UNIVERSITY OF ABERDEEN

Renewable Energy 1: Solar and Geothermal (EG501J)

Geothermal Energy:

1. General Overview of the Energy Mix

Jeff Gomes

September 2015

Outline

(Hellisheiði Geothermal Power Station)

- Energy Consumption
- Economics of Geothermal Energy
- Basics of a Power Plants






Energy:
Production & Demand







Overview of the Energy Industries

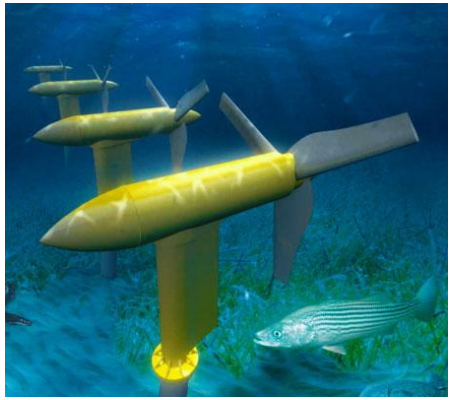
We use energy to provide:

- Electricity
- Heat
- Transport

Overview of the Energy Industries

From:

- Fossil fuels:
  - Oil;
  - Gas;
  - Coal;
- Nuclear;
- Hydroelectricity;
- Wind;
- Solar;
- Maritime (wave, tide etc);
- Geothermal;
- Etc.



Overview of the Energy Industries

Major Issues:

- Rising energy demand;
- Need to stabilise atmospheric CO_2 at 550ppm;
- Aging fleet of coal & nuclear plant;
- Concerns about storage of nuclear waste;
- Declining oil & gas reserves 30- 50 years;
- Only 70 years of uranium left;
- Reduce reliance on hydrocarbons.

Policy drivers:

- Low Carbon Society;
- Security of Supply;
- Fuel Poverty;

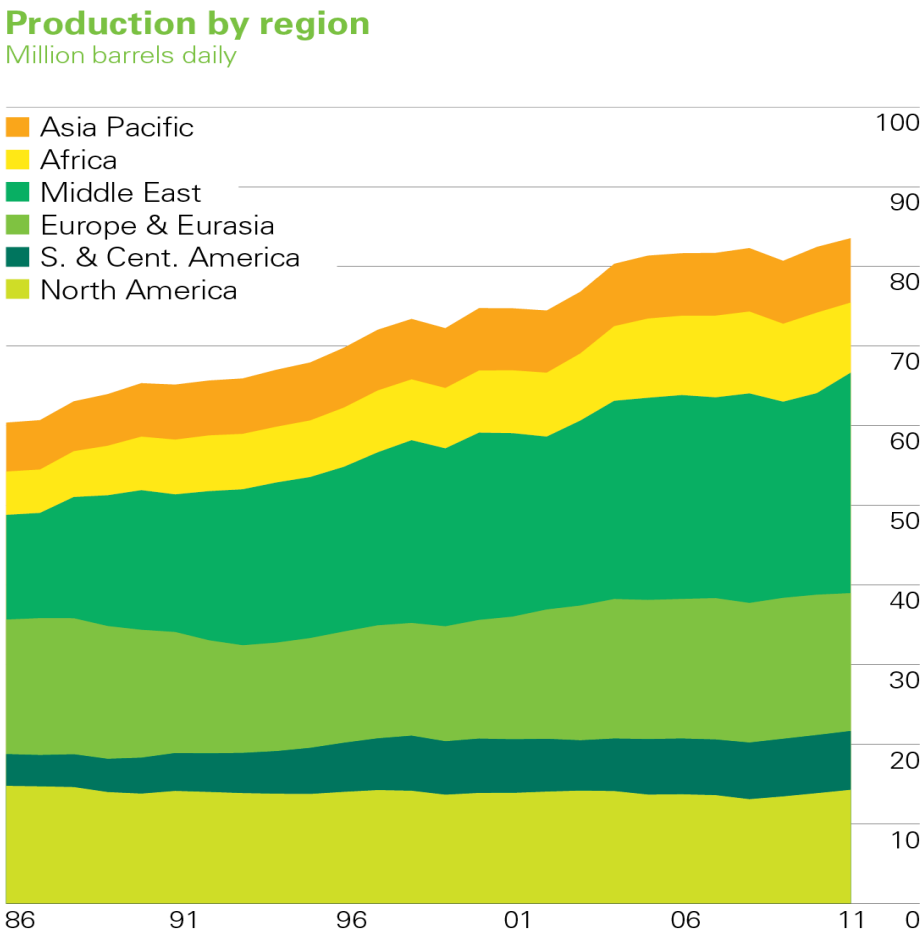


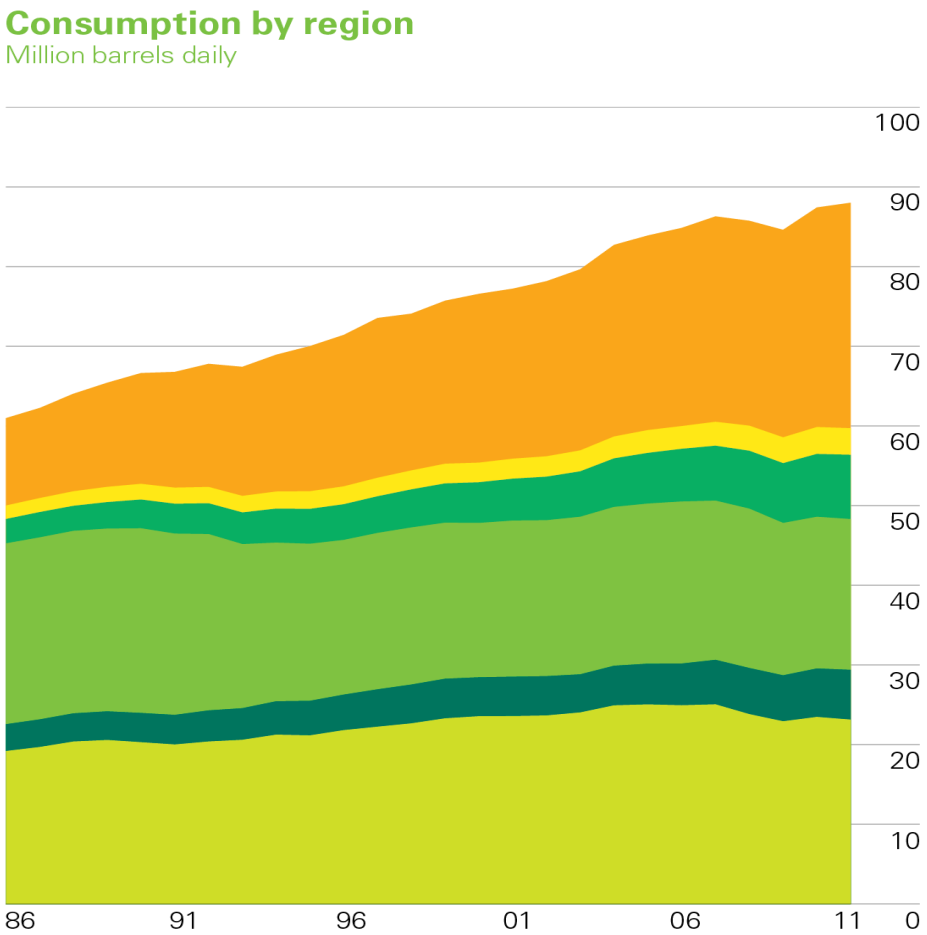



Growth Trends (1985-2010):

UNIVERSITY OF ABERDEEN

Oil Production/Consumption





World oil production increased by 1.1 million b/d in 2011, with OPEC accounting for nearly all of the increase despite a 1.2 million b/d reduction in Libyan production. The US had the largest growth in non-OPEC supply for a third consecutive year. World oil consumption increased by roughly 600,000 b/d. All of the net growth came from emerging economies in Asia, South & Central America, and the Middle East, offsetting declines in Europe and North America.

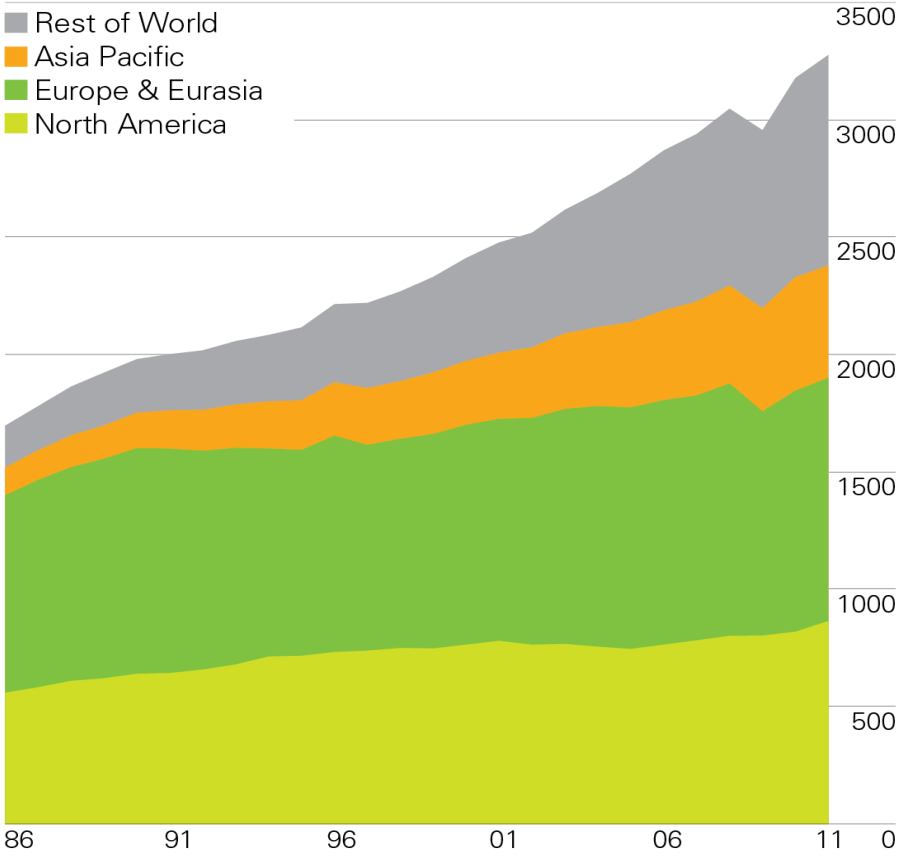
Source: BP Statistical Review of World Energy (2012)

Growth Trends (1985-2010):

