Pathways to 2050:
Three possible UK energy strategies

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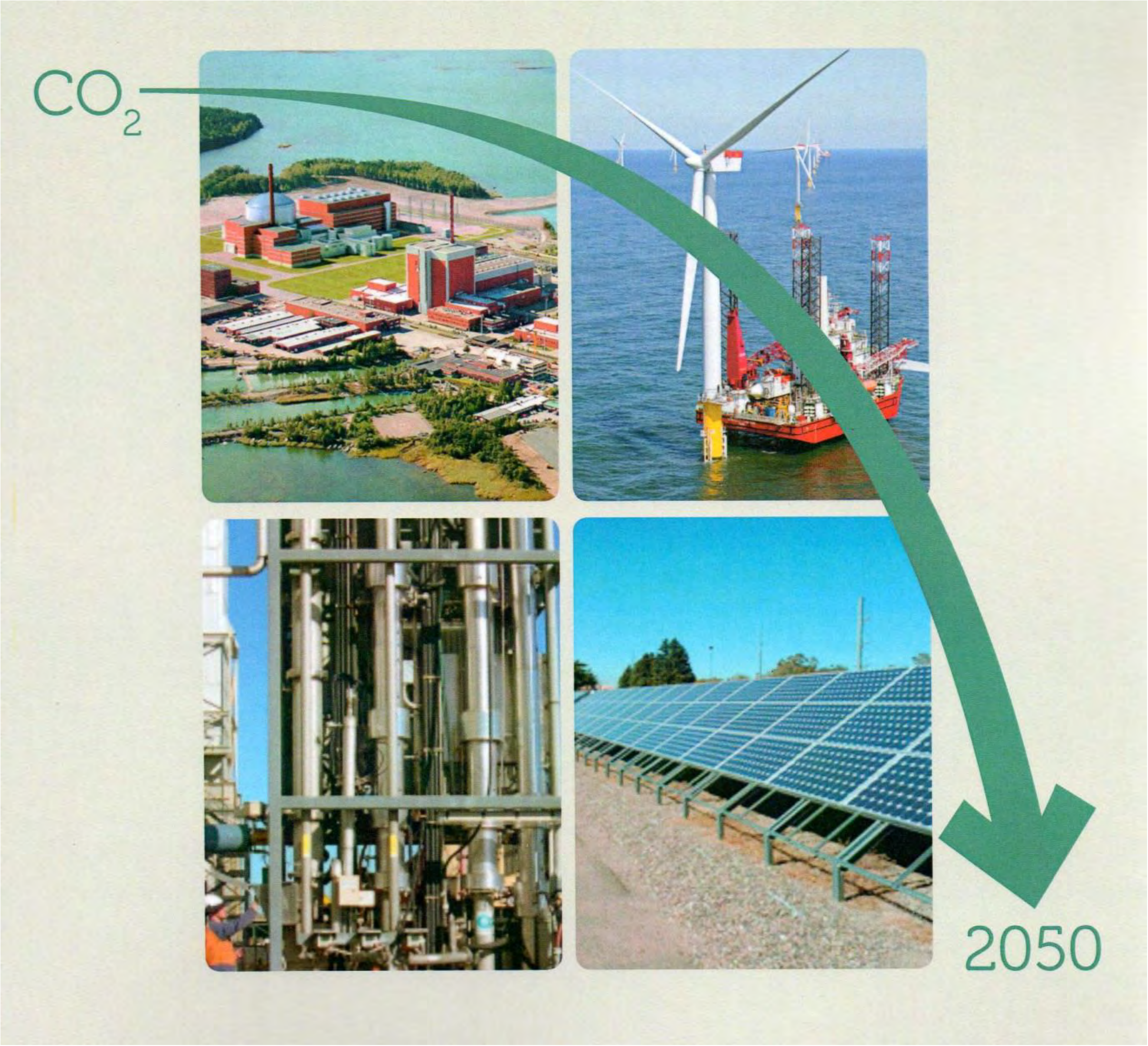

Pathways to 2050:
Three possible UK energy strategies
Report of a British Pugwash Working Group

Presentation at University College, London 14 February 2013 by:

Dr Christopher Watson – convenor of the Working Group and general editor

Dr Christine Brown – champion of the ‘High Nuclear’ Pathway

Prof David Elliott and **Dr David Finney** – co-champions of the ‘High Renewables’ Pathway

Dr Ian Crossland – champion of the ‘Intermediate’ Pathway

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Summary

- Introductions and acknowledgements
- Objectives of this British Pugwash project
- UK Government energy planning 1998-2012
- The current UK energy supply system
- Why does the UK energy system need to change?
- Technologies to be considered for future developments
- The DECC ‘Pathways to 2050 Calculator’
- Presentations by the three champions:
  - The High Nuclear Pathway
  - The High Renewables Pathway
  - The Intermediate Pathway
- A comparison of the three Pathways
- Issues to take into account in reaching a decision
- Conclusions and recommendations

Acknowledgements

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- Our reviewers, most of whose comments have been incorporated in the final text.
- Sarah Graham-Brown for all her work in preparing the manuscript for publication.
- The Network for Social Change for a grant to support the cost of printing and distributing this report.

Objectives of this British Pugwash project

- To promote a meaningful public debate about UK energy policy, based on realistic alternatives.
- To present three ‘possible’ Pathways to 2050, which all meet the UK’s international commitments on GHG emissions, and identify the prospects and risks associated with each. Here ‘possible’ means based on technologies which have either:
  - already reached commercial maturity, or
  - can be expected to do so in time to be rolled out as planned by 2050.
- To emphasise the need for strong government leadership, taking rapid decisions on energy policy. Leaving it all to ‘the market’ is not a realistic option, given the urgency of the task.
- To avoid being distracted by the uncertainties in climate change modelling.

UK government energy planning 1998-2012

Our report gives a detailed account of the evolution of UK energy policy since 1998.

In brief, there have been four phases:

- **1998-2006** (Tony Blair) early moves towards creating a low-carbon economy, by cutting the UK's CO_2 emissions, and possibly some private sector nuclear 'new build'.
- **2007-2008** Gordon Brown supports inclusion of nuclear power alongside other low-carbon technologies. However a Nuclear Power White Paper recognises that there are still public concerns about this.
- **2008-2009** The Climate Change Act is passed , which commits the UK to a cut of at least 80% in GHG emissions by 2050, and a reduction of at least 26% by 2020, both against a 1990 baseline, with periodic reports to Parliament on progress.
- **2009-2012**. The government announces an intention to go ahead with 16 GW of 'new build' nuclear power stations, and to give support to the development of CCS. DECC publishes its 'Pathways to 2050 Calculator' (of which more later), and a 'Low Carbon Transition Plan' (not really a plan)
  - **November 2012** Edward Davey publishes the 2012 Energy Bill, designed to create an 'Electricity Market', to help the private sector take investment decisions.

The current UK energy supply system

- **The current UK energy system produces some 300 GW of 'primary' energy. Of this**
  - about 105 GW is used to generate ~37 GW of electricity supplied to end users,
  - non-electric end use is for heating (~53 GW), transport (~78 GW)& industrial processes (~44 GW)
  - some 90 GW of primary energy is lost in the process of converting it into usable form.
- **The primary energy used to generate electricity comes predominantly from:**
  - gas 46%, coal 29%, and nuclear 16%,
  - all other sources together contribute about 10%.
- **The end use of electricity is divided between:**
  - domestic consumption 12 GW (heating, cooling, lighting & appliances),
  - industrial use 12 GW (predominantly metallurgical & heavy engineering),
  - public and commercial consumption 12 GW
- Demand for electrical energy is subject to strong seasonal and diurnal variations – from 20 GW in a hot summer to 60 GW in a cold winter, and by a factor of 60-70% during the course of a typical day. There are also exceptional demand variations (eg a Cup Final or an eclipse of the sun). There are similar variations in the (four times larger) gas demand.
- Balancing supply with the demand for both electricity and gas is the responsibility of the National Grid Company, and is managed by special supply contracts and by drawing on energy storage (eg at Dinorwig) and interconnects.

Why does the UK energy system need to change?

