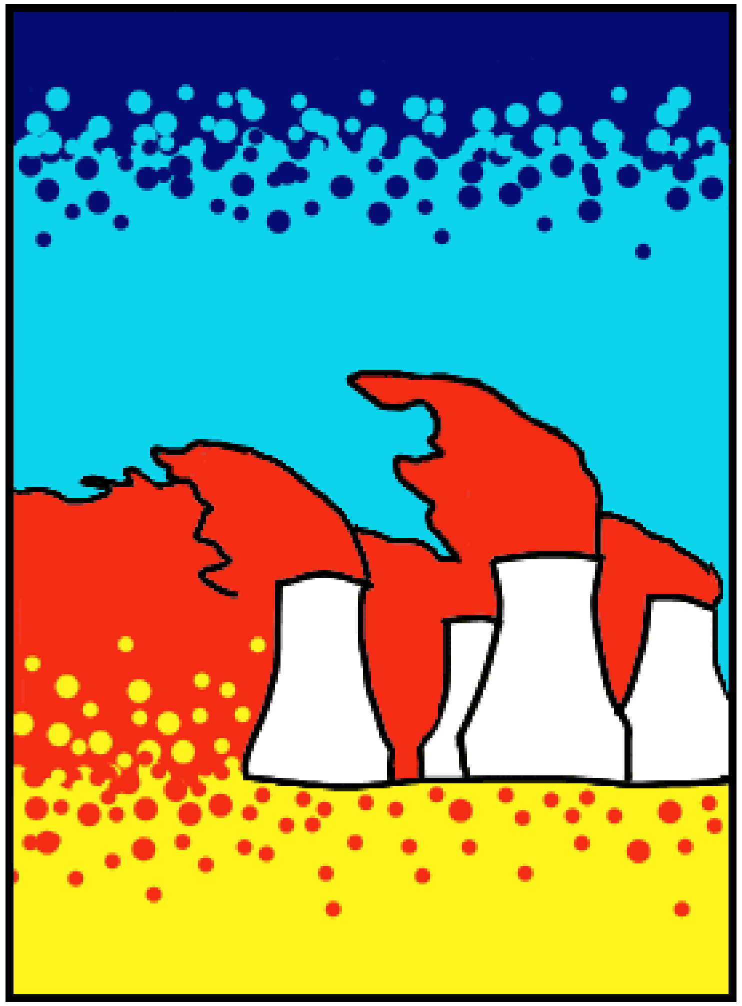
Physics of Sustainability

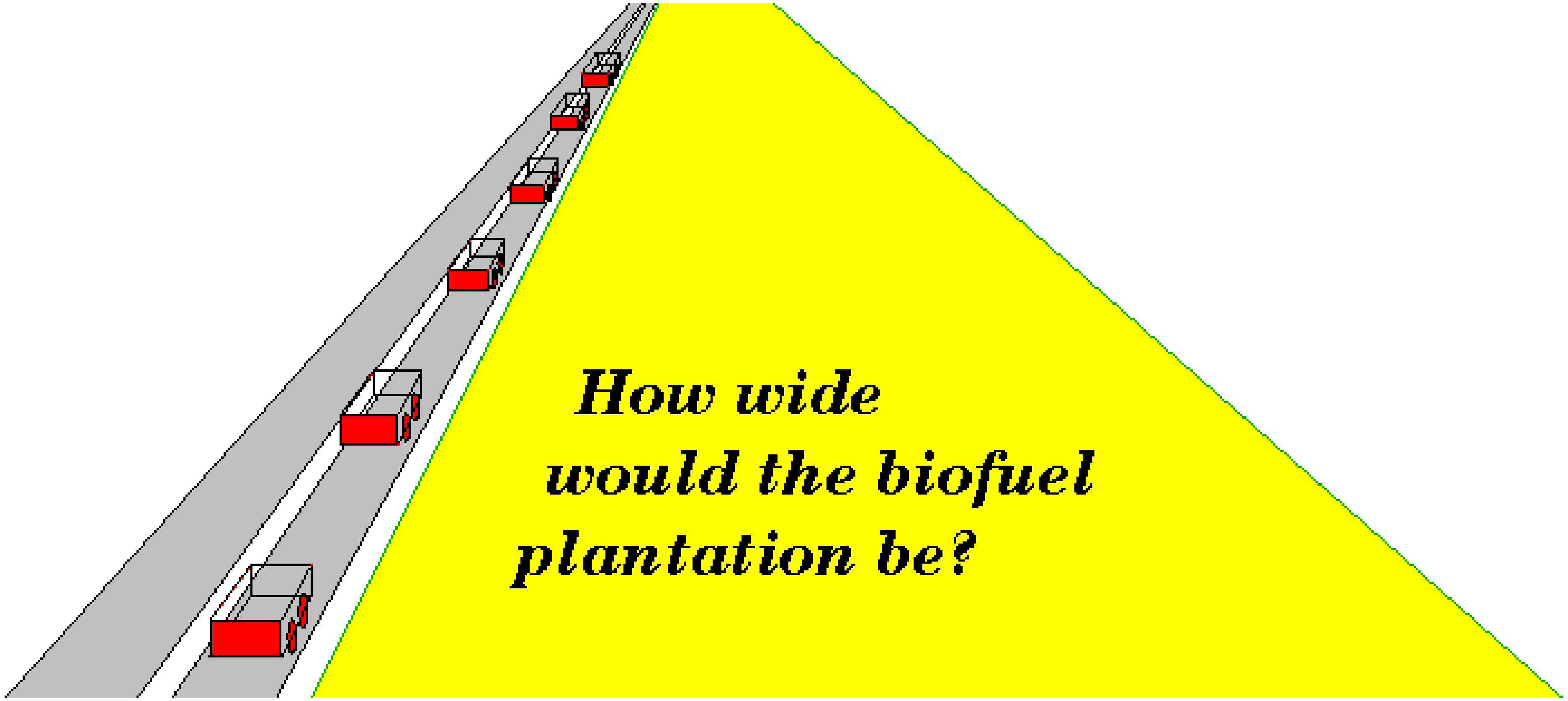
A UK Perspective

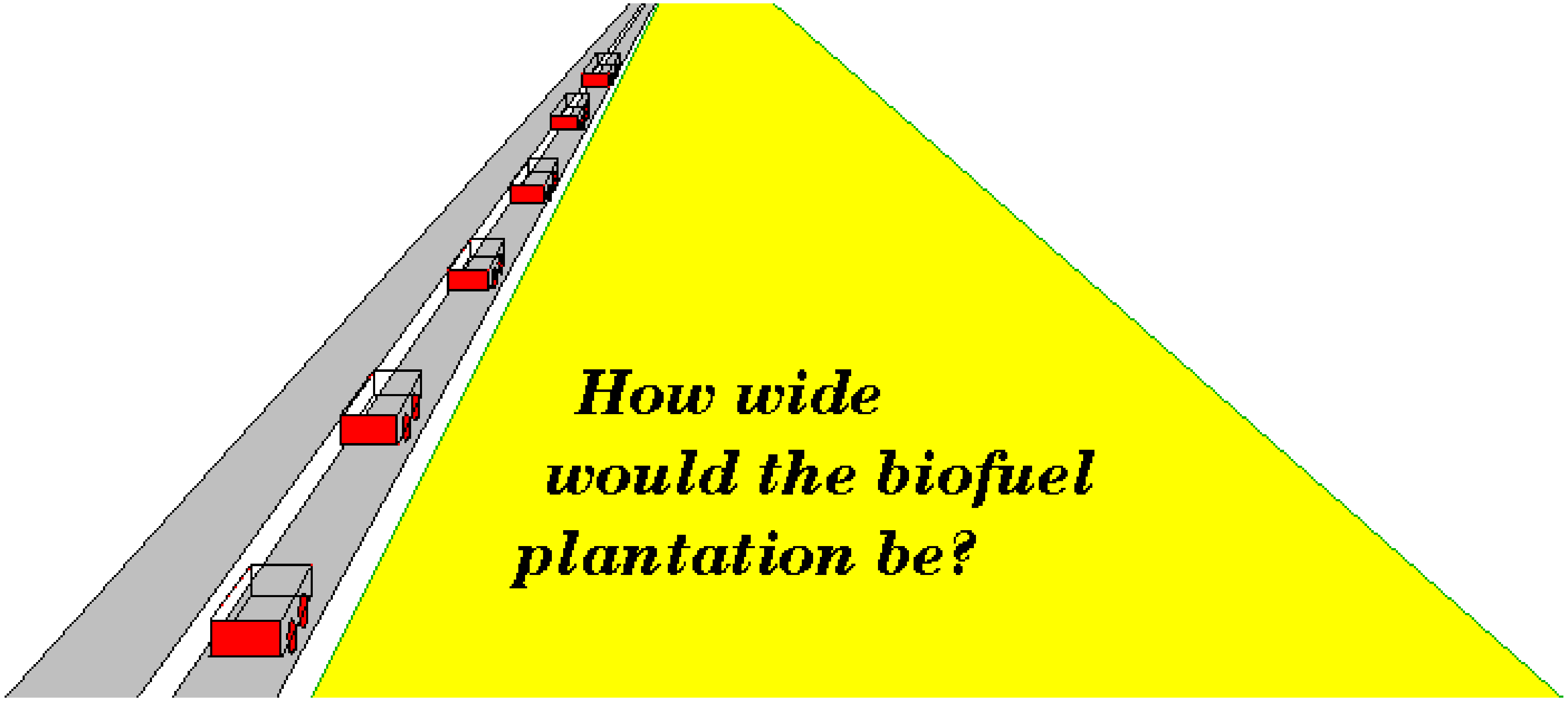


David MacKay FRS

Cavendish Laboratory
University of Cambridge

www.withouthotair.com

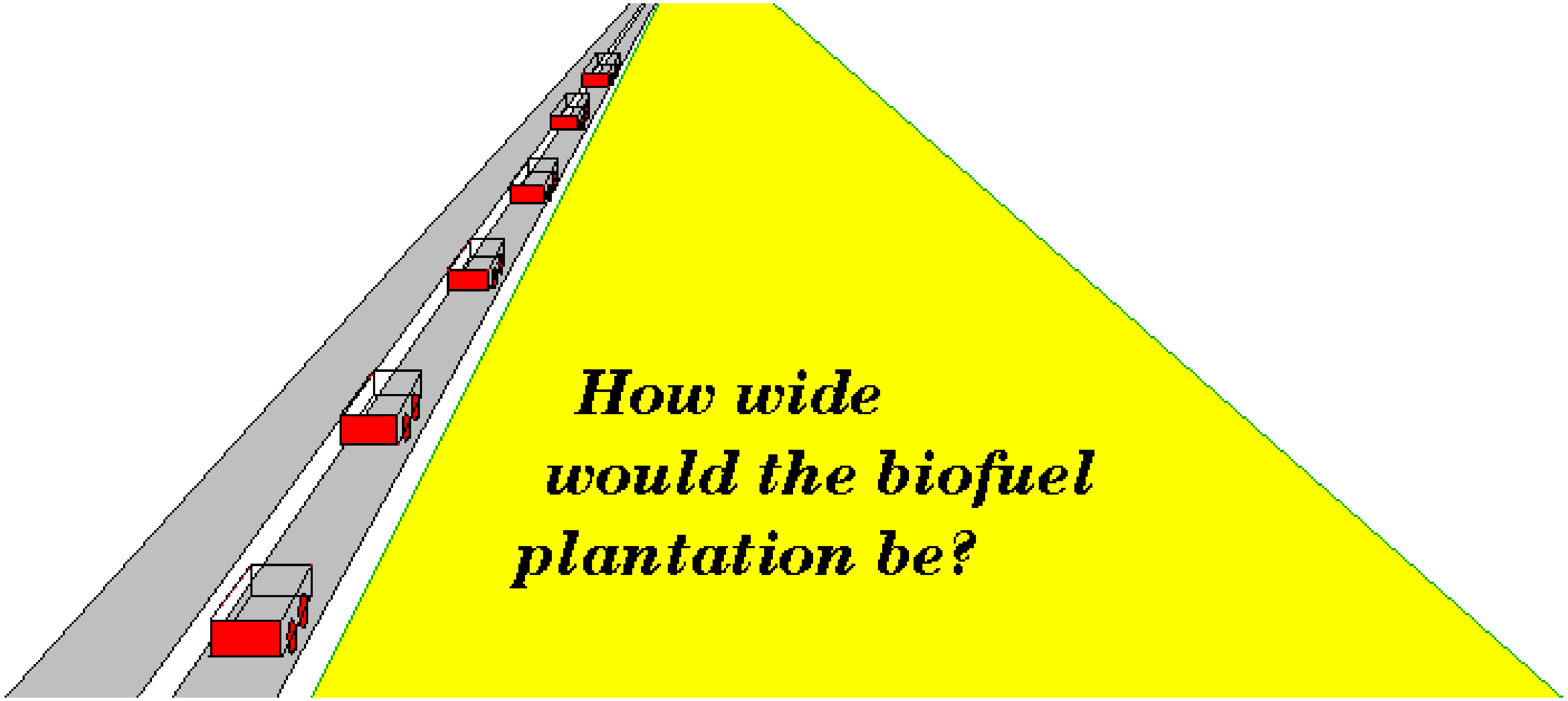

How wide
would the biofuel
plantation be?



One lane of cars

60 miles per hour

30 miles per gallon
1200 litres of biofuel per hectare per year
80 metres car-spacing



One lane of cars

60 miles per hour

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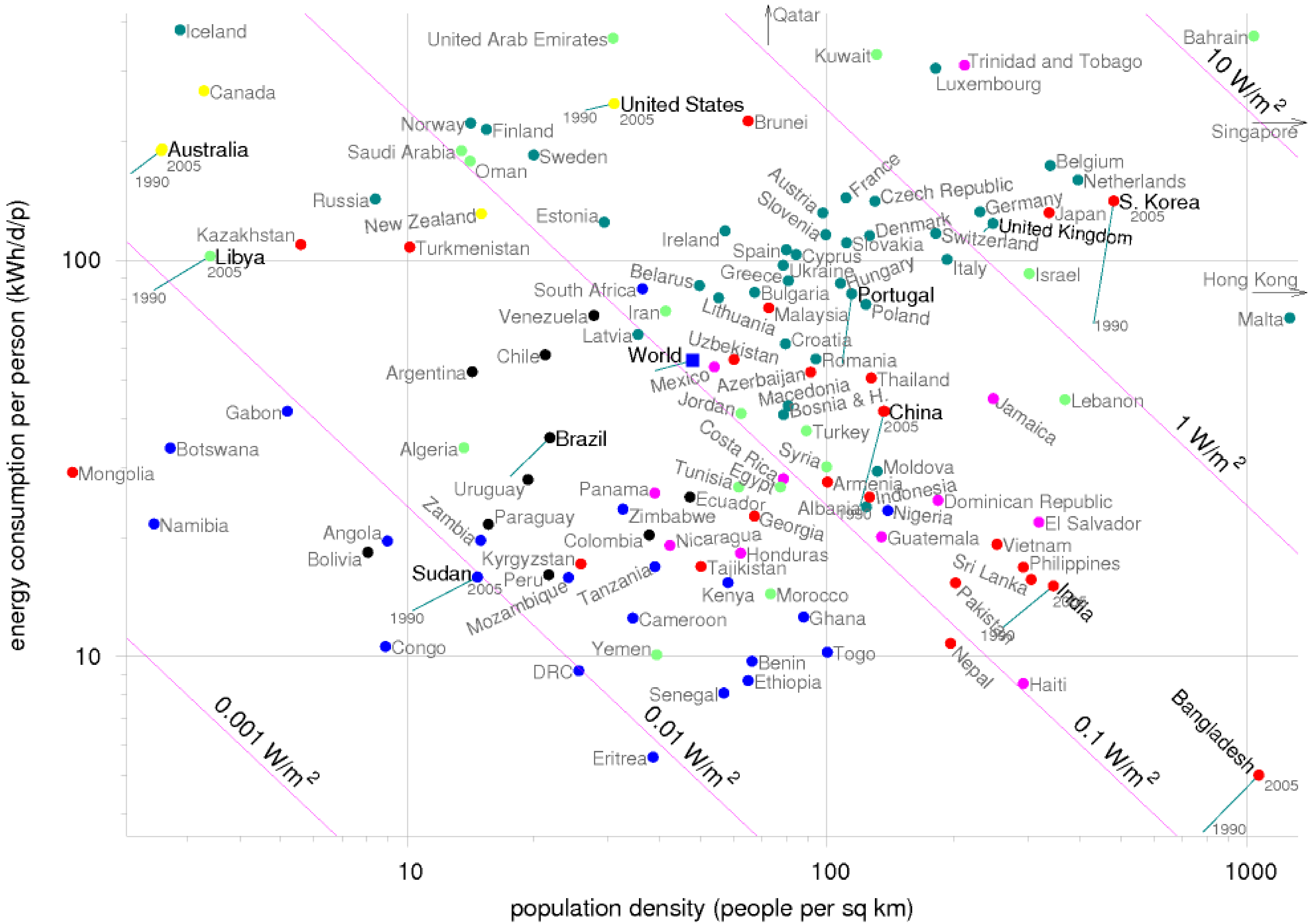
30 miles per gallon

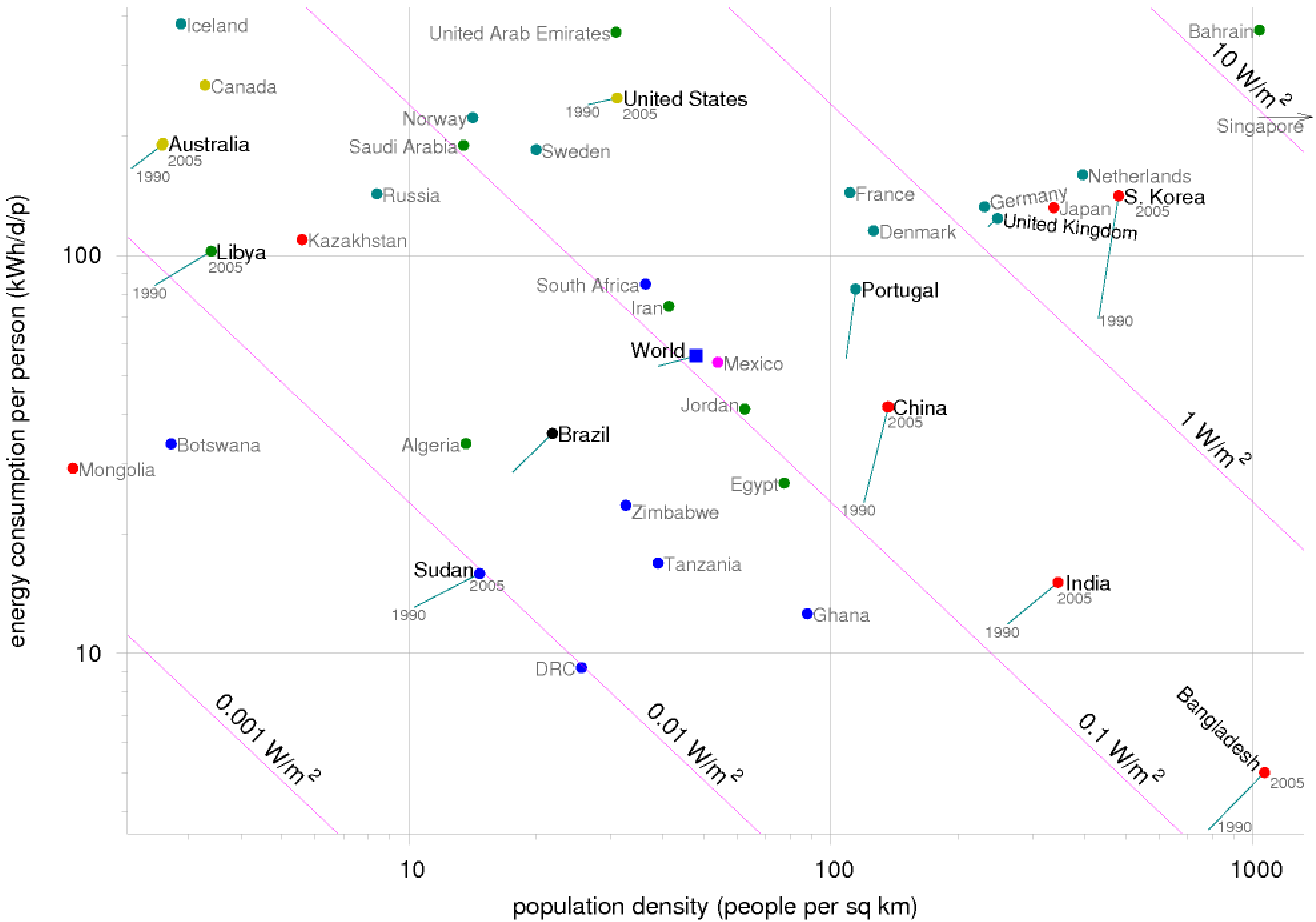
1200 litres of biofuel per hectare per year

80 metres car-spacing

= 8 kilometres wide



energy consumption per person (kWh/d/p)
population density (people per sq km)
10
100
1000
0.001 W/m²
0.01 W/m²
0.1 W/m²
1 W/m²
10 W/m²
Iceland
Canada
Australia
Libya
Mongolia
Namibia
Botswana
Gabon
Kazakhstan
Russia
Norway
Finland
Saudi Arabia
Oman
Sweden
New Zealand
Estonia
Turkmenistan
United Arab Emirates
United States
Brunei
Qatar
Kuwait
Trinidad and Tobago
Luxembourg
Bahrain
Singapore
Hong Kong
Malta
Belgium
Netherlands
S. Korea
Japan
Germany
United Kingdom
Switzerland
Czech Republic
France
Austria
Slovenia
Denmark
Slovakia
Ireland
Spain
Cyprus
Italy
Israel
Greece
Ukraine
Hungary
Portugal
Poland
Bulgaria
Belarus
South Africa
Iran
Malaysia
Lithuania
Venezuela
Latvia
Croatia
Uzbekistan
Chile
World
Romania
Mexico
Azerbaijan
Thailand
Argentina
Macedonia
Bosnia & H.
Jordan
China
Jamaica
Lebanon
Turkey
Costa Rica
Syria
Algeria
Brazil
Uruguay
Tunisia
Egypt
Moldova
Armenia
Indonesia
Panama
Ecuador
Dominican Republic
Albania
Nigeria
Zimbabwe
Georgia
El Salvador
Paraguay
Zambia
Angola
Colombia
Nicaragua
Guatemala
Vietnam
Bolivia
Kyrgyzstan
Honduras
Philippines
Sri Lanka
Sudan
Peru
Tajikistan
Tanzania
Mozambique
Kenya
Morocco
Pakistan
India
Cameroon
Ghana
Congo
Yemen
Togo
Nepal
DRC
Benin
Ethiopia
Haiti
Senegal
Bangladesh
Eritrea
1990
2005



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population density (people per sq km)
10
100
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Iceland
United Arab Emirates
Bahrain
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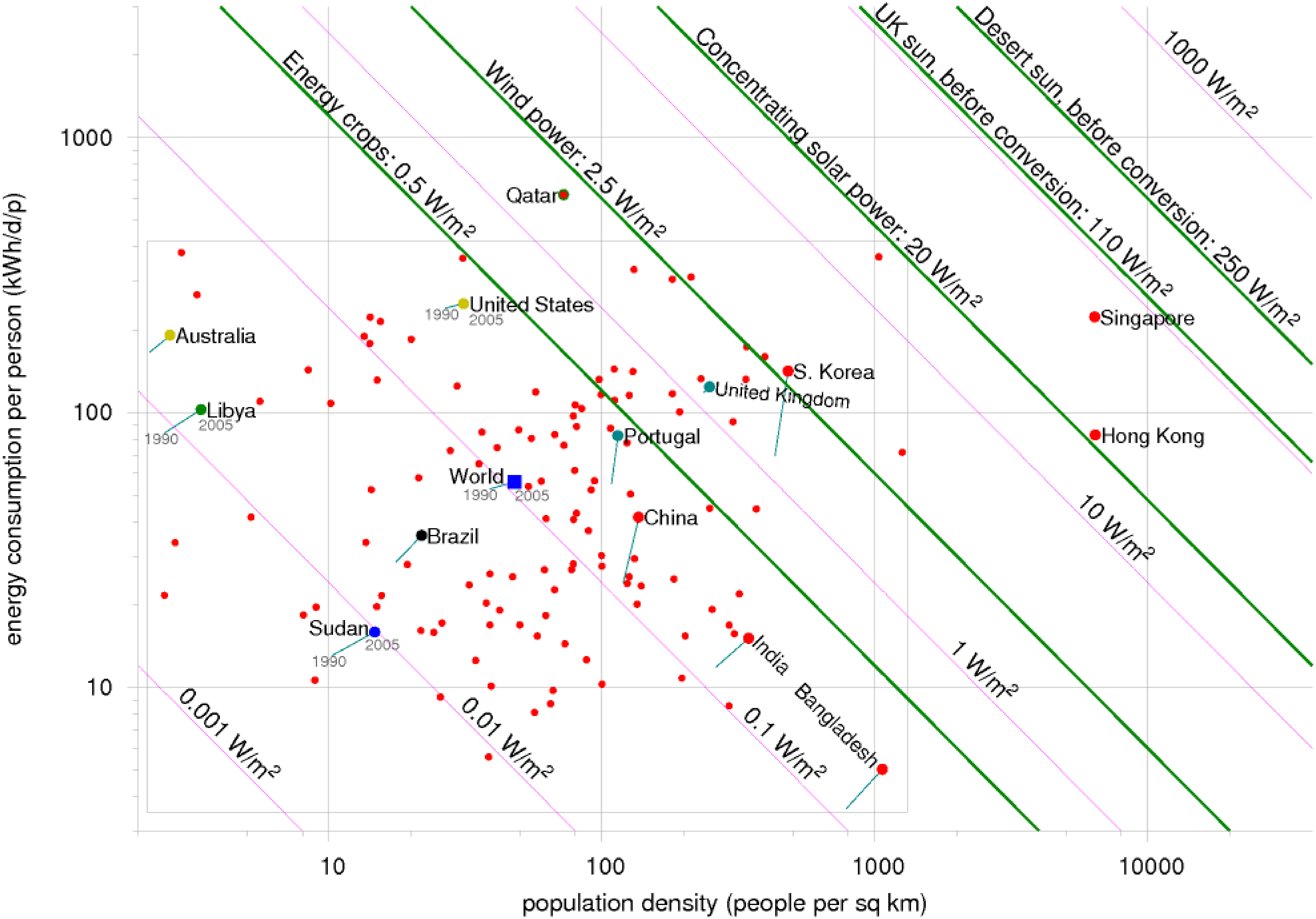
United States
1990
2005
Norway
Singapore
Australia
2005
1990
Saudi Arabia
Sweden
Russia
France
Netherlands
Germany
Japan
S. Korea
2005
United Kingdom
Denmark
Kazakhstan
Libya
2005
1990
South Africa
Iran
Portugal
1990
World
Mexico
Jordan
China
2005
1990
Brazil
Botswana
Algeria
Mongolia
Egypt
Zimbabwe
Tanzania
Sudan
2005
1990
India
2005
1990
Ghana
DRC
Bangladesh
2005
1990
0.001 W/m2
0.01 W/m2
0.1 W/m2
1 W/m2
10 W/m2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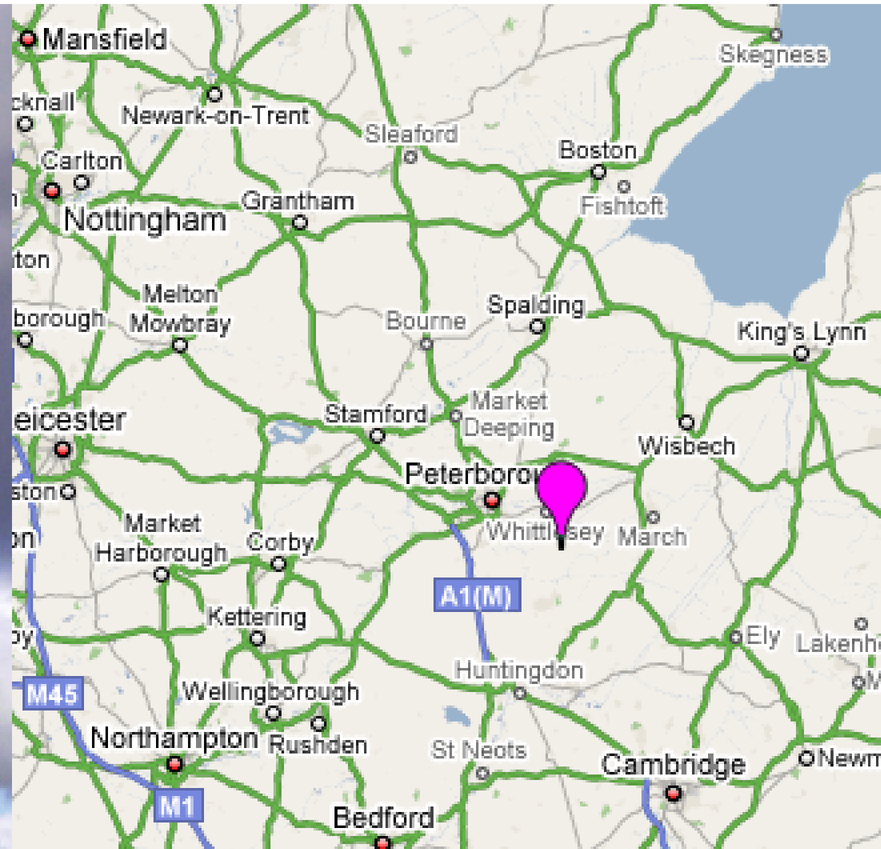
population density (people per sq km)

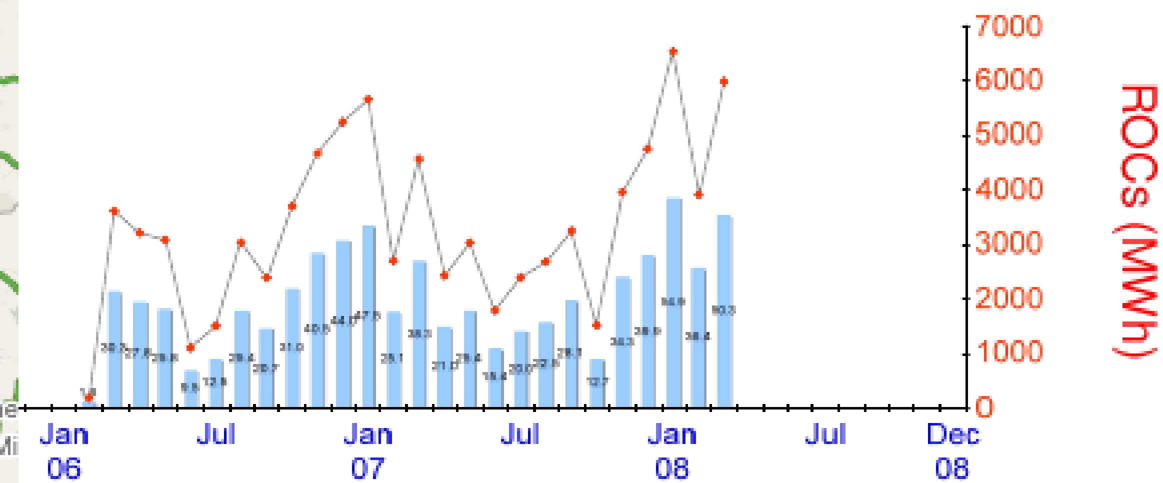
82m diameter

Glass Moor, Peterborough, Cambridgeshire



R.O. ID **R00159RQEN**

Current TIGC (kW) 16,000



Annual Summary

Year	Annual TIGC (kW)	Annual ROCs (MWh)	Annual LF (%)
2002	0	0	
2003	0	0	
2004	0	0	
2005	0	0	
2006	16,000	31,645	
2007	16,000	38,635	27.6

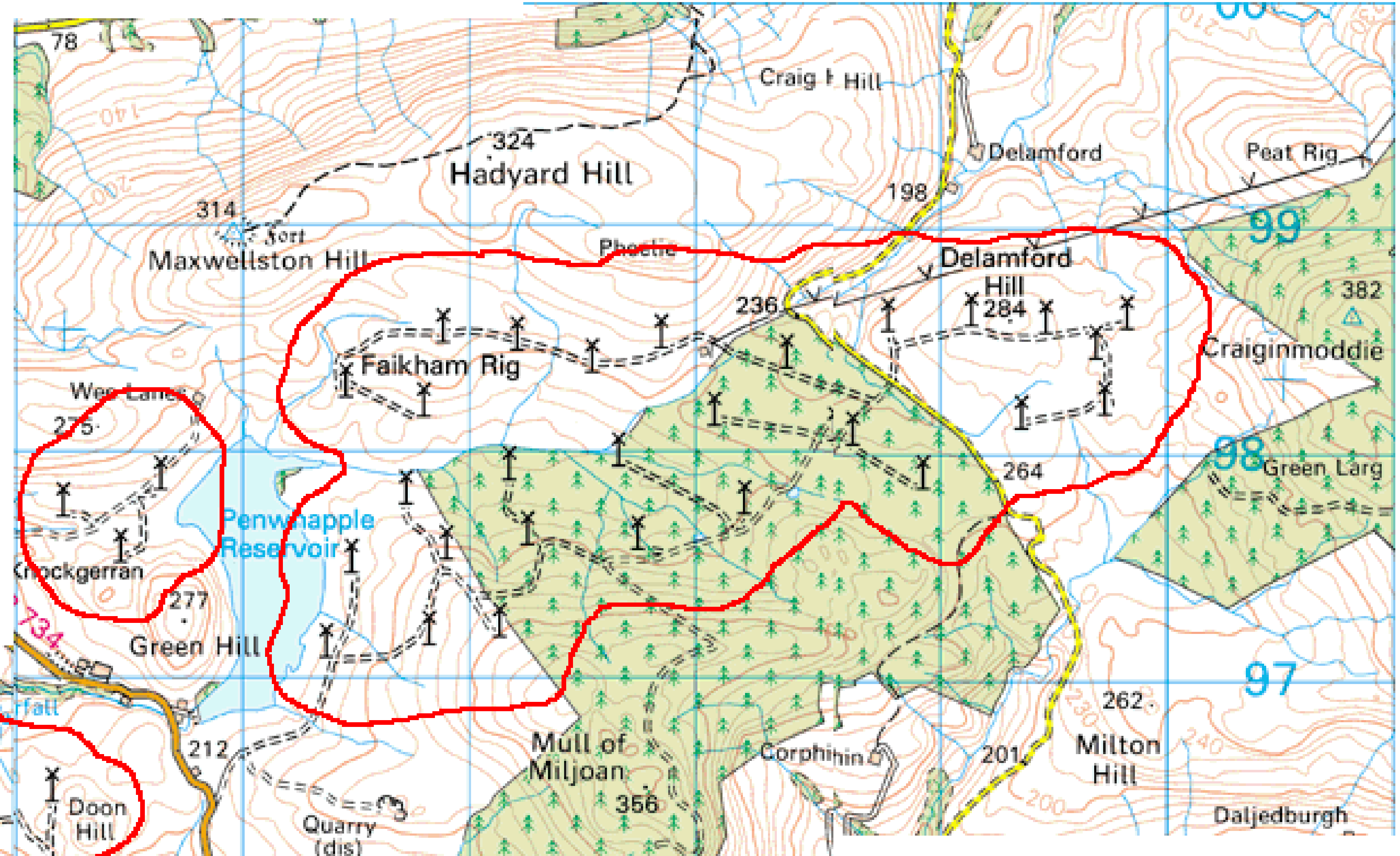
Turbine Summary

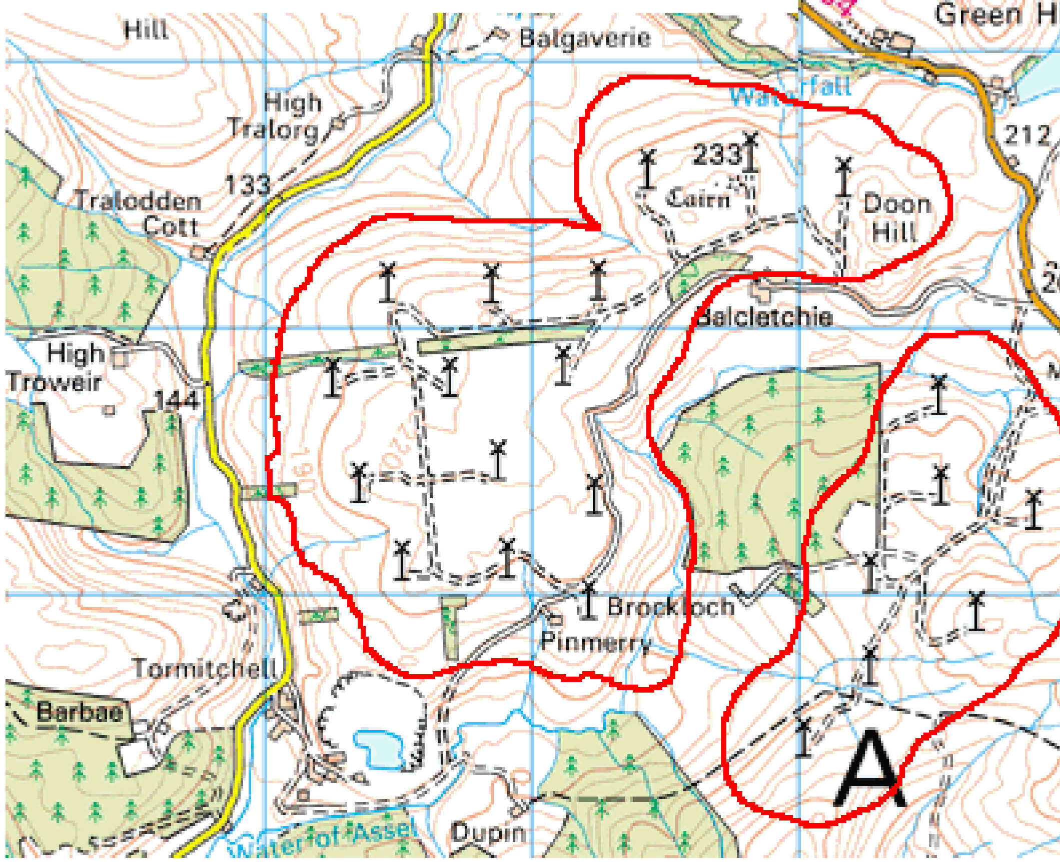
Wind turbine model	REPower
No of turbines	8
Size of turbine (kW)	2,000
Rotor diameter (m)	82
Hub height (m)	59

Average 4.4 MW from 2 km^2

Power per unit area: 2.2 W/m^2

Hadyard Hill

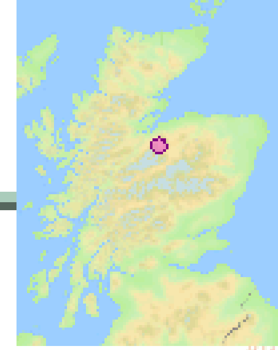


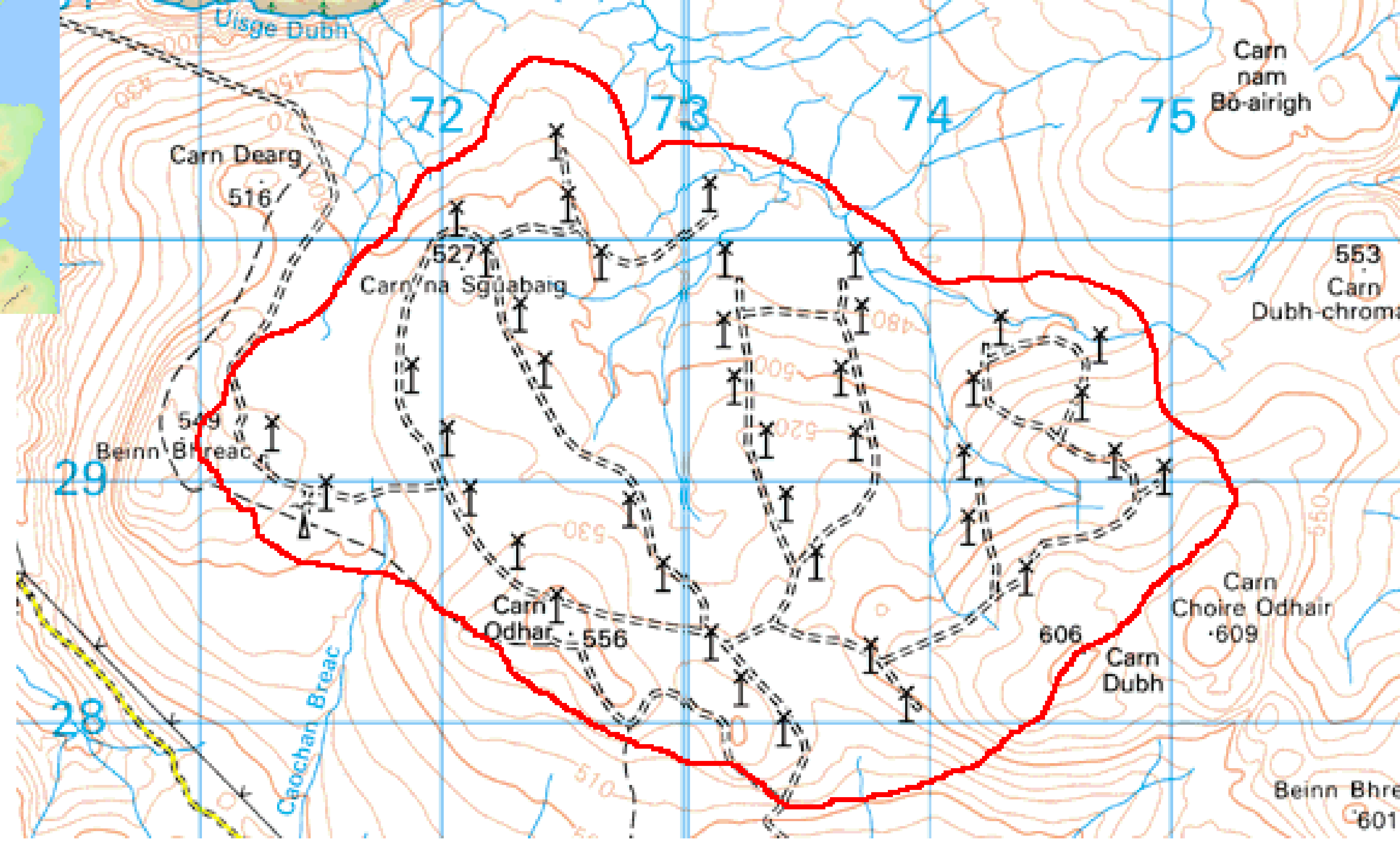


Average 29 MW from 10.2 km^2

Power per unit area: 2.8 W/m^2

Farr windfarm





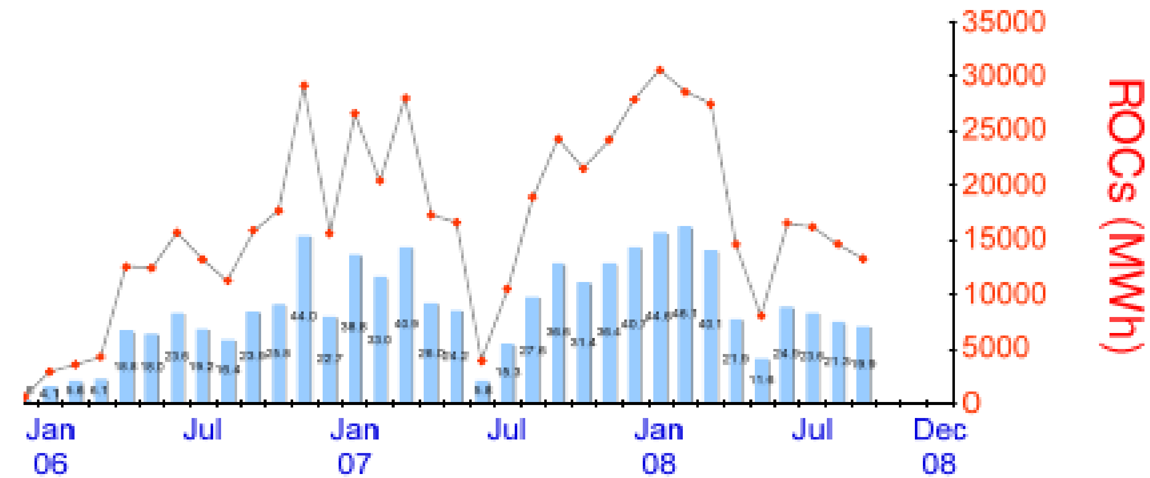
92MW Capacity

Average 27 MW from 8 km^2

Power per unit area: 3.4 W/m^2

Load factor 29.7%

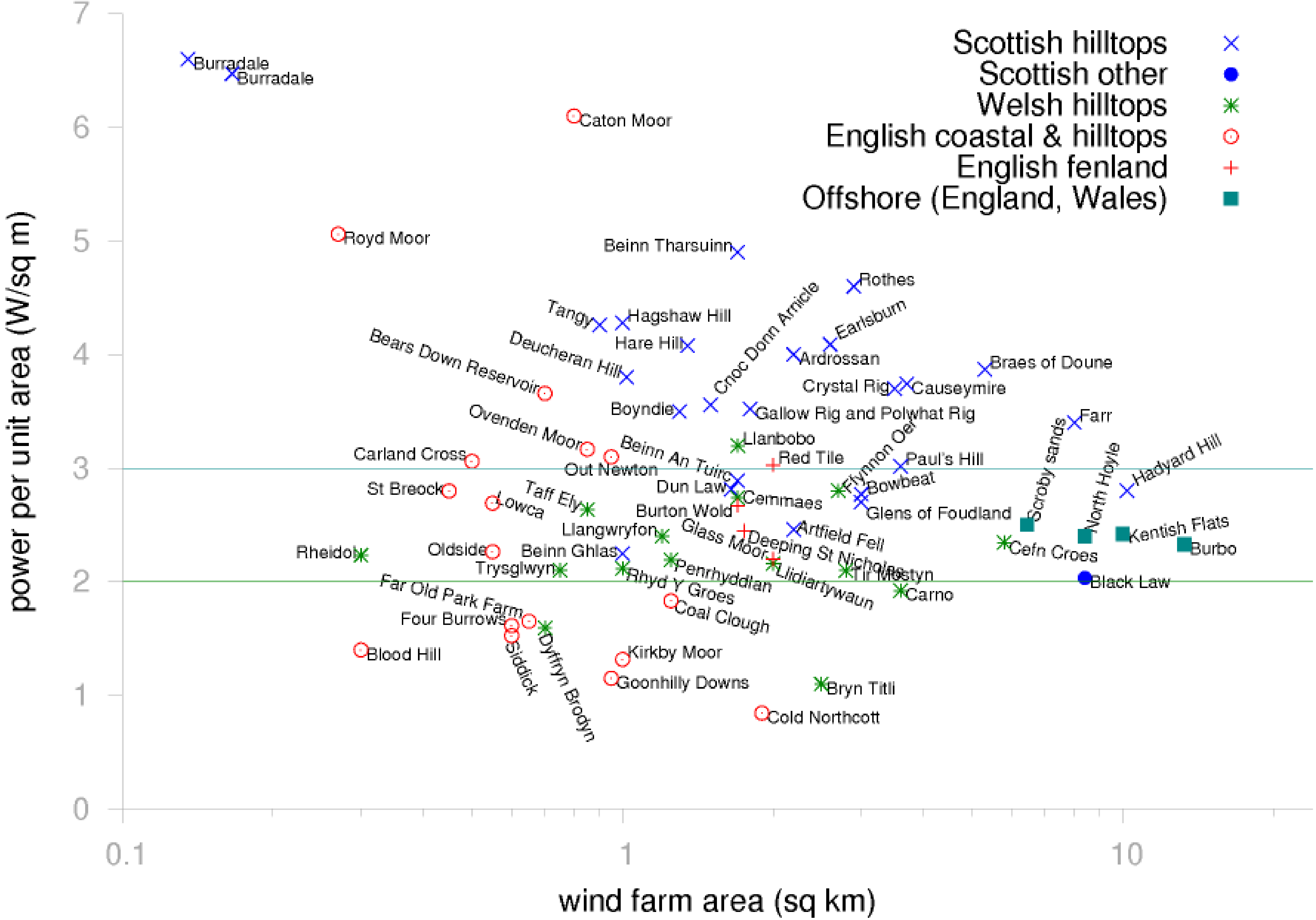
photo by richard1151

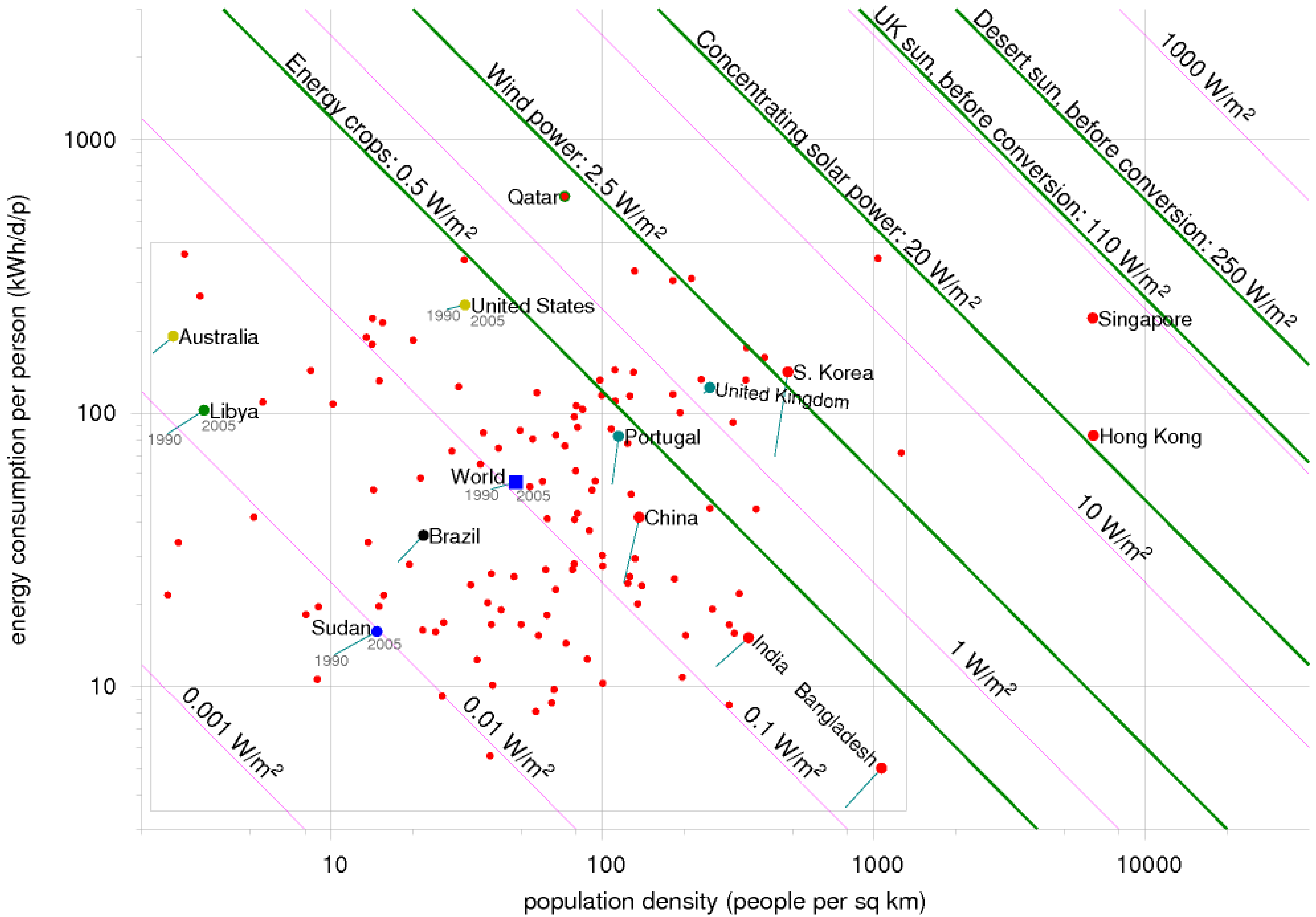


Annual Summary			
Year	Annual TIGC (kW)	Annual ROCs (MWh)	Annual LF (%)
2002	92,000	0	
2003	92,000	0	
2004	92,000	0	
2005	92,000	519	
2006	92,000	153,419	19.0
2007	92,000	239,520	29.7

