Generating the Future:
last gasp or second wind for the various technology options

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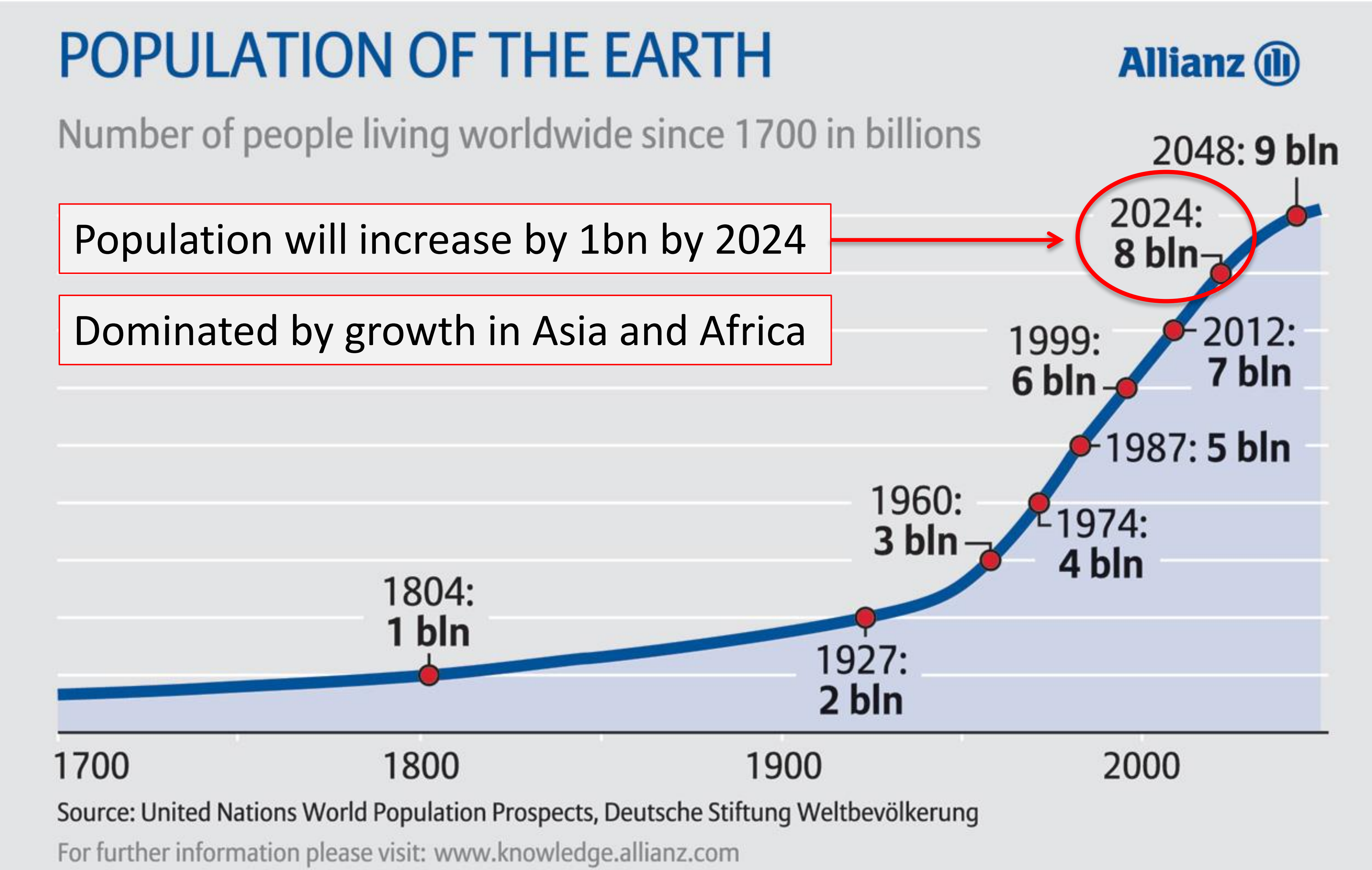
University of Bath I-SEE
April 2014


3002
PAVEMENT
© Bubbles

Contrasting Access to Energy

Contrasting Access to Energy

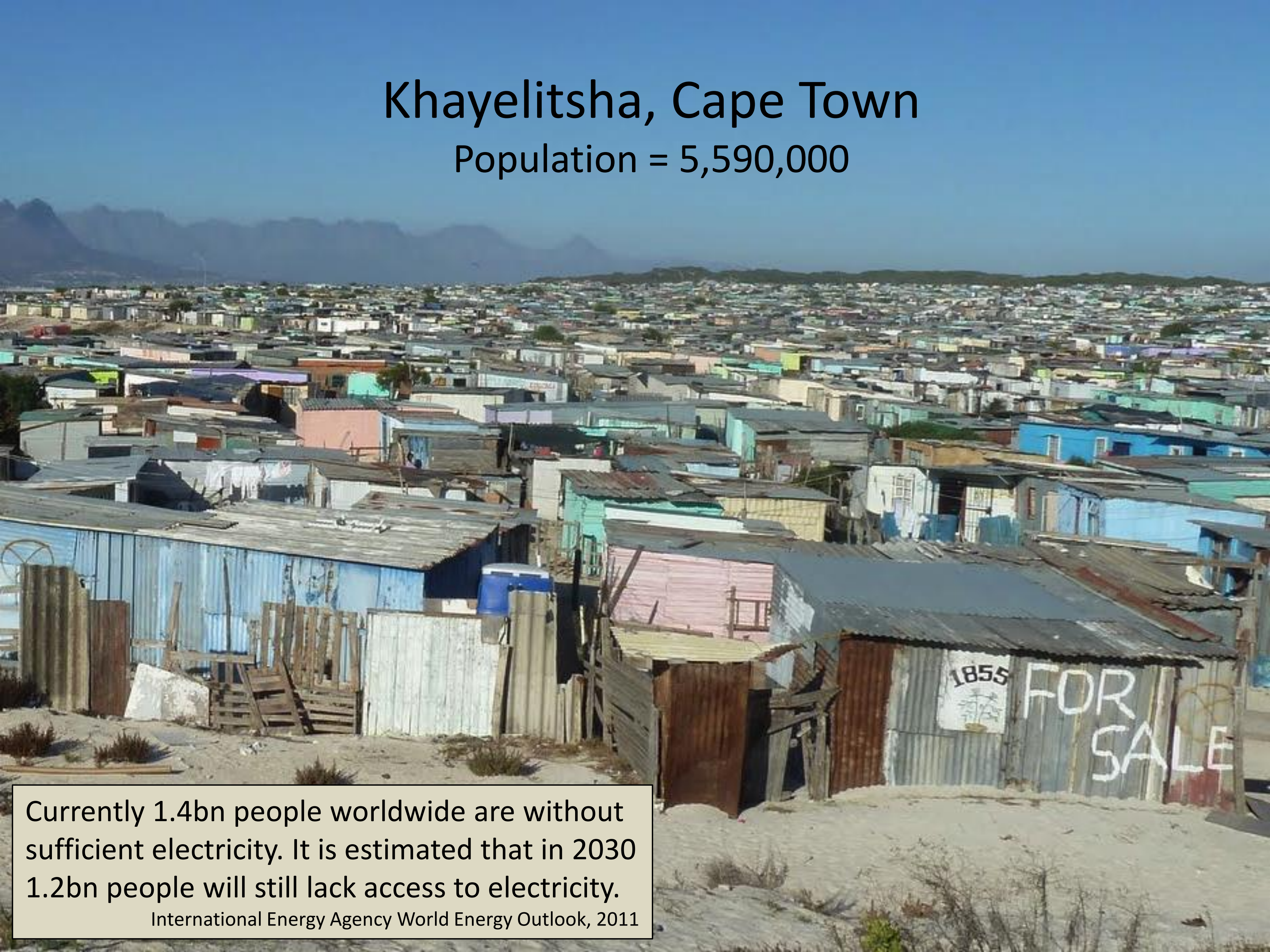


POPULATION OF THE EARTH
Allianz
Number of people living worldwide since 1700 in billions
Population will increase by 1bn by 2024
Dominated by growth in Asia and Africa
2048: 9 bln
2024: 8 bln
2012: 7 bln
1999: 6 bln
1987: 5 bln
1974: 4 bln
1960: 3 bln
1927: 2 bln
1804: 1 bln
1700
1800
1900
2000
Source: United Nations World Population Prospects, Deutsche Stiftung Weltbevölkerung
For further information please visit: www.knowledge.allianz.com


Manchester census 2011
Population = 503,100
1bn ≅ 2,000 cities the size of Manchester

