



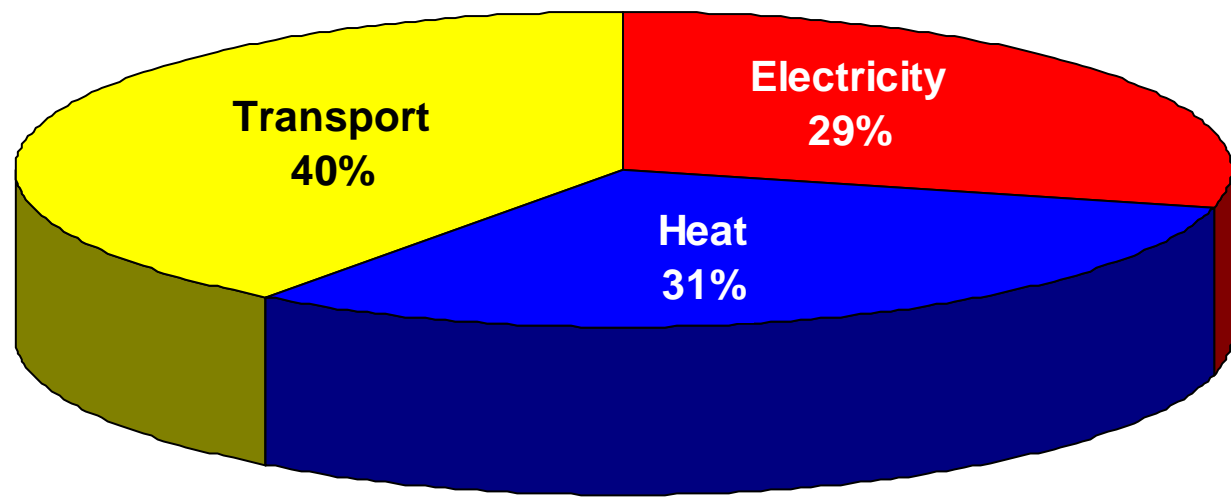
Electrical Energy Consumption and Markets

Ken Mitchell / Geraint Jewell



Electricity Supply

UK Carbon Sources 2010 - 505 Mt CO2

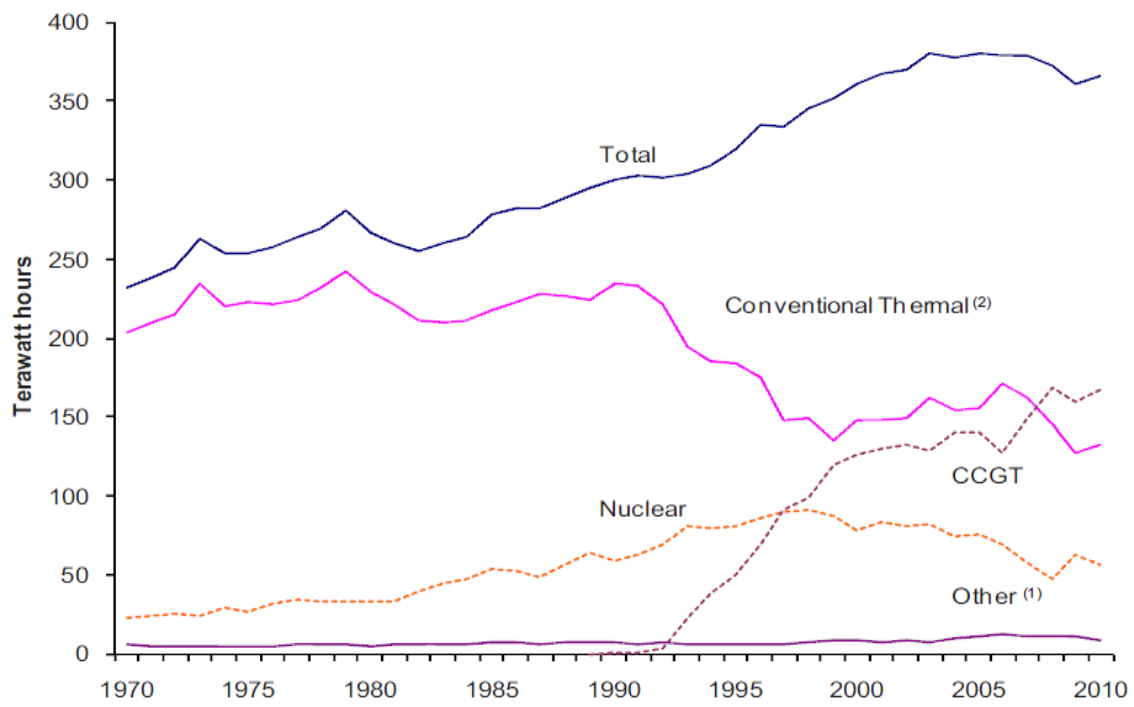


Source: National Grid



Electricity Supply

Increase in total electricity supplied and type of plant 1970-2010



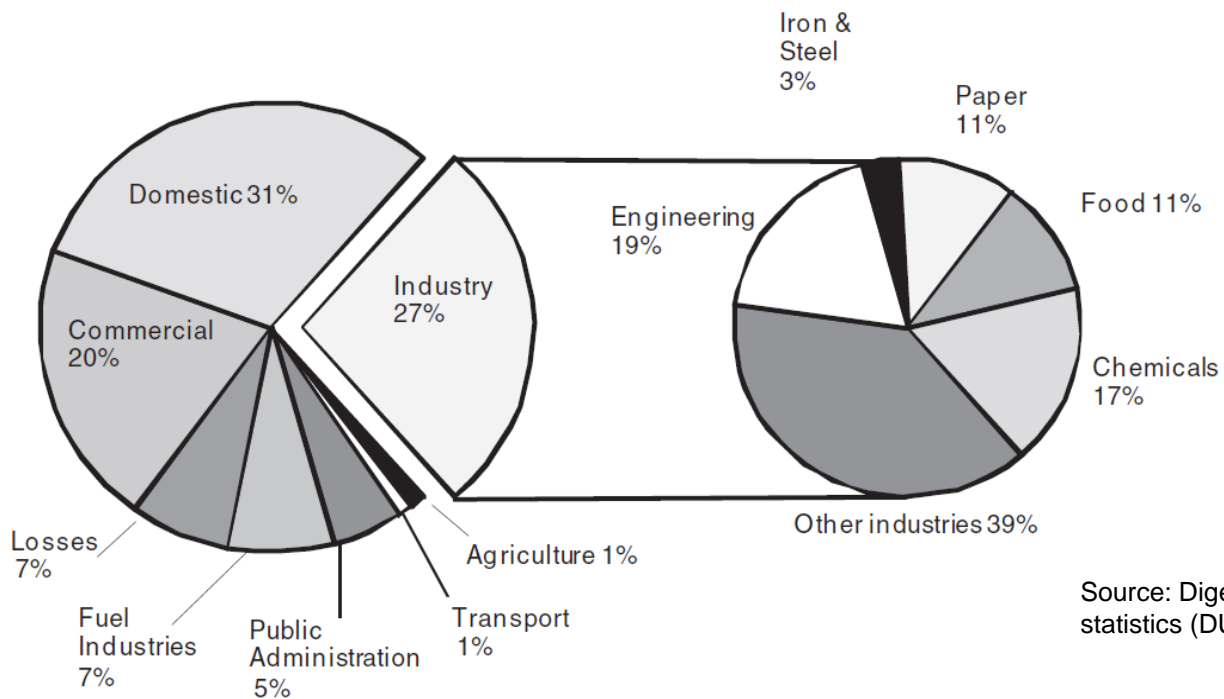
Source: Digest of UK energy statistics (DUKES) 2011