Turbine Summary	
Wind turbine model	Bonus 2.3
No of turbines	40
Size of turbine (kW)	2,300
Rotor diameter (m)	
Hub height (m)	

Powers per unit area of British wind farms, v farm size





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energy consumption per person (kWh/d/p)
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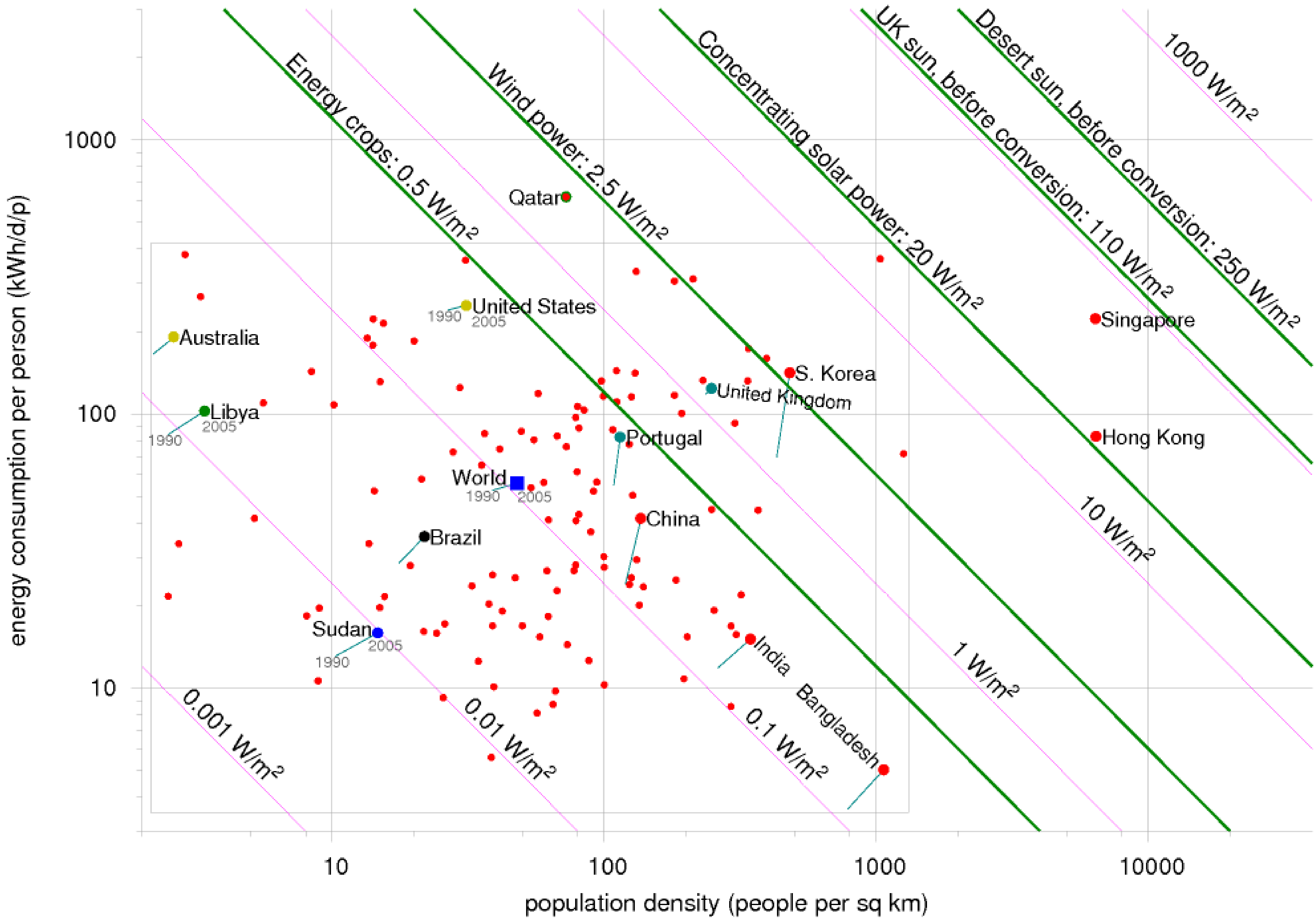
population density (people per sq km)


To get 17 kWh/d per person from wind (on average):
[all UK electricity, today]
One 2-MW turbine for every 700 people
Roughly 60-fold increase over today's UK wind
Area of wind farms: roughly 7% of UK



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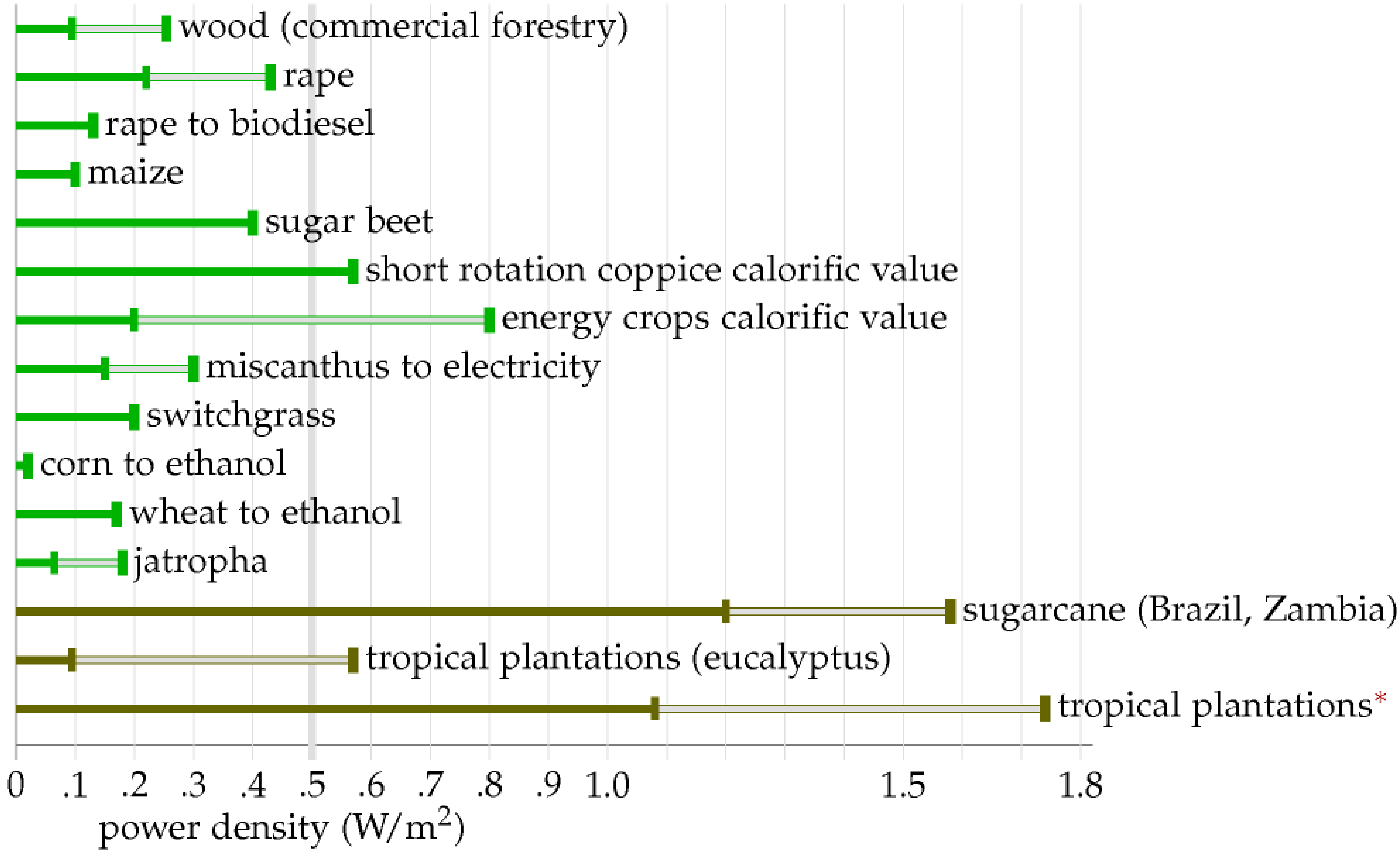
Hong Kong

Miscanthus

Dr Emily Heaton is 5'4" (163 cm) tall

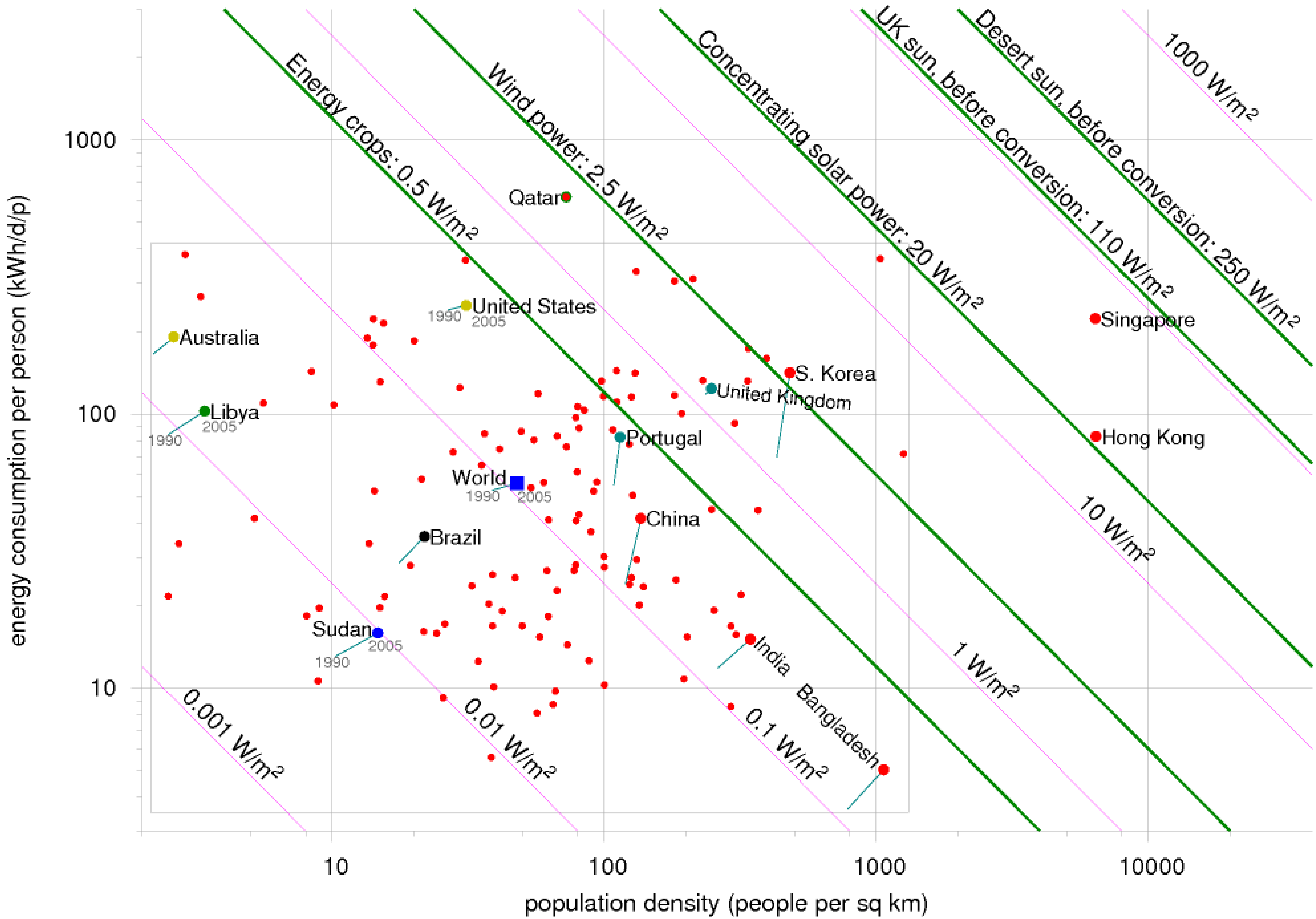
Photo provided by the University of Illinois

Plant power per unit area



* assumes genetic modification, fertilizer application, and irrigation

For sources, see D J C MacKay (2008) Sustainable Energy - without the hot air



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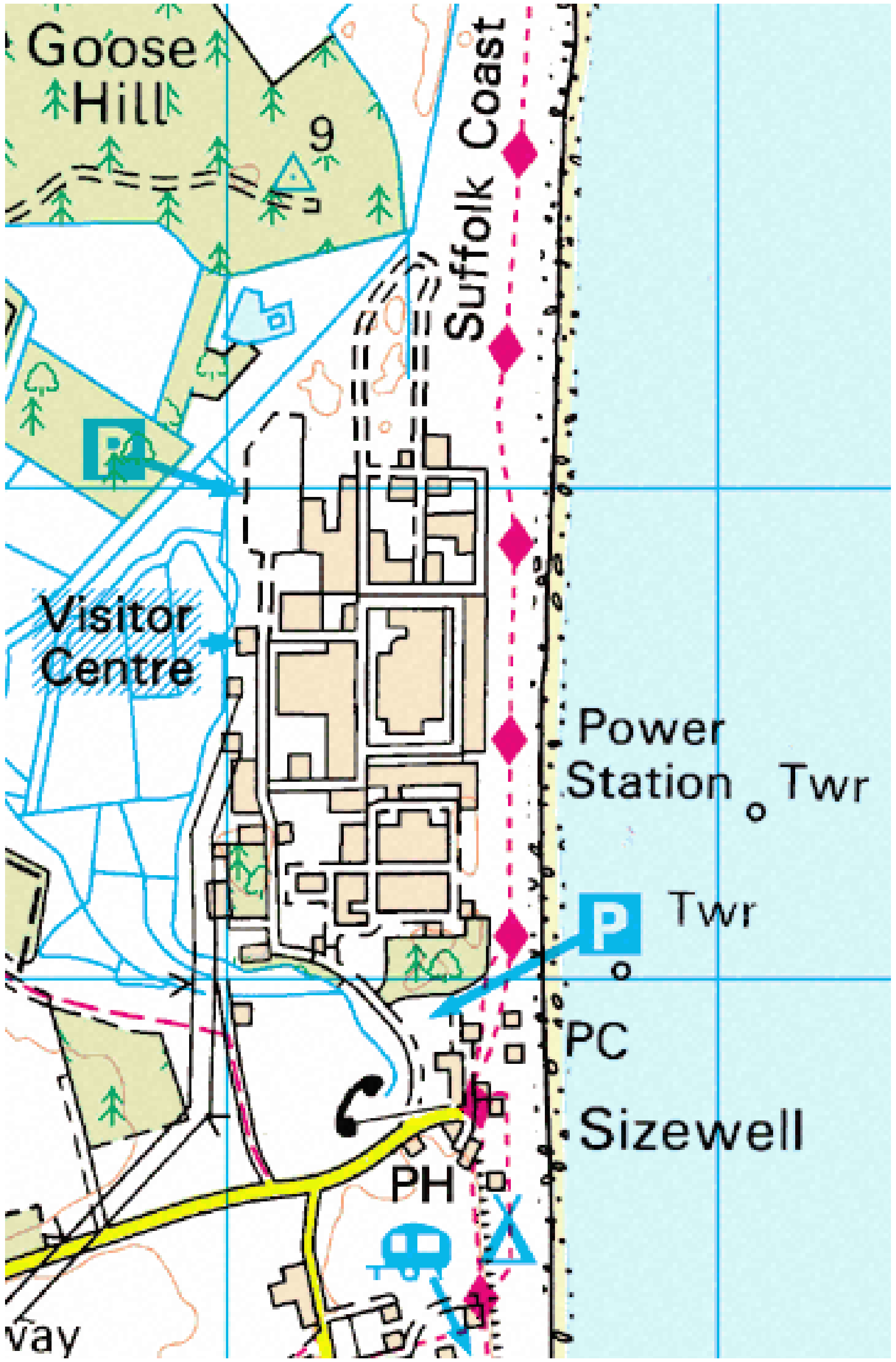
Singapore
Hong Kong

All renewables are diffuse

Power per unit land area	
Wind	$2.5\,W/m^2$
Plants	$0.5\,W/m^2$
Solar PV panels	$5–20\,W/m^2$
Tidal pools	$3\,W/m^2$
Tidal stream	$8\,W/m^2$
Rain-water (highlands)	$0.24\,W/m^2$
Concentrating solar power (desert)	$15–20\,W/m^2$

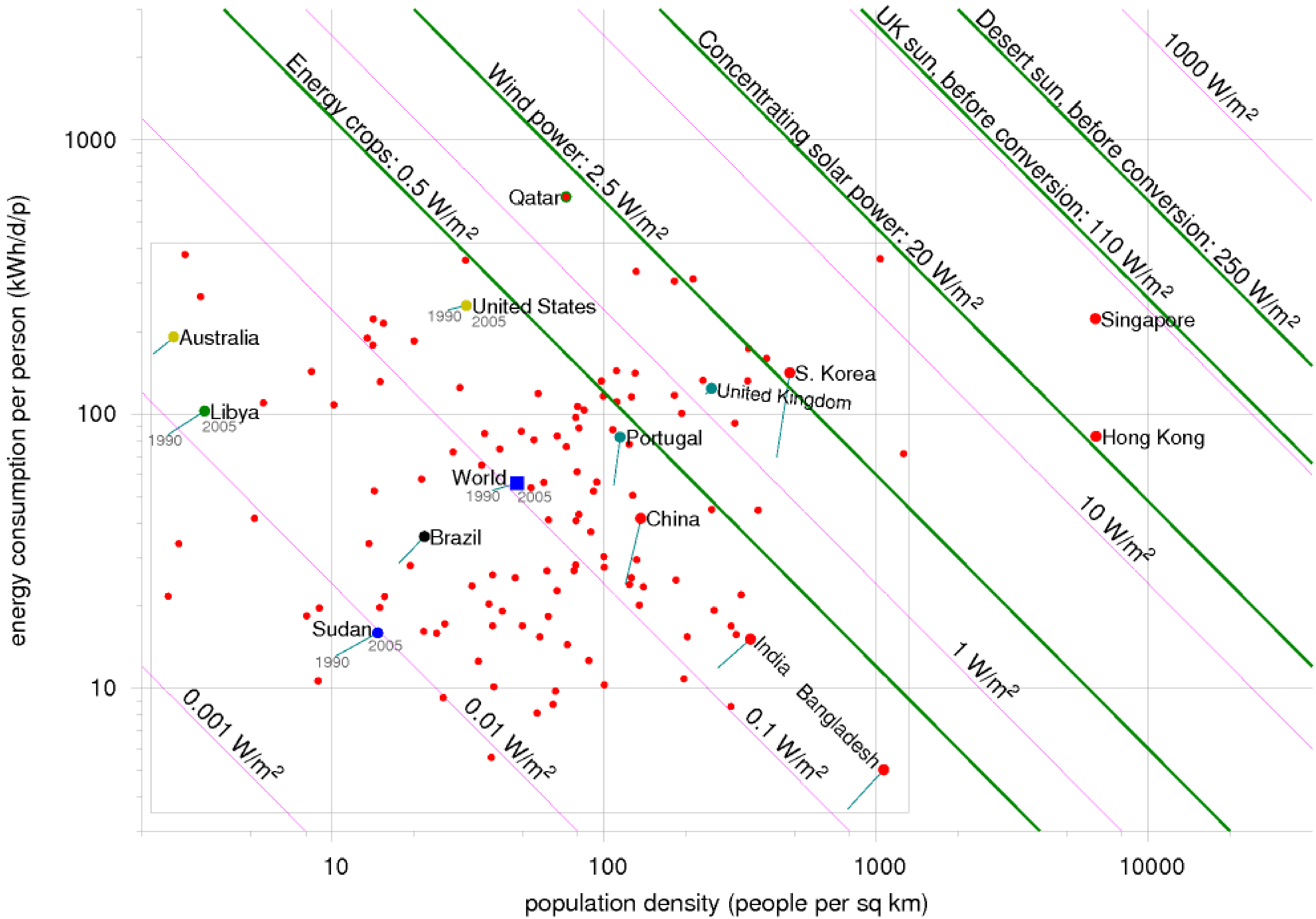
Nant-y-Moch by Dave Newbould
www.origins-photography.co.uk

- To make a difference, renewable facilities have to be country-sized



Nuclear	
Fission	$1000\,\mathrm{W/m^2}$

A consultation exercise in full swing



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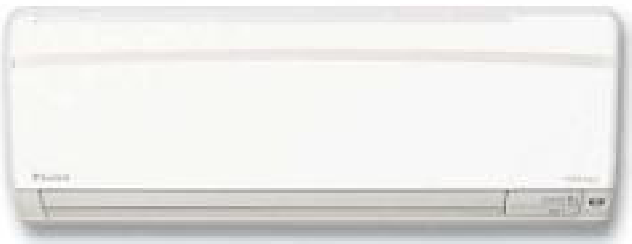
energy consumption per person (kWh/d/p)
population density (people per sq km)

How to get the UK off fossil fuels

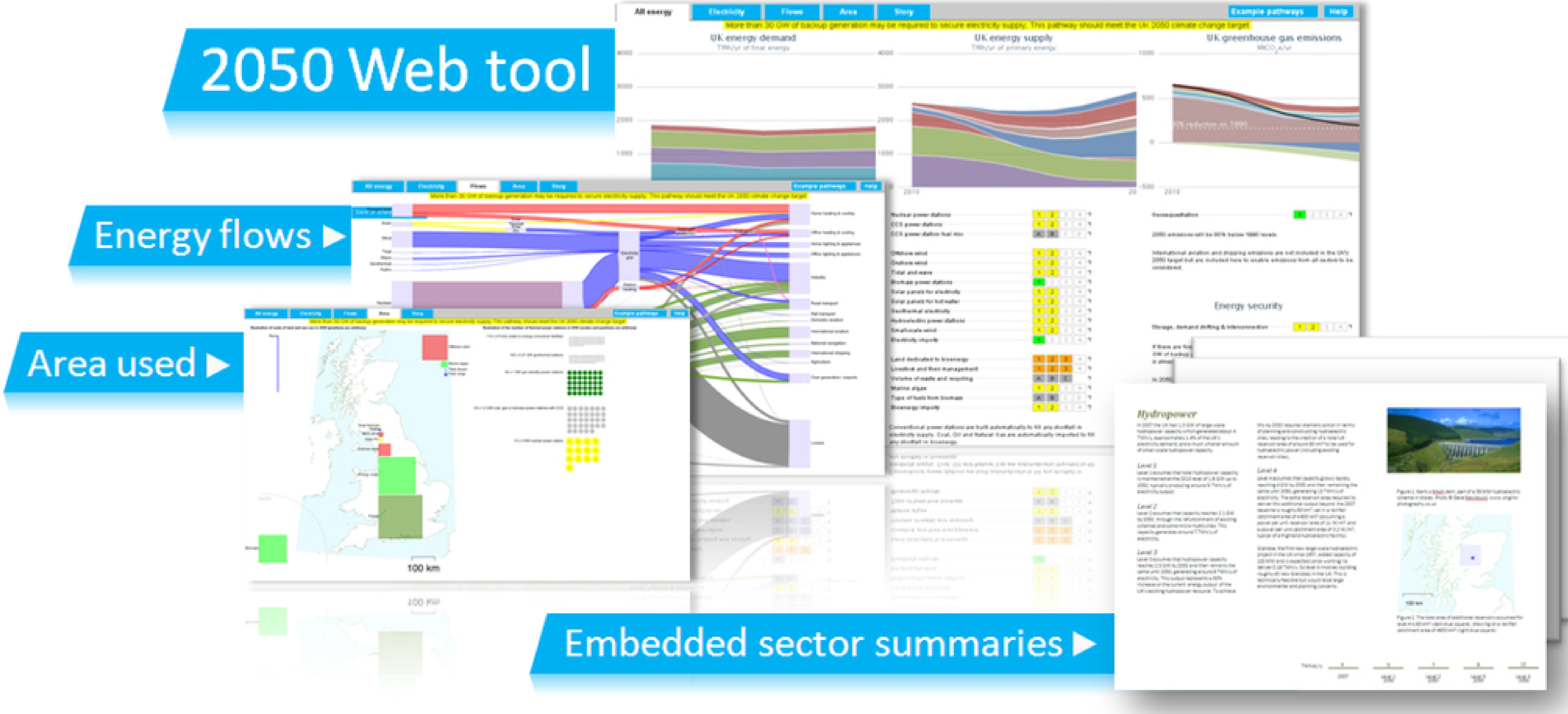
- Transport, Heating, Electricity
  - Electrify all transport
  - Insulate all buildings; read all meters
  - Electrify all building-heating
    - air-source or ground-source heat pumps
    - (some combined-heat-and-power where low-carbon fuel available)



  - Our renewables
  - Nuclear? (stop-gap?)
  - 'Clean coal'? (stop-gap)
  - Other people's renewables
  - Storage + interconnectors, to match supply to demar

- Research and innovation
- Public and political engagement

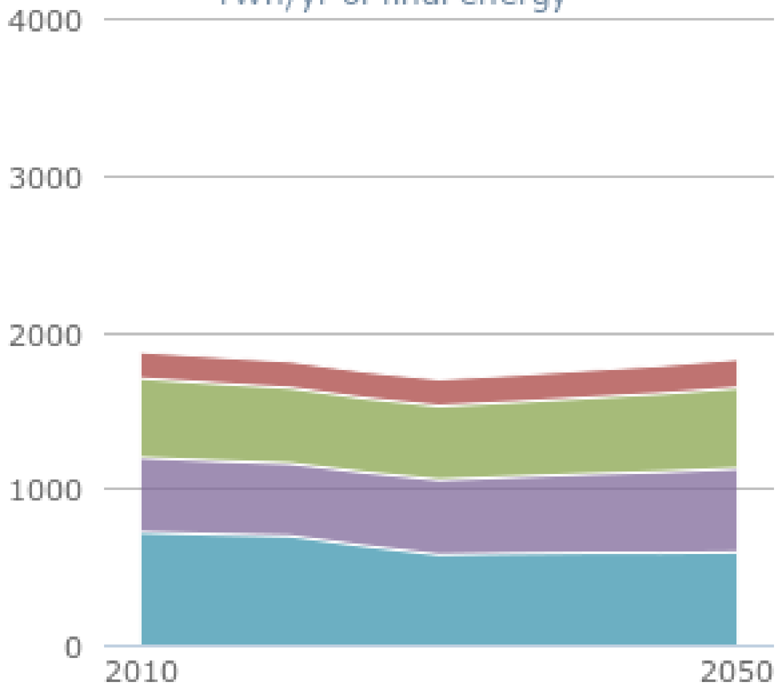
2050 pathways



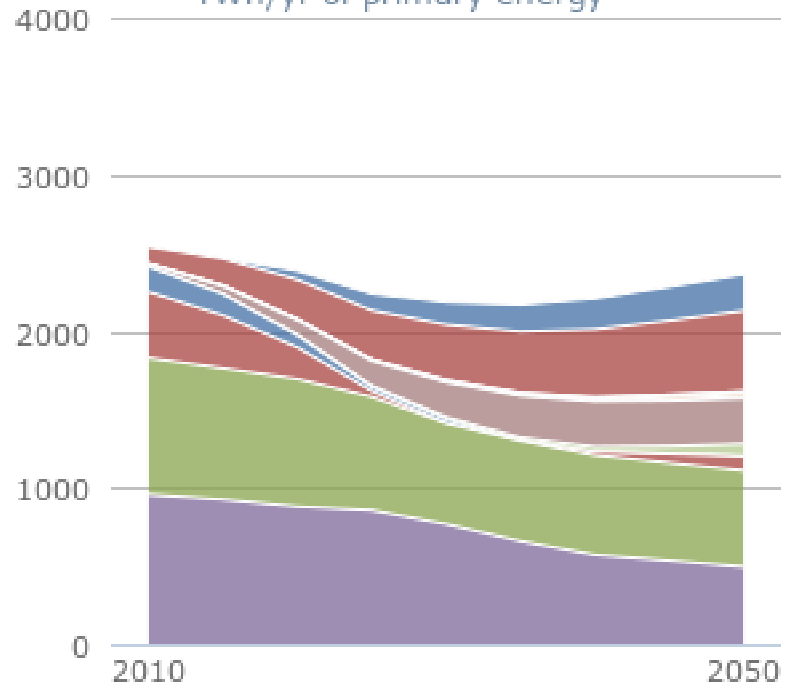
2050-calculator-tool.decc.gov.uk

All energy | Electricity | Flows | Area | Story | Example pathways | Help

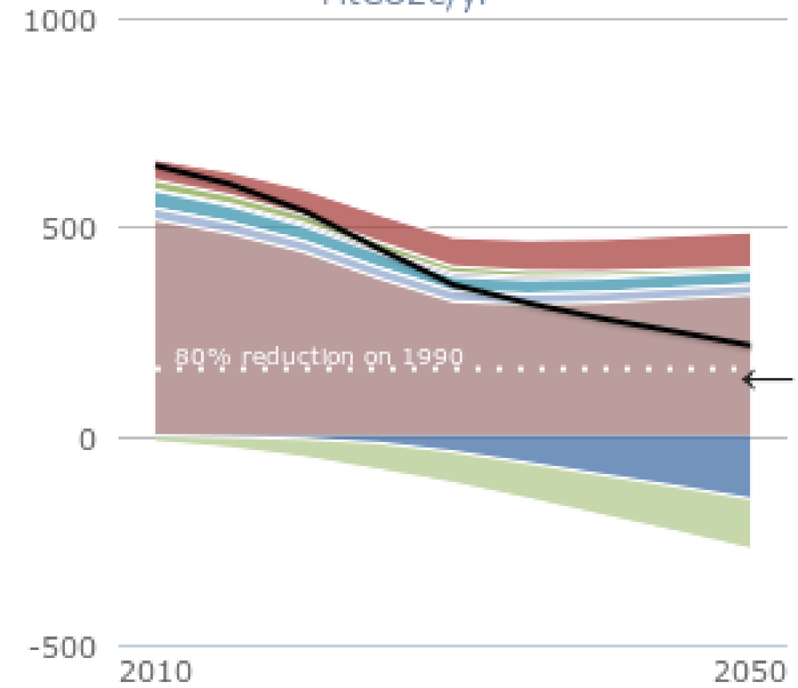
UK energy demand
TWh/yr of final energy



UK energy supply
TWh/yr of primary energy



UK greenhouse gas emissions
MtCO2e/yr



Domestic transport behaviour	1	2	3	4	i
Domestic transport electrification	1	2	3	4	i
Domestic freight	1	2	3	4	i
International aviation	1	2	3	4	i
International shipping	A	B	C	D	i
Average temperature of homes	1	2	3	4	i
Home insulation	1	2	3	4	i
Home heating electrification	A	B	C	D	i
Home heating that isn't electric	A	B	C	D	i
Home lighting & appliances	1	2	3	4	i
Electrification of home cooking	A	B			i
Growth in industry	A	B	C		i
Energy intensity of industry	1	2	3		i
Commercial demand for heating and cooling	1	2	3	4	i
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Nuclear power stations	1	2	3	4	i
CCS power stations	1	2	3	4	i
CCS power station fuel mix	A	B	C	D	i
Offshore wind	1	2	3	4	i
Onshore wind	1	2	3	4	i
Tidal and wave	1	2	3	4	i
Biomass power stations	1	2	3	4	i
Solar panels for electricity	1	2	3	4	i
Solar panels for hot water	1	2	3	4	i
Geothermal electricity	1	2	3	4	i
Hydroelectric power stations	1	2	3	4	i
Small-scale wind	1	2	3	4	i
Electricity imports	1	2	3	4	i
Land dedicated to bioenergy	1	2	3	4	i
Livestock and their management	1	2	3	4	i
Volume of waste and recycling	A	B	C		i
Marine algae	1	2	3	4	i
Type of fuels from biomass	A	B	C	D	i
Bioenergy imports	1	2	3	4	i

Conventional power stations are built automatically to fill any shortfall in electricity supply. Coal, Oil and Natural Gas are

Geosequestration	1	2	3	4	i

2050 emissions will be 72% below 1990 levels.

International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.

Energy security

Storage, demand shifting & interconnection	1	2	3	4	i

If there are five cold, almost windless, winter days in 2050, then up to 27 GW of backup generation capacity will be required to ensure that electricity is always available. i

In 2050, 40% of primary energy will be imported.

Save or share this pathway

The 2050 Pathways Approach

DEPARTMENT OF ENERGY & CLIMATE CHANGE

- For each demand sector, and each supply sector
  - lay out the range of what's technically possible
    - or what might be technically possible
  - four trajectories

Behaviour and demand projected; only current commercially proven technology

    - level 1: No effort towards security of supply, energy saving, or climate change

A rate of infrastructure build commensurate with "dash for gas". Can include technologies that have been demonstrated but not deployed at commercial scale

    - level 2: Effort likely to be viewed as achievable by most or all stakeholders

Build rates would require structural change to markets. Significant behaviour change and efficiency measures adoption. Any technology that has been demonstrated in the laboratory.

    - level 3: Effort unlikely to happen without significant change from current syste
ms

Very high levels of behaviour change. Any technology that is physically possible and might be developed + deployed before 2050. A level of build effort commensurate with that pursued during World War II, or the American efforts for a manned moon landing.

    - level 4: Effort at the extreme upper end of the believable scale
- Build a model of the energy system
  - - a calculator that computes the consequences of any set of choices ('pathway')
- Explore which pathways meet goals of
  - energy security
  - carbon emissions reductions

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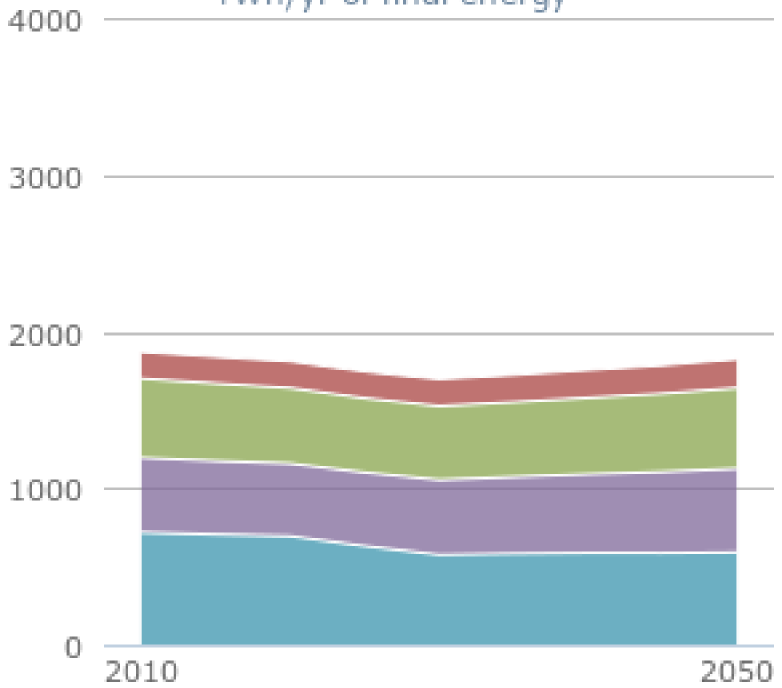

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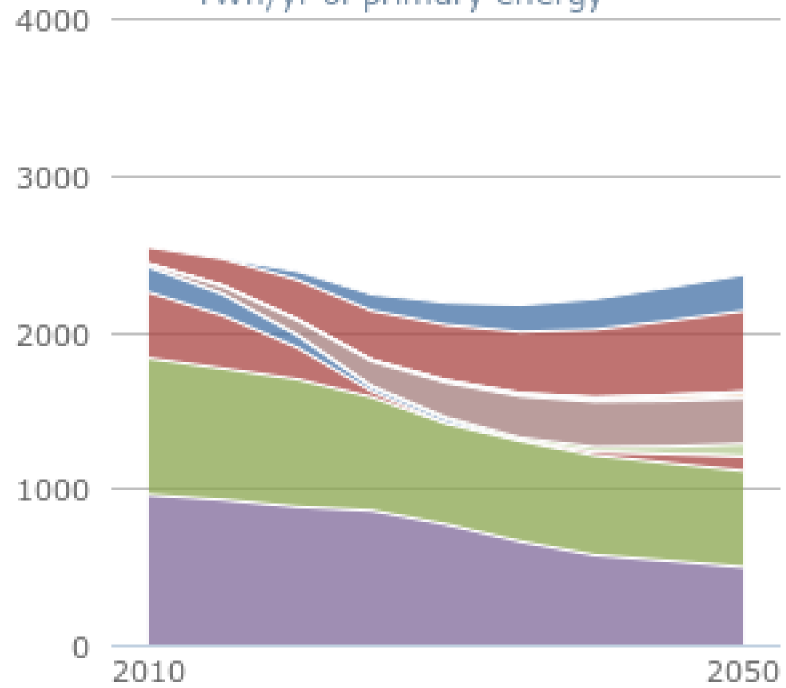

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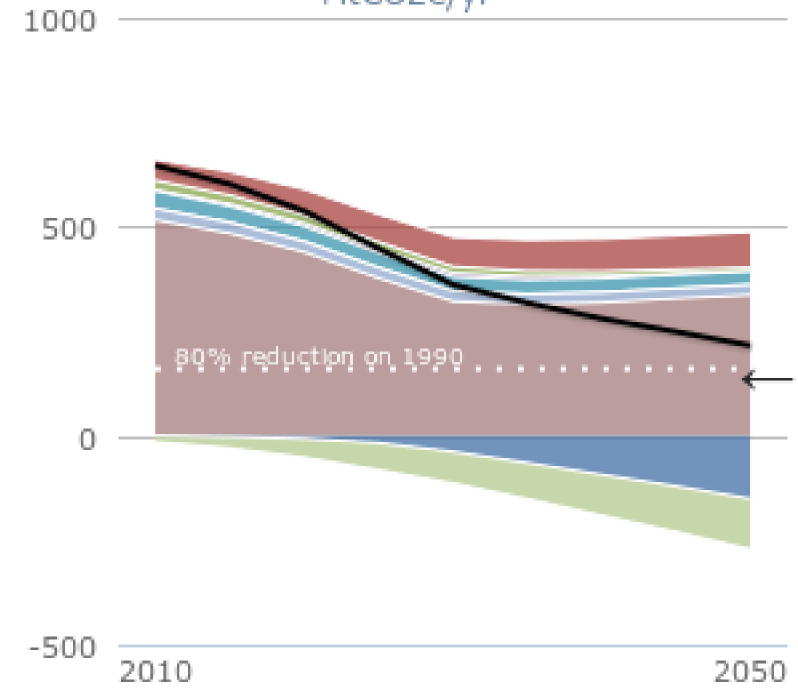

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Energy security

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If there are five cold, almost windless, winter days in 2050, then up to 27 GW of backup generation capacity will be required to ensure that electricity is always available. i

In 2050, 40% of primary energy will be imported.

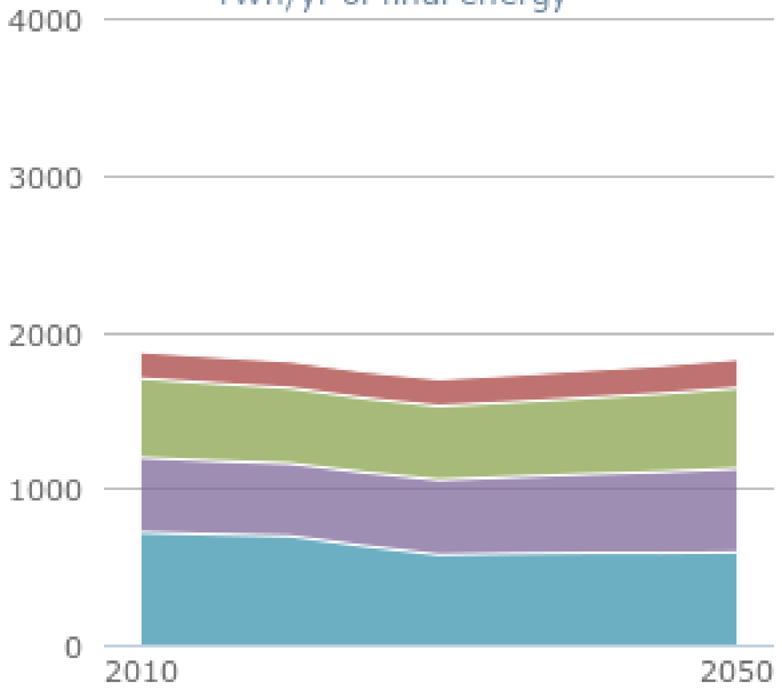
Save or share this pathway

Demand-side options - Transport

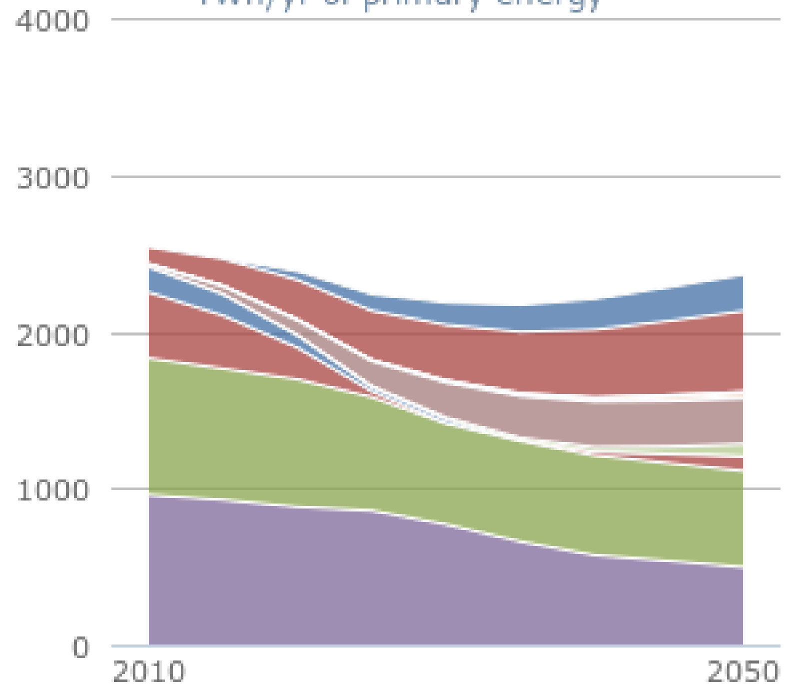
Have small frontal area per person
Have small weight per person
Go slowly
Go steadily
Convert energy
efficiently

All energy | Electricity | Flows | Area | Story | Example pathways | Help

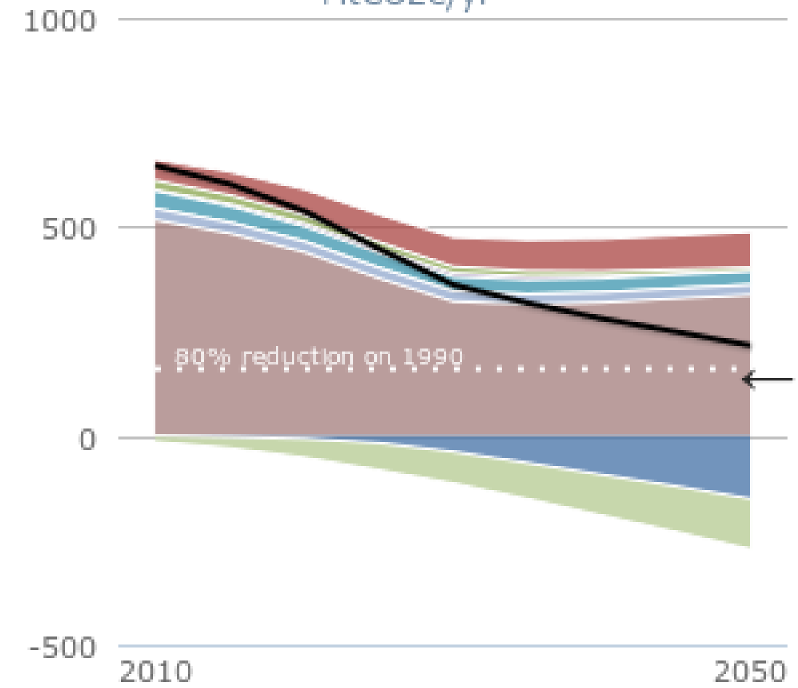
UK energy demand
TWh/yr of final energy



UK energy supply
TWh/yr of primary energy



UK greenhouse gas emissions
MtCO2e/yr



Domestic transport behaviour	1	2	3	4
Domestic transport electrification	1	2	3	4
Domestic freight	1	2	3	4
International aviation	1	2	3	4
International shipping	A	B	C	D
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		

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	2	3	4
Onshore wind	1	2	3	4
Tidal and wave	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	
Marine algae	1	2	3	4
Type of fuels from biomass	A	B	C	D
Bioenergy imports	1	2	3	4

Conventional power stations are built automatically to fill any shortfall in electricity supply. Coal, Oil and Natural Gas are

Geosequestration	1	2	3	4

2050 emissions will be 72% below 1990 levels.

