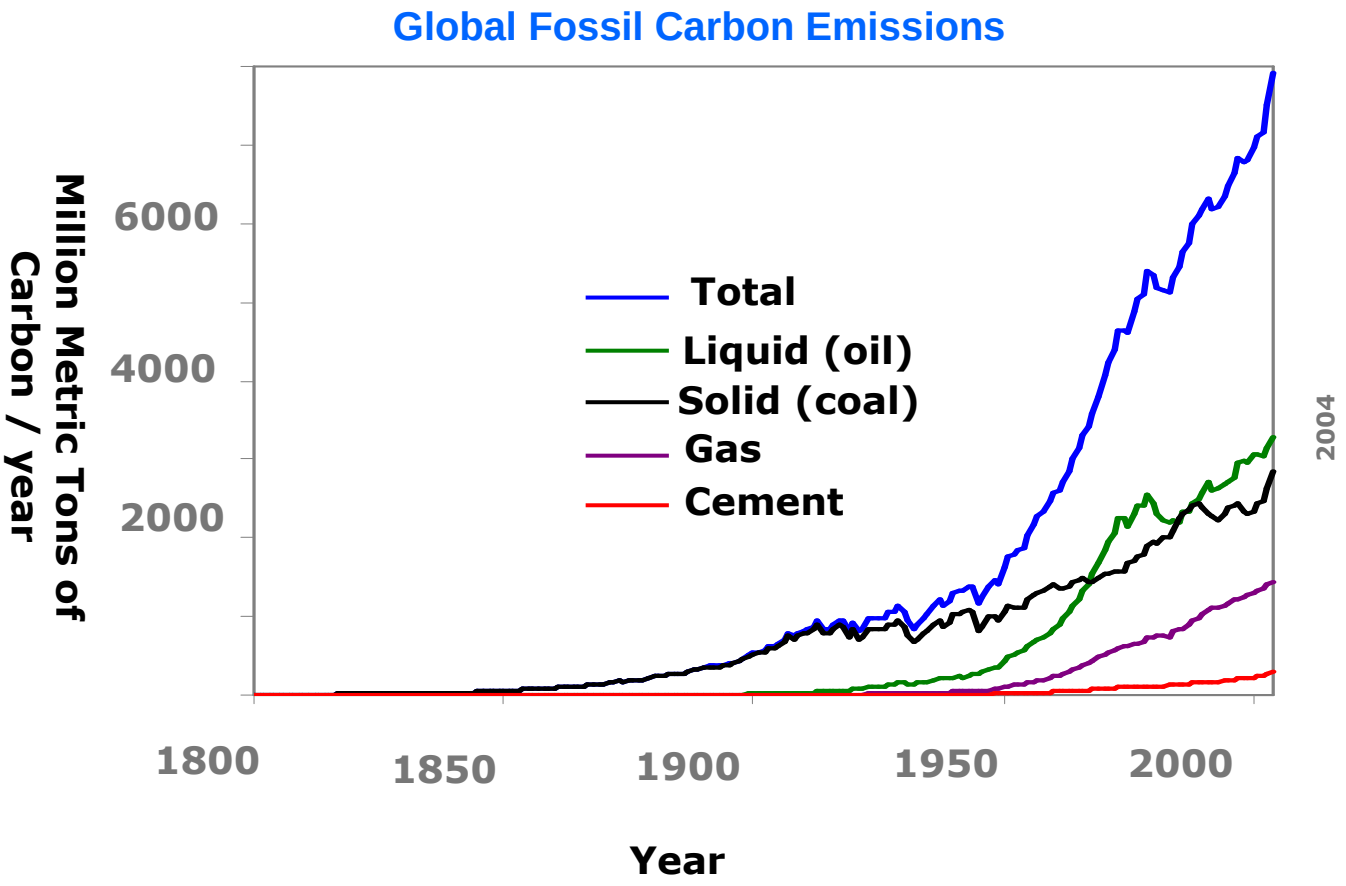
Source CSIRO (2008) and BP (2007), IEA (2006)

Sources of Energy – metric tons of C/yr

- **The world runs on fossil energy**

  BUT

- **Fossil energy use emits greenhouse gases → global warming**

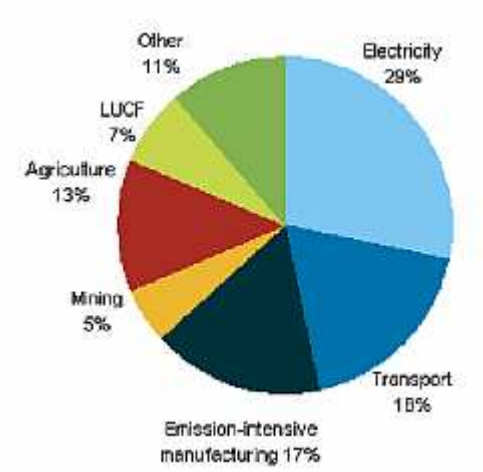


Source CSIRO 2008 and CDIAC, DOE
http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm

Global CO_2 –e Emissions by sector

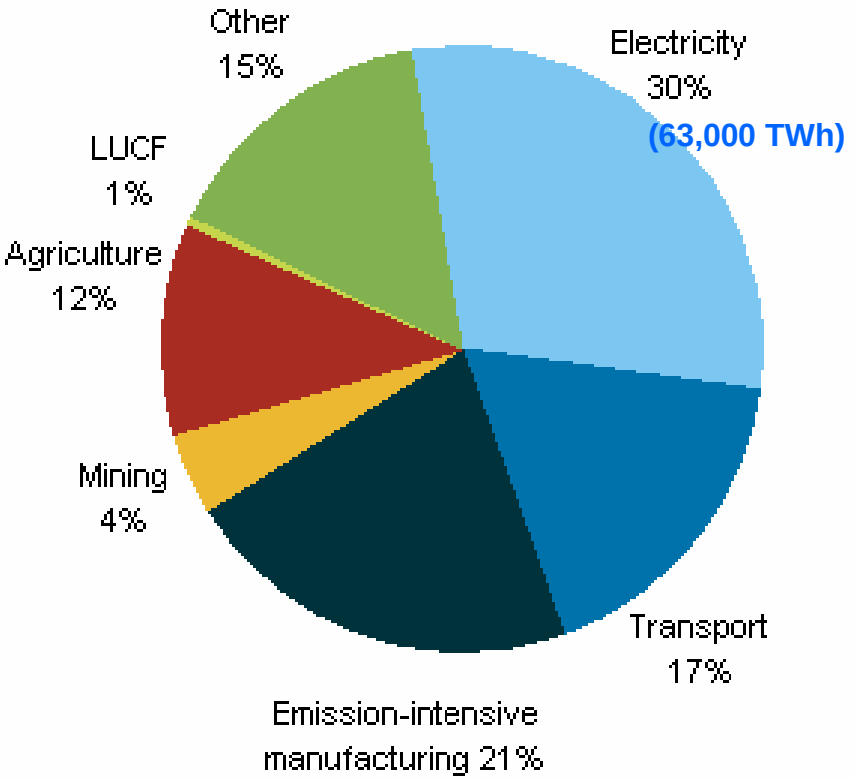
By 2050 expect a 340% increase in total generation

2005



(18,307 TWh)

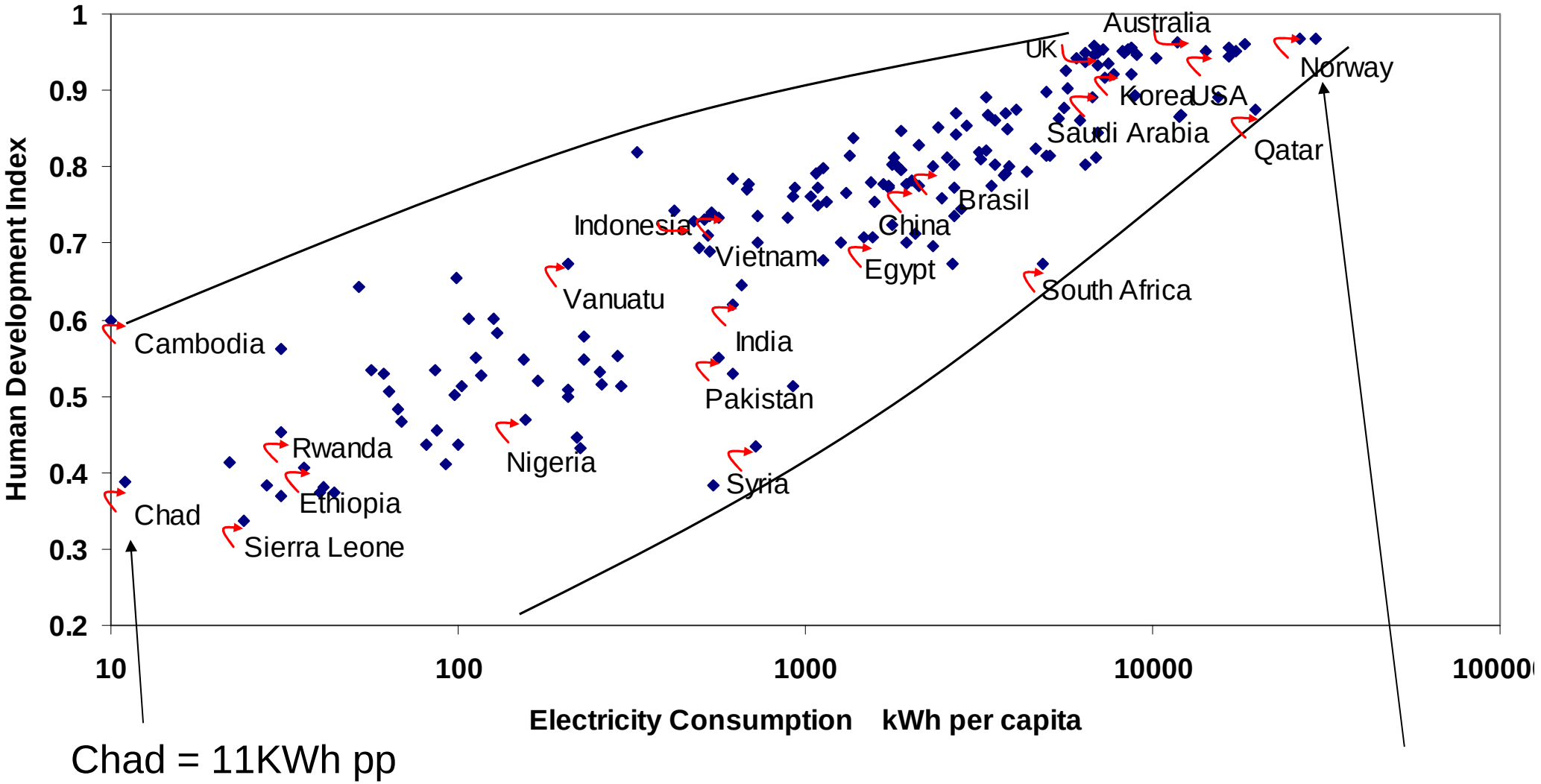
2050



(63,000 TWh)