Total of ~ 400000 GWh produced in the UK per annum



Electricity Demand

Electricity demand by sector in 2010



Source: Digest of UK energy statistics (DUKES) 2011

Total demand 384003 GWh

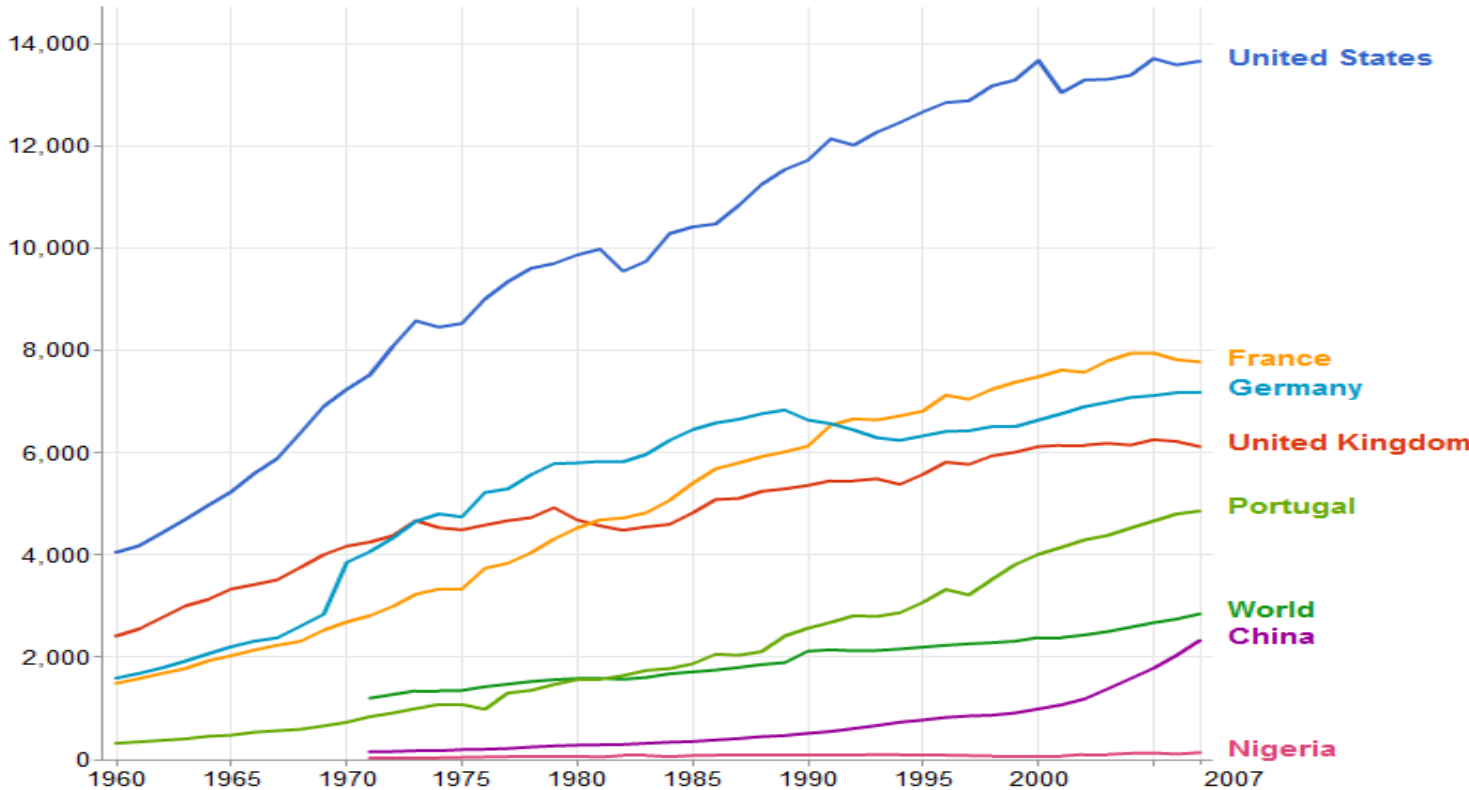
Industry demand 104499 GWh



Electricity Demand

Electric Power Consumption (kWh per capita)

(Electric power consumption measures the production of power plants less transmission, distribution, and transformation losses and own use by power plants)