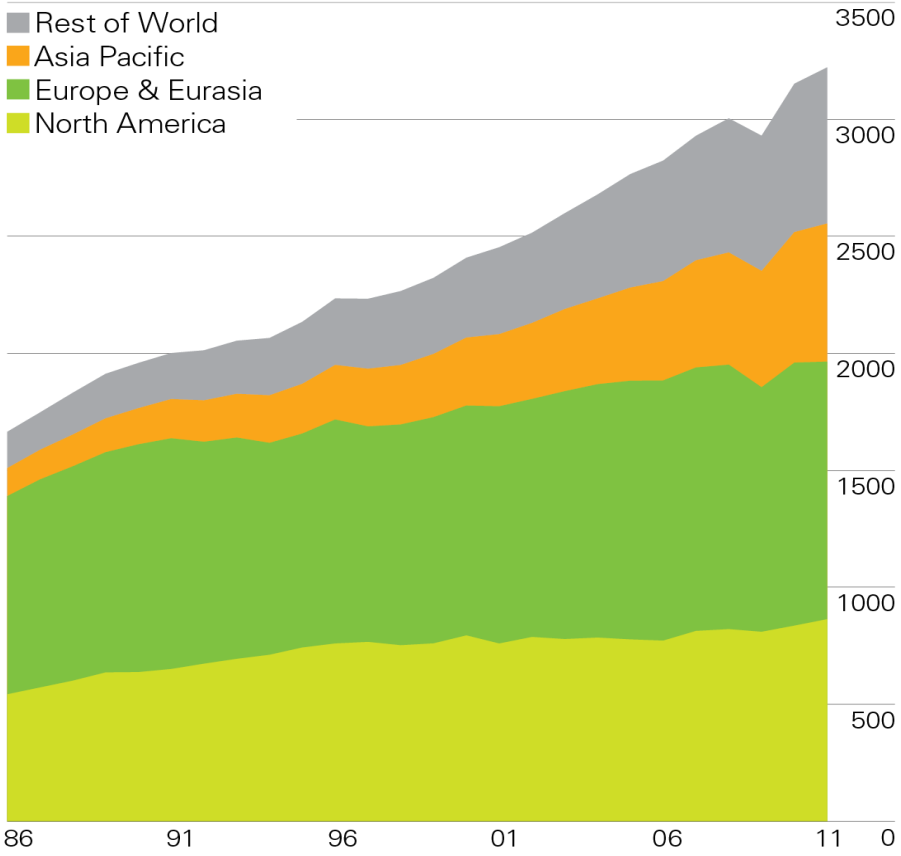
UNIVERSITY OF ABERDEEN

Natural Gas Production/Consumption

Production by region
Billion cubic metres



Consumption by region
Billion cubic metres



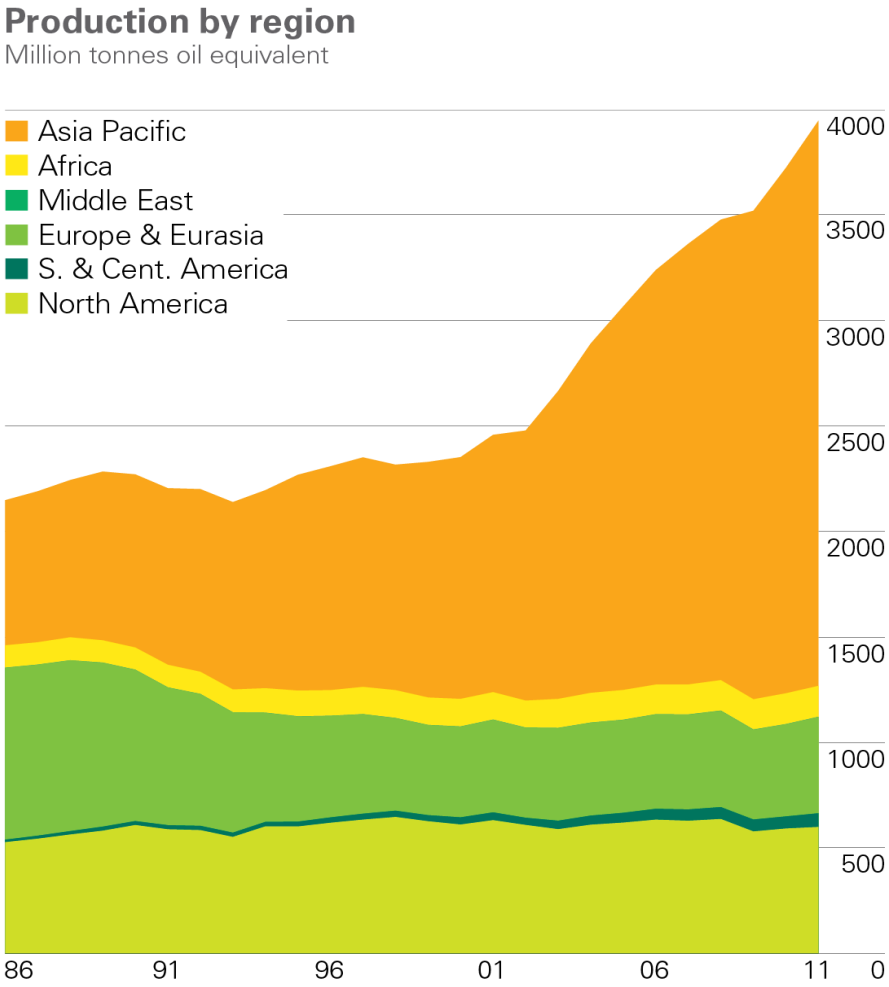
World natural gas production increased by 3.1% in 2011. While the US saw the largest national increase, the Middle East recorded the largest regional increment to production. Production growth in Russia and Turkmenistan was partly offset by a large decline in European production. Natural gas consumption increased by 2.2%, with below-average growth in all regions but North America. The European Union experienced the sharpest decline in natural gas consumption (–9.9%) on record.

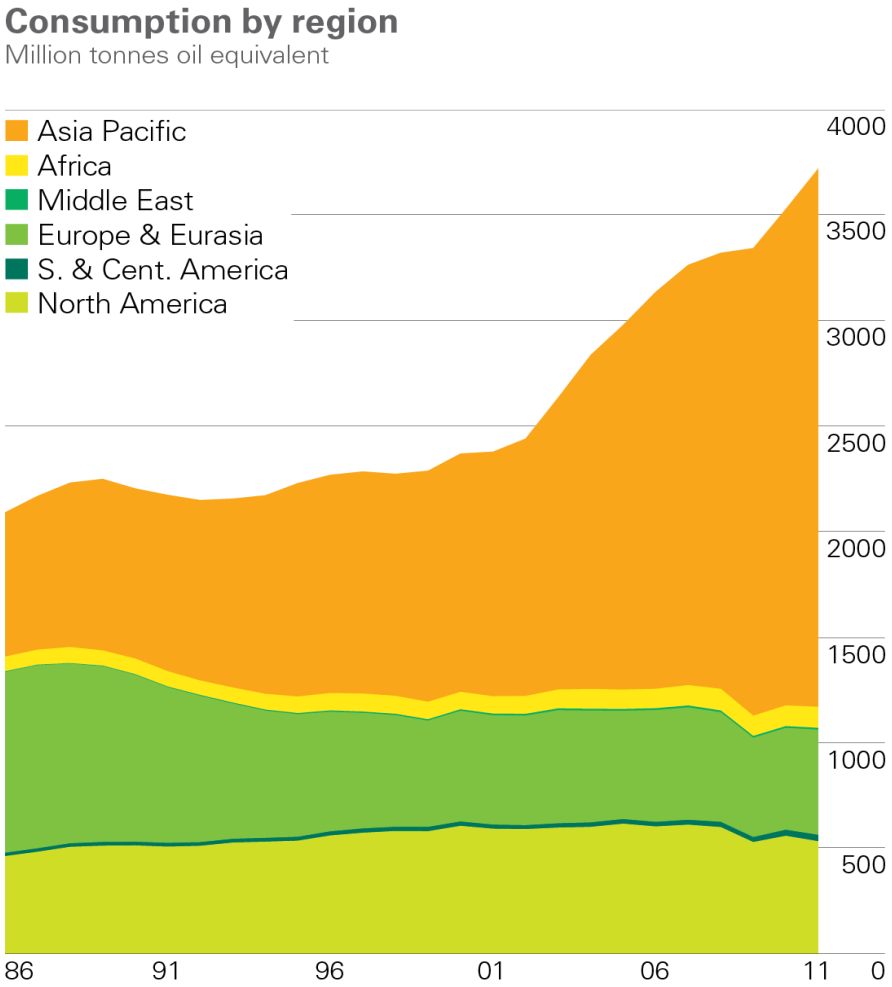
Source: BP Statistical Review of World Energy (2012)

Growth Trends (1985-2010):

UNIVERSITY OF ABERDEEN

Coal Production/Consumption





Coal was again the fastest-growing fossil fuel. Global production grew by 6.1%. The Asia Pacific region accounted for 85% of global production growth, led by an 8.8% increase in China, the world's largest supplier. Global coal consumption increased by 5.4%, with the Asia Pacific region accounting for all of the net growth. Elsewhere, large declines in North American consumption were offset by growth in all other regions.

BP Statistical Review of World Energy 2012

Growth Trends (1985-2010):

	Production 2010	Historical Growth	Growth(%)
Oil	86M mbo/day	1M mbo/year	1.2
Coal	3.6B Toe	160M toe/year	4.4
Gas	3150B m^3	60B m^3/year	1.9

toe: Tonnes oil equivalent
mbo: million barrel of oil

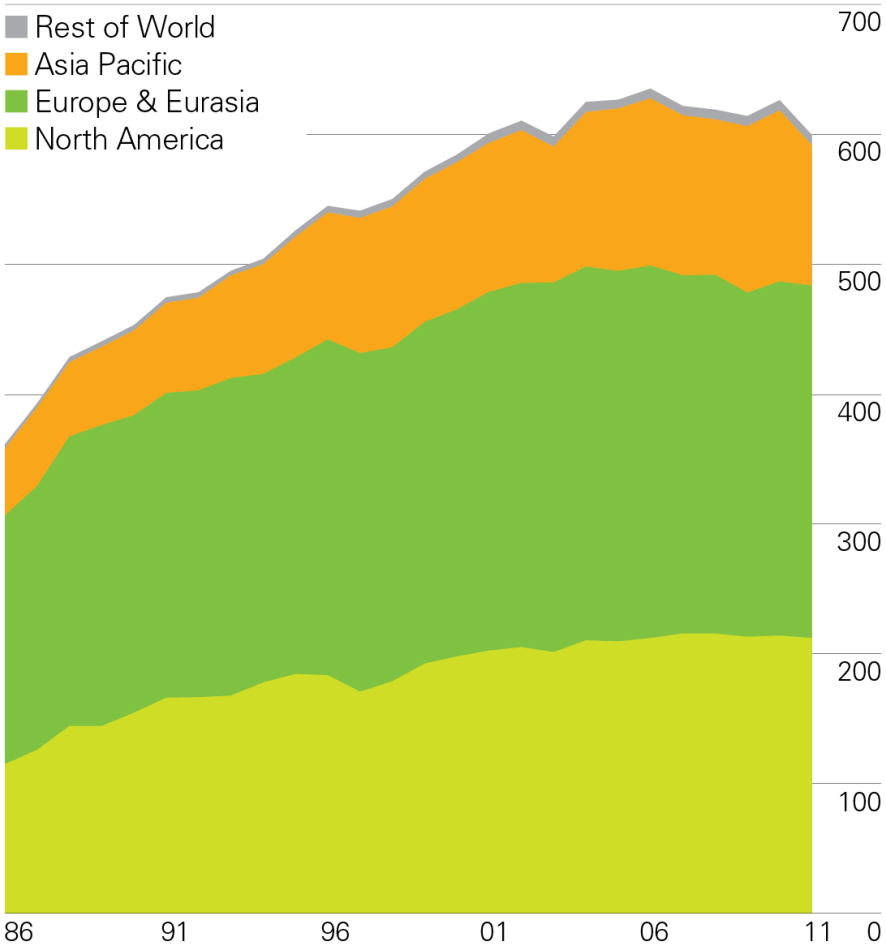
1 toe = 11.63 MWh = 41.87 GJ = 39.7M BTU
1 toe = 7.4 barrel of oil equivalent (boe)
1 barrel of oil = 159 litres

Growth Trends (1985-2010):

UNIVERSITY OF ABERDEEN

Nuclear energy consumption by region

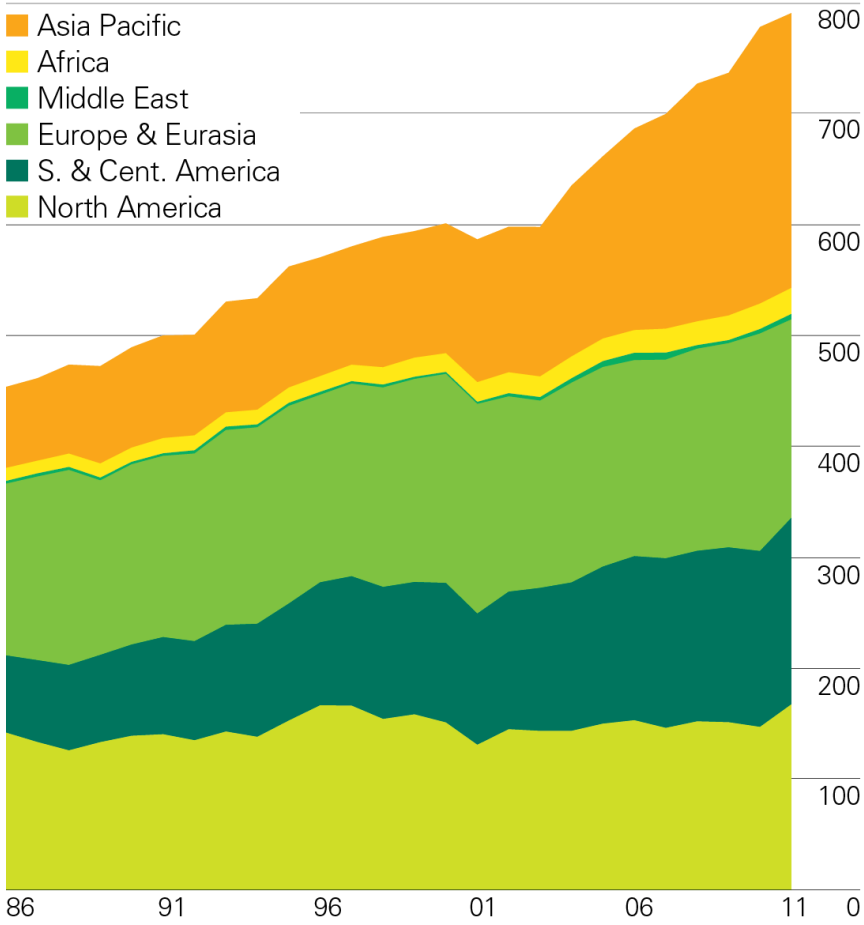
Million tonnes oil equivalent



World nuclear power generation declined by 4.3%, the largest decline on record. Japanese nuclear output fell by 44.3%, and German output fell by 23.2%.

Hydroelectricity consumption by region

Million tonnes oil equivalent



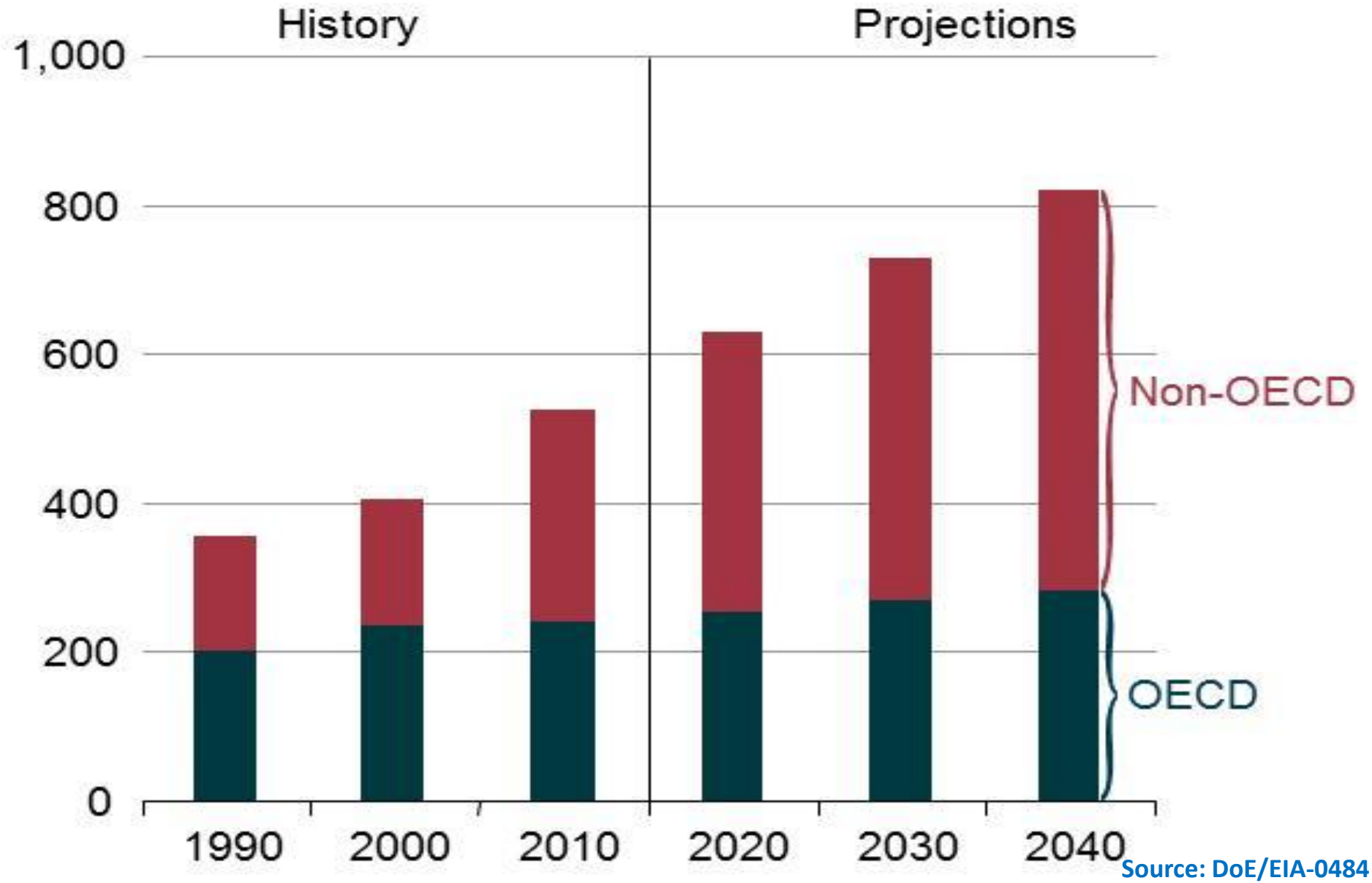
Global hydroelectric output grew by a below-average 1.6%. Strong growth in North America (+13.9%) was offset by drought-related declines in Europe & Eurasia and Asia Pacific.