- Its fossil fuel component generates an unacceptable amount of CO_2. Capturing & storing this CO_2 is a possible solution to this problem, but this technology has still to be proven commercially, so it is risky.
- Our nuclear reactor fleet, which now generates 70% of our low-carbon electricity, is obsolescent. 14 reactors have already been shut down: all but three of the remaining 16 are due to close by 2025.
- Our indigenous oil & gas reserves are declining: we already import ~40% of our gas and by 2025 DECC foresees that 70% of our oil and gas could be imported. This would make us uncomfortably dependent on potentially unstable countries.
- The UK is currently lagging behind several advanced economies in exploiting its potentially rich renewable energy resources

Conclusion: We anticipate that the UK will have to re-build its energy supply infrastructure almost completely during the next 40 years, at a cost of about £3 trillion. This is a heroic, but not utterly unrealistic task.

Technologies to be considered for future developments

- Improved energy efficiency in the home, industry & commerce
- 3rd Generation Nuclear Technology - possible candidates are:
  - EPR (the European PWR developed by Areva, being built in Finland etc)
  - AP1000 (the Westinghouse PWR now being built in the US & China)
  - ABWR (the GE-Hitachi BWR being operated in Japan and built in China)

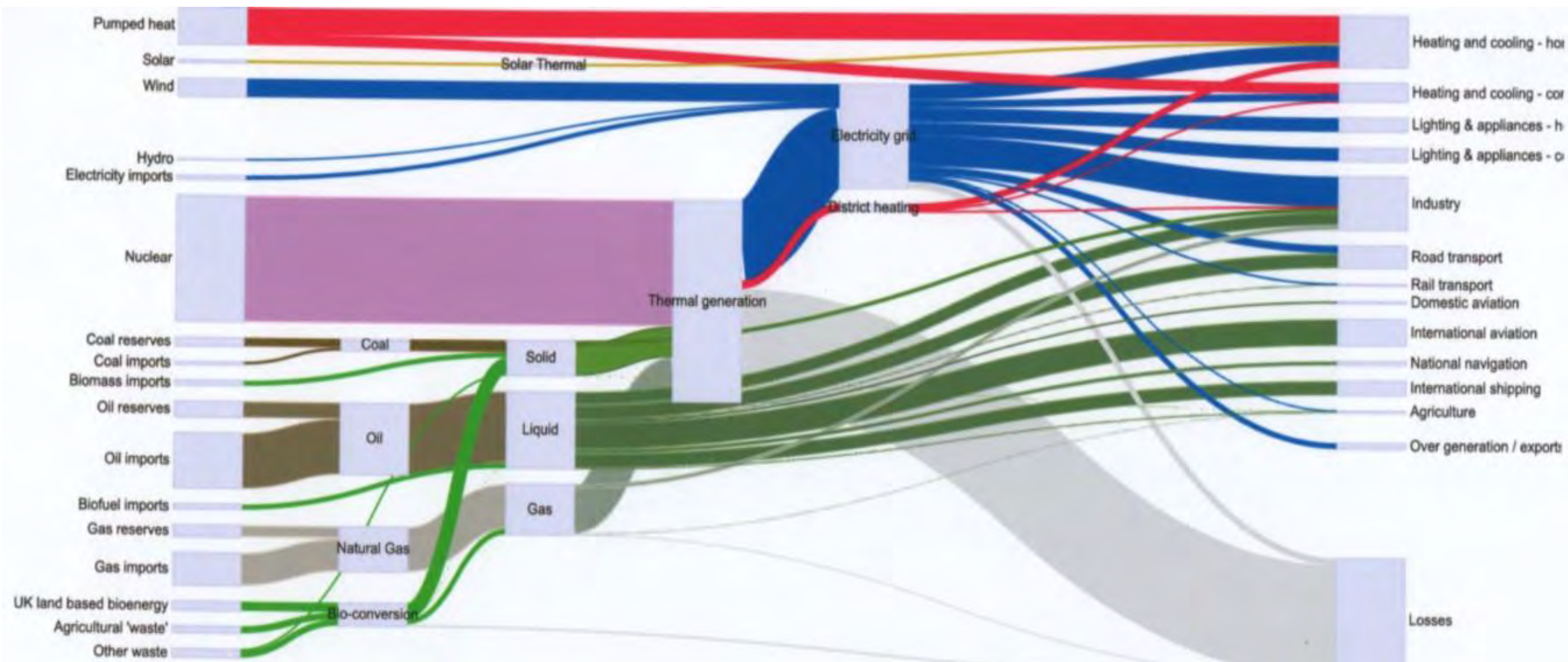
We have rejected as unrealistic the option of leapfrogging to a 4th Generation reactor

- Wind energy – possible candidates are onshore and offshore
- Solar energy – possible candidates are PV and solar thermal
- Bioenergy – this class includes energy crops & agricultural wastes
- Wave , tidal stream, tidal range, hydro and geothermal energy
- Carbon Capture and Storage (CCS) – there are several variants

The DECC 'Pathways to 2050 Calculator'

- This software tool has been used extensively in our work. Made publicly available by DECC in 2010, it enables the user to develop an energy strategy for the UK, and compute its key parameters, including capacities, emissions & costs
- Our report explains how we have used it, and identifies a few of its weaknesses. It incorporates a lot of relevant DECC data.
- Outputs from the Calculator include graphics, reproduced on pp130-136 of our report. Especially useful is the 'Sankey diagram' (next slide), showing the energy flows through the system, and demonstrating energy conservation.
- The Calculator requires the user to set 43 parameters, half of which influence energy demand, and half the system's supply mix.
- The Calculator shows that all three British Pugwash Pathways achieve an 80% reduction in GHG emissions by 2050
- All three Pathways also pass its 'intermittency stress test'

A typical Sankey Diagram



The High Nuclear Pathway

Presentation by Christine Brown

HIGH NUCLEAR PATHWAY OBJECTIVES

- Meet GHG emission targets by 2050
- Provide Clean Energy
- Provide security of supply
- Limit reliance on CCS to reduce GHG emissions
- Realistic approach to reducing energy demand
- Concentrate effort on proven technology and rebuild skills

- Credible
- Safe and reliable
- Economically viable
- Political and Public acceptable
- Compatible with UK’s non-proliferation commitments

HIGH NUCLEAR PATHWAY
Energy Demand

Energy Demand From	2010	2050	% change from 2010 to 2050
	GWav	GWav	
Lighting & Appliances	19.5	21.1	+8%
Heating & Cooling	57.8	54.7	-5%
Transport	80.1	60.2	-25%
Industry	58.9	39.6	-33%
Agriculture	1.3	1.3	0
TOTAL	**217.6**	**176.8**	**-19%**

TOTAL ENERGY DEMAND FALLS BY 19% BY 2050

High Nuclear Pathway Electricity Demand

Electricity Demand	2010	2050	% Change
	GWav	GWav	%
Lighting & Appliances	17.7	21.1	+19
Heating and Cooling	6.5	16.7	+156
Transport	0.9	7.2	+687
Industry	15.1	23.1	+153
Agriculture	0.5	0.5	+7
TOTAL	**40.2**	**68.6**	**+71%**

TOTAL ELECTRICITY DEMAND INCREASES BY 71%

High Nuclear Pathway
Primary Energy Breakdown

Primary Energy	2010	2050
	%	%
Natural gas	38	5
Oil	34	16
Coal	18	0
Wind	1	2
Nuclear	6	58
Bioenergy	2	9
Solar	0	1
Environmental Heat	0	8
Hydro	1	0
Wave	0	0
Geothermal	0	0

High Nuclear Pathway Electricity Supply Breakdown

Electricity Supply	2010	2050
	%	%
Unabated Thermal	80.7	0.0
Nuclear Power	14.0	74.5
CCS	0	17
Off Shore Wind	1.1	6.2
On Shore Wind	2.9	1.4
Hydro	1.3	0.8
Tidal and Wave	0	0
Geothermal	0	0
Solar PV	0	0
TOTAL SUPPLIED TO GRID	**43.3 GW av**	**86 GWav**

Cf. TOTAL ELECTRICITY DEMAND IN 2050 of 68.6GWav

HIGH NUCLEAR PATHWAY
New Build

EPR Under Construction
Olkilouto, Finland

2nd under construction at Flamanville

ABWR under Construction
Lungmen, Taiwan

4 ABWR units in operation
4 ABWR under construction

HIGH NUCLEAR PATHWAY
Spent Fuel Management (1)

Thermal reactor fuel has a useful life of 3 to 7 years.