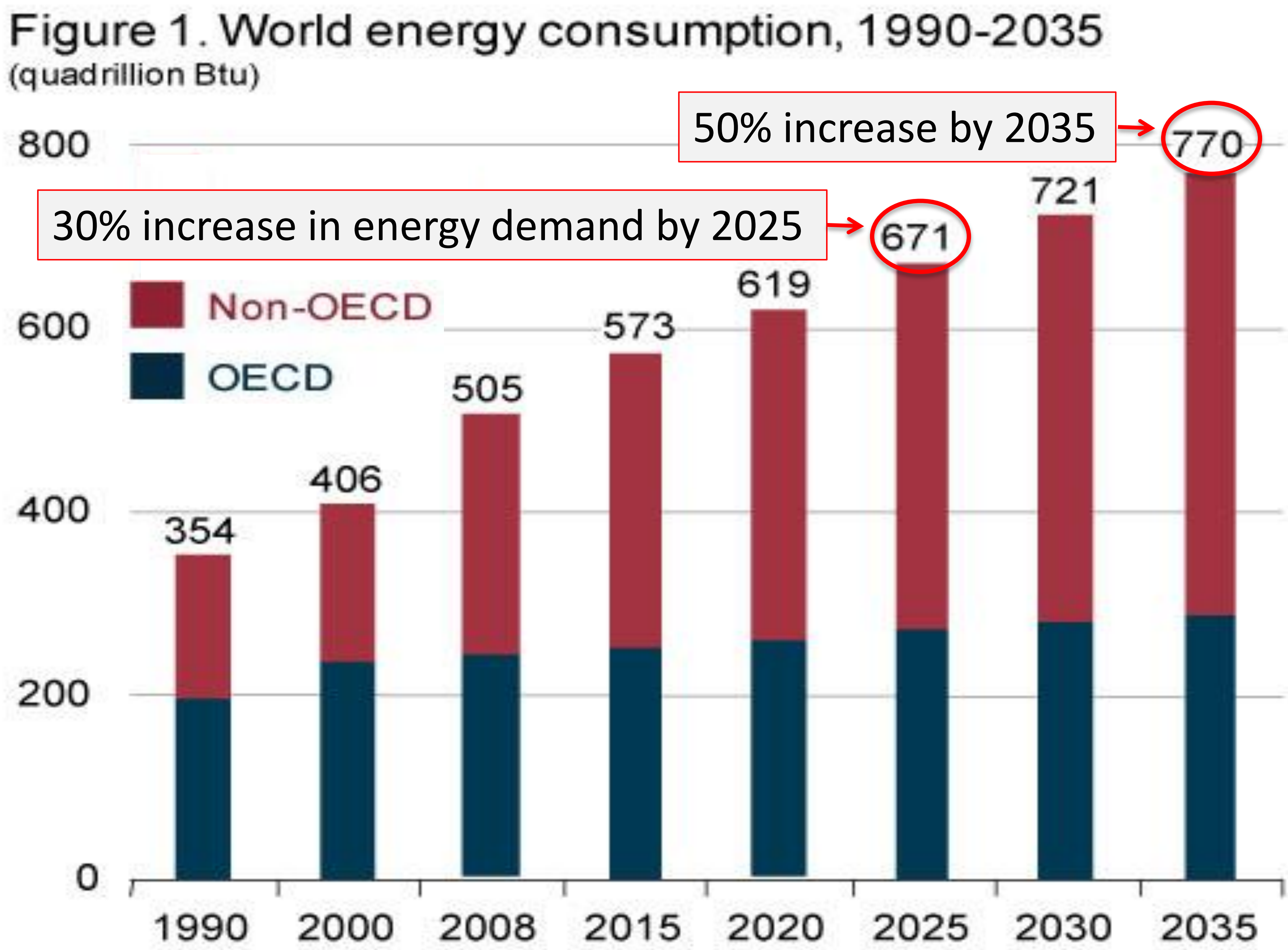
Khayelitsha, Cape Town

Population = 5,590,000

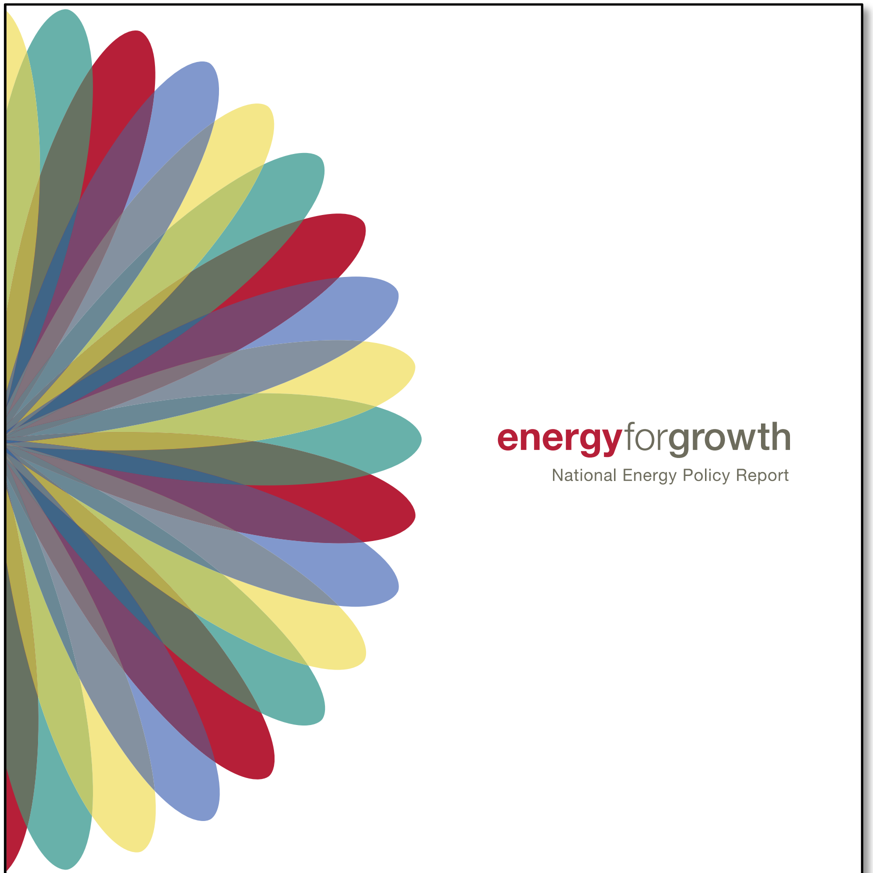


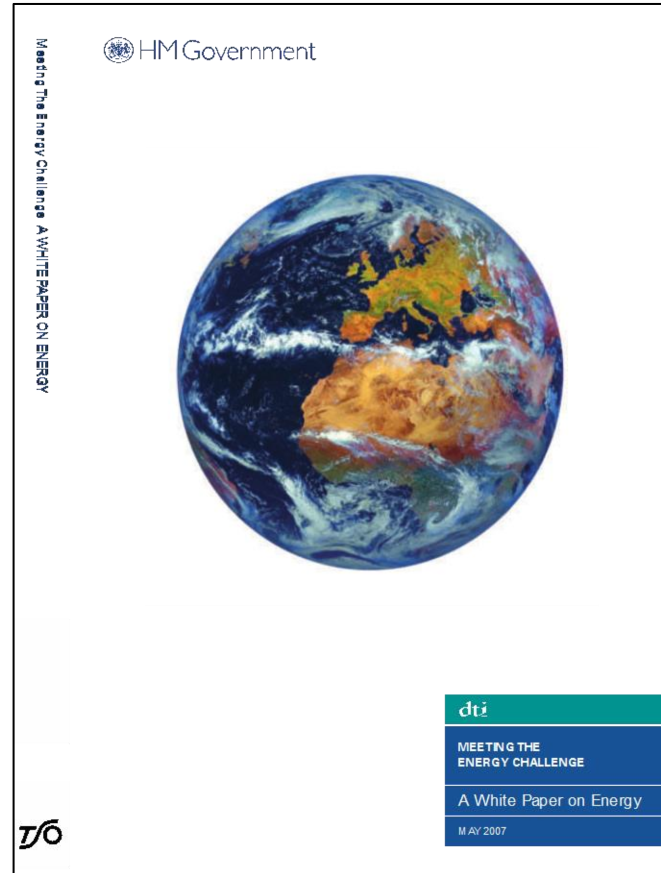
Currently 1.4bn people worldwide are without sufficient electricity. It is estimated that in 2030 1.2bn people will still lack access to electricity.

International Energy Agency World Energy Outlook, 2011



Source – IEA World Energy





Low Carbon

Affordable

Secure

Efficient

The Science Challenge

- Stabilise atmospheric CO_2 at 450 - 500ppm by 2050
- UK legislation to reduce carbon by 80%by 2050
- Migrating to a Low-Carbon economy through a series of carbon budgets

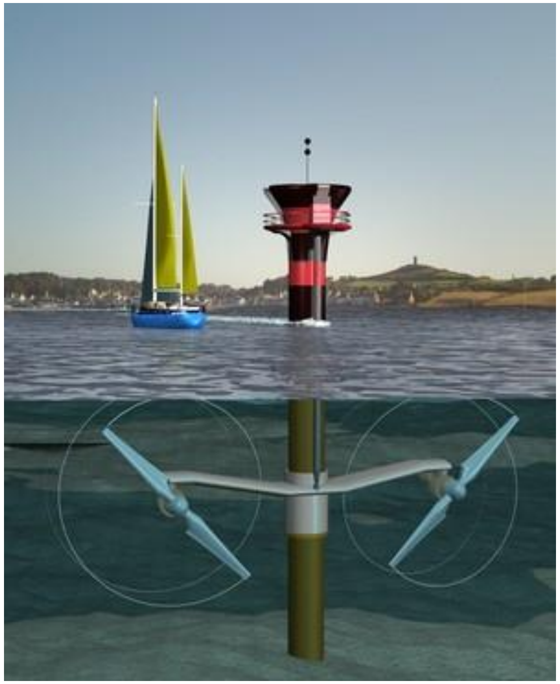
The Engineering Solution

- Did anyone in Government check out whether it was deliverable??!!