Source: BP Statistical Review of World Energy (2012)

jefferson.gomes@abdn.ac.uk

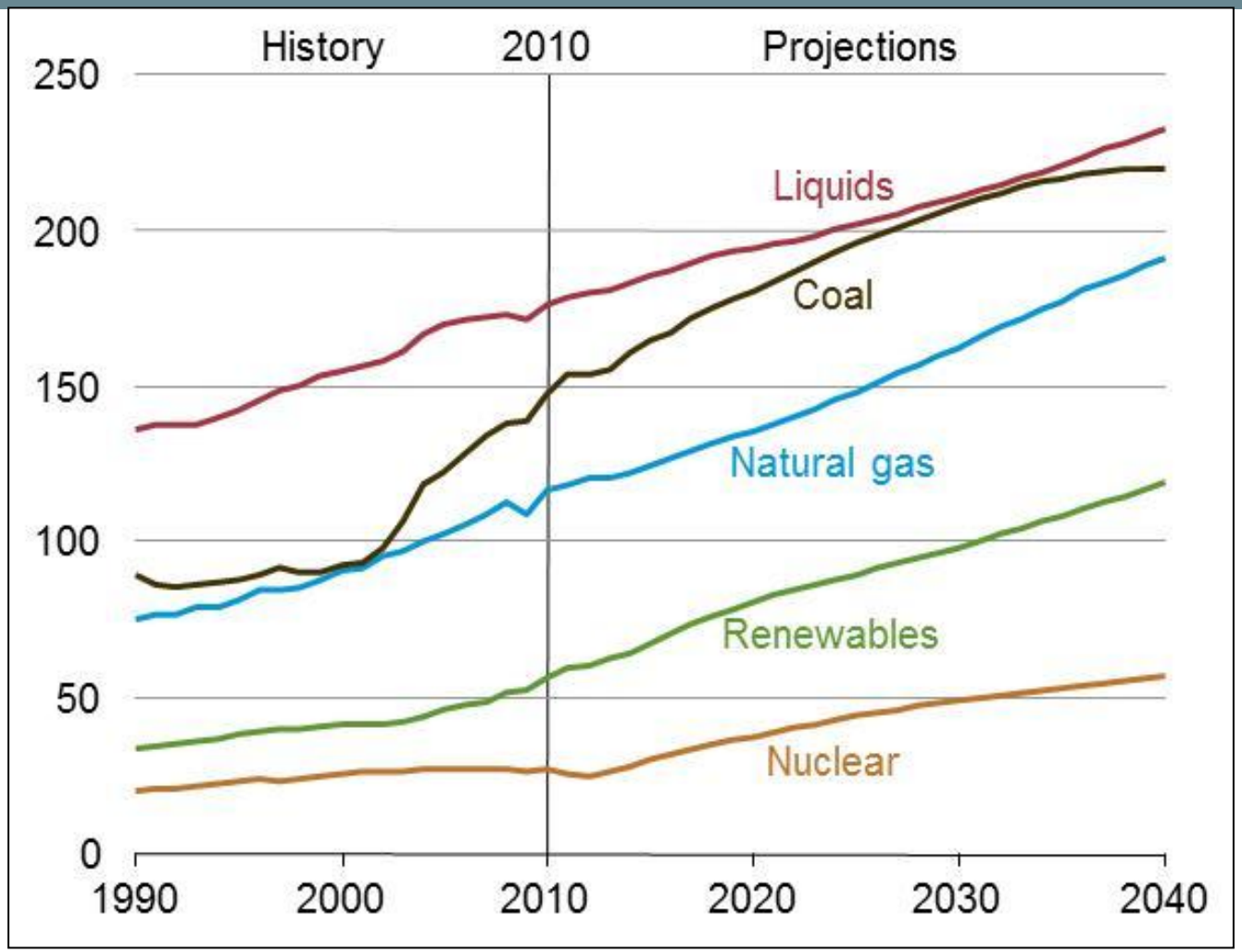
World Energy Consumption (10^{15} BTU)

UNIVERSITY OF ABERDEEN



Source: DoE/EIA-0484

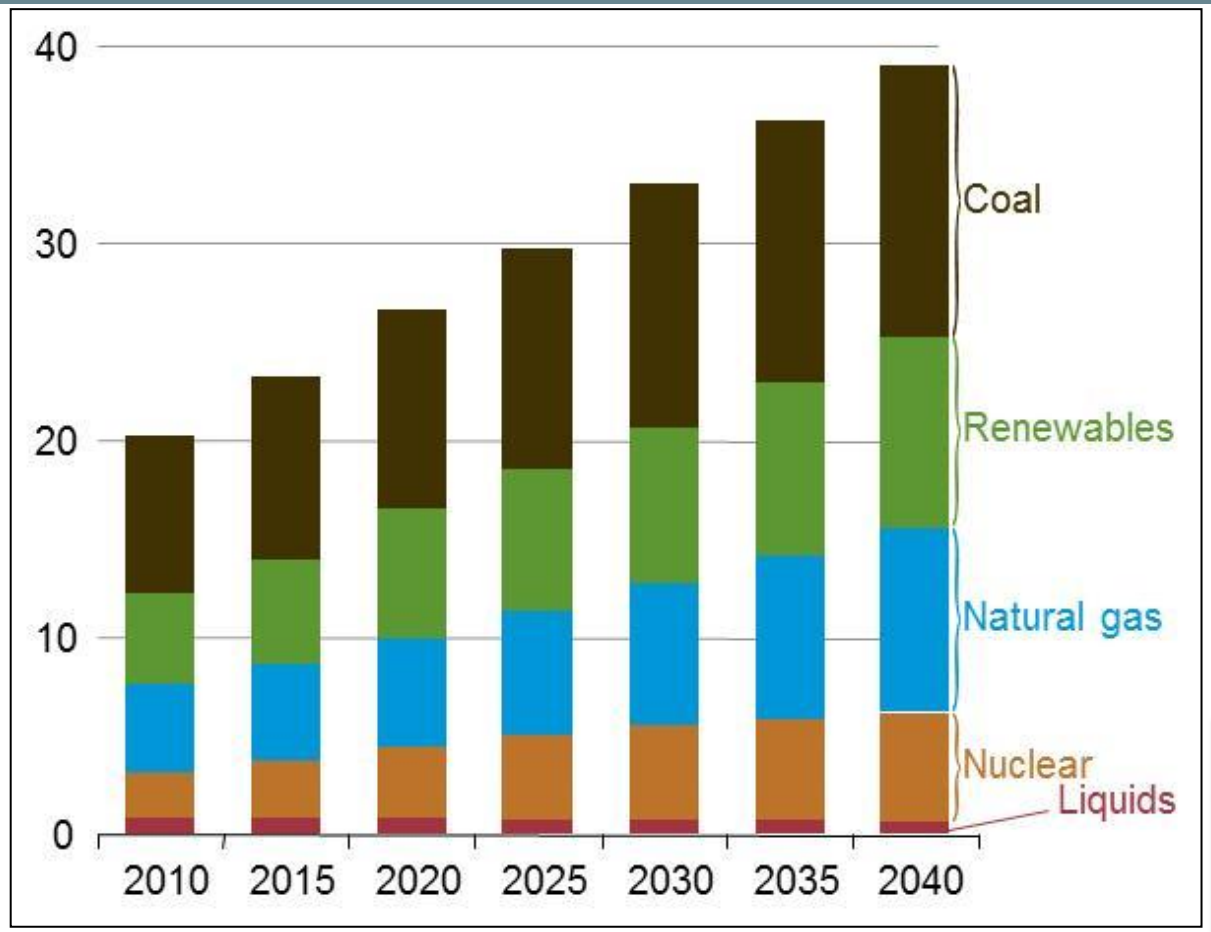
World Energy Consumption (fuel type, 10^{15} BTU)



Source: DoE/EIA-0484

- Petroleum liquids fuels: crude oil and lease condensate, natural gas plant liquids, bitumen, extra-heavy oil, and refinery gains;
- Other liquids fuels: gas-to-liquids, coal-to-liquids, kerogen and biofuels.

World Net Electricity Generation (fuel type, 10^{12} kWh)



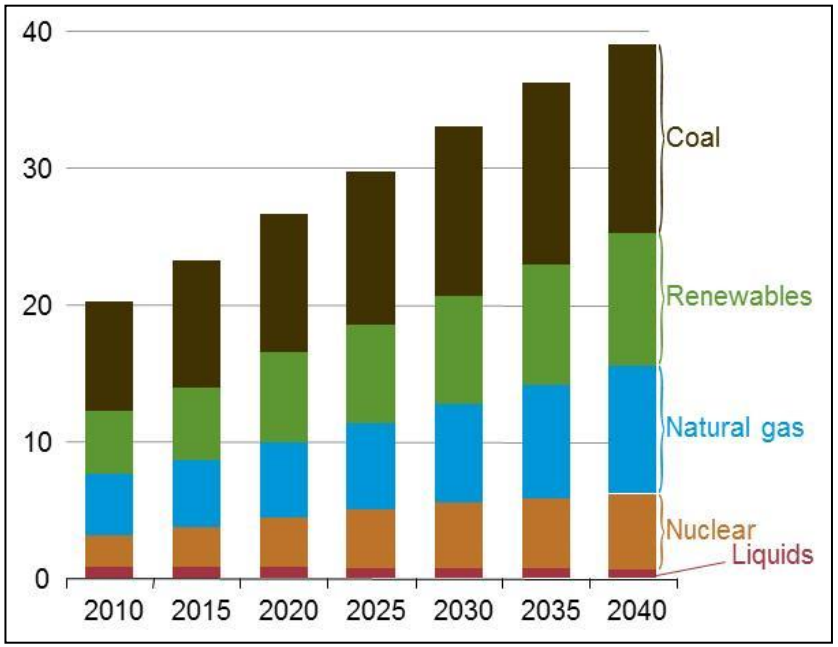
Variation (2010-40):

Liquids	**-1.0 %**
Nuclear	2.5%
Natural Gas	2.5%
Renewables	2.8%
Coal	1.8%
WORLD	**2.2%**

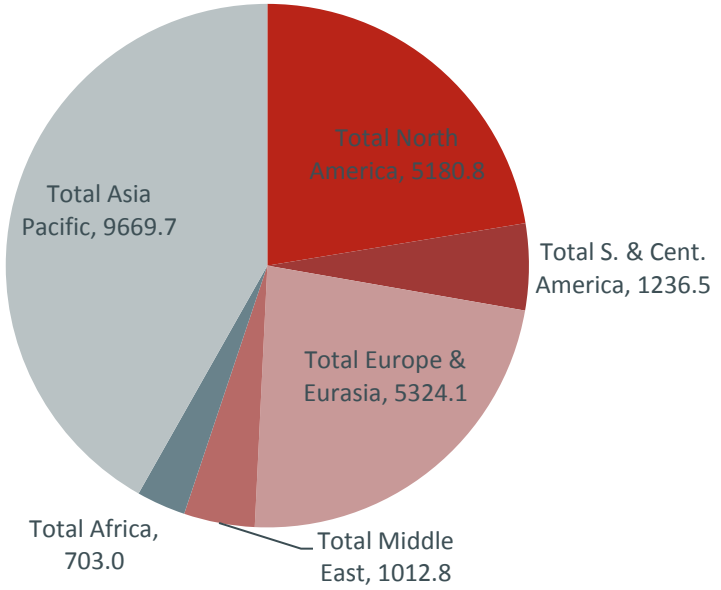
Conversion: 1 kWh = 3412.15 BTU

Source: DoE/EIA-0484

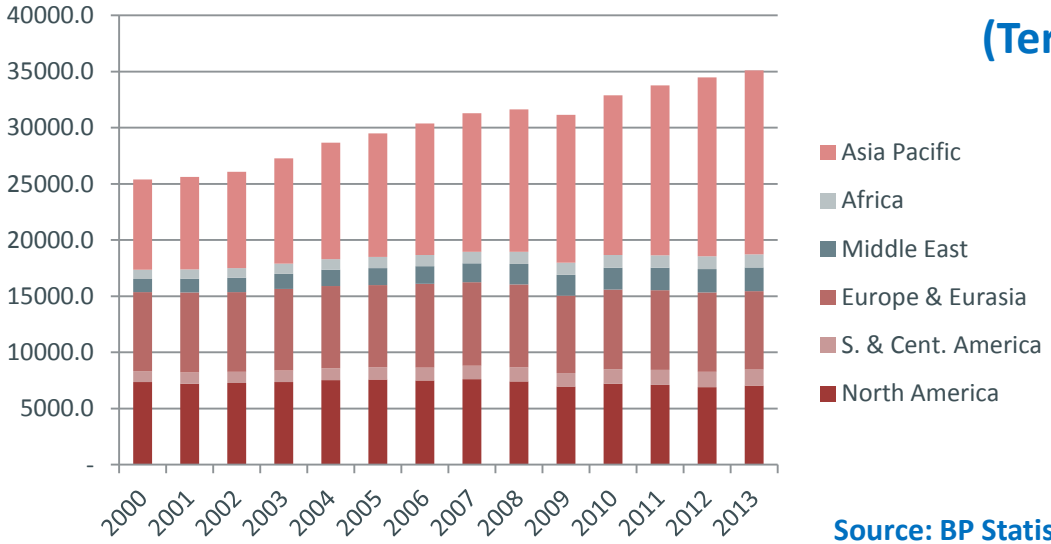
World Energy



World electricity generation (10^{12} kWh)