After discharge it remains radioactive and produces significant heat

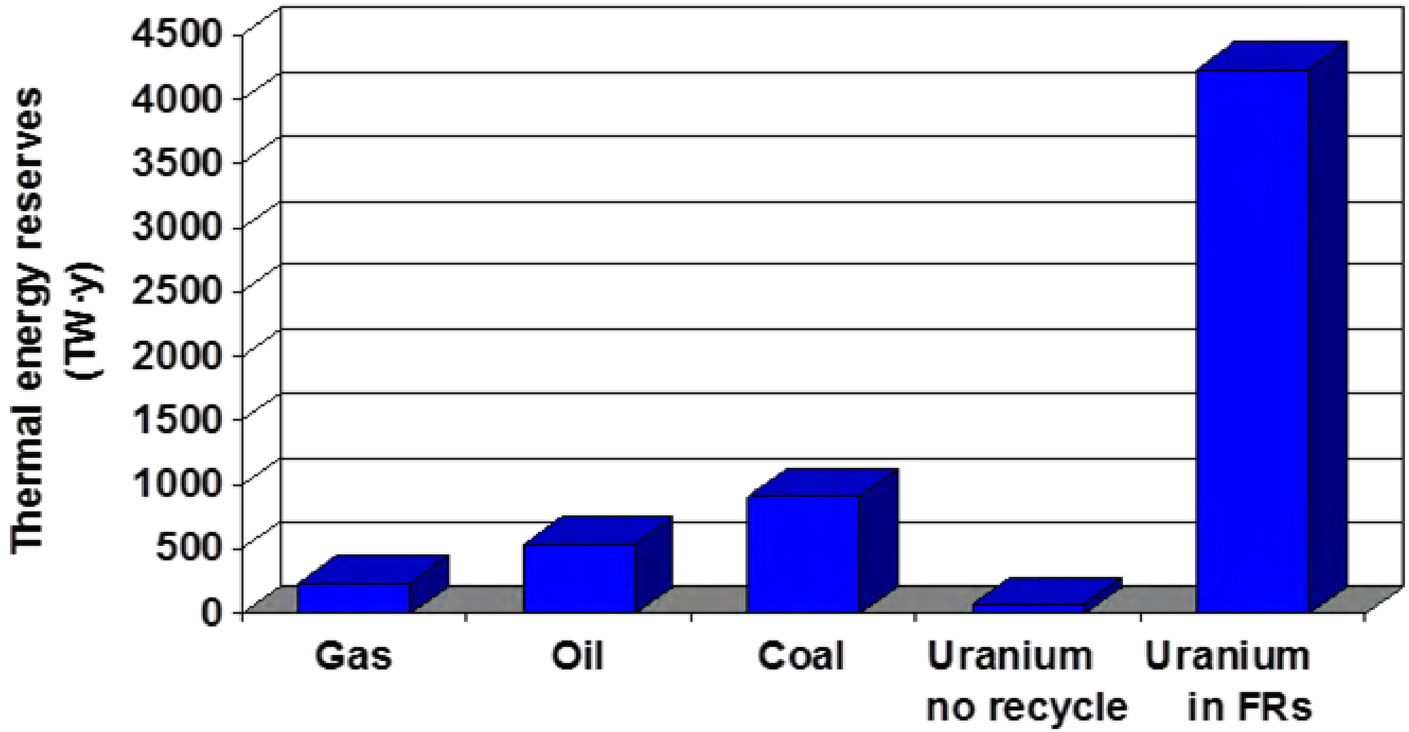
Initially cooled under water in storage ponds next to reactor

After 9 -12 months cooling requirements drop and alternative management options can be considered depending on fuel cycle chosen

- Open - spent fuel disposed of directly in a GDF
- Closed - spent fuel recycled to generate more energy

HIGH NUCLEAR PATHWAY

Fuel Cycle



SUSTAINABLE USE OF RESOURCES

Source: US DOE Energy Information Administration *International Energy Outlook 2004*, DOE/EIA-0484(2004). Note: Gas and Oil include speculative reserves; Coal and Uranium do not.

HIGH NUCLEAR PATHWAY
Spent Fuel Management (2)

“In the rush to construct nuclear reactors, the management of spent fuel and radioactive waste, including planning for its disposal, must no longer be an afterthought.”

“Spent fuel should be reprocessed only when there is a clear plan for its re-use.”

If nuclear power is part of the government’s energy policy then “this policy should specify the requirements for managing spent fuel and radioactive wastes, including sufficient capacity for interim storage, as well as initiating plans for delivering timely geological disposal from the outset”

Ref. “Fuel Cycle Stewardship in a Nuclear Renaissance” – The Royal Society Science Policy Centre Report October 2011.

HIGH NUCLEAR PATHWAY CONCLUSIONS

- Delivers energy security with the required 80% reduction in GHG emissions by 2050
- The clock is ticking fast – UK needs to act now
- Nuclear power has the potential to ensure energy security for years beyond 2050 but requires proper management of spent fuel
- Requires 27 3GWe reactors to be built within the next 40 years – history supports such a build rate
- The technology exists and is tried and tested

Can we afford to ignore this clean, secure source?

The High Renewables Pathway

Presentation by:

Prof. David Elliott (The Open University)

Dr David Finney

10 countries get nearly 100% of electricity supplied by renewables, mostly from hydro:

Albania, Angola, Bhutan, Burundi, Costa Rica, D R Congo, Lesotho, Mozambique, Nepal, Paraguay, Tajikistan and Zambia

A further 30 developing countries obtain 60-90% of their electricity from renewables, again mostly hydro

Hydro provides nearly **all the electricity** in *Norway,* most of it in *Iceland,* up to 60% in *Austria, Canada, New Zealand* and *Sweden.*

Two countries are aiming to get 100% of total energy from renewables by 2050: *Denmark, New Zealand*

Germany **is aiming for 80% of electricity by 2050**

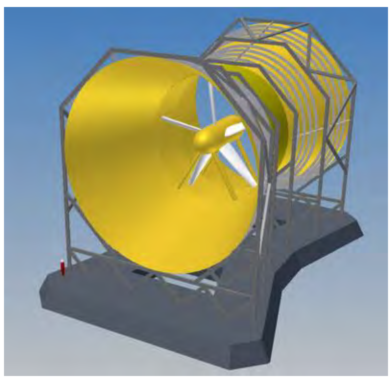
Several countries in the EU are Non-nuclear:*Austria, Denmark, Italy, Ireland, Portugal, Greece, and soon Germany and Belgium.*

Tidal Wind Solar Hydro

1kW PV array

Mini hydro-MW

2MW turbines in an offshore wind farm



Tidal 2MW unit

Connecting: solar installation at Perivale

Macro hydro-GW

Wave

CSP

Biomass

Two recent Electricity scenarios

Electricity Generating Option	WWF proposal for 2030 Installed GWn	WWF proposal for 2030 Output GW av	Poyry proposal for 2050 Installed GWn	Poyry proposal for 2050 Output GW av	Poyry proposal for 2050 Output TWh
Offshore wind	52	19	156	57	501
On-shore wind	20	4	33	7	61
Photovoltaics	10	1	38	3	27
Tidal stream/ wave/hydro	12	3	31	7	63
Biomass,other Geothermal	10	3	6	1.5	13
Total Renewables	104	30	264	75.5	665

Our chosen scenario for 2050

(The DECC Calculator forces retention of some fossil fuels)

Energy source	Installed Capacity GWn	Output GW av	Comment
Offshore wind	76	34	Half of Poyry
On-shore wind	31	9	
Solar (PV & thermal)	41	9	
Tidal stream/wave/hydro	35	10	
Environmental heat	7	7	
Biomass & waste	38	38	
Geothermal	4	3	
Total Renewables	232	110	
Non-renewable	51	51	Still some fossil fuel
Total energy produced	283	161	Includes a lot of exports