Source: www.treasury.gov.au/lowpollutionfuture/report

HDI vs Electricity consumption / capita 2005



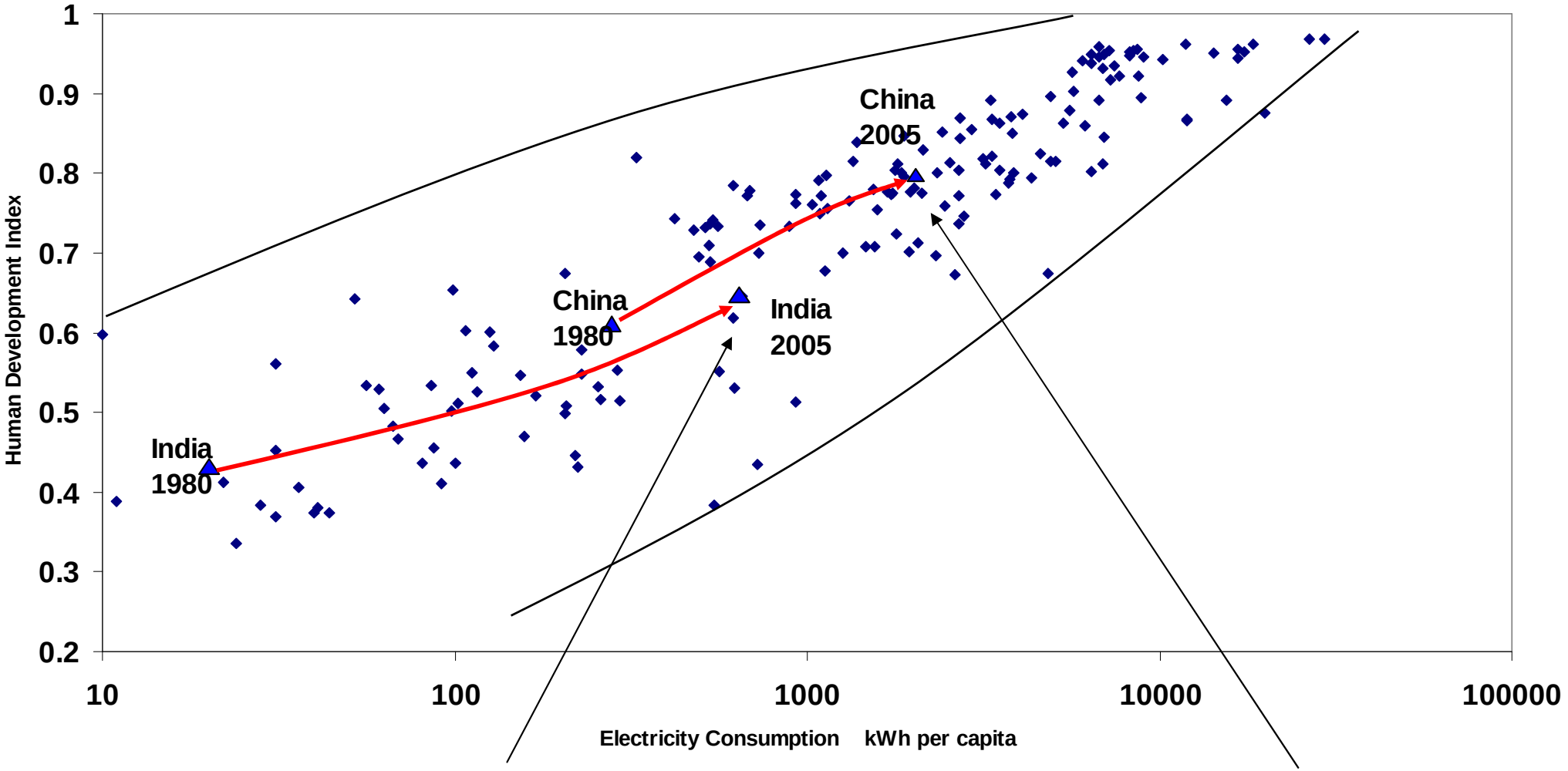
Chad = 11KWh pp

Iceland= 29,430KWh pp

HDI – Healthy life, access to knowledge & standard of living

Source UN 2008

HDI vs Electricity consumption / capita 2005



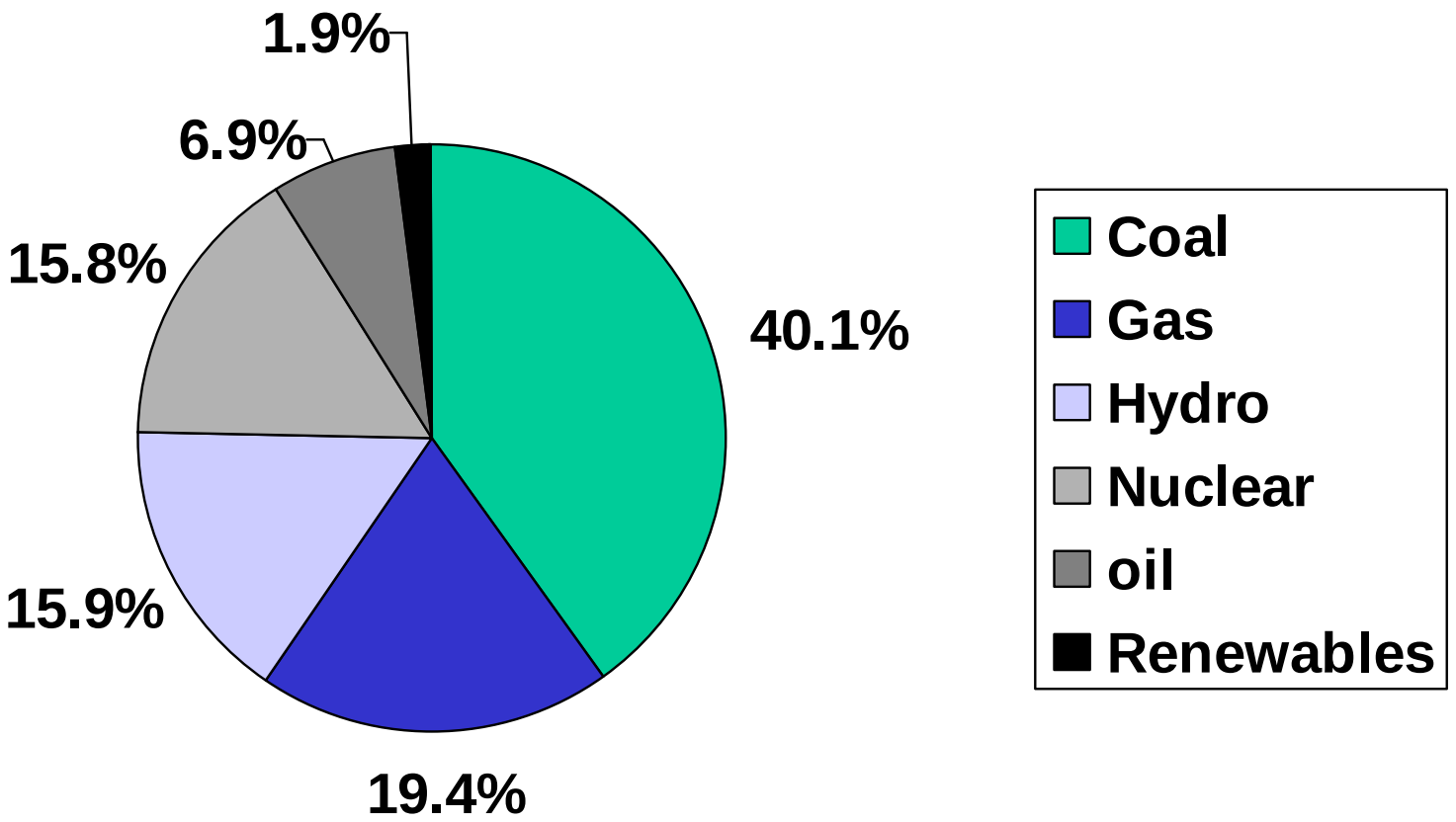
India = 618 KWh pp

China = 1684 KWh pp

HDI – Healthy life, access to knowledge & standard of living

Source UN 2008

World electricity supply 2005 (18,307 TWh)



Australian Treasury estimates by 2050 coal will generate 53% of the 63,000TWh world electricity supply

Source: www.treasury.gov.au/lowpollutionfuture/report

Terminology

Normally stated per hour (eg Kilowatt hour KWh)

- **Watt – a unit of power equal to 1 joule per second (equal to 1/746th of 1 horse-power)**
- **Kilowatt (KWh) - 10^3 think of ten 100 watt globes burning for an hour. A portable camping generator**
- **Megawatt (MWh) – 10^6 think of power to 800 homes. A modern wind turbine (2MW each or 80MW for farm)**
- **Gigawatt (GWh) – 10^9 1 typical French nuclear plant**
- **Terawatt (TWh) - 10^{12} world demand was 18,307 TWh in 2005**