International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.

Energy security

Storage, demand shifting & interconnection	1	2	3	4

If there are five cold, almost windless, winter days in 2050, then up to 27 GW of backup generation capacity will be required to ensure that electricity is always available.

In 2050, 40% of primary energy will be imported.

Save or share this pathway

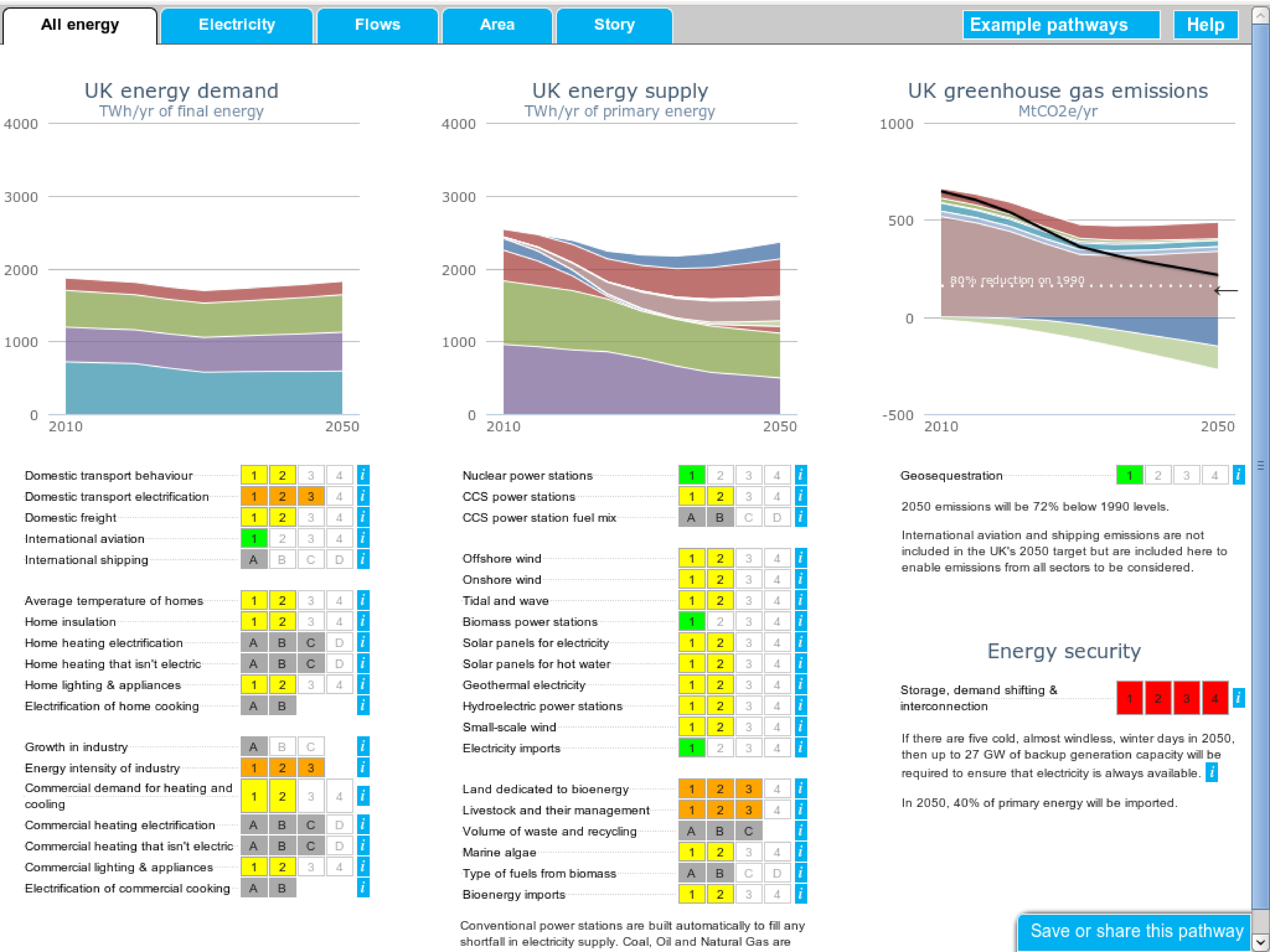
Demand-side options - heating

options for energy-saving:

- Reduce temperature difference
  - Turn the thermostat down
- Reduce leakiness
- Increase CoP of heat-creation

$$\underset{(\text{kWh/d})}{\boxed{\text{Heat loss}}} = \underset{(\text{kWh/d/°C})}{\text{Leakiness}} \times \underset{(\text{°C})}{\text{Average temperature difference}}$$

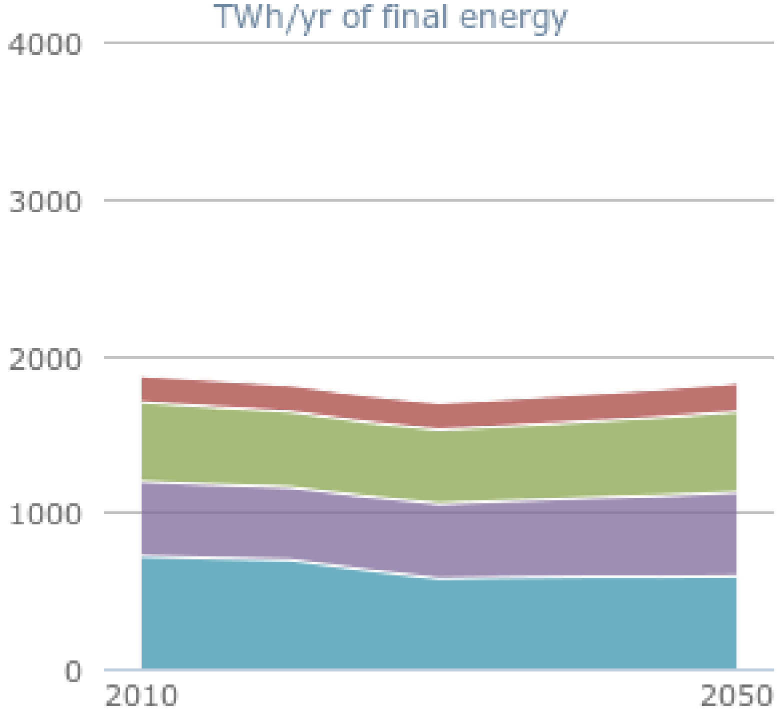
$$\text{Power required} = \boxed{\text{Heat loss}} \Big/ \begin{matrix}\text{Coefficient of performance} \\ \text{of heat-creation}\end{matrix}$$


All energy
Electricity
Flows
Area
Story
Example pathways
Help
UK energy demand
TWh/yr of final energy
4000
3000
2000
1000
0
2010
2050
UK energy supply
TWh/yr of primary energy
4000
3000
2000
1000
0
2010
2050
UK greenhouse gas emissions
MtCO2e/yr
1000
500
0
-500
80% reduction on 1990
2010
2050
Domestic transport behaviour 1 2 3 4 i
Domestic transport electrification 1 2 3 4 i
Domestic freight 1 2 3 4 i
International aviation 1 2 3 4 i
International shipping A B C D i
Average temperature of homes 1 2 3 4 i
Home insulation 1 2 3 4 i
Home heating electrification A B C D i
Home heating that isn't electric A B C D i
Home lighting & appliances 1 2 3 4 i
Electrification of home cooking A B i
Growth in industry A B C i
Energy intensity of industry 1 2 3 i
Commercial demand for heating and cooling 1 2 3 4 i
Commercial heating electrification A B C D i
Commercial heating that isn't electric A B C D i
Commercial lighting & appliances 1 2 3 4 i
Electrification of commercial cooking A B i
Nuclear power stations 1 2 3 4 i
CCS power stations 1 2 3 4 i
CCS power station fuel mix A B C D i
Offshore wind 1 2 3 4 i
Onshore wind 1 2 3 4 i
Tidal and wave 1 2 3 4 i
Biomass power stations 1 2 3 4 i
Solar panels for electricity 1 2 3 4 i
Solar panels for hot water 1 2 3 4 i
Geothermal electricity 1 2 3 4 i
Hydroelectric power stations 1 2 3 4 i
Small-scale wind 1 2 3 4 i
Electricity imports 1 2 3 4 i
Land dedicated to bioenergy 1 2 3 4 i
Livestock and their management 1 2 3 4 i
Volume of waste and recycling A B C i
Marine algae 1 2 3 4 i
Type of fuels from biomass A B C D i
Bioenergy imports 1 2 3 4 i
Conventional power stations are built automatically to fill any shortfall in electricity supply. Coal, Oil and Natural Gas are
Geosequestration 1 2 3 4 i
2050 emissions will be 72% below 1990 levels.
International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.
Energy security
Storage, demand shifting & interconnection 1 2 3 4 i
If there are five cold, almost windless, winter days in 2050, then up to 27 GW of backup generation capacity will be required to ensure that electricity is always available. i
In 2050, 40% of primary energy will be imported.
Save or share this pathway

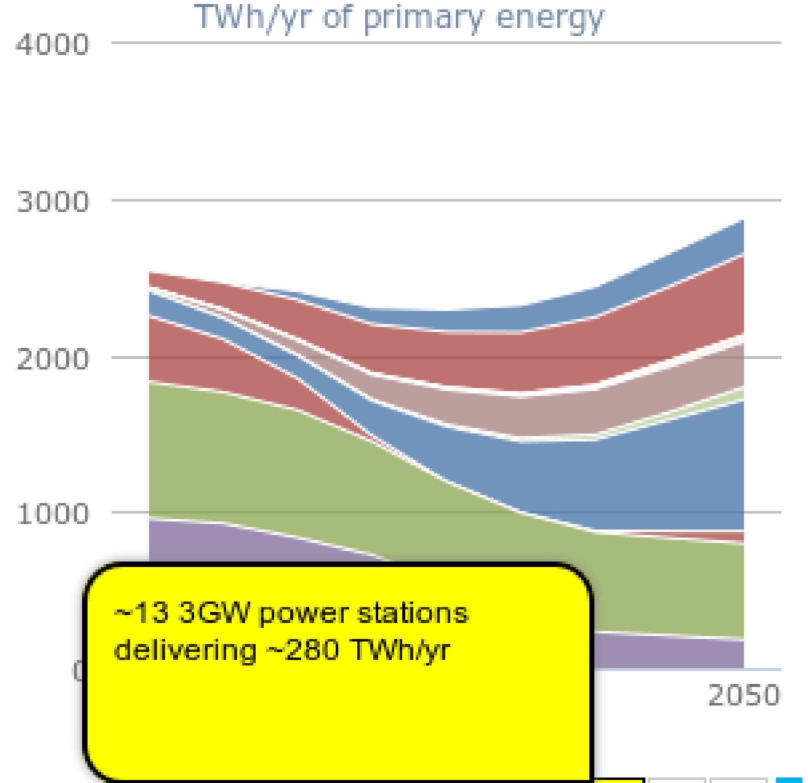
All energy | Electricity | Flows | Area | Story | Example pathways | Help

This pathway should meet the UK 2050 climate change target

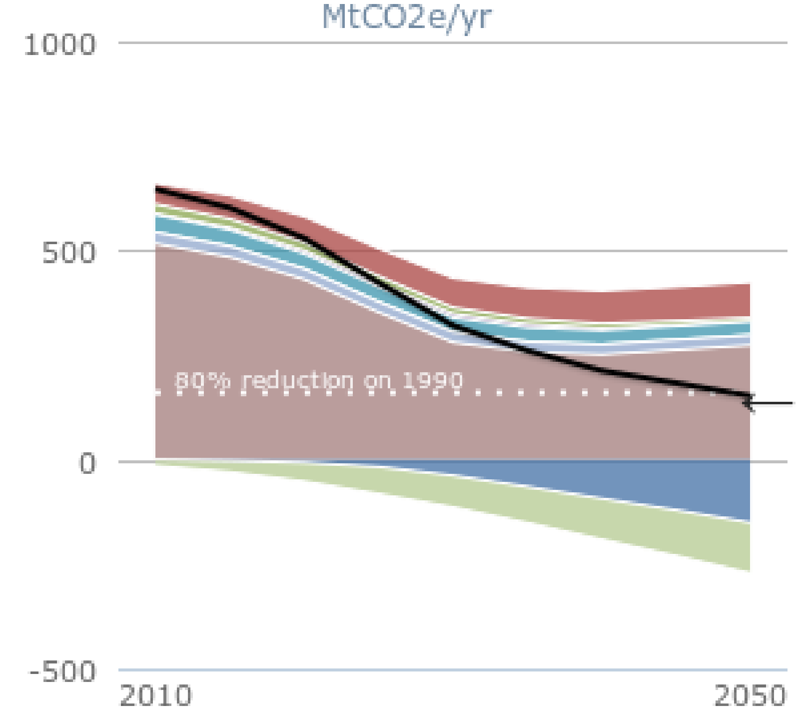
UK energy demand
TWh/yr of final energy



UK energy supply
TWh/yr of primary energy



UK greenhouse gas emissions
MtCO2e/yr



Demand				
Domestic transport behaviour	1	2	3	4
Domestic transport electrification	1	2	3	4
Domestic freight	1	2	3	4
International aviation	1	2	3	4
International shipping	A	B	C	D
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	2	3	4
Onshore wind	1	2	3	4
Tidal and wave	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	
Marine algae	1	2	3	4
Type of fuels from biomass	A	B	C	D
Bioenergy imports	1	2	3	4

Conventional power stations are built automatically to fill any shortfall in electricity supply. Coal, Oil and Natural Gas are

Emissions				
Geosequestration	1	2	3	4

2050 emissions will be 80% below 1990 levels.

International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.

Energy security

Storage, demand shifting & interconnection	1	2	3	4

If there are five cold, almost windless, winter days in 2050, then up to 15 GW of backup generation capacity will be required to ensure that electricity is always available.

In 2050, 53% of primary energy will be imported.

Save or share this pathway

Offshore Wind

In 2007 the UK had around 0.4 GW of offshore wind capacity, and at the end of 2010, 1.3 GW. All of these were fixed to the seabed by solid foundations, with no floating offshore turbines yet present in the UK.

Level 1

Level 1 assumes that only the current turbines and those already advanced in the planning process are built. Offshore wind capacity initially rises from 1 GW to 8 GW in 2025 then reduces to zero by 2045 as decommissioned sites are not replanted. 8 GW is equivalent to around 1400-5.8 MW turbines (although in reality turbines would have different capacities) and generates around 29 TWh/y at 2025.

Level 2

Level 2 assumes that capacity increases to 60 GW by 2040 and is then maintained. This means building and maintaining about 10 000 of the 5.8-MW turbines in total. In this scenario the sea area occupied by wind farms is about 10 800 km^2, about half the area of Wales. It requires maintaining the same build rate that Germany achieved for onshore turbines from 2000 to 2010 over a 20-year period in the UK and in an offshore environment. 60 GW of offshore wind turbines generates around 237 TWh/y in 2050.

Level 3

Level 3 assumes that capacity rises to 45 GW by 2025, and to 100 GW by 2050, which is equivalent to around 17 000 5.8-MW turbines. The sustained installation rate is 5 GW per year. Installing 5 GW per year might require roughly 30 jack-up barges and means building offshore wind turbines at a rate never before achieved in any country. The sea area occupied by wind farms is 18 000 km^2, close to the area of Wales. The combined weight of steel and concrete in these turbines is roughly 0.4 tonnes for every Briton. 60 GW of offshore wind turbines generates around 395 TWh/y in 2050.

Level 4

Level 4 assumes that capacity rises to 68 GW by 2025, and to 236 GW by 2050 – a 180-fold increase from 2010. The sustained installation rate required is 6 GW per year of fixed turbines (which requires roughly 30 jack-up barges) plus 6 GW/y of floating turbines. In total, this is equivalent to about 40 000 5.8-MW turbines being built by 2050. The costs of offshore wind installation and maintenance increase with the distance from shore and water depth. For level 4, the sea area occupied by wind farms is over 42 000 km^2, roughly twice the area of Wales, including both fixed and floating turbines. If 236 GW of the 5.8 MW turbines were arranged uniformly along 3400 km of coastline, there would be 12 of them per kilometre, generating around 929 TWh/y in 2050. The combined weight of steel and concrete in these turbines is 0.9 tonnes for every Briton.

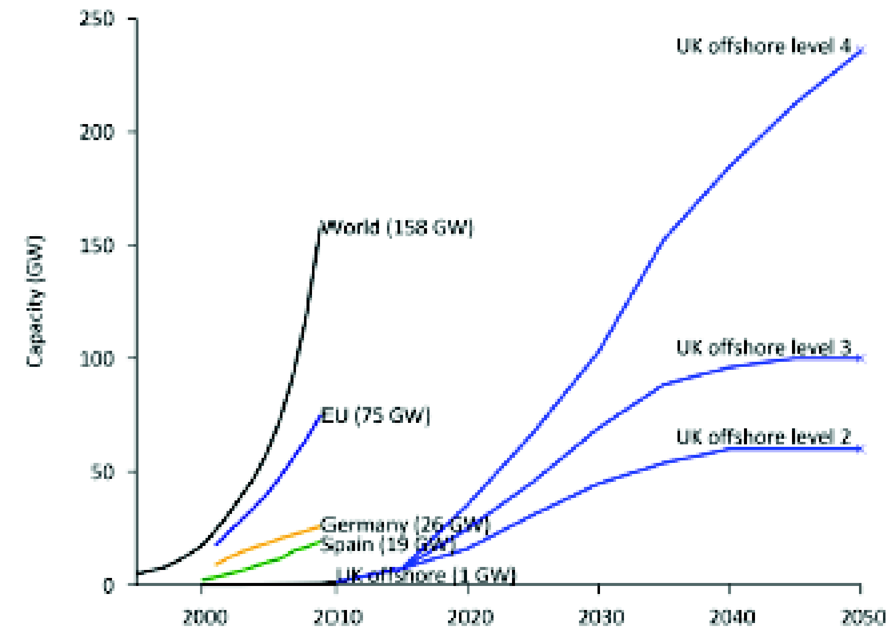


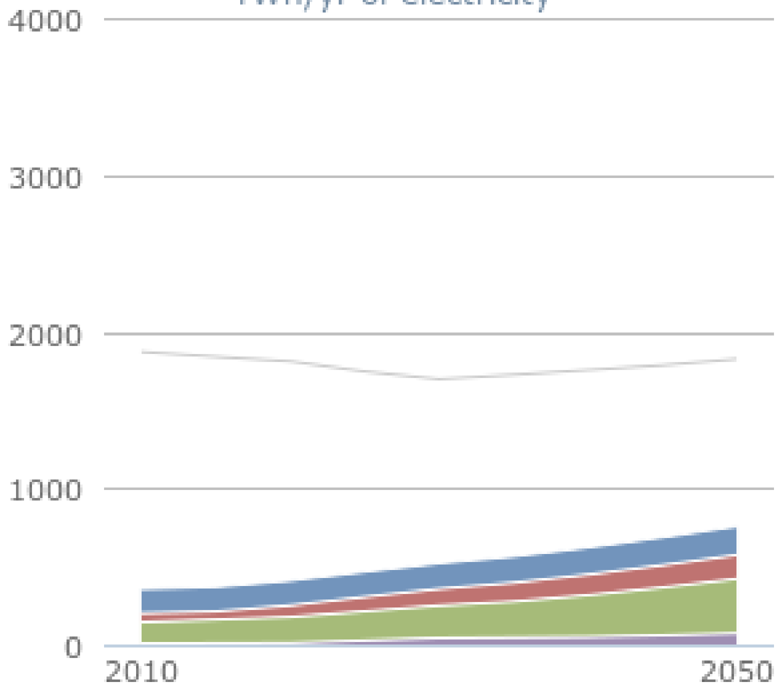
Figure 1. UK offshore wind capacity versus time, historic (to 2010) and assumptions (from 2010 onwards), compared with onshore wind in Spain, Germany, EU, and world totals.

All energy | Electricity | Flows | Area | Story | Example pathways | Help

This pathway should meet the UK 2050 climate change target

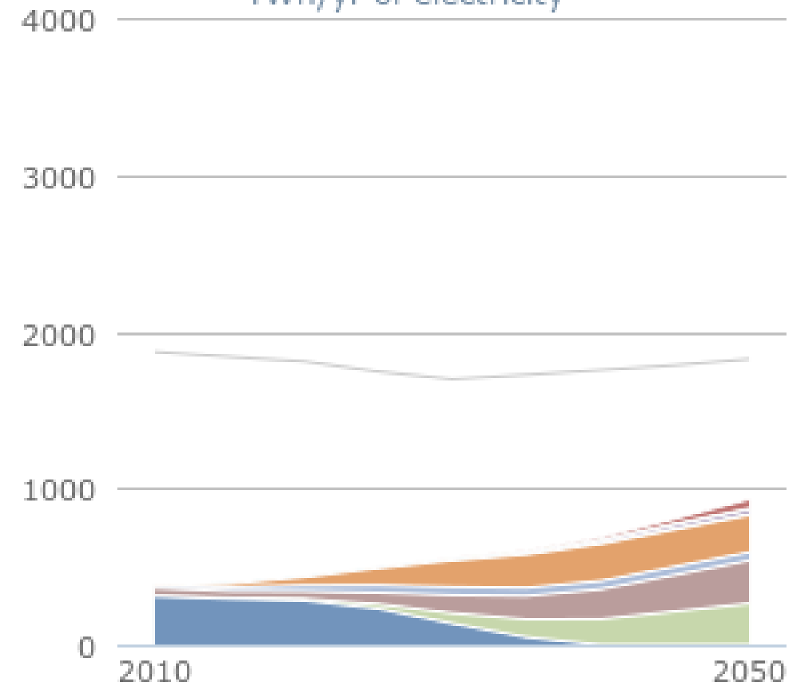
UK electricity demand

TWh/yr of electricity



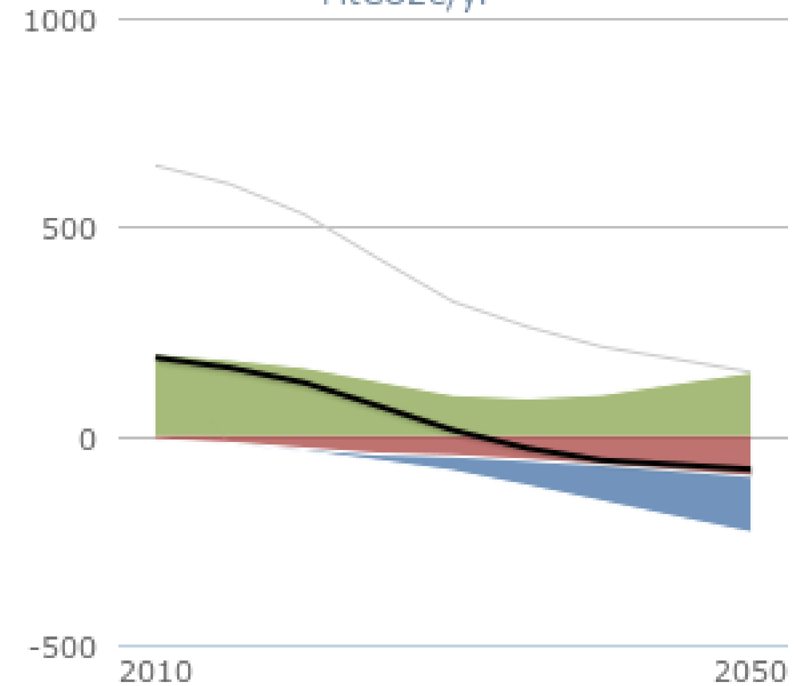
UK electricity supply

TWh/yr of electricity



reenhouse gas emissions from electri

MtCO2e/yr



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

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

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Geosequestration	1	2	3	4	i

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Energy security

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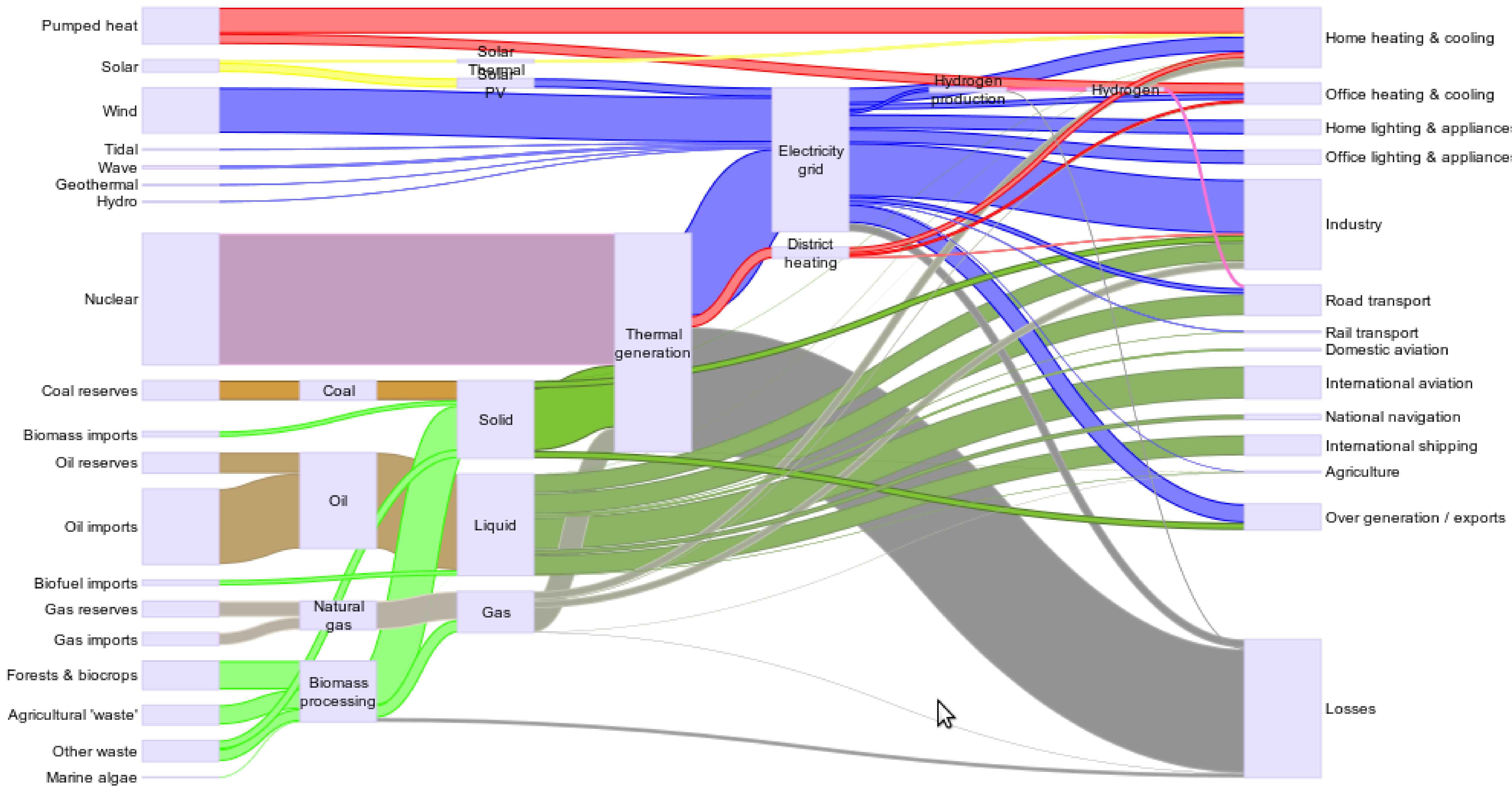
Save or share this pathway

All energy | Electricity | **Flows** | Area | Story | Example pathways | Help

This pathway should meet the UK 2050 climate change target



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International shipping	A	B	C	D	i
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Home insulation	1	2	3	4	i
Home heating electrification	A	B	C	D	i

Nuclear power stations	1	2	3	4	i
CCS power stations	1	2	3	4	i
CCS power station fuel mix	A	B	C	D	i
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Onshore wind	1	2	3	4	i
Tidal and wave	1	2	3	4	i
Biomass power stations	1	2	3	4	i
Solar panels for electricity	1	2	3	4	i

Geosequestration	1	2	3	4	i

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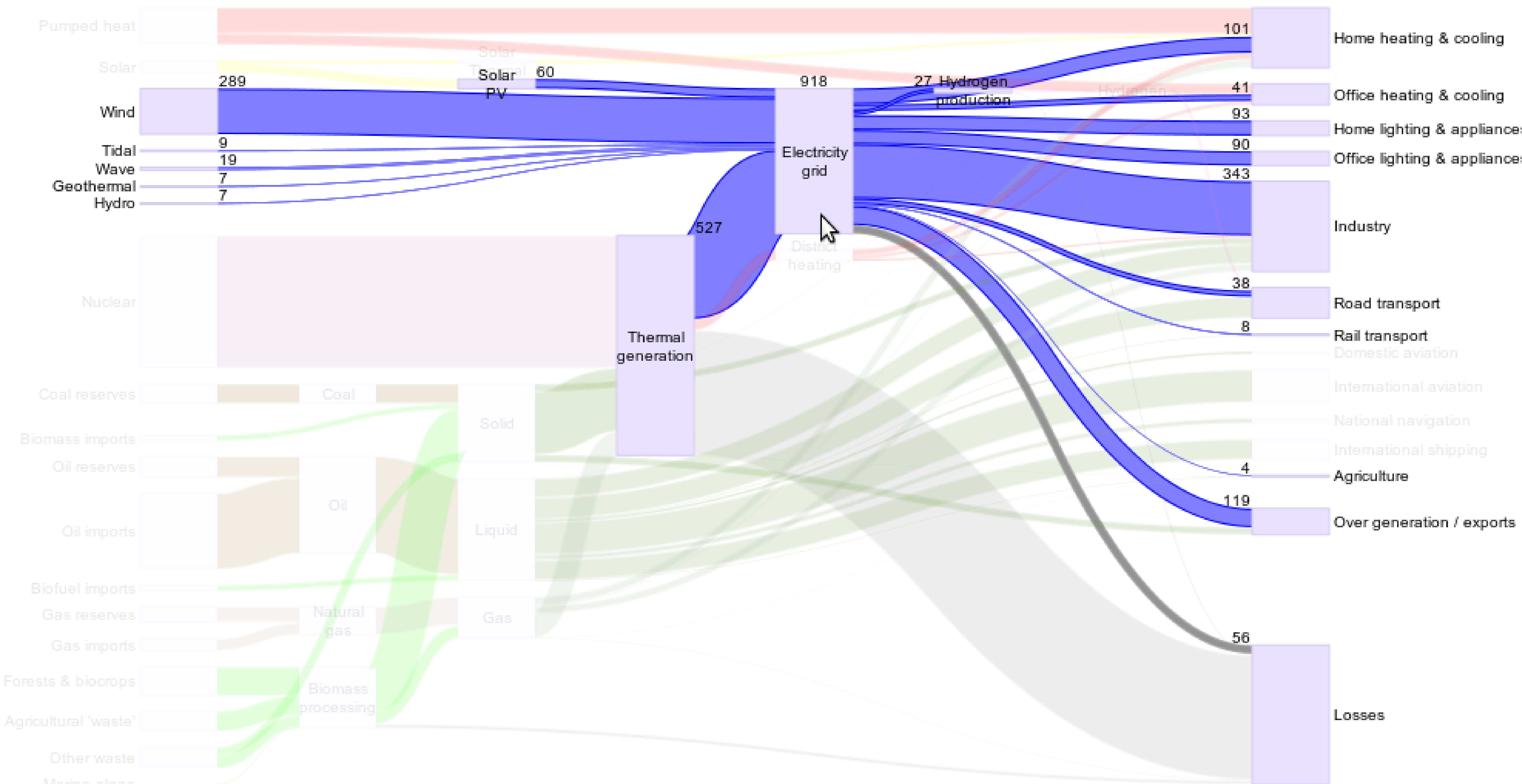
Save or share this pathway

All energy | Electricity | **Flows** | Area | Story | Example pathways | Help

This pathway should meet the UK 2050 climate change target



Domestic transport behaviour	1	2	3	4	i
Domestic transport electrification	1	2	3	4	i
Domestic freight	1	2	3	4	i
International aviation	1	2	3	4	i
International shipping	A	B	C	D	i
Average temperature of homes	1	2	3	4	i
Home insulation	1	2	3	4	i
Home heating electrification	A	B	C	D	i

Nuclear power stations	1	2	3	4	i
CCS power stations	1	2	3	4	i
CCS power station fuel mix	A	B	C	D	i
Offshore wind	1	2	3	4	i
Onshore wind	1	2	3	4	i
Tidal and wave	1	2	3	4	i
Biomass power stations	1	2	3	4	i
Solar panels for electricity	1	2	3	4	i

Geosequestration	1	2	3	4	i

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Save or share this pathway

Electricity | Flows | Area | Story | Example pathways | Help

land and sea use in 2050 (positions are arbitrary)

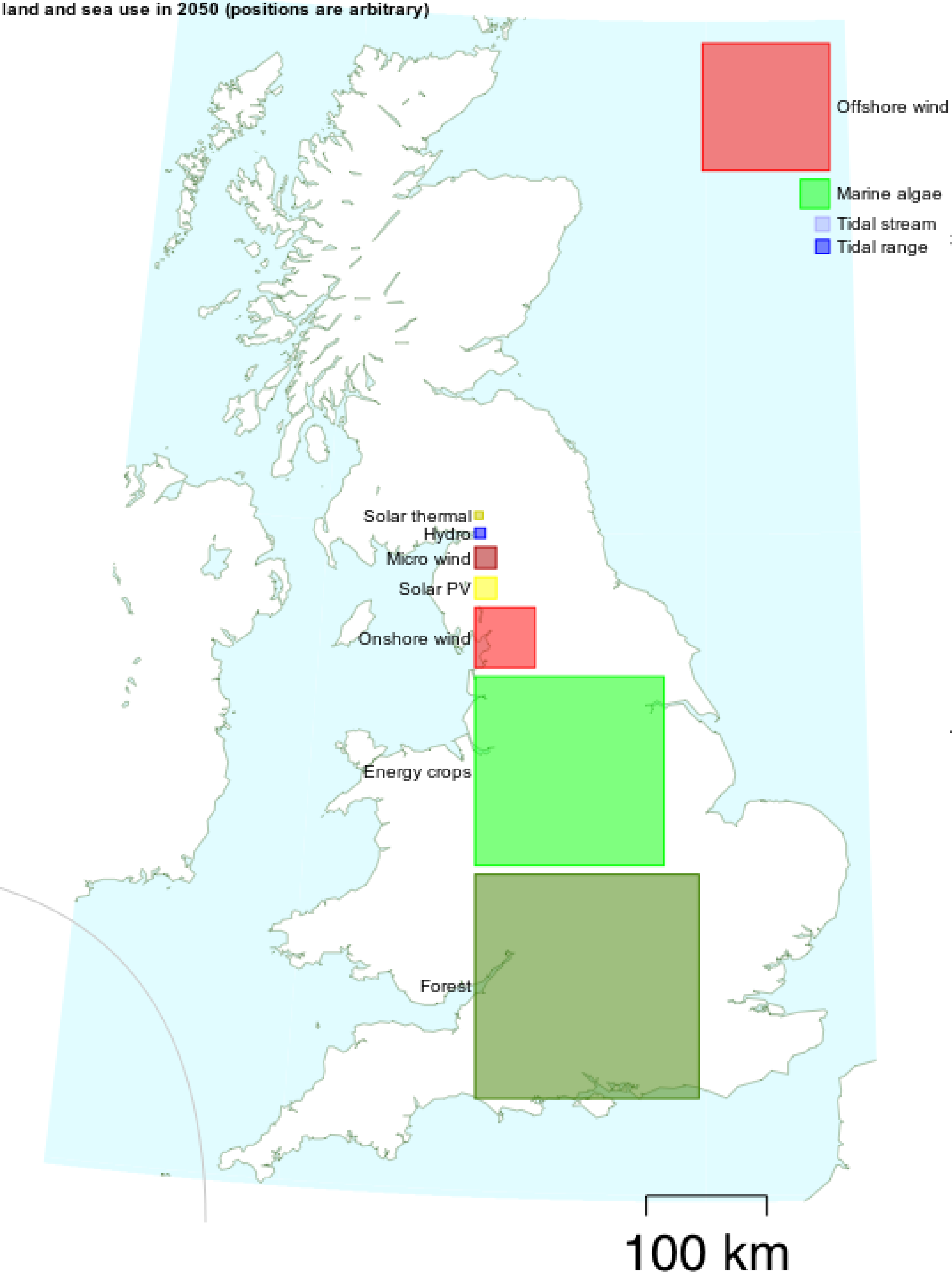
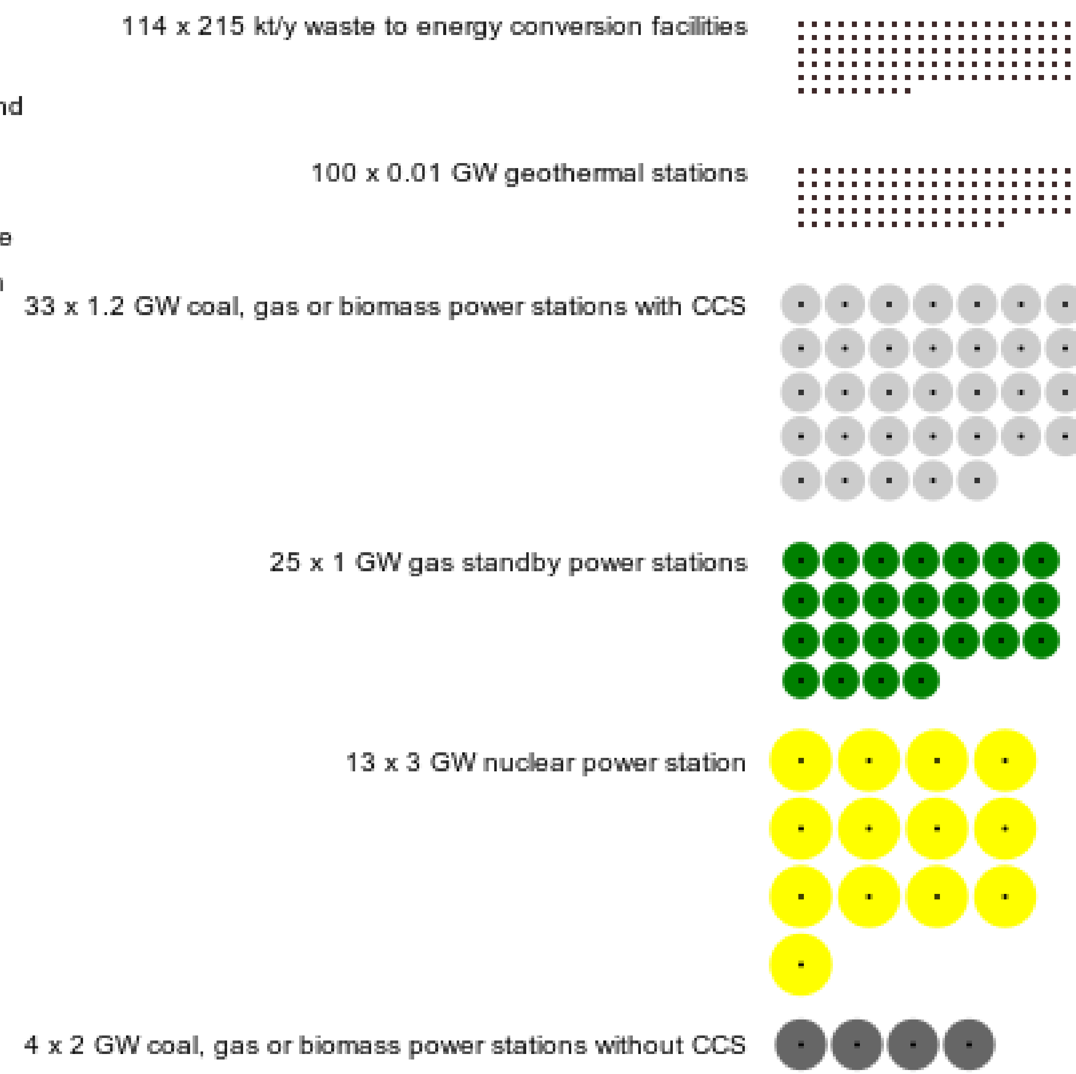
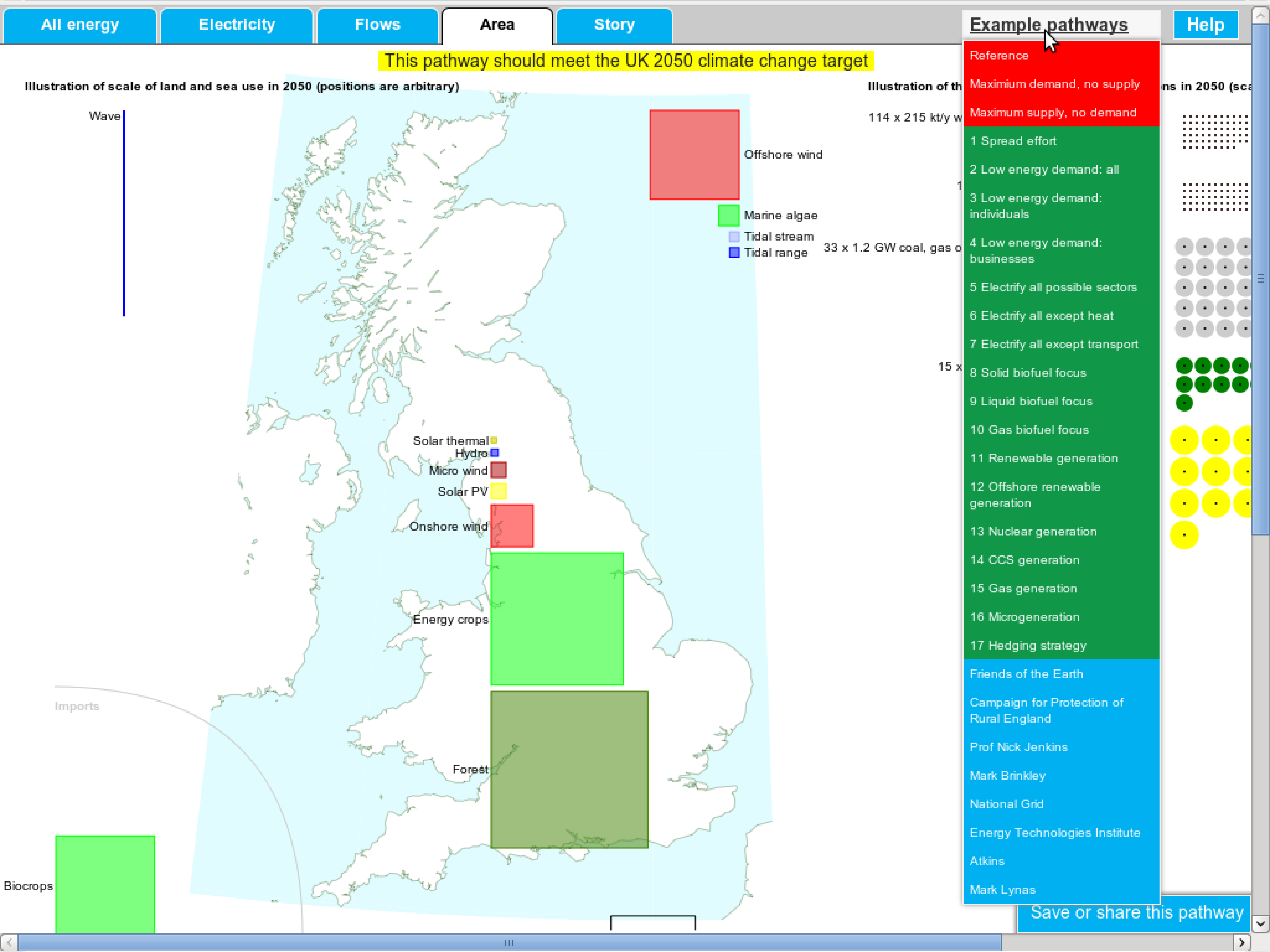


Illustration of the number of thermal power stations in 2050 (scales and positions are arbitrar