Earth
Air
Fire
Water

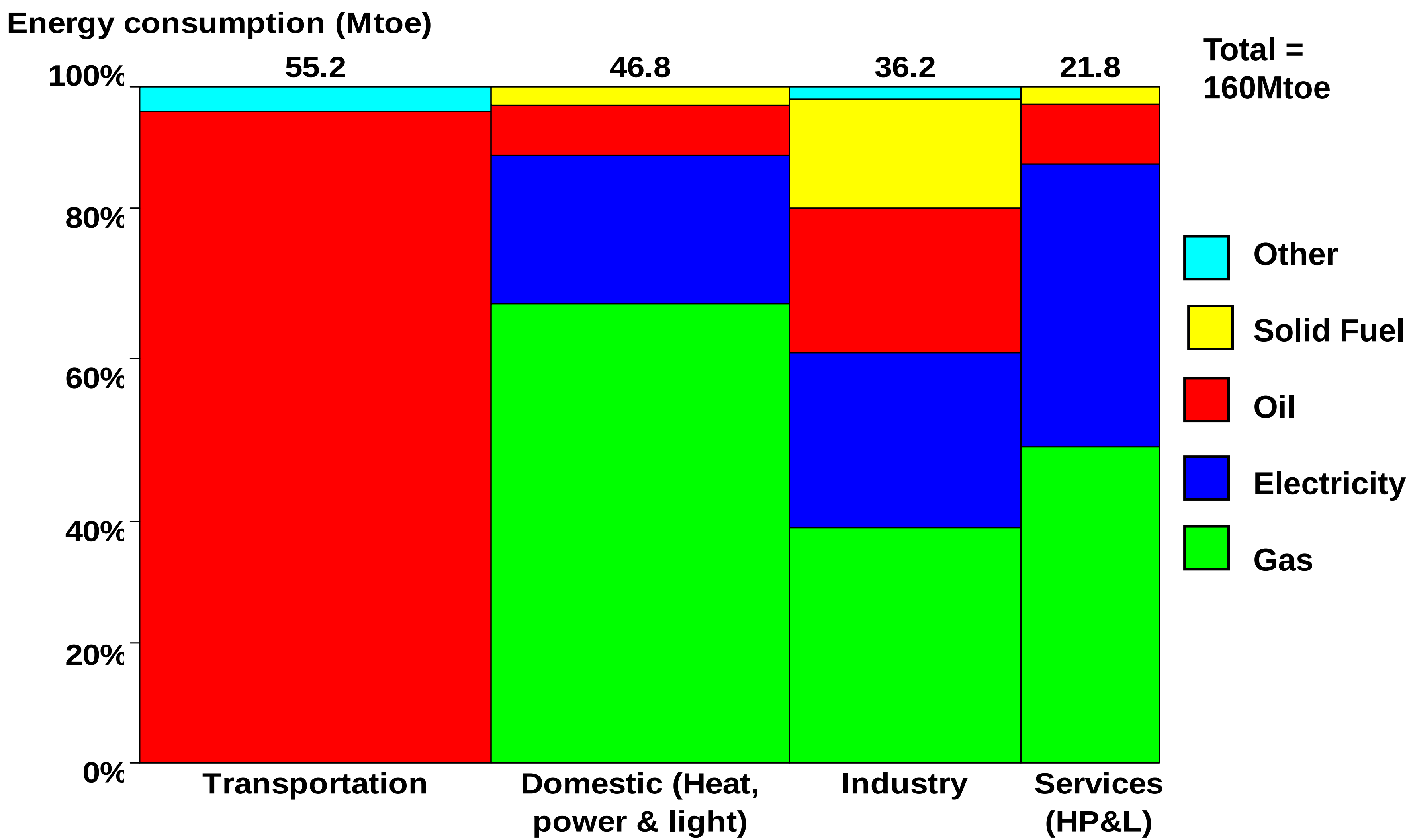




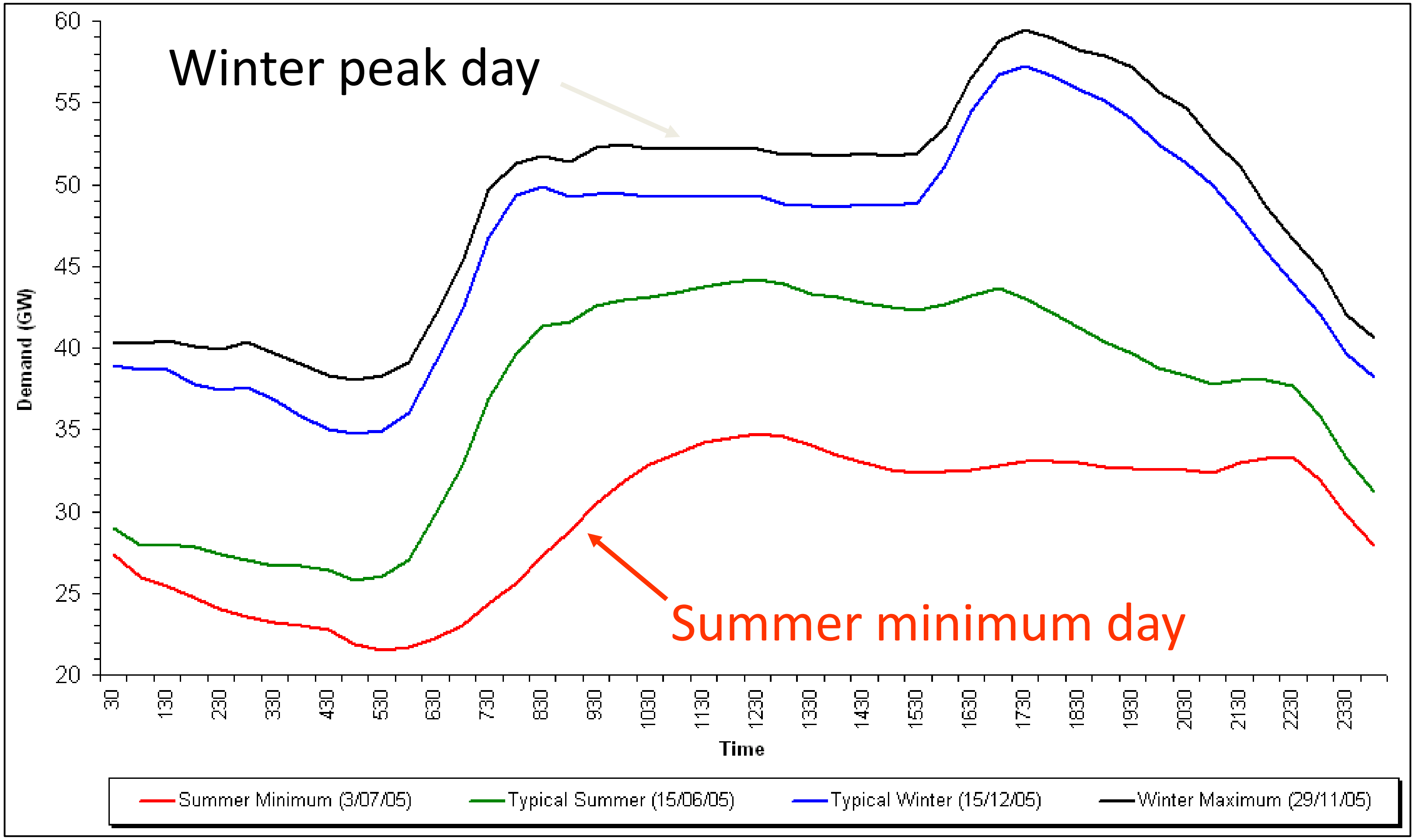



Nuclear, Wind, Biomass, Hydro, Marine, Solar

Breakdown of UK Energy Demand



Electricity Demand Varies

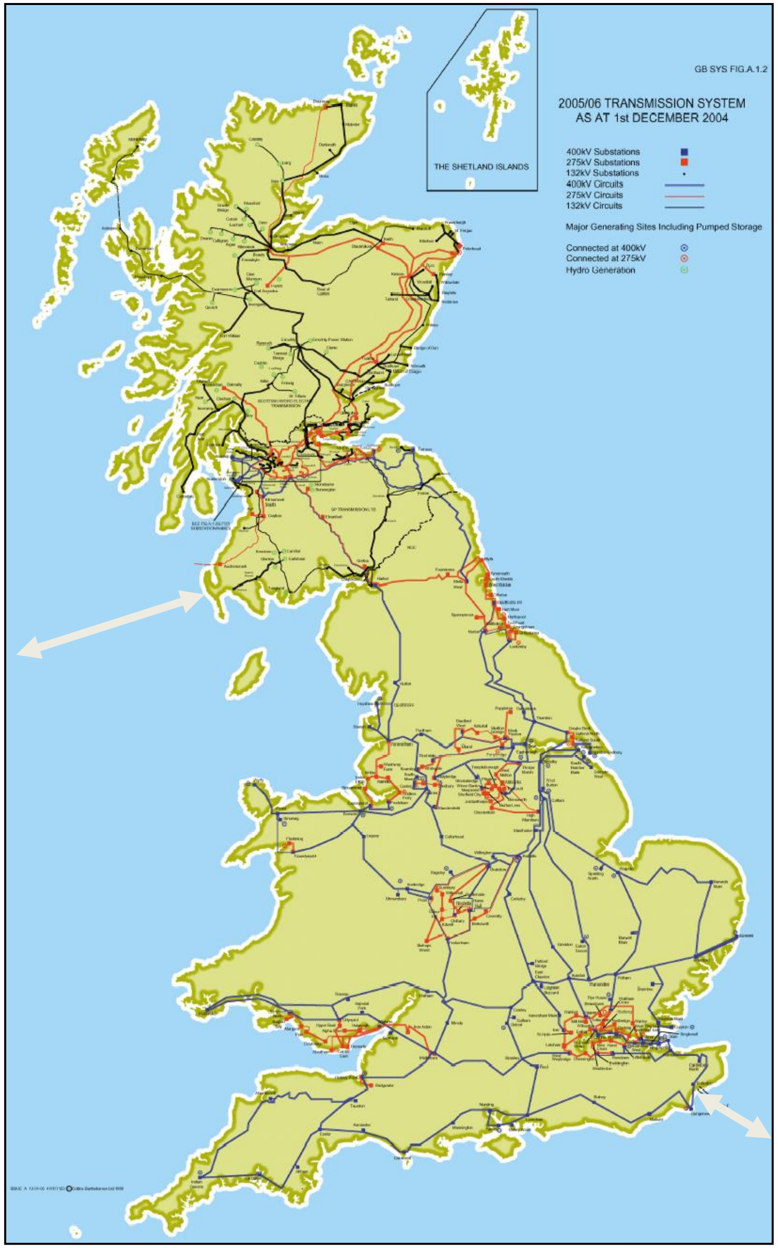


Source: National Grid 7-year Statement 2006 (GB demand)

Energy Sources for UK electricity 7 Dec 2010 1800hrs (very similar situation on our coldest day last year)

• CCGT (gas)	23559MW	39.8%
• Coal	22511MW	38.1%
• Nuclear	7804MW	13.2%
• Interconnect with France	1000MW	1.7%
• Pumped storage	1824MW	3.1%
• Oil	1695MW	2.9%
• Hydro	461MW	0.8%
• OCGT	149MW	0.3%
• Wind	152MW	0.3%
Total	**59155MW**	

A Single Network

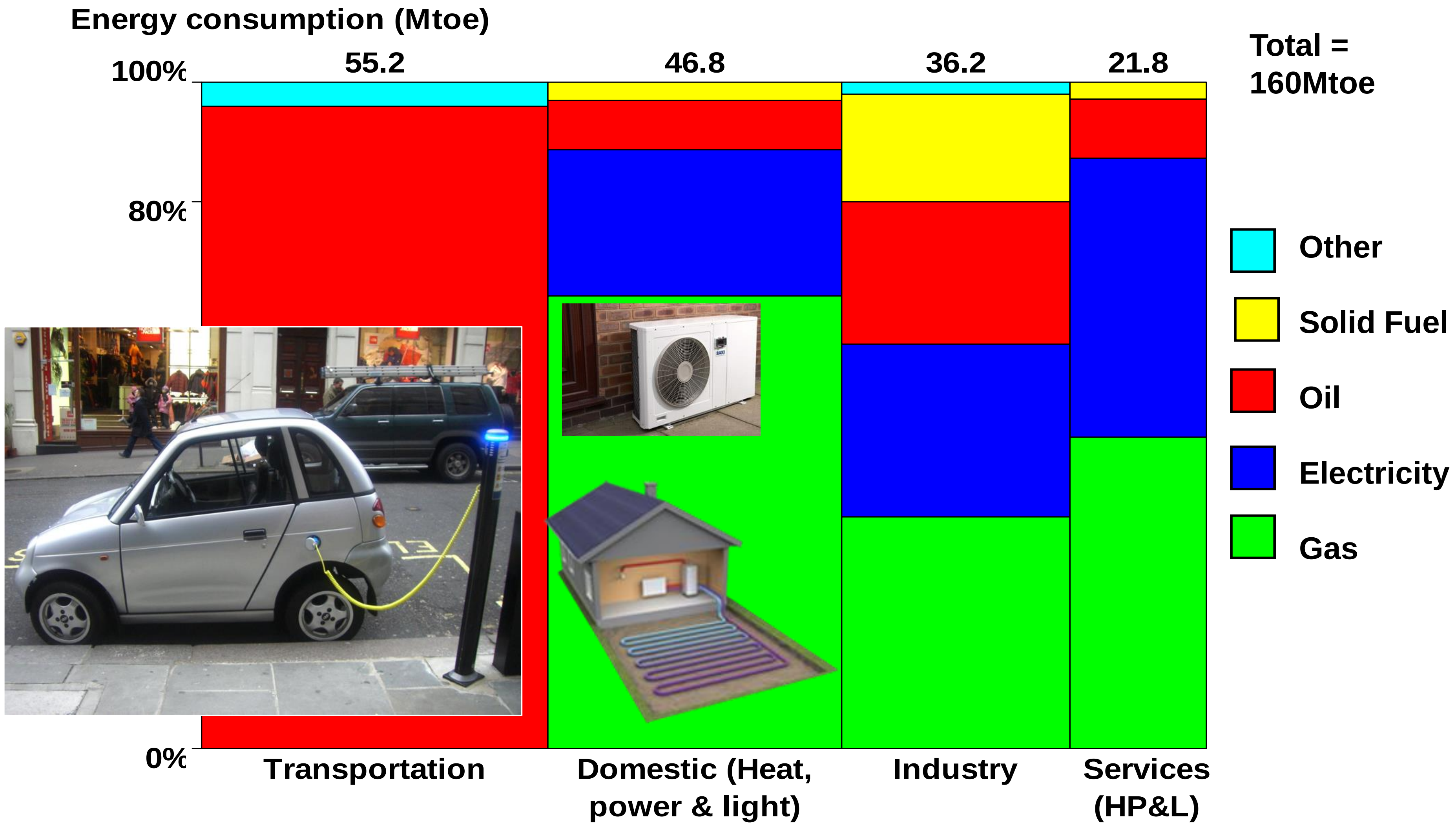


Link to Northern Ireland (500MW)

Many Companies!

Link to France (2000MW)

Breakdown of UK Energy Demand



Generating the Future and Electric Vehicles

What we need to meet 2050 targets

	Electricity Generated	What you need to build
Onshore wind	6.5 GW(av)	24GW (Installed)
Offshore Wind	11.4	38
Solar Voltaics	7.2	72
Wave	3.8	9.4
Tidal Stream	1.4	2.8
Tidal Barage	2.0	8.5
Hydro	0.9	2.3
Total	**33.2**	**157**

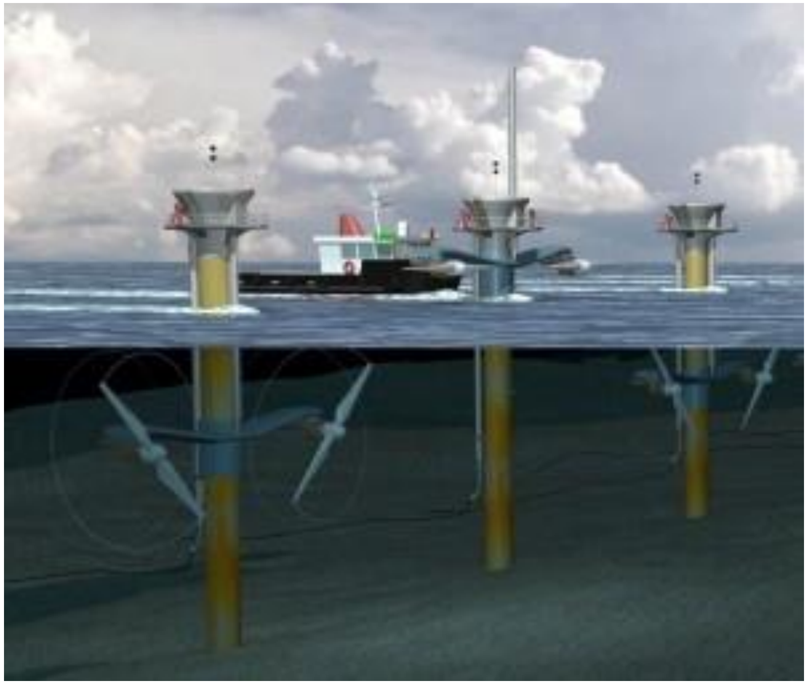
What we need in physical assets

Onshore wind	9600 2.5MW turbines
Offshore Wind	38 London Arrays
Solar Voltaics	25million 3.2kw solar panels
Wave	1000 miles of Pelamis m/c
Tidal Stream	2300 SeaGen Turbines
Tidal Barage	1 Severn Barage
Hydro	1000 hydro schemes

1000 miles Pelamis machine

(3 miles a month for the next 40yrs:
a London tube train a day)

2500 Sea Gen Marine Turbines



Newport
Cardiff
Severn Estuary
Bristol Channel
Weston-super-mare
SEVERN TIDAL POWER BARRAGE
M5
N

25million
Solar panels

9600 2.5MW turbines

Offshore
Wind
38
London
Arrays

Walney Wind Farm

102 turbines

367 MW

73km²

(London array:
175 turbines, 245km², 630MW)

What we need

Onshore wind	9600 2.5MW turbines
Offshore Wind	38 London Arrays
Solar Voltaics	25million 3.2kw solar panels
Wave	1000 miles of Pelamis m/c
Tidal Stream	2300 SeaGen Turbines
Tidal Barage	1 Severn Barage
Hydro	1000 hydro schemes
Nuclear/CCS	**80 new power plants**
Demand reduction	**At least 30%**

No Silver Bullets

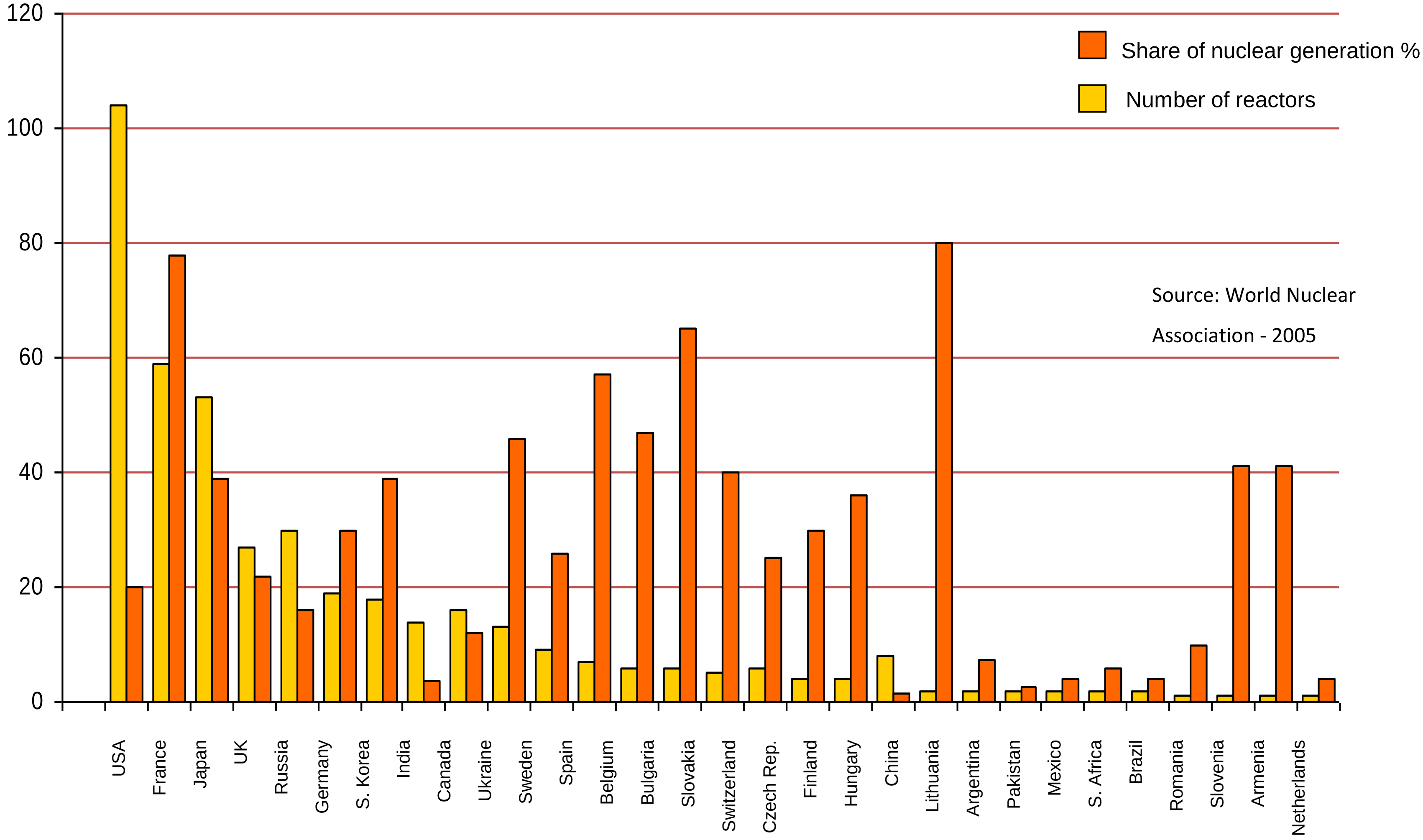
- Demand reductions across all sectors of the economy will be essential through a combination of increased efficiency and behavioural change
- Full suite of low carbon energy supply technologies needed including nuclear and fossil with carbon capture and sequestration