Energy demand cut by 40% by 2050

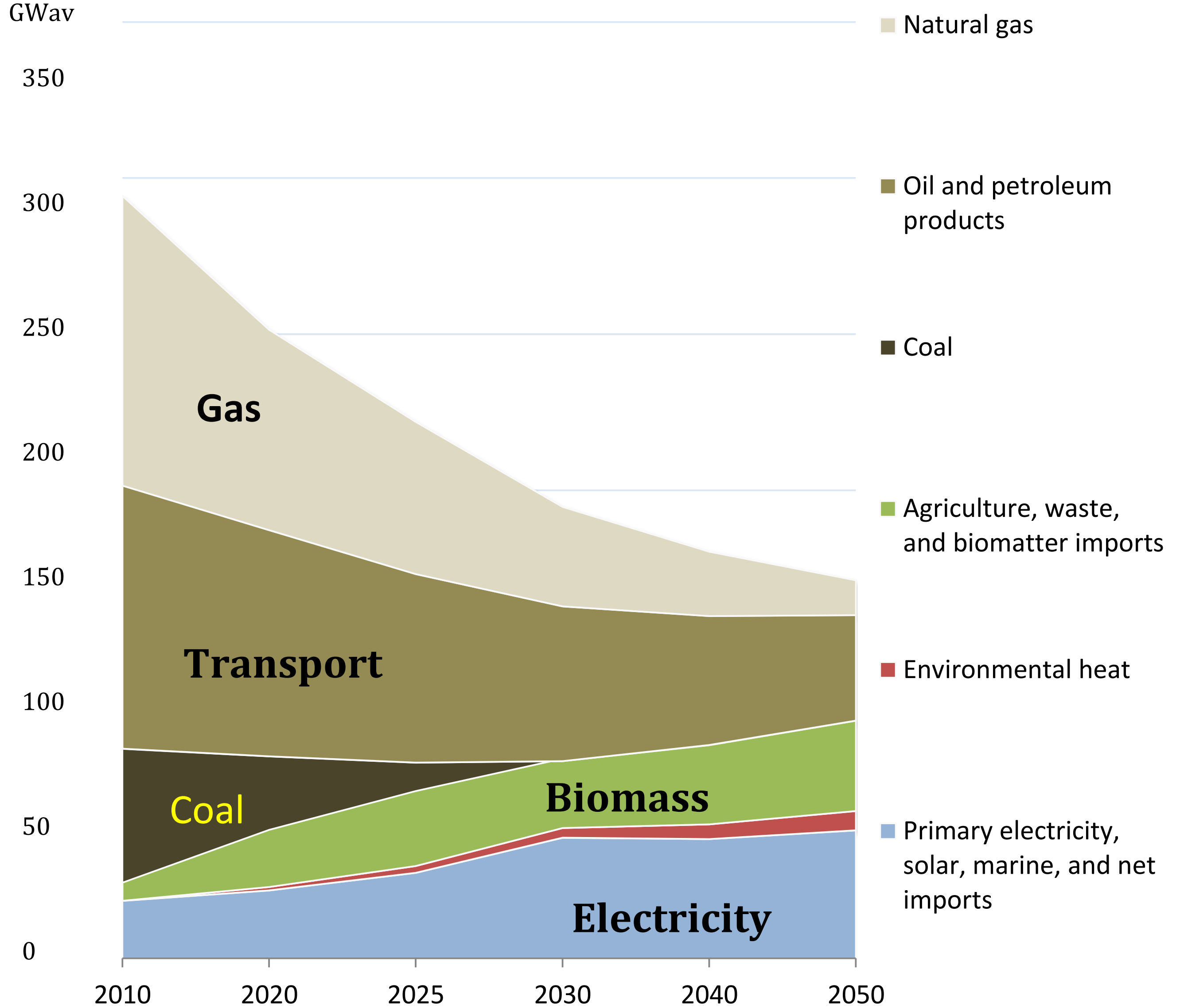
EU target is a 20% cut by 2020

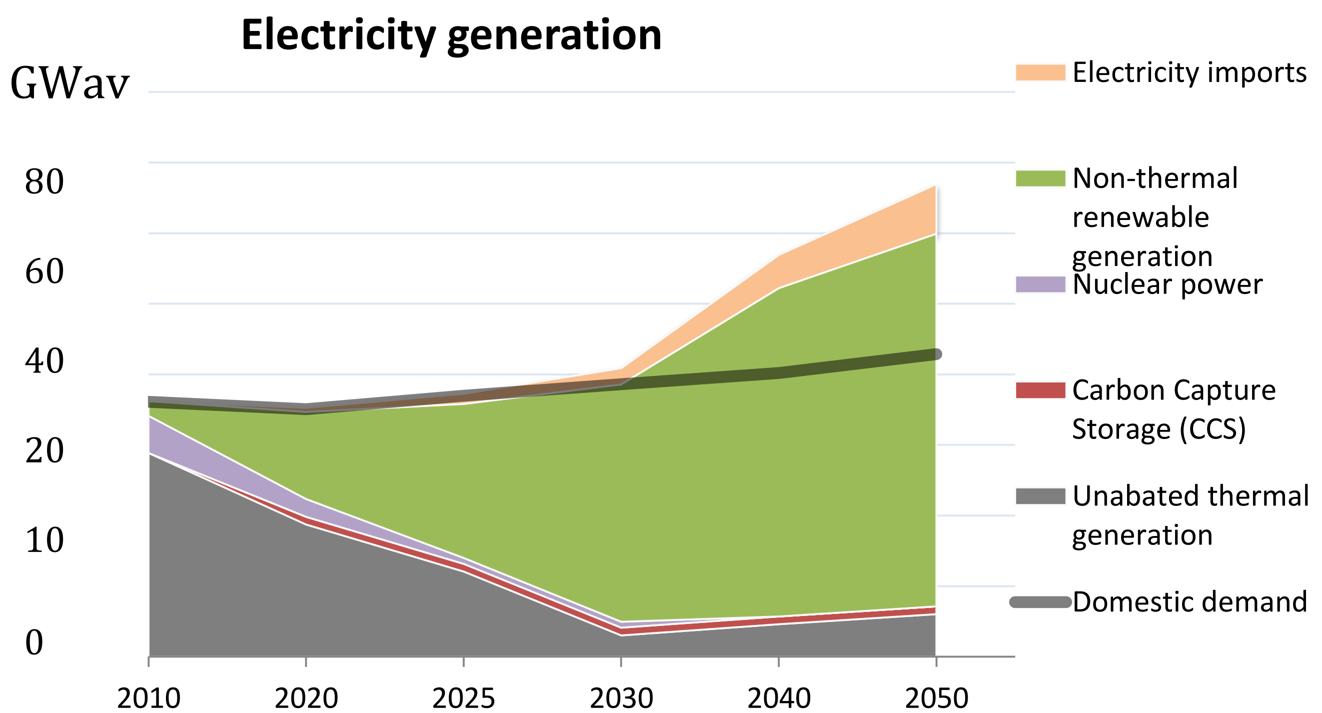
DECC says 40% savings are possible in key UK sectors by 2030, including industry

Germany is aiming to cut primary energy use by 50% by 2050

The Environmental Change Institute says that the 54 GW of gas and oil and 23 GW of electricity now consumed in the building sector could be cut to 11 GW of renewable electricity supplied by the grid by 2050. Carbon emissions from this sector would then be zero