Source: International Energy Agency, World Bank – World Development Indicators



E-Futures

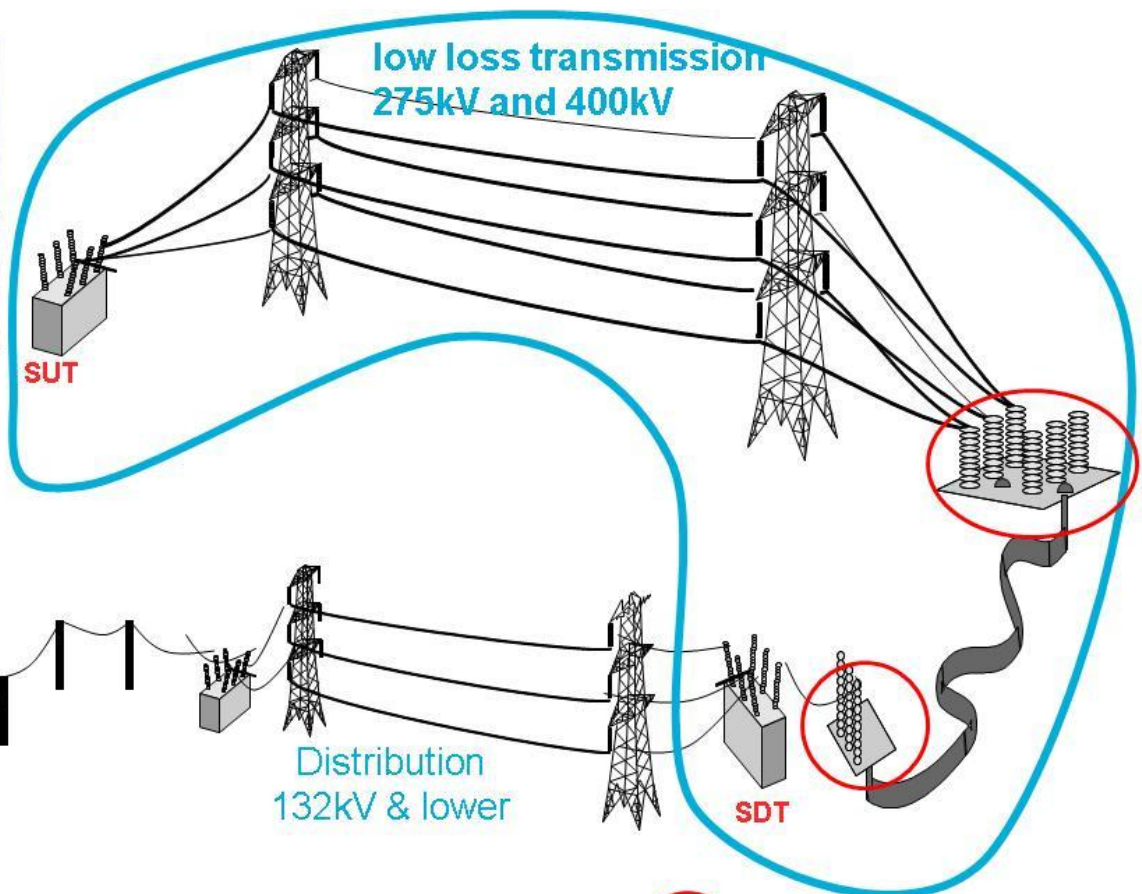
UK electrical network



Generation



Supply

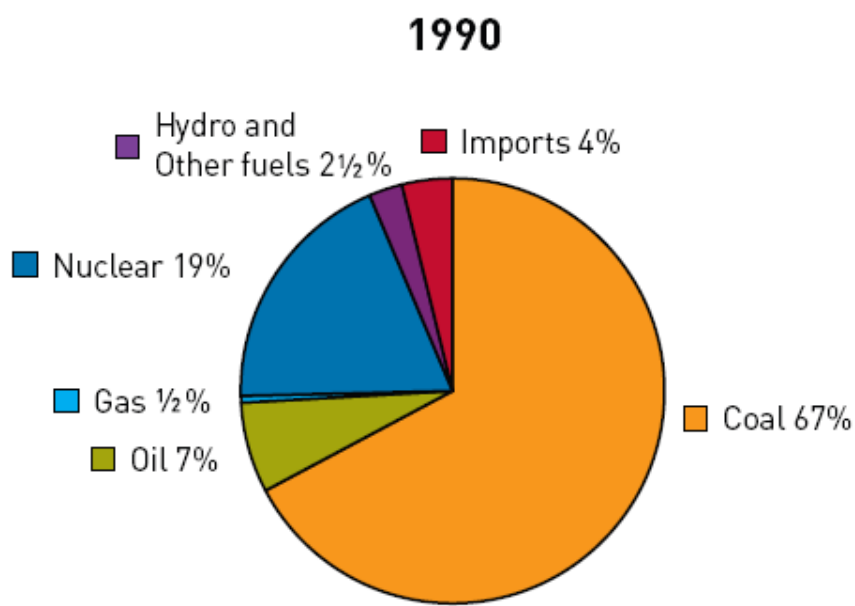


SUT - 'Step Up Transformer' SDT - 'Step Down Transformer' ○ Substation

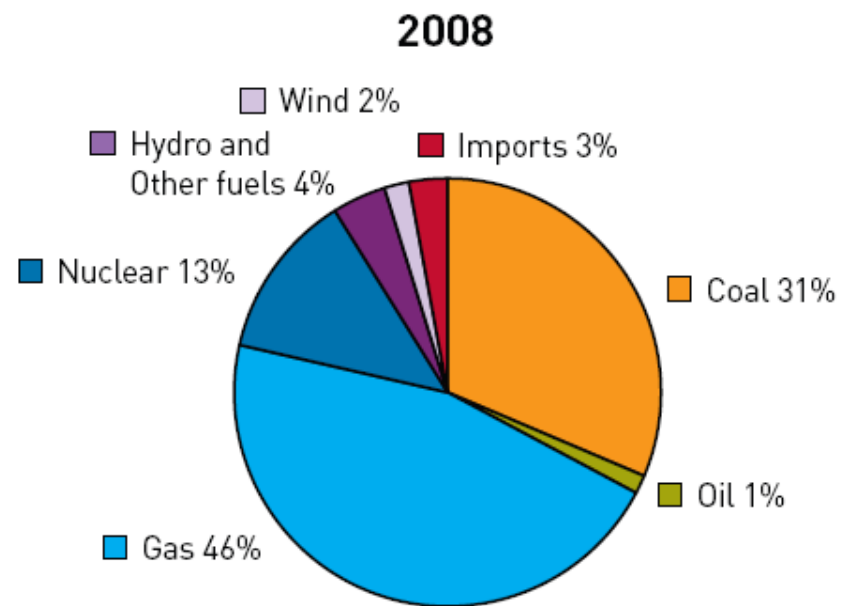


Electricity Supply

Fuel used in electricity generation in 1990 and 2008



Hydro includes both natural flow and pumped storage



Source: Digest of UK energy statistics (DUKES) 2009

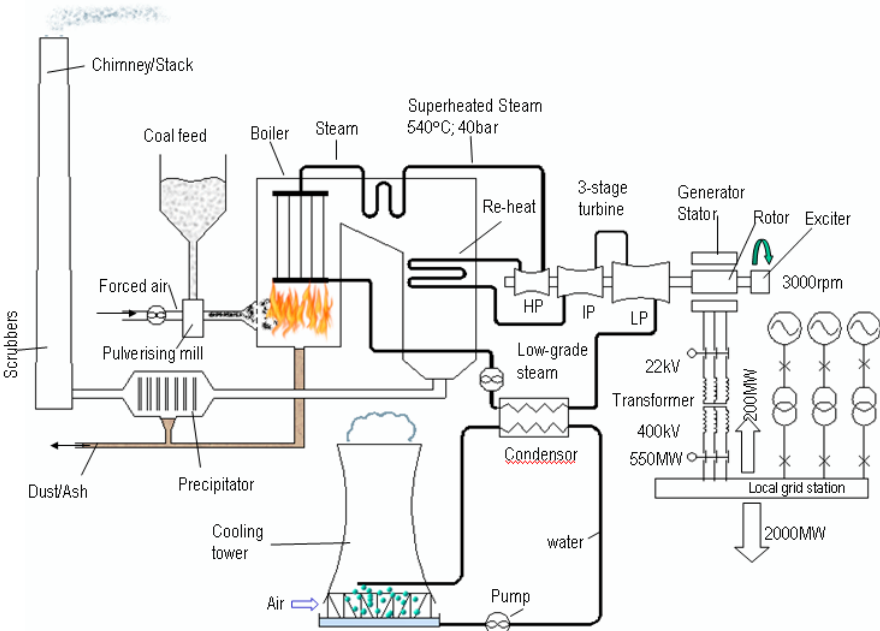
- Diversity required to protect the supply of electricity from fuel availability difficulties and cost fluctuations
- Diversity required to cover the different operational conditions as no energy storage in the system (e.g. fast response for rapid load changes)



Electricity Generation

Thermoelectric Power Station

- Burns fossil fuel (coal,oil etc.) to generate steam which drives steam turbine connected to the electrical generator
- Usually sited near source of fuel (e.g. coalfield) and plentiful supply of cooling water (e.g. river or coast)





Electricity Generation

COAL & OIL

- Relatively cheap
- Slow response to load fluctuation (4 – 8 hours to start-up)
- Practical thermal efficiency $\approx 35\text{-}37\%$
- 500MW per machine is typical (but up to 1000MW are possible)
- Run 24hours/day BASE LOAD stations

NUCLEAR

- Low fuel costs
- High construction and decommissioning costs
- Handling/storage of nuclear waste
- Practical thermal efficiency $\approx 40\%$
- 500MW per machine
- Run 24hours/day i.e. BASE LOAD stations

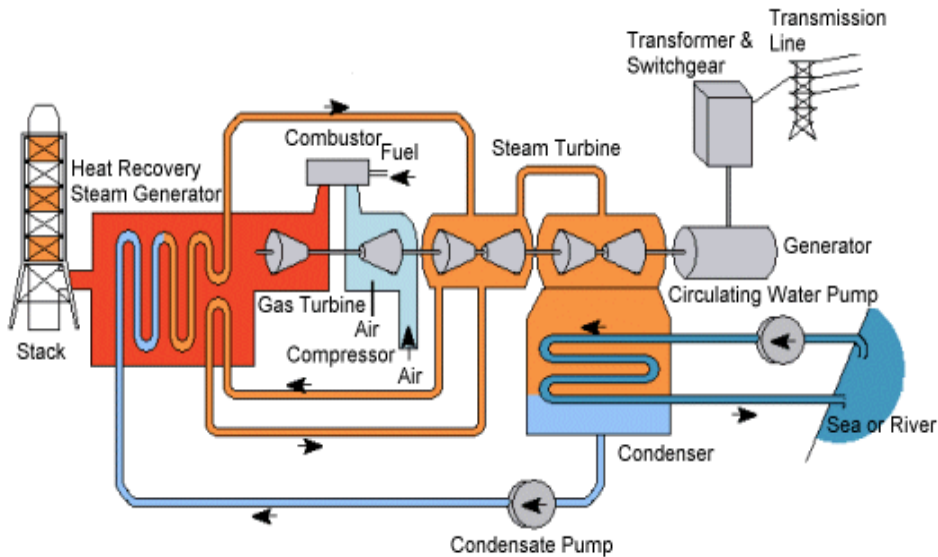
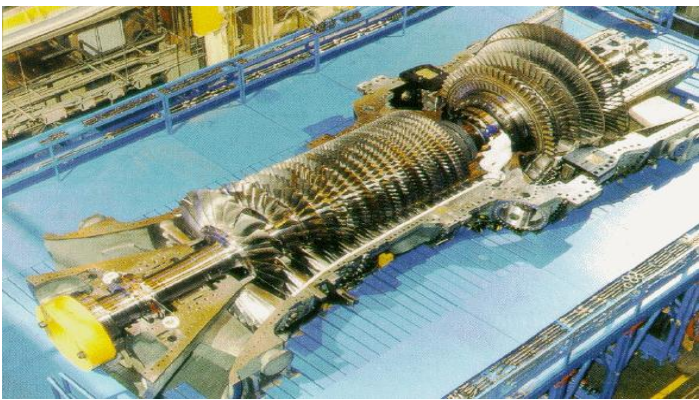




Electricity Generation

COMBINED CYCLE GAS TURBINES (CCGT)