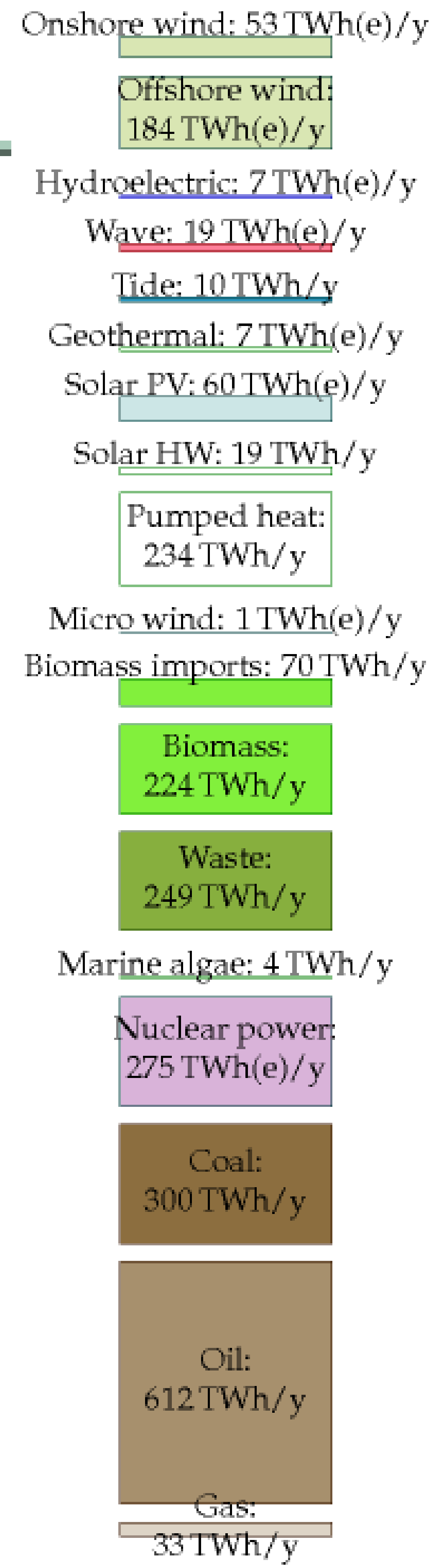




All energy
Electricity
Flows
Area
Story
Example pathways
Help
This pathway should meet the UK 2050 climate change target
Illustration of scale of land and sea use in 2050 (positions are arbitrary)
Wave
Offshore wind
Marine algae
Tidal stream
Tidal range
Solar thermal
Hydro
Micro wind
Solar PV
Onshore wind
Energy crops
Forest
Imports
Biocrops
Illustration of th
ns in 2050 (sca
114 x 215 kt/y w
33 x 1.2 GW coal, gas o
15 x
Reference
Maximium demand, no supply
Maximum supply, no demand
1 Spread effort
2 Low energy demand: all
3 Low energy demand: individuals
4 Low energy demand: businesses
5 Electrify all possible sectors
6 Electrify all except heat
7 Electrify all except transport
8 Solid biofuel focus
9 Liquid biofuel focus
10 Gas biofuel focus
11 Renewable generation
12 Offshore renewable generation
13 Nuclear generation
14 CCS generation
15 Gas generation
16 Microgeneration
17 Hedging strategy
Friends of the Earth
Campaign for Protection of Rural England
Prof Nick Jenkins
Mark Brinkley
National Grid
Energy Technologies Institute
Atkins
Mark Lynas
Save or share this pathway

Innovation needs (top 6) for the UK

- Efficiency
  - building insulation
  - vehicles (electric and hydrogen?)
- Wind
- Heat pumps
- Biomass- and waste-to-good-things
- Carbon Capture and Storage
- Energy Storage
  - electricity storage
  - interconnectors; smart demand-management
  - seasonal heat stores



2050-calculator-tool.decc.gov.uk

What we need for most 2050 pathways

- Amazing insulation

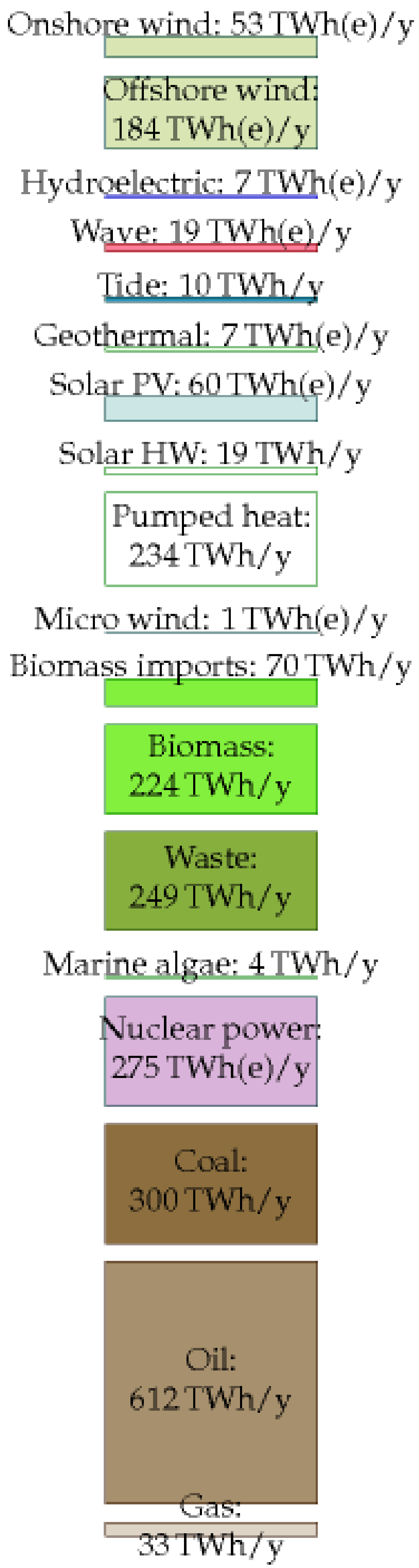
Thermablok

and cheap building-retrofit

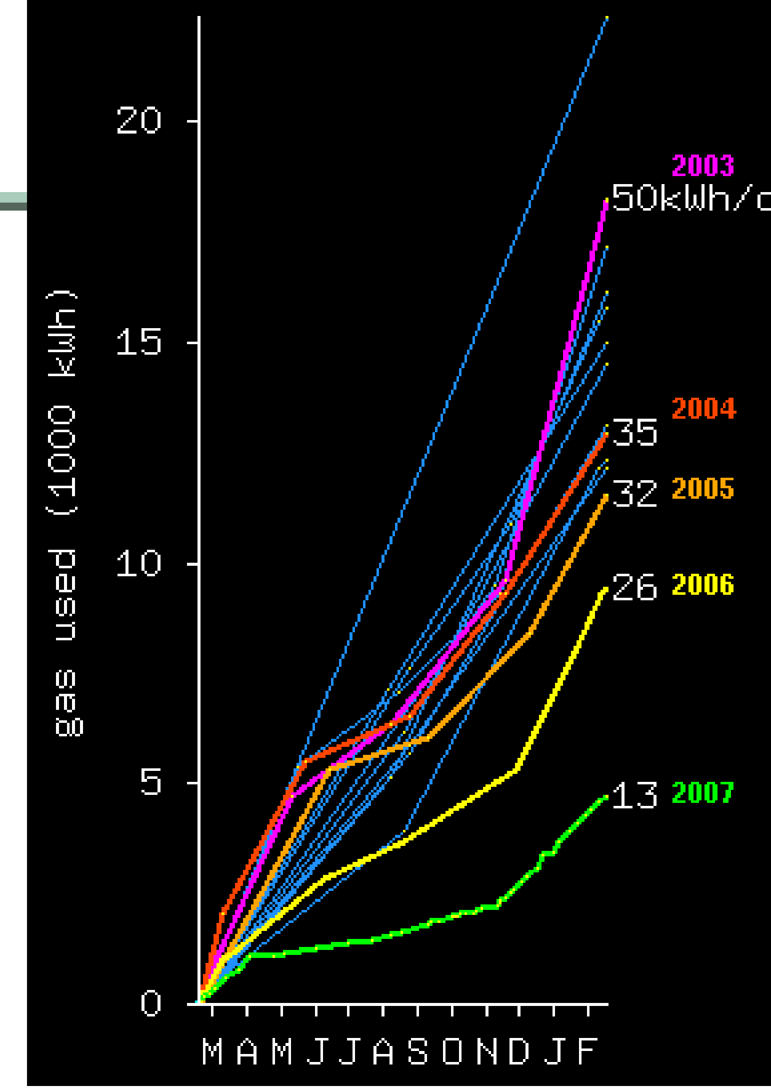
- Electric vehicles

  - batteries
  - capacitors

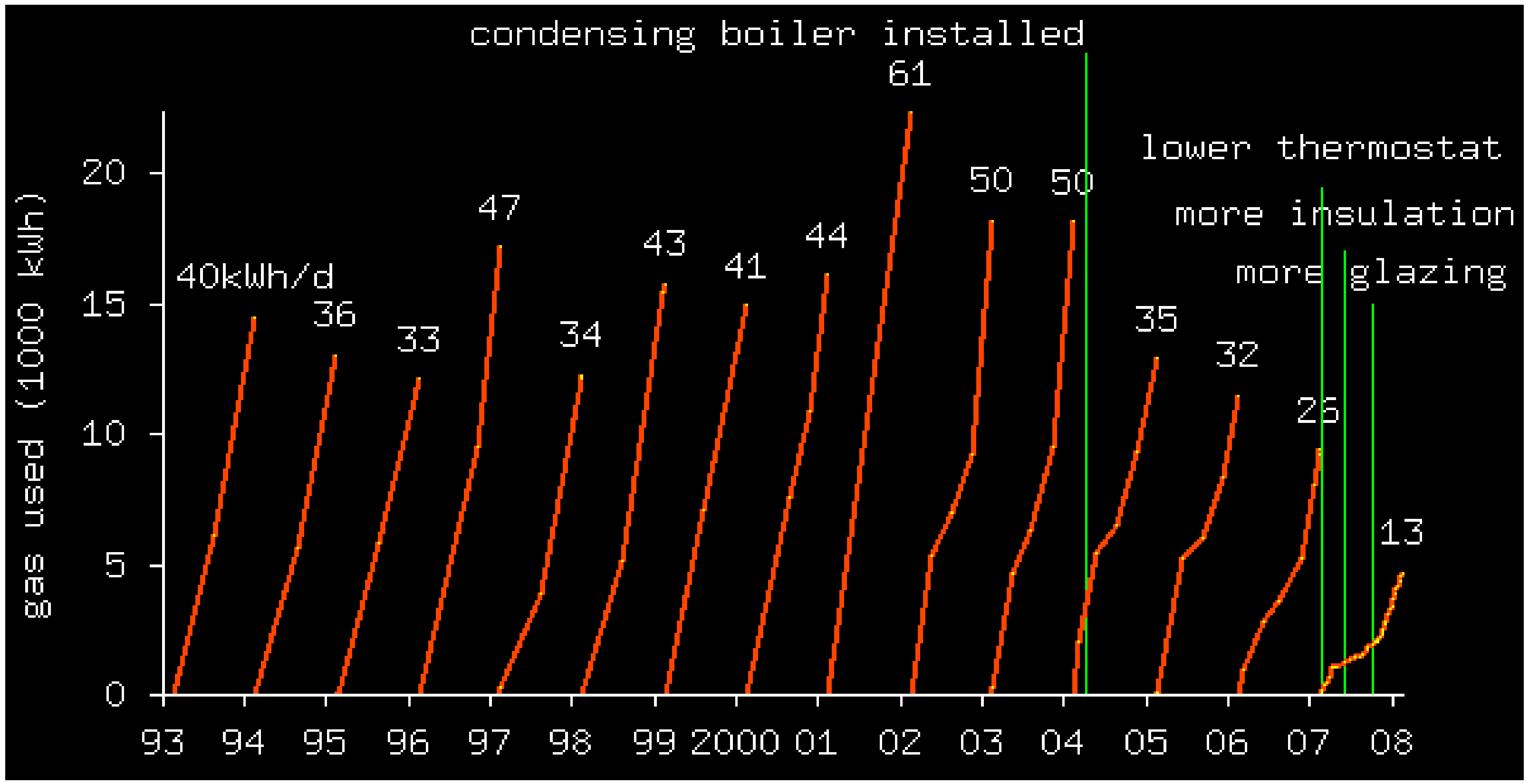
- Smart meters and smart controls that induce behaviour change



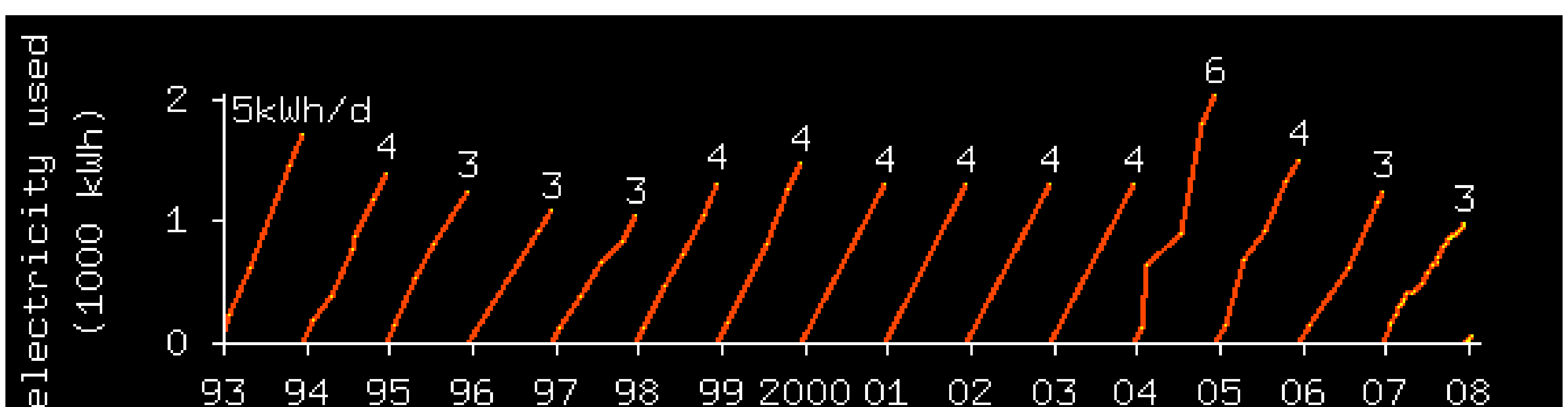
Read your meters!

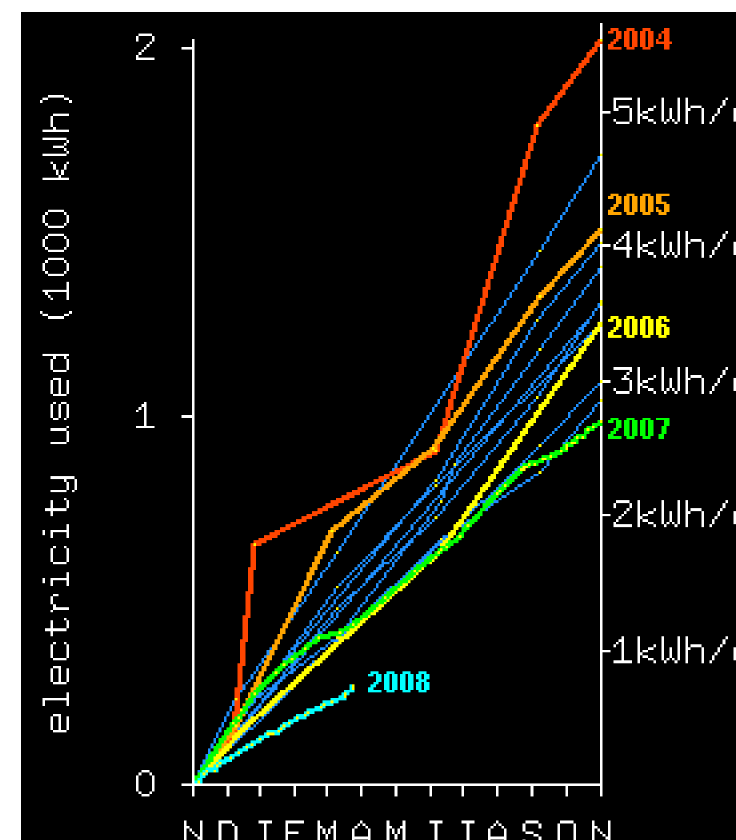


Gas



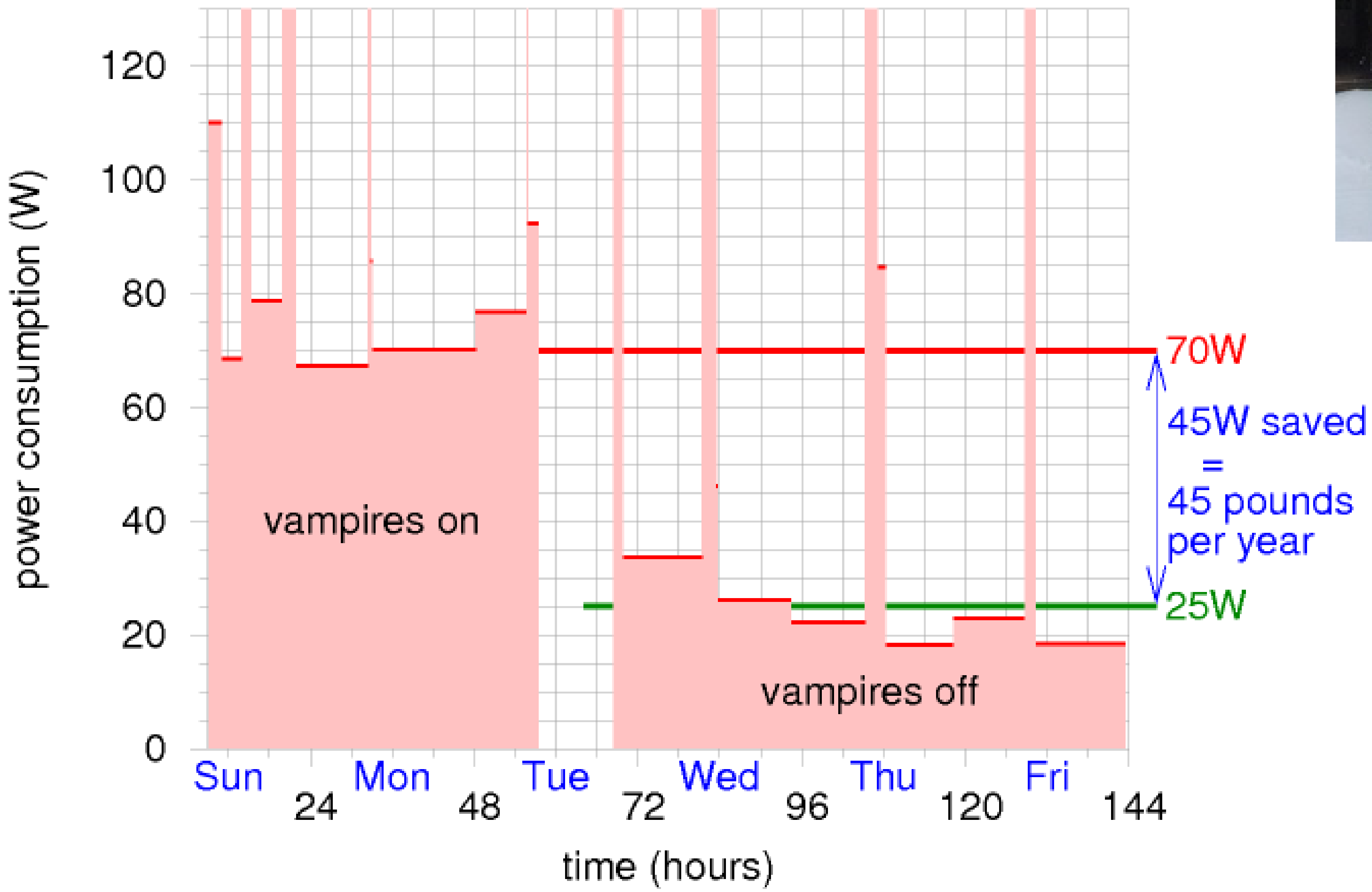
Electricity





Efficiency in the offing

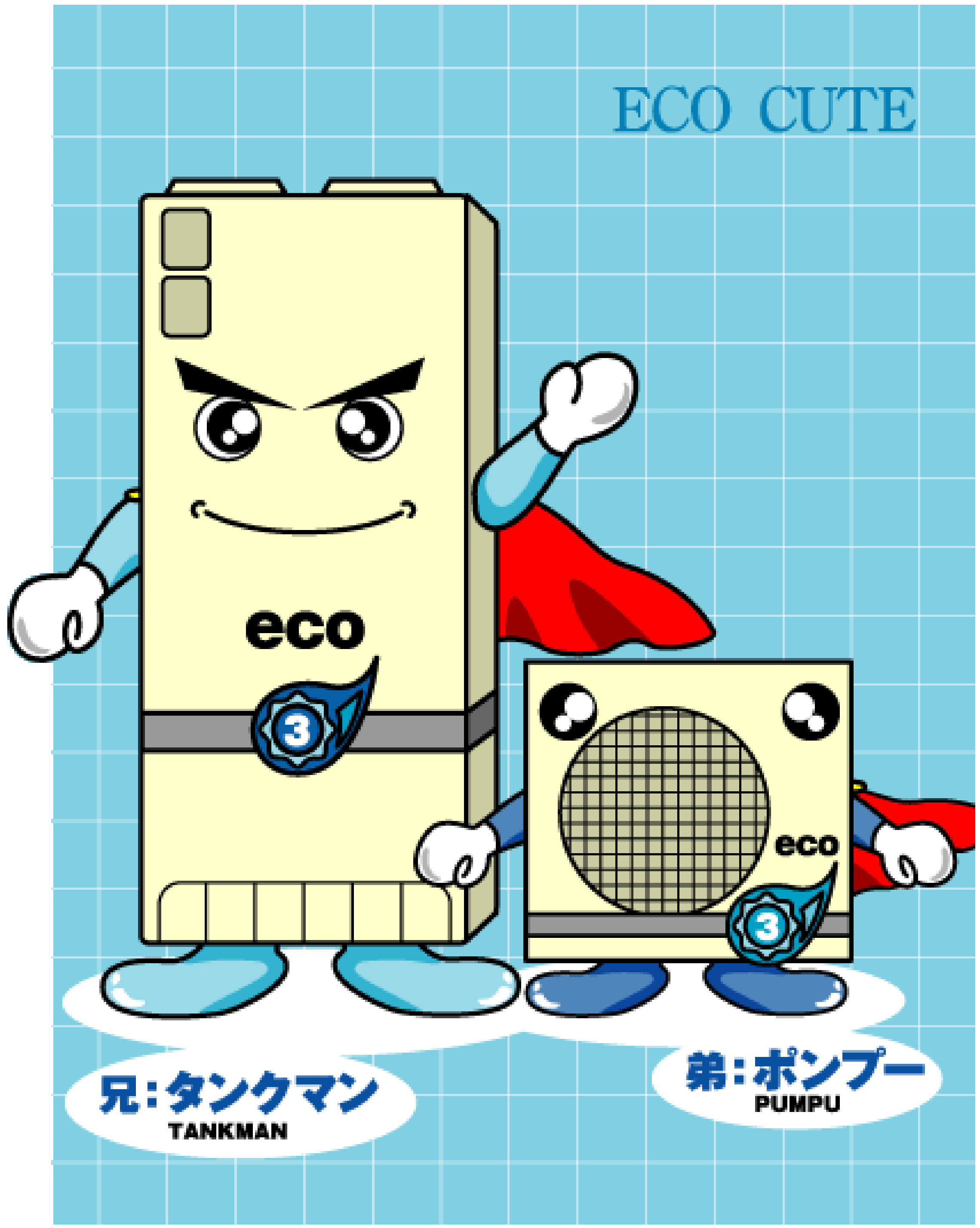
- Electricity

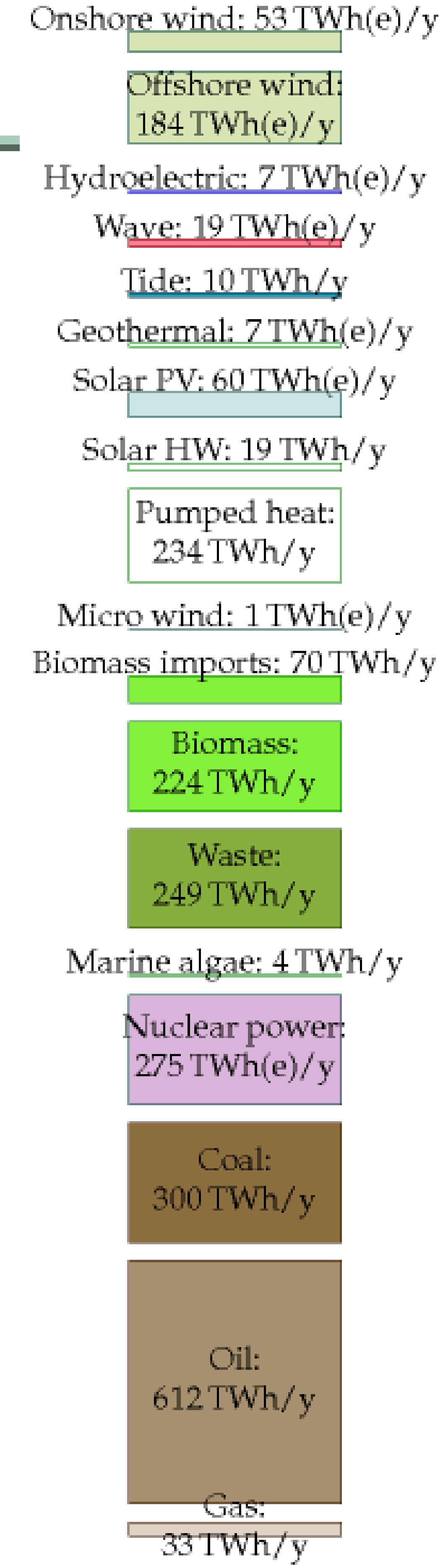


- is there anyone there?
- do they feel ok?

What we need for most 2050 pathways

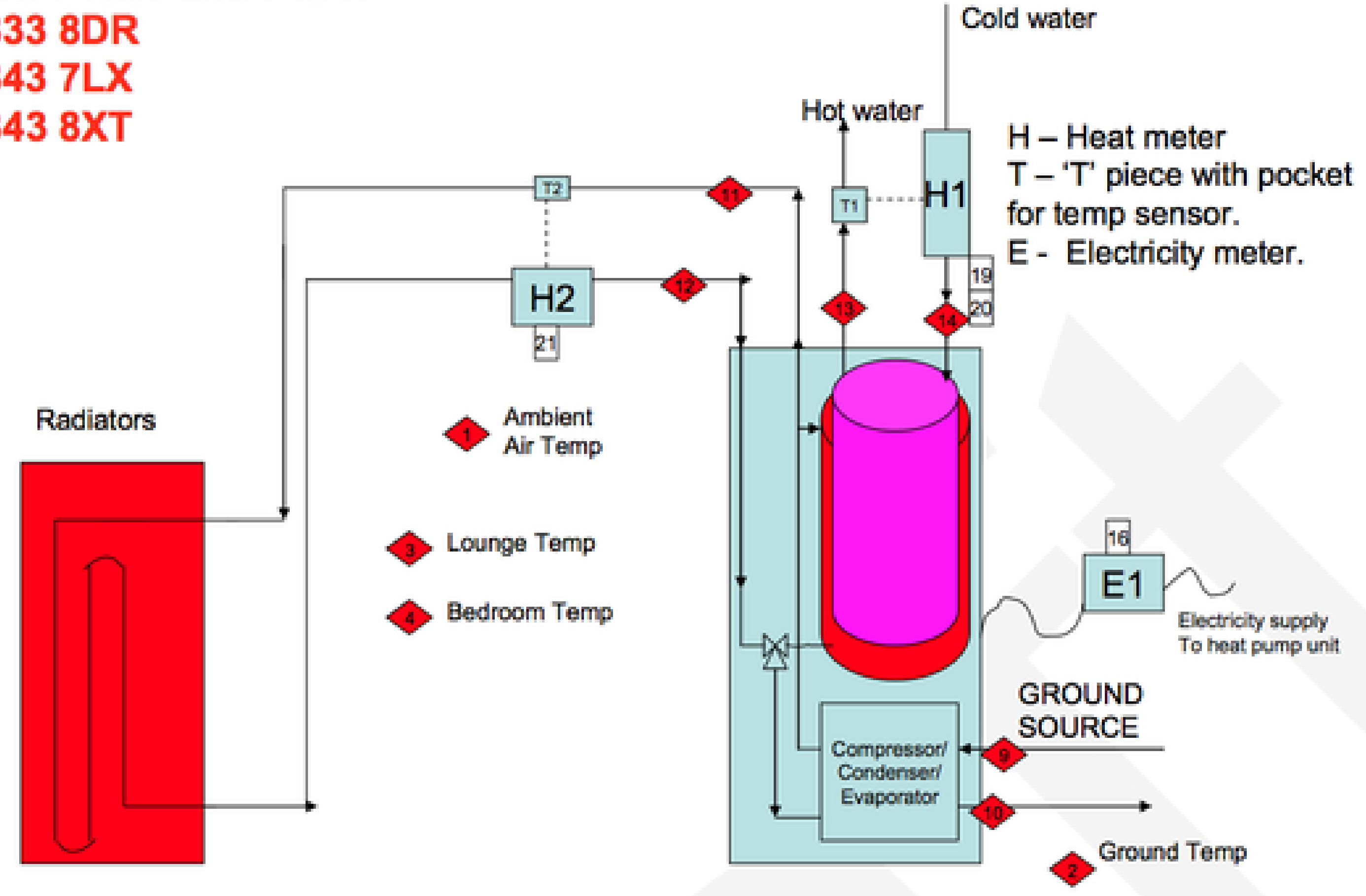
- Heat pumps that work





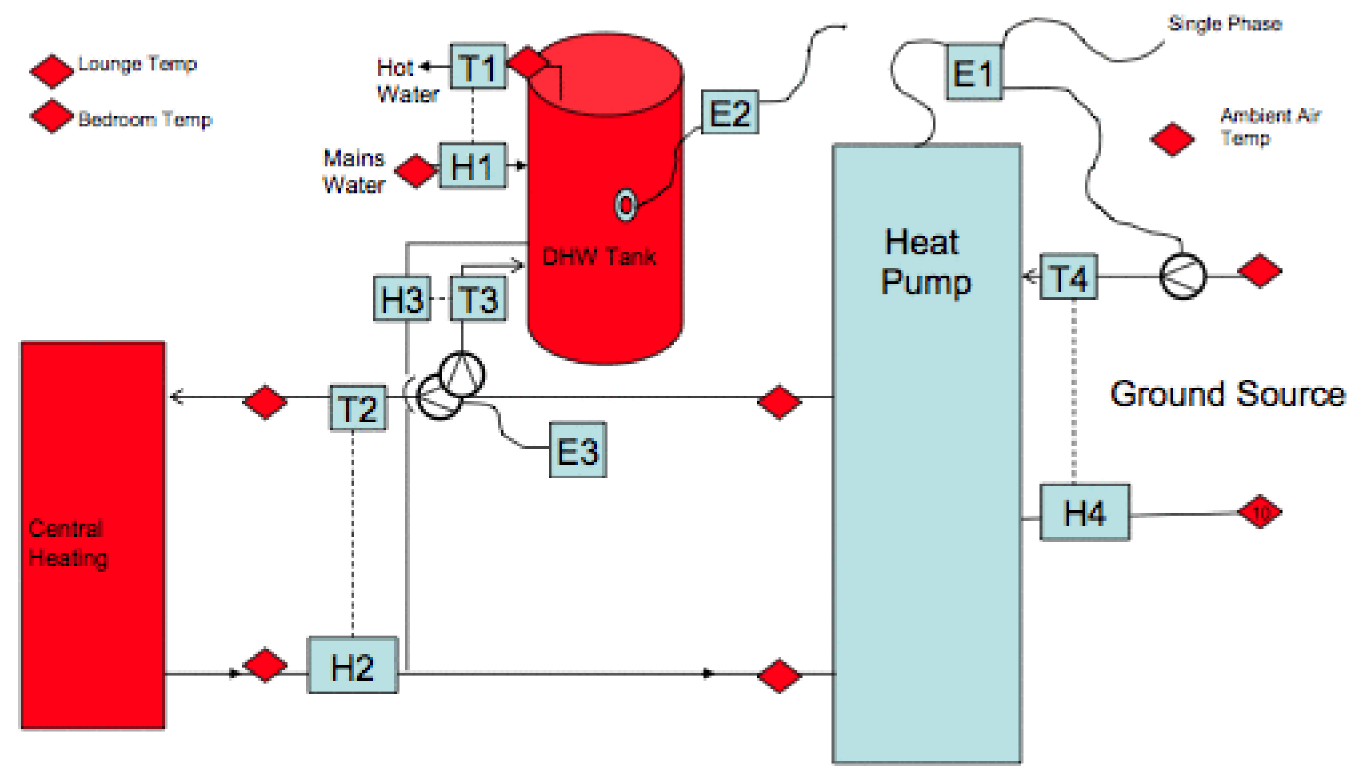
Heat pumps

NIBE F1220 and F1240
AB33 8DR
AB43 7LX
AB43 8XT

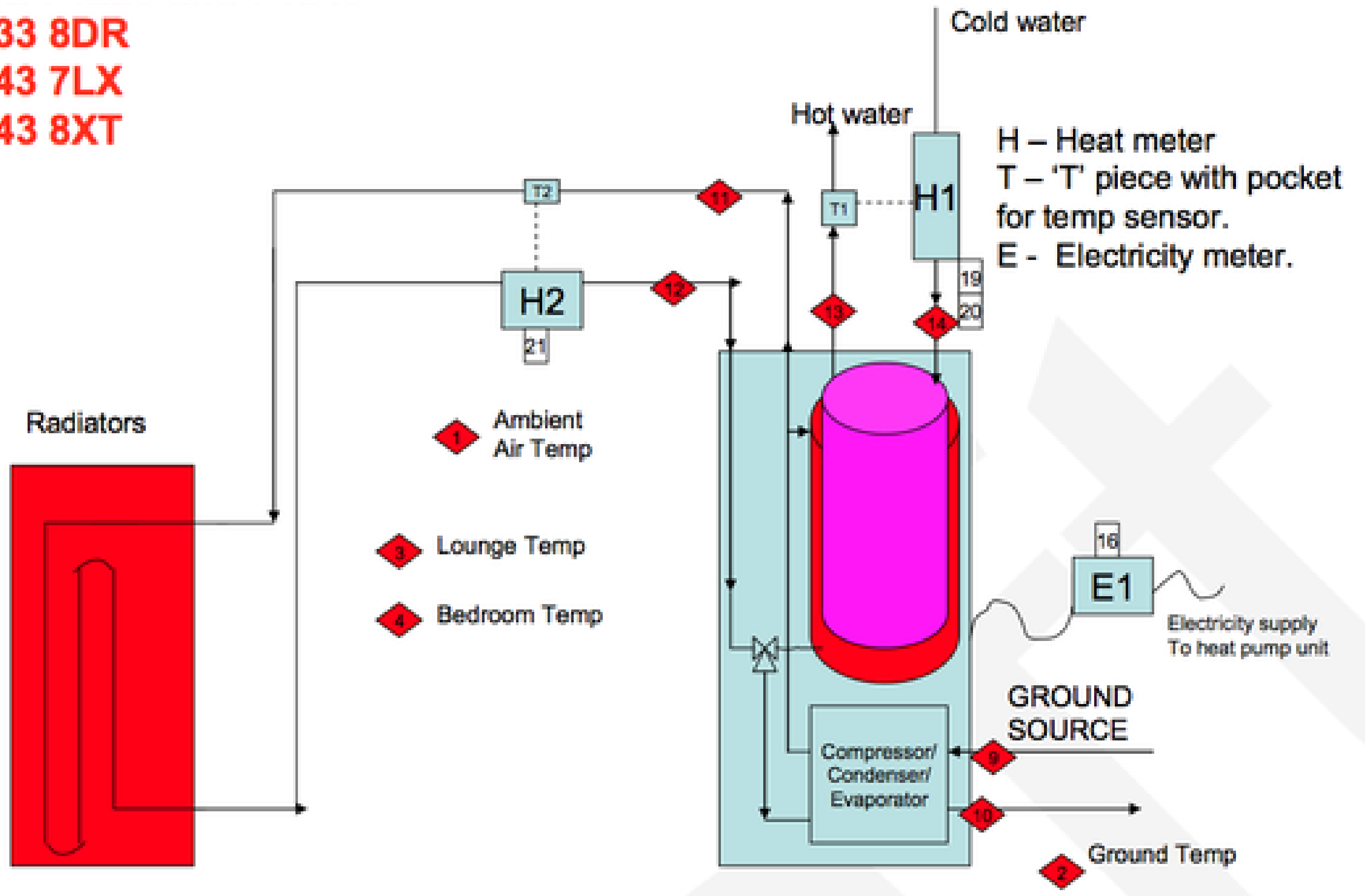


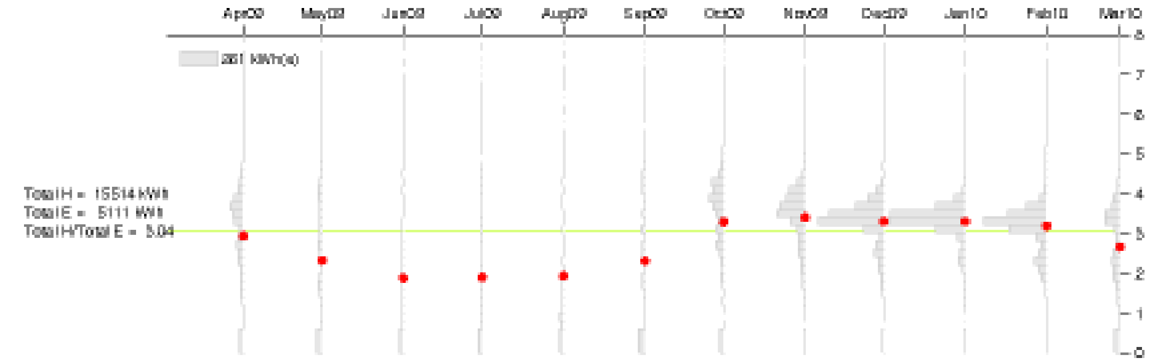
Calorex 3.5 kW GSHP
460FAU, 462MEW, 465BCU

T – 'T' piece with pocket for sensor.
H – Heat meter.
E - Electricity meter.



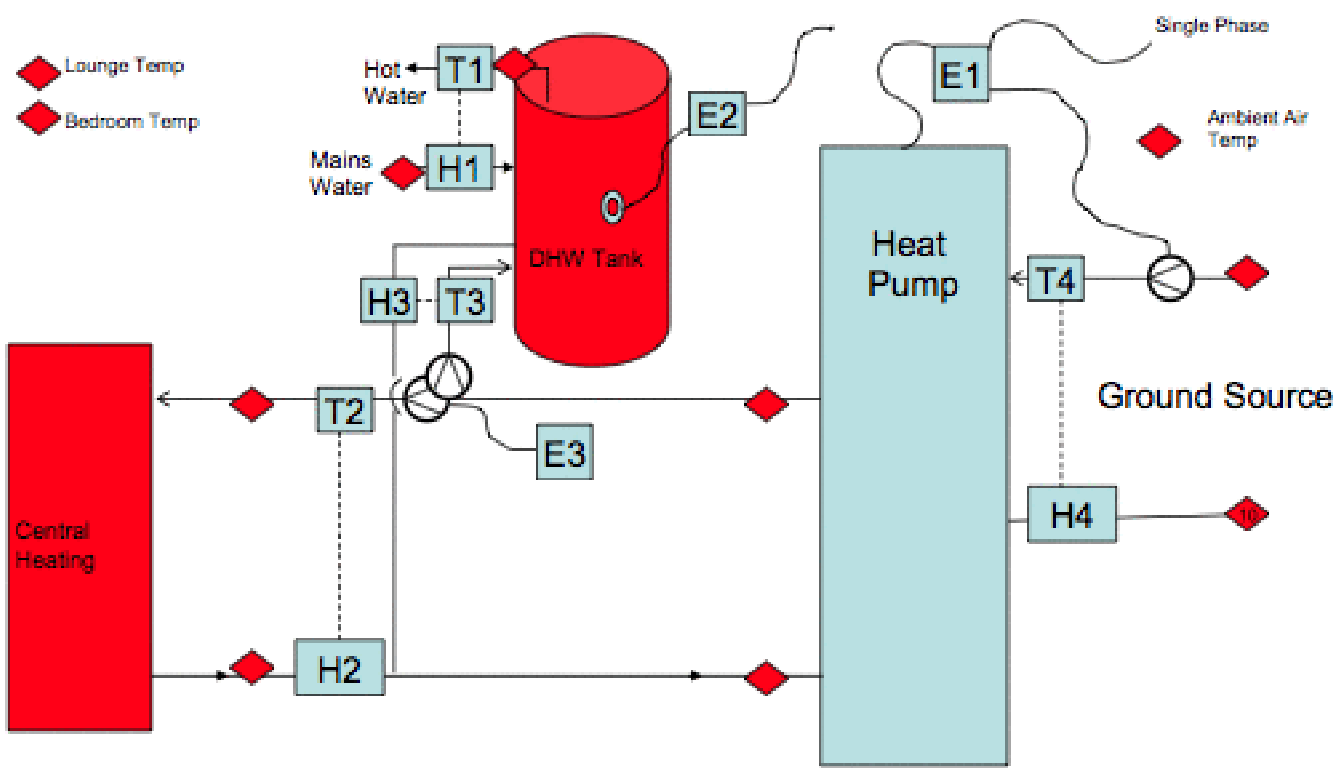
NIBE F1220 and F1240
AB33 8DR
AB43 7LX
AB43 8XT

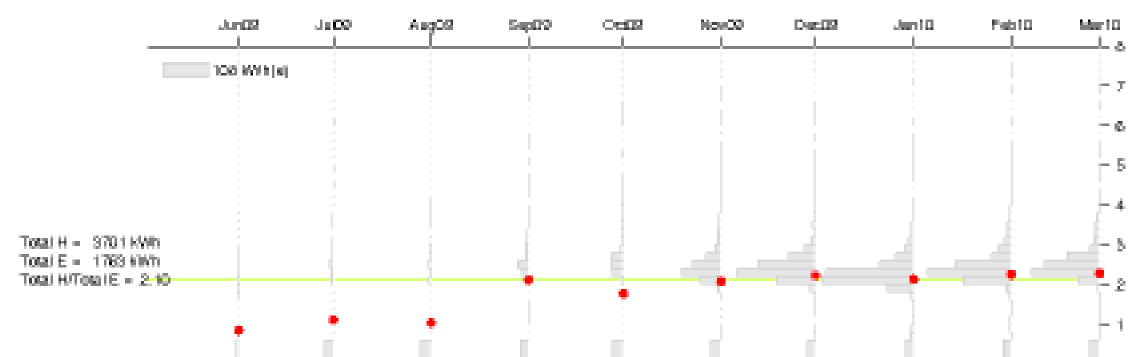


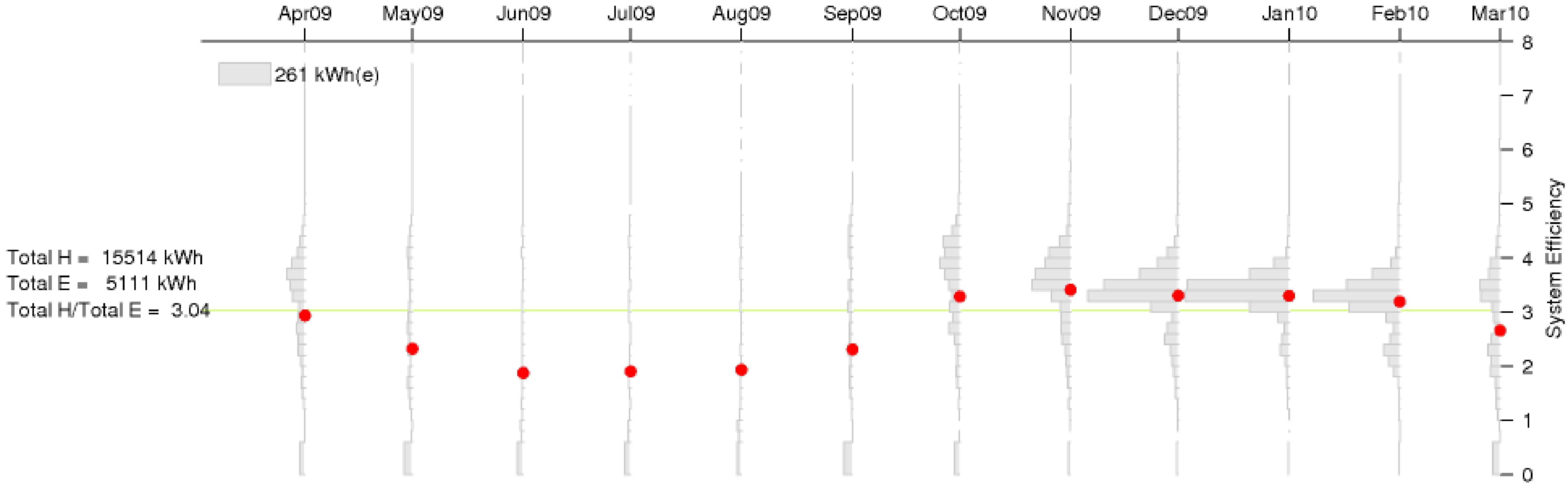


Calorex 3.5 kW GSHP
460FAU, 462MEW, 465BCU

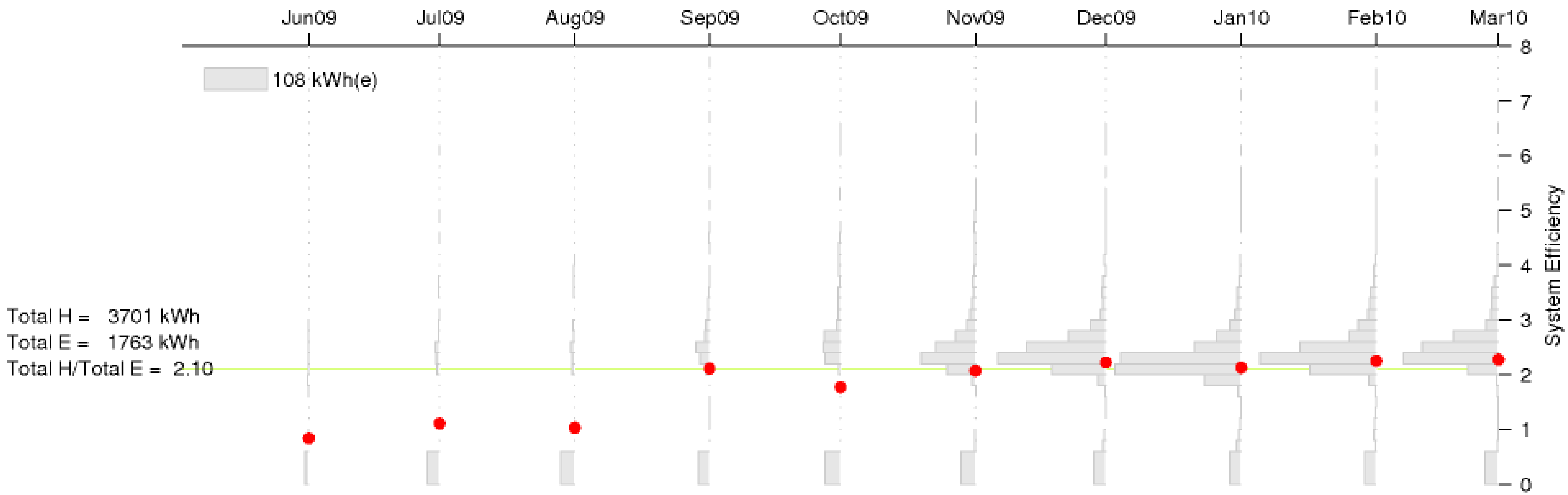
T – 'T' piece with pocket for sensor.
H – Heat meter.
E - Electricity meter.