Primary energy supply

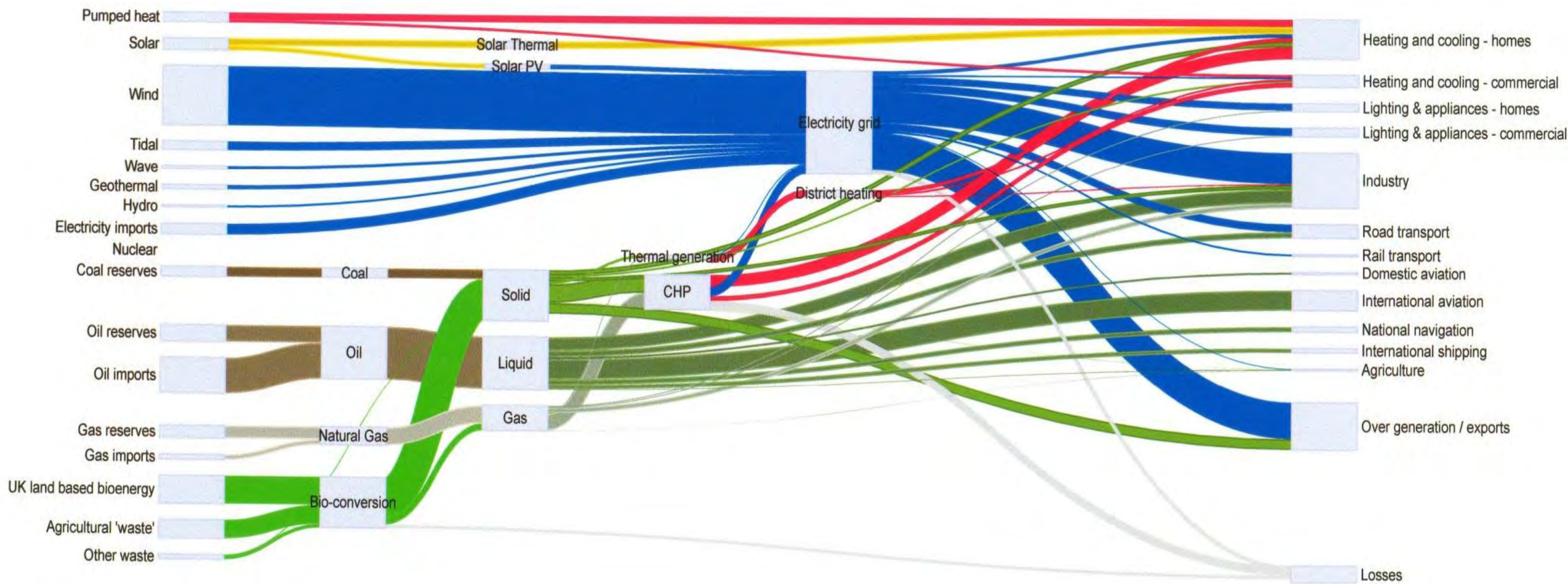




Pugwash High Renewables- DECC calculator

Excess wind generation exported via 15GW inter-connector

DECC Sankey diagram for High Renewables

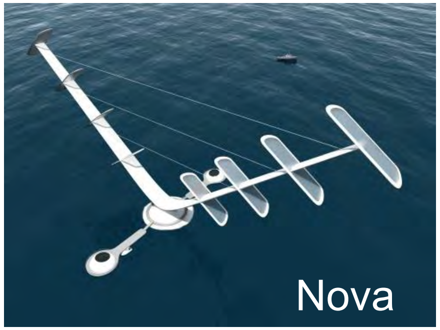


The DECC software won't let us replace all the fossil fuel with renewables.

We wanted to use some of the excess electricity from wind generation to make hydrogen for use in backup plants rather than fossil fuel.

The DECC Calculator simply exports it all. Note the very low losses

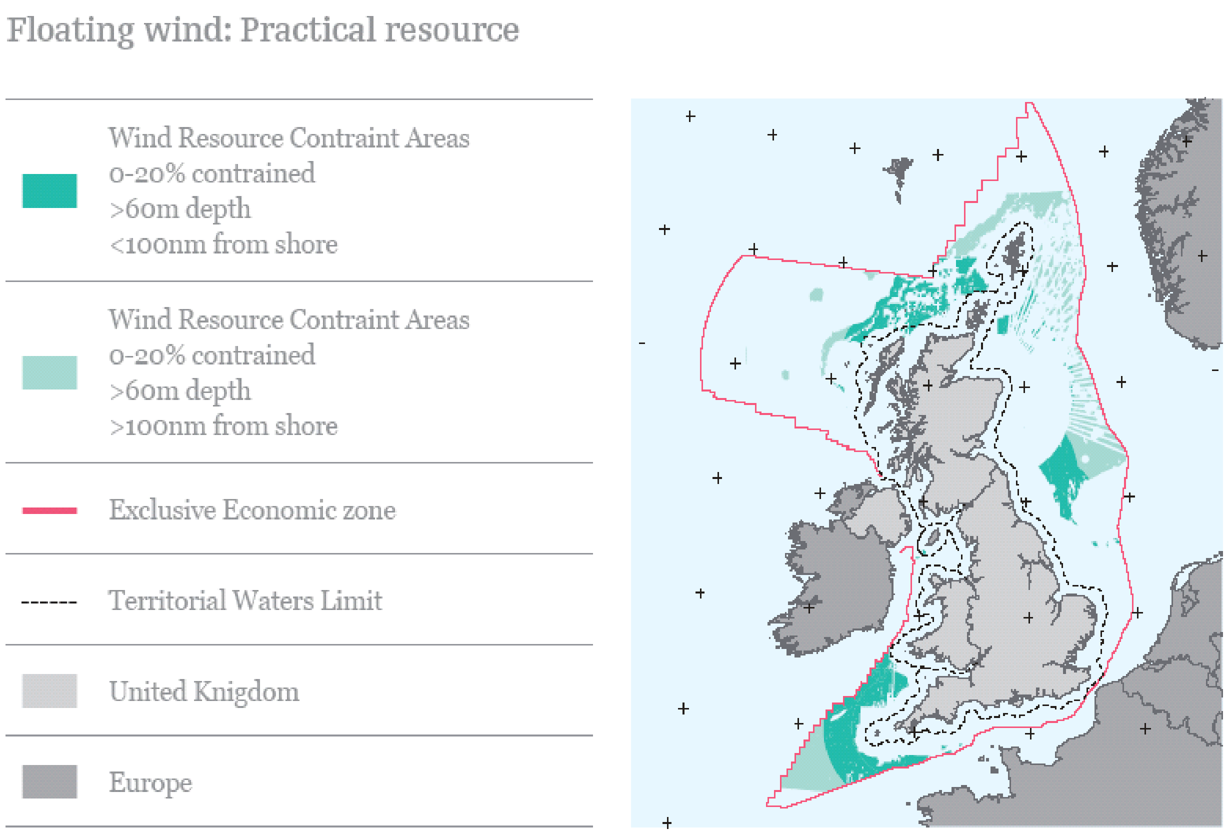
Marine inputs

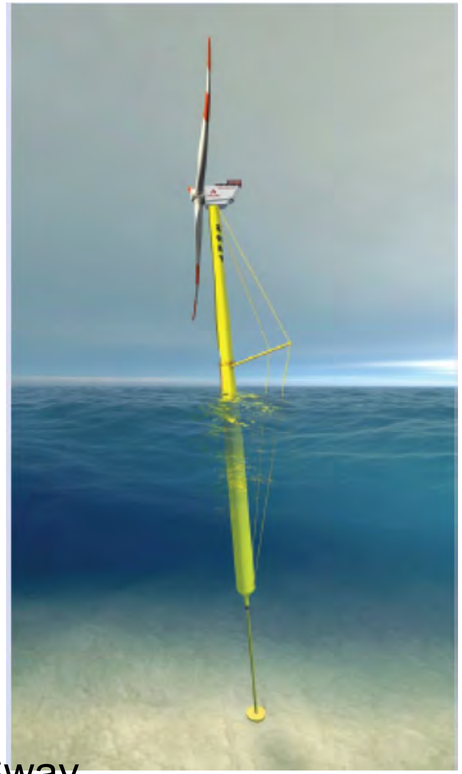


Our choice is well within the potential resource of

UK offshore wind, wave, tidal, amounting to 531 GW

(466 GW wind, 33GW tidal stream, 18GW wave, 14GW tidal range)