- A gas turbine generator generates electricity and the waste heat is used to raise steam to generate additional electricity via a steam turbine
- Very fast response (Start-up 2 – 3 minutes)
- Currently cheap (availability of natural gas and turbine technology)
- Usually relatively low power (often sited near to load centres)
- 10-300MW per machine
- Practical thermal efficiency $\approx 60\%$
- More efficient so use less fuel





Electricity Generation

COMBINED HEAT AND POWER

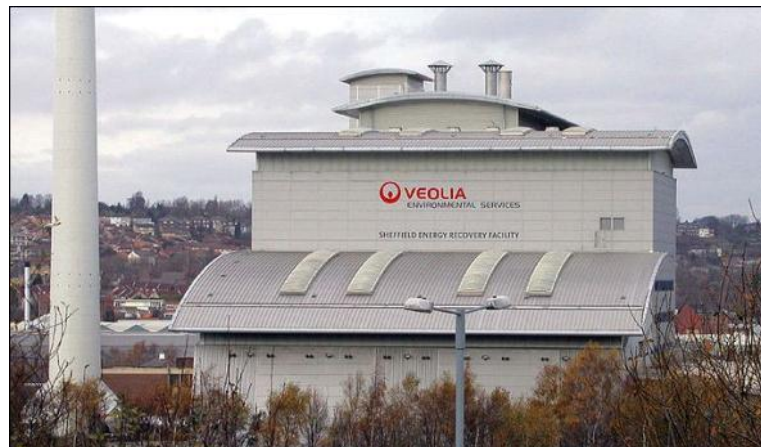
- Either waste heat from gas turbines used to provide heating
OR, heat from combustion of fuel for heating also used to raise steam and drive turbine for electricity
- Sheffield Heat and Power – incineration of refuse, used for district heating and provides electricity

Utilises 225000 tonnes of household waste per annum

Produces 60MW of heat to 140 buildings (including the University) through 44km pipes ($\approx 120000\text{MWh/annum}$)

19MW of electrical power (≈ 22600 homes)

Over 12000 tonnes CO_2 prevented/annum

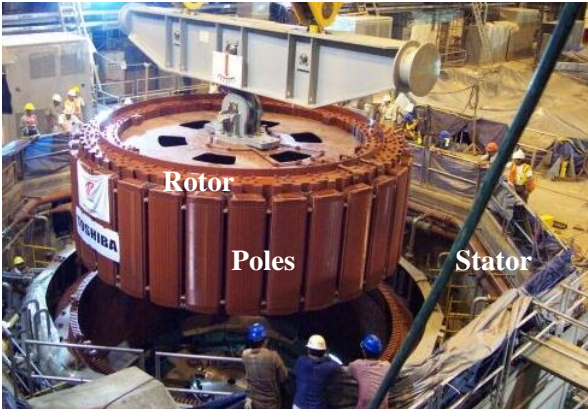




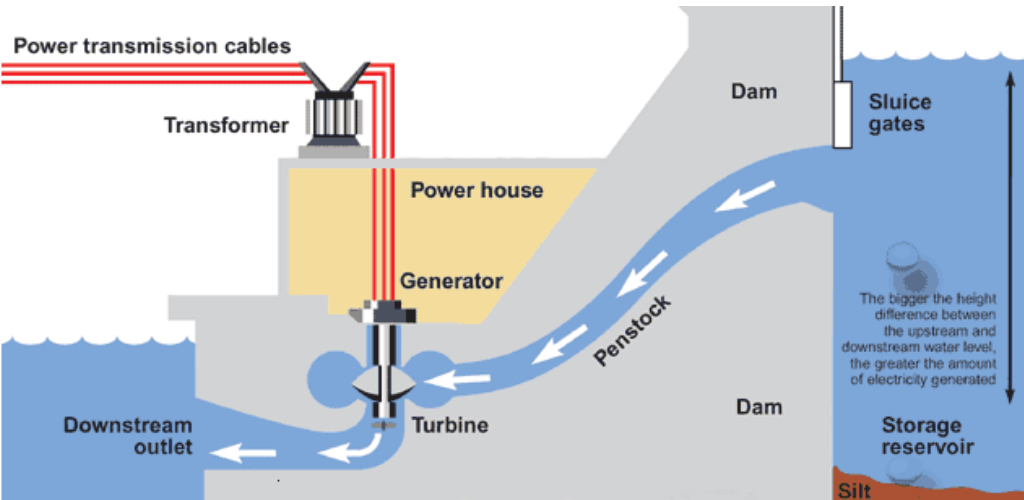
Electricity Generation

HYDRO-ELECTRIC – NATURAL FLOW

- Geography (not prevalent in UK, most in Scotland)
- In other countries Hydro can be significant (Norway 99% is Hydro)



500MVA, 15kV, 200 rpm generator
Diameter 9.2m; 2.3m long, 378 Slots

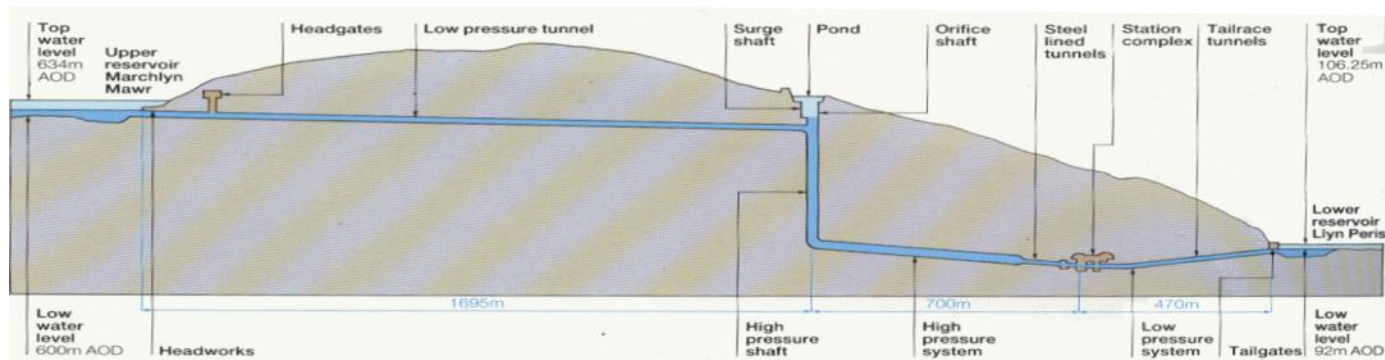
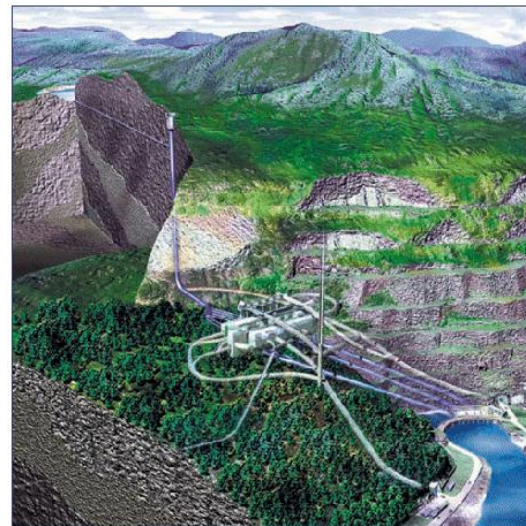




Electricity Generation

HYDRO-ELECTRIC – PUMPED STORAGE

- Used to meet peak demands (peak lopping)
- Head of water pumped back electrically when demand is low and electricity is cheap
- Fast response
- E.g. 1740MW Station, Dinorwig, Wales
 - 6 pump/generator sets
 - 1740MW generation (typically 5 hours/day)
 - 1650MW pumping (typically 7 hours/day)
 - Zero to full output in under 16s