World Electricity Supply by Source - 1971 to 2005 TWh

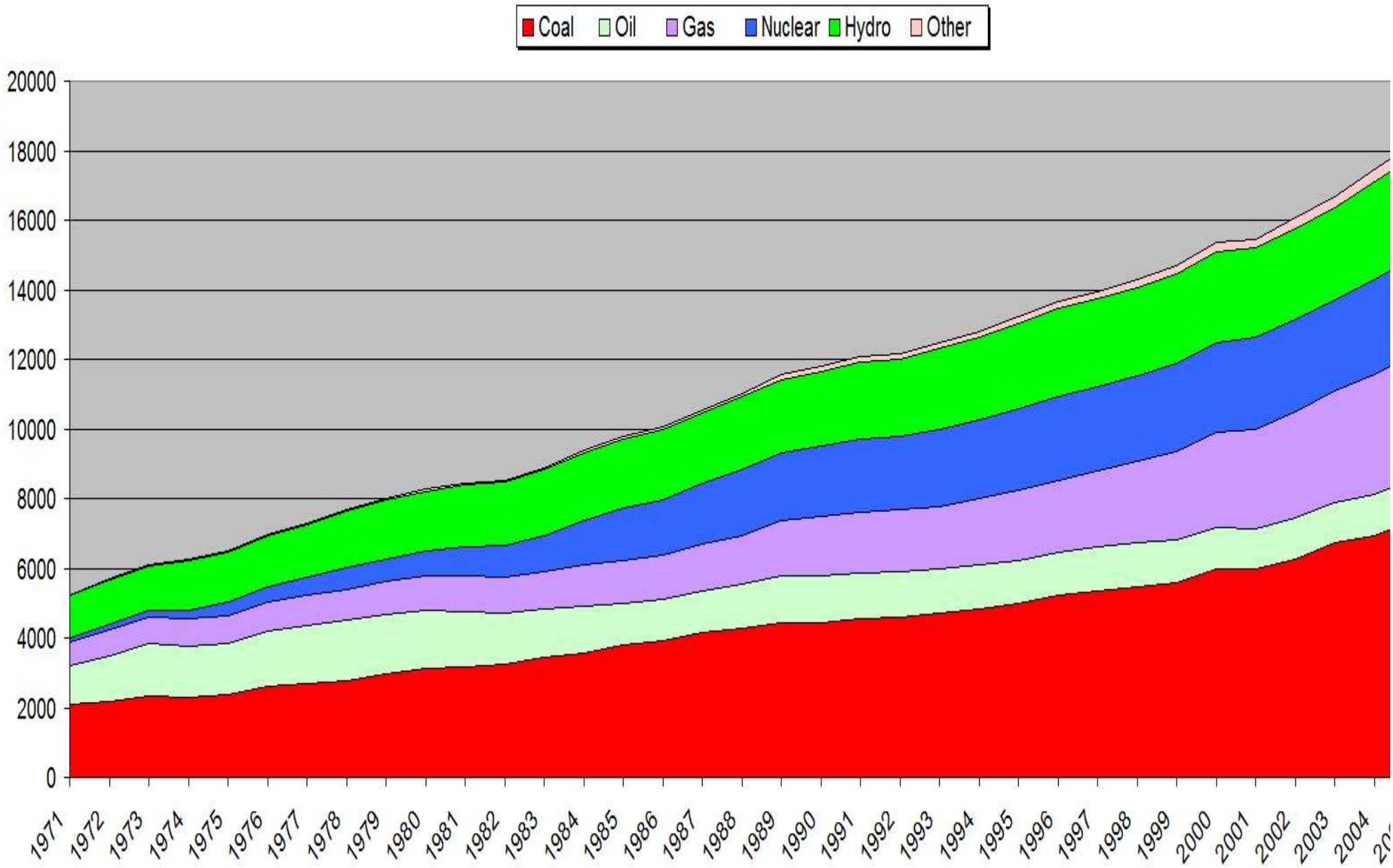
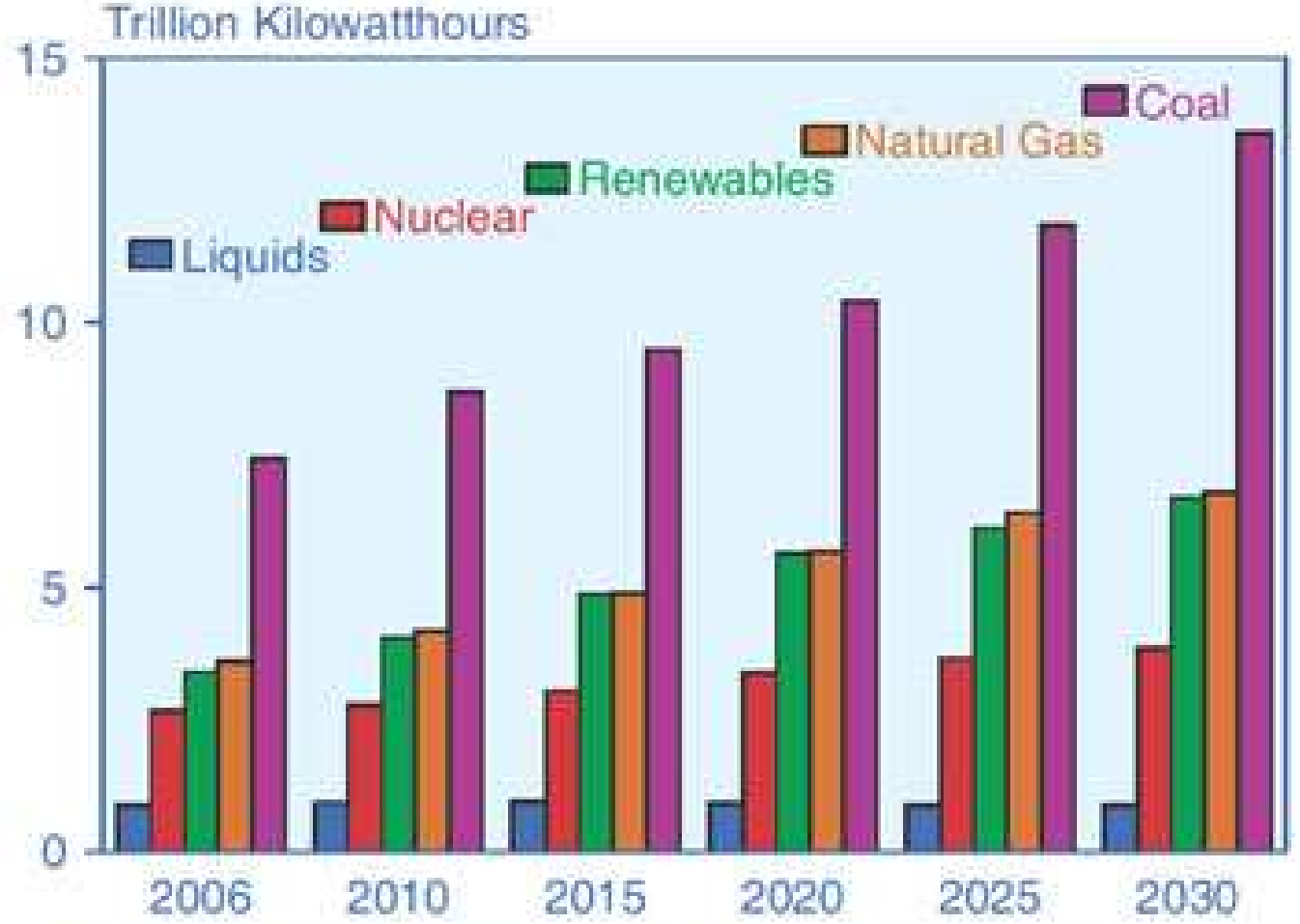
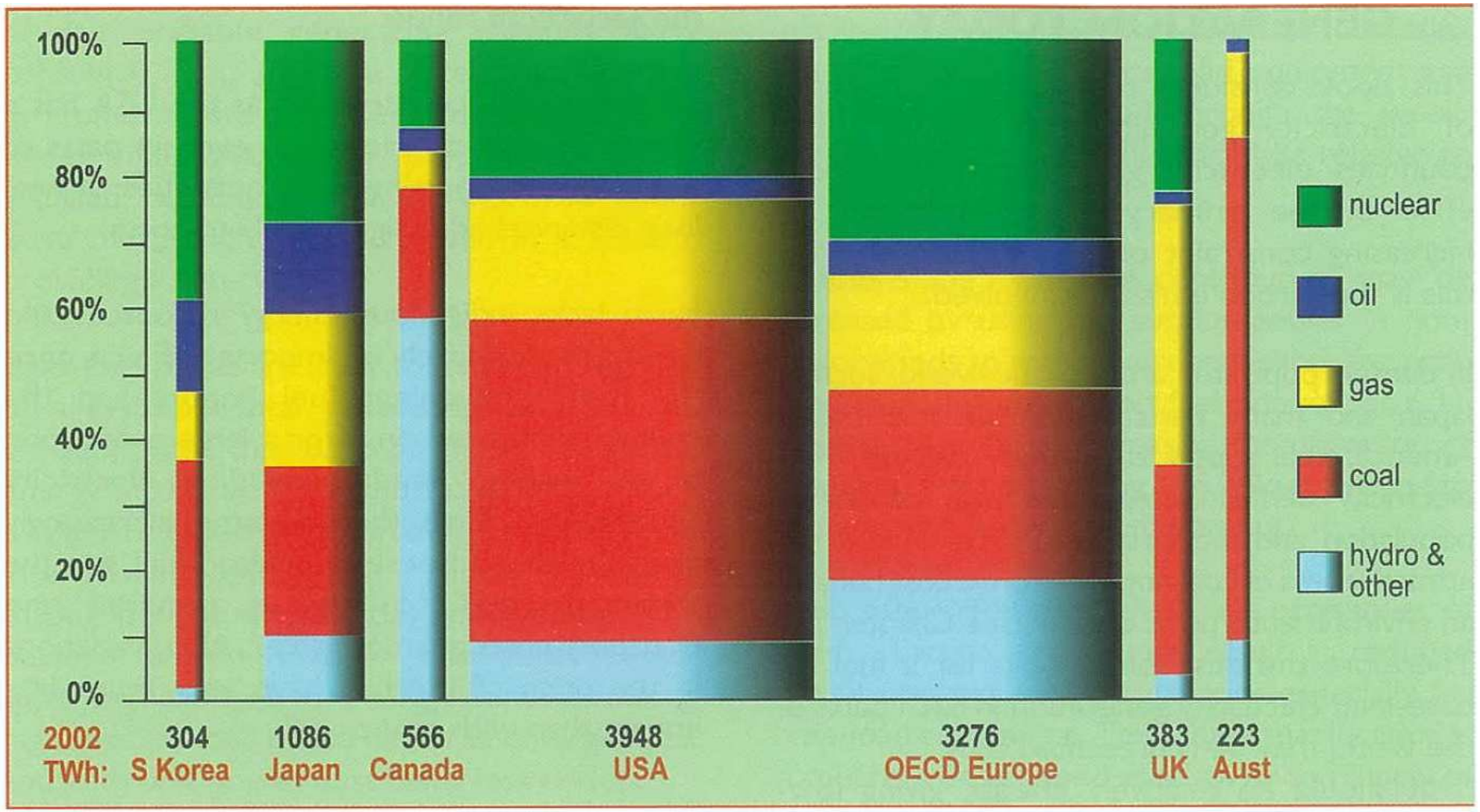


Figure 51. World Electricity Generation by Fuel, 2006-2030



Sources: **2006:** Derived from Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

Power Generation Sources 2002



Width of each bar is indicative of power generated (gross production)

Source: OECD/IAEA 2003 "Electricity Information" 2002, Table 4.

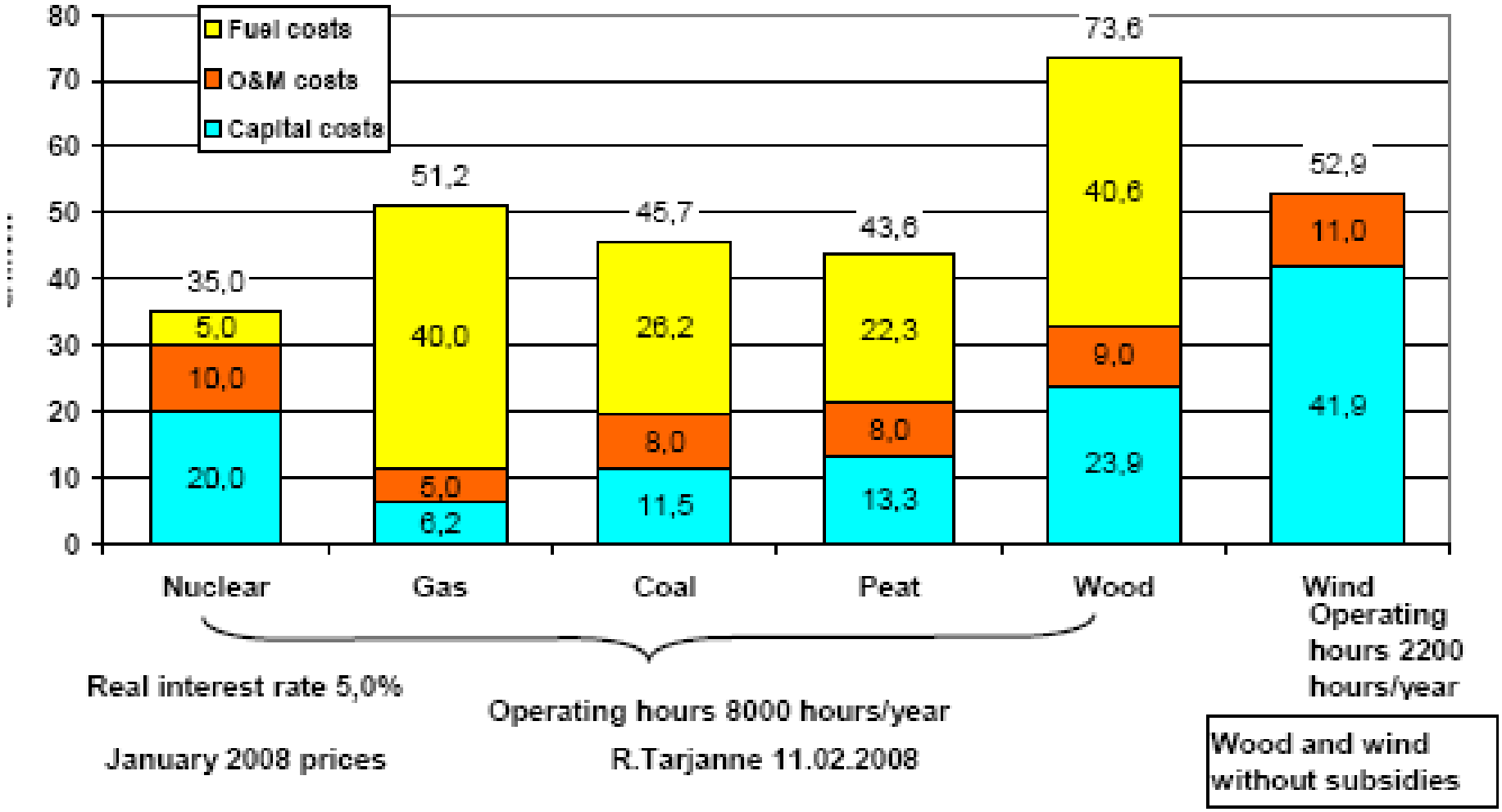
How do countries choose optimal electricity supply?

