

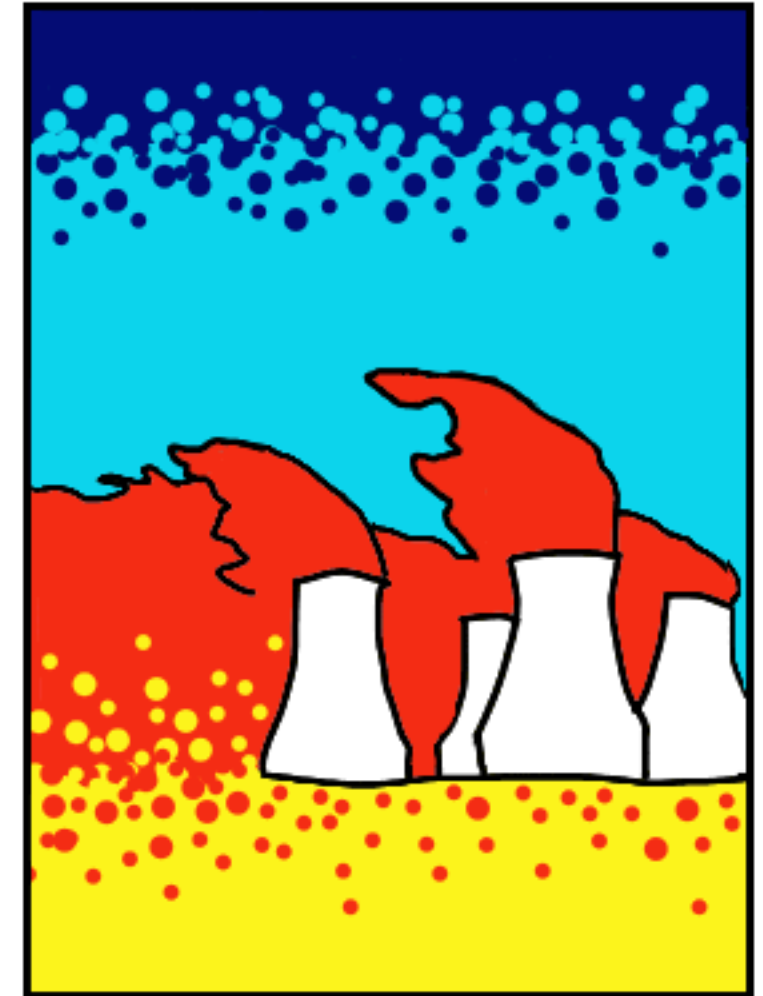
Sustainable Energy

- without the hot air

David MacKay FRS

Cavendish Laboratory
University of Cambridge

www.withouthotair.com



We have an addiction to fossil fuels, and it's not sustainable

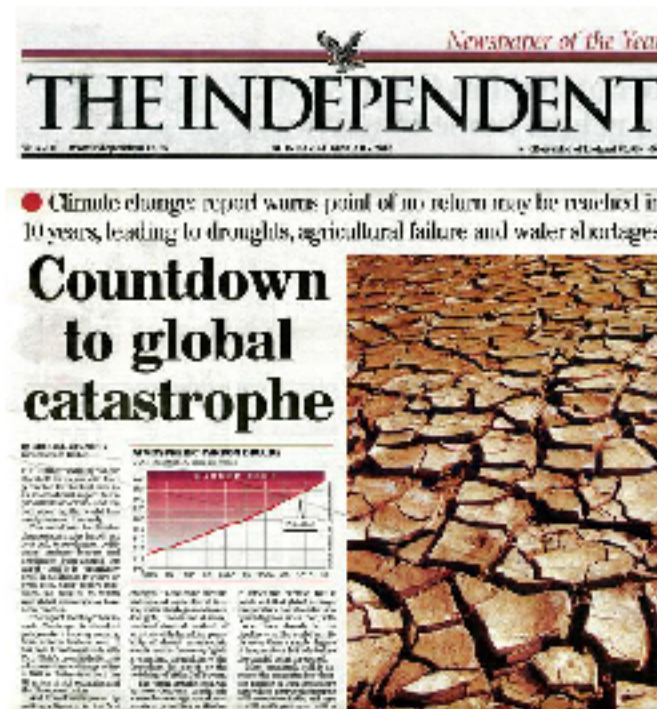
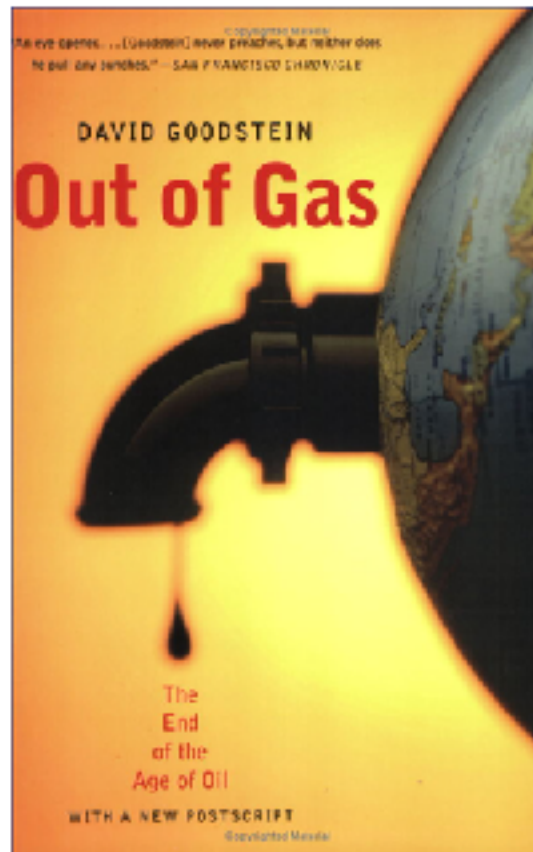


Photo by Terry Cavner



Newspaper of the Year

THE INDEPENDENT

No 5,700 www.independent.co.uk

MONDAY 24 JANUARY 2005

★ (Republic of Ireland €0.95) 60p

● Climate change: report warns point of no return may be reached in 10 years, leading to droughts, agricultural failure and water shortages

Countdown to global catastrophe

BY MICHAEL MCCARTHY
Environment Editor

THE GLOBAL warming danger threshold for the world is clearly marked for the first time in an international report to be published tomorrow – and the bad news is, the world has nearly reached it already.

The countdown to climate-change catastrophe is spelled out by a task force of senior politicians, business leaders and academics from around the world – and it is remarkably brief. In as little as 10 years, or even less, their report indicates, the point of no return with global warming may have been reached.

The report, *Meeting The Climate Challenge*, is aimed at policymakers in every country, from national leaders down. It has been timed to coincide with Tony Blair's promised efforts to advance climate change policy in 2005 as chairman of both the G8 group of rich countries and the European Union.

And it breaks new ground by putting a figure – for the first time in such a high-level docu-