Electricity Generation

WIND POWER



SOLAR POWER



WAVE POWER

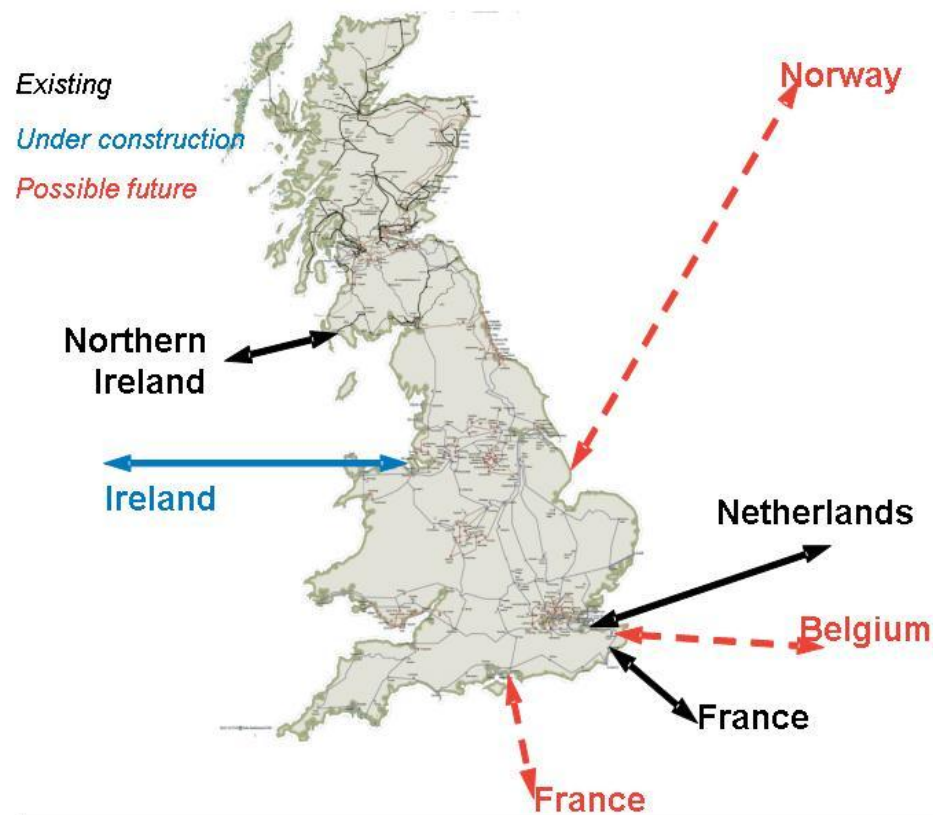


TIDAL POWER





Interconnectors



GB-Netherlands (BritNed)

- ◆ Subsea cable laid (~260km)
- ◆ Converter stations at Massvlakte and Grain constructed
- ◆ Operational beginning 2011

GB-Belgium (Nemo) ~ currently 2019

- ◆ 1000 MW, 150km sub sea cable
- ◆ Connection secured in GB and Belgium

GB-France (IFA2) ~ currently 2018

- ◆ 1,000MW, 170km sub sea cable
- ◆ Feasibility stage

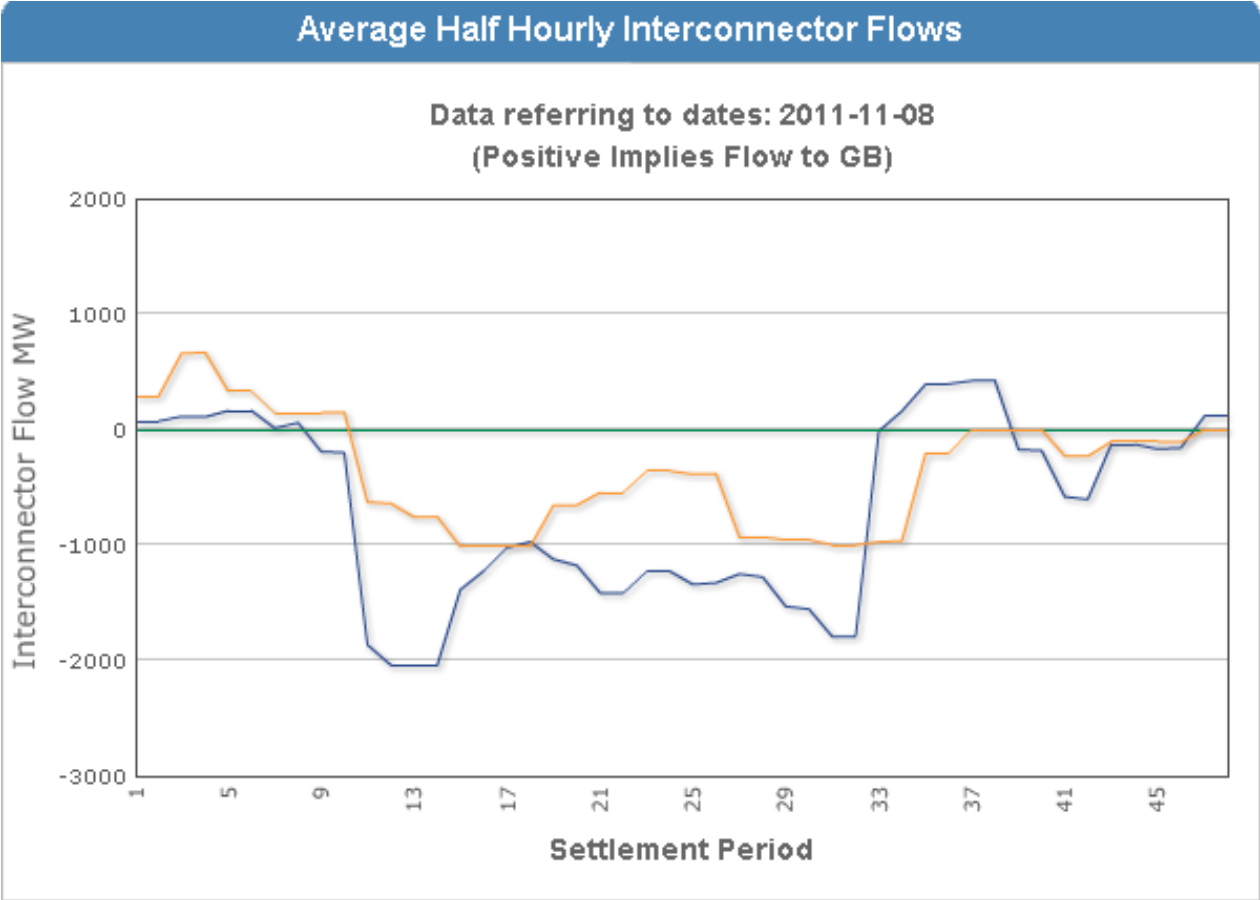
GB-Norway (NSN) ~ currently 2018/2020

- ◆ 1,000MW, 850km sub sea cable
- ◆ Connection secured in Norway

...security of supply and shared resources...