A country's choice will depend on one or a combination of:-

- Costs – capital, operating and fuel
- Fuel prices (and efficiency)
- Technology and internal capability
- Load demand characteristics
- Capacity and backup
- Fuel supply security
- Safety of options
- Environmental impacts
- Security of supply
- Exposure to GHG politics and costs

Making the Choice - Costs

ELECTRICITY GENERATION COSTS, WITHOUT EMISSION TRADING
2008 Euros /MWh

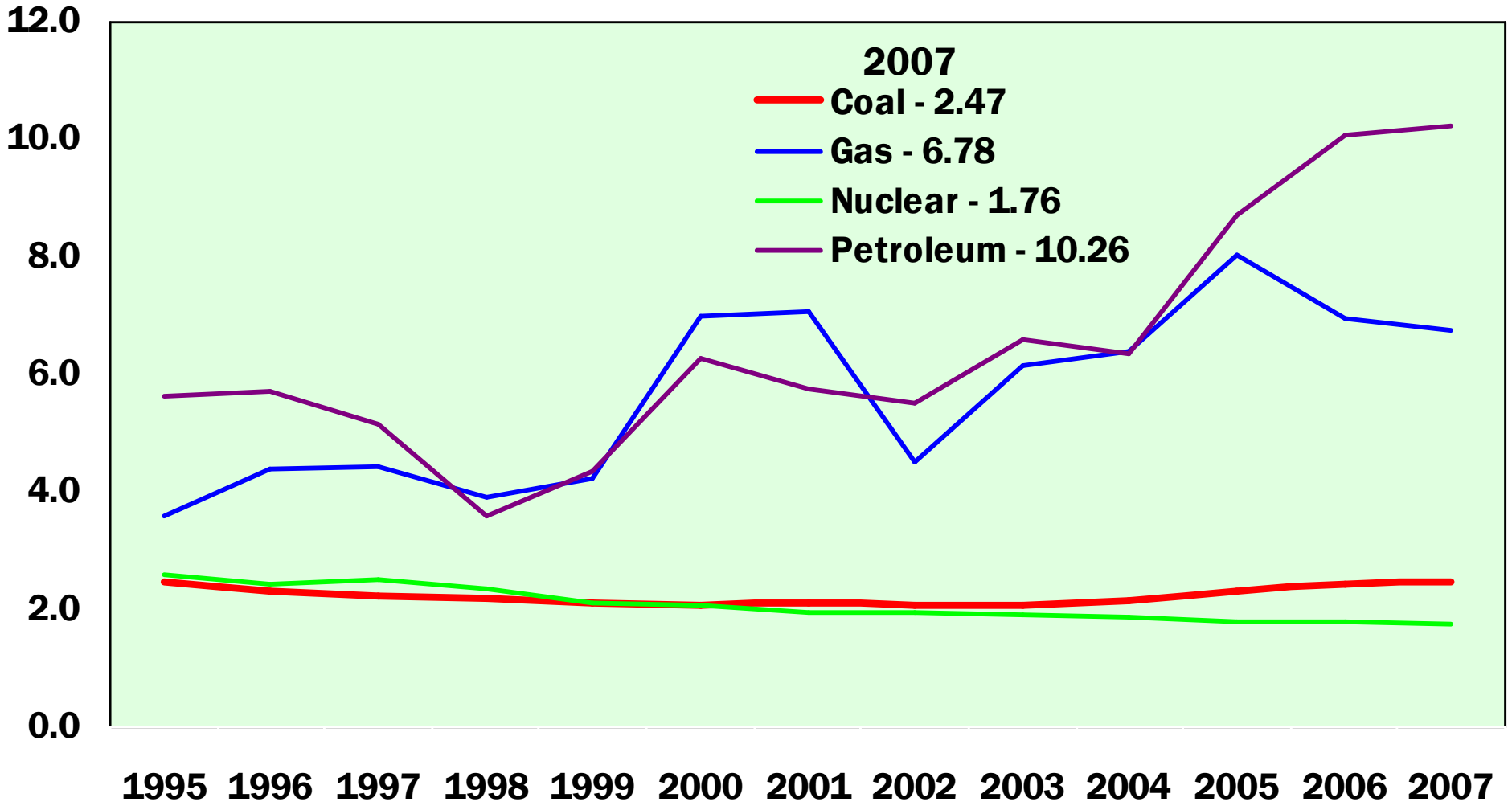


Source **COMPARISON OF ELECTRICITY GENERATION COSTS** Tarjanne Risto, Kivistö Aija 2008
https://oa.doria.fi/bitstream/handle/10024/39685/isbn9789522145888.pdf

Making the Choice - Costs

U.S. Electricity Production Costs

1995-2007, *In 2007 cents per kilowatt-hour*



Production Costs = Operations and Maintenance Costs + Fuel Costs

Source: Global Energy Decisions

Updated: 5/08

Making the Choice – Fuel Efficiency (in USA)

- **Fuel Efficiency** refers to the % of energy contained in the fuel that is converted to electricity
  - **Coal**: Steam turbine Ave 34%. single cycle most common
  - **Natural Gas**: gas turbine (steam) ave 40%, Combined cycle up to 60%
  - **Hydro:** Turbine blades up to 90%
  - **Nuclear-generated electricity** Nuclear fission (fuel burn is design dependant approx 50%) then heat exchange to steam turbines 37% thermal efficiency
  - **Oil:** Internal combustion or steam turbine (ave 37%) combined cycle not common. Small reciprocating engines in remote areas
  - **Solar:** Photovoltaic in past 30% now often 40% conversion efficiency

Making the Choice - Technology

- **Coal** – Steam turbines. Lot of old plants with long remaining life - hard to improve emissions and efficiency technologies but easy to buy off the shelf. Dominated by big capacity. CO2 disposal needs major research
- **Natural Gas** – Gas steam turbine easy to buy off the shelf. Range of capacity
- **Hydro** – Well understood turbines but whole system. mainly big capacity.
- **Nuclear** –Long approval and construction timeframes with high level of technical complexity. Special skills needed & few suppliers. Complex U enrichment processes. Mainly 1GW plus
- **Oil** – Simple thermal technology purchase off the shelf. Range of capacities
- **Geothermal:** Still emerging, water quality dependant. Small capacity so far
- **Wind , sun, ocean**– Emerging, new designs and prototypes developing. Very large footprint. Low capacity in each unit need energy farms

Information
Fossil Fuels - Burning

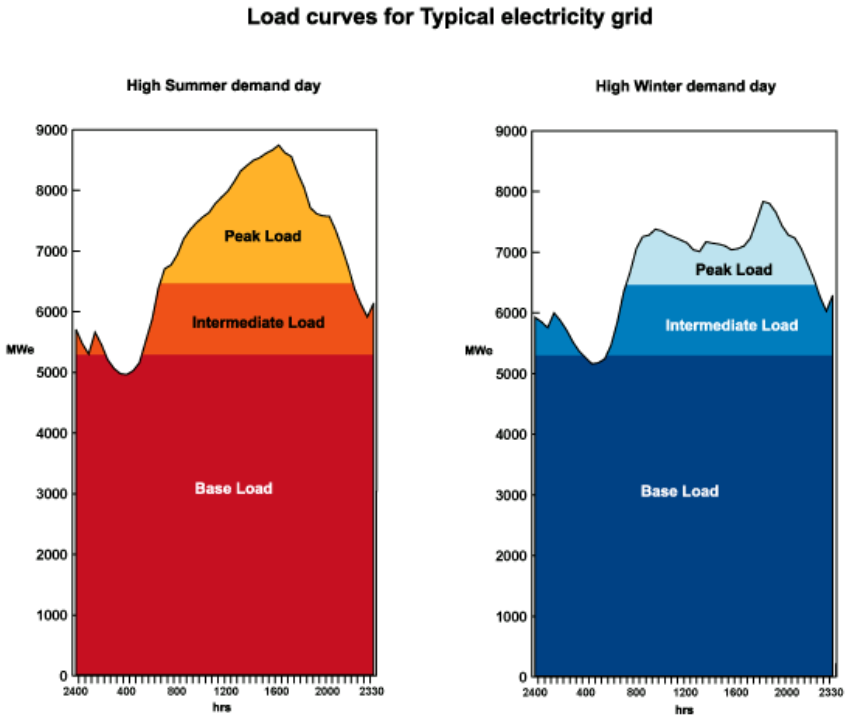
- Coal, oil, and gas consist largely of carbon and hydrogen. The process that we call "burning" actually is chemical reactions with oxygen in the air.
- For the most part, the carbon combines with oxygen to form carbon dioxide (CO2), and the hydrogen combines with oxygen to form water vapor (H20). In both of these chemical reactions a substantial amount of energy is released as heat.
- Since heat is what is needed to instigate these chemical reactions, we have a chain reaction: reactions cause heat, which causes reactions, which cause heat, and so on.
- Once started the process continues until nearly all of the fuel has gone through the process (i.e., burned), or it runs out of oxygen or until something is done to stop it. Of course, the reason for arranging all this is to derive the heat.