Nuclear Fission Around the World

- 435 plants in operation, in 31 countries
- Providing 14% of the world's power
- 60 being built in 13 countries notably China, South Korea and Russia
- 137 on order or planned
- A further 295 proposed
- Major steps being taken in the US, France, and elsewhere
- Significant further capacity being created by plant upgrading. Plant Life Extensions maintaining capacity

Source: World Nuclear Association & IAEA PRIS database, as at March 2013

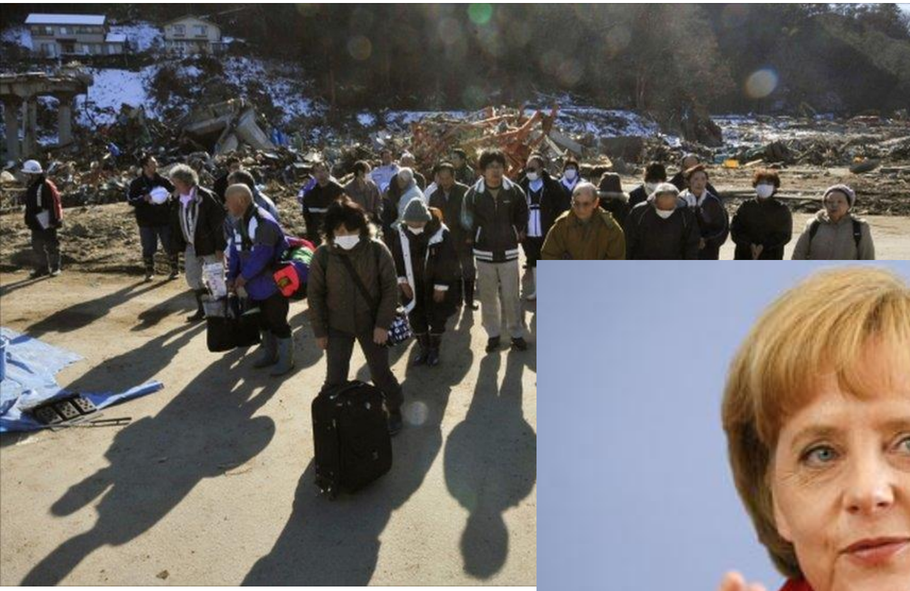
Nuclear Share of Electricity Generation



Electricity

- Nuclear energy is used to produce electricity
  - ~18% UK,
  - ~ 20% USA 103 reactors
  - ~ 75% France 58 reactors
  - ~ 32% Switzerland
  - ~ 30% Japan
  - ~ 16% Russia
  - ~ 5% Mexico
  - ~ 2.5% Brazil

  - ~16% Worldwide




REUTERS

China

- Huge energy growth 17 operating reactors
- 28 reactors under construction
- 5-6 fold growth planned by 2020 to at least 58GWe
  - 4% of electricity

  Then 200GWe by 2030 and 400 by 2050?
- NPT member, potential Asian supplier

India

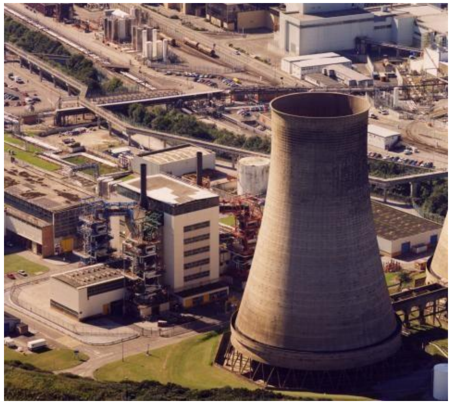
- Nuclear now 2.8% of electricity
- 20 units in operation
- 8 reactors under construction
- 20 further units planned
- 100-fold growth planned 2002-2052 (26%)
  - = 9.2% per year
  - Global growth 1970-2004 = 9.2% per year
- Not party to the NPT, but recent US-India deal

UK Nuclear Generation

Magnox
- Calder Hall

AGR Heysham

PWR
- Sizewell 'B'




You are entering a Nuclear Licensed Site
Magnox South Ltd

Oldbury

Wylfa

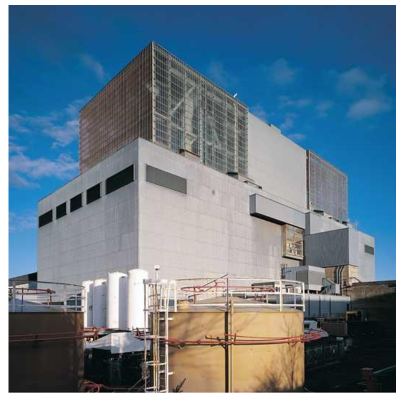
Latina Italy

Tokai Mura Japan

Hartlepool

Hinkley B

Heysham1



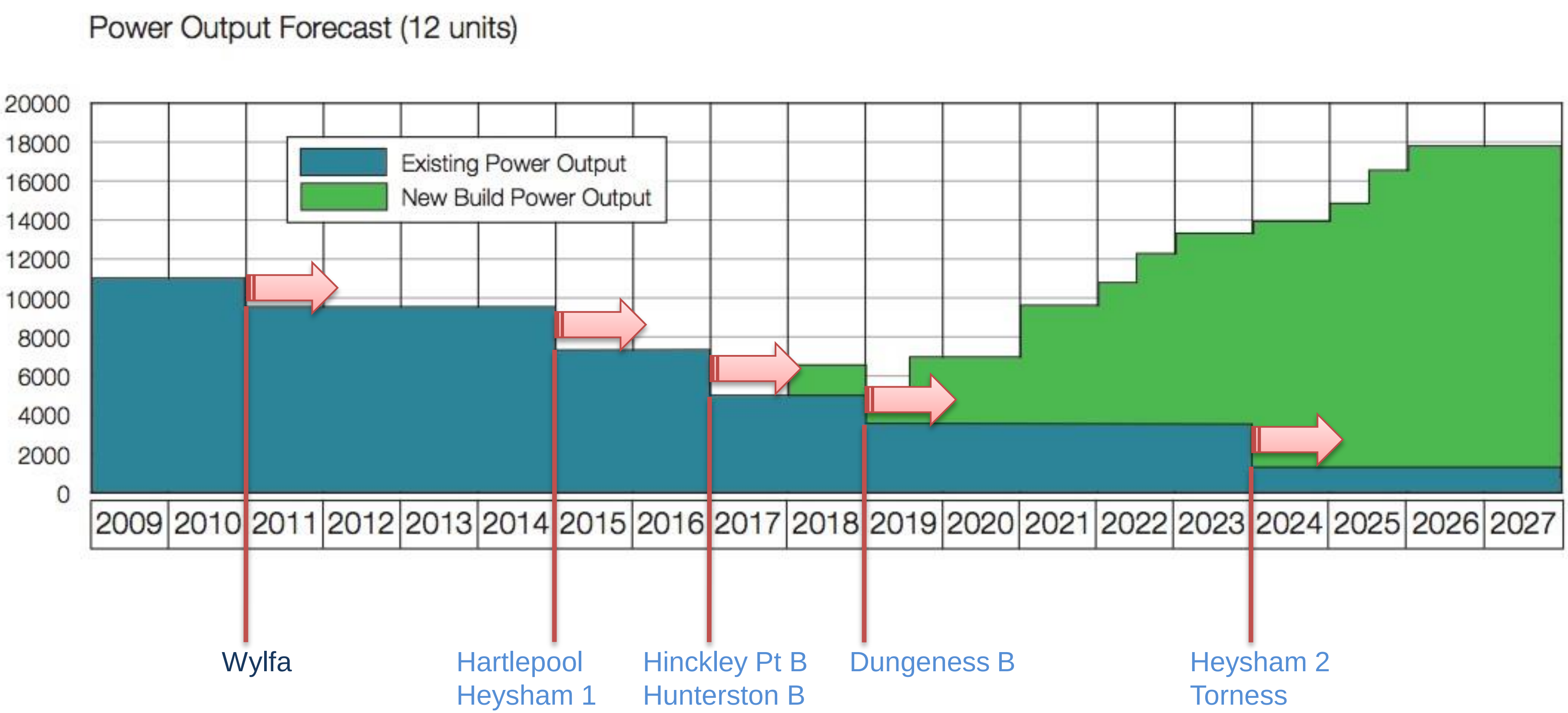
Hunterston B

Heysham 2

Dungeness

Torness

Nuclear Generating Capacity in the UK including new build



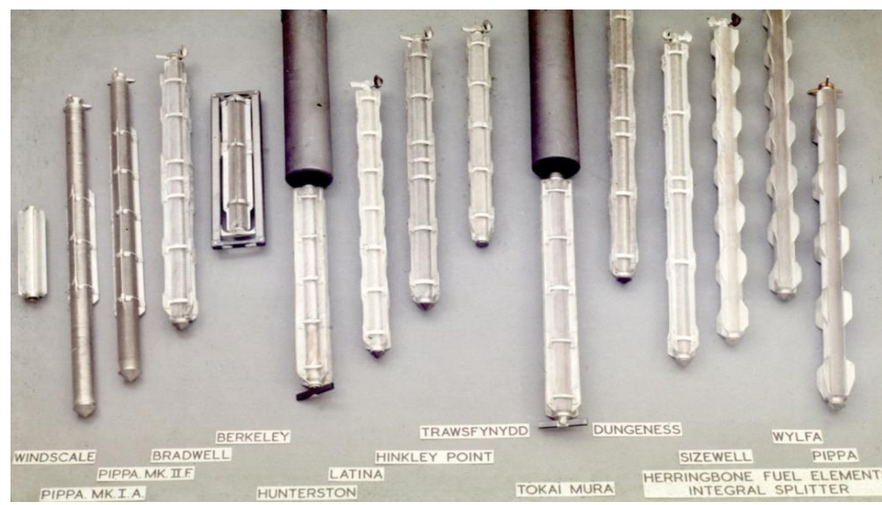
Cogent Report, “Next Generation: Skills for New Nuclear Build”, 2010

Consequences of Historic Choices

Range of Processes, Products and Wastes

The reactor programmes led to many supporting secondary programmes

- Extraction of military material in various forms
- Development of many types of reactor fuel for military & civil programmes
- Development of many aspects of reprocessing technology and reprocessing plants



The Legacy of the UK’s historic reactor and fuel cycle choices and privatisation of electricity supply

- A very large bill for clean up and decommissioning (much of it attributable to the early initial military mission)
- Low public and political confidence in the ability to ‘sort out’ and dispose of wastes safely
- Vulnerability to ‘market forces’ and events and decisions outside the UK’s control

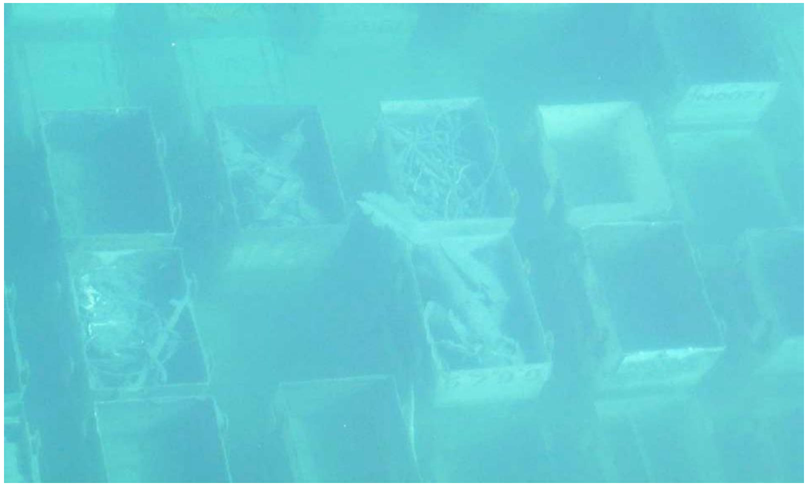
Windscale ~1960
First Generation Reprocessing and Storage Facilities

Legacy storage in Ponds and Silos

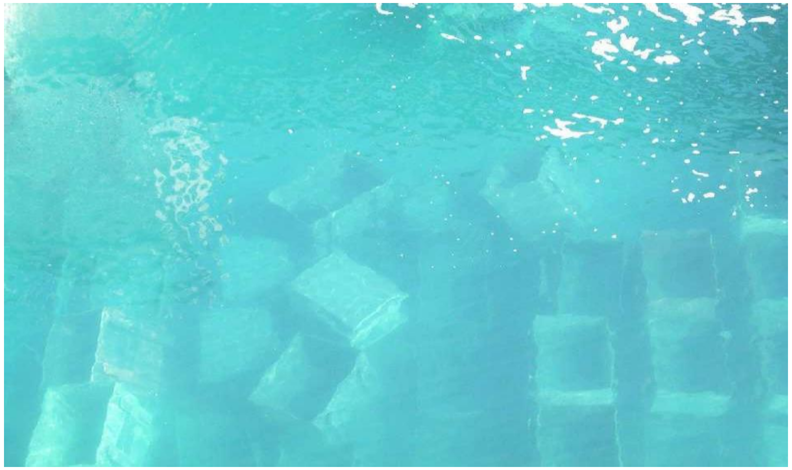
All processes generated wastes

- In early days storage of miscellaneous un-segregated fuels and experimental wastes in ponds and silos was considered adequate.On the basis that disposal methods would be developed in the near future.