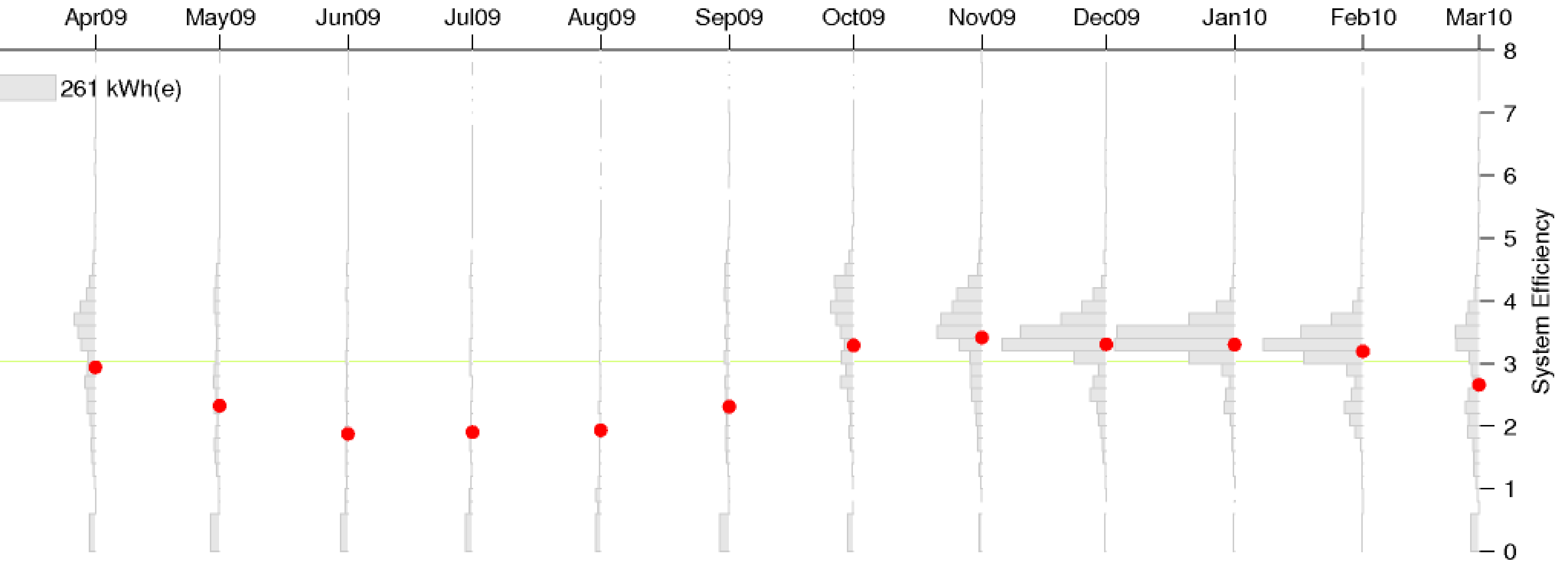




Apr09
May09
Jun09
Jul09
Aug09
Sep09
Oct09
Nov09
Dec09
Jan10
Feb10
Mar10
261 kWh(e)
Total H = 15514 kWh
Total E = 5111 kWh
Total H/Total E = 3.04
System Efficiency
0
1
2
3
4
5
6
7
8



Jun09
Jul09
Aug09
Sep09
Oct09
Nov09
Dec09
Jan10
Feb10
Mar10
108 kWh(e)
Total H = 3701 kWh
Total E = 1763 kWh
Total H/Total E = 2.10
System Efficiency
0
1
2
3
4
5
6
7
8



Apr09
May09
Jun09
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Aug09
Sep09
Oct09
Nov09
Dec09
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Feb10
Mar10
261 kWh(e)
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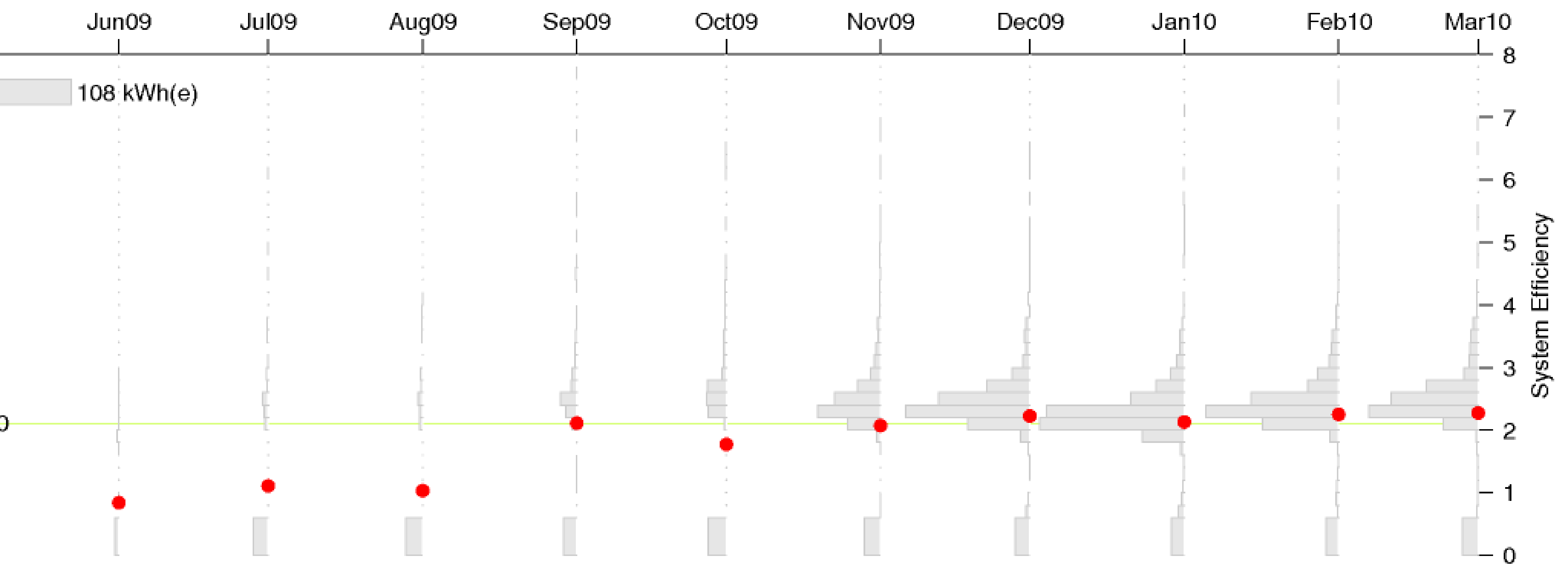

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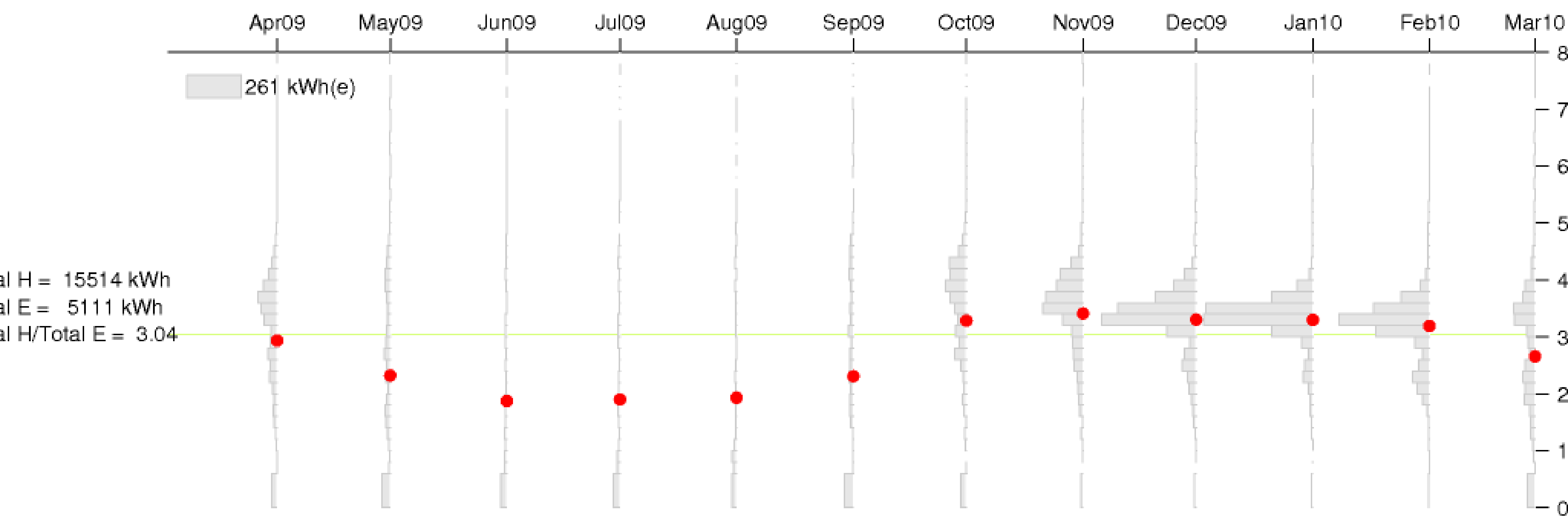

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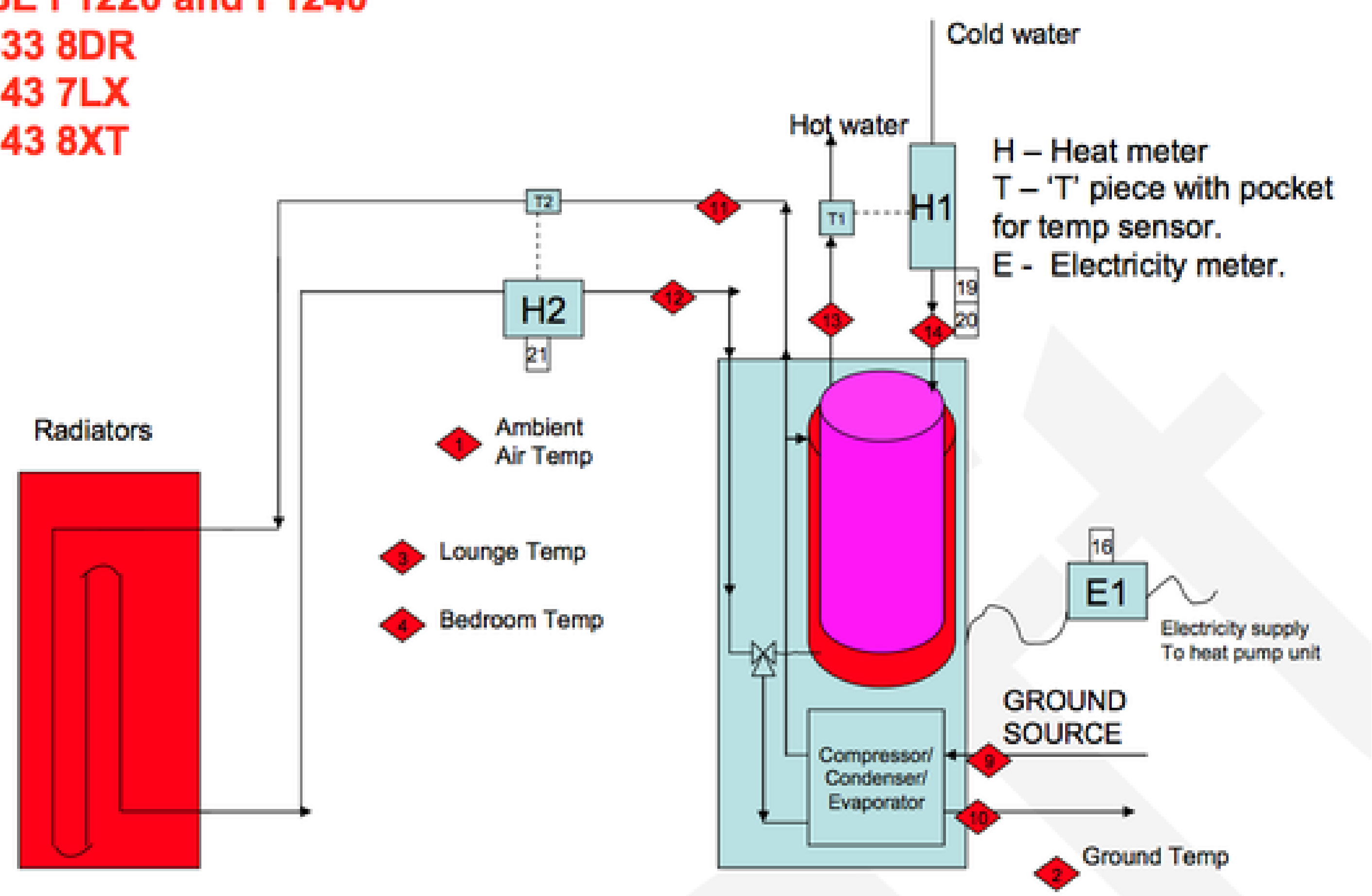

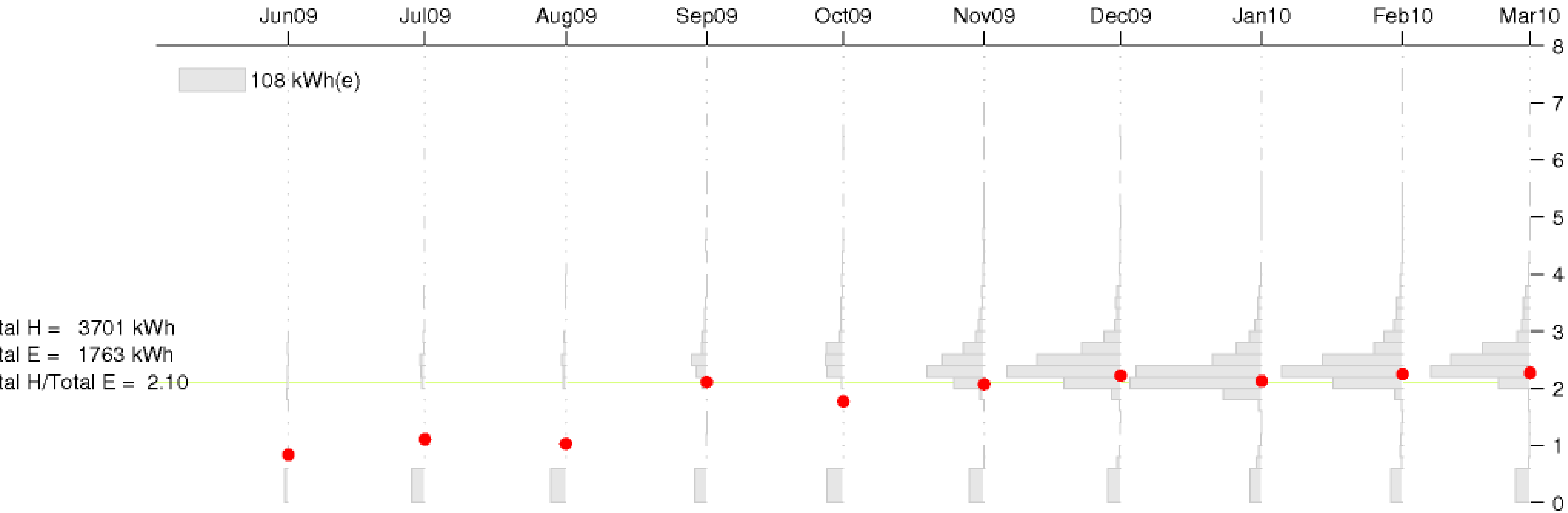

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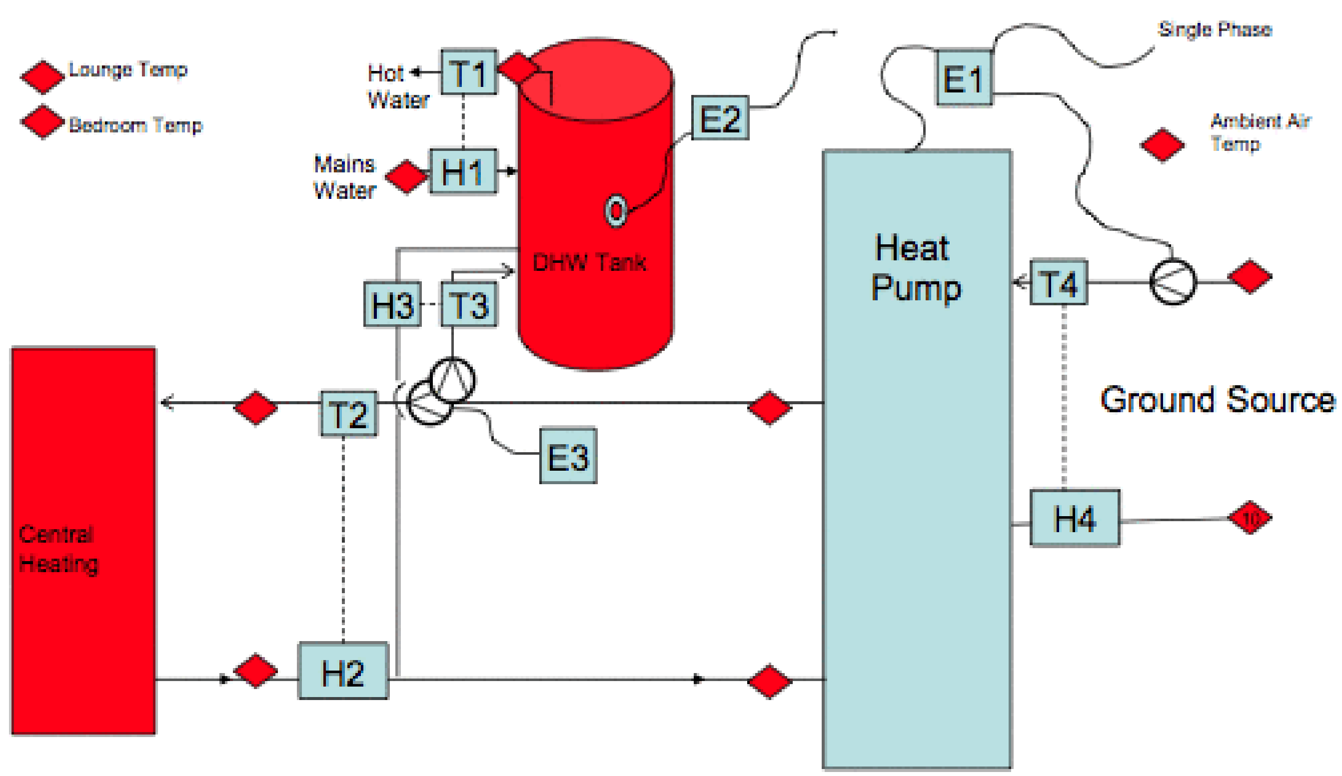
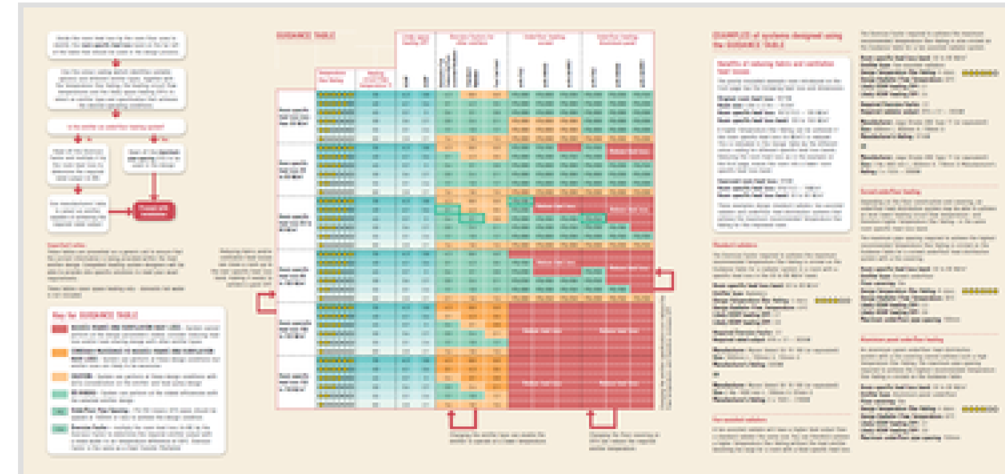
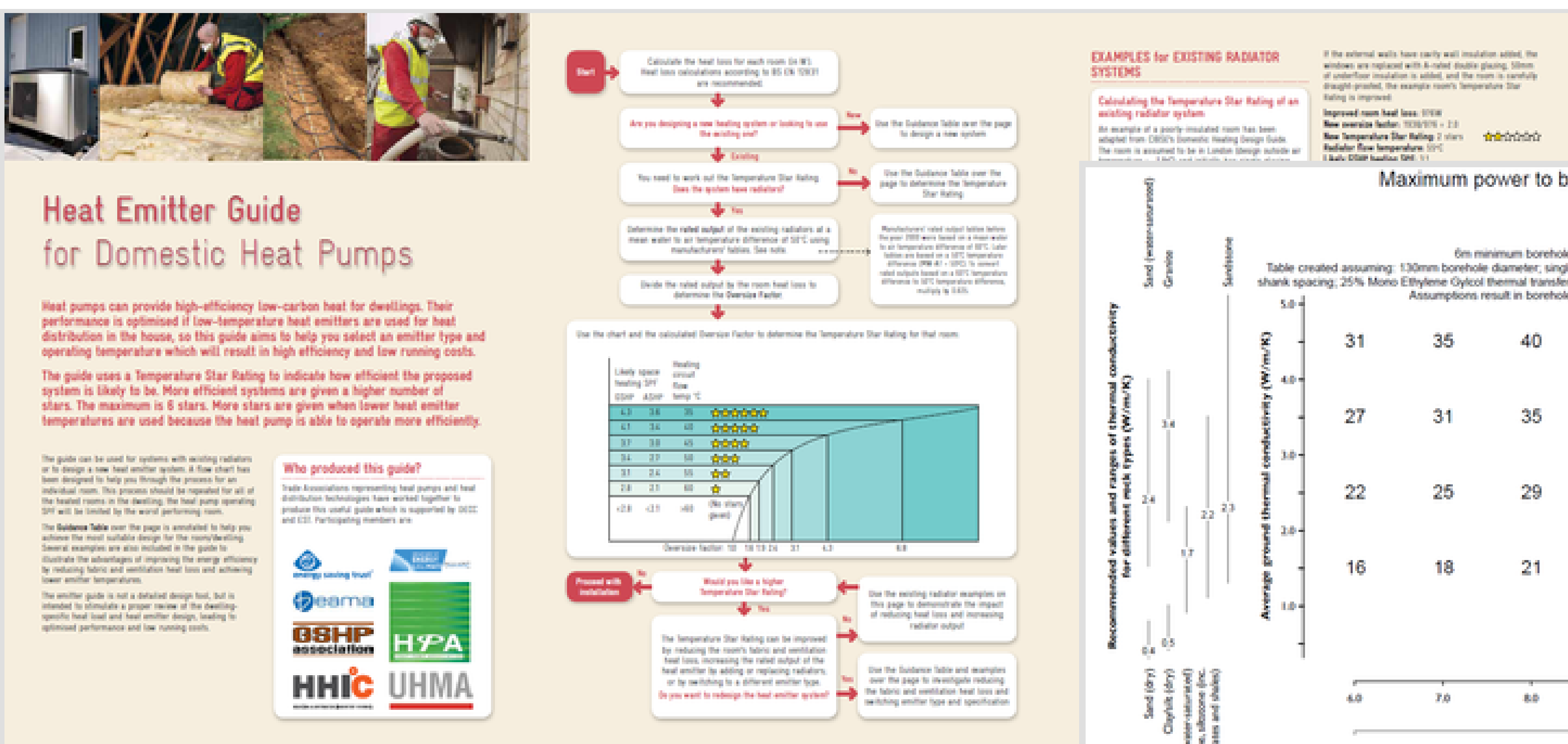
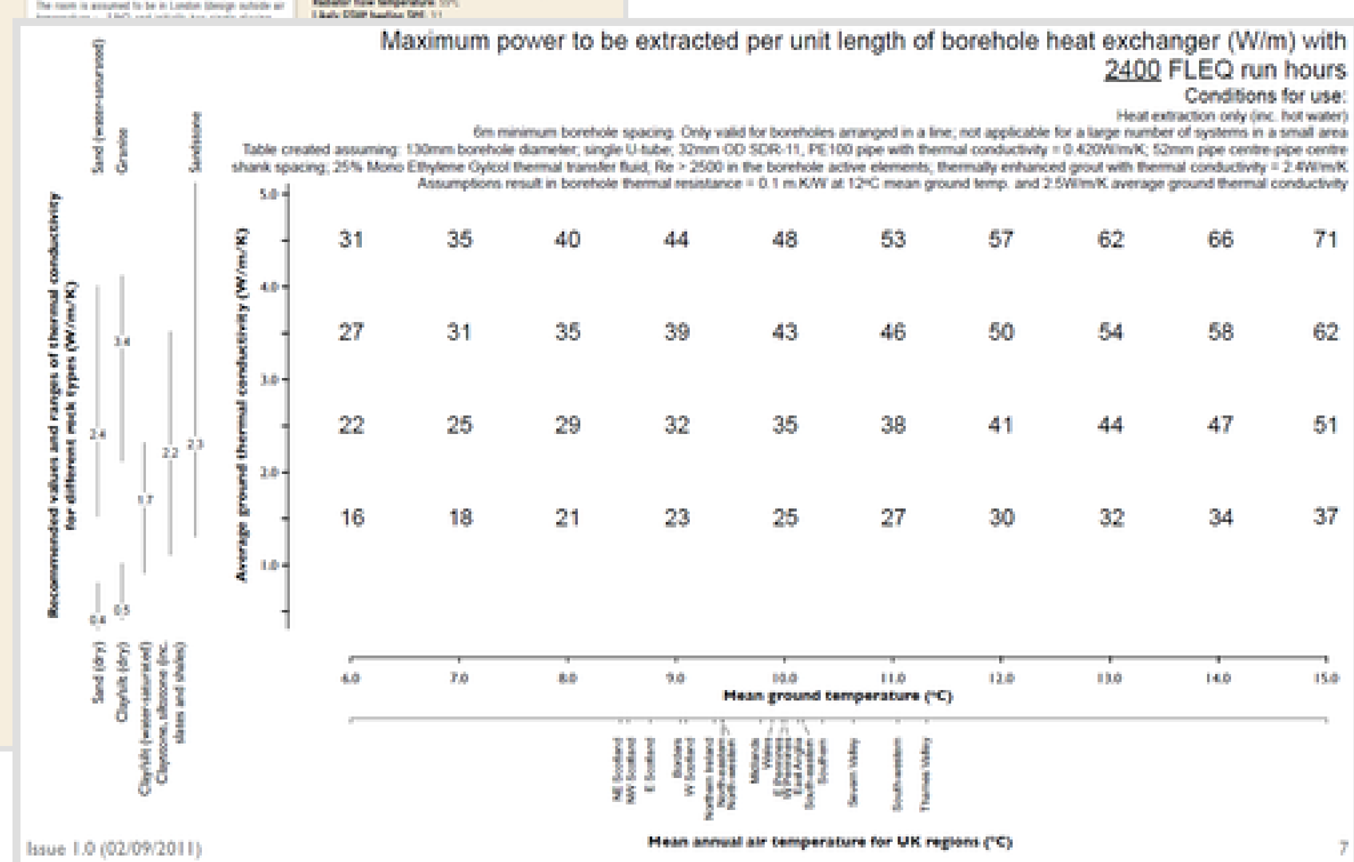


Standards for Heat-pump Installations

Chris Wickins and
the Microgeneration Certification Scheme
Heat-pump Working Group

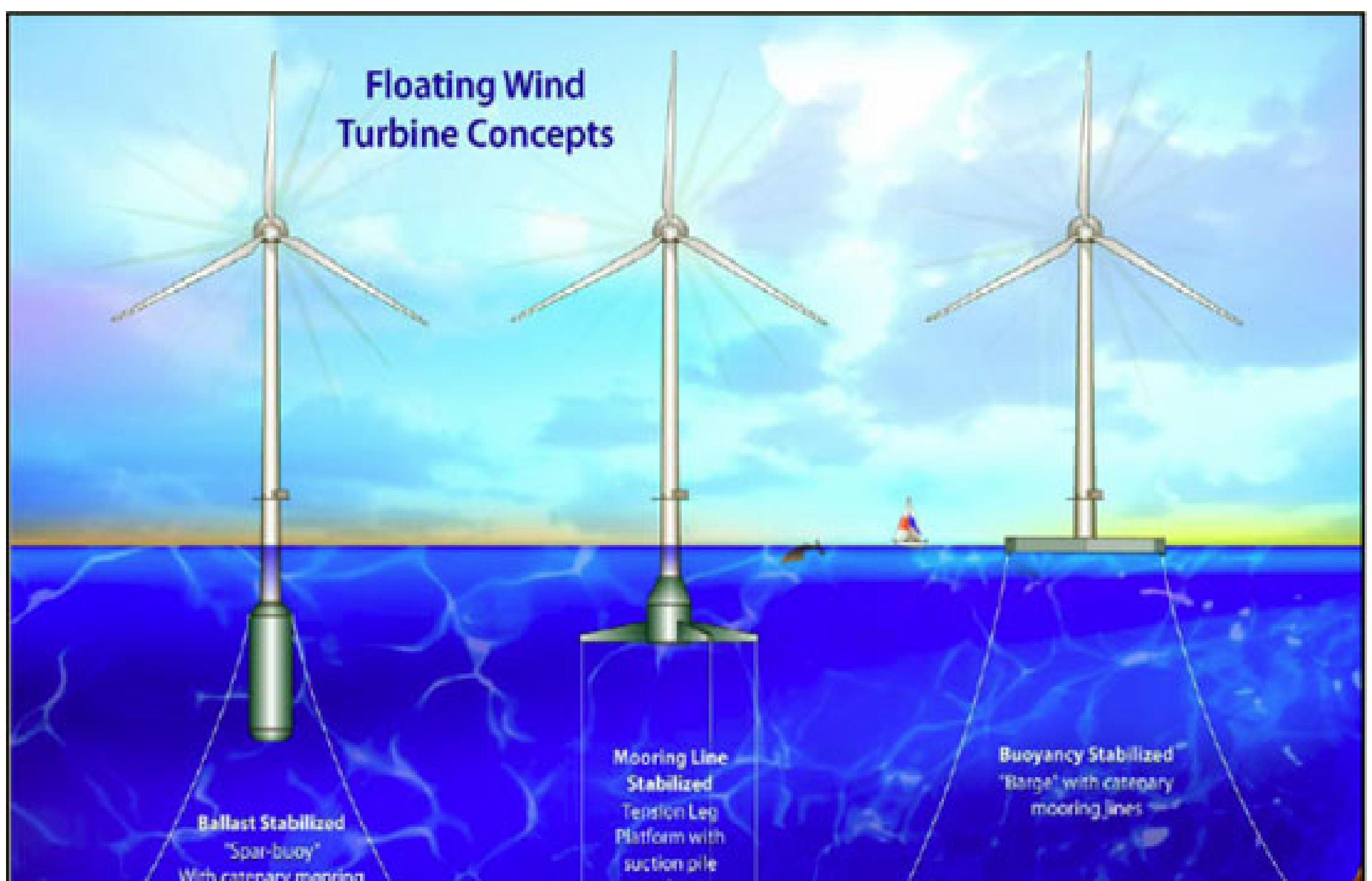






What we need for most 2050 pathways

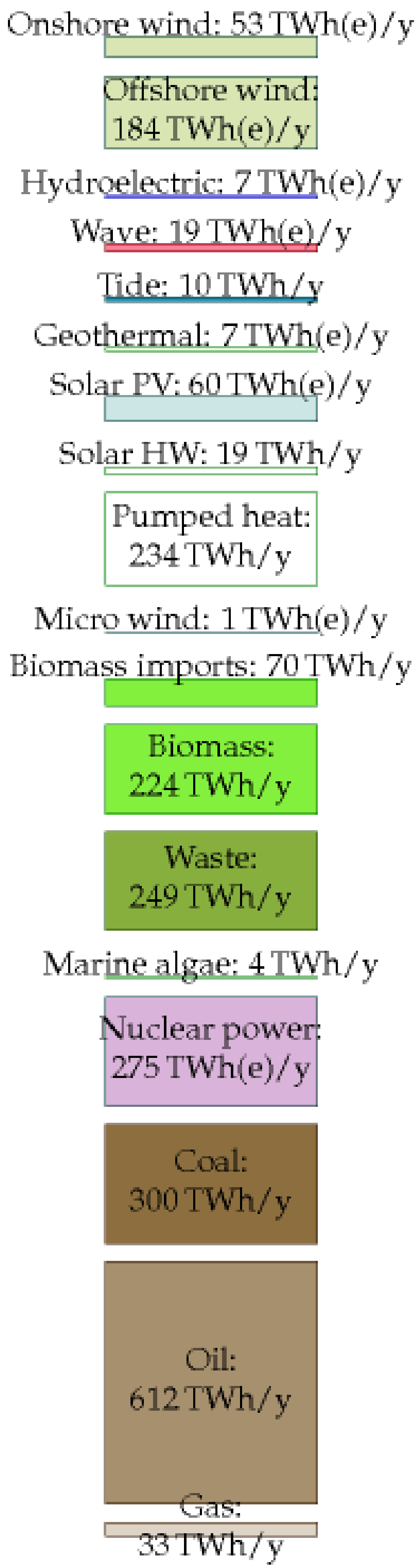
- Cheaper wind, especially offshore



Onshore wind: 53 TWh(e)/y
Offshore wind: 184 TWh(e)/y
Hydroelectric: 7 TWh(e)/y
Wave: 19 TWh(e)/y
Tide: 10 TWh/y
Geothermal: 7 TWh(e)/y
Solar PV: 60 TWh(e)/y
Solar HW: 19 TWh/y
Pumped heat: 234 TWh/y
Micro wind: 1 TWh(e)/y
Biomass imports: 70 TWh/y
Biomass: 224 TWh/y
Waste: 249 TWh/y
Marine algae: 4 TWh/y
Nuclear power: 275 TWh(e)/y
Coal: 300 TWh/y
Oil: 612 TWh/y
Gas: 33 TWh/y

What we need for most 2050 pathways

- Biomass-to-good stuff
- Waste-to-good stuff
  - what are the best uses of biomass?



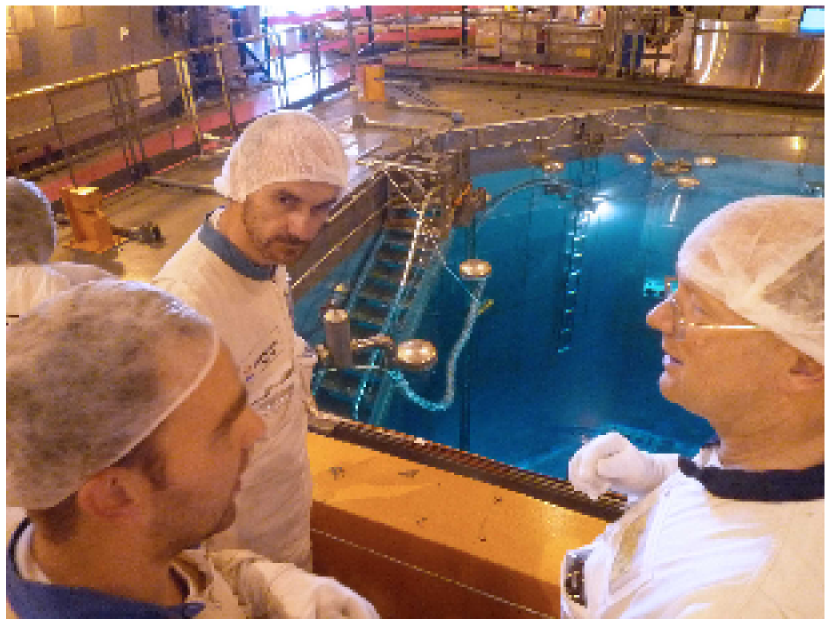
EPI

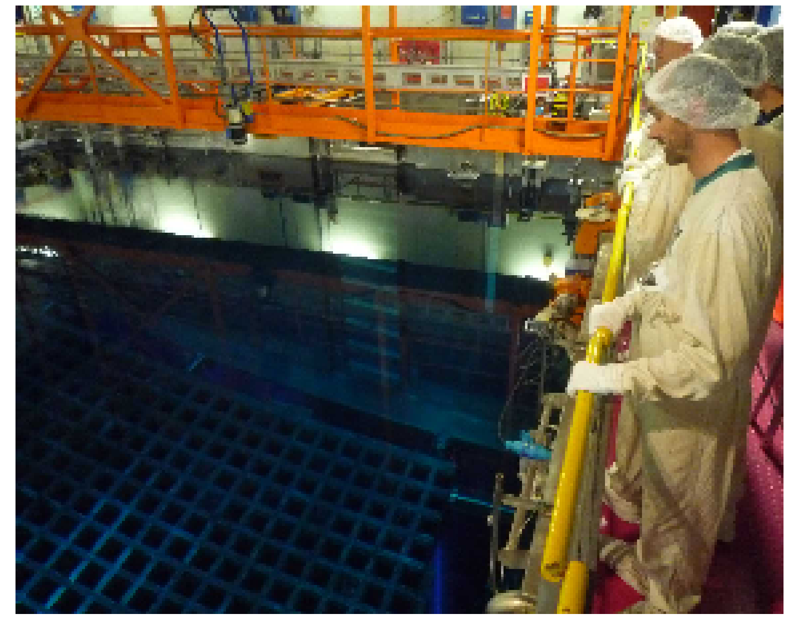
- Pyrolysis -
  - converting municipal waste to gas

Drax

What we need for most 2050 pathways

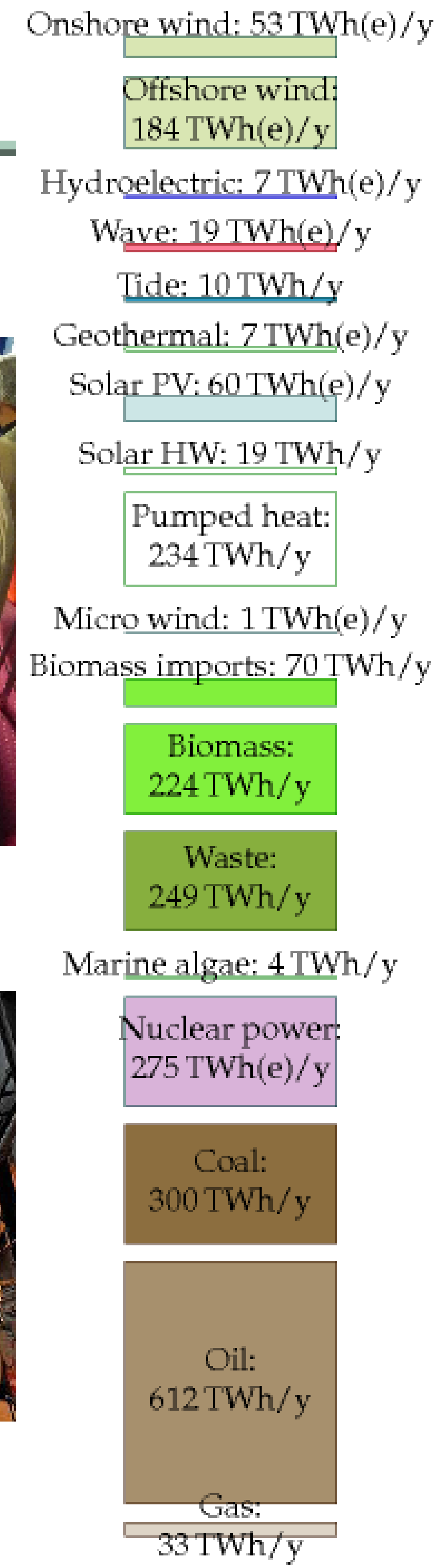
- Proliferation-resistant, safe, low-waste nuclear power



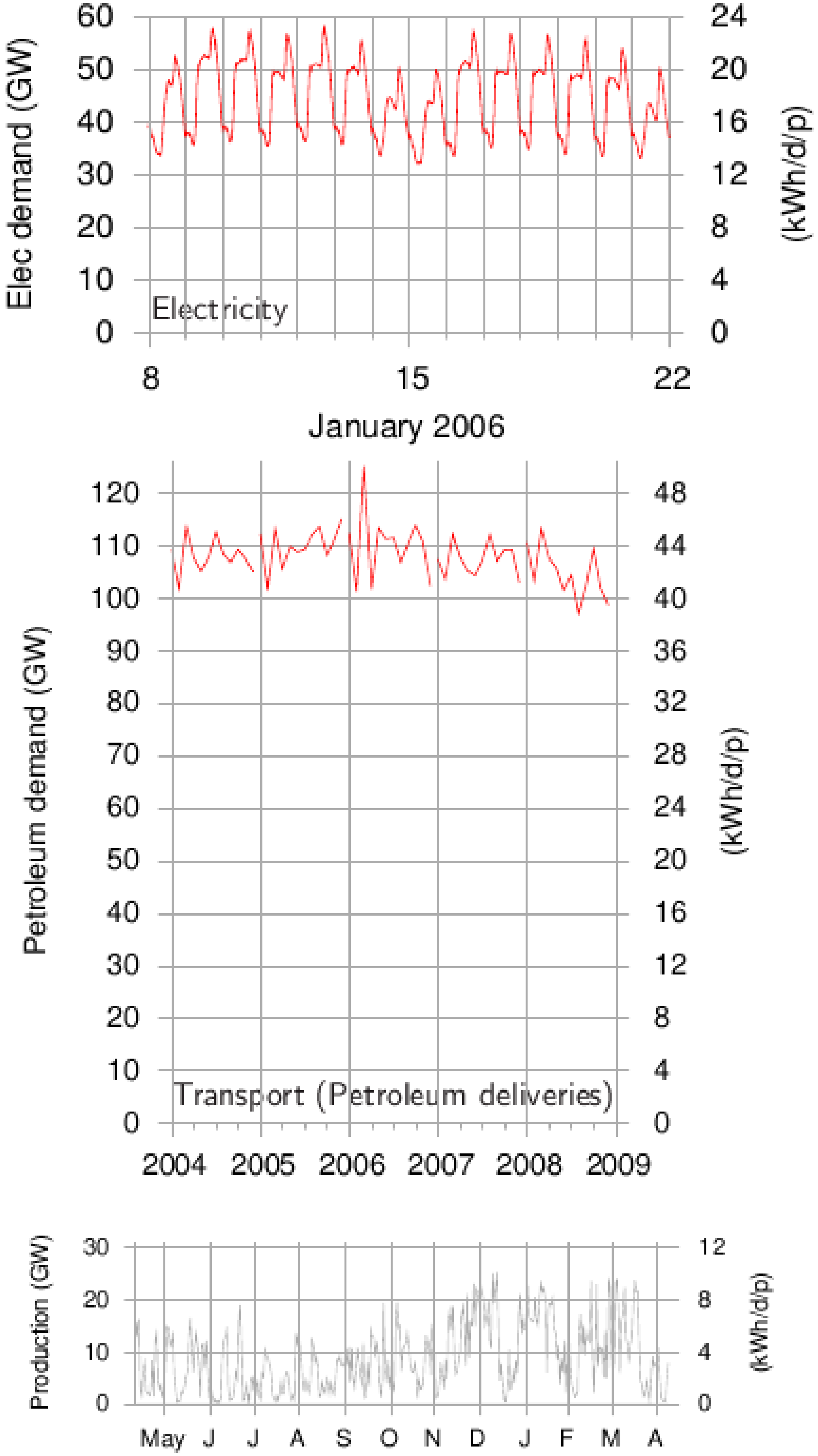


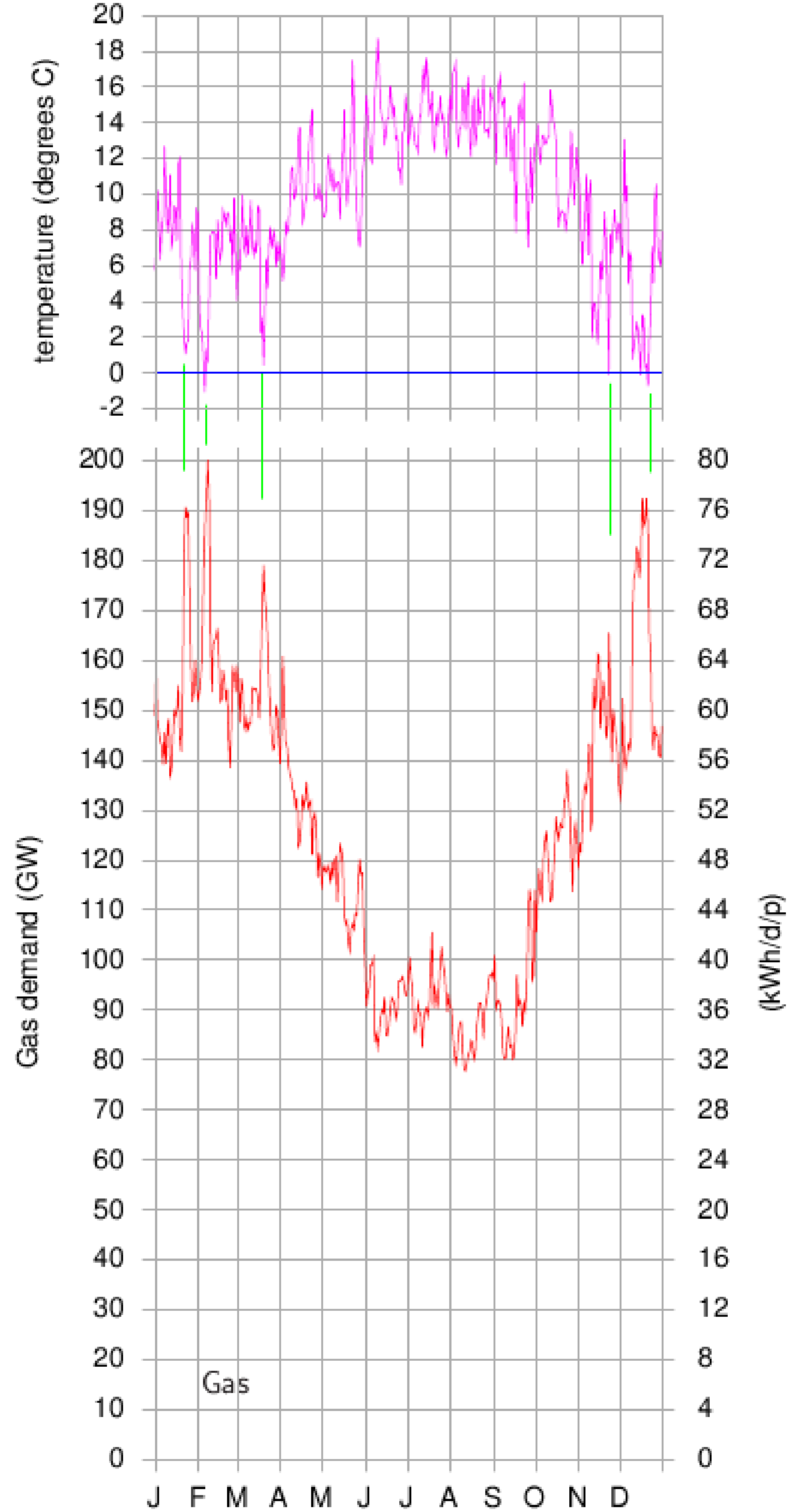
- Carbon capture and storage at scale

- Smart grids
- Interconnectors and storage



Transport, heating, electricity; wind





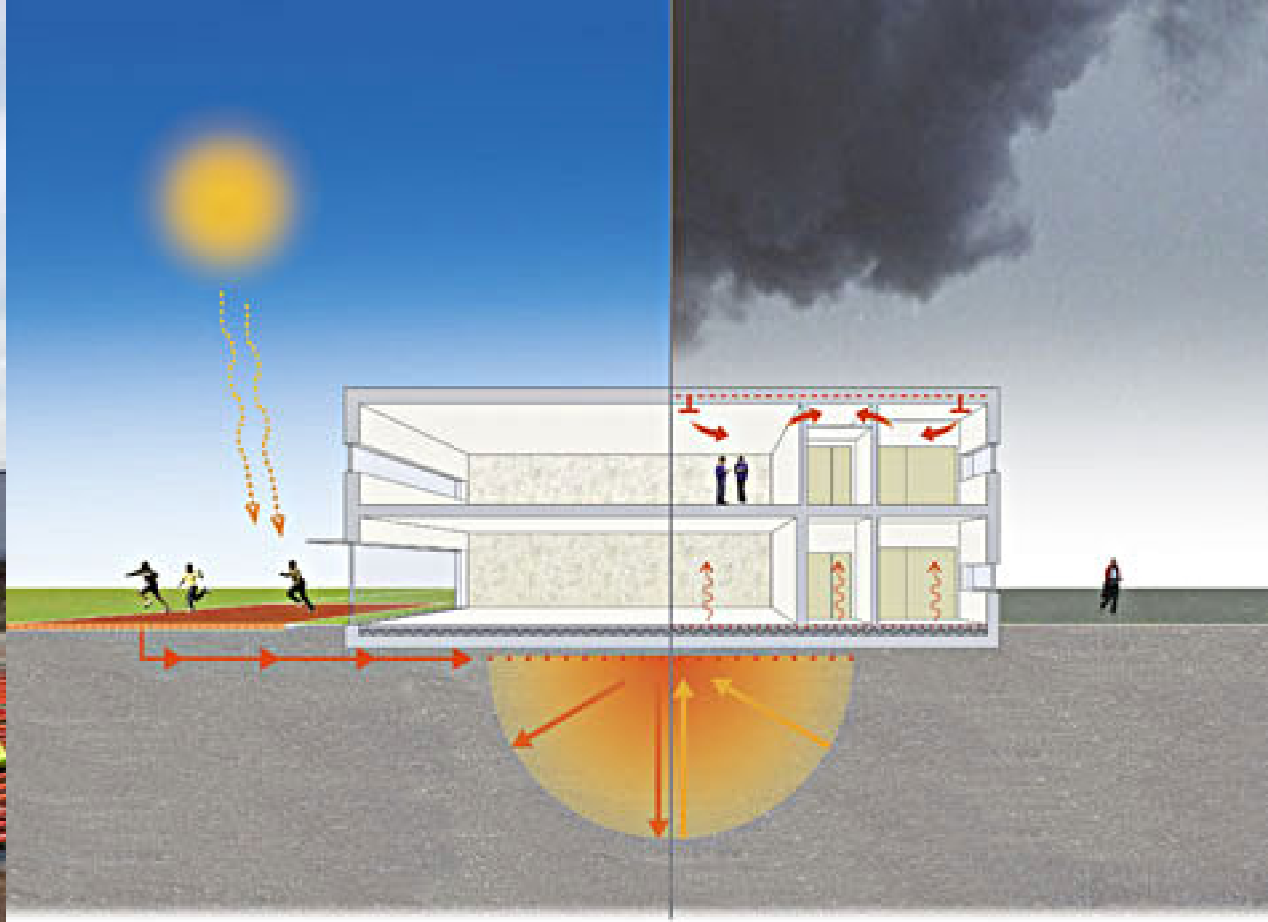
Electricity, gas, and transport demand; and fictional wind (assuming 33 GW of capacity), all on the same vertical scale.