Electricity Generation (Terawatt-hours)



CO_2 Emissions (Million tonnes)

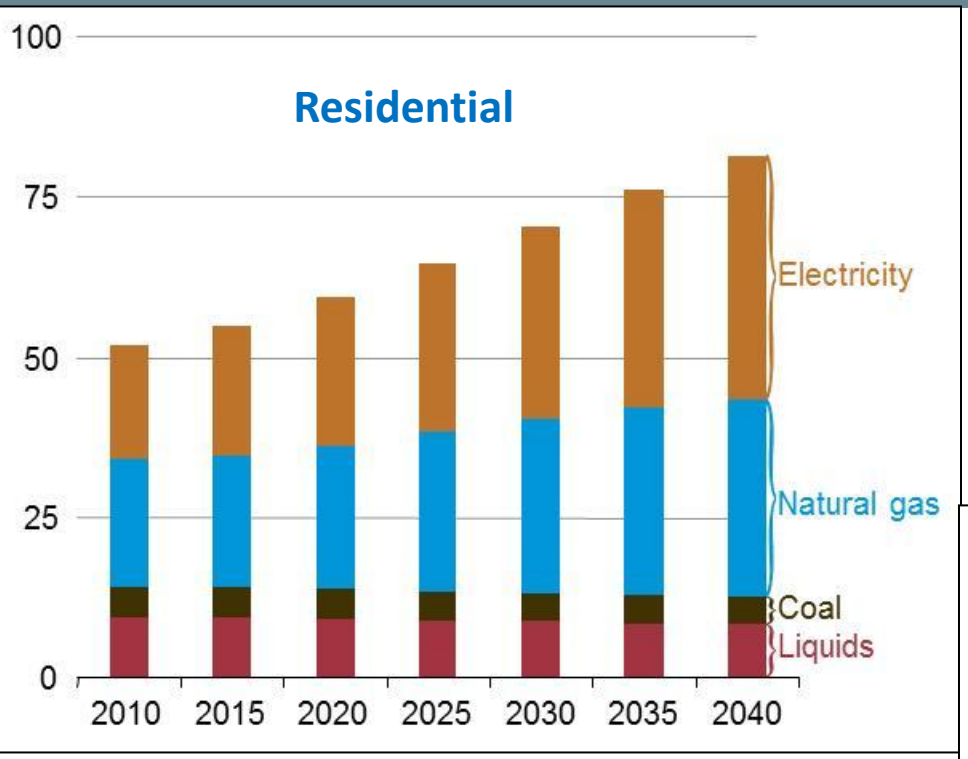
Source: BP Statistical Review of World Energy (2014)

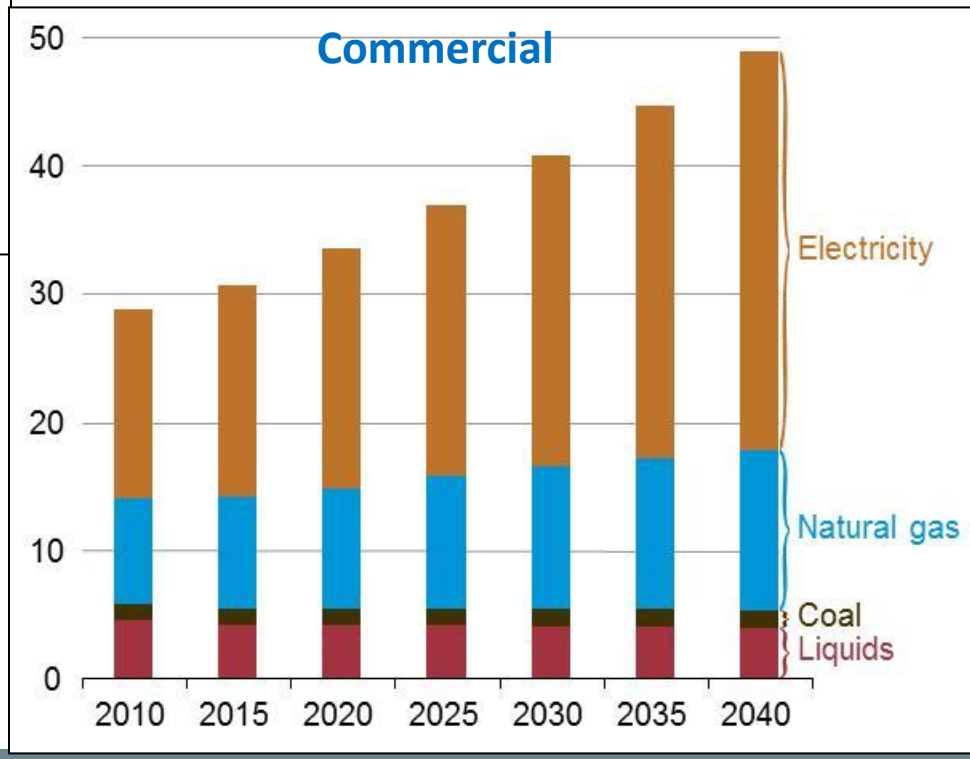
World liquid consumption (10^{15} BTU)

- Petroleum and other liquid fuels are the main component of energy sector energy;
- Transport accounts for 63% of total growth in energy consumption over 2010-40;
- Transport Sector (2010-40): **+36x10^{15} BTU**;
- Industry Sector (2010-40): **+25x10^{15} BTU**;

Source: DoE/EIA-0484

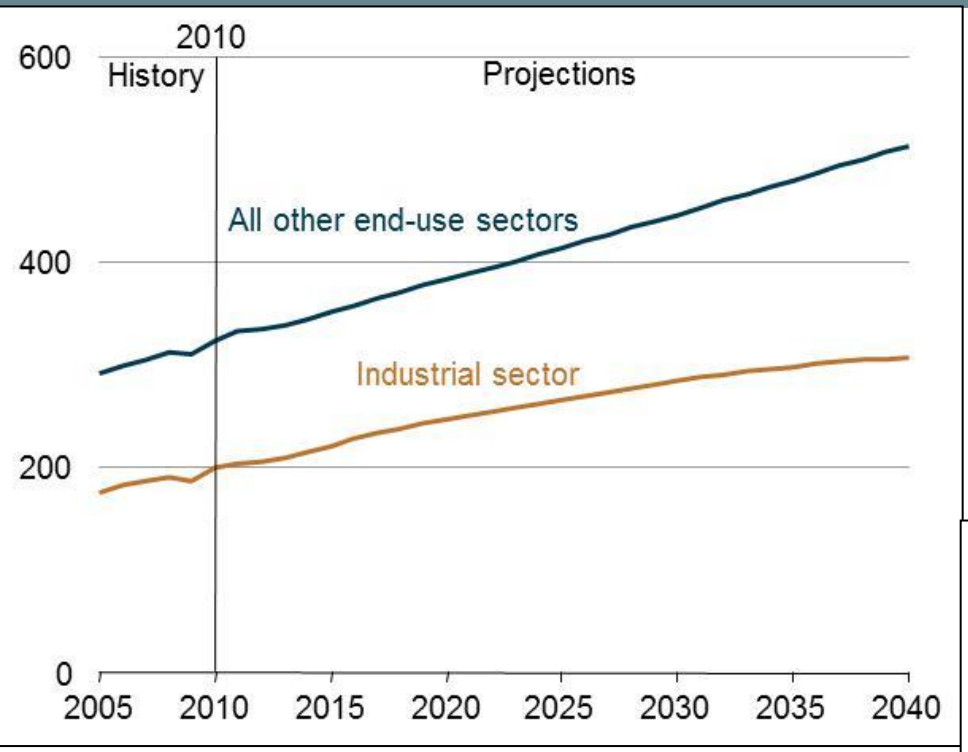
World Residential/Commercial Consumption (10^{15} BTU)

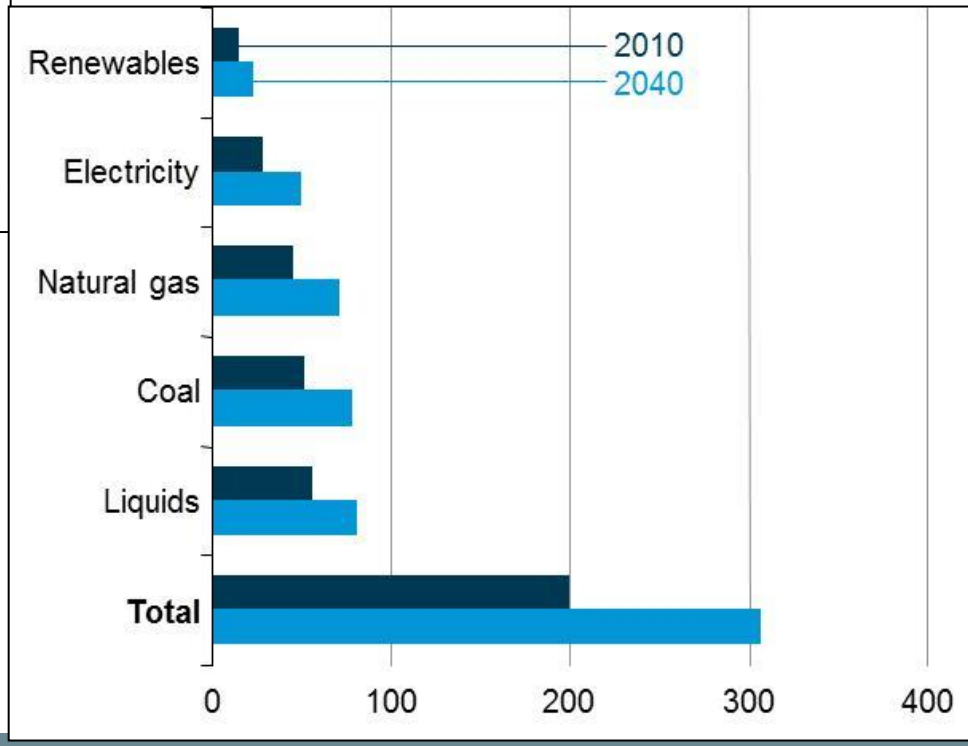




Source: DoE/EIA-0484

World Industrial Sector Consumption (10^{15} BTU)





Source: DoE/EIA-0484

Energy Consumption: Transport Sector (10^{15} BTU)