- The ponds are now over 50yrs old. Fuel and cladding corrosion and the cumulative effects of operations are affecting retrieval and characterisation of wastes



Legacy Ponds

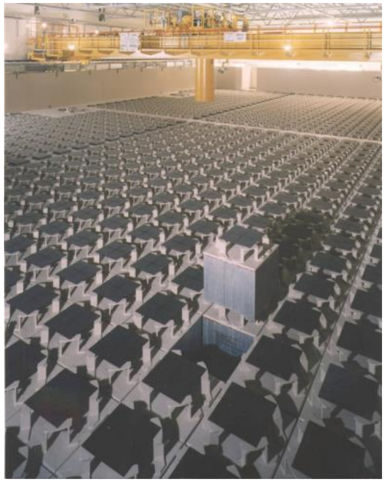


Waste treated and packaged

- New modern plants designed and constructed
- Product waste forms compatible with disposal concepts
- Waste arisings treated in “real time”

Modern Plants Supporting Reprocessing and Waste Treatment

- Since around 1980 new plants have been designed to include waste treatment and identified routes for disposal
- Wastes from new plants is being treated as it arises, and is in a condition for immediate final disposal



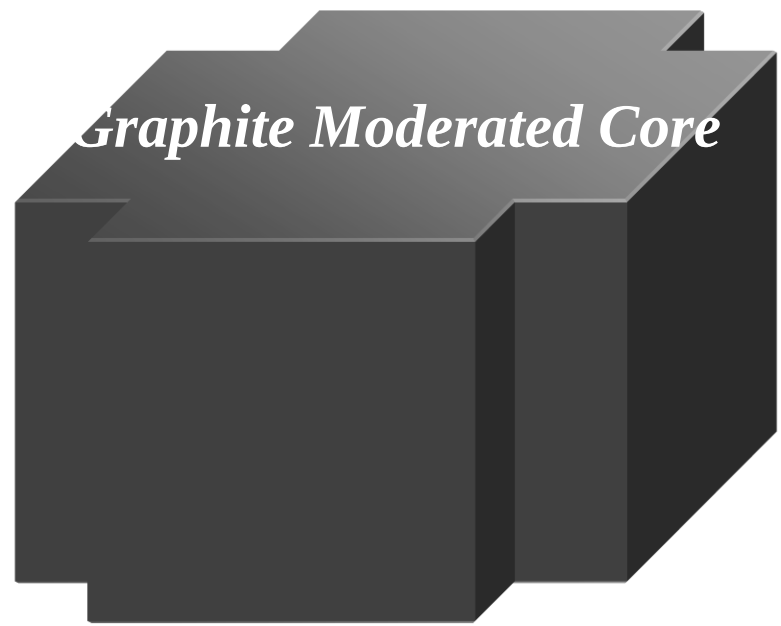
Reactor Size

- Depends on Moderator
  - **Graphite reactors very large**
  - **Water much more compact**

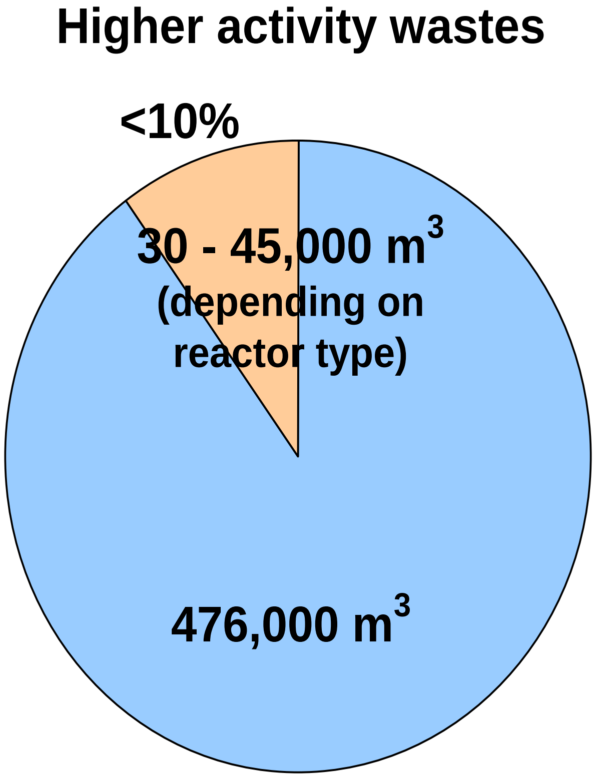
A smaller core means lower construction costs and lower decommissioning costs

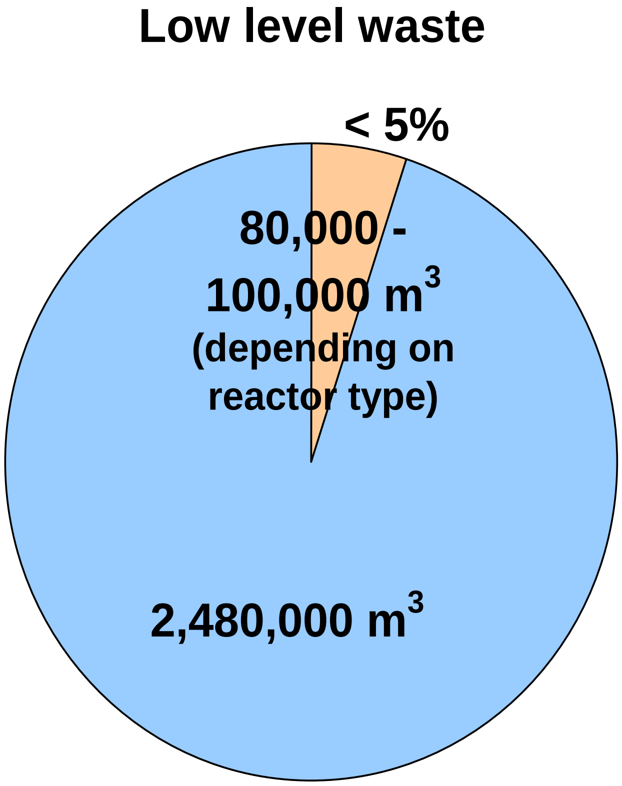
- Depends on heat removal
  - **Energy density**
  - **Temperature limits on fuel**

Water moderated core



Wastes from a new build programme would be less than 10% of the existing inventory

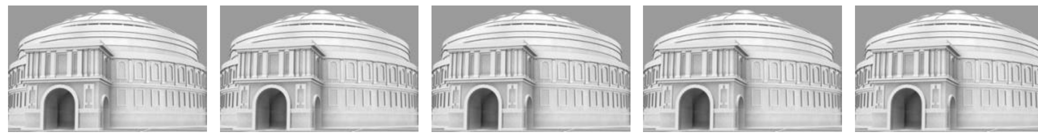
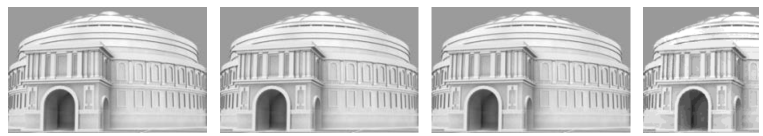
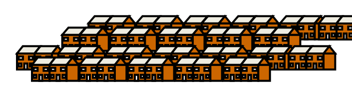


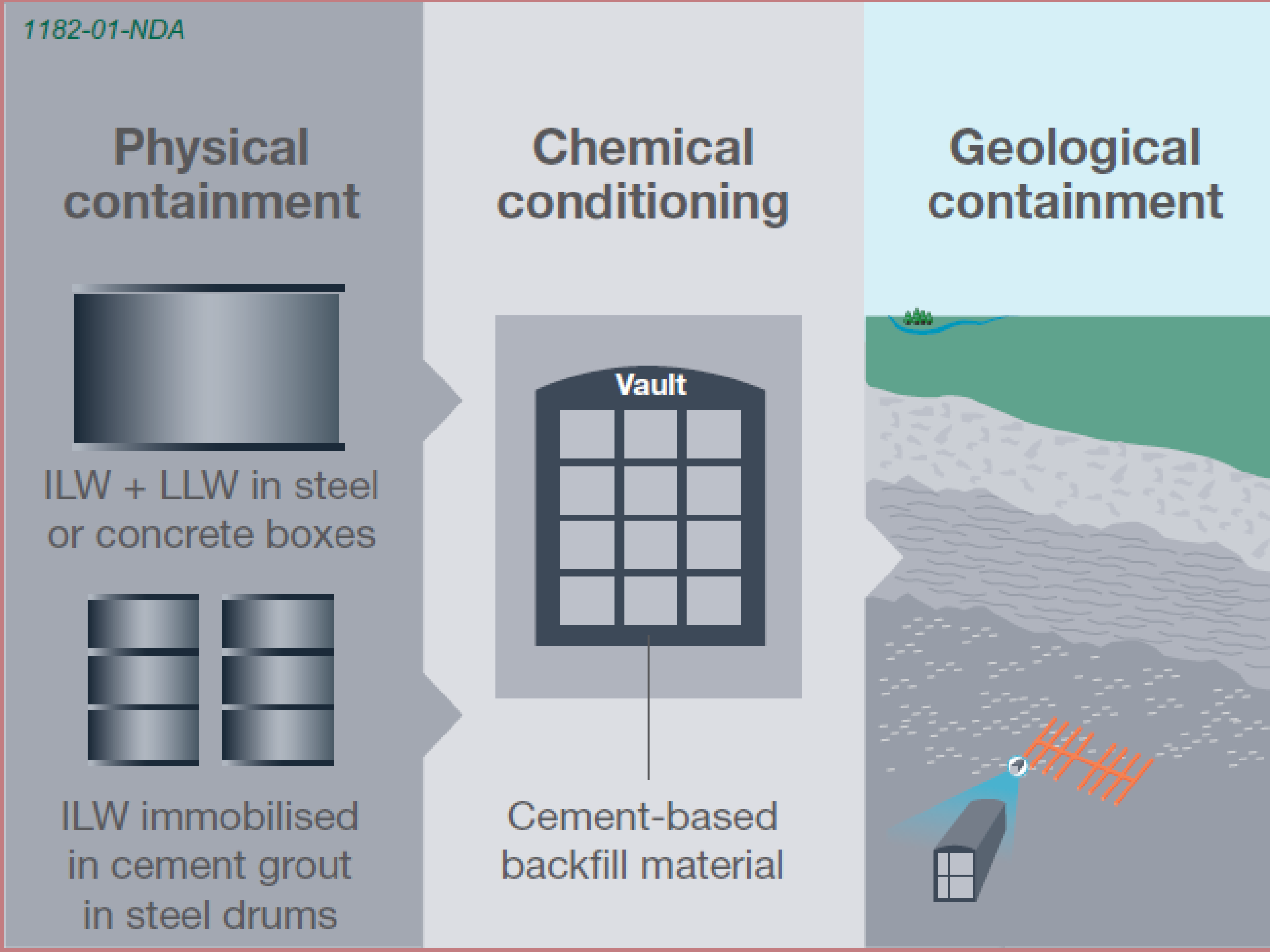


CORWM baseline inventory

From 60 years operation of 10 GW of PWR reactors

How big is that in everyday terms?

	Volume	**Volume equivalent**	
Total lifetime arisings of higher activity wastes from existing nuclear programme	~480,000 m^3		5 Albert Halls
Comprising:			
ILW	~350,000 m^3		3.6 Albert Halls
Uranium & Plutonium	~78,300 m^3		0.8 Albert Halls
LLW (non-Drigg)	~37,000 m^3		0.4 Albert Halls
Spent Fuel & HLW	~9,500 m^3		0.1 Albert Halls (or about 46 semi detached houses) 


1182-01-NDA
Physical containment
ILW + LLW in steel or concrete boxes
ILW immobilised in cement grout in steel drums
Chemical conditioning
Vault
Cement-based backfill material
Geological containment