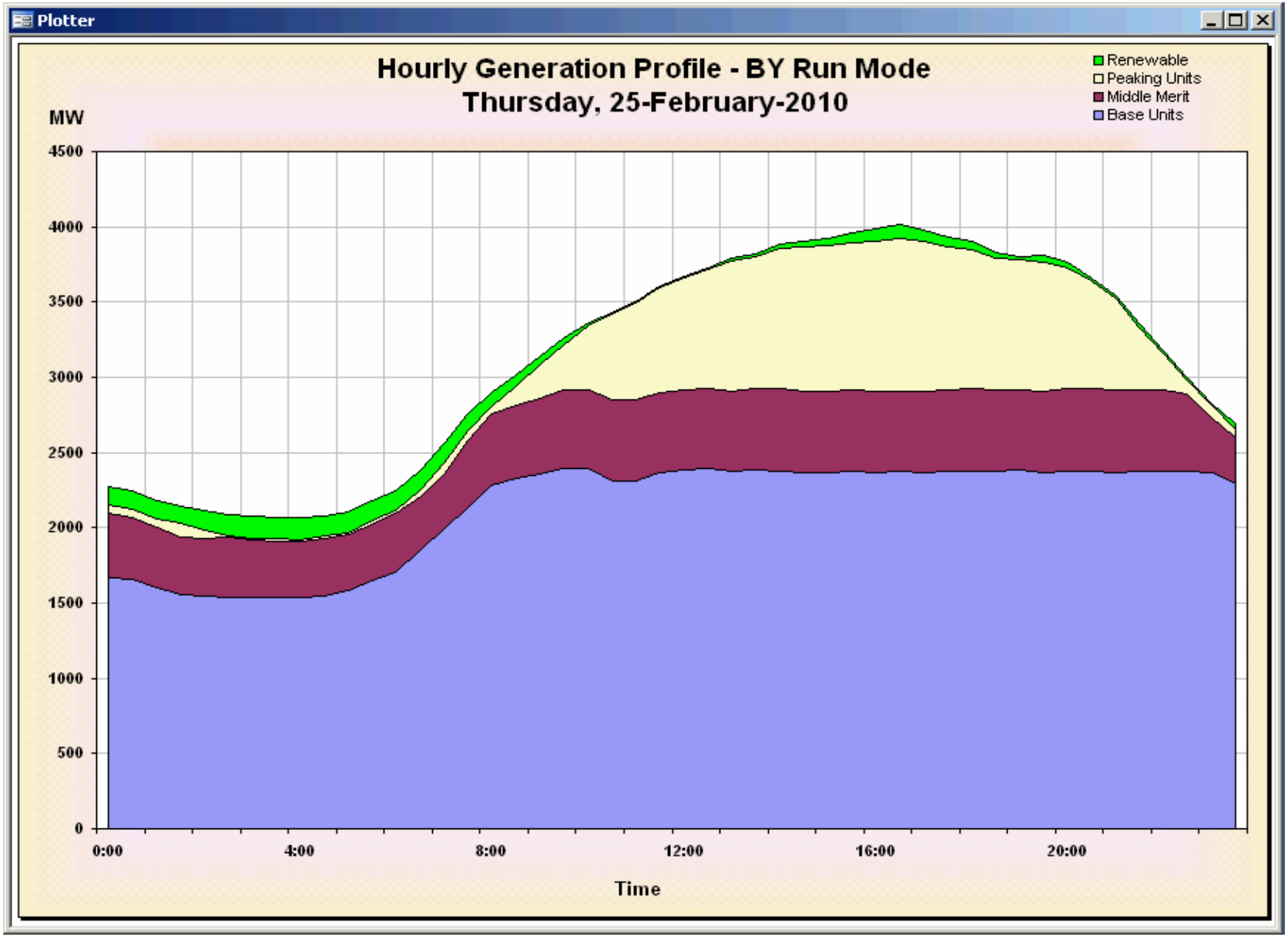
Making the Choice –
Baseload vs Intermediate vs Peaking

- **Baseload** is the minimum amount of power that a utility or distribution company must make available to its customers.

- **Peaking plant** provide power for peaks or spikes in customer power demand and are smaller and more responsive types of power plants. These plants are generally higher operating costs

An electricity supply system needs both base load and peaking capacity and may also use combinations of spinning reserve and intermediate load plants.
It is usually a capital cost / operating cost balance and one of providing appropriate response times to demand changes





SWIS Grid Generation profile 25th Feb 2010: Source - Western Power

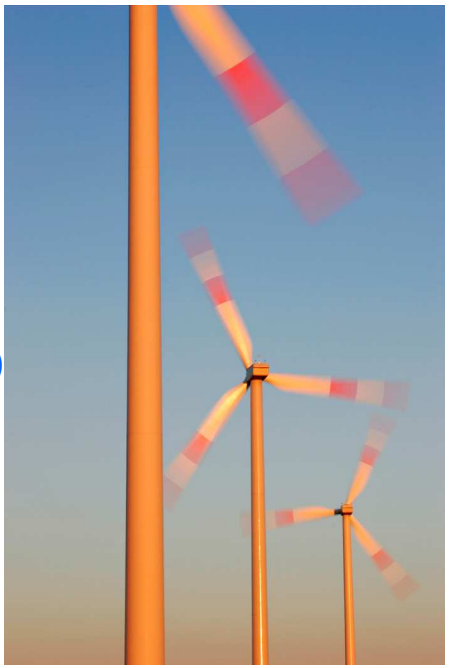
Making the Choice – Meeting load demand and capacity

- **Coal** best for large capacity base load (300MW to 1GW)
- **Gas** best for peaking load and can be used for variety of capacity large and small and base load
- **Hydro** Good for all load types & capacity depending on design
- **Nuclear** Only really good for base load and dominantly 1GW capacity but smaller units are being developed
- **Oil** Best for intermediate load and smaller capacity remote locations
- **Renewable** Load and capacity is energy-source dependant

Making the Choice - Capacity Factor

There are a number of measures commonly used to compare efficiency. Two of the more common are capacity and fuel efficiency.

- **Capacity factor refers to the** actual amount of electricity generated by a facility, as a percentage of what such a facility could produce if it ran 24 hours a day, seven days a week. In 2005,
  - **US Coal plants** 70%,
  - **Natural gas plants** 40%
  - **Hydro** high ?90%
  - **Nuclear** US 90%, (whole of life world wide 77%) (IAEA)
  - **Wind plants** 30%



Source: gnep http://www.gnep.energy.gov/

Making the Choice – Fuel Supply Security

- **Coal:** Large variation in quality of coal. Reserves around the world but vary in quality. Current reserves for 250 years. Very easy to transport.
- **Natural Gas:** Abundant reserves but dominantly in Russia & Middle East. Pipeline and LNG transport often needed to get to where needed
- **Hydro:** Majority of suitable sites now developed. Limited flexibility in where can be built. Very dependant on water supply (rainfall and runoff management)
- **Nuclear:** Abundant uranium in stable political countries (esp Australia and Canada). Supply price dependent. Fuel quantities very small but special transport and enrichment needed.
- **Oil:** Reserves dominantly in Middle East. Lot of competing uses transport, chemicals etc. Easy to transport
- **Geothermal:** Hot spots location may not be close to end user
- **Wind , sun, ocean:** Dependant on local conditions. May not be close to end user (especially in cold climates).

Making the Choice - Safety
Catastrophic or Pervasive

- **Coal:** major accidents in mines common (in 2006 4,749 Chinese coal miners were killed), 1000s of deaths due to air pollution in China each year (source Wikipedia)
- **Natural Gas:** Most danger related to production and transport. 167 people killed in offshore gas platform explosion – Piper Alpha in 1988
- **Hydro:** Catastrophic - worst accident the Banqiao Dam failure in Southern China in 1975 resulted in the deaths of 171,000 people and left millions homeless. (source Wikipedia)
- **Nuclear:** Only fatal accident 1986 Chernobyl accident (a Russian design fundamentally flawed). The initial death toll was 31 people with another 10 deaths later due to Thyroid cancer. Thousands exposed to radiation. In particular radiation accumulated in food that was then eaten.
- **Oil:** Most accidents occur upstream or during fuel transport
- **Renewables:** Small number and usually construction related

Making the Choice - Environmental Impacts – We get nothing for nothing

- **Coal:** Burning coal produces Particulates, NOx and SOx as well as CO2 – causing acid rain, smog and breathing difficulties. (Almost 50% of Australia's total SO2 emissions are from electricity generation).

- **Natural Gas:** Some sources high in CO2, NOx and SOx. Need special treatment. If converted to LNG for transport extra fuel used and CO2 emitted

- **Hydro:** Floods large areas, displacing communities & drowning ecosystems and silting may reduce long term efficiency. Biggest impacts are the flooding of vegetation and the associated decay and release of methane. However some countries use "run of river" generation with no damming just channel direction into turbines. Then significant season variation.

Making the Choice - Environmental Impacts – We get nothing for nothing

- **Nuclear:** Very small volume of waste but has very long high radioactive half life unless further enriched and reprocessed. Under water storage remains an interim solution, but quantity and half life of waste reducing with new generation technology

- **Oil:** High CO2, SOx, NOx emissions, some transportation issues (e.g. Exxon Valdez)

- **Renewables :** Wind, solar and biomass arrays, at a scale needed for public power generation, have very large physical footprints. Significant visual and noise impacts

Information –
Waste management

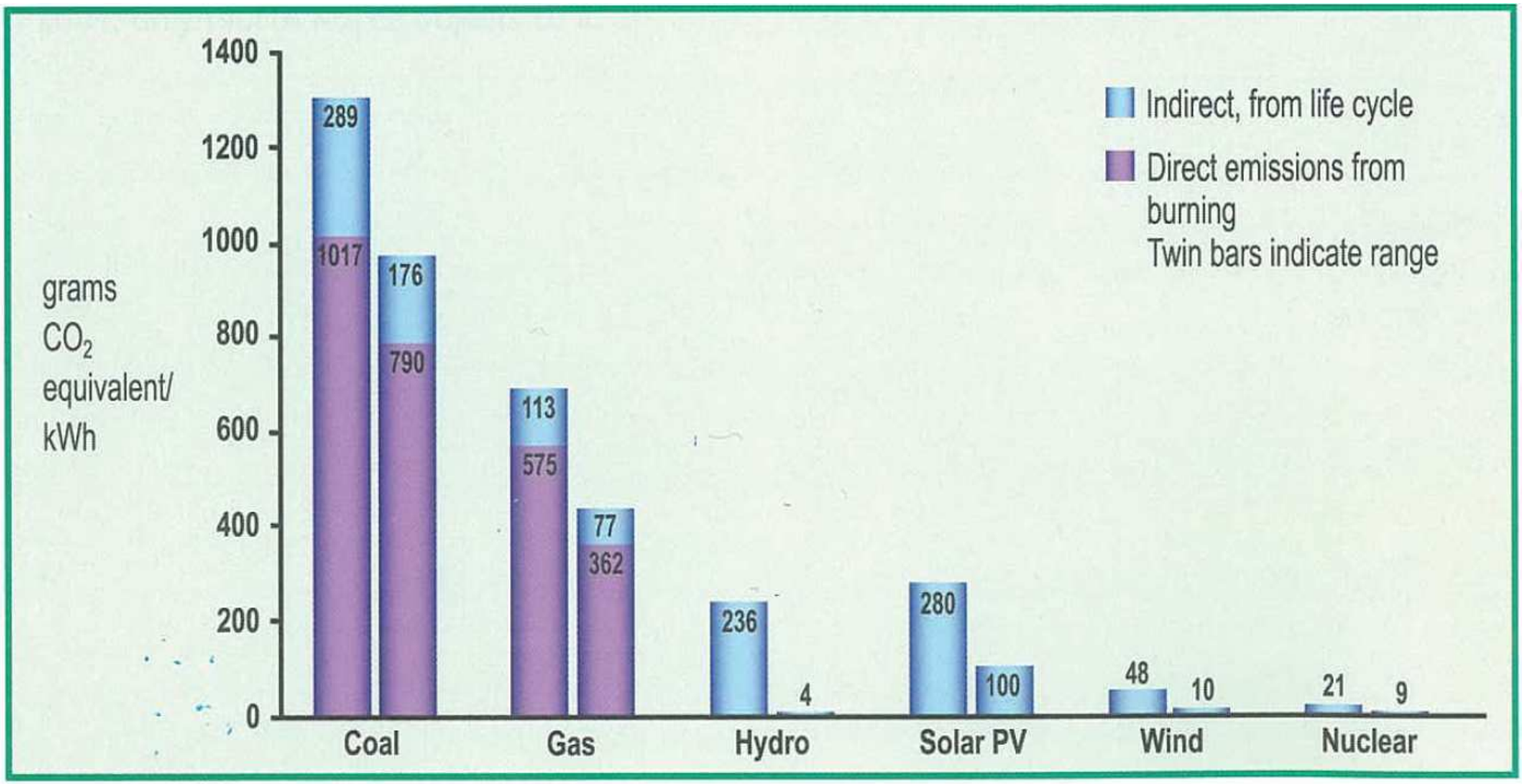
But not all waste is atmospheric

If you received all of your electricity for your lifetime from **nuclear**, your total share of the waste would fit in a Coke can

If your electricity is generated from **coal**, your share of the Fly Ash waste would fill 4 dump trucks.