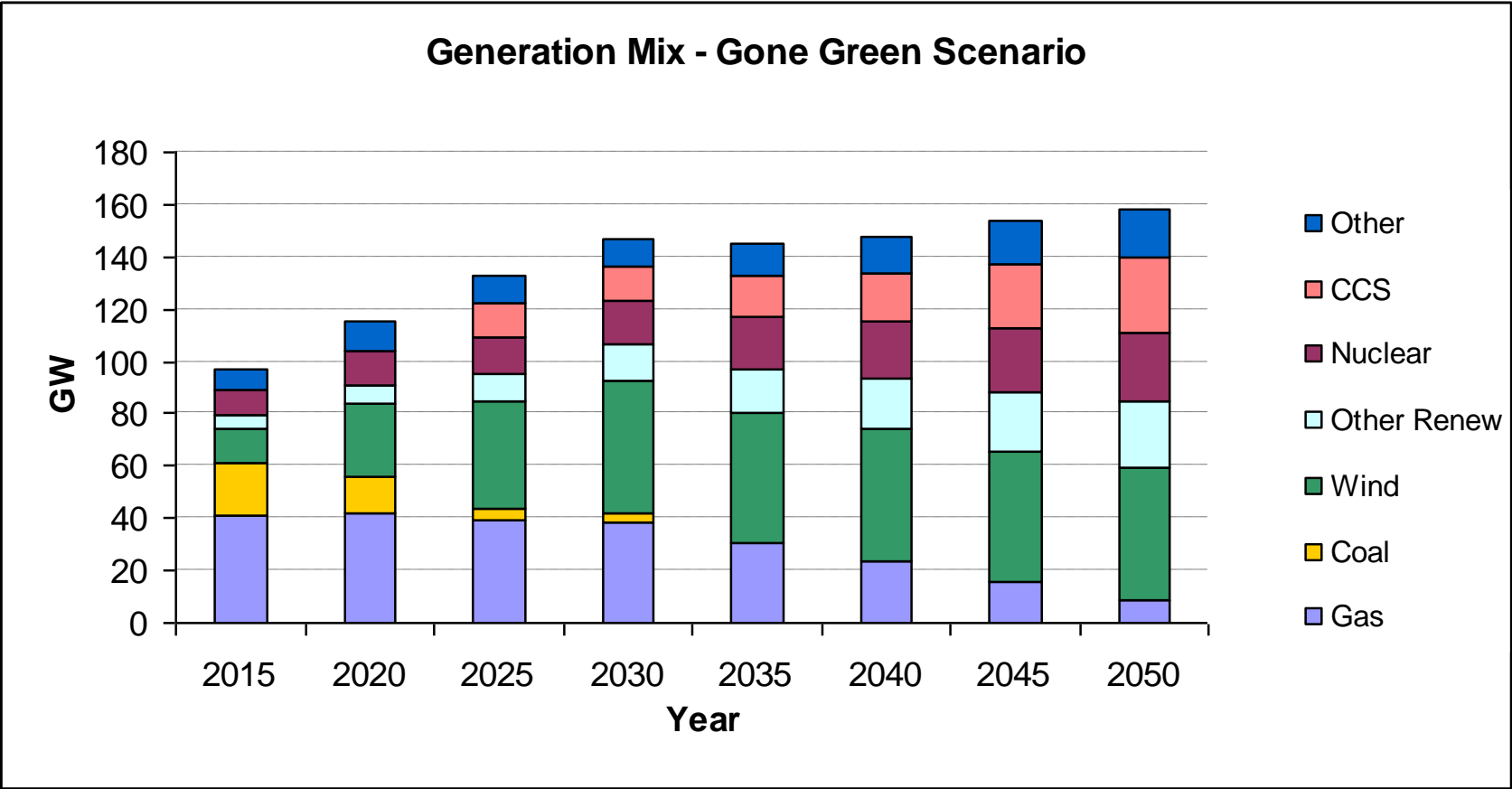
Interconnectors



☒ French Interconnector ☒ Irish Interconnector (Moyle) ☒ Dutch Interconnector



Electricity Generation - Projections



Source: National Grid



Frequency variation

- National Grid has statutory obligation to keep frequency within $\pm 1\%$ of 50Hz
- Affects the efficiency and performance of electrical equipment
- Mechanical power = Electrical Power (frequency = 50 Hz)
- Mechanical power > Electrical Power (frequency > 50 Hz)
- Mechanical power < Electrical Power (frequency < 50 Hz)





Frequency



50.0 Hz



Generation



Demand

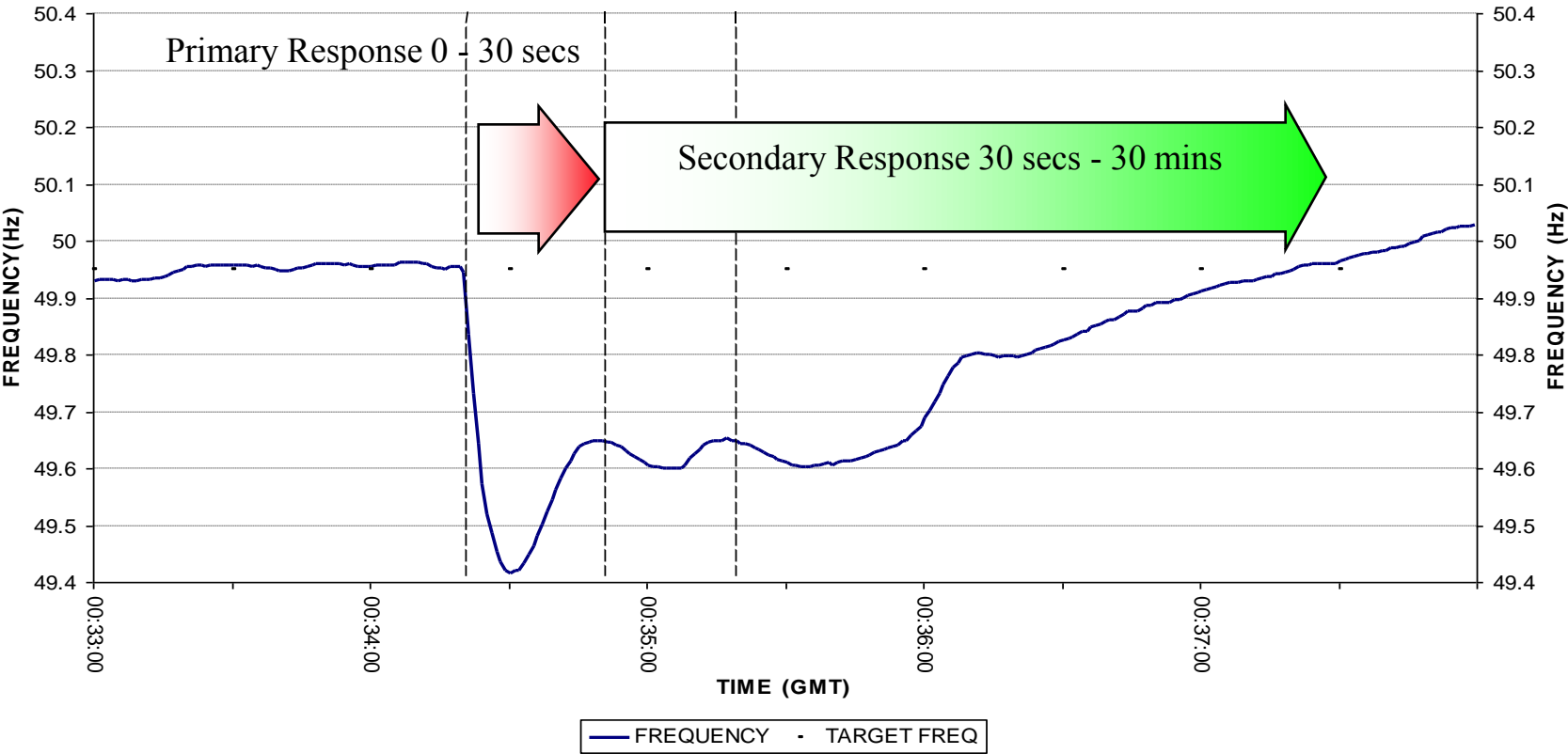
- 50.0 Normal operating frequency
- 50.5 Upper statutory limit
- 52.0 Generators tripping
- 49.5 Lower statutory limit
- 48.8 Demand disconnection starts
- 47.0 Demand disconnection complete

Slide courtesy of National Grid



Frequency

Frequency Trace, 26-May-2003



Source: National Grid



Effects of weather

Weather Effect



Temperature

(1° C fall in **freezing** conditions)



Wind

(10 mph rise in **freezing** conditions)



Cloud cover

(clear sky to thick cloud)



Precipitation

(no rain to heavy rain)



Temperature

(1° C rise in **hot** conditions)