Department of Energy & Climate Change

Llywodraeth Cymru
Welsh Government

Department of the Environment
www.doeni.gov.uk

Consultation

Review of the Siting Process for a Geological Disposal Facility

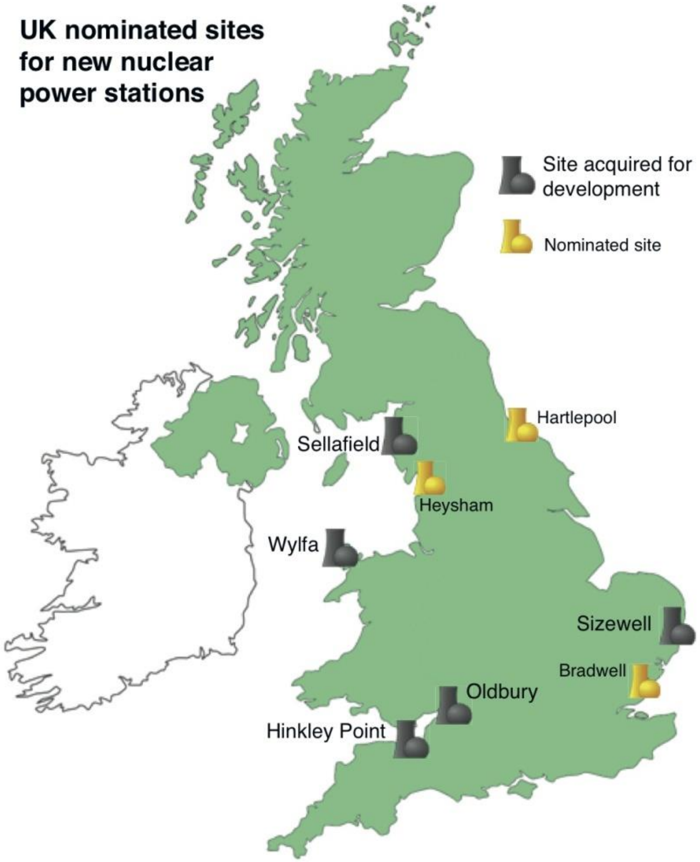
September 2013

URN 13D/250

Consequences of Electricity Market Privatisation

Sites for New Nuclear Power Stations listed in National Policy Statement

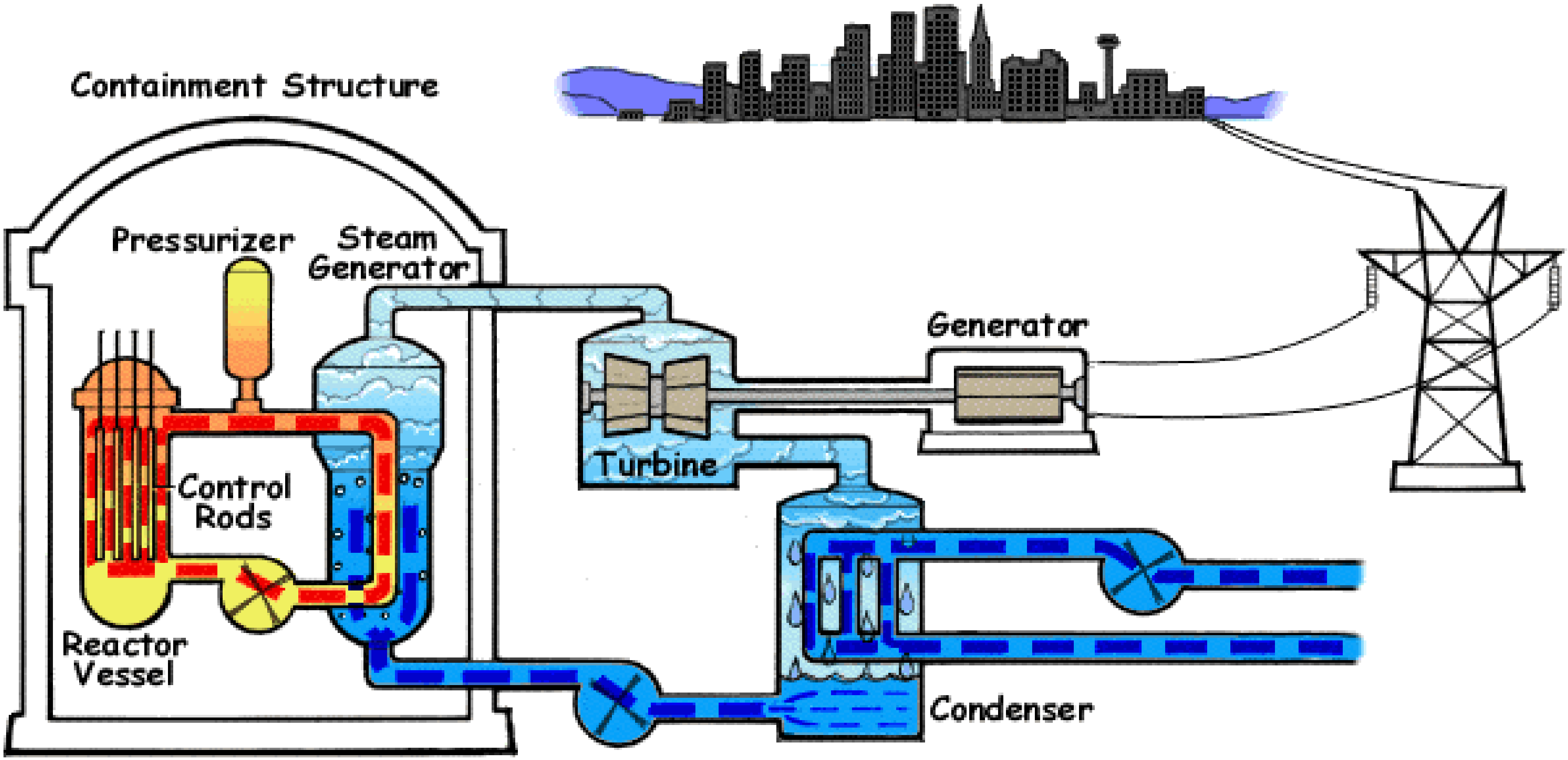
- 11 sites were nominated in Spring 2009
- 10 approved in principle – Dungeness rejected
- A further consultation has taken place – 2 other Cumbrian sites removed from draft list, leaving a likely list of just 8



Source: NAMRC

Supporting or Interested Utilities

PWR (Pressurized Water Reactor)



Olkiluoto 3 Finland & Flamanville 3 France

Flamanville 3

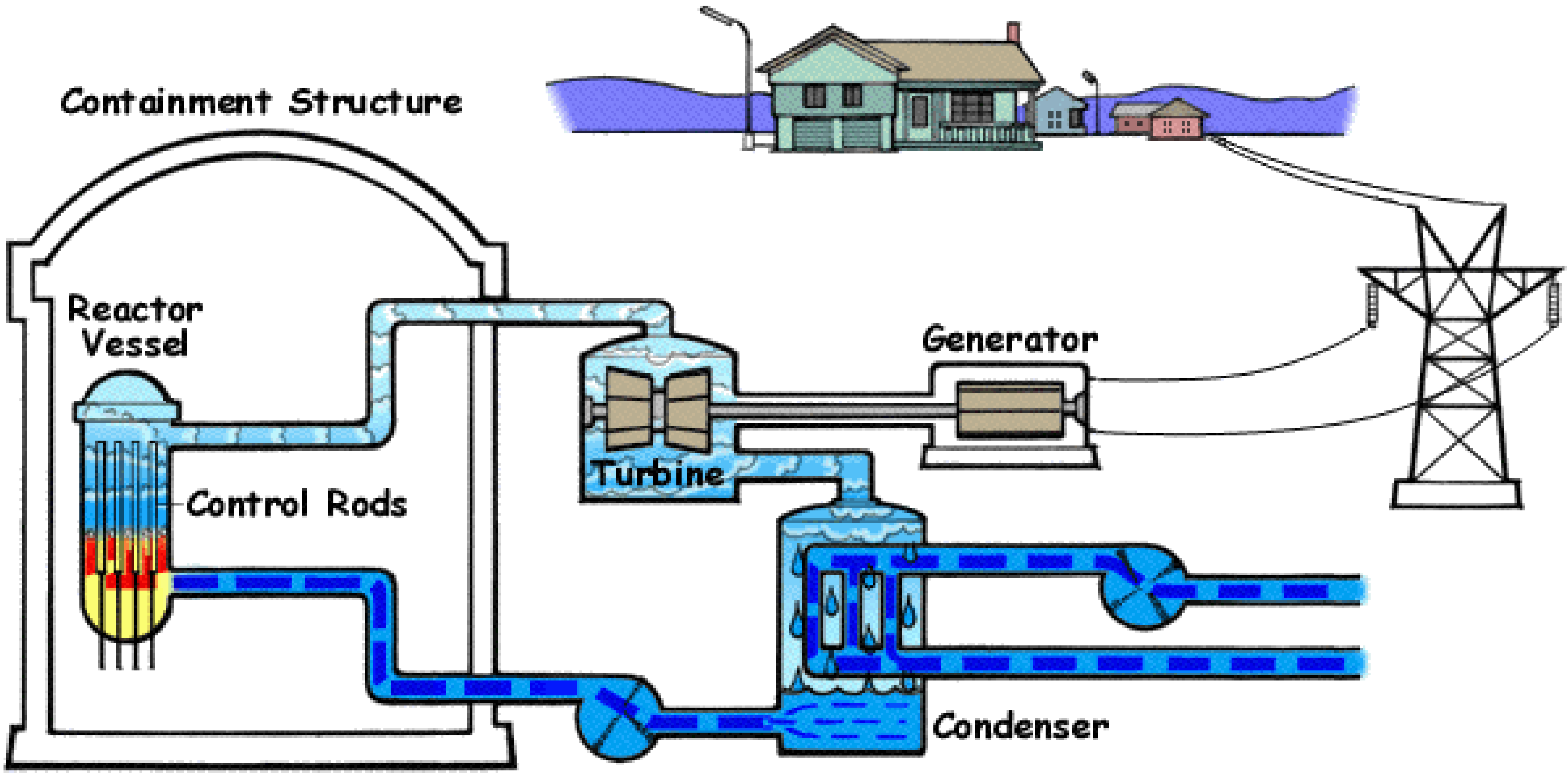
Olkiluoto 3 Finland

HITACHI

HORIZON

NUCLEAR POWER

BWR (Boiling Water Reactor)



Kashiwazaki-Kariwa Power station Japan

Generation III … ABWR

Kashiwazaki 6 & 7, Japan

Online

Hamaoka 5, Japan

Online

Shika 2, Japan

Online,

Lungmen 1& 2 Taiwan

Online 2014

Shimani 3, Japan

Online 2014?

Ohma, Japan

Approved

Higashidori 1&2, Japan

Planning

USA

Studies

IBERDROLA

NU GEN

suez

VATTENFALL

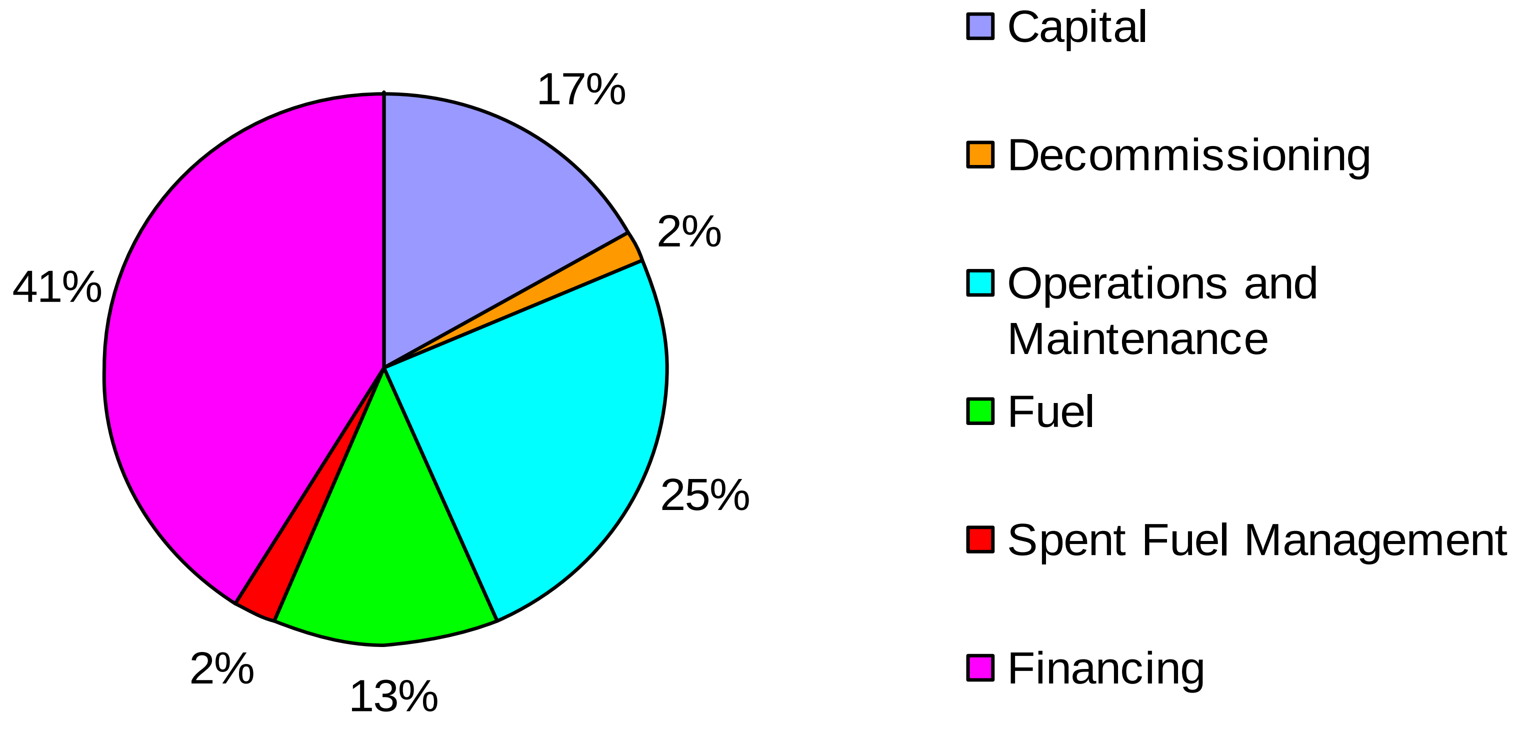
Scottish and Southern Energy

Westinghouse AP1000

“New Build” Plant Technology – Gen III+

- These plants are already designed and being built internationally
- Will be built to already established materials and design practices
- Use of international codes and standards proven by existing plant experience
- Similar modes of construction welding, bolting etc
- Replacement materials justified by plant experience
- Materials will be ‘new‘ vintage materials produced by modern (e.g. steelmaking) methods
- Plants will come on line from 2014 to 2035 – to last for >60 years