Source Toro Energy

CO2-e from Electrical Power Sources (2000)



Source: IAEA 2000.

CO2-e from Electrical Power Sources (2007)

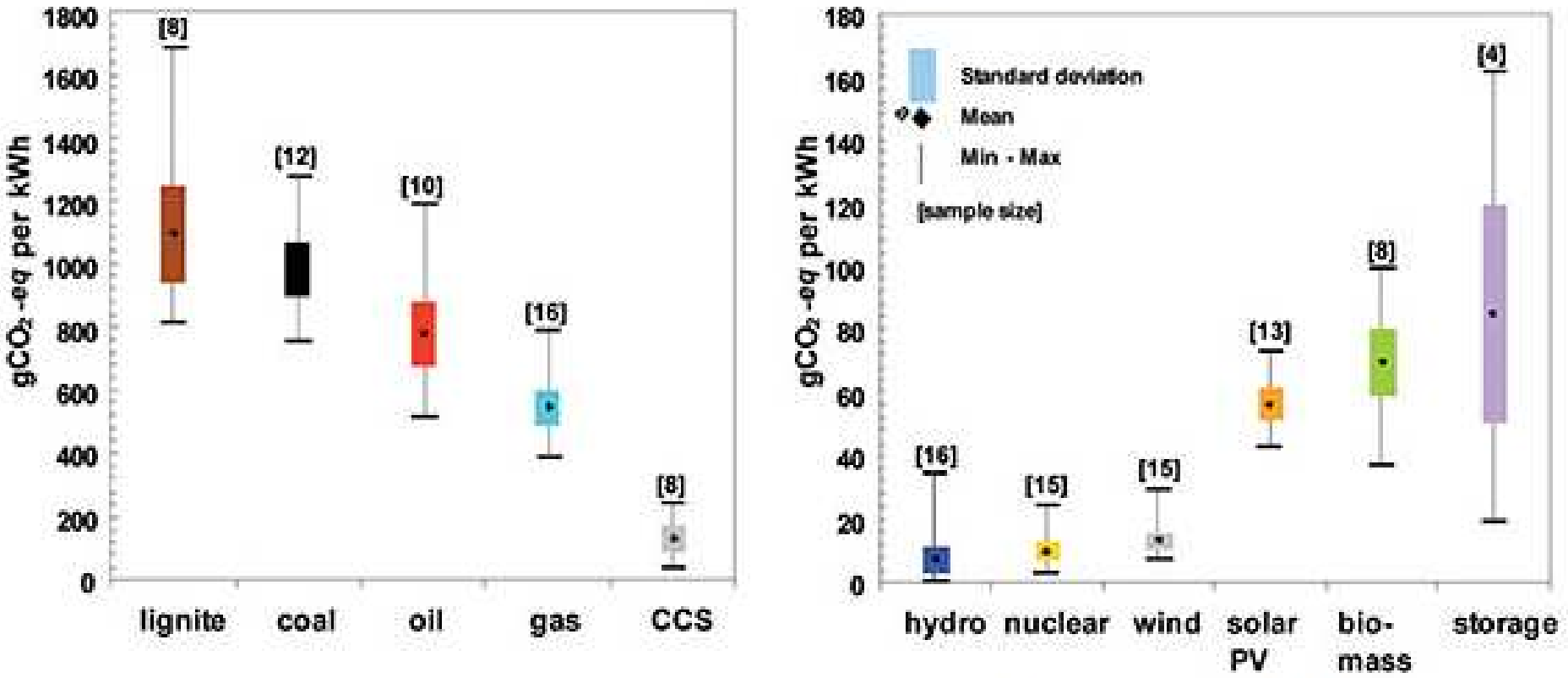


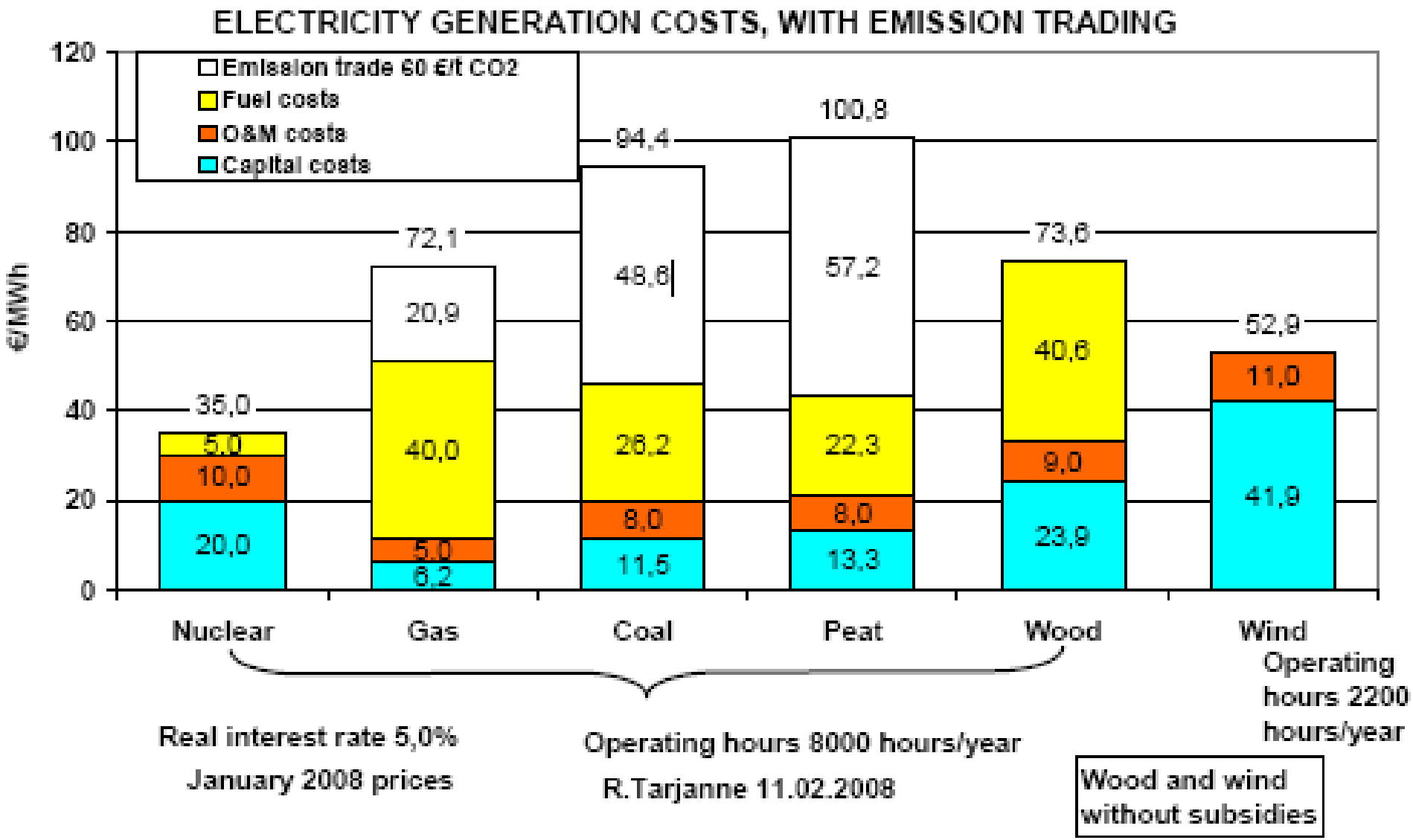
Figure 1. Life cycle GHG emissions for selected power generation technologies. Source: [WEISSER, D., A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies, Energy 32 (2007) 1543-1559]. Left panel: fossil technologies. Right panel: non-fossil technologies

Source: http://www.iaea.or.at/OurWork/ST/NE/judge-nuclear.html

CO2 Production and Disposal Challenges

- **Coal:** a major source of man made CO2 production. Some people are skeptical that a cost and technology effective system can be developed in time
- **Natural Gas:** Lower CO2 than coal and an important transition alternative. May have lot of CO2 in reservoir and produced with methane
- **Hydro:** Low operating CO2 emissions (but methane produced by vegetation decay)
- **Nuclear:** Very low whole of life CO_2 emissions (none in generation)
- **Oil:** High CO2 and may have associate methane or CO2 in reservoir and produced with oil and burnt or emitted to get oil (especially in Middle East)
- **Renewables:** Most CO2 is from original construction materials

Emission trading and CO2 2008 (Euros / MWh)



Source **COMPARISON OF ELECTRICITY GENERATION COSTS** Tarjanne Risto, Kivistö Aija 2008
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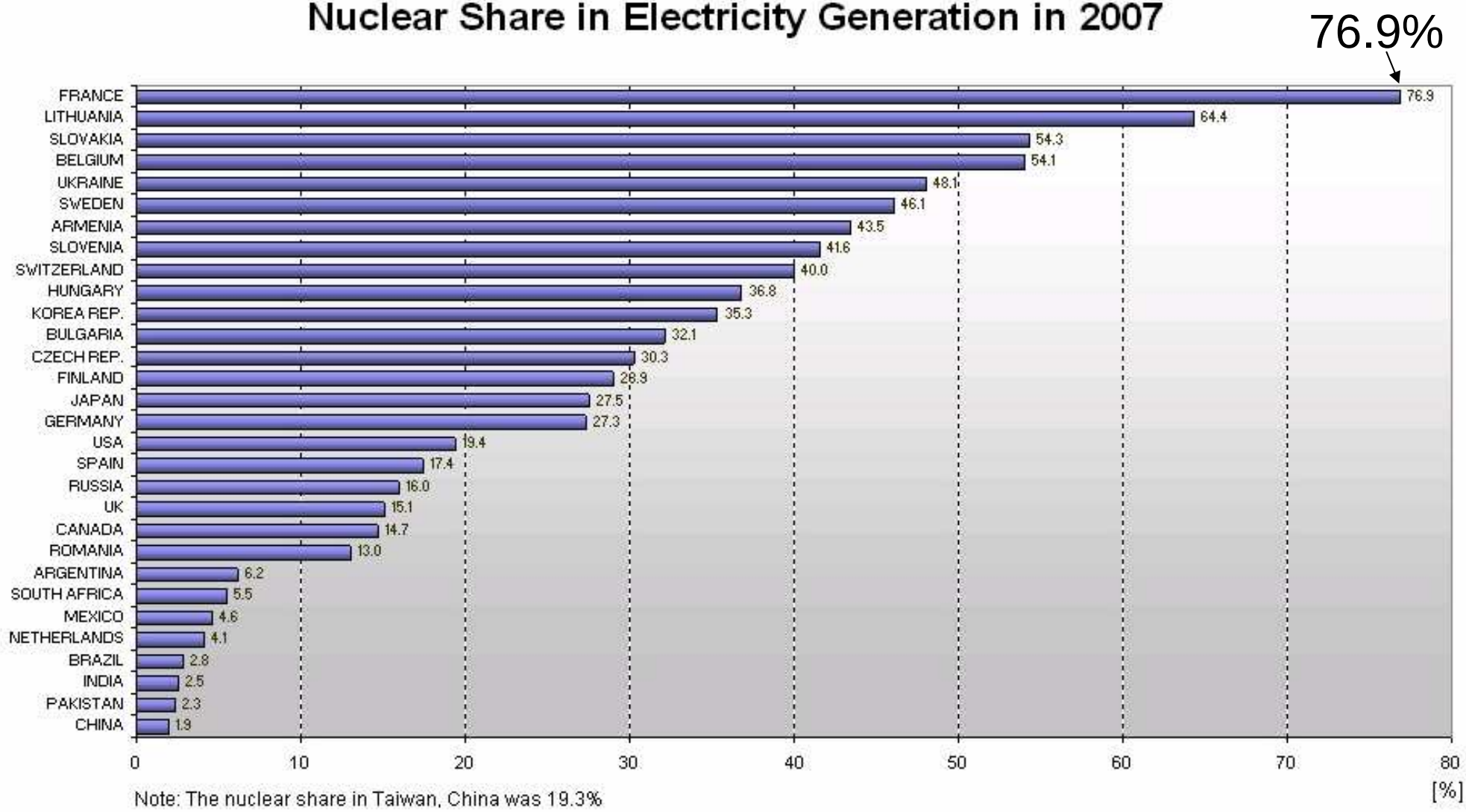
Nuclear Share in Electricity Generation in 2007