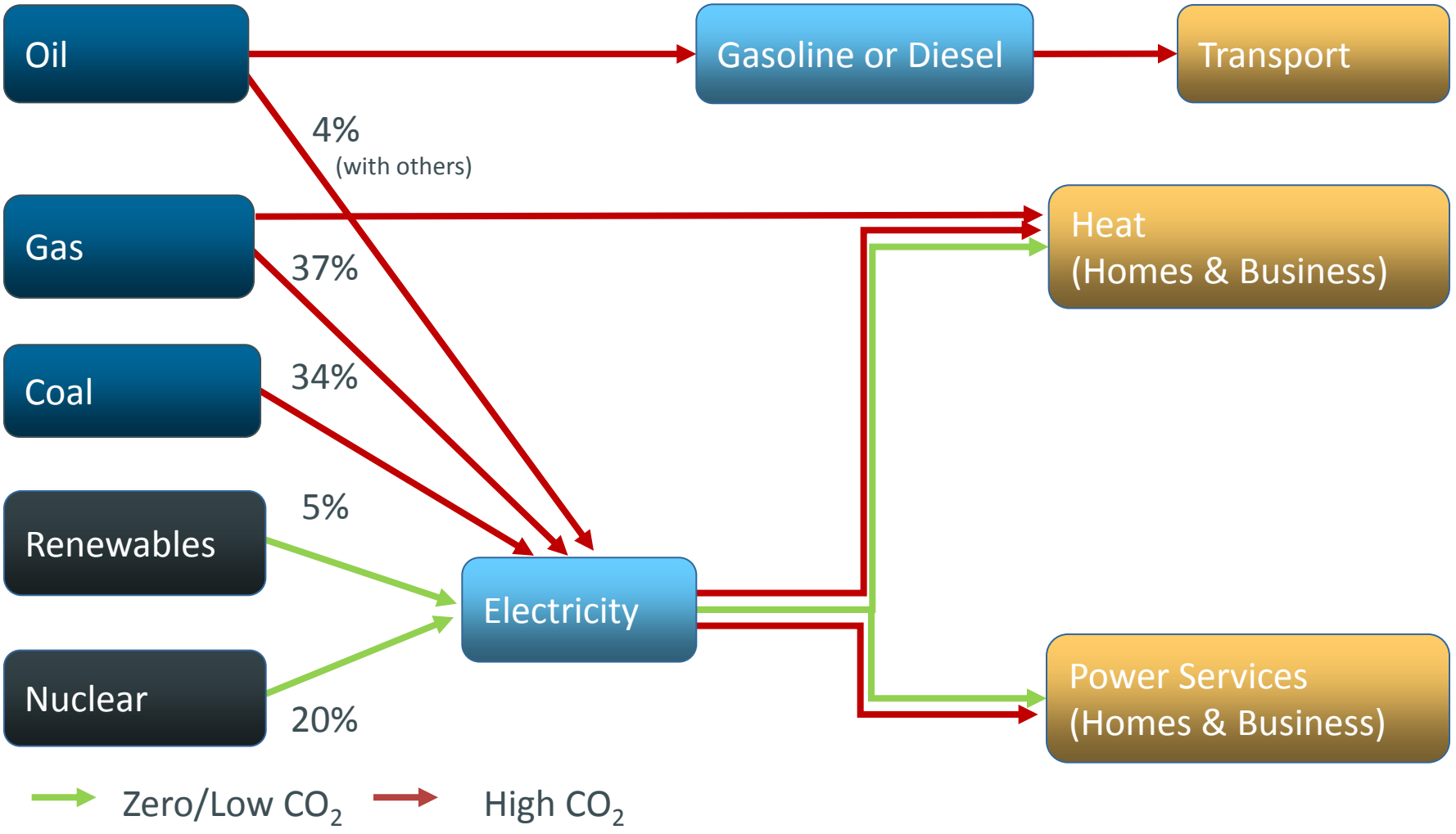
UNIVERSITY OF ABERDEEN

Region	2010	2015	2020	2030	2040	Aver. Annual % change
OECD	**57.9**	**56.0**	**55.9**	**54.5**	**55.5**	**-0.1**
Americas	32.7	32.5	32.5	31.7	32.9	0.0
Europe	18	16.3	16.2	15.7	15.7	-0.5
Asia	7.1	7.2	7.1	7.0	7	-0.1
Non-OECD	**43.1**	**50.3**	**56.4**	**68.3**	**83.9**	**2.2**
Europe and Euroasia	6.7	8.0	8.5	9.5	10.6	1.5
Asia	19.9	23.5	28.0	37.0	49.2	3.1
Middle-East	6	7.4	8.1	8.6	9.5	1.5
Africa	3.8	4.0	4.1	4.5	4.8	0.8
Central and South America	6.6	7.3	7.7	8.8	9.8	1.3
TOTAL	**101.0**	**106.2**	**112.2**	**122.8**	**139.5**	**1.1**

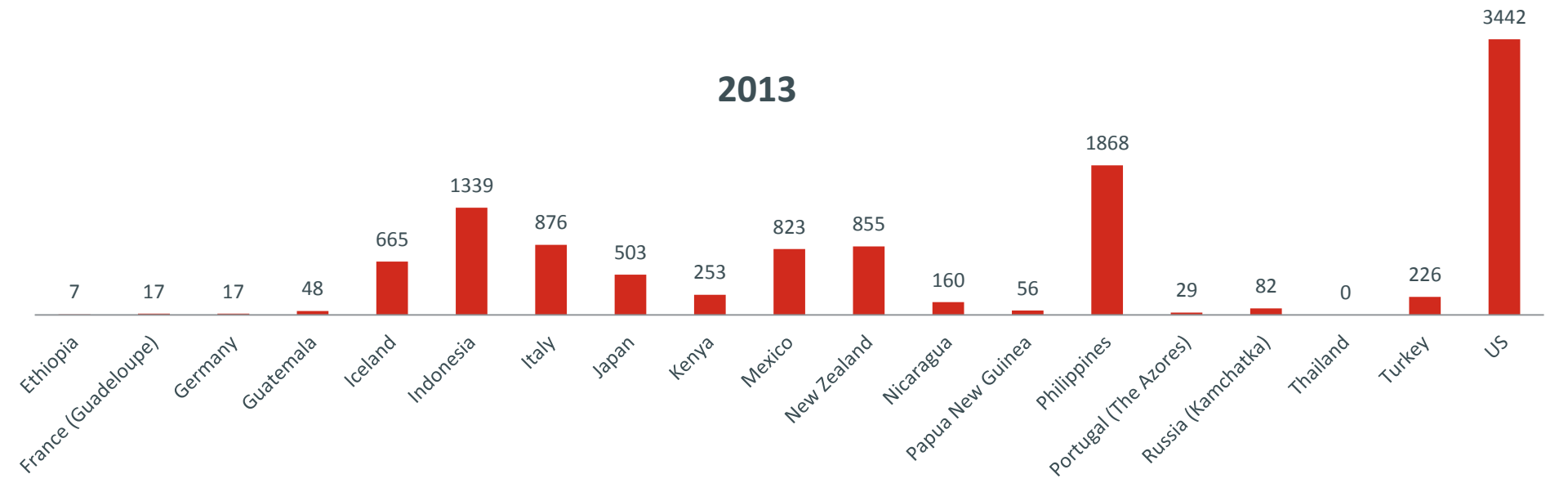
Energy used to move people and goods by road, rail, air, water and pipeline.

Source: DoE/EIA-0484

Energy Mix in UK



Geothermal Power Capacity (MW) Cumulative Installed



- Nearly 12GW supplied to 24 countries worldwide;
- Electricity attends the need of more than 60M people;
- Indonesia: 23% of all electricity generated by geothermal sources and;
- Iceland: Fully powered by renewables with geothermal producing 17% of the electricity and 87% of the heating;

Source: BP Statistical Review of World Energy (2014)

10 Largest Power Plants of the World (2011)

UNIVERSITY OF ABERDEEN

Rank	Plant	Country	Capacity (MW_{el})	Aver. Annual Elect. Gen. (TWh)	Plant Type
1	3-Gorges Dam	China	22500	98.1	Hydro
2	Itaipu Dam	Brazil/Paraguay	14000	98.2	Hydro
3	Guri Dam	Venezuela	10235	53.41	Hydro
4	Tucurui Dam	Brazil	8370	21.4	Hydro
5	Kashiwaazaki-Kariwa NPP	Japan	8212	24.63	Nuclear
6	Grand Coulee Dam	USA	6809	21	Hydro
7	Longtan Dam	China	6426	18.7	Hydro
8	Bruce NPP	Canada	6272	36.25	Nuclear
9	Uljin NPP	South Korea	6157	44.81	Nuclear
10	Yeonggwang NPP	South Korea	6139	48.16	Nuclear

Wikipedia

Largest Power Plants by Energy Source (2011)

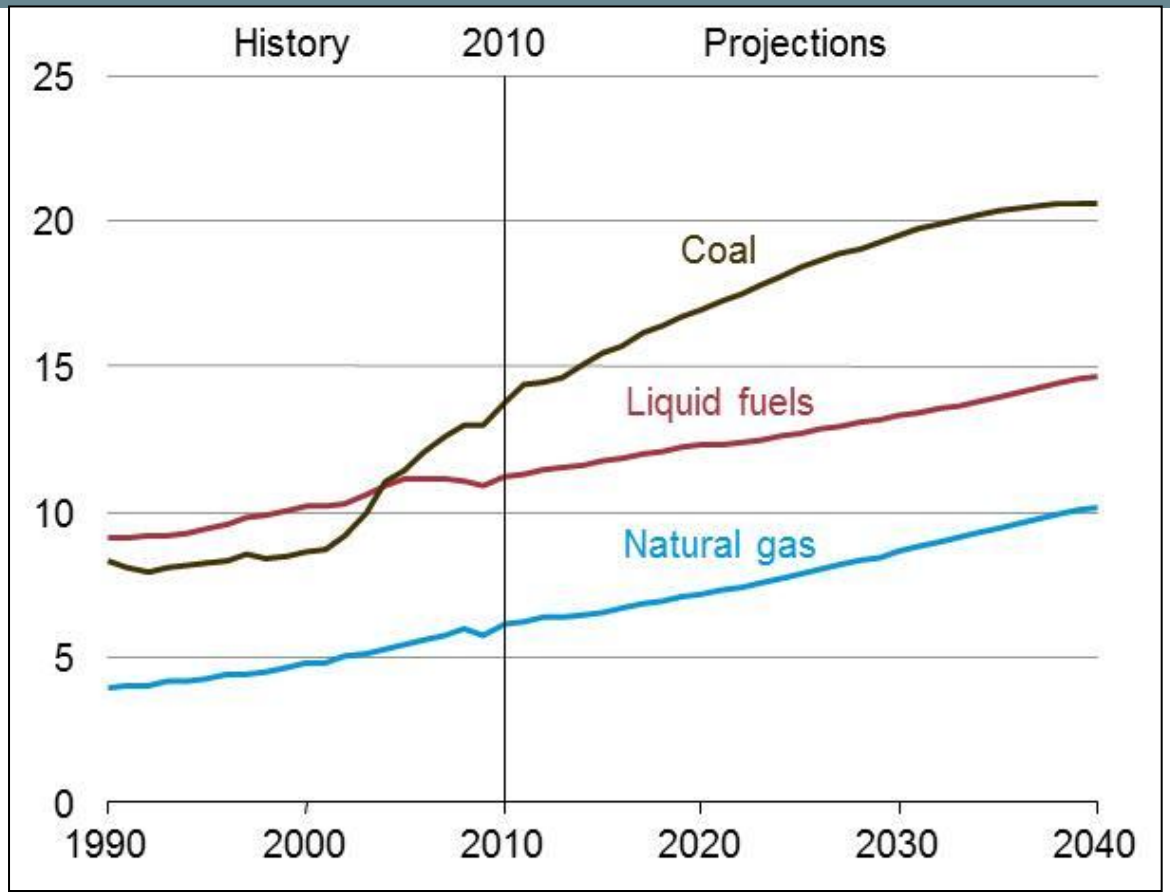
UNIVERSITY OF ABERDEEN

Rank	Plant	Country	Capacity (MW_{el})	Plant Type
1	3-Gorges Dam	China	22500	Hydro
2	Kashiwaazaki-Kariwa NPP	Japan	8212	Nuclear
3	Taichung Power Plant	Taiwan	5780	Coal
4	Shoaiba Power Plant	Saudi Arabia	5600	Fuel Oil
5	Surgut-2 Power Plant	Russia	5597	Natural Gas
6	Eesti Power Plant	Estonia	1615	Oil Shale
7	Shatura Power Plant	Russia	1500	Peat
8	Alta Wind Energy Center	USA	1020	Wind (onshore)
9	Tilbury B Power Station	UK	750	Biofuel
10	**Hellisheioi Power Station**	**Iceland**	**303**	**Geothermal**
11	Sihwa Lake Tidal Power Station	South Korea	254	Tidal
12	Agua Calient Solar Project	USA	251	Solar
13	Agucadora Wave Farm	Portugal	2	Marine (wave)

Wikipedia

jefferson.gomes@abdn.ac.uk

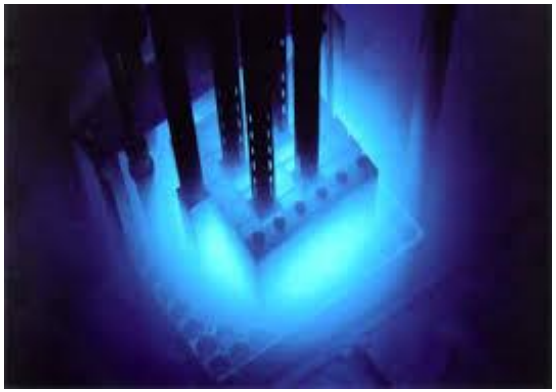
World Energy-related CO_2 Emissions (in billion metric tons)



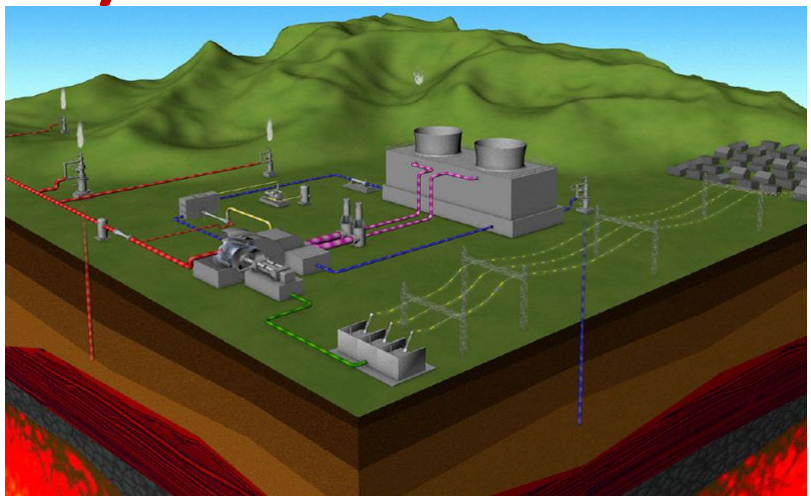
Source: DoE/EIA-0484

1 cubic ton =40 cubic feet = 1.133 cubic meters

- Increase of coal power stations → Increase coal consumption → more GHC (Greenhouse gases);
- Growth in consumption of liquid fuels and natural/shale gas over the next 30 years;
- Solar, wind, biomass (renewables) will benefit from intensive R&D and will continue to grow, but;
- Solar and wind: unlikely to produce more than 25% of world demand of electricity by 2050.