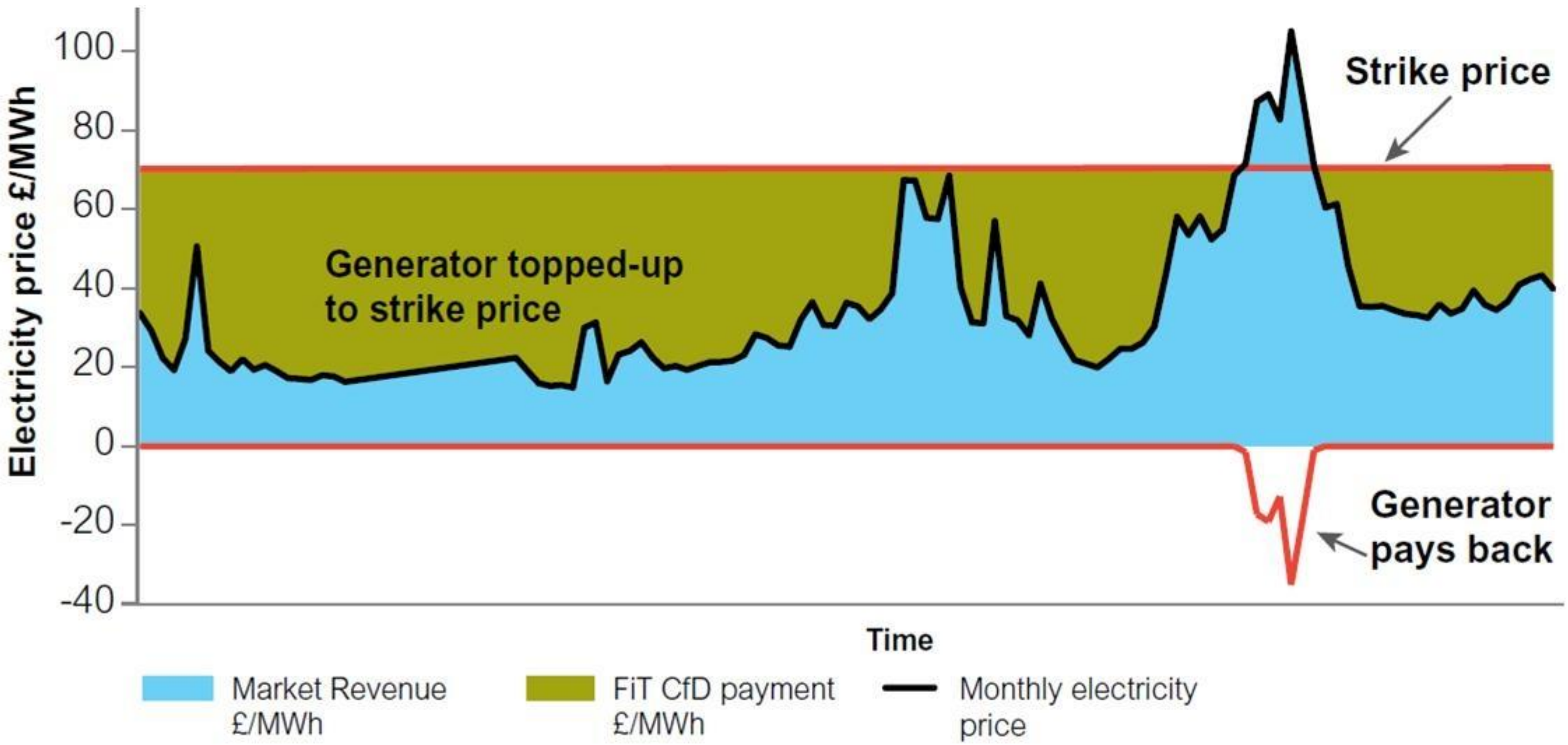
Nuclear Reactor Capital and Finance Costs



Costs dominated by capital required to construct and timescale to finance before returns flow

Electricity Market Reform

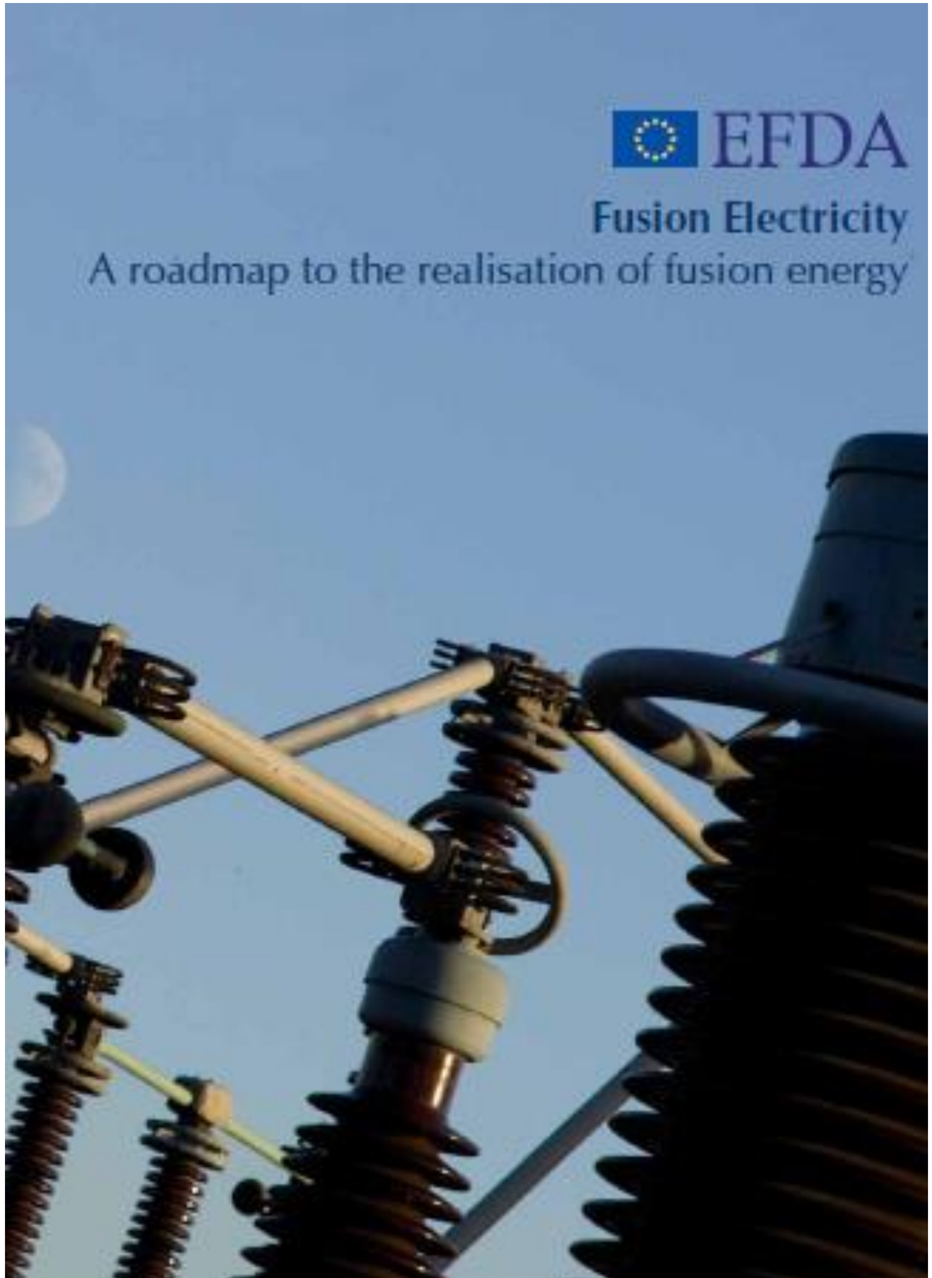
- Carbon Floor Price
- Capacity Markets
- Contracts for Difference



Small Modular Reactors

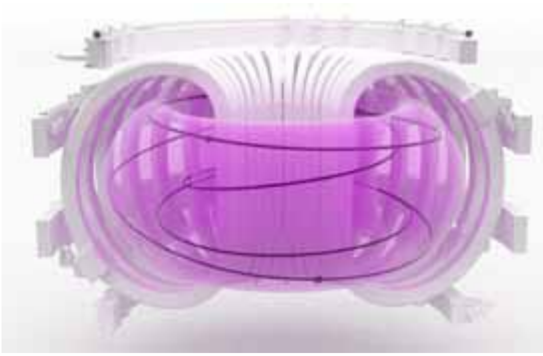
- Now seen by some as very attractive
- Economics more favourable with 21Century manufacturing technology
- Better from a grid management perspective
- May be possible to re-examine some of the UK's smaller old Magnox sites
- Export potential to areas with no large scale grid

What about Fusion?

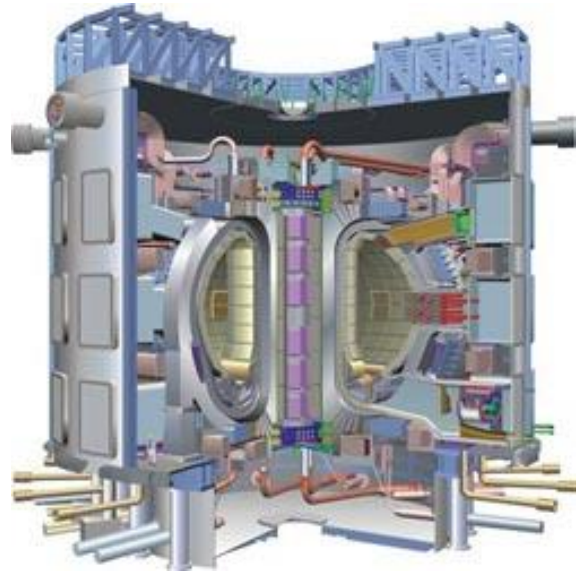

EFDA
Fusion Electricity
A roadmap to the realisation of fusion energy

International Thermonuclear Experimental Reactor (*ITER*), the world's largest nuclear fusion reactor

Challenges



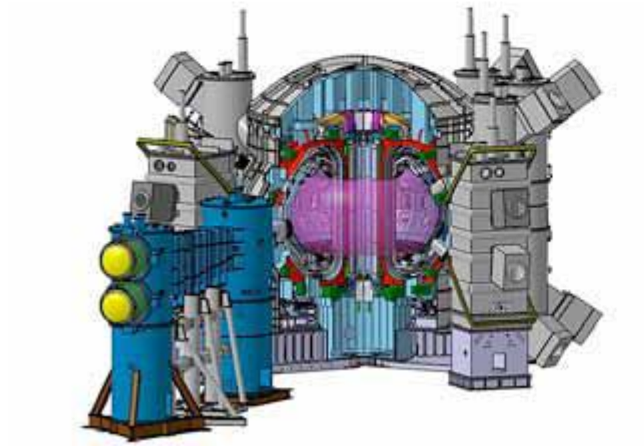
Confining hot plasmas



Making ITER a success

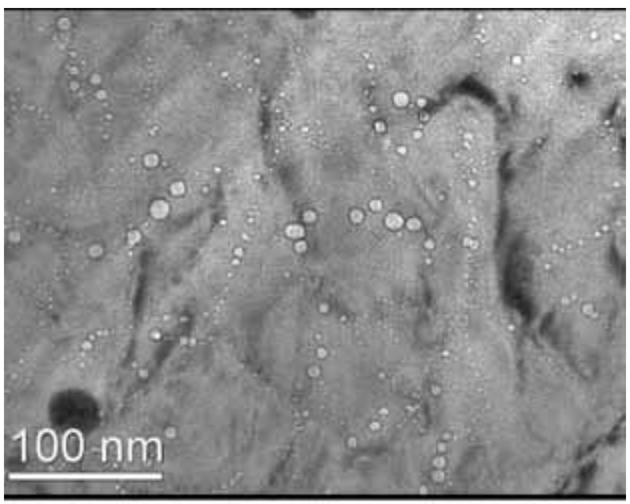
Maximising value from JET in the UK

DEMO: when to start?: how to finance?