ATMOSPHERIC CARBON DIOXIDE

CO₂ concentration, parts per million



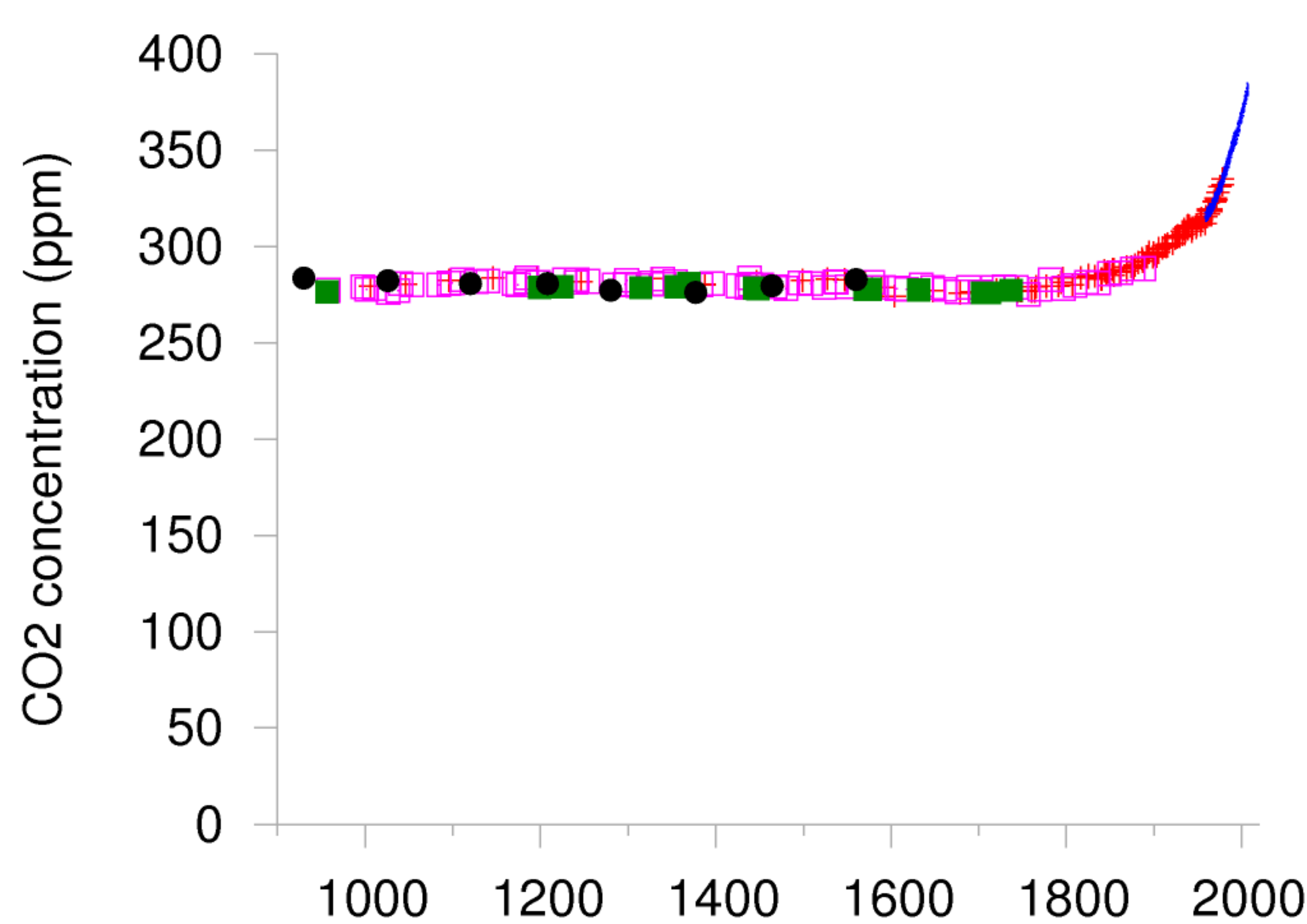
changes. These could include widespread agricultural failure, water shortages and major droughts, increased disease, sea-level rise and the death of forests – with the added possibility of abrupt catastrophic events such as “runaway” global warming, the melting of the Greenland ice sheet, or the switching-off of the Gulf Stream.