Energy Conversion: Reapplication of Fundamental Physics



jefferson.gomes@abdn.ac.uk

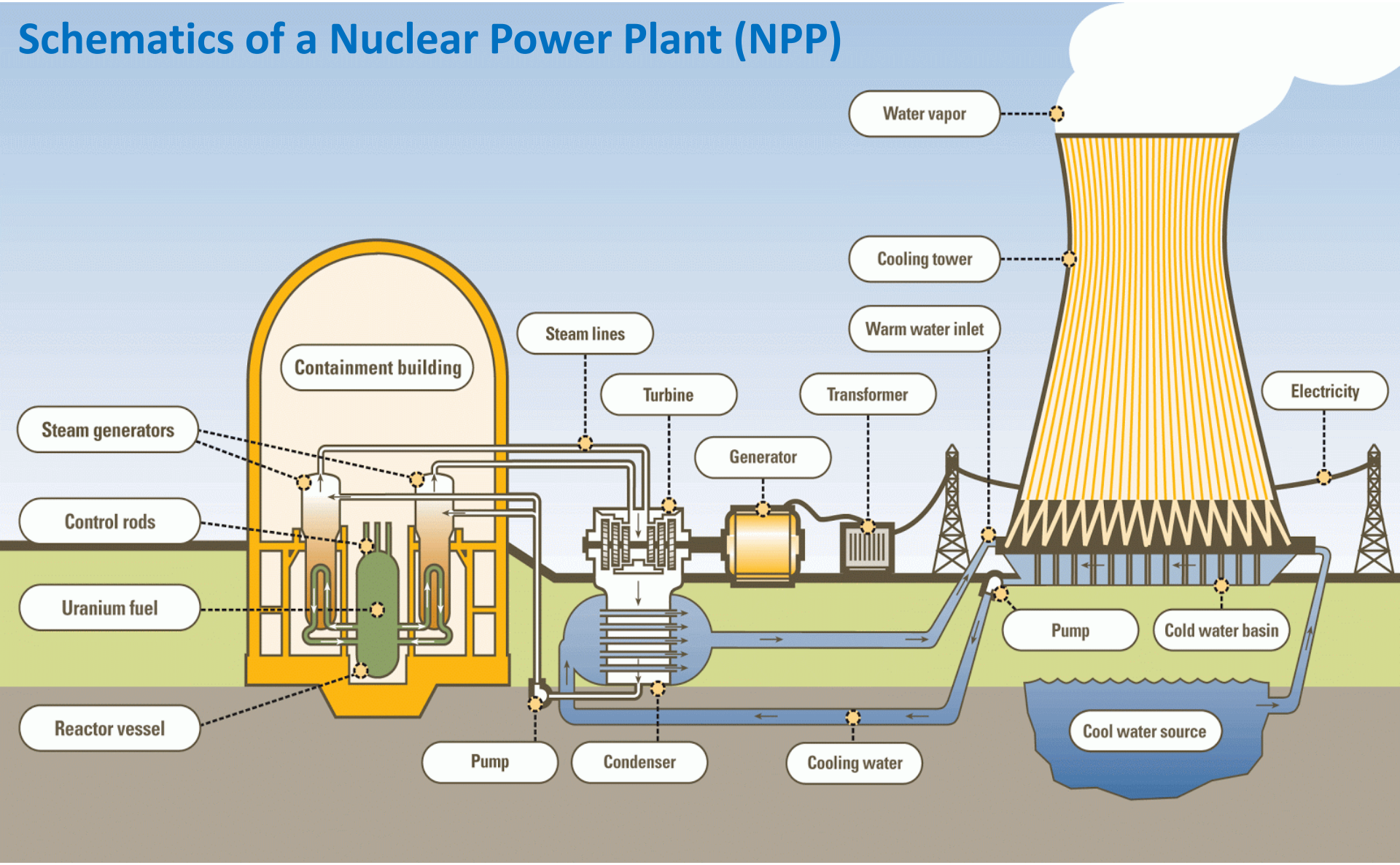
Why Geothermal (or why pursue a diverse energy matrix)??

- To address **CLIMATE CHANGE** we must:
  - ✓ improve efficiency and;
  - ✓ reduce use of fossil fuel-based energy source.
- GHG emissions should be mitigated by the development of new cost-effective technologies:
  - ✓ Carbon Capture Storage and Transportation (CCST);
  - ✓ Nuclear →Management of nuclear waste storage;
  - ✓ Low-carbon energy sources (i.e., renewables);
  - ✓ Integrated Gasification Combined Cycle (IGCC):
    - Converting carbon-based fuels into syngas (gas-synthesis - mainly H_2, CO);
    - Combined steam (e.g., Rankine) and gas (e.g., Brayton) cycles using advanced turbines with high thermal efficiency;
- Energy security: most countries do not have fossil-fuel resources to sustain their economies.

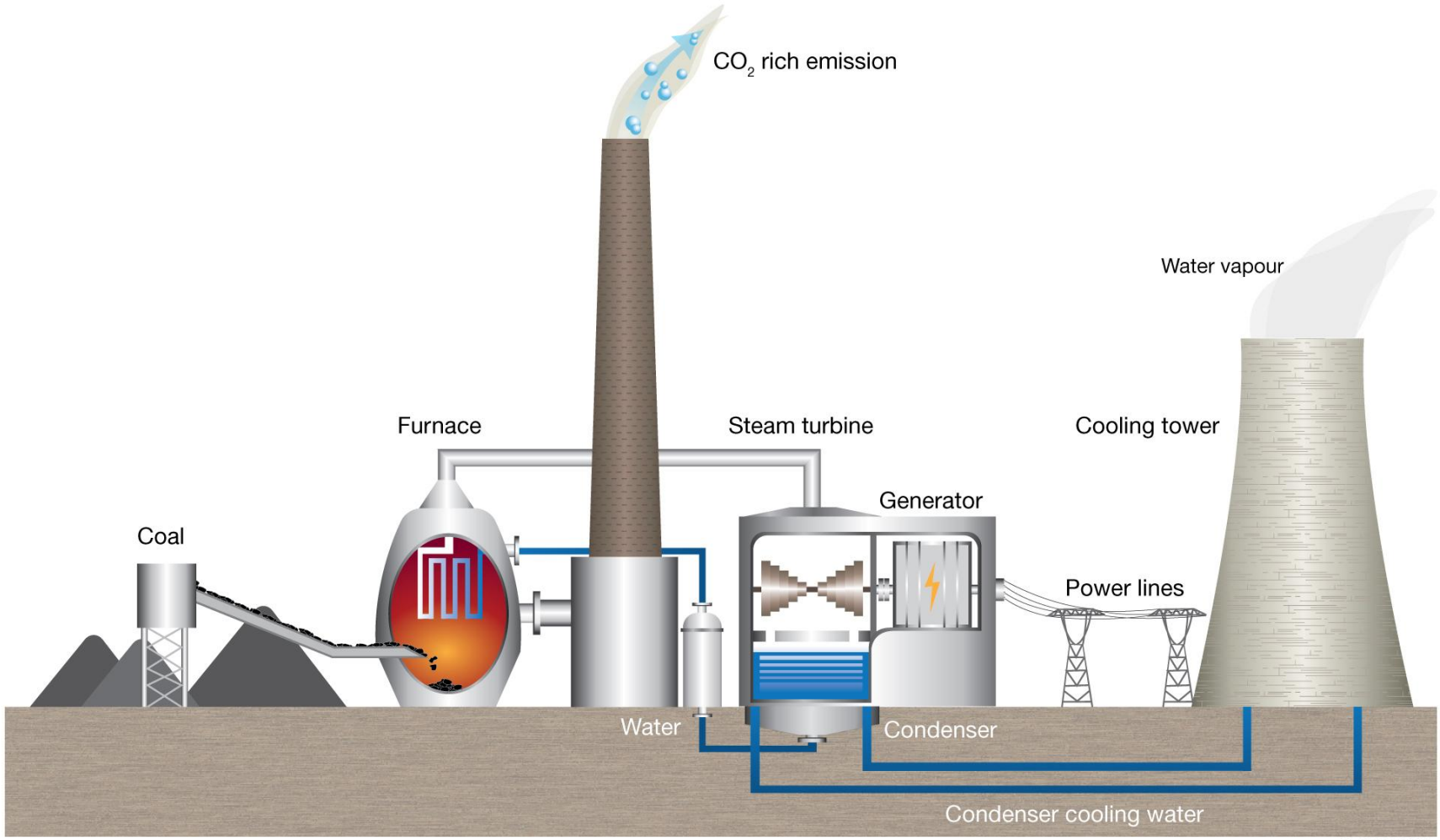
How Power Plants Work? Heat Sources!

UNIVERSITY OF ABERDEEN

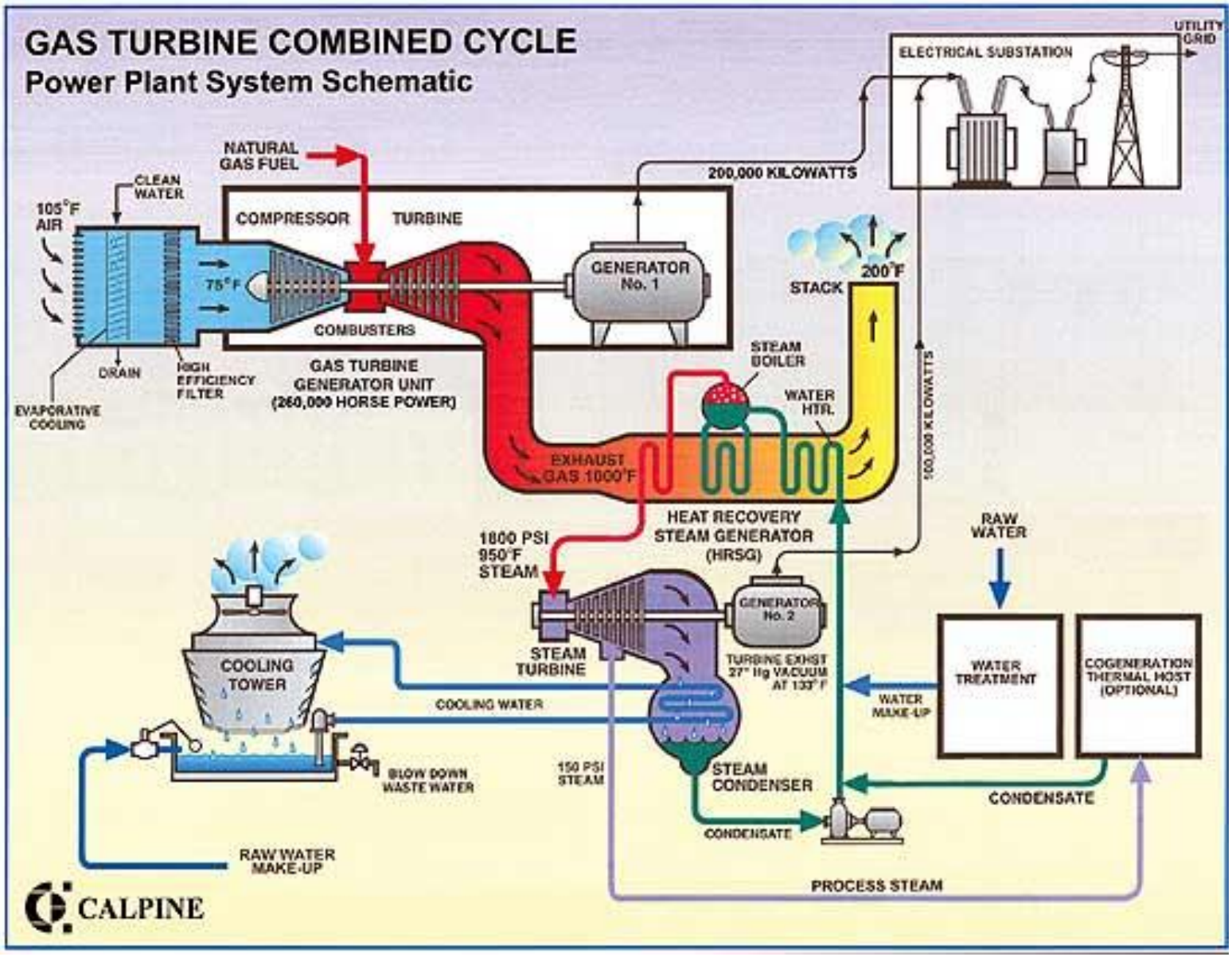
Schematics of a Nuclear Power Plant (NPP)



Schematics of a Coal-Fired Power Station



How Power Plants Work? Heat Sources!