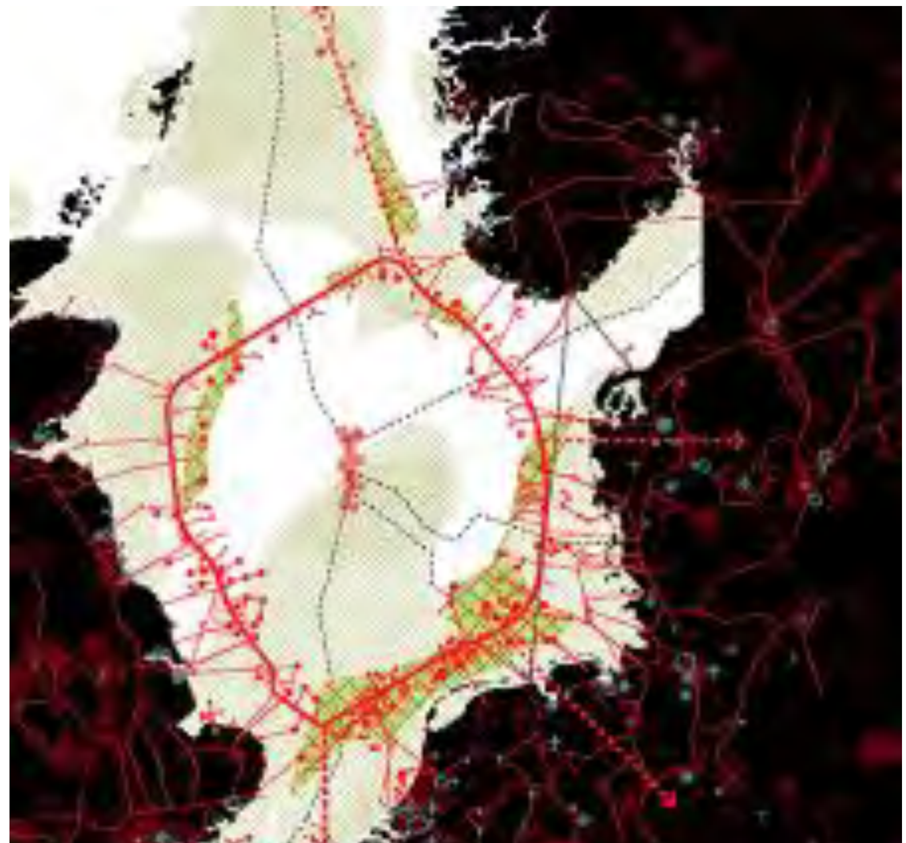



Sway

‘Offshore Valuation’, Public Interest Research Centre www.offshorevaluation.org/

Floating
array

Ring main
for the North
Sea



Combined Heat and Power/District Heating

The Royal Academy of Engineering commented that *'Larger district systems, incorporating a CHP facility and providing heating are significantly more efficient than*

domestic level installations.

Central systems may be more efficient and are likely to offer much greater energy storage than do systems designed for individual household'.

'Heat: degrees of comfort?' Royal Academy of Engineering, 2012, www.raeng.org.uk/heat

District Heating

Around 60% of Denmark's domestic/commercial heat is supplied by DH. Some fossil fired, some also fired by biomass. By 2050 it wants 40% of this to be solar fed, with *inter-seasonal* heat stores.

DH can also be fed by *large* heat pumps.

About 60% of the total energy input for Stockholm's Central Heat Network is provided by six l180 MW heat pumps, total heat supply capacity 420 MW(th). Helsinki in Finland has 90MW heat pump plant, feeding its district heating network. The network supplies over 93% of Helsinki's heat.

Biomass wood chip for combustion

Sources-energy crops (SRC), forestry wastes.

Biogas from Anaerobic Digestion- biomethane

Sources: Farm wastes, land fill gas, sewage gas,food waste

Land use

10% of UK land area used for energy crops

e.g. fast growing non-food Short Rotation Coppice

_72% of UK land is used for agricultural purposes (forestry excluded). Changes in farming practice and perhaps changes in diet would be needed.

But no biomass would be imported

Pugwash High Renewable Scenario summary of results

- The scenario balances total energy supply and demand using renewables for nearly all needs, with no biomass imports
- Even when variable renewables are low, supply meets demand with no need for fossil back up
- It is cheaper than the Pugwash High Nuclear and Intermediate scenarios and reduces emissions more
- Cumulative emissions are 12% less than High Nuclear and 14% less than Intermediate scenarios
- The net income from electricity exports set against imports would earn the UK £15.6 billion p.a.
- With the wind-to-gas backup option, it could be 100% renewable

The Intermediate Pathway

Presentation by Dr Ian Crossland

Aims of the Intermediate Pathway

- 80% reduction in GHG emissions on 1990 levels by:
  - Reduction in demand
  - Electrification of supply coupled with low carbon electricity generators
- High level of achievability
- Mixture of high output sources - general rejection of small output sources especially where they need a lot of development (PV, geothermal, small scale wind etc)
- More ambition with respect to energy demand than supply
- Standby generation ≤10% of total capacity

DEMAND

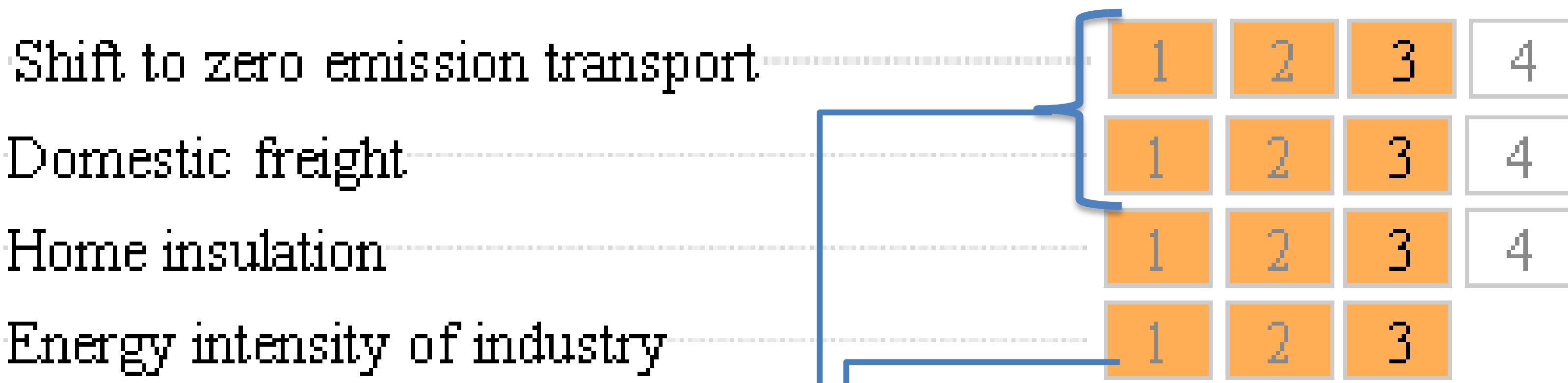
Domestic transport behaviour	1	2	3	4
Shift to zero emission transport	1	2	3	4
Choice of fuel cells or batteries	1	2	3	4
Domestic freight	1	2	3	4
International aviation	1	2	3	4
International shipping	1	2	3	4
Average temperature of homes	1	2	3	4
Home insulation	1	2	3	4
Home heating electrification	A	B	C	D
Home heating that isn't electric	A	B	C	D
Home lighting & appliances	1	2	3	4
Electrification of home cooking	A	B		
Growth in industry	A	B	C	
Energy intensity of industry	1	2	3	
Commercial demand for heating and cooling	1	2	3	4
Commercial heating electrification	A	B	C	D
Commercial heating that isn't electric	A	B	C	D
Commercial lighting & appliances	1	2	3	4
Electrification of commercial cooking	A	B		

SUPPLY

Nuclear power stations	1	2	3	4
CCS power stations	1	2	3	4
CCS power station fuel mix	A	B	C	D
Offshore wind	1	1.3	3	4
Onshore wind	1	2	3	4
Wave	1	2	3	4
Tidal Stream	1	2	3	4
Tidal Range	1	2	3	4
Biomass power stations	1	2	3	4
Solar panels for electricity	1	2	3	4
Solar panels for hot water	1	2	3	4
Geothermal electricity	1	2	3	4
Hydroelectric power stations	1	2	3	4
Small-scale wind	1	2	3	4
Electricity imports	1	2	3	4
Land dedicated to bioenergy	1	2	3	4
Livestock and their management	1	2	3	4
Volume of waste and recycling	A	B	C	D
Marine algae	1	2	3	4
Type of fuels from biomass	A	B	C	D
Bioenergy imports	1	2	3	4
Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