Pumped storage

Dinorwig - 10 GWh energy; 2 GW maximum power

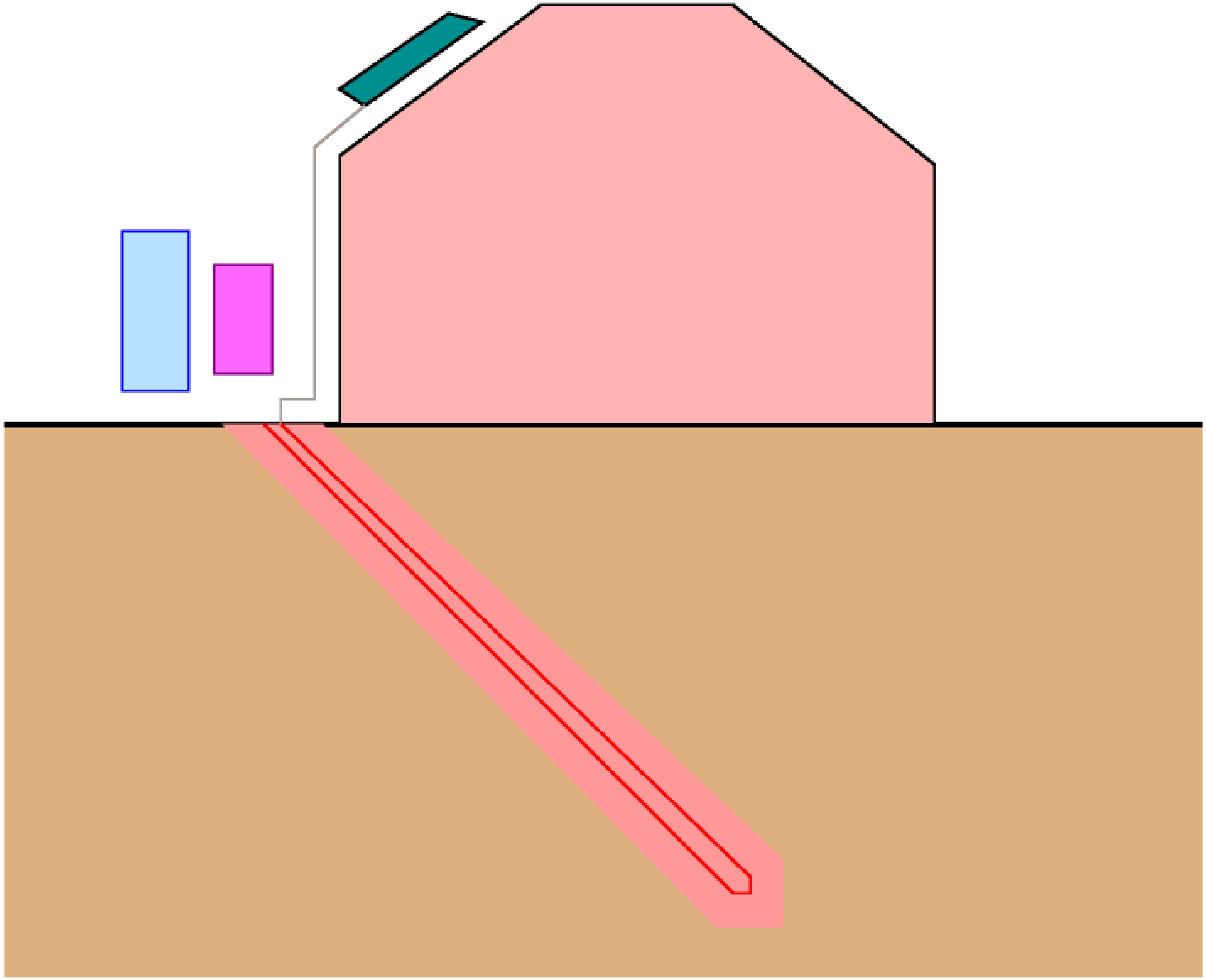
Seasonal heat stores

- Especially for old buildings

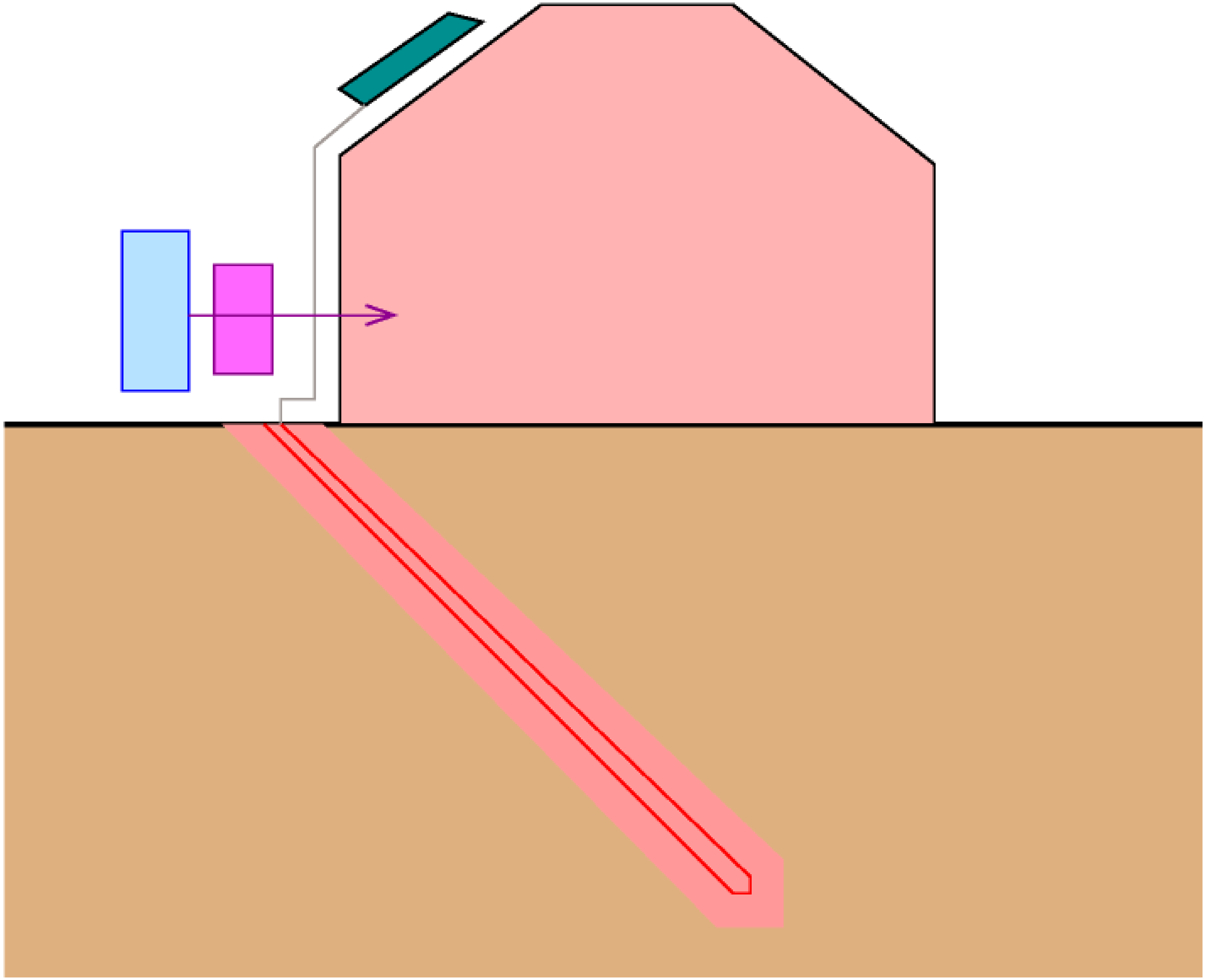

ICAX
CAMFAUD



ICAX

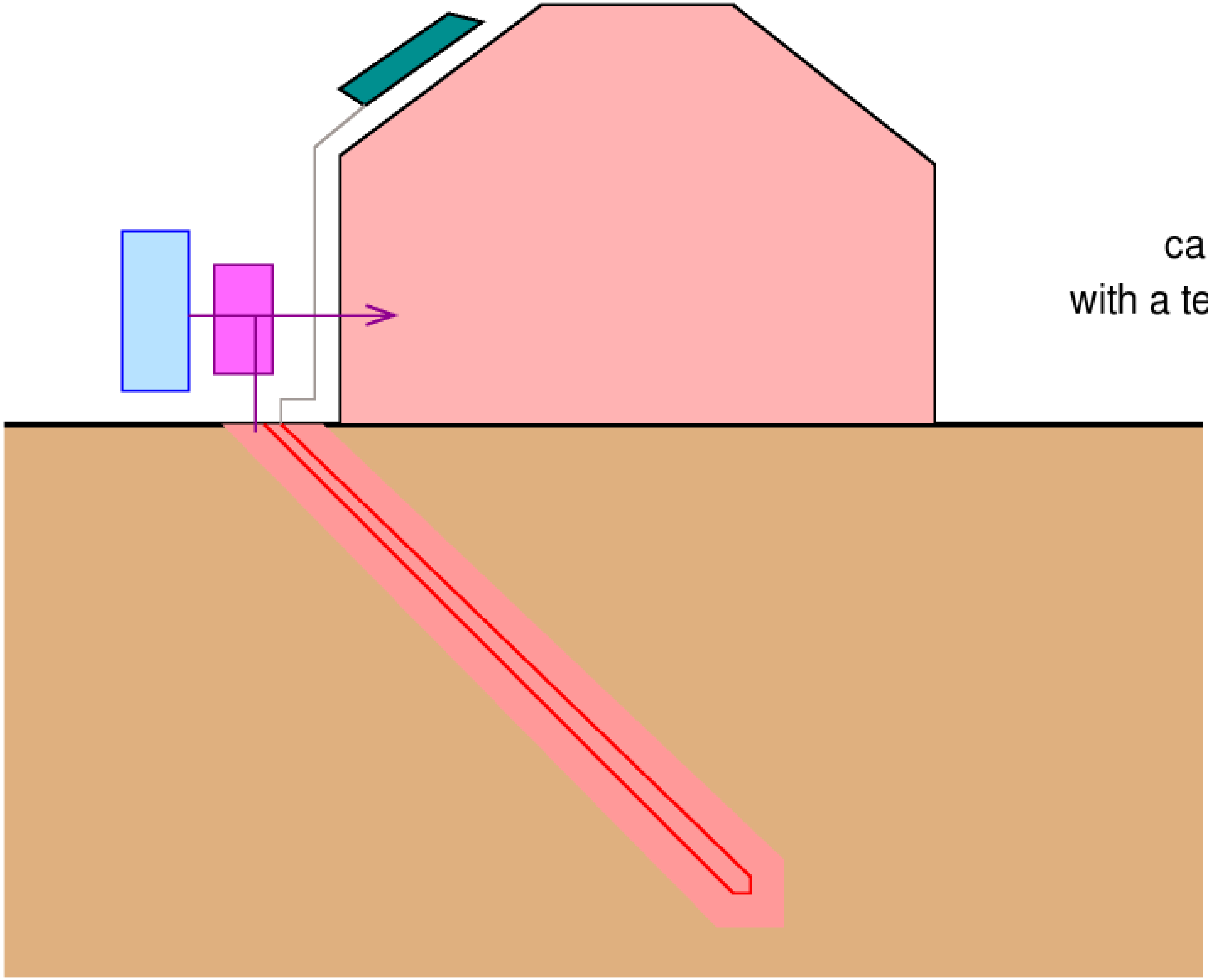
Seasonal heat store, solar panel, and heat pump



Seasonal heat store, solar panel, and heat pump



Seasonal heat store, solar panel, and heat pump



6-month diffusion length of heat in rock is about 6m.

A 20-m cylinder, radius 6 m, can store 24 kWh/d * 6 months with a temperature increase of 3.4 C

MAX FORDHAM

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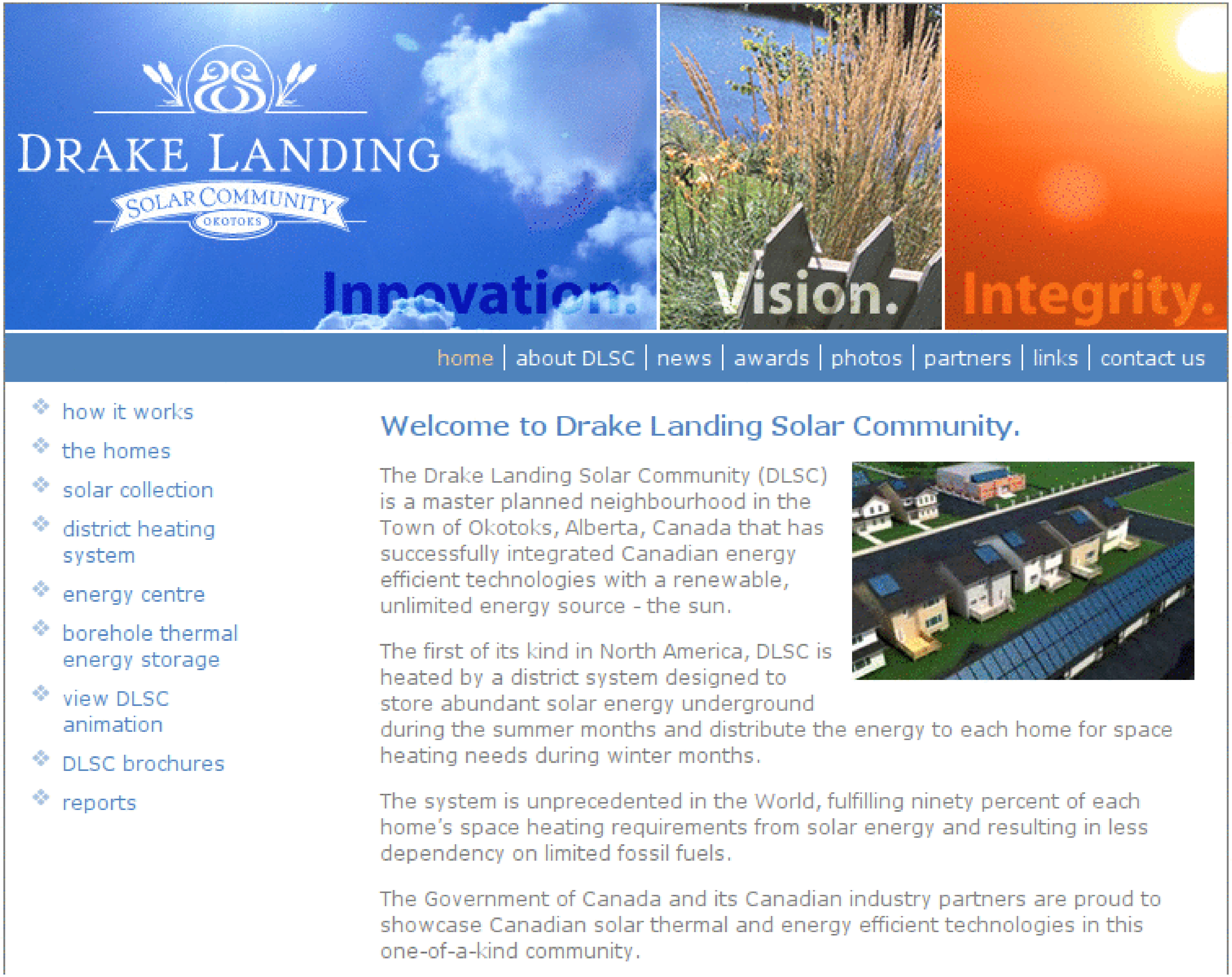
BEAUFORT COURT:

RENEWABLE ENERGY SYSTEMS HEADQUARTERS

Seasonal heat store for community heating



DRAKE LANDING SOLAR COMMUNITY OKOTOKS

Innovation. Vision. Integrity.

home | about DLSC | news | awards | photos | partners | links | contact us

- how it works
- the homes
- solar collection
- district heating system
- energy centre
- borehole thermal energy storage
- view DLSC animation
- DLSC brochures
- reports

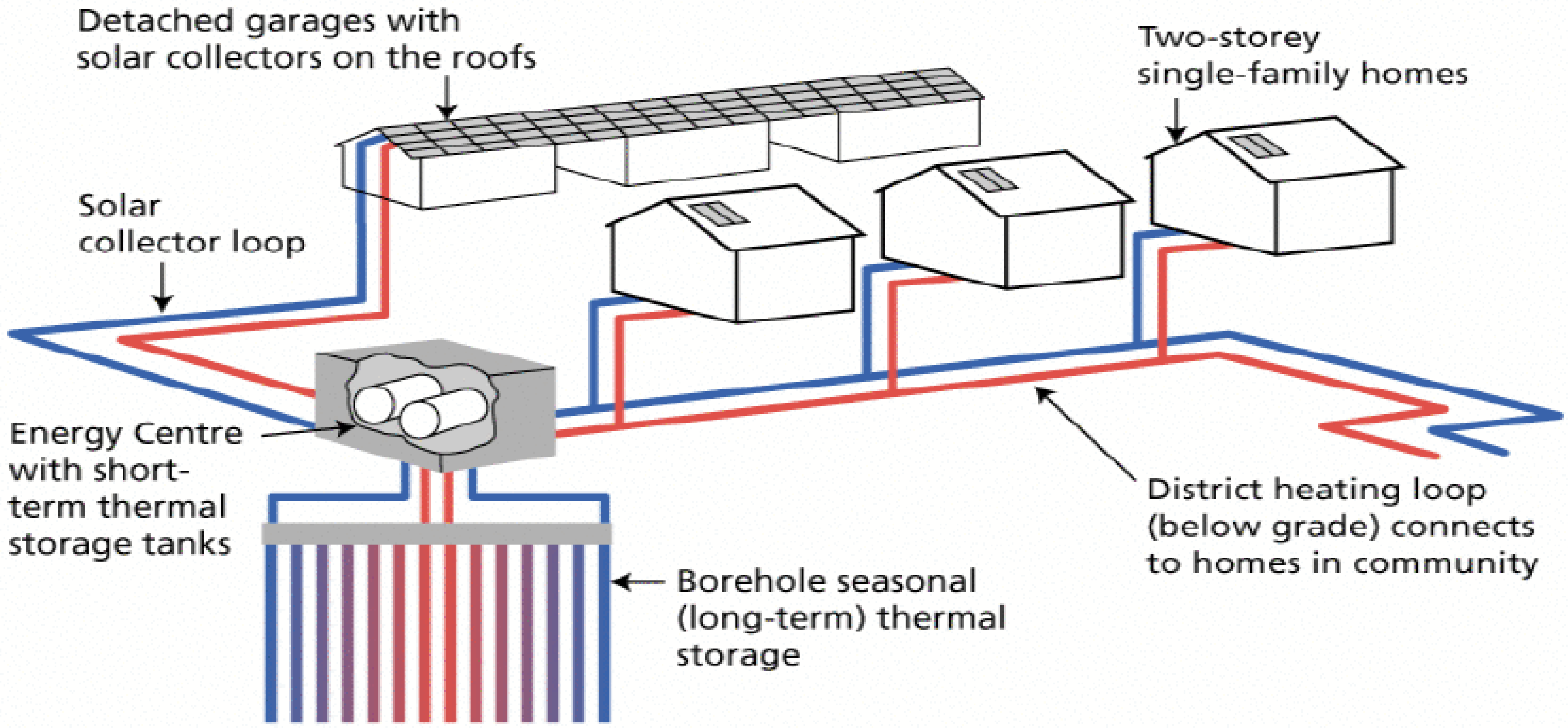
Welcome to Drake Landing Solar Community.

The Drake Landing Solar Community (DLSC) is a master planned neighbourhood in the Town of Okotoks, Alberta, Canada that has successfully integrated Canadian energy efficient technologies with a renewable, unlimited energy source - the sun.

The first of its kind in North America, DLSC is heated by a district system designed to store abundant solar energy underground during the summer months and distribute the energy to each home for space heating needs during winter months.

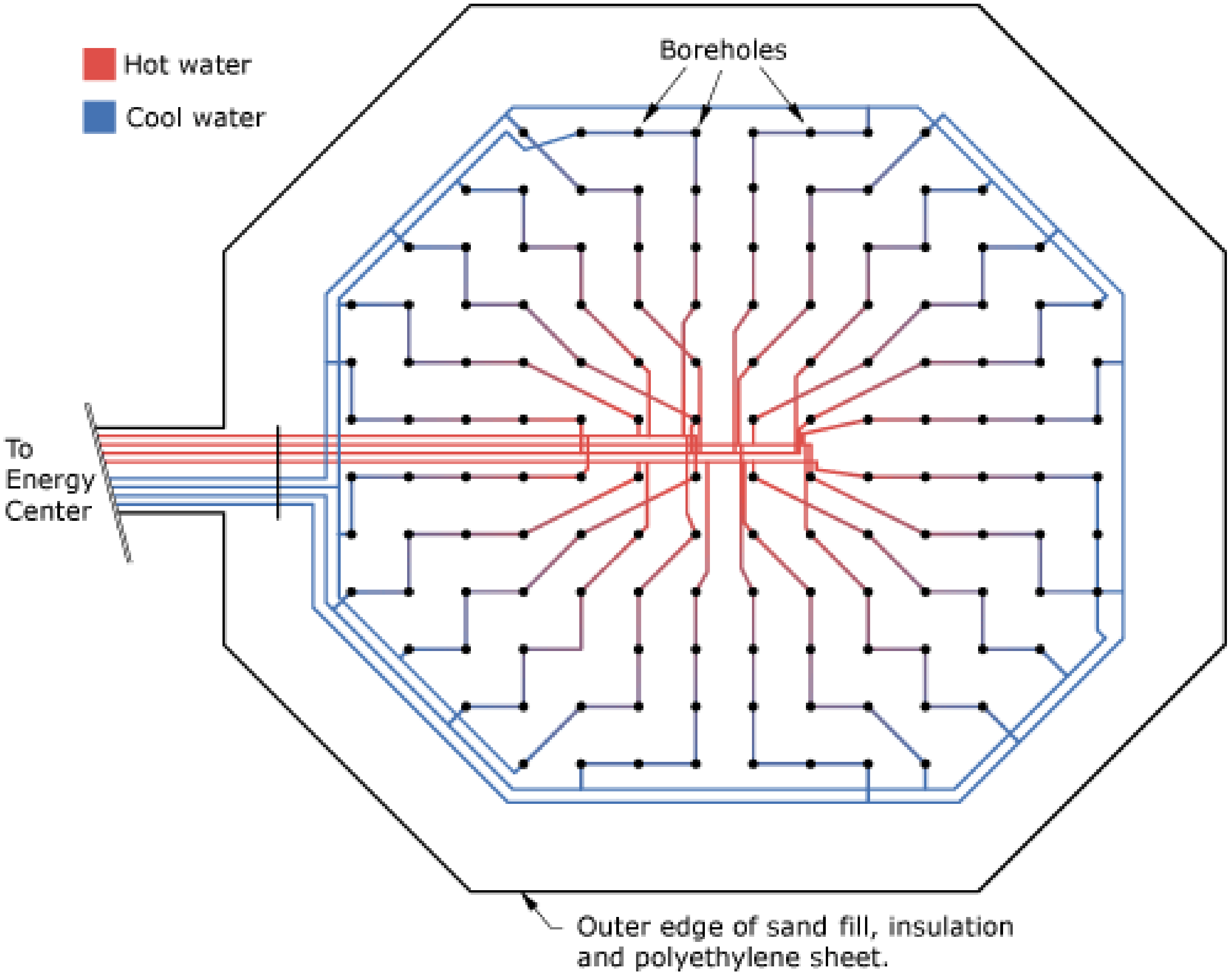
The system is unprecedented in the World, fulfilling ninety percent of each home's space heating requirements from solar energy and resulting in less dependency on limited fossil fuels.

The Government of Canada and its Canadian industry partners are proud to showcase Canadian solar thermal and energy efficient technologies in this one-of-a-kind community.


Detached garages with
solar collectors on the roofs
Two-storey
single-family homes
Solar
collector loop
Energy Centre
with short-
term thermal
storage tanks
District heating loop
(below grade) connects
to homes in community
Borehole seasonal
(long-term) thermal
storage



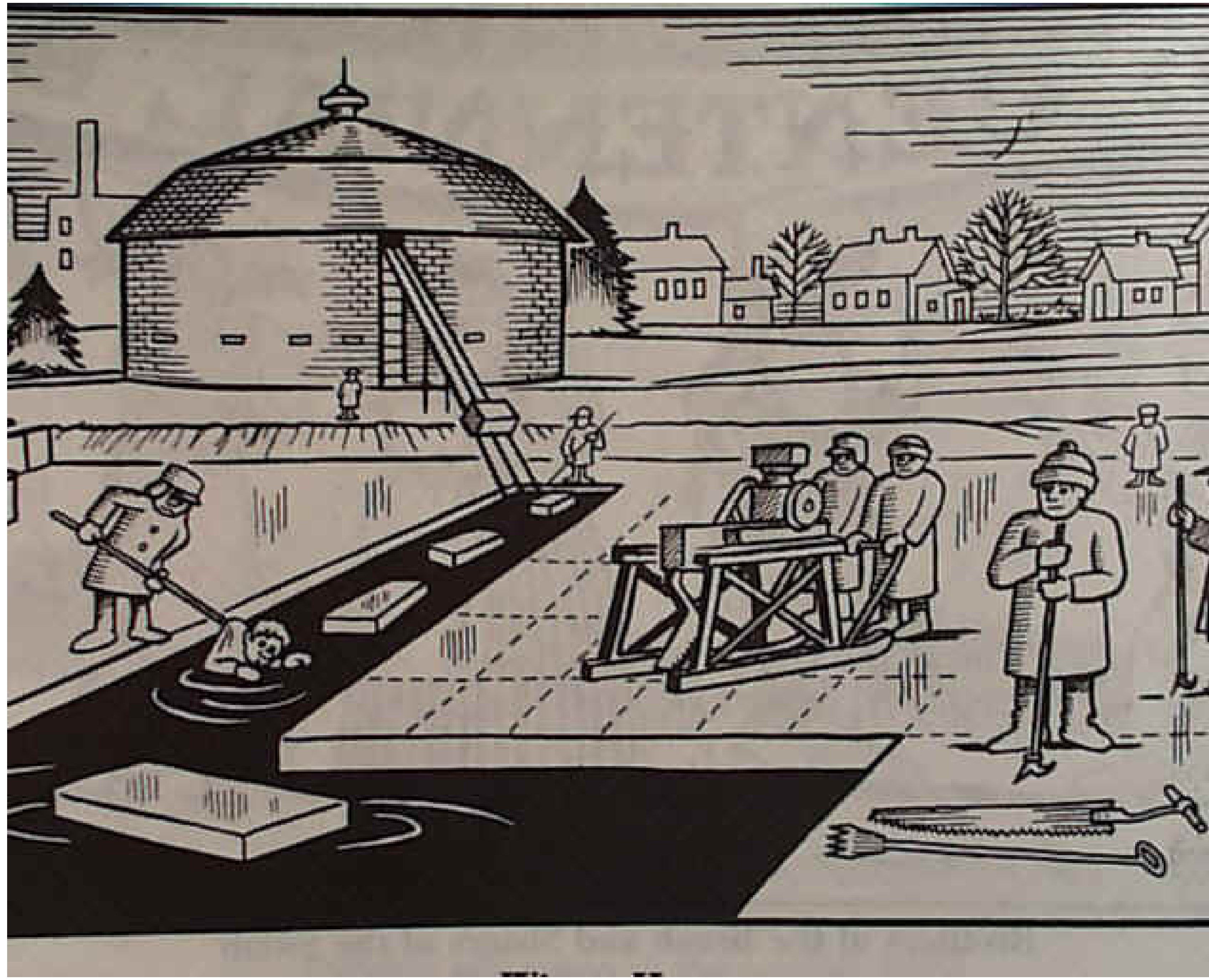




heat store: 37m deep, 35m wide

roughly 1 GWh(th) - roughly 100 kWh/d per dwelling, for 50 dwellings, for 100 days

Similar size and function to ice house!



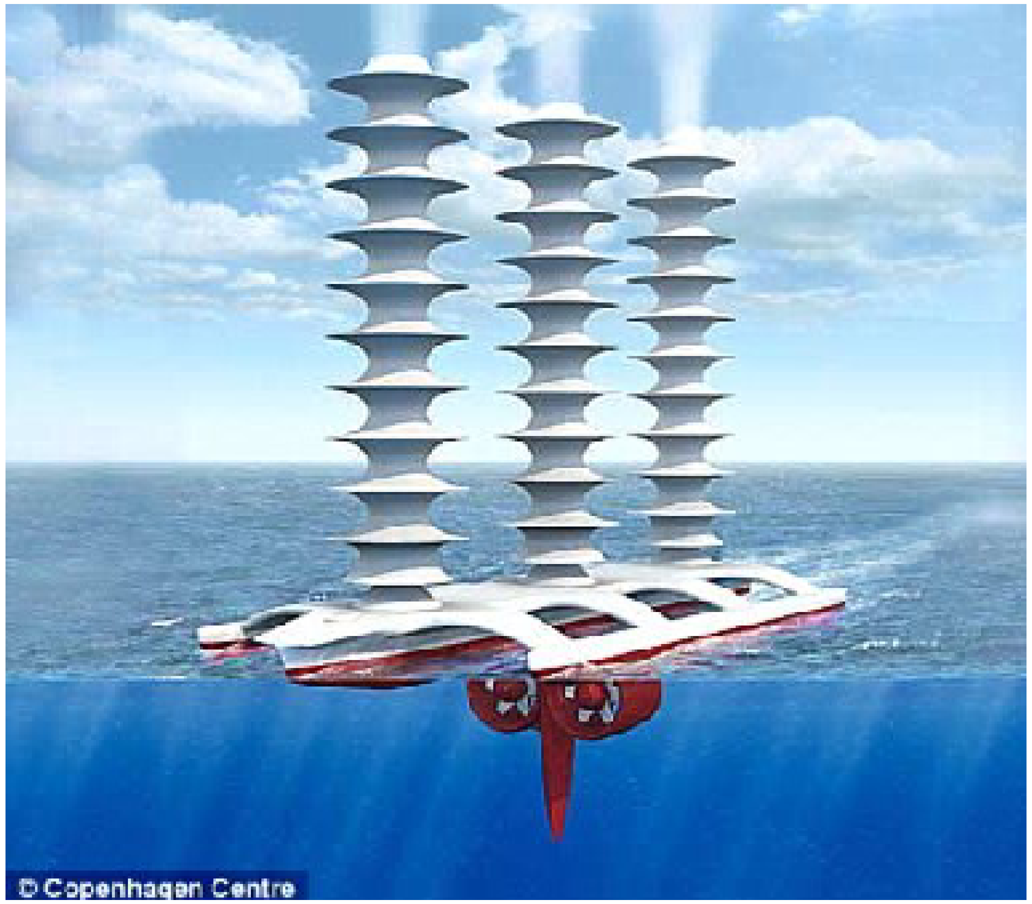
International energy trade

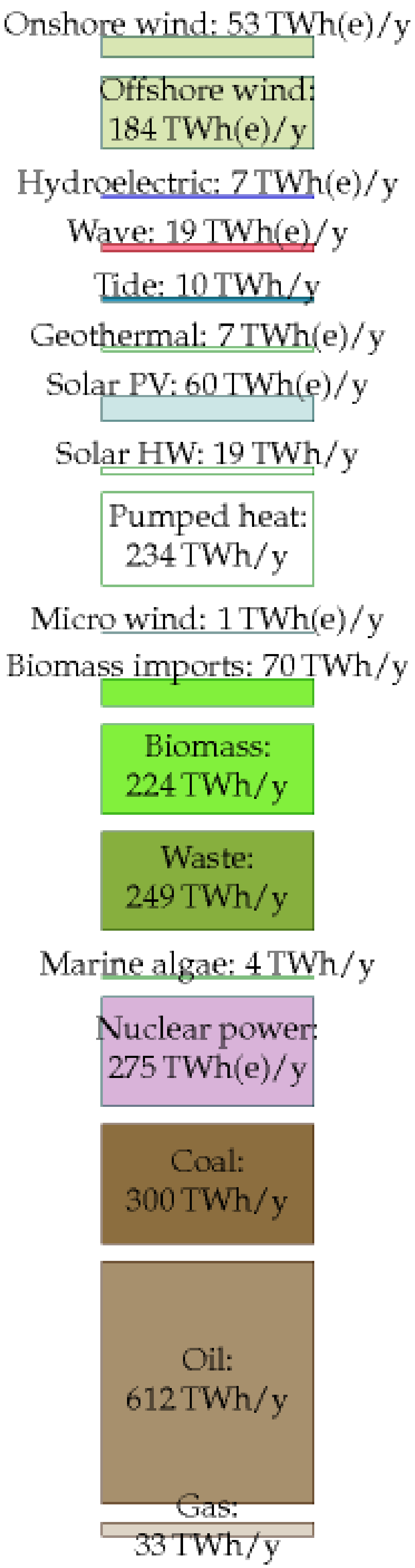
In the 1890s Norway exported 340,000 tons of ice each year.

London Canal Museum

What we need for most 2050 pathways

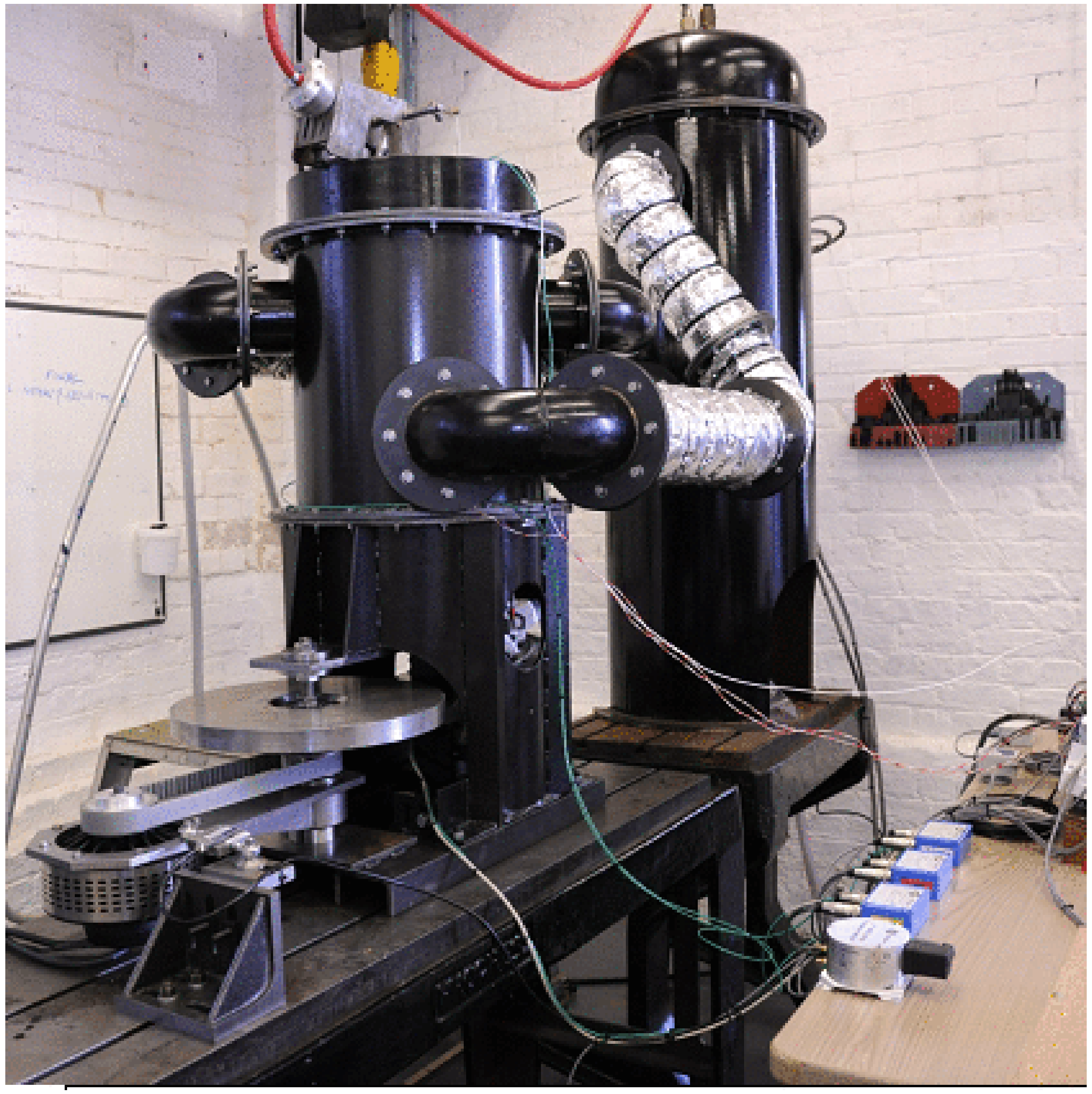
- Backup plans
  - eg, in case low-cost electric vehicles don't materialise
    - hydrogen
  - or in case climate sensitivity turns out bigger than expected
    - geoengineering research