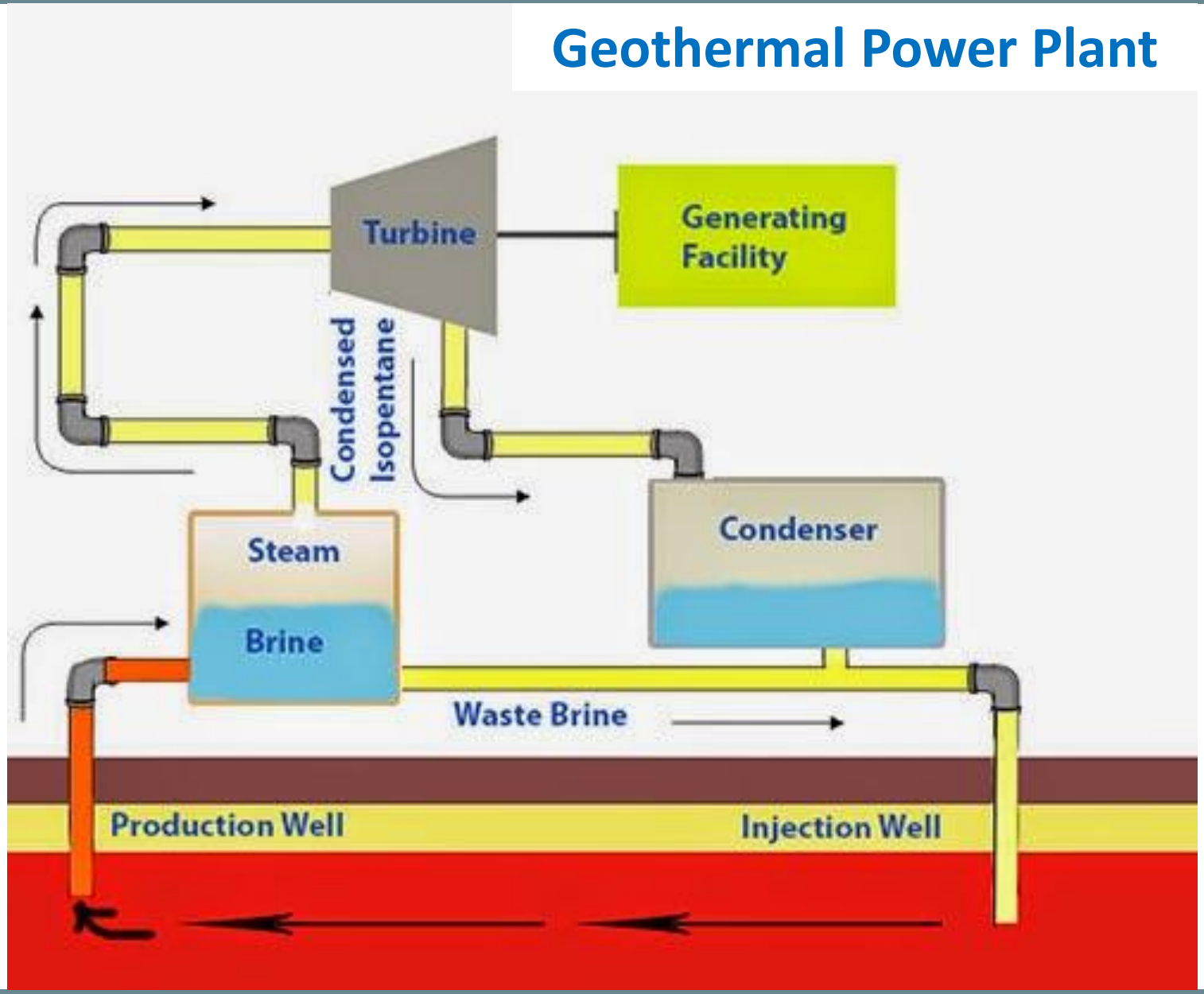


Schematics of a Natural Gas Power Station

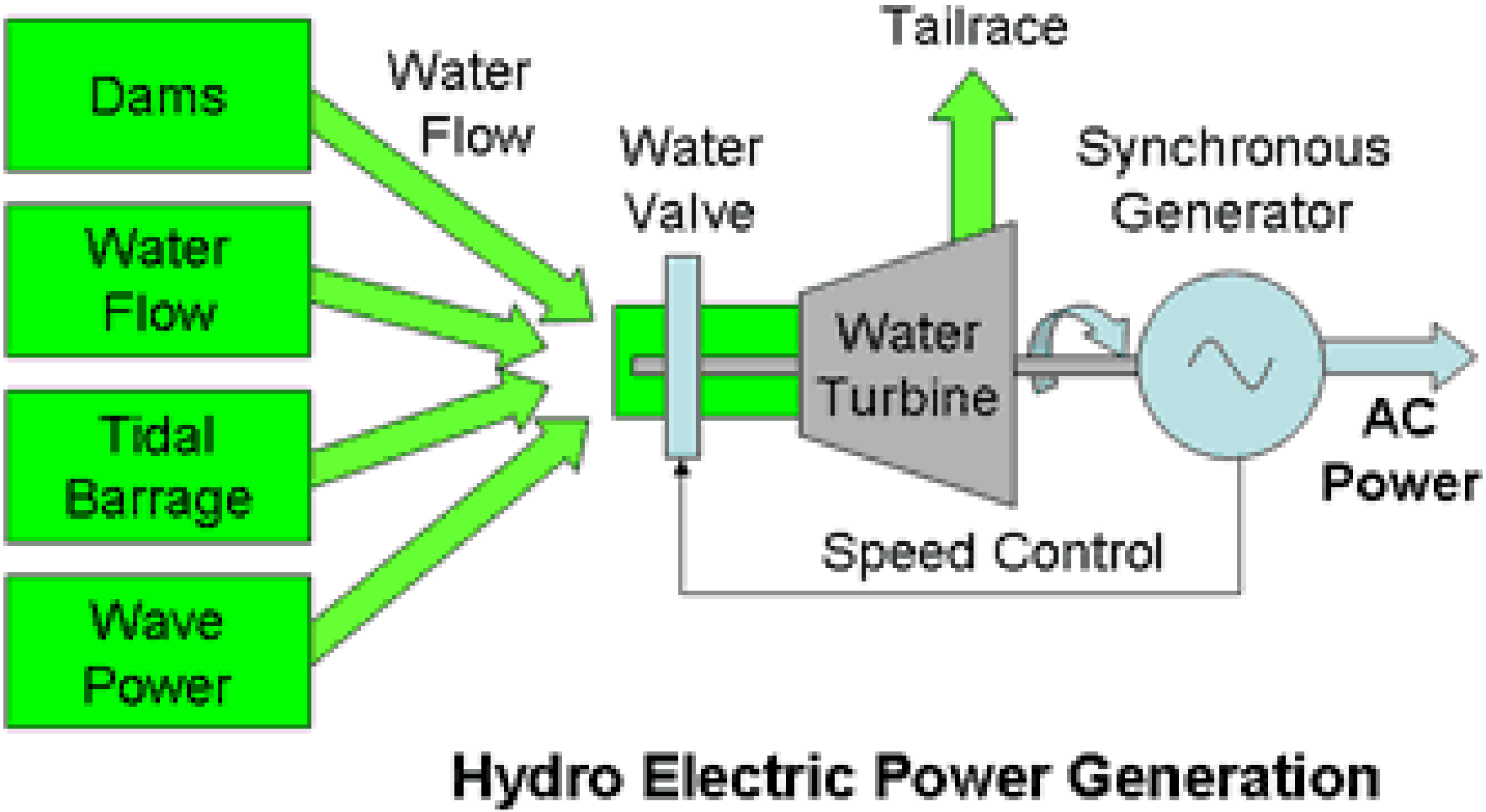
How Power Plants Work? Heat Sources!

UNIVERSITY OF ABERDEEN

Geothermal Power Plant

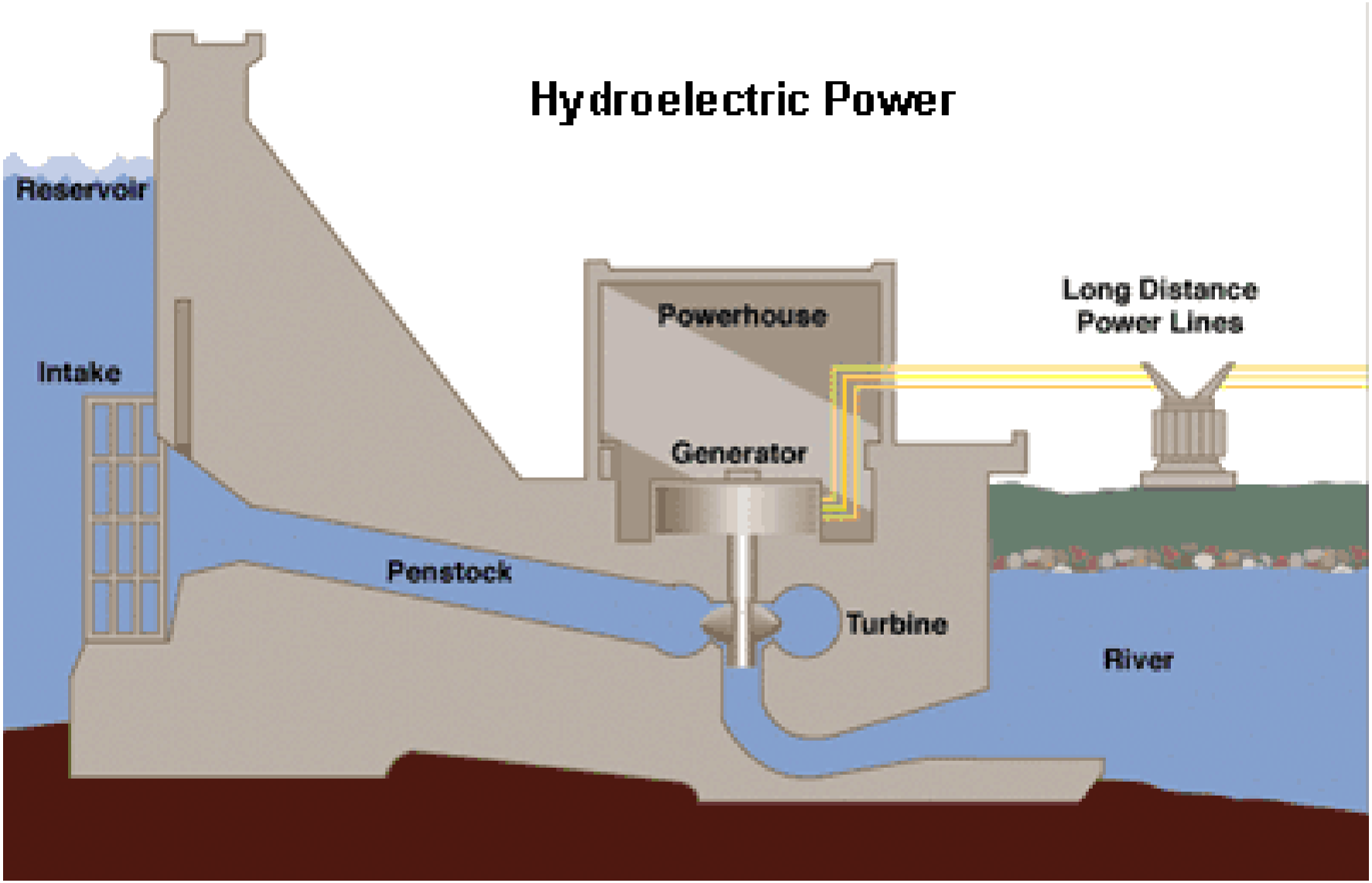


How Power Plants Work? Momentum Sources!