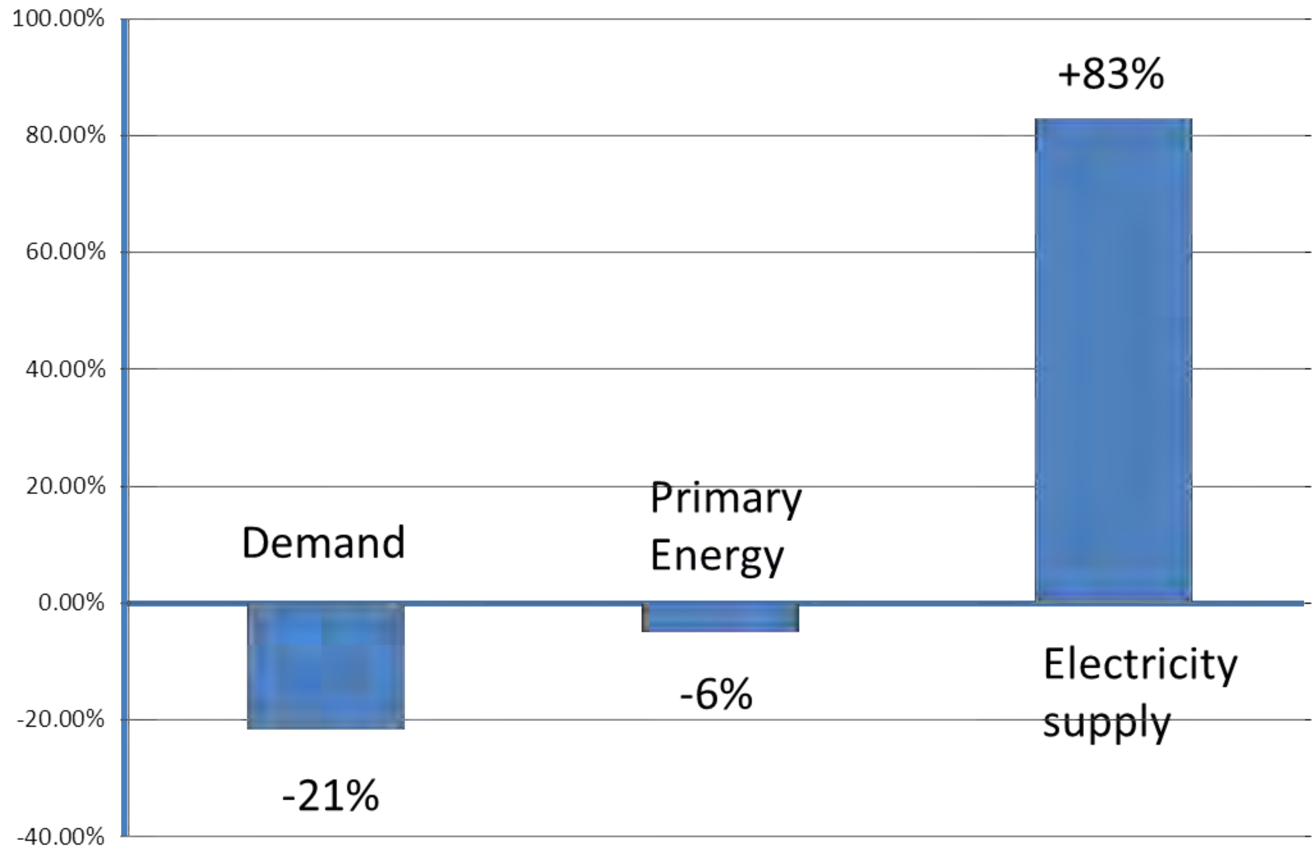
Reduction in demand at 2050

- Demand at 2050 reduced by 21.5% on 2010 as a result of four “very ambitious” (i.e. Level 3) choices:



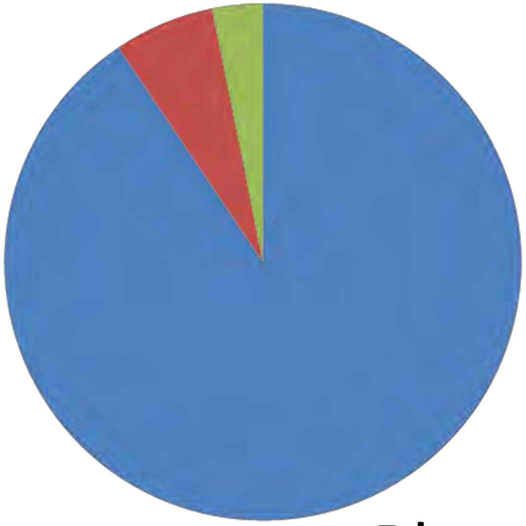
- Reduction in demand comes primarily from
  - Transport -31%
  - Industry -33%