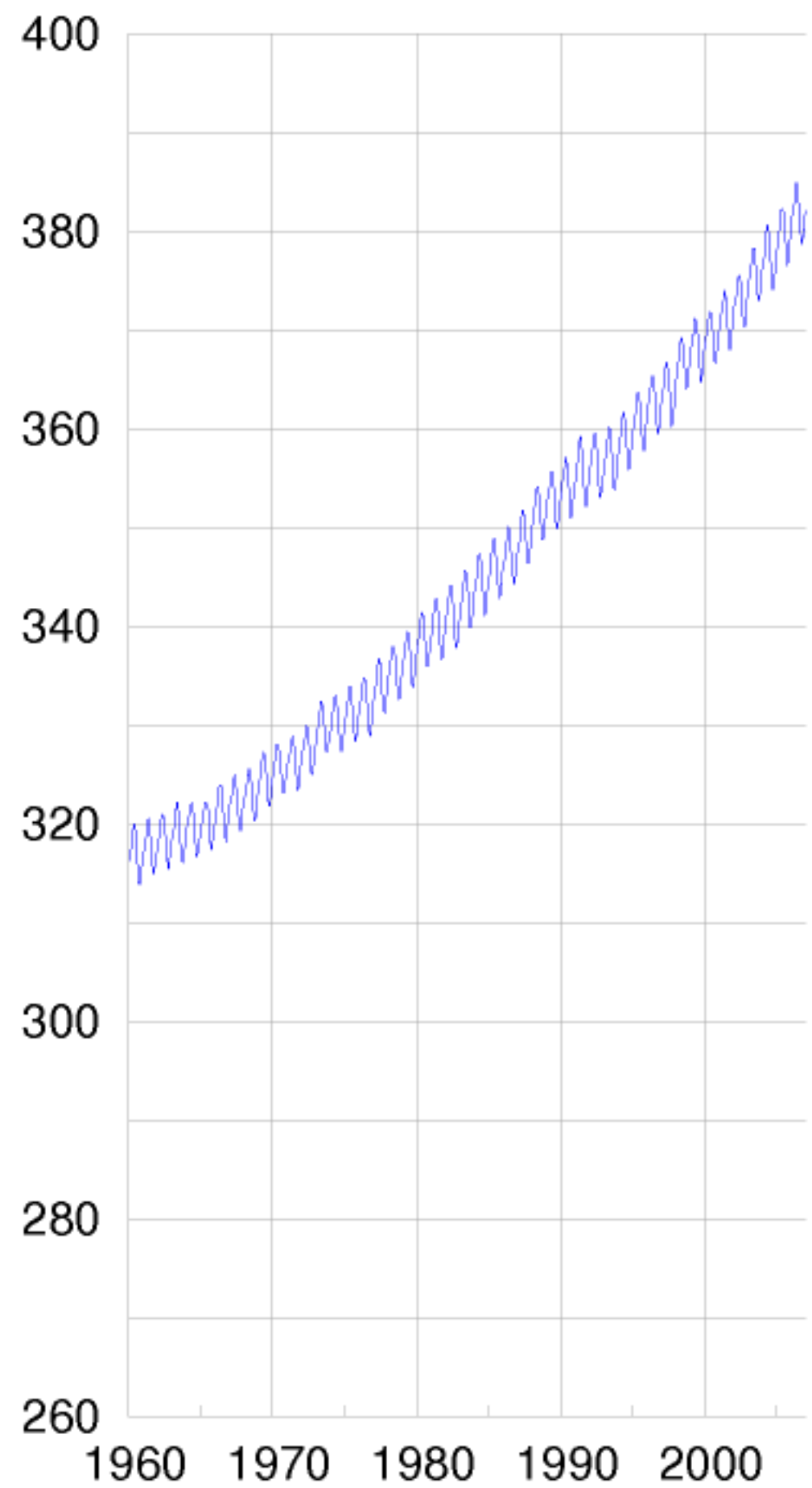
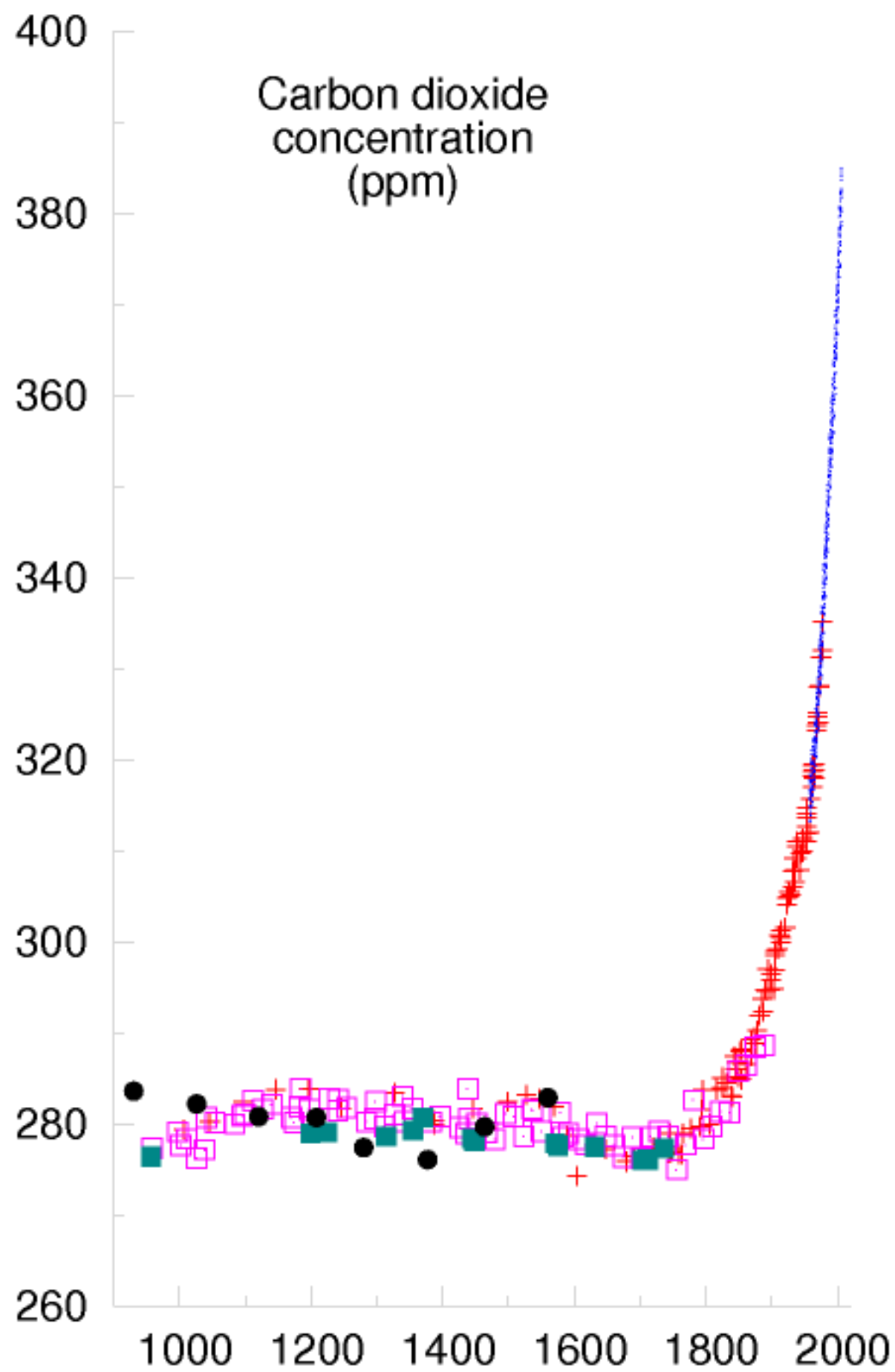
The report says this point will be two degrees centigrade above the average world temperature prevailing in 1750 before the industrial revolution,