Demand Response

+ 1%

+2%

+3%

+2%

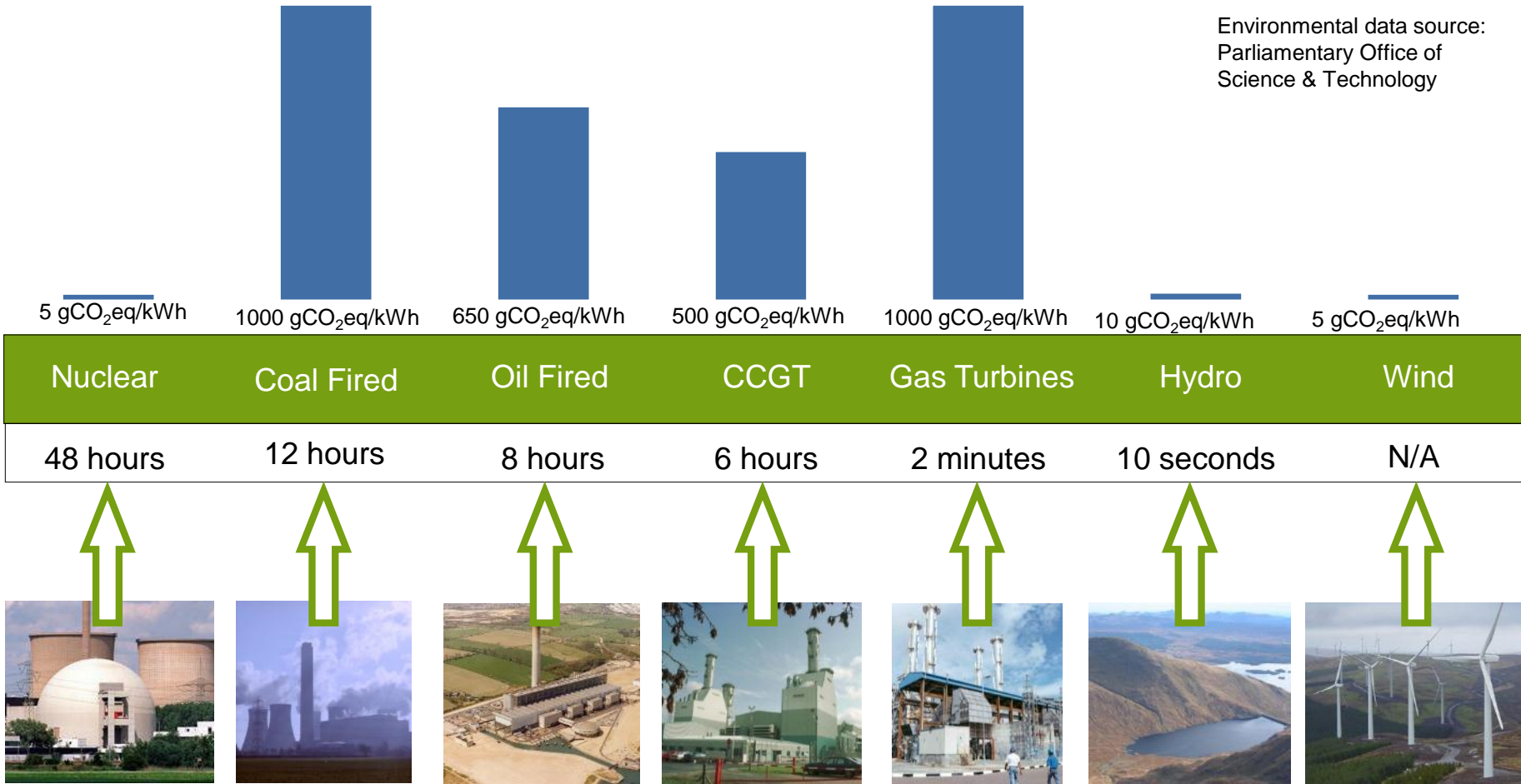
+1%

Generating Units (500MW)





Forward planning



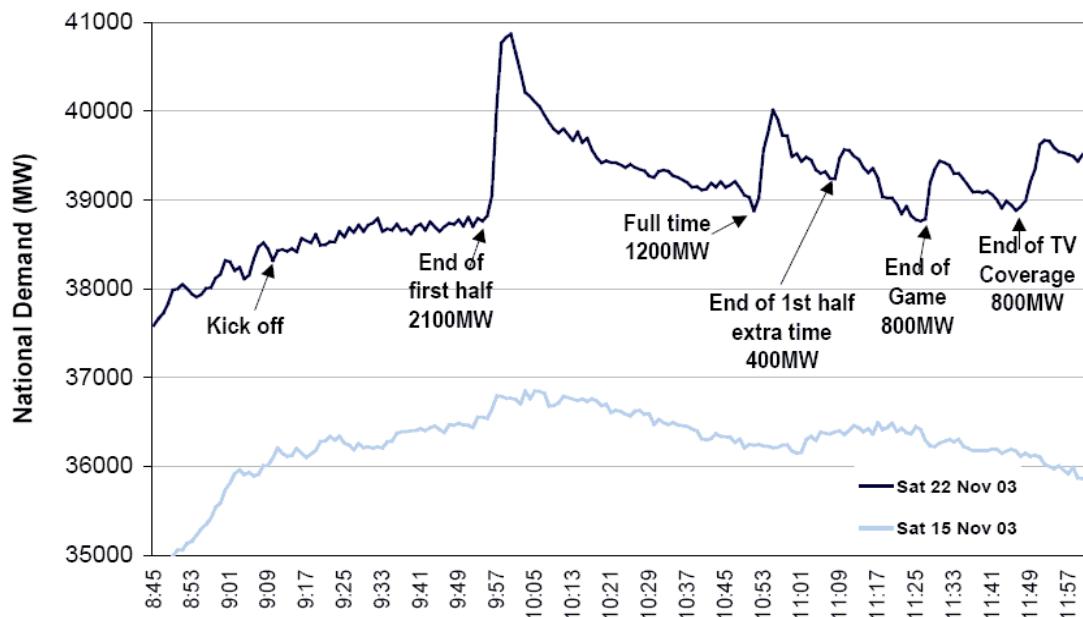


E-Futures

Electricity Demand

TV PICKUPS

- Peaks caused by kettles, toilet flushing (water pumps) in intervals and end of programmes
- National Grid spend significant effort in monitoring TV schedules and weather to try and predict future demand.



England vs Australia Rugby World Cup Final (22/11/2003)

4/7/1990,	World Cup Semi-final (West Germany v England)	2,800MW
22/1/1984,	The Thornbirds,	2,600MW
21/6/2002	World Cup (England v Brazil),	2,570MW
29/4/2011	Wedding of Prince William and Kate Middleton	2,400MW
12/6/2002,	World Cup (Nigeria v England)	2,340MW
5/6/2001	Eastenders (Who shot Phil Mitchell?)	2,290MW
8/5/1985	Dallas (Who shot JR?)	2,290MW
20/4/1991	Darling Buds of May	2,200MW
22/11/2003	Rugby World Cup Final	2,110MW
18/4/1994	Coronation Street	2,100MW