Change in energy demand & supply 2010 to 2050

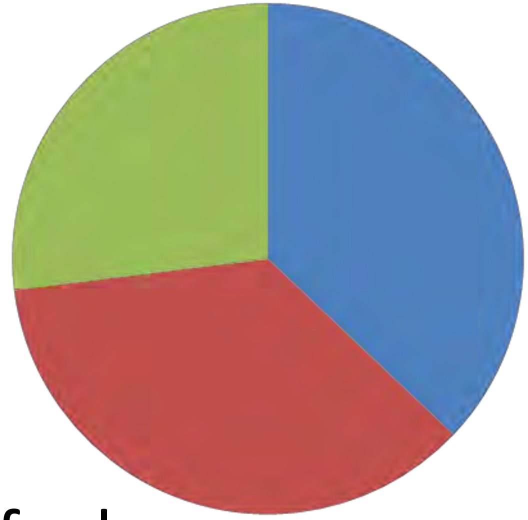


Intermediate pathway
Balance of primary supply

2010

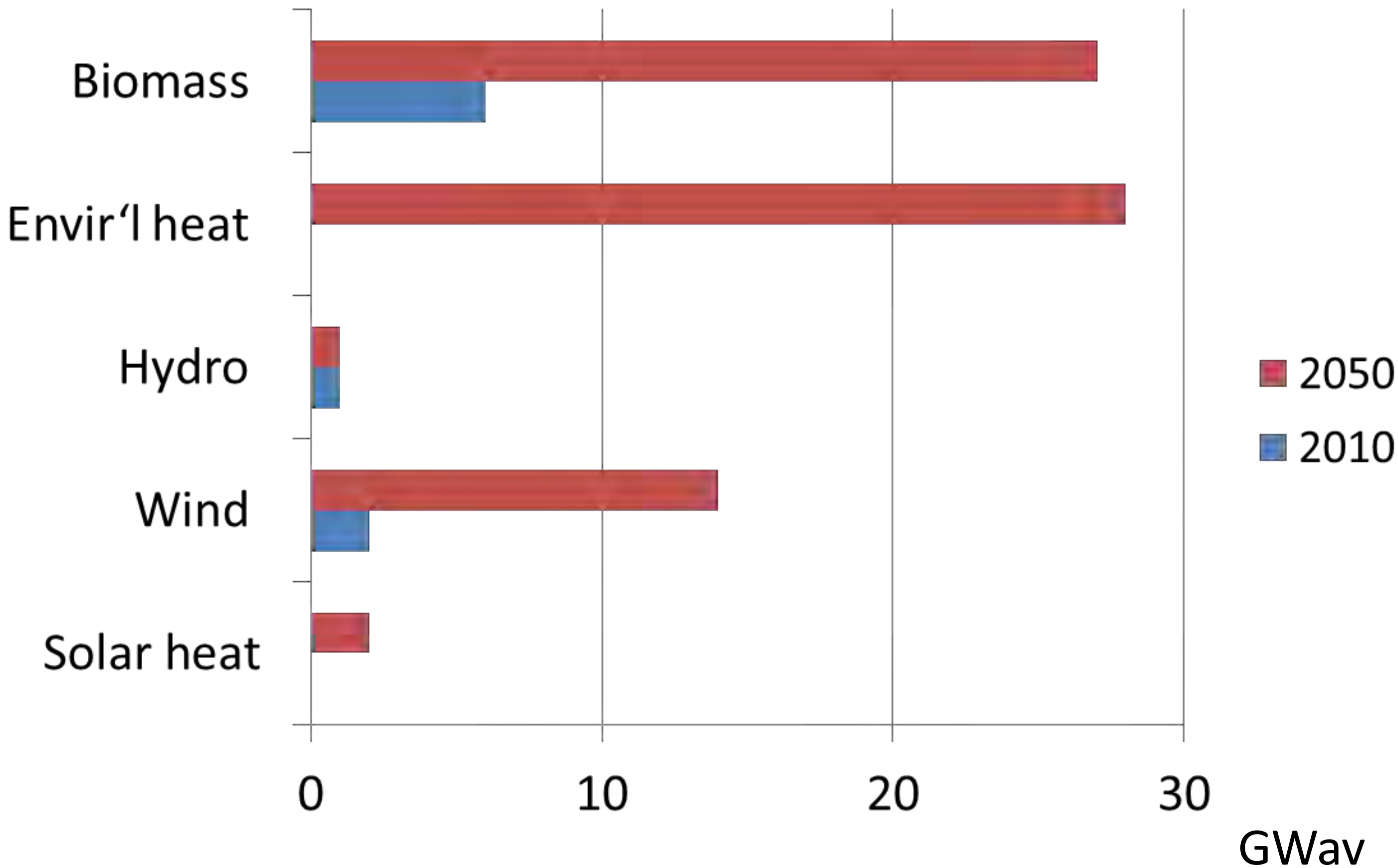


2050

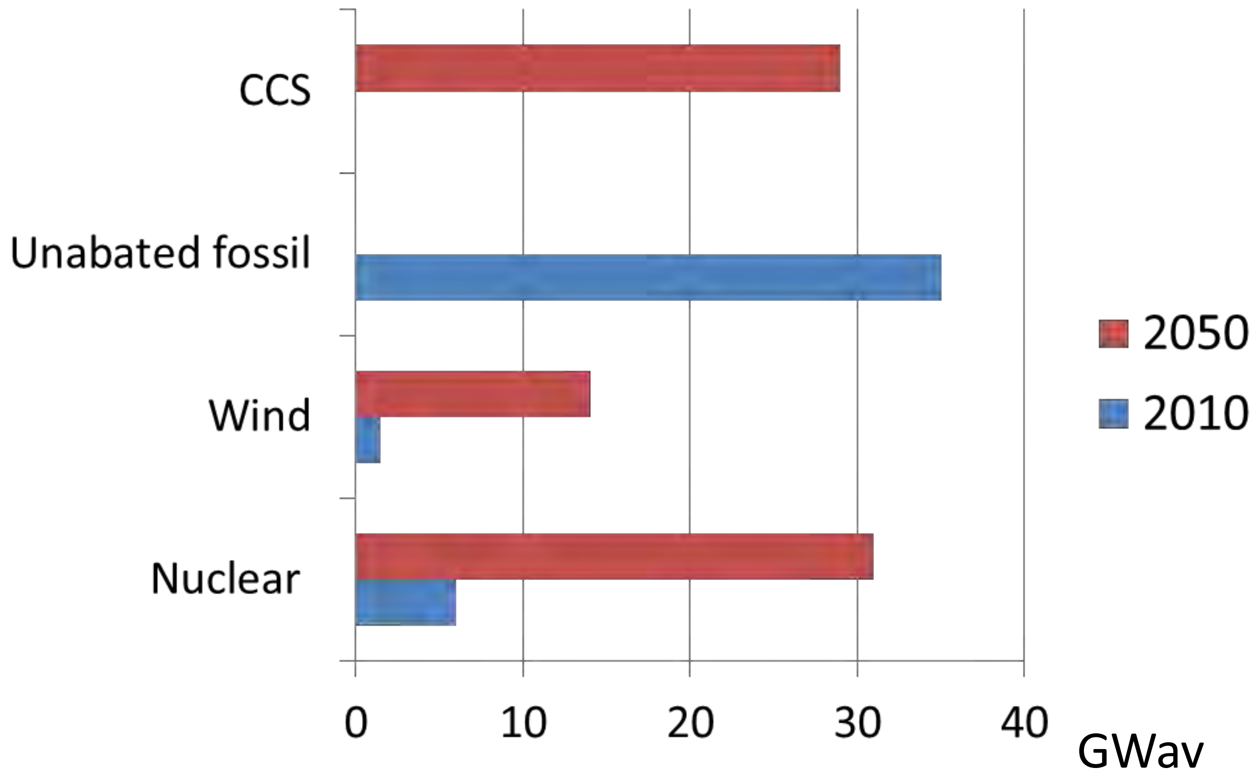


Blue – fossil fuels
Red – nuclear
Green - renewables

Intermediate pathway
Composition of renewables



Intermediate pathway
Electricity production 2010 & 2050



Intermediate pathway Conclusions

- A roughly equal combination of CCS, nuclear and renewables enables the 80% reduction in GHG emissions to be met. Pathway is broadly similar to NGC, Markal
- Some “very ambitious” targets for energy savings but no heroic assumptions
- An essential element is the use of biofuels with CCS to produce “negative” emissions. Without this, the 80% reduction cannot be met

A comparison of the three Pathways

High Nuclear (HN), High Renewables (HR) and Intermediate (Int)

- All three Pathways achieve some reduction in end-user demand by 2050 (HN and Int ~20%, HR ~40%). Larger reductions are controversial.
- All three approximately double the electrical energy supplied, because of end-use electrification, but the HR capacity is much higher, so as to give a reserve to cope with renewables intermittency
- Two of the three Pathways expand the Nuclear fleet beyond the immediate ‘new build’ scale (HN 80 GWe, Int 39 GWe). The third eliminates it altogether.
- All three Pathways include some renewable energy capacity, but the amounts vary greatly (HN 18 GW, Int 40 GW, HR 181 GW)
- All three include some CCS (HR 2 GW, HN 21 GW, Int 51 GW)
- All three achieve the 80% reduction in emissions by 2050: the HR Pathway achieves reductions earlier, because it has no nuclear build
- All three Pathways are estimated to cost £3 trillion over the period 2010-2050. The differences between them are less than the uncertainties.

Issues to take into account in reaching a decision

- Technical risk:
  - Nuclear – none of the 3rd generation designs under consideration is yet fully proven
  - Renewables – apart from onshore wind, none of the technologies are yet fully commercially competitive, and onshore wind has land use and public acceptability issues
  - CCS – there is as yet no full-scale commercial plant anywhere in the world, and there are uncertainties about its cost and infrastructure requirements
- Commercial risk: trends in the cost of all the relevant technologies are hard to predict
- UK industrial infrastructure: we have lost much of our historic nuclear capability, and have not yet created a capability for rapid manufacture of renewable or CCS technology on the required scale

Issues to take into account in reaching a decision

continued

- Safety issues: a major nuclear disaster has occurred somewhere in the world about once every decade. There is also ongoing public concern about radioactive waste disposal.
- Environmental issues: biocrop and onshore wind make high demands on UK land (10% and 1% respectively of the UK land area for the High Renewables Pathway). Extensive industrial activity on upland peat areas would threaten its ability to sequester CO_2.
- Nuclear non-proliferation commitments: the UK has a special position as a Nuclear Weapon state
- International trade: the UK needs to position itself to benefit from the new energy market
- Public opinion and national politics: recent polls have sent ambiguous signals about public preferences and concerns, and there is as yet no cross-party political consensus about the right way forward. The only universal message seems to be ‘not in my back yard’.

Conclusions and recommendations

- During the next 40 years, the UK will have to rebuild its energy infrastructure almost completely, at a cost of ~ £3 trillion. This is a heroic, but not completely unrealistic task.
- There is no public or cross-party consensus about the technologies which should be used, and no clear government lead. A decision is urgently needed, because of the imminent climate change threat.
- British Pugwash has put forward three very different Pathways, each of which draws on a broadly credible set of technologies, has a roughly similar cost, and meets the UK commitment to reducing its GHG emissions by 80% by 2050.
- Each Pathway has advantages and risks, and a decision between them needs to be taken by exercising judgement on the probabilities, taking account of both quantifiable and unquantifiable issues.
- We urge the government to exercise leadership, and to come forward with a single plan with:
  - named technologies,
  - target dates for the construction of full-scale commercial plants of the chosen types,
  - a management team capable of implementing that plan, and
  - a set of government-funded inducements to the private sector to play its part in implementation.
- We hope that this report will encourage a prompt public debate on UK energy policy.