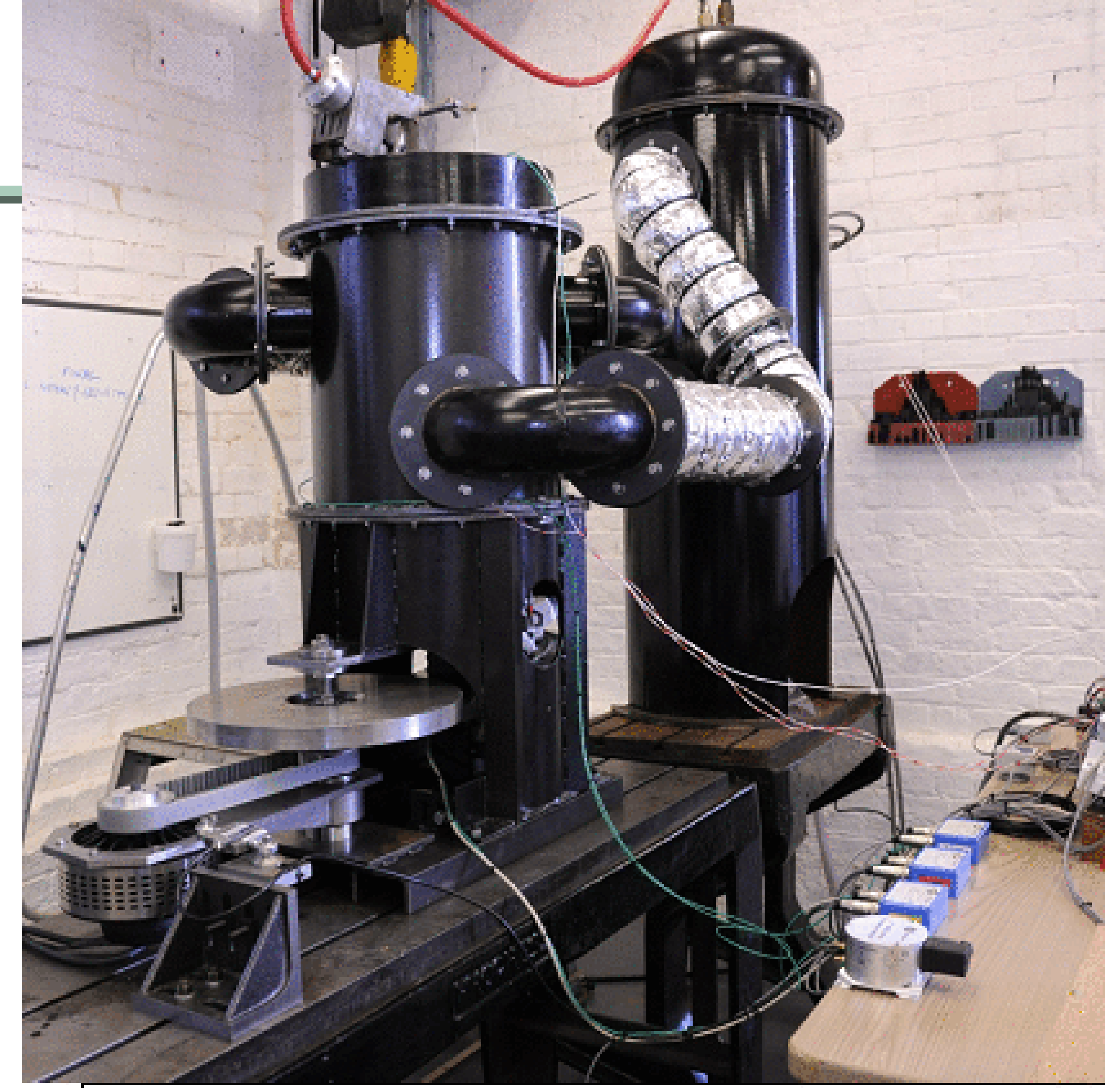
Novel heat pumps

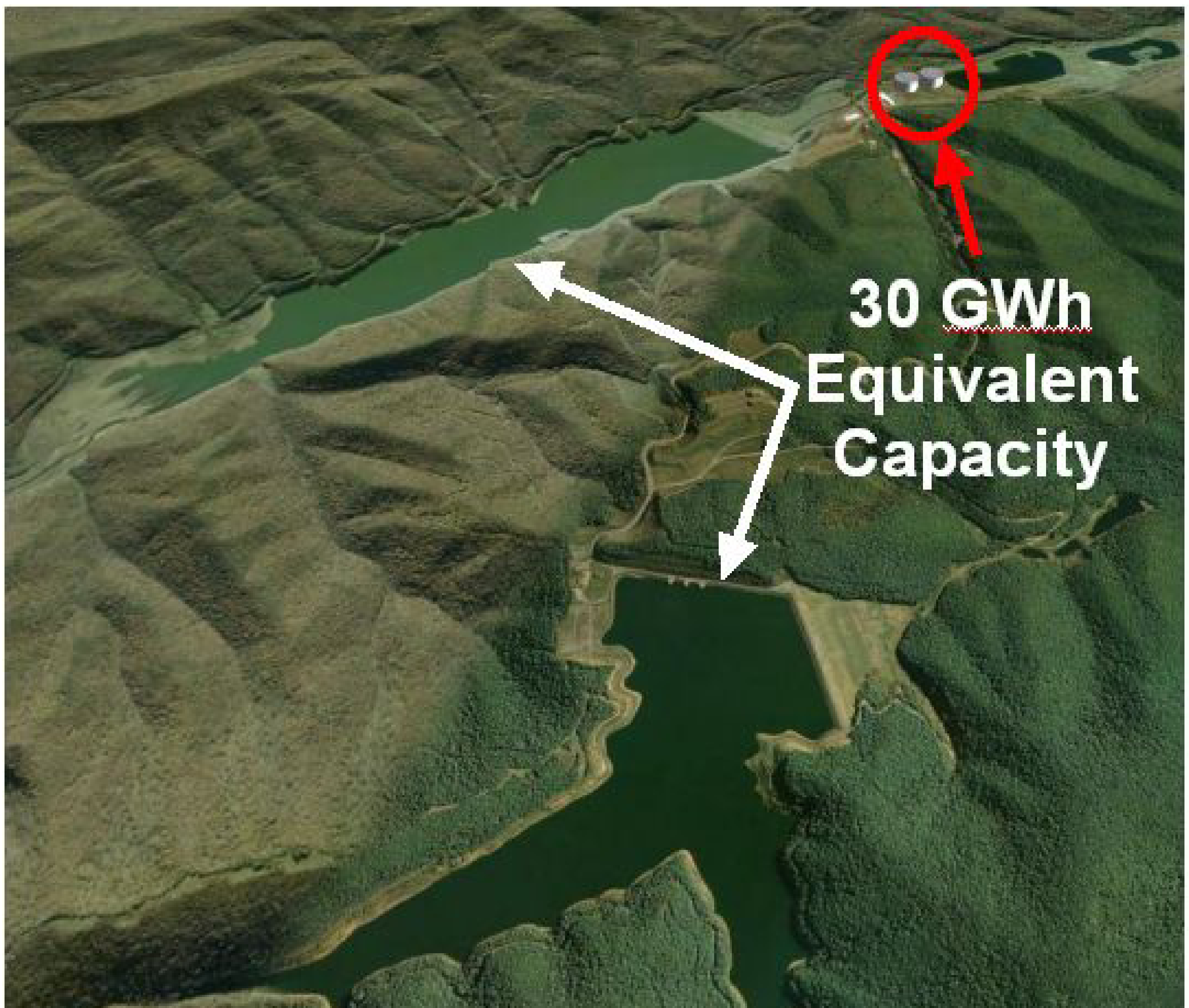
Isentropic

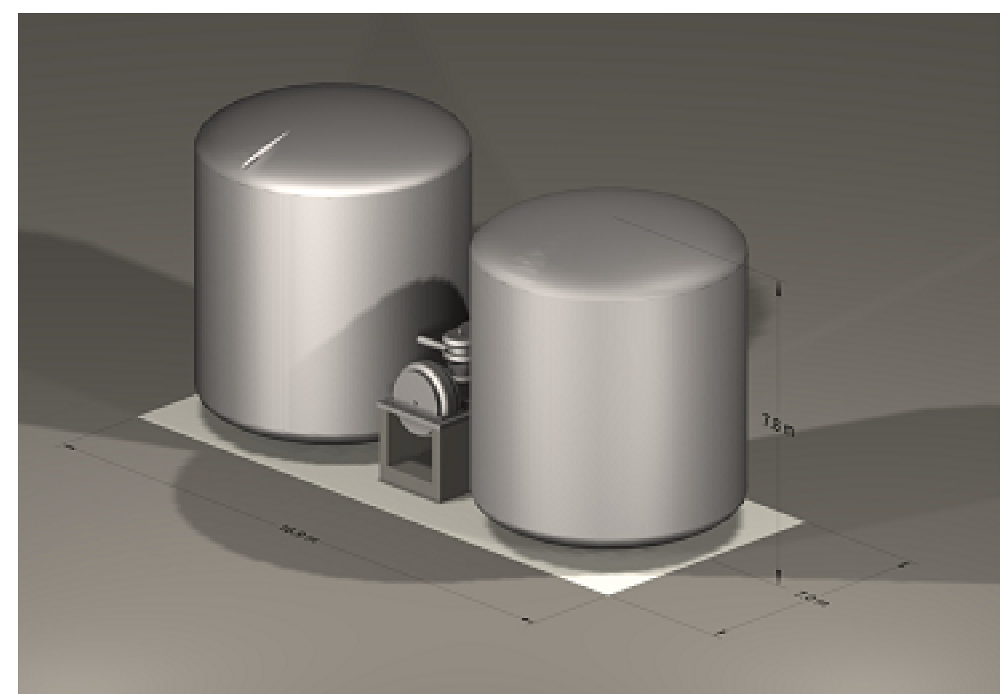


Novel storage technologies

Isentropic







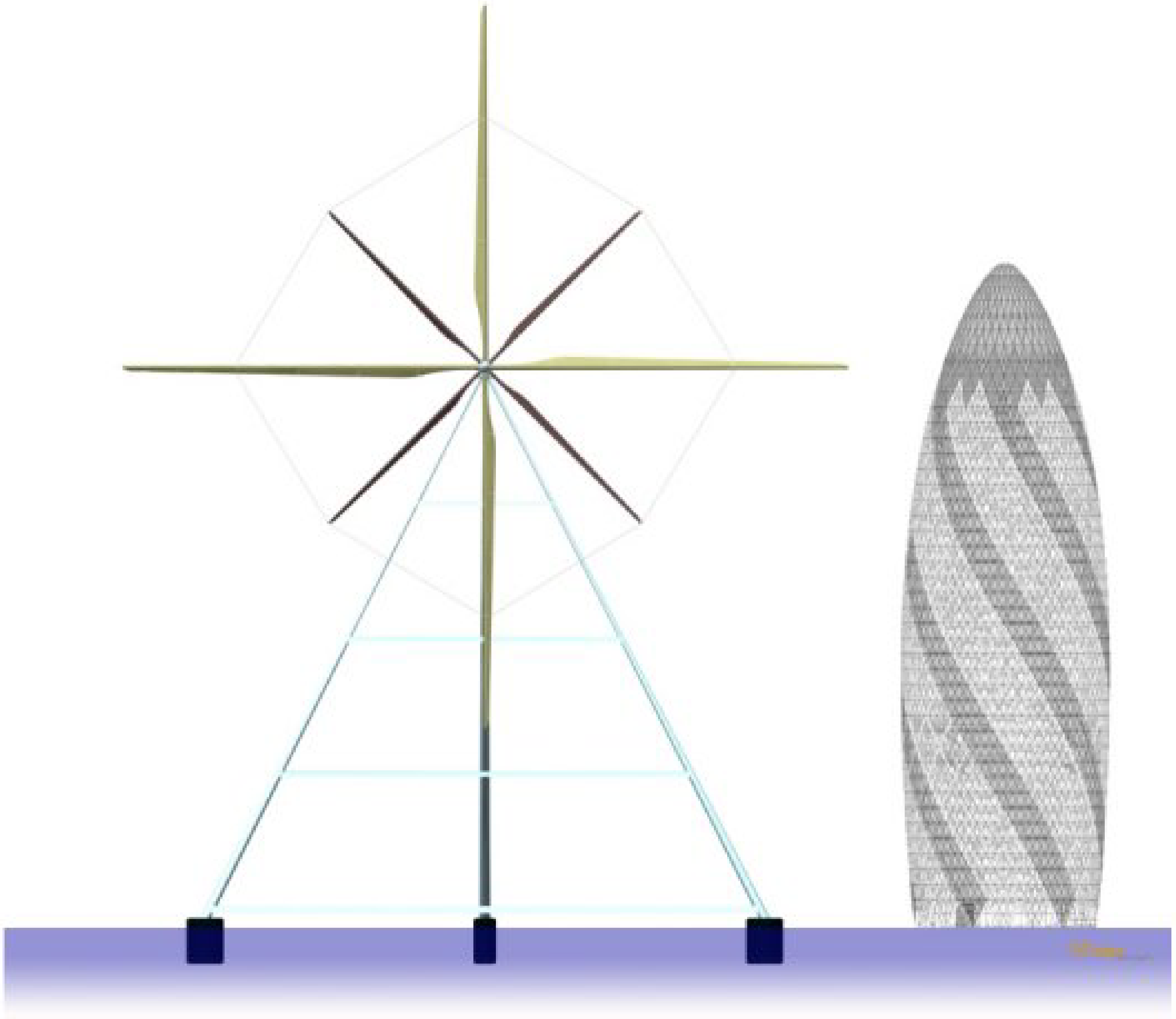
Isentropic's storage schematic 2MW, 16MWh pumped heat electrical storage

Energy storage in underwater wind bags?

Seamus Garvey

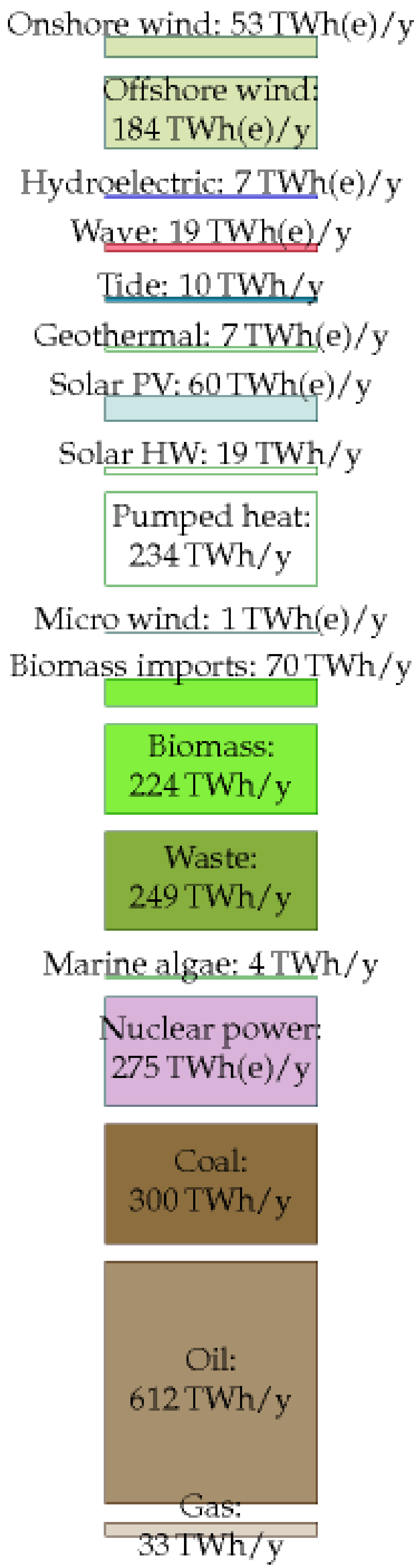
Novel wind turbines

Seamus Garvey

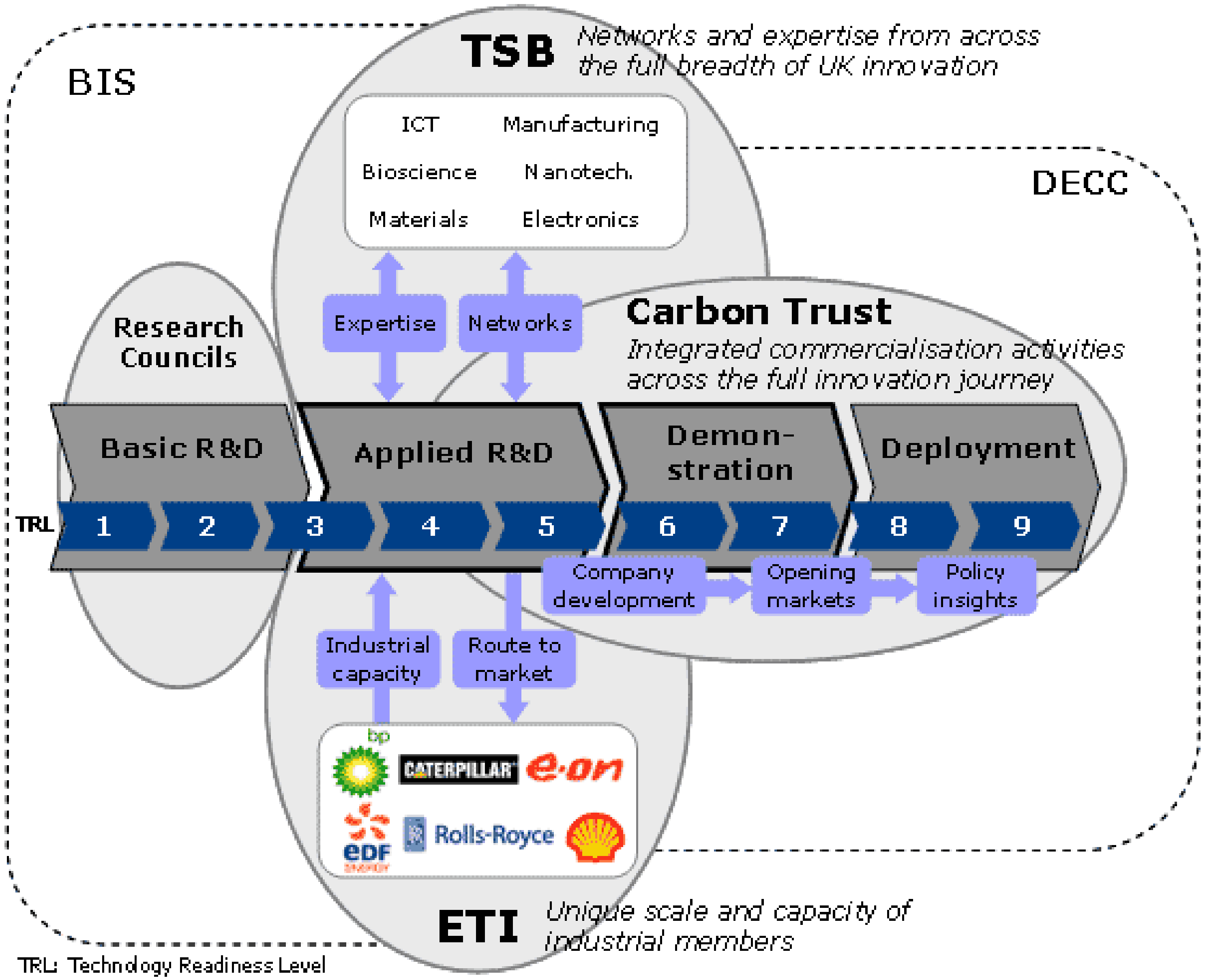


Innovation needs (top 6) for the UK

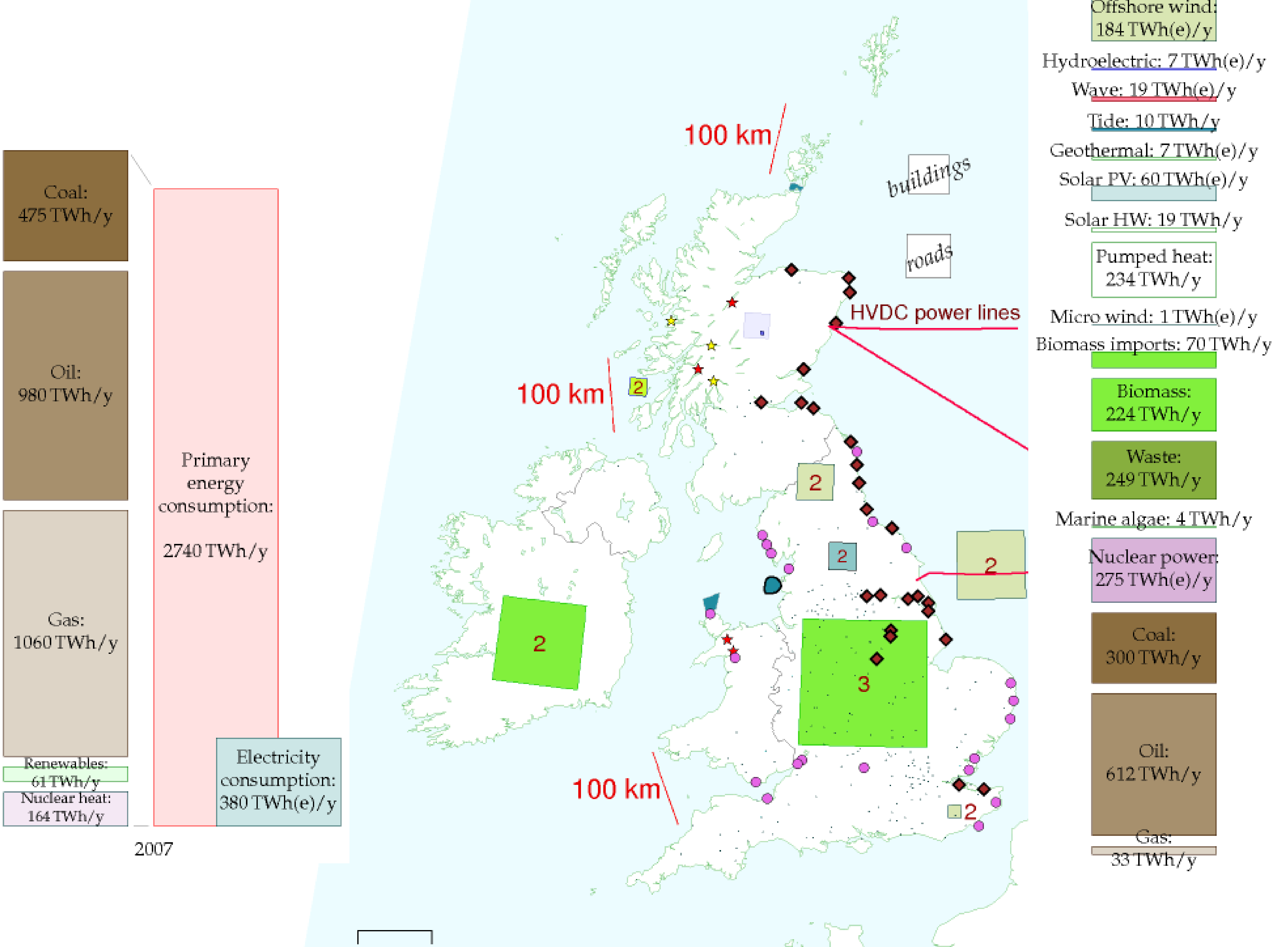
- Efficiency
  - building insulation
  - vehicles (electric and hydrogen?)
- Wind
- Heat pumps
- Biomass- and waste-to-good-things
- Carbon Capture and Storage
- Energy Storage
  - electricity storage
  - interconnectors; smart demand-management
  - seasonal heat stores



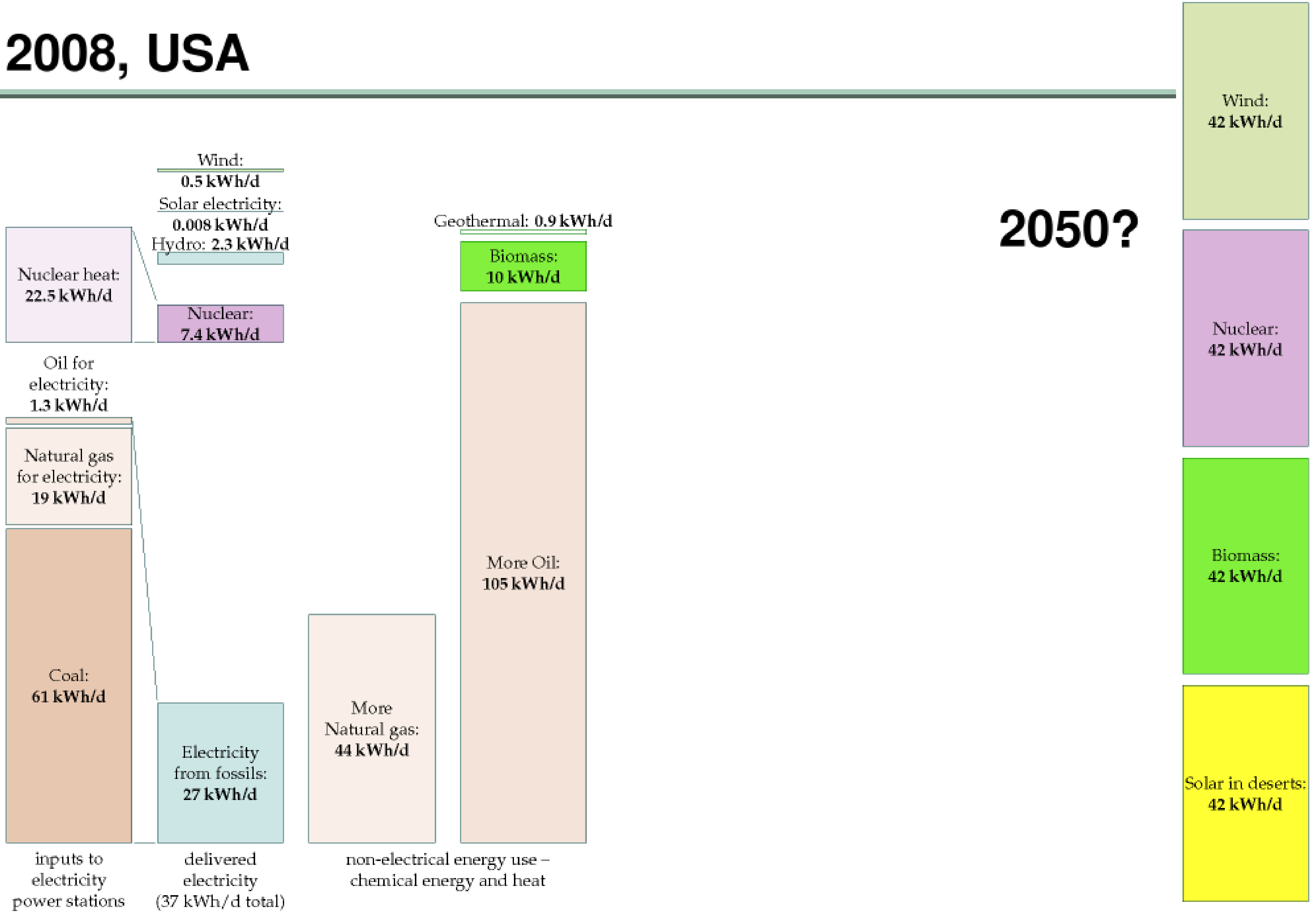
UK support for Energy Research + Development



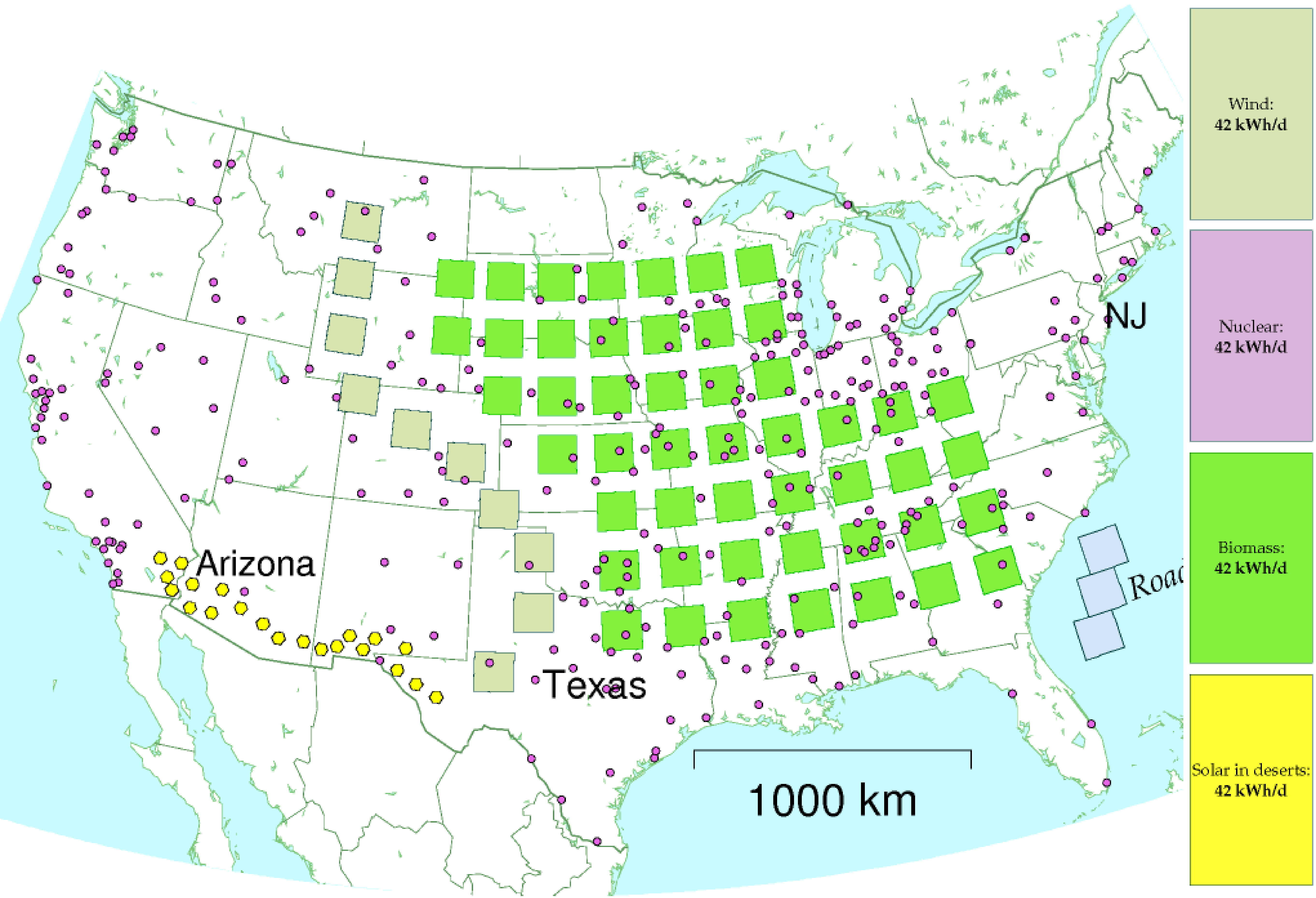
Pathway alpha - supply side



2008, USA



Total Electricity consumption is 37 kWh/d/p - of which coal delivers 18 kWh/d/p



2100 GW of wind (60-fold increase)

525 one-gigawatt nuclear power stations (five-fold increase)

Personalized

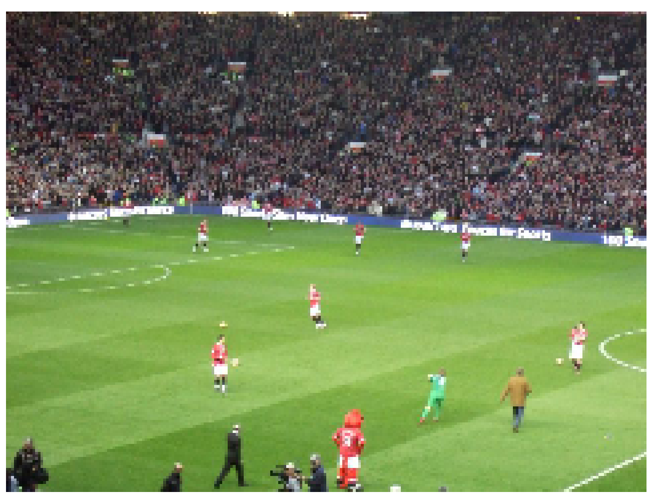
Wind:
42 kWh/d

One 2-MW turbine for every 300 people

Nuclear:
42 kWh/d

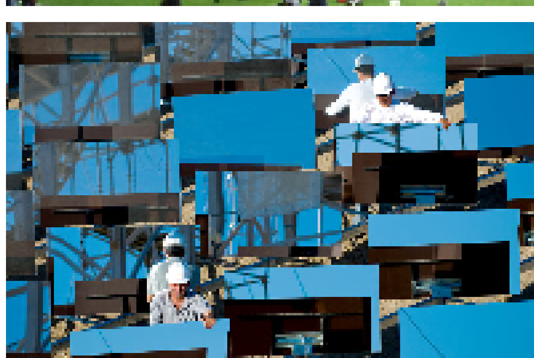
7 nukes for LA
5 nukes for Chicago
4 nukes for Houston
2 nukes for San Diego
1 nuke for Denver CO
1 nuke for Boston MA
1 nuke for Las Vegas NV
1 nuke for Portland OR...

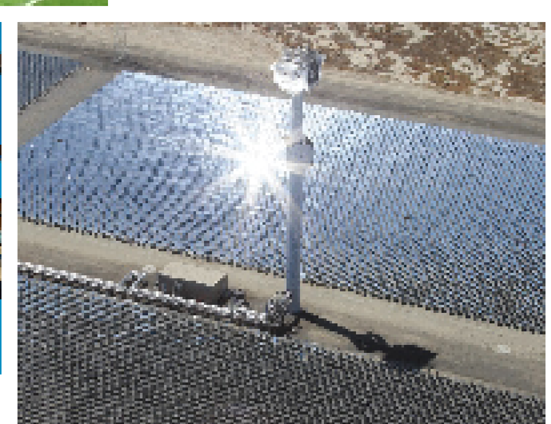
Biomass:
42 kWh/d



4000 sq m per person

Solar in deserts:
42 kWh/d





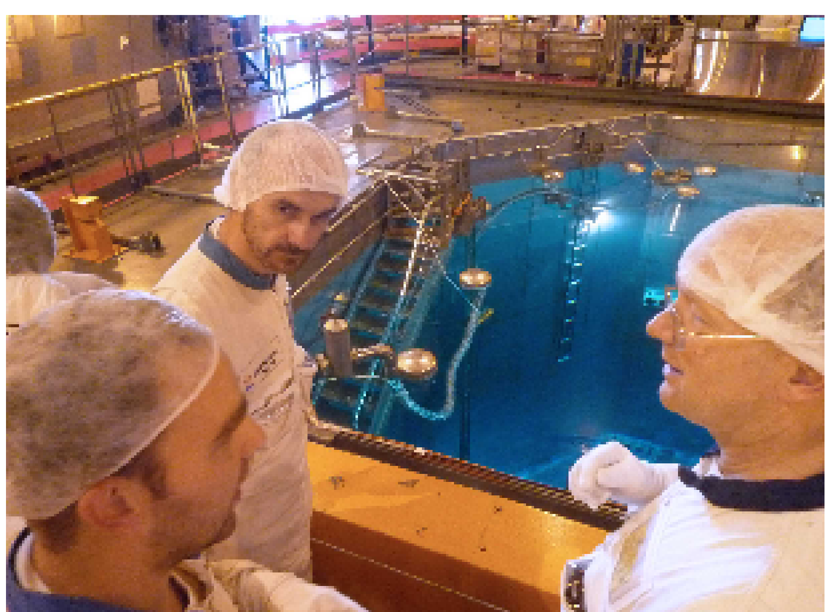
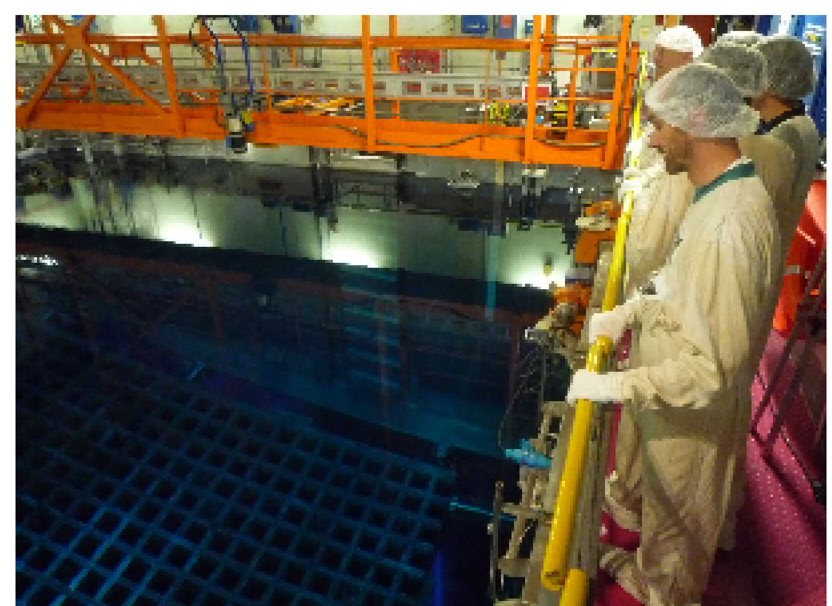
30 eSolar mirrors per person; &
one tower for every 400 people

Innovation needs (additional) for the world

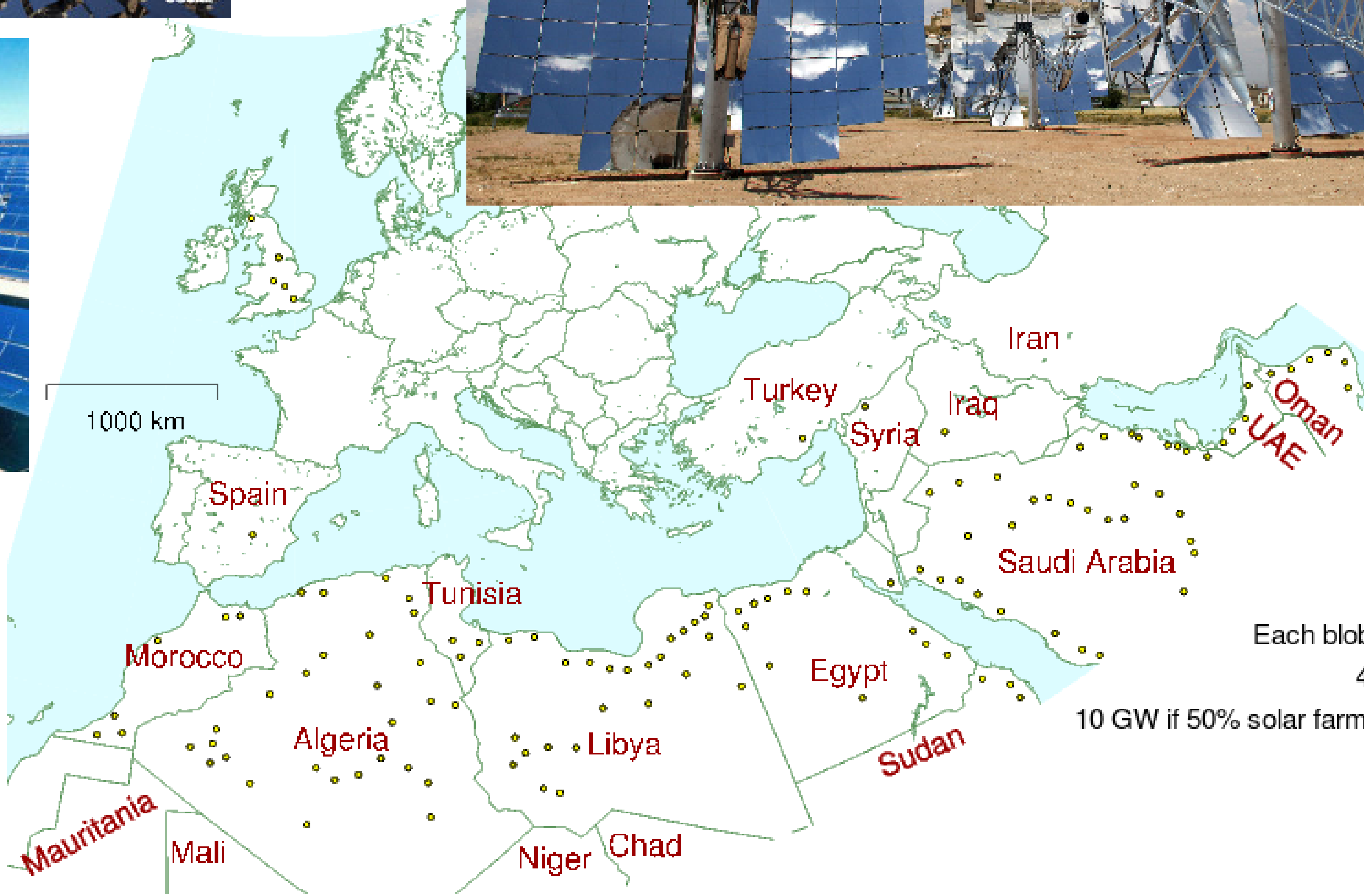
- Solar power


- Deep geothermal

- Proliferation-resistant, safe, low-waste nuclear power

Concentrating solar



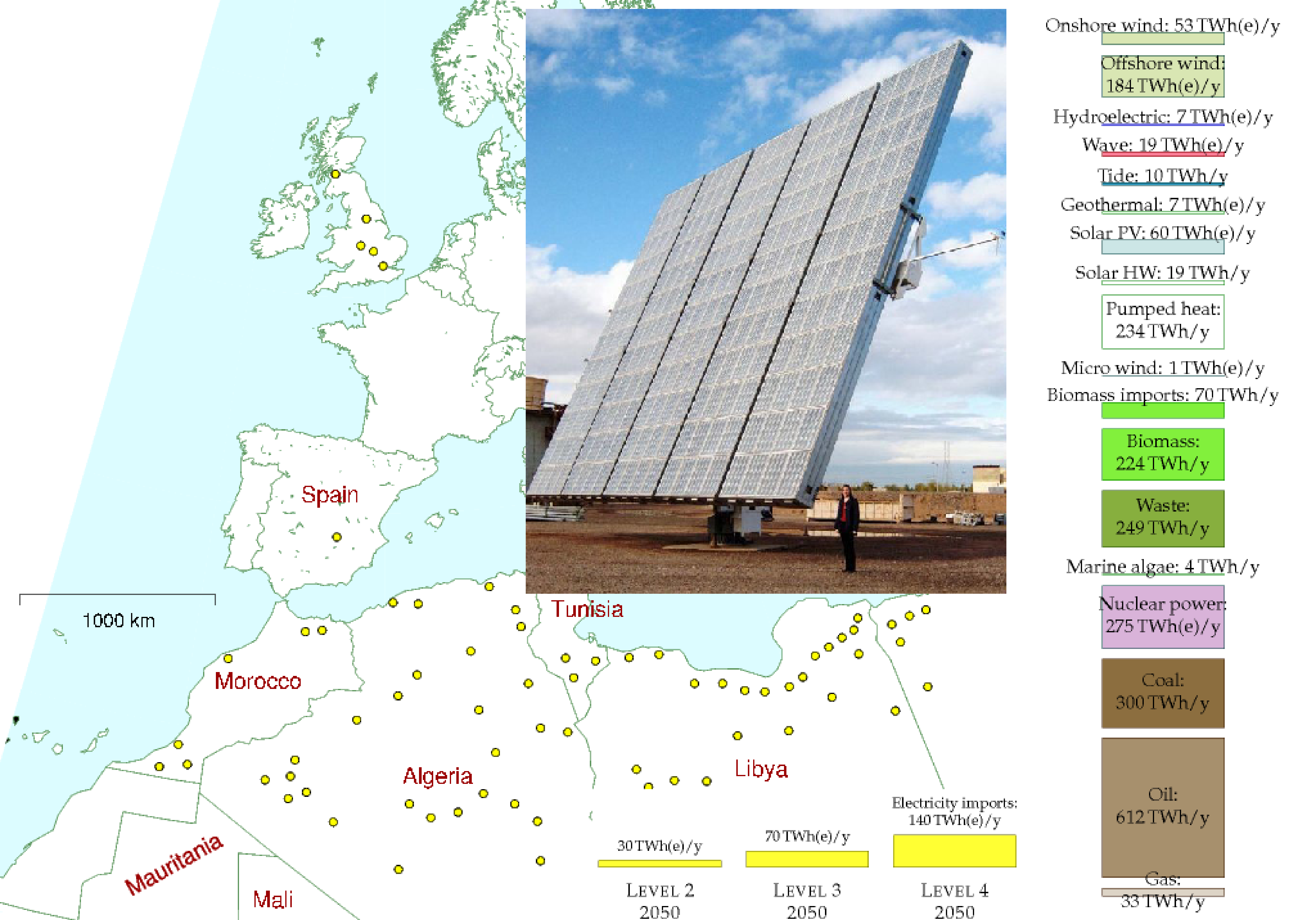
Each blob: 1500 sq km;
44km diameter;
10 GW if 50% solar farm, at 15 W/sq m.
100 TWh/year

140 kWh/d

peak 25 kW

Concentrating photovoltaic by Amonix - Photo by David Faiman.


www.stirlingenergy.com
one dish: 160 kWh/d
peak 25 kW



Spain
1000 km
Morocco
Algeria
Tunisia
Libya
Mauritania
Mali
Onshore wind: 53 TWh(e)/y
Offshore wind: 184 TWh(e)/y
Hydroelectric: 7 TWh(e)/y
Wave: 19 TWh(e)/y
Tide: 10 TWh/y
Geothermal: 7 TWh(e)/y
Solar PV: 60 TWh(e)/y
Solar HW: 19 TWh/y
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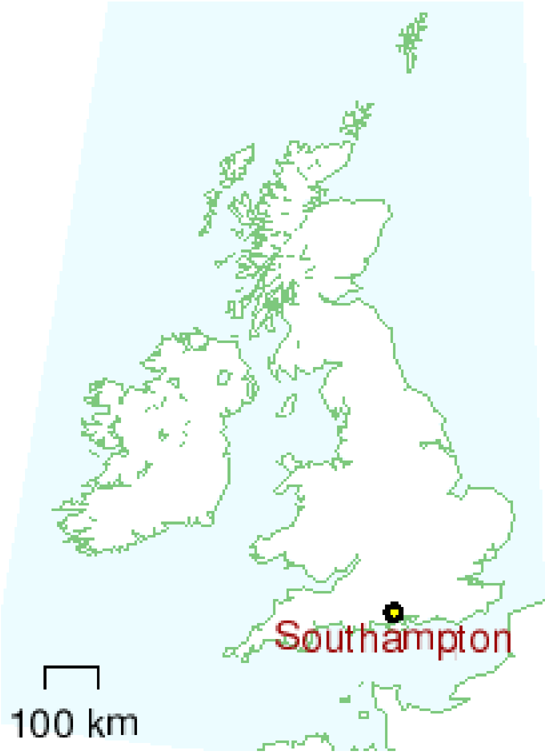
Marine algae: 4 TWh/y
Nuclear power: 275 TWh(e)/y
Coal: 300 TWh/y
Oil: 612 TWh/y
Gas: 33 TWh/y
30 TWh(e)/y
Level 2 2050
70 TWh(e)/y
Level 3 2050
Electricity imports: 140 TWh(e)/y
Level 4 2050

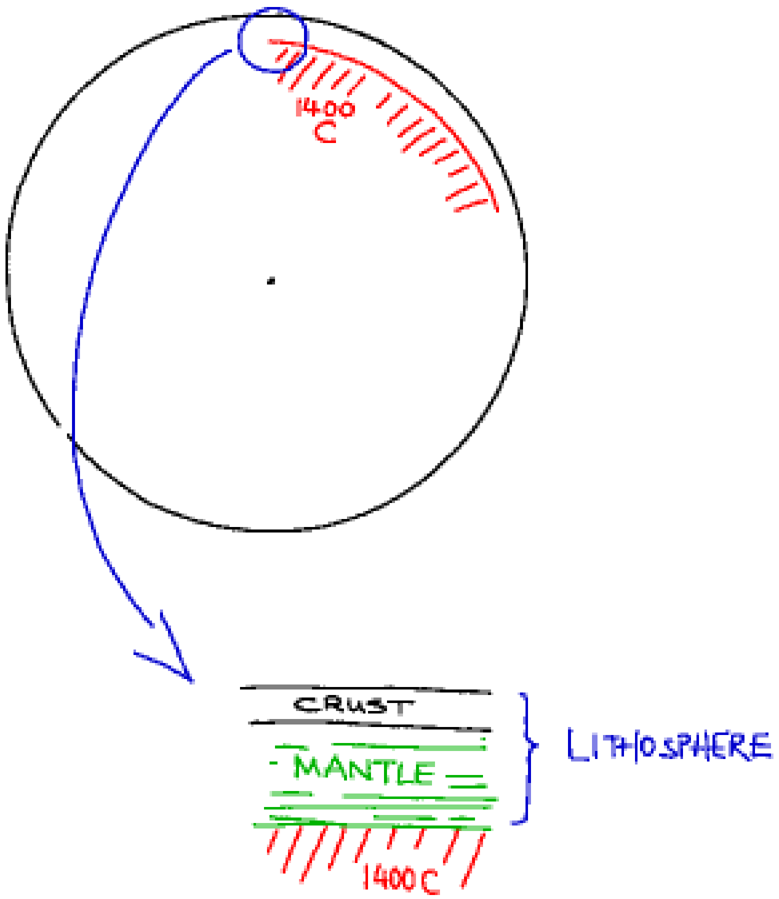
Geothermal

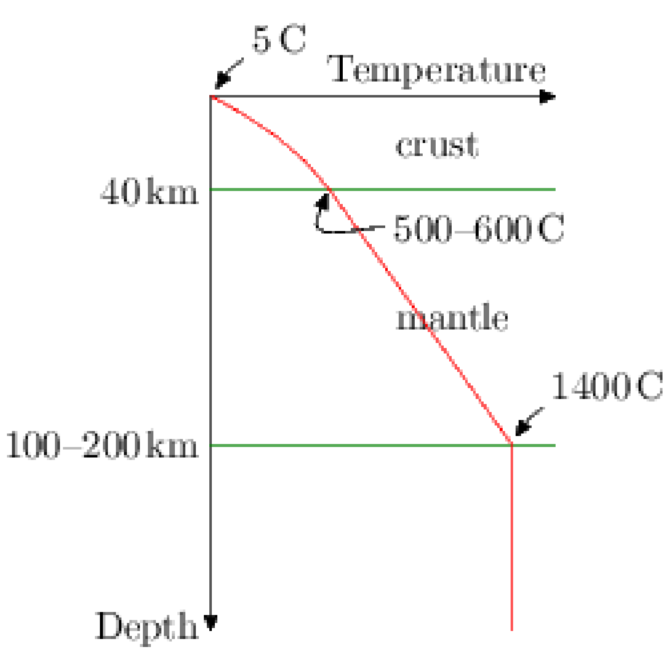
Nesjavellir, Iceland

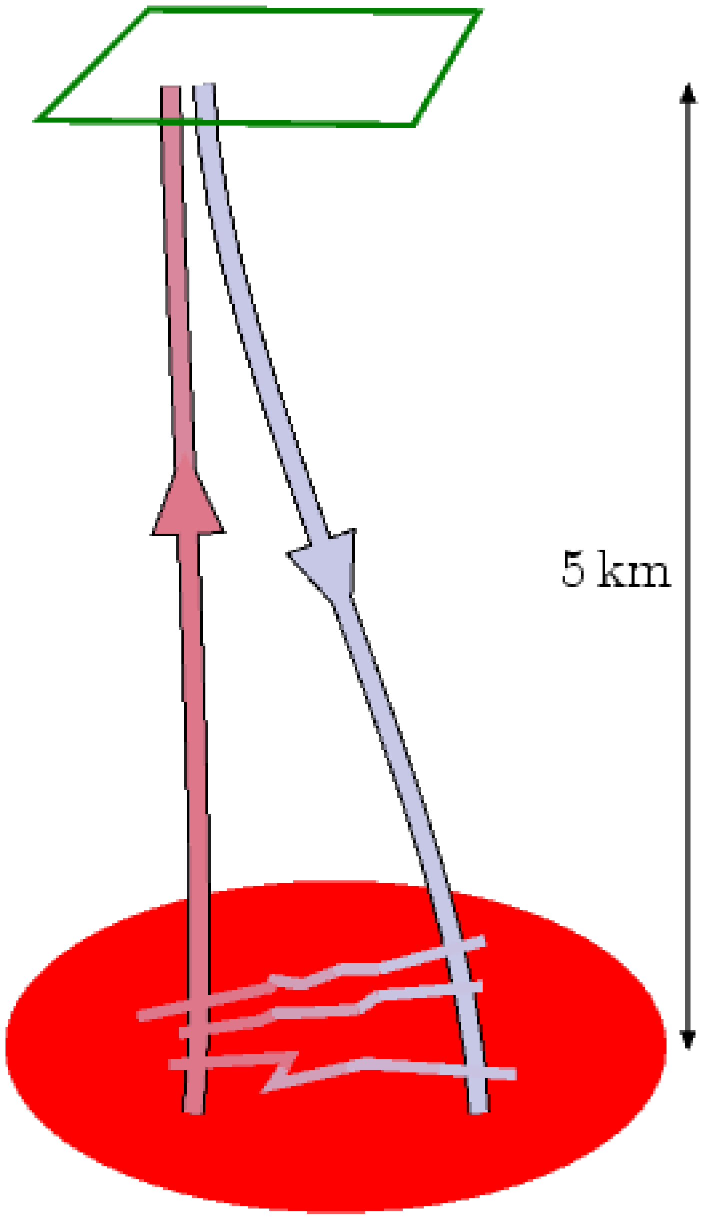
Average geothermal electricity generation in Iceland in 2006 was 300 MW (24 kWh/d/person)



Geothermal







'Hot dry rock'

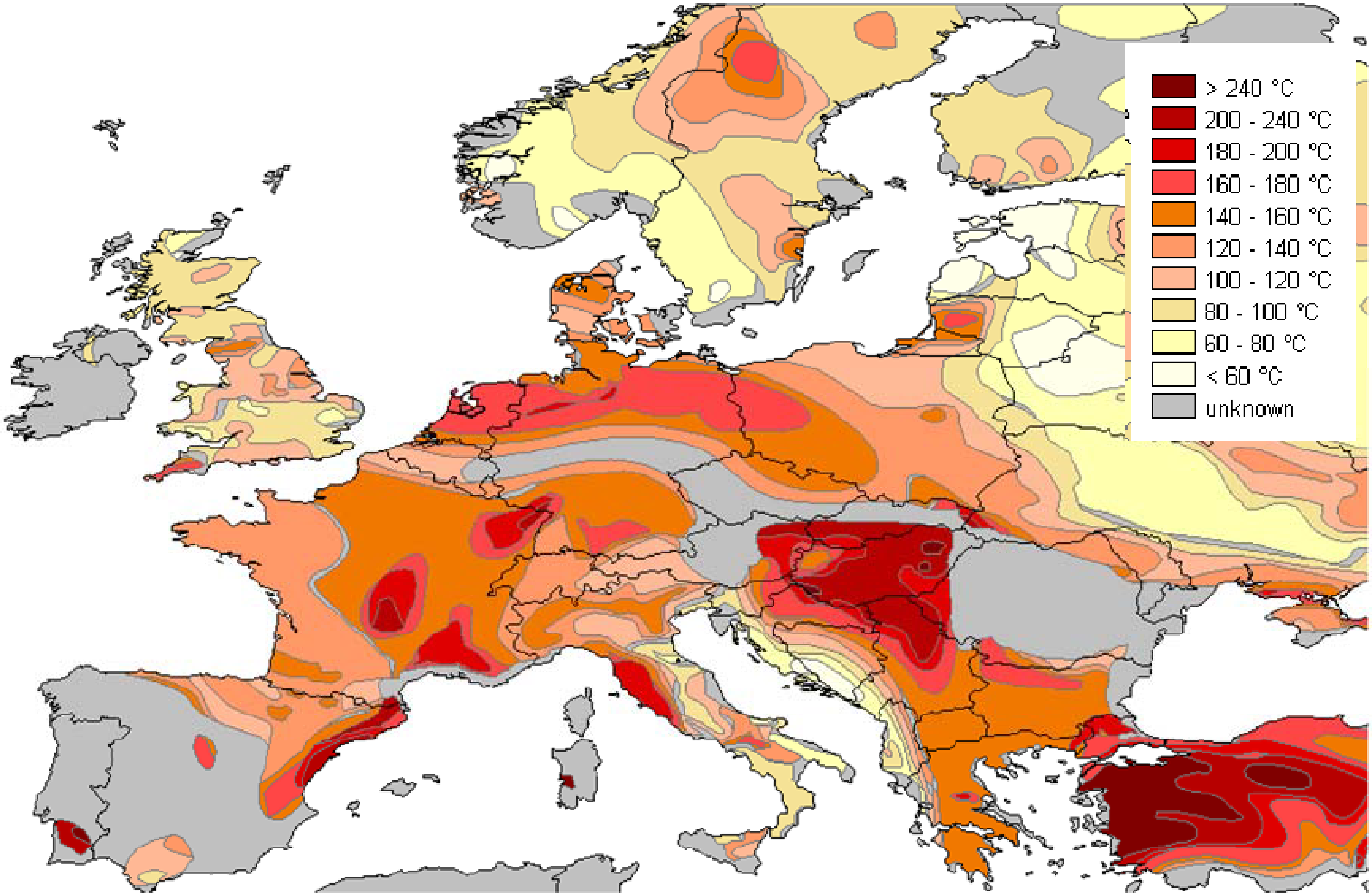


Figure 3-8: Temperature at 5000 m Depth for Hot Dry Rock Geothermal Power Technology /BESTEC

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Utah geothermal plant runs into cold-water problem

Geothermal plant's cold water means it buys nearly as much power as it makes.