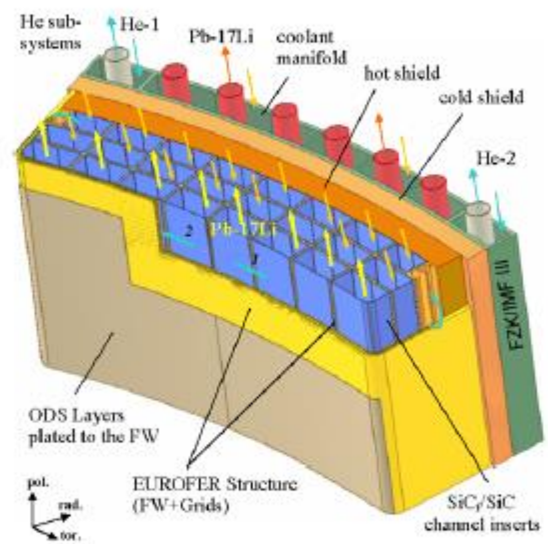


Collaborating with Japan
Preparing for advanced ITER regimes

Controlling the plasma
Solving heat exhaust issues



Coping with neutron damage
Replacing key components



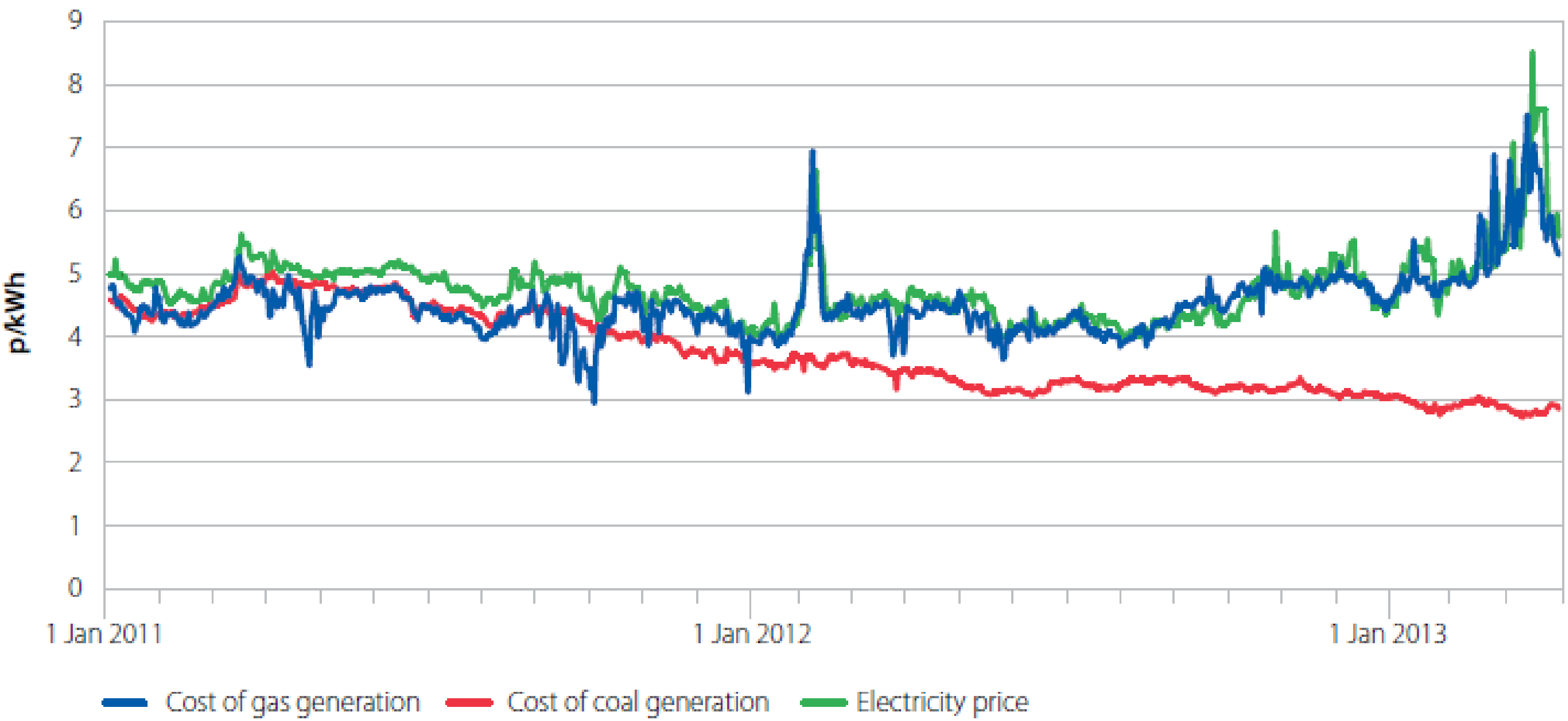
Blanket materials and tritium handling

Concept design way too expensive:
need to get the capital costs down

Or will Gas obtained by the process of fracking become the preferred fuel of the 21st century…?

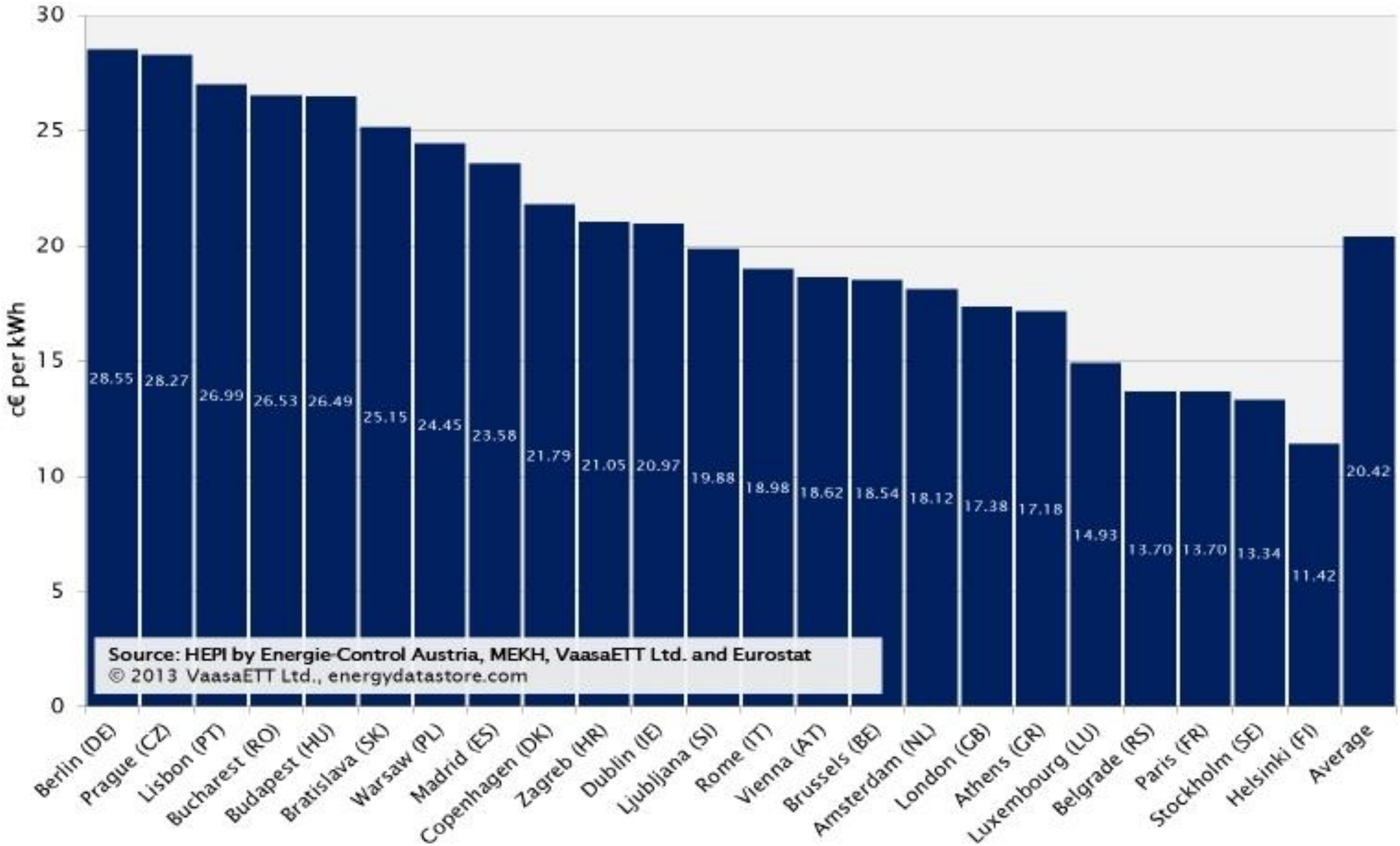
Energy Costs

Figure B2.1: Short-run cost of gas and coal generation and electricity price (January 2011 to March 2013)

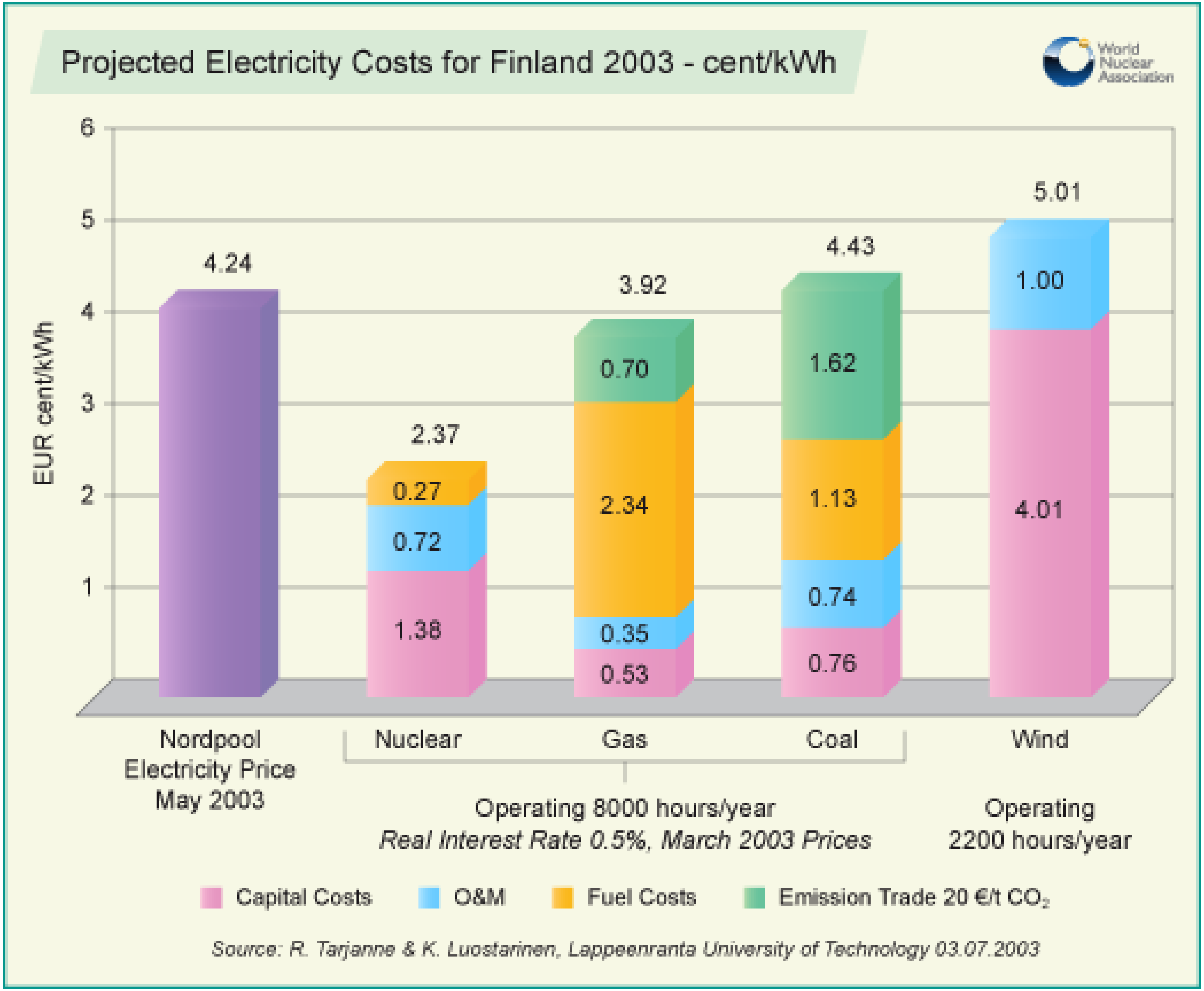


Source: *UK Power day-ahead data*, WMBA (accessed 9 May 2013); *System Average Price data*, National Grid (accessed 9 May 2013); *Coal ARA data*, ICIS, (accessed 12 May 2013); CCC calculations.
Notes: Assumes plant efficiency 49% for gas and 35% for coal (based on average for existing fleet). Carbon intensity 378 g/ CO_2kWh for gas and 1,000 g/ CO_2kWh for gas. Based on day-ahead electricity and gas prices, and coal monthly forward price.

Figure 4. Residential electricity prices including taxes at PPS (September 2013)



Technology	region or country	At 10% discount rate	At 5% discount rate
Nuclear	OECD Europe	8.3-13.7	5.0-8.2
	China	4.4-5.5	3.0-3.6
Black coal with CCS	OECD Europe	11.0	8.5
Brown coal with CCS	OECD Europe	9.5-14.3	6.8-9.3
CCGT with CCS	OECD Europe	11.8	9.8
Large hydro-electric	OECD Europe	14.0-45.9	7.4-23.1
	China: 3 Gorges	5.2	2.9
	China: other	2.3-3.3	1.2-1.7
Onshore wind	OECD Europe	12.2-23.0	9.0-14.6
	China	7.2-12.6	5.1-8.9
Offshore wind	OECD Europe	18.7-26.1	13.8-18.8
Solar photovoltaic	OECD Europe	38.8-61.6	28.7-41.0
	China	18.7-28.3	12.3-18.6


Projected Electricity Costs for Finland 2003 - cent/kWh
World Nuclear Association
EUR cent/kWh
6
5
4
3
2
1
4.24
2.37
0.27
0.72
1.38
3.92
0.70
2.34
0.35
0.53
4.43
1.62
1.13
0.74
0.76
5.01
1.00
4.01
Nordpool Electricity Price May 2003
Nuclear
Gas
Coal
Wind
Operating 8000 hours/year
Real Interest Rate 0.5%, March 2003 Prices
Operating 2200 hours/year
Capital Costs
O&M
Fuel Costs
Emission Trade 20 €/t CO2
Source: R. Tarjanne & K. Luostarinen, Lappeenranta University of Technology 03.07.2003

Energy is too important to omit ANY single technology. We need them all but we need them to be clean and environmentally sustainable

Gas T/G Aero Coal/Steam T&D Wind Solar Hydro Nuclear

…technology for energy … & a balanced portfolio

No Silver Bullets

- Demand reductions across all sectors of the economy will be essential through a combination of increased efficiency and behavioural change
- Full suite of low carbon energy supply technologies needed including nuclear and CCS

All technologies and attention to demand reduction essential