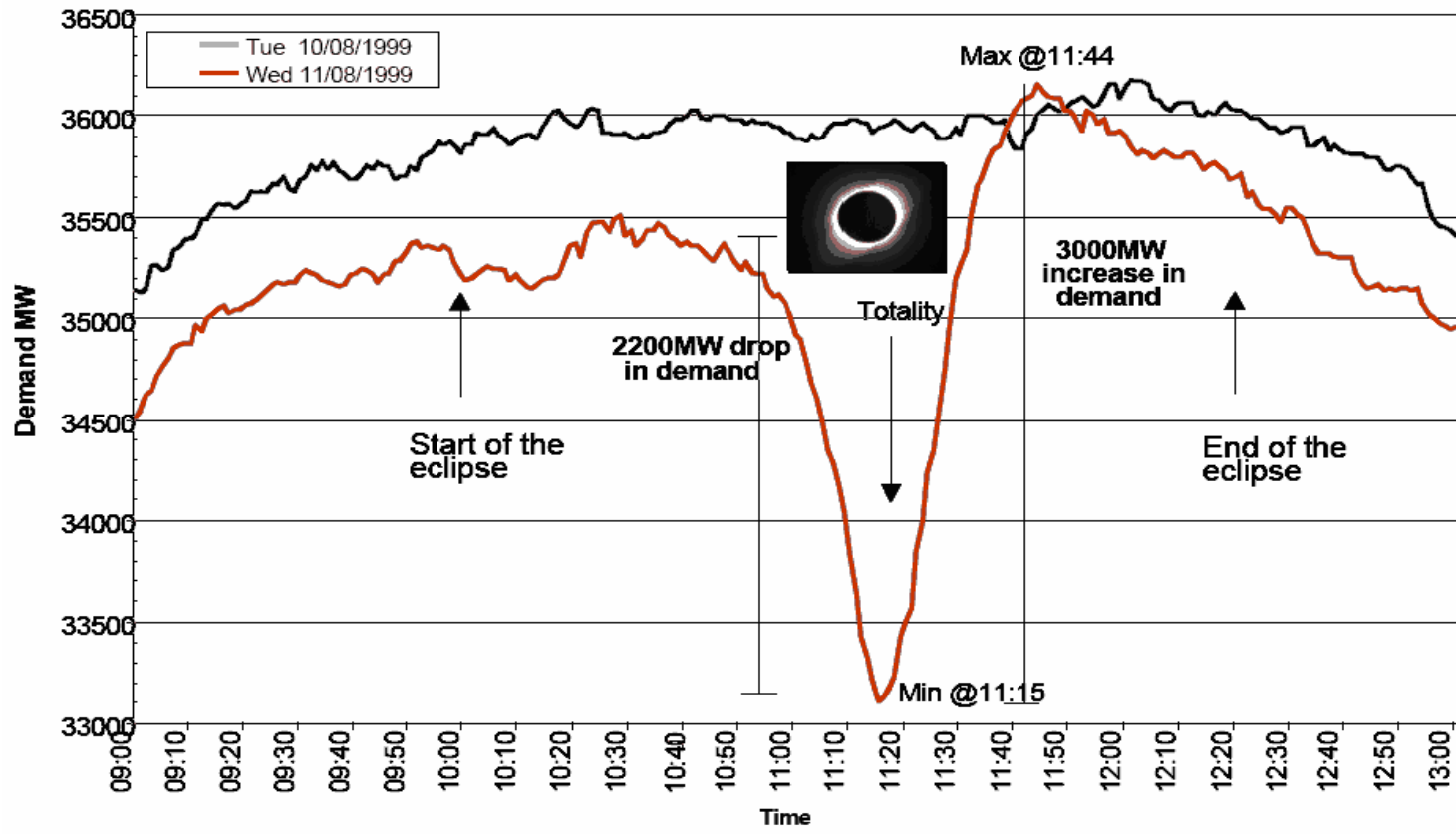
Top 10 TV Pickups



Electricity Demand

UNUSUAL EVENTS

- Solar Eclipse 11th AUGUST 1999 – 3000MW Pickup following eclipse





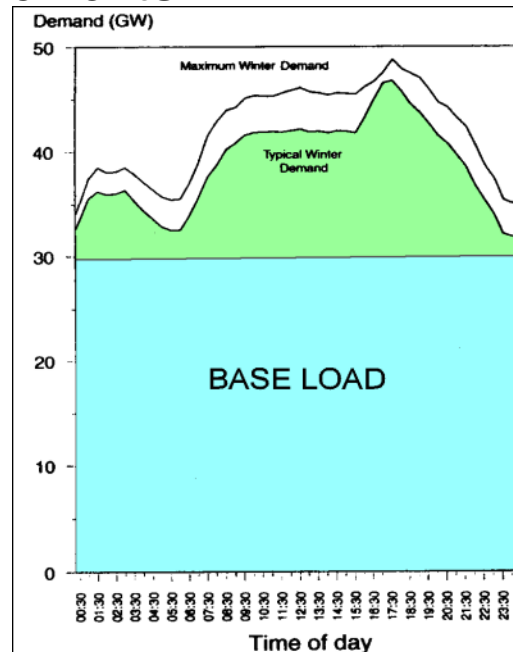
Electricity Demand

BASE LOAD

- To cope with demand changes, a base load is defined - provided by high efficiency power stations
- Minimum amount of power that a distribution company must make available for its customers, or amount of power required to meet minimum demands based on reasonable expectations of customer requirements
 - Fast response generators kept in reserve to deal with peak loads
 - Peak power is expensive as generators are idle for most of the time
 - Proportion of Generators are operated $\approx 75\%$ load to allow overhead for peak demands and/or compensate for faulted generators
 - Pumped storage hydro also used for peak demands

In addition to meeting demand it is crucial that voltage and frequency maintained

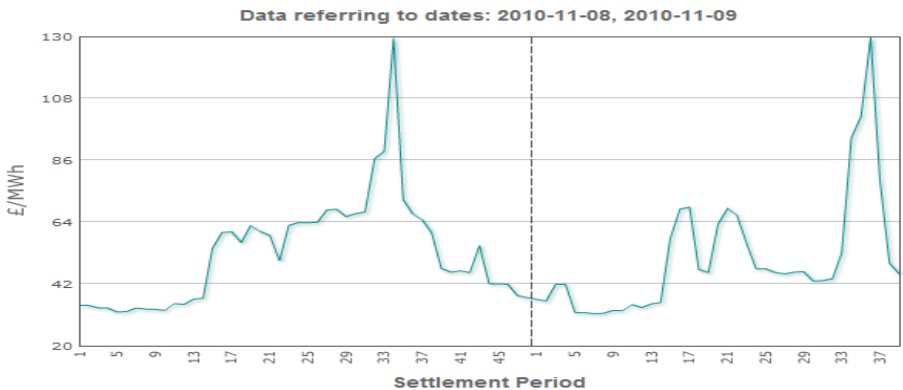
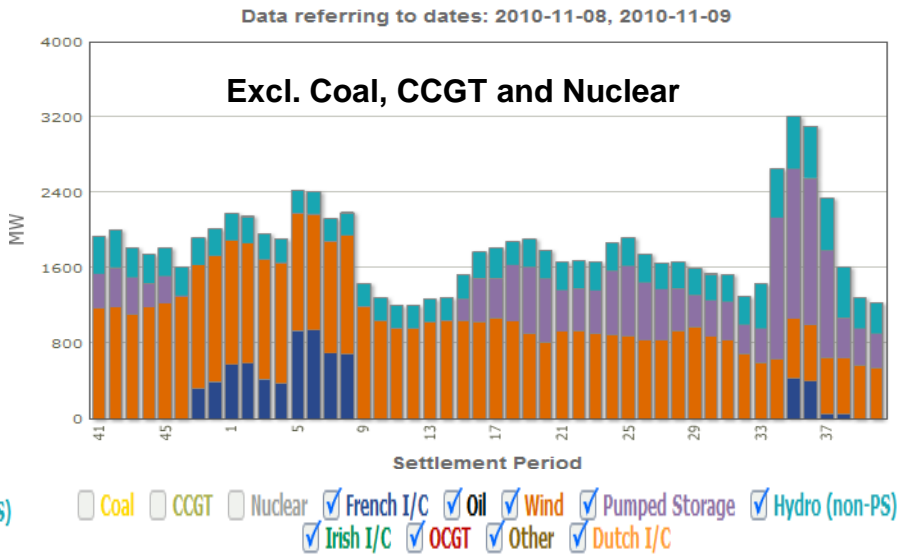
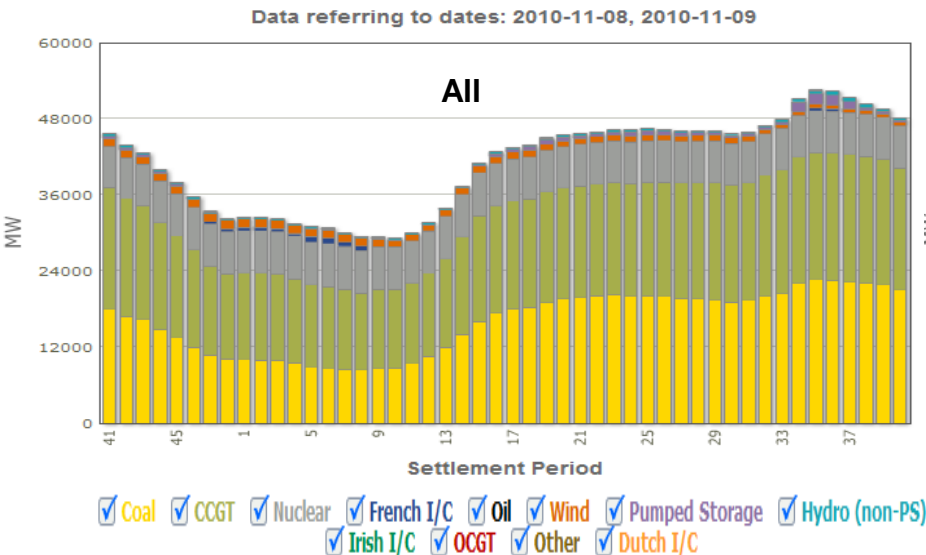
Domestic Voltage: $230V \pm 10\%$ 50Hz $\pm 1\%$





Electricity Generation

Electrical generation by type of plant



Wholesale cost of electricity

http://www.bmreports.com/bsp/bsp_home.htm