By Steven Oberbeck

The Salt Lake Tribune

Updated: 09/18/2009 08:07:32 AM MDT

Click photo to enlarge

Pipefitter Rod Hooley prepares to work hot water... (Steven Oberbeck/ The Sa Lake Tribune)

Raser Technologies Inc. long has boasted its new Hatch geothermal power plant near the west-central Utah city of Beaver would launch a new era of energy production -- one in which electricity would be produced from low-temperature underground water that wasn't viewed as hot enough to produce power.

Yet six months after Raser flipped the switch on the plant and began generating power, the company is buying almost as much electricity to keep the place running as the plant is producing.

The problem: The plant can't operate at full capacity because its production wells are producing geothermal water that isn't hot enough, even though its temperature is higher than the 180 degrees Raser initially said it would need.

17:29 GMT, Tuesday, 15 December 2009

Swiss geologist in quakes trial

The head of a geothermal energy company has gone on trial in Switzerland accused of damaging property by triggering earthquakes.

Markus Haering's company had been working with the authorities in Basel to try to convert the heat in deep-seated rocks into electricity.

But the project was suspended in 2006 when drilling triggered the quakes.

They caused no injuries but led to $9m (£5.54m) of damage. Mr Haering denies
property.

The project was shut down permanently last week after a government study found that similar quakes caused by th
millions of dollars worth of damage each year.

Major fault line

Appearing in court in Basel on Tuesday, Mr Haering rejected allegations that he deliberately damaged properties
were aware of the risks.

He said those involved had "very little knowledge of seismicity" before drilling began in the Petit-Huningue area of

But the project leaders had an emergency plan and "every minute, we knew what was going on and were able to a

One of the earthquakes generated had a 3.4 magnitude.

The Swiss government report concluded that if the project had been allowed to continue there was a 15% chance of it triggering a quake powerful enough to cause damage of up to $500m.

However it was unlikely to activate the major fault line that runs beneath Basel, which led to a huge quake that devastated the city in 1356.

Mr Haering faces up to five years jail if the judge finds he intentionally damaged property. A verdict is expected next week.

Google-backed Geothermal Startup Suspends Drilling Project

By Katie Fehrenbacher | Sep. 3, 2009, 8:49am PDT | 1 Comment 9

A project that was supposed to show the potential of turning the heat from hot rocks deep in the earth into a clean power source, from a startup backed by Google.org, Kleiner Perkins, Khosla Ventures and the Department of Energy, has hit a snag — literally. Geothermal startup AltaRock Energy said yesterday that it has "encountered a number of physical difficulties," while drilling at a site in Northern California, or as the New York Times put it, the drilling snagged on surface rock formation. As a result, the $17 million drilling project, which started in June, is being suspended indefinitely, the company says.

It marks the latest setback for AltaRock, the list of which New York Times reporter James Glanz has been chronicling. It ranges from one of AltaRock's drills not being able to pierce hard rock deep in the earth, to concerns raised over the potential for earthquakes that occurred during a similar style of drilling in Basel, Switzerland. AltaRock has raised $26.25 million from Khosla Ventures, Kleiner Perkins Caufield & Byers, Vulcan Capital and Google.org and won $6.24 million in funds from the Department of Energy.

AltaRock, founded in 2007, has been betting on a more advanced form of geothermal power called "enhanced geothermal," an approach that doesn't require existing steam vents or subterranean water sources. Conventional geothermal energy, which has been used for

Getting off fossil fuels is not easy, but it is possible

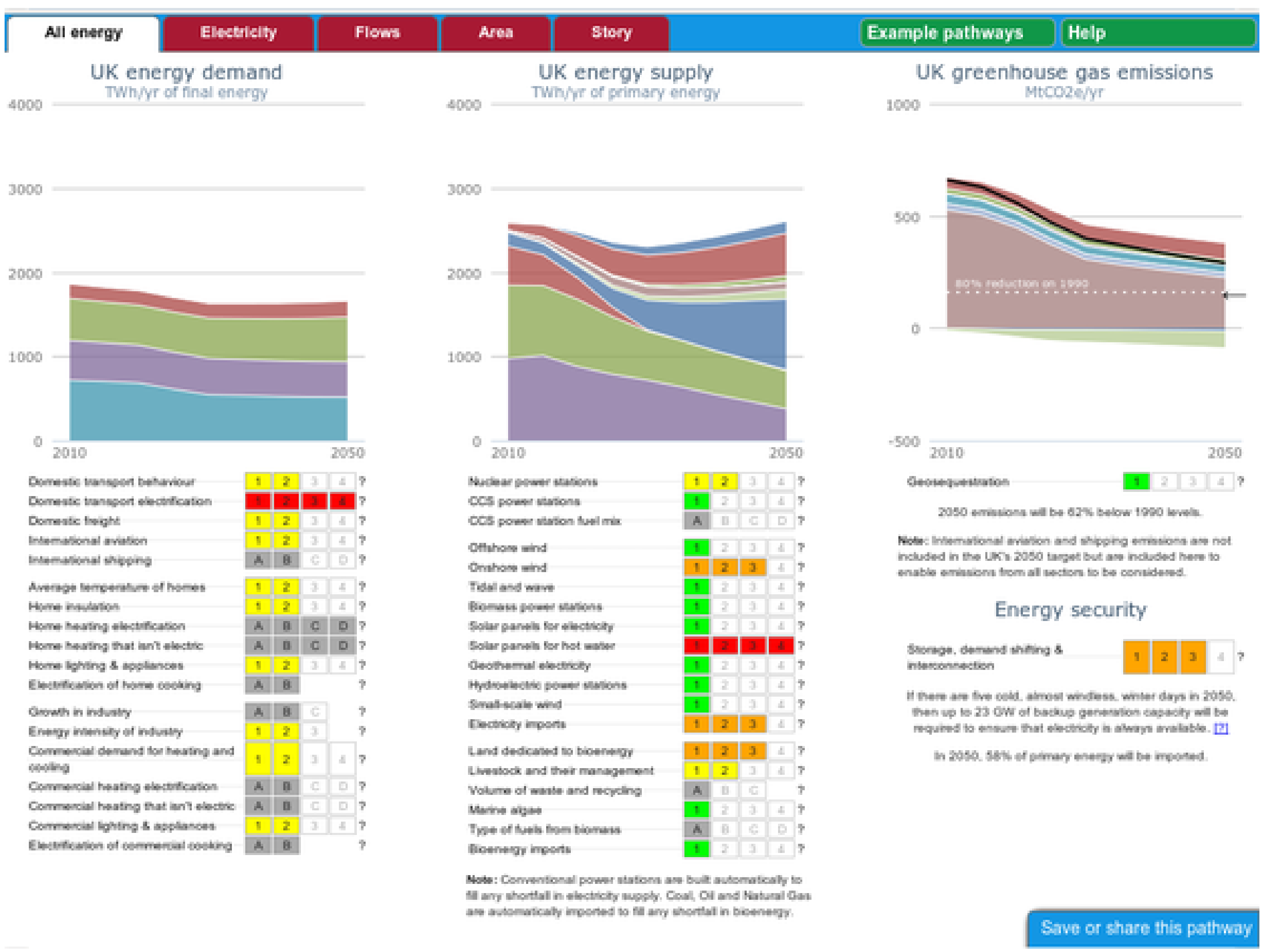
- A Plan that adds up must have some or all of:
  - country-sized renewable facilities
  - renewables from other people's countries
  - lots of nuclear power and 'clean coal'
- And efficiency too of course

'Okay - it's agreed; we announce - "to do nothing is not an option!" then we wait and see how things pan out...'

Lowe, Private Eye

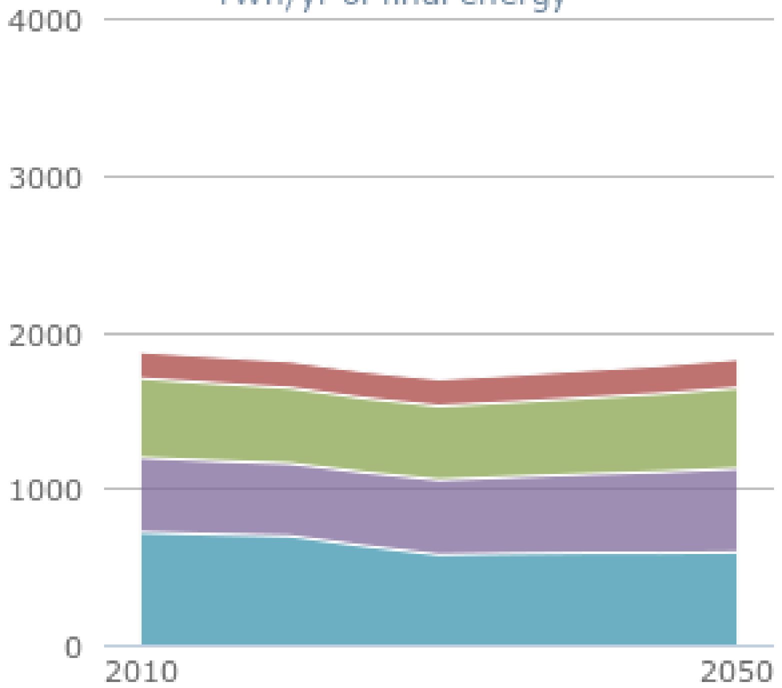
What we need for most 2050 pathways

- Public and political support for a numerate approach
- An ever-improving energy model for the UK
  - coming later:
    - costs
    - a more detailed hour-by-hour balancing model

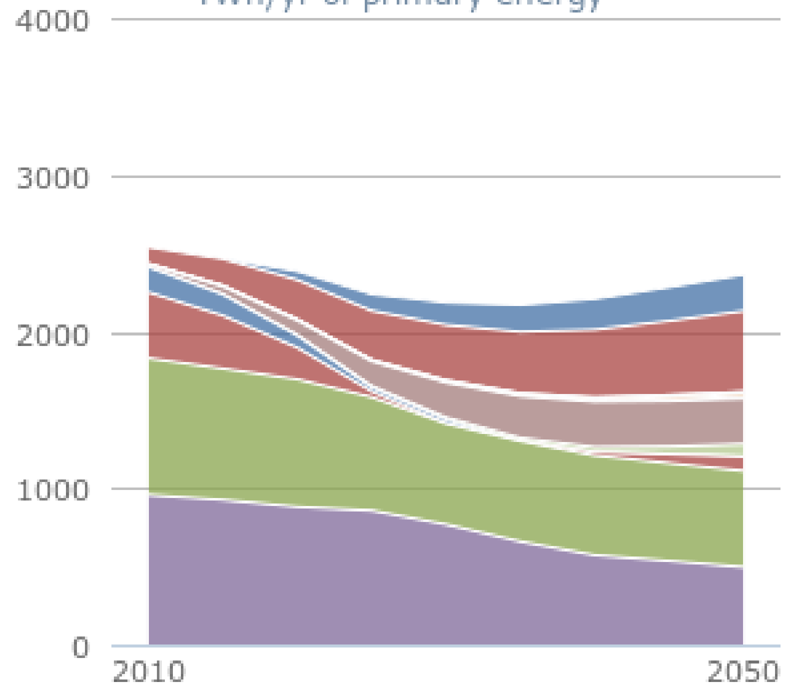


All energy | Electricity | Flows | Area | Story | Example pathways | Help

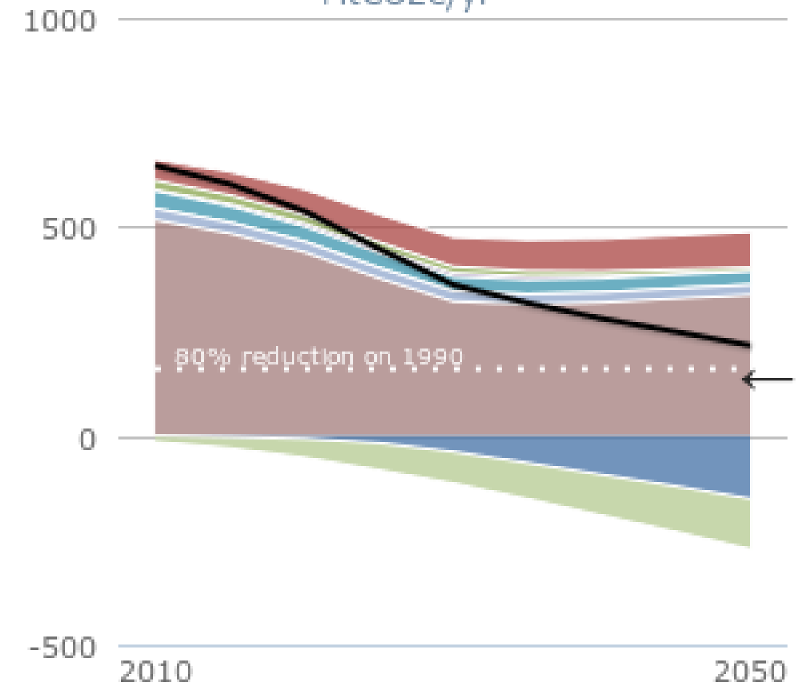
UK energy demand
TWh/yr of final energy



UK energy supply
TWh/yr of primary energy



UK greenhouse gas emissions
MtCO2e/yr



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

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

Conventional power stations are built automatically to fill any shortfall in electricity supply. Coal, Oil and Natural Gas are

Geosequestration	1	2	3	4	i

2050 emissions will be 72% below 1990 levels.

International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.

Energy security

Storage, demand shifting & interconnection	1	2	3	4	i

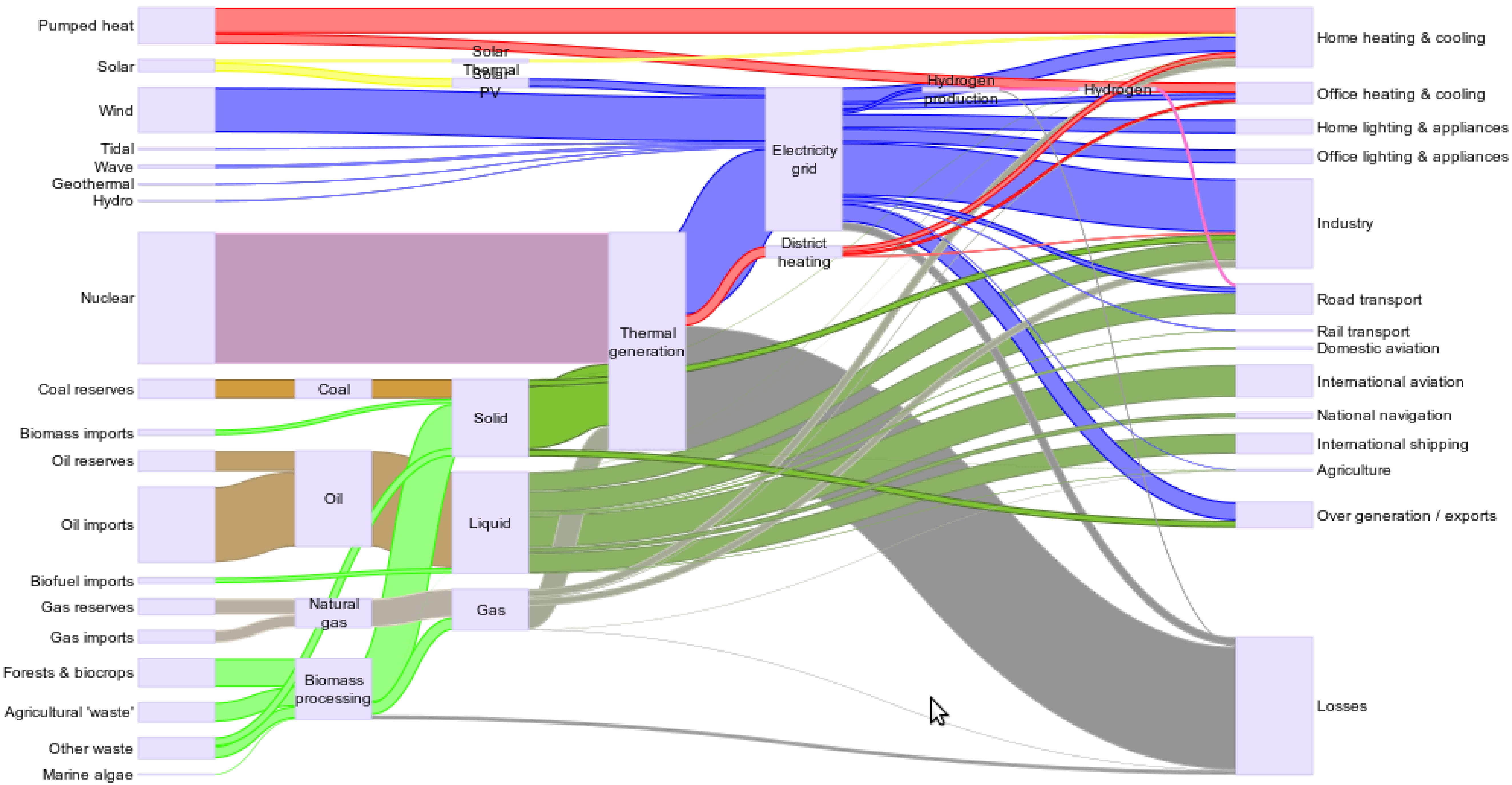
If there are five cold, almost windless, winter days in 2050, then up to 27 GW of backup generation capacity will be required to ensure that electricity is always available. i

In 2050, 40% of primary energy will be imported.

Save or share this pathway

All energy | Electricity | **Flows** | Area | Story | Example pathways | Help

This pathway should meet the UK 2050 climate change target



- Domestic transport behaviour: 1 2 3 4 (1–2 selected)
- Domestic transport electrification: 1 2 3 4 (1–3 selected)
- Domestic freight: 1 2 3 4 (1–2 selected)
- International aviation: 1 2 3 4 (1 selected)
- International shipping: A B C D (A selected)

- Average temperature of homes: 1 2 3 4 (1–2 selected)
- Home insulation: 1 2 3 4 (1–2 selected)
- Home heating electrification: A B C D (A–C selected)

- Nuclear power stations: 1 2 3 4 (1–2 selected)
- CCS power stations: 1 2 3 4 (1–2 selected)
- CCS power station fuel mix: A B C D (A–B selected)

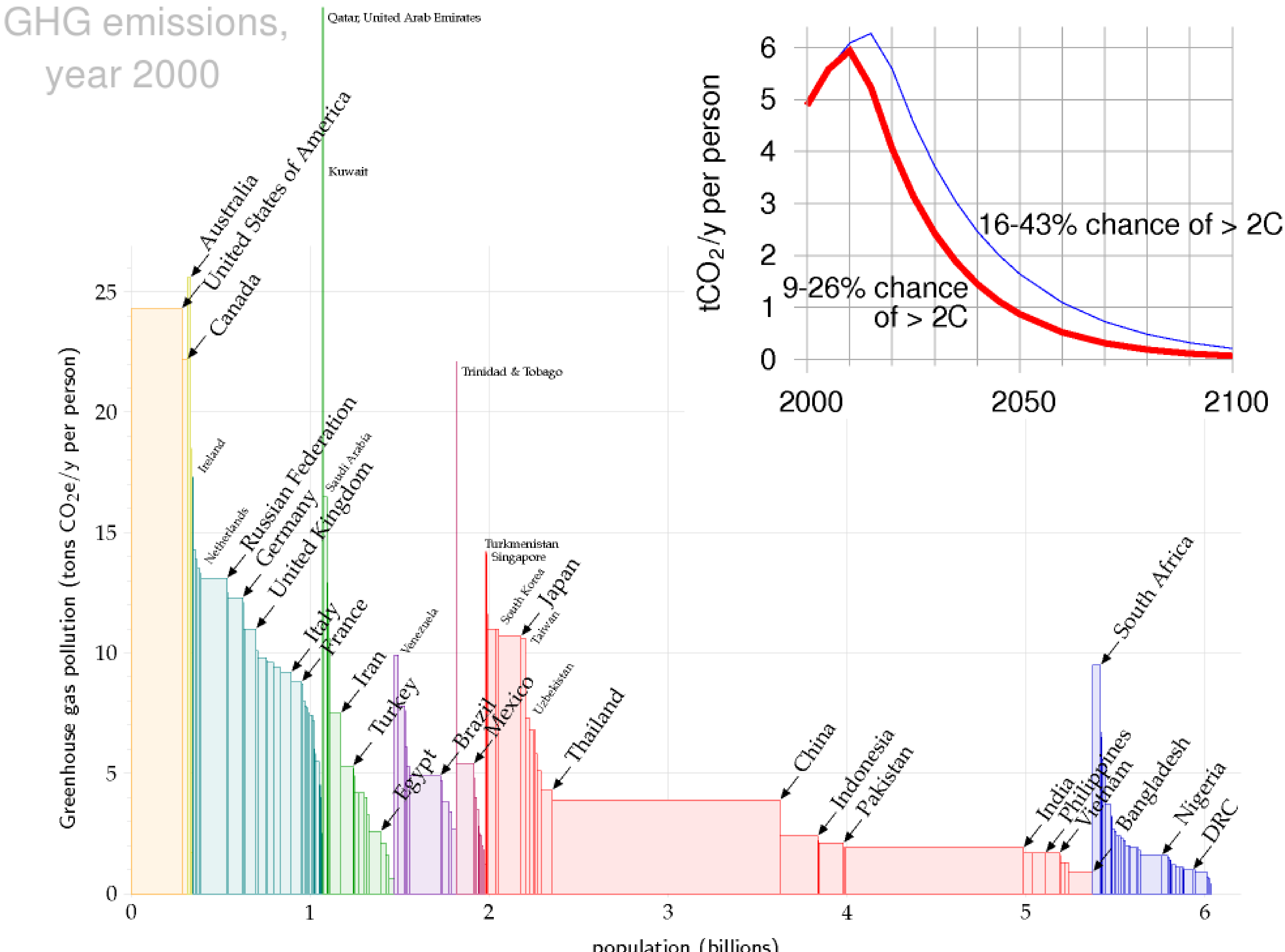
- Offshore wind: 1 2 3 4 (1–2 selected)
- Onshore wind: 1 2 3 4 (1–2 selected)
- Tidal and wave: 1 2 3 4 (1–2 selected)
- Biomass power stations: 1 2 3 4 (1 selected)
- Solar panels for electricity: 1 2 3 4 (1–2 selected)

- Geosequestration: 1 2 3 4 (1 selected)

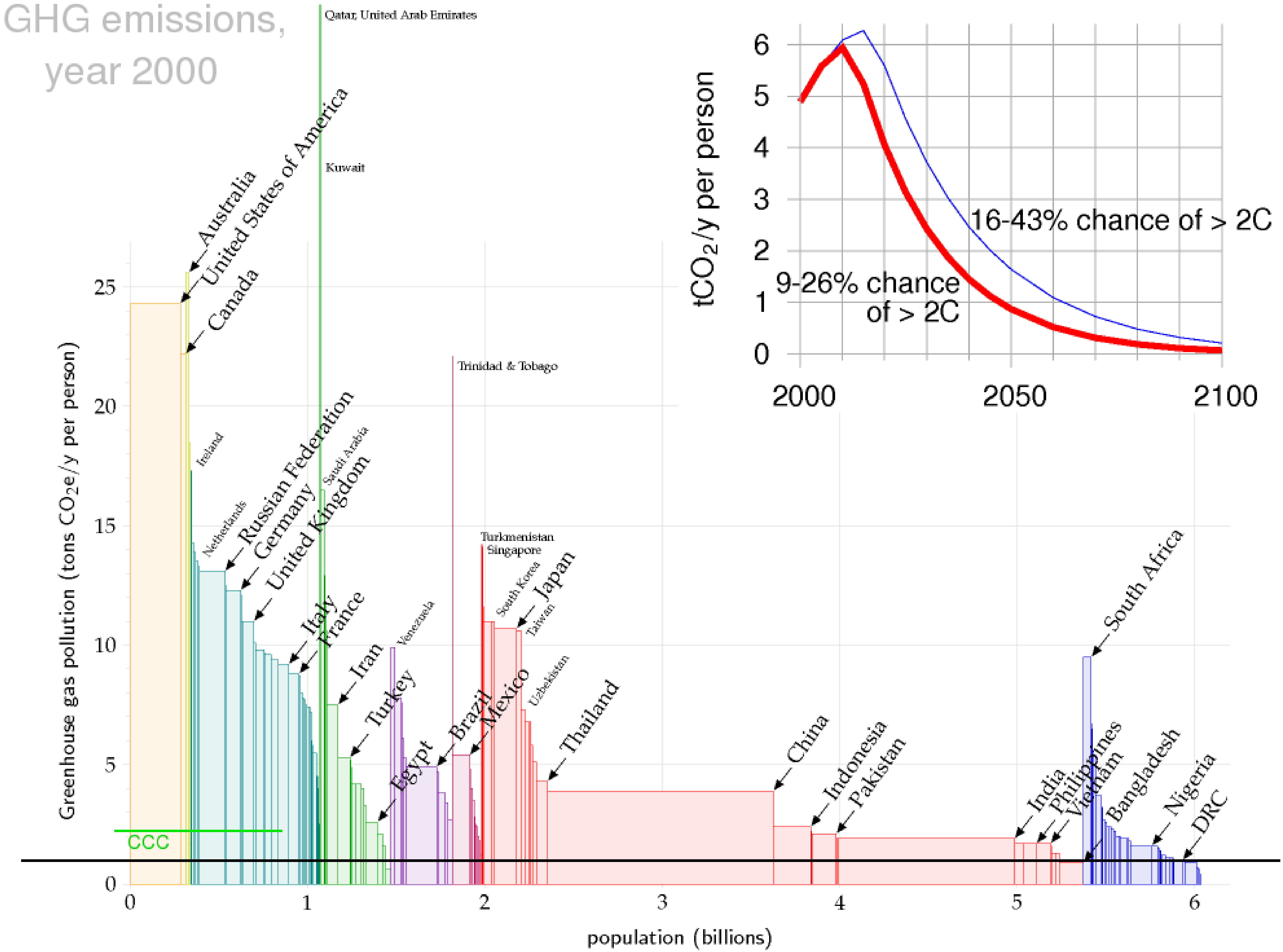
2050 emissions will be 80% below 1990 levels.

International aviation and shipping emissions are not included in the UK's 2050 target but are included here to enable emissions from all sectors to be considered.

Save or share this pathway



Data source: Climate Analysis Indicators Tool (CAIT) Version 4.0. (Washington, DC: World Resources Institute, 2007).



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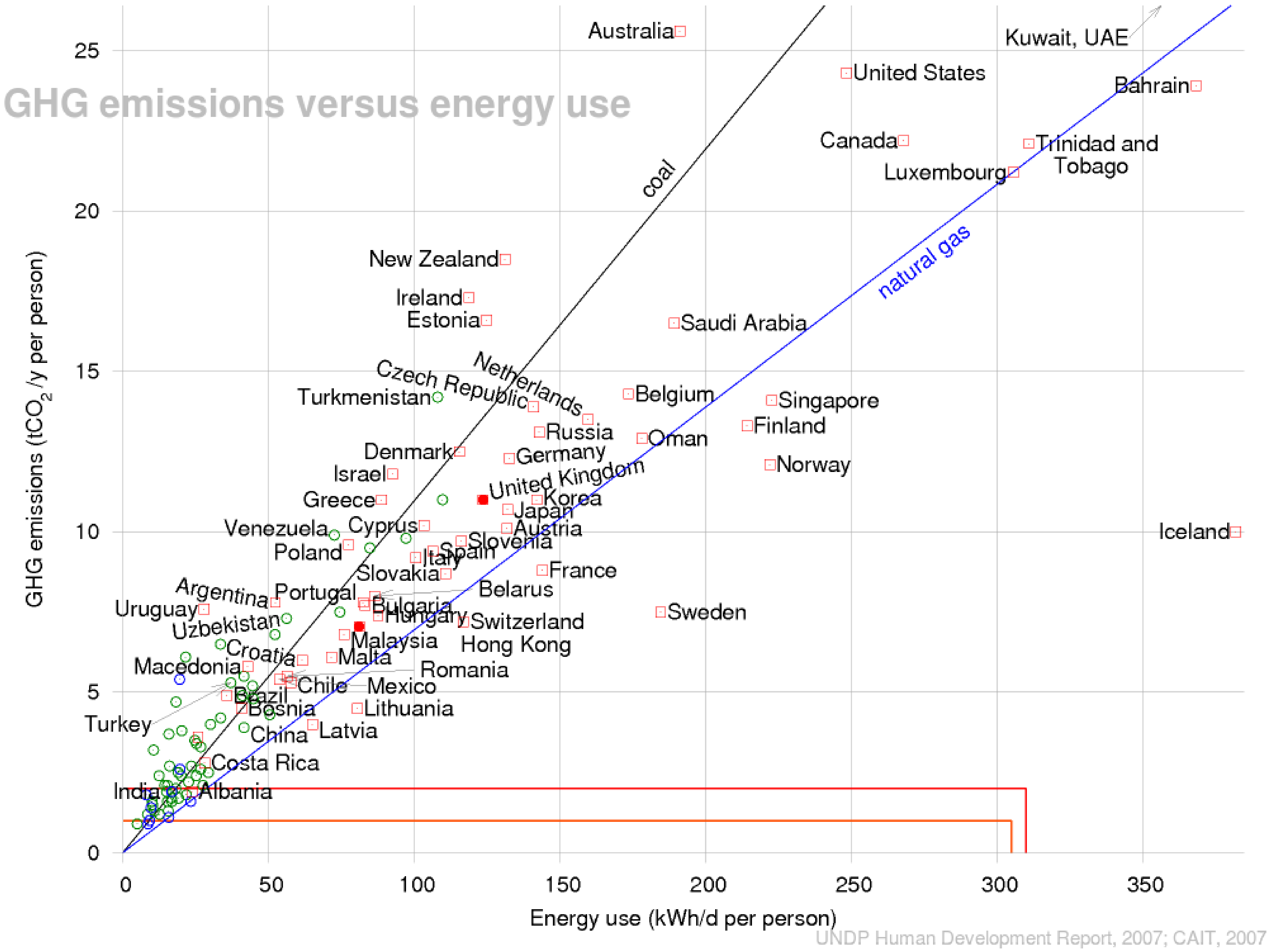
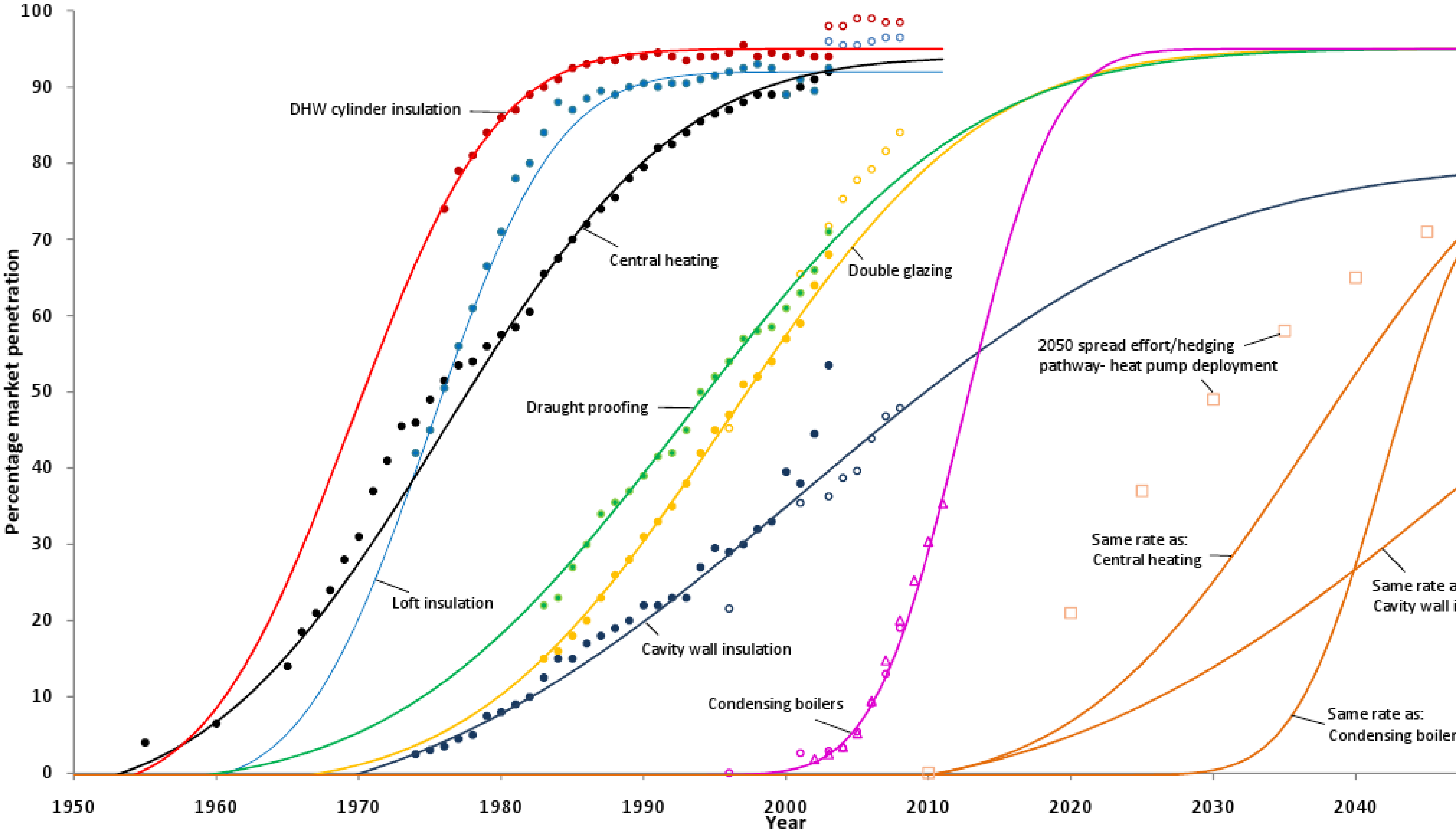
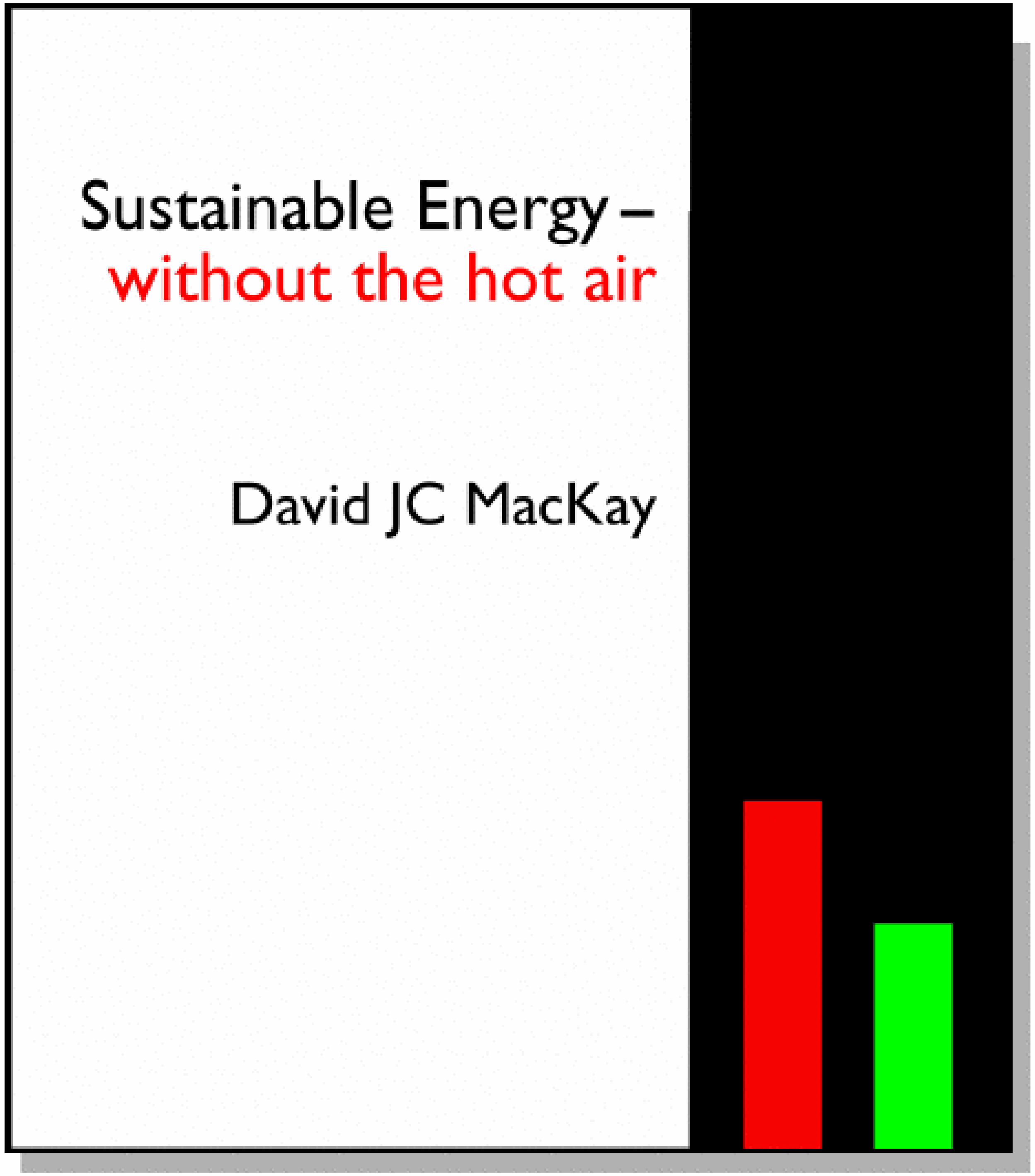


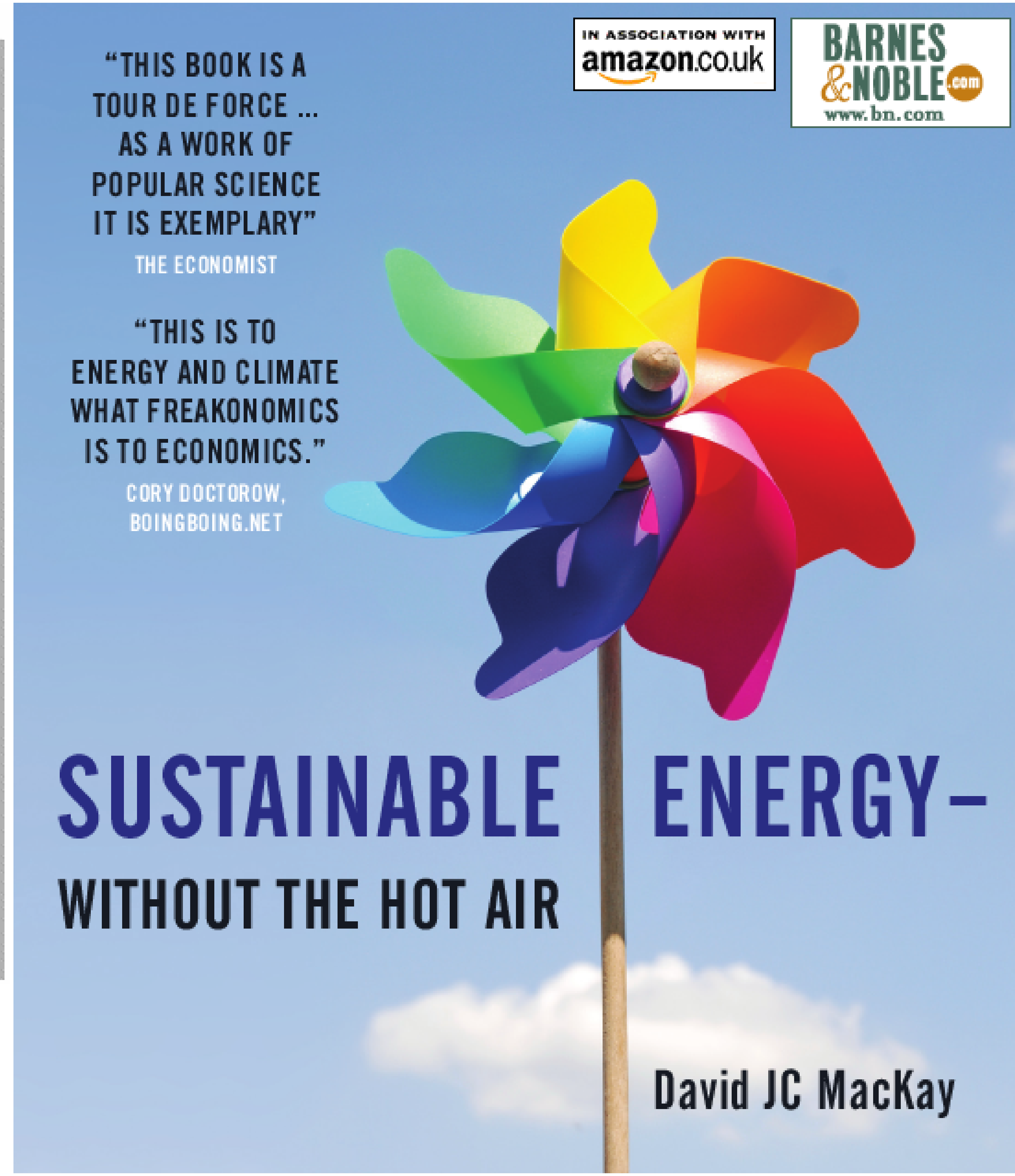
GHG emissions versus energy use
GHG emissions (tCO_2/y per person)
Energy use (kWh/d per person)
0
5
10
15
20
25
0
50
100
150
200
250
300
350
coal
natural gas
Australia
Kuwait, UAE
United States
Bahrain
Canada
Trinidad and Tobago
Luxembourg
New Zealand
Ireland
Estonia
Saudi Arabia
Czech Republic
Netherlands
Turkmenistan
Belgium
Singapore
Finland
Russia
Oman
Denmark
Germany
Norway
Israel
United Kingdom
Greece
Korea
Japan
Venezuela
Cyprus
Austria
Iceland
Poland
Slovenia
Spain
Italy
Slovakia
France
Argentina
Portugal
Belarus
Uruguay
Bulgaria
Hungary
Switzerland
Uzbekistan
Malaysia
Hong Kong
Croatia
Malta
Macedonia
Romania
Chile
Mexico
Brazil
Bosnia
Lithuania
Turkey
China
Latvia
Costa Rica
India
Albania
Sweden
UNDP Human Development Report, 2007; CAIT, 2007

Deployment curves



Updated after data produced by **Prof. Dennis Loveday**. "Market penetration of energy-efficiency related measures" (2003)





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