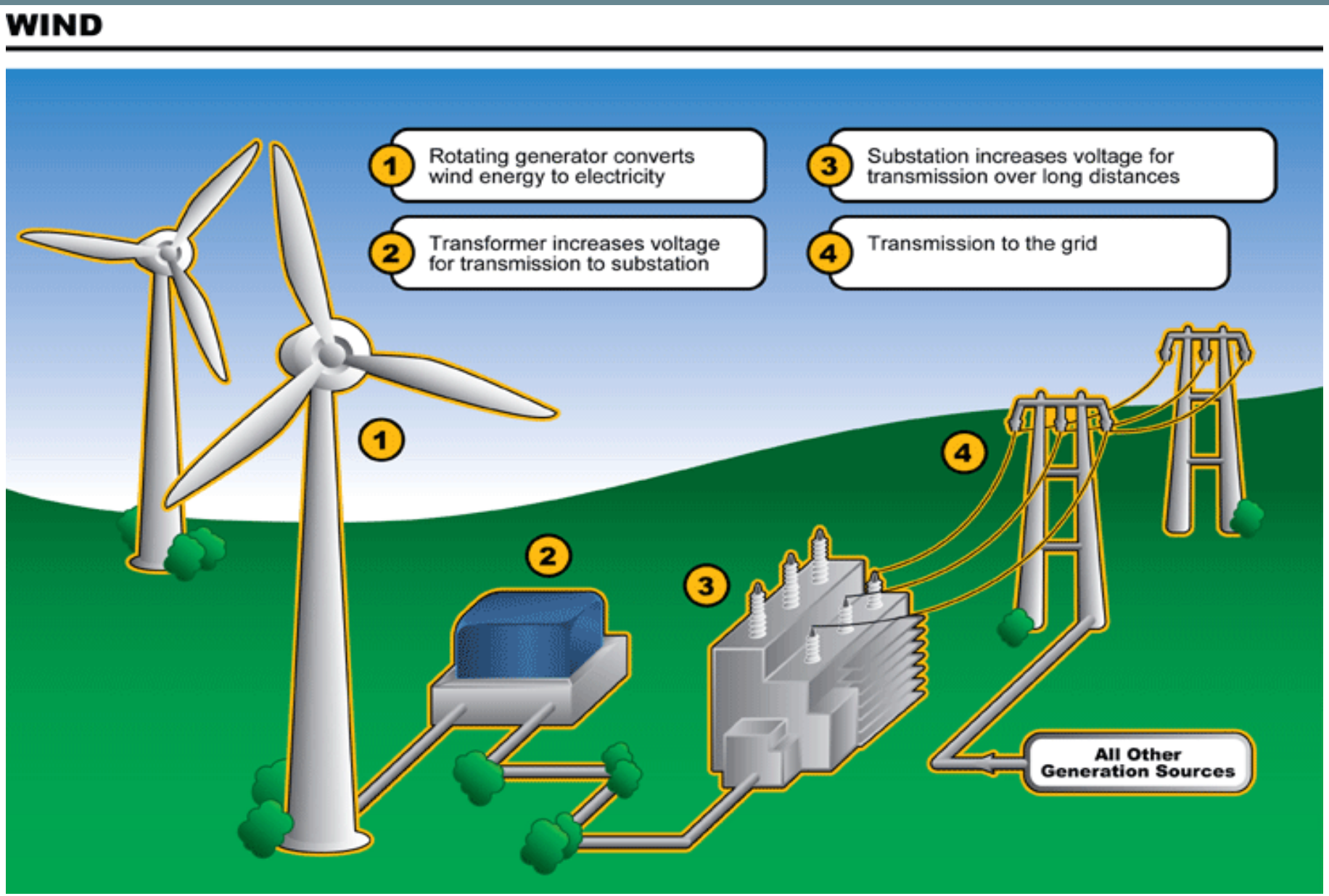


Hydro Electric Power Generation

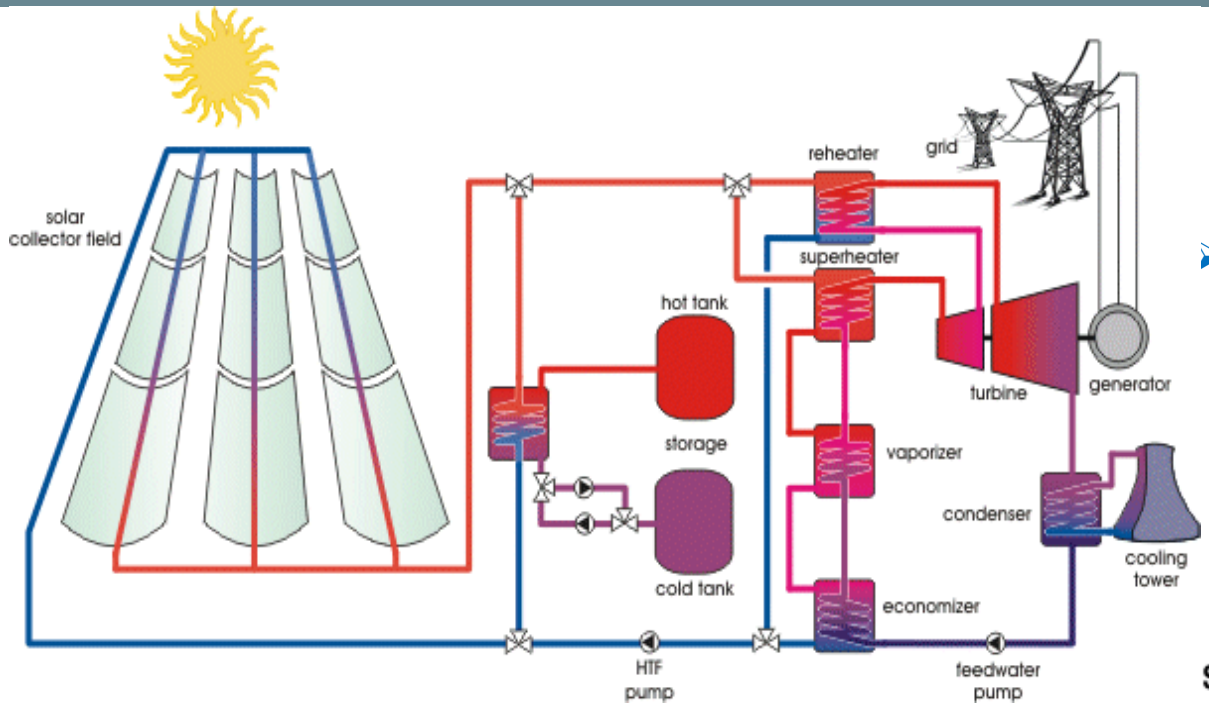
How Power Plants Work? Momentum Sources!



How Power Plants Work? Momentum Sources!

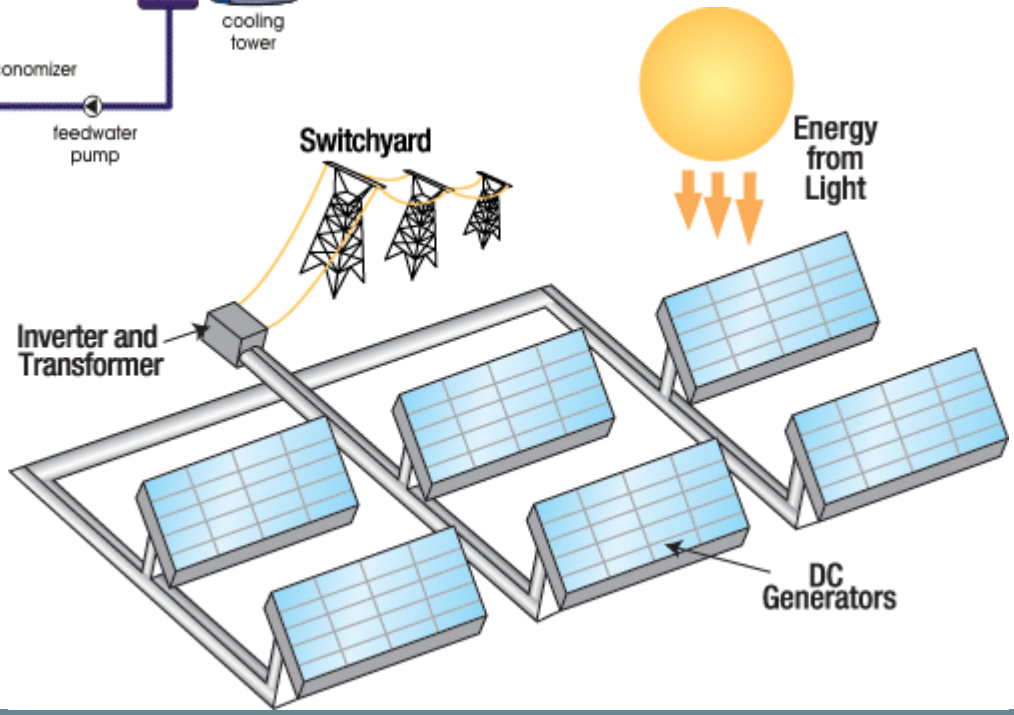


How Power Plants Work? And Solar?



- Heat Source: thermal radiation to boil water or;

- Photovoltaic (solar cells): direct conversion of the electromagnetic radiation from the Sun to electricity.



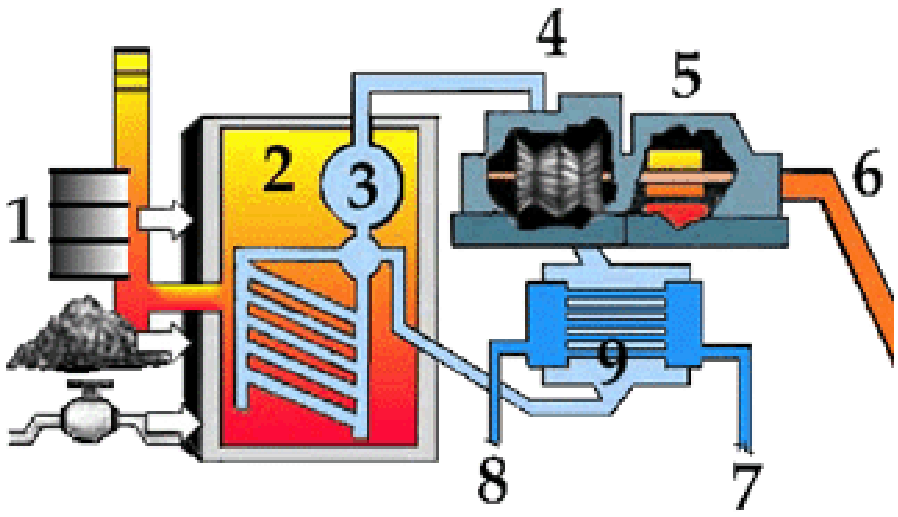
How Power Plants Work?

- The vast majority of power plants are based on elements of the following workflow:
  1. Generate heat;
  2. Boil water;
  3. Produced steam is used to turn a (set of) turbine(s);
  4. Turbines are linked with generator to;
  5. Produce electricity.

- We saw that:
  - Fossil fuels and nuclear: 1-5;
  - Hydro and wind: based on momentum transfer + 4-5;
  - Geothermal: undergrounded heated water + 2-5;
  - Solar: (a) solar radiation + 2-5 or,
    (b) photovoltaic cells + 5.

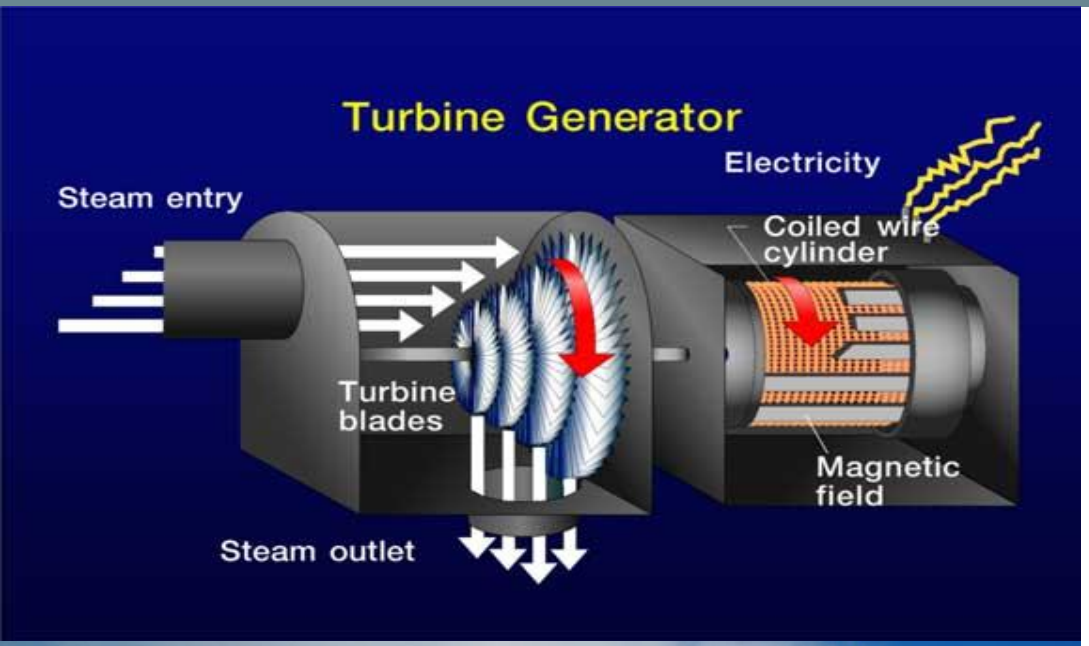
How Power Plants Work? (summary)

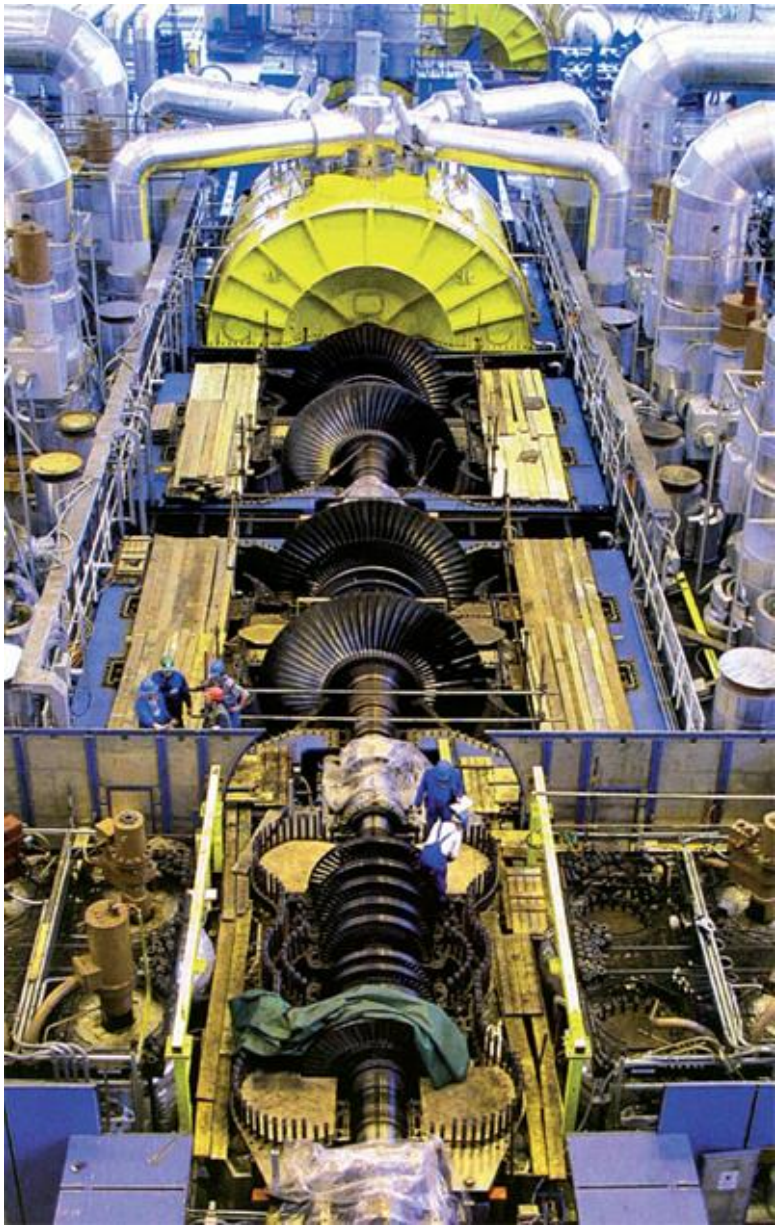
1. Energy Source (coal, oil, NG, nuclear, etc) is 'burnt' generating heat in the;
2. Boiler. Heat is transferred into the water-steam cycle (3-4-9-3);
3. Steam (at high temperature and pressure) produced by the water vaporisation is driven towards a;
4. Steam turbine that promotes an *isentropic expansion* and produces **work**;
5. The **work** is transferred to a generator responsible to produce;
6. Electricity that is linked to the power grid;
7. After the expansion (in the turbine), steam (low temperature and pressure) is driven into the condenser (9), where it is transformed in water and returns to the Boiler (2);



- System 7-8-9 comprises condenser and cooling waste water.

Power Plants: Turbine Generator





Summary

- Multiple energy sources: fossil-fuel, renewables, nuclear, etc;
- Demand and production of energy mix;
- Thermal and momentum energy sources;

Additional Reading

- BP Statistical Review of World Energy 2013: http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013.pdf
- Annual Energy Outlook 2014 with Projections to 2014 (DoE/EIA-0383): http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf
- Annual Energy review 2011 (DoE/EIA-0384): http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf
- Energy for a Sustainable Future: Reports and Recommendations (2010), The Secretary-General's Advisory Group on Energy and Climate Change (AGECC): http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGECC%20summary%20report%5B1%5D.pdf
- The Future of Geothermal Energy: https://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf
- R. DiPippo (2012) 'Geothermal Power Plants'; Butterworth Heinemann.