Note: The nuclear share in Taiwan, China was 19.3%

The EU is changing it's Position on Nuclear Power

- **The European Union has been a global leader on the issue of Climate Change.**

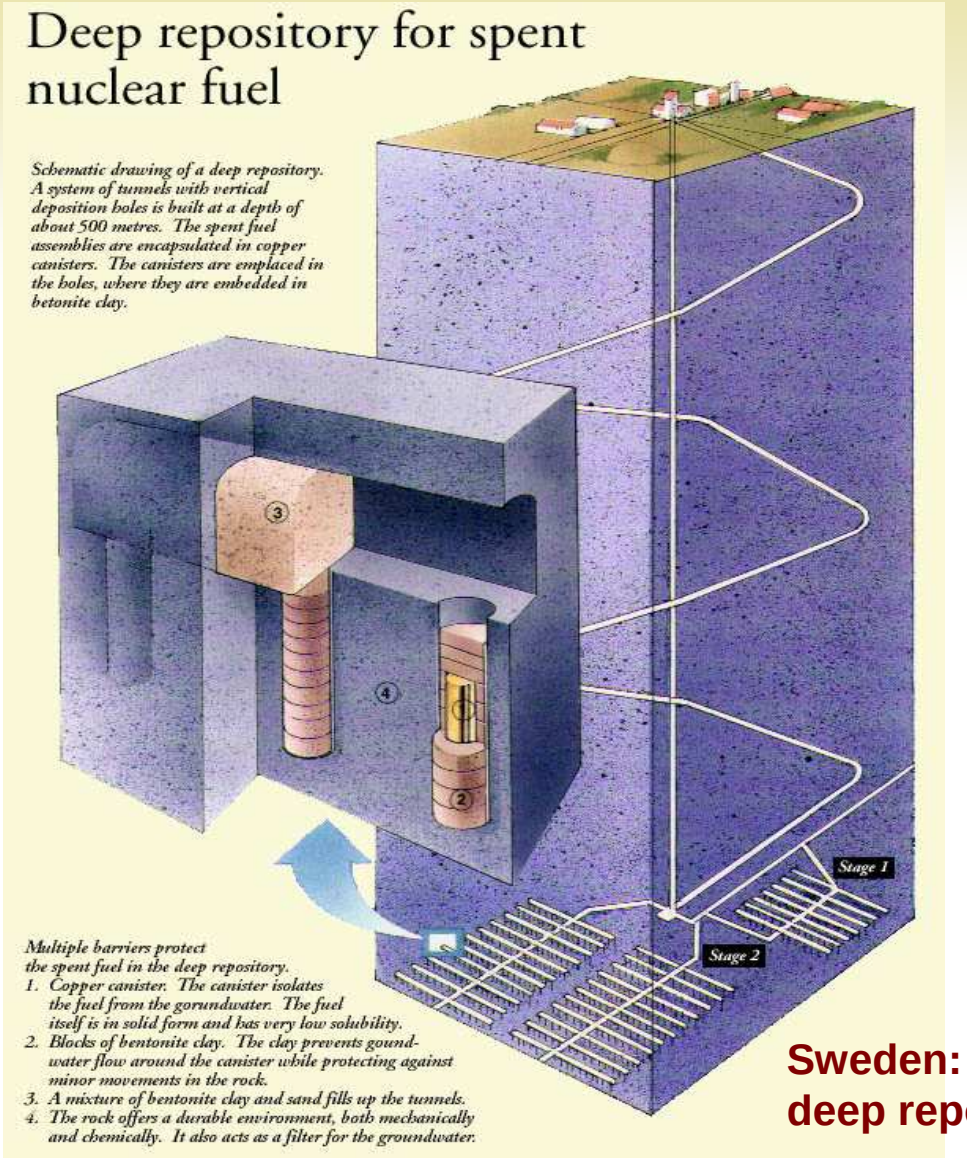
- **Within the last two years:**
  - **The UK has committed to accelerate nuclear build program to replace its 19 reactors producing 20 % share of electricity generation and to add capacity**
  - **Germany has reversed an earlier decision to phase out nuclear and is extending operating licenses for its nuclear reactors (17 producing 25% electricity) from 40 to 60 years while importing more nuclear power from interconnected neighbours**
  - **Sweden added to the list of EU countries to restart building of nuclear power stations after a 30 year pause (10 reactors, 50% electricity)**

- **31 % EU electricity is nuclear already**

- **President Obama has stated that the US cannot meet its climate change goals without more nuclear power and the Chairman of the IPCC, Dr Rajendra Pachauri, has extended that comment to also represent the challenge globally.**

Source Ziggy Switkowski 2009 Paydirt's 2009 Uranium Conference

Spent Fuel Handling and Storage:



Sweden: ASPÖ spent fuel deep repository design

Finland: spent fuel deep repository design

The Future -Generation IV Reactors

The Generation IV International Forum (GIF) was initiated in 2000

This task force is developing six nuclear reactor technologies for deployment between 2020 and 2030. Four are fast neutron reactors.

All of these operate at higher temperatures than today's reactors. In particular, four are designated for hydrogen production.

All six systems represent advances in sustainability, economics, safety, reliability and proliferation-resistance.

Joint development of the next generation of nuclear technology.

- Led by the USA, Argentina, Brazil, Canada, China, France, Japan, Russia, South Korea, South Africa, Switzerland, and the UK along with the EU
- Most of these are party to the Framework Agreement (FA) which formally commits them to participate in the development of one or more Generation IV systems selected by GIF for further R&D.

Sourcehttp://www.world-nuclear.org/info/inf77.html

Information: Types of renewable electricity generation

- Some renewable electricity sources such as hydro, OTEC, bio-energy, solar thermal electricity with thermal storage and geothermal can be used as base load sources.

- Some renewable electricity sources including wind, solar without storage, and run-of-river hydro are variable in their output and are often unpredictable in output and so must be used in conjunction with peaking or intermediate load generators such as gas.

- Type and location dependant on average wind speeds, solar radiation levels, ocean conditions, geothermal gradient, available biomass, distance from demand.

- Biomass relies on agricultural land being used instead for energy rather than food or timber production - impacts now being felt in rising world food prices especially in underdeveloped world

Major technology innovation for the storage (physical or chemical) and retrieval of electrical energy is still needed

Ways Forward – Short term

The answer in the short term is doing what we do now but much better.

- Improving the energy efficiency of fossil fuels. The largest savings are from improving the efficiency of coal-fired plants, which alone could provide savings of between 1.4 Gt CO2 to 2.0 Gt CO2.
  - On a regional basis, just less than half the global savings would come from OECD countries, with the remainder from developing countries. (IEA 2008)
- Shift to natural gas as a transition fuel gives better efficiency and lower CO2 emissions plus gas to liquids (syn fuel)
- Improved building codes wrt thermal protection in buildings
- Increased use of nuclear at least in the period before renewable base load options become available

Ways Forward – Longer term

But in the foreseeable long term we need new:-

- Technology changes associated with large scale energy storage and recovery – allowing greater use of renewables.
- Smarter and cheaper renewables from sun, ocean and hydrogen
- Develop smarter nuclear solutions – especially smaller and users of waste fuel be willing as a community to research and test and store waste.
- Innovative carbon capture, conversion and sequestration but be ready if costs prove to be prohibitive.
- Geothermal base load electricity (and industrial and domestic heating)

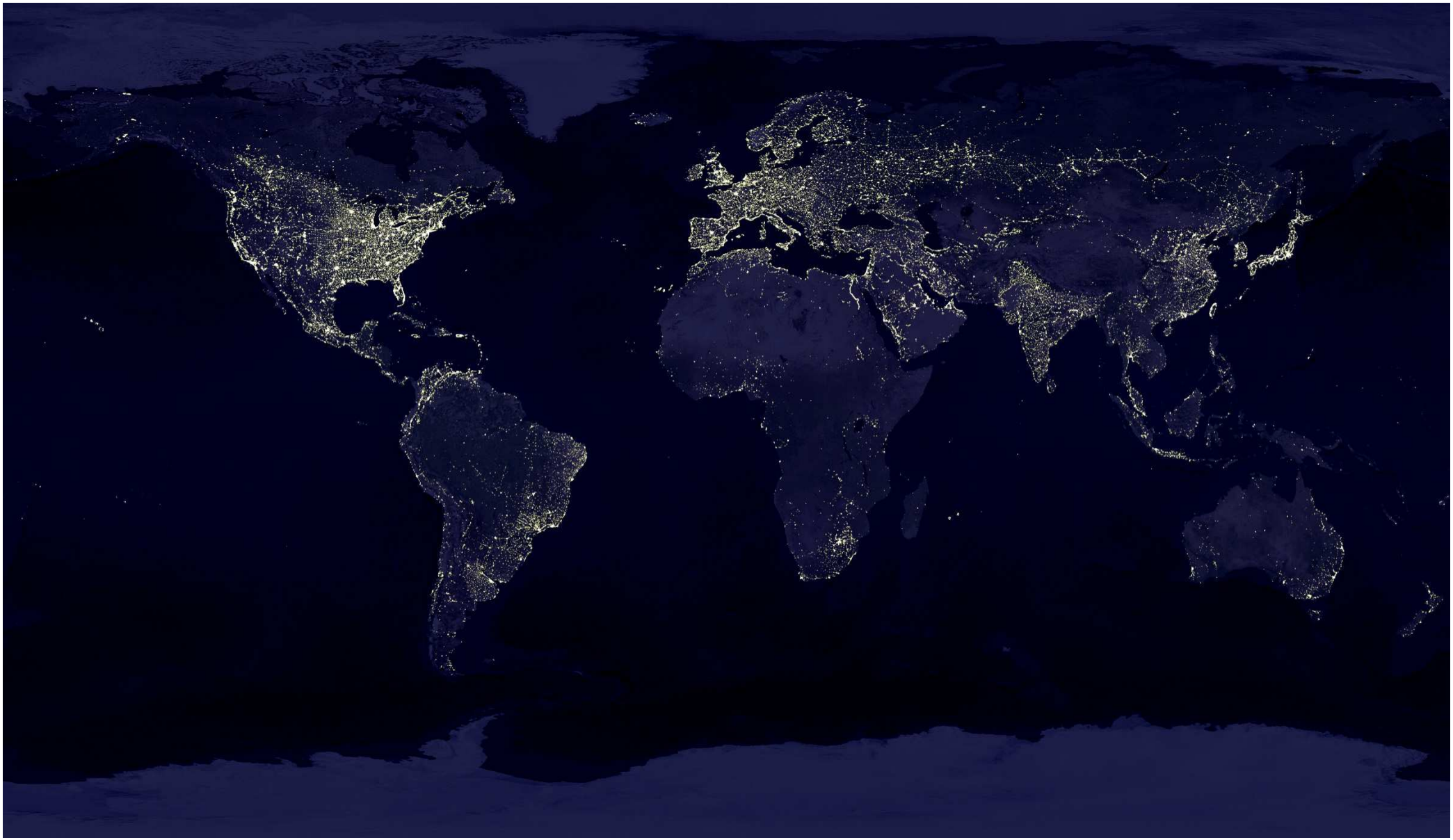
Information- Nuclear Energy Predictions UxC 'Mid-case'

2007	2020	2050
31 Countries	55 Countries	86 Countries
439 Reactors	630 Reactors	>700 Reactors

- **China** building 2/ year for next 15 years – now being increased
- **Russia** building 2/ year for next 15 years
- **India** building 1/ year going forward
- **USA** 17 siting approvals for 26 new reactors: Govt loans for 2
- **Europe** Italy, Germany, Sweden, UK – reversing non-nuclear policies
- **France** continuing build programme

Source Toro Energy investor brief and UxC

Do you think we will we have to turn the lights off?