to affect the climate. But it points out that global average temperature has already risen by 0.8 degrees since then, with more rises already in the pipeline – so the world has little more than a single degree of temperature latitude before the crucial point is reached.

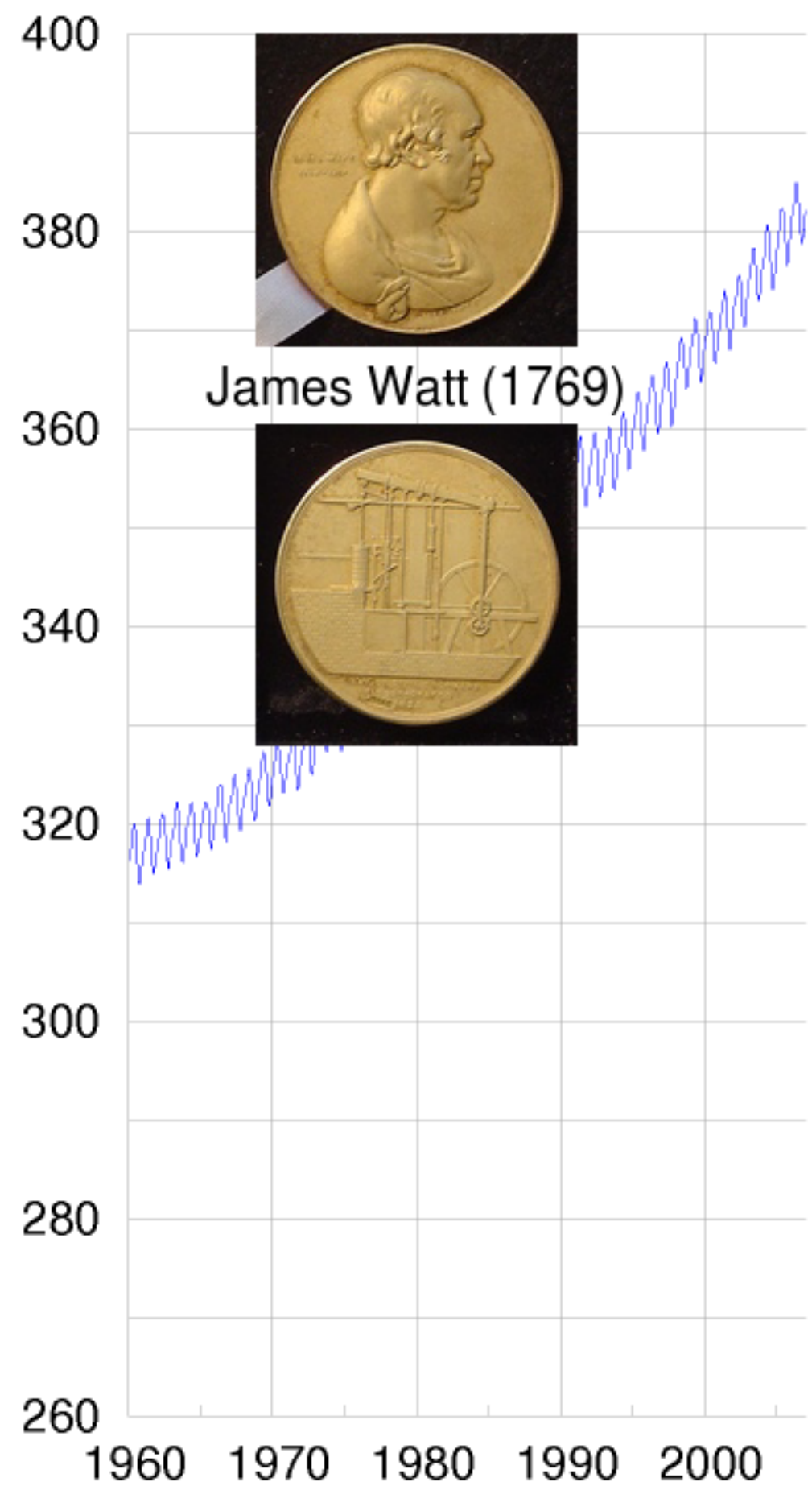