Additional Information

Information: Australia's geothermal potential

Source Geoscience Australia

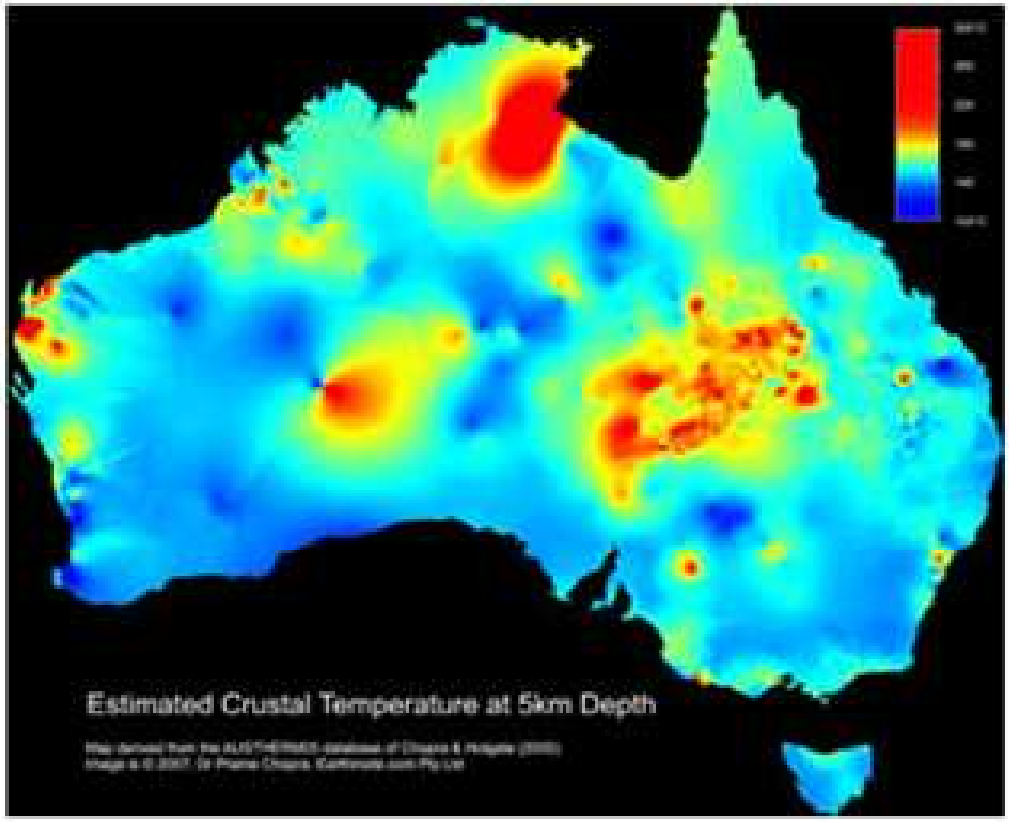


Figure 2 Map of crustal temperature across Australia at five kilometre depth using the AUSTHERM05 database. This map has been derived from proprietary information owned by Earth Energy Pty Ltd ACN 078 964 735.

Most high crustal temperature areas away from main population centres

http://www.ga.gov.au/minerals/research/national/geothermal/index.jsp#granite

Meeting electricity needs
Production Cost comparisons (2005)

- **Production Costs**
  - **Coal** **2.21 cents** US per kilowatt hour – balanced capital and fuel
  - **Gas** **7.51 cents** US per kilowatt hour – dominated by fuel cost
  - **Hydro** Dominated by capital cost
  - **Nuclear** **1.72 cents** US per kilowatt hour – dominated by capital cost
  - **Oil** **8.09 cents** US per kilowatt hour – dominated by fuel cost
  - **Geothermal:** Dominantly capital but considerable operating
  - **Wind , sun, ocean** Dominantly capital cost but hidden costs associated with back up capacity

Transmission cost and energy loss may add to delivery costs if generation remote from use

Information
Environmental Pollution – Fossil Fuels

Combustion of fossil fuels produce many pollutants including:

- **SOX** - Acid rain kills fish and trees, impacts on arable land productivity, damage to buildings plus is associated with many types of respiratory diseases, including coughs and colds, asthma, bronchitis, and emphysema.
- **NOX**- irritate the lungs, cause bronchitis and pneumonia, and lower resistance to respiratory infections such as influenza; at higher levels it can cause pulmonary edema
- **CO** - educes the amount of oxygen available to the body tissues and weakens heart contractions .
- **Particulates**- when inhaled, can scratch or otherwise damage the respiratory system, causing acute and/or chronic respiratory illnesses.
- **Hydrocarbons** - cause smog and are important in the formation of ozone
- **Toxic metals** have a variety of harmful effects

Source Bernard L. Cohen

Performance and costs data of the power plants, the price level of January 2008

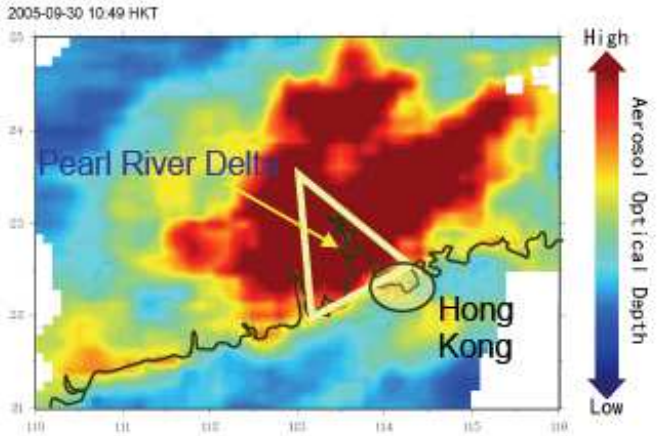
INPUT DATA January 2008 prices

	NUCLEAR	GAS	COAL	PEAT	WOOD	WIND
ELECTRIC POWER [MW]	1500	400	500	150	30	3
NET EFFICIENCYRATE [%]	**37 %**	**58 %**	**42 %**	**40 %**	**33 %**	**-**
INVESTMENT COST [million €]	4125	280	650	225	81	3,9
SPECIFIC INVMENT COST [€/kW]	**2750**	**700**	**1300**	**1500**	**2700**	**1300**
FUEL PRICE [€/MWh]	**1,85**	**23,20**	**11,00**	**8,90**	**13,40**	**-**
FUEL COST OF ELECTRICITY PRODUCTION [€/MWh]	5,00	40,00	26,19	22,25	40,61	-
OPERATION AND MAINTENANCE COSTS, WHEN 8000 h/a [€/MWh]	**10,00**	**5,00**	**8,00**	**8,00**	**9,00**	**11,00**
SHARE OF V'BLE O&M COSTS [%]	50 %	65 %	70 %	50 %	40 %	40 %
ECONOMIC LIFETIME [a]	**40**	**25**	**25**	**25**	**25**	**25**
EMISSION PRICE [t/CO2]	**23**	**23**	**23**	**23**	**23**	**23**
FULL LOAD UTILIZATION [h/a]	**8000**	**8000**	**8000**	**8000**	**8000**	**2200**
CAPACITY FACTOR [%]	91,3 %	91,3 %	91,3 %	91,3 %	91,3 %	25,1 %

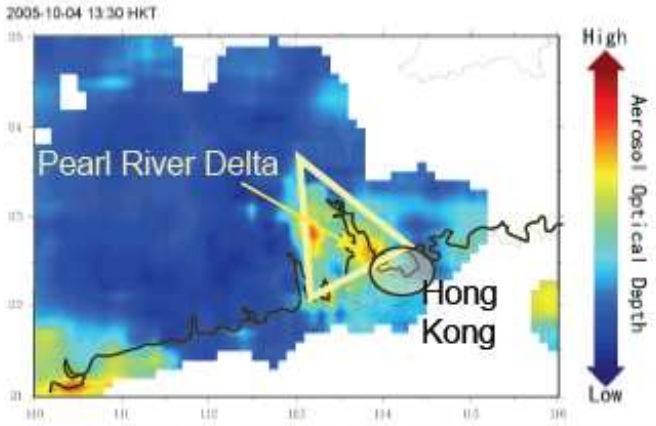
Variation of Air Pollution with Economic Activities

- Visibility in the region improves when economic activities reduce.

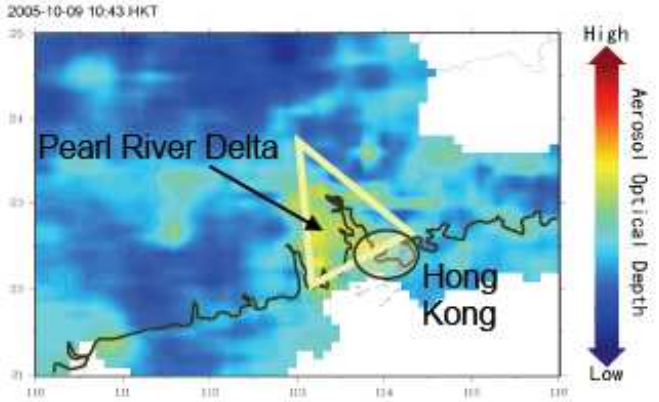
Sources: Hong Kong Observatory, NASA



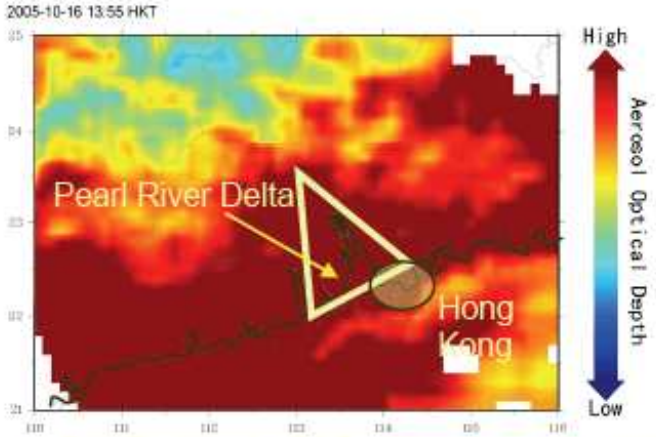
30 September 2005, Eve of National Day



4 October 2005, 4 days into the National Day Holiday



9 October 2005, last day of the holiday



16 October 2005, one week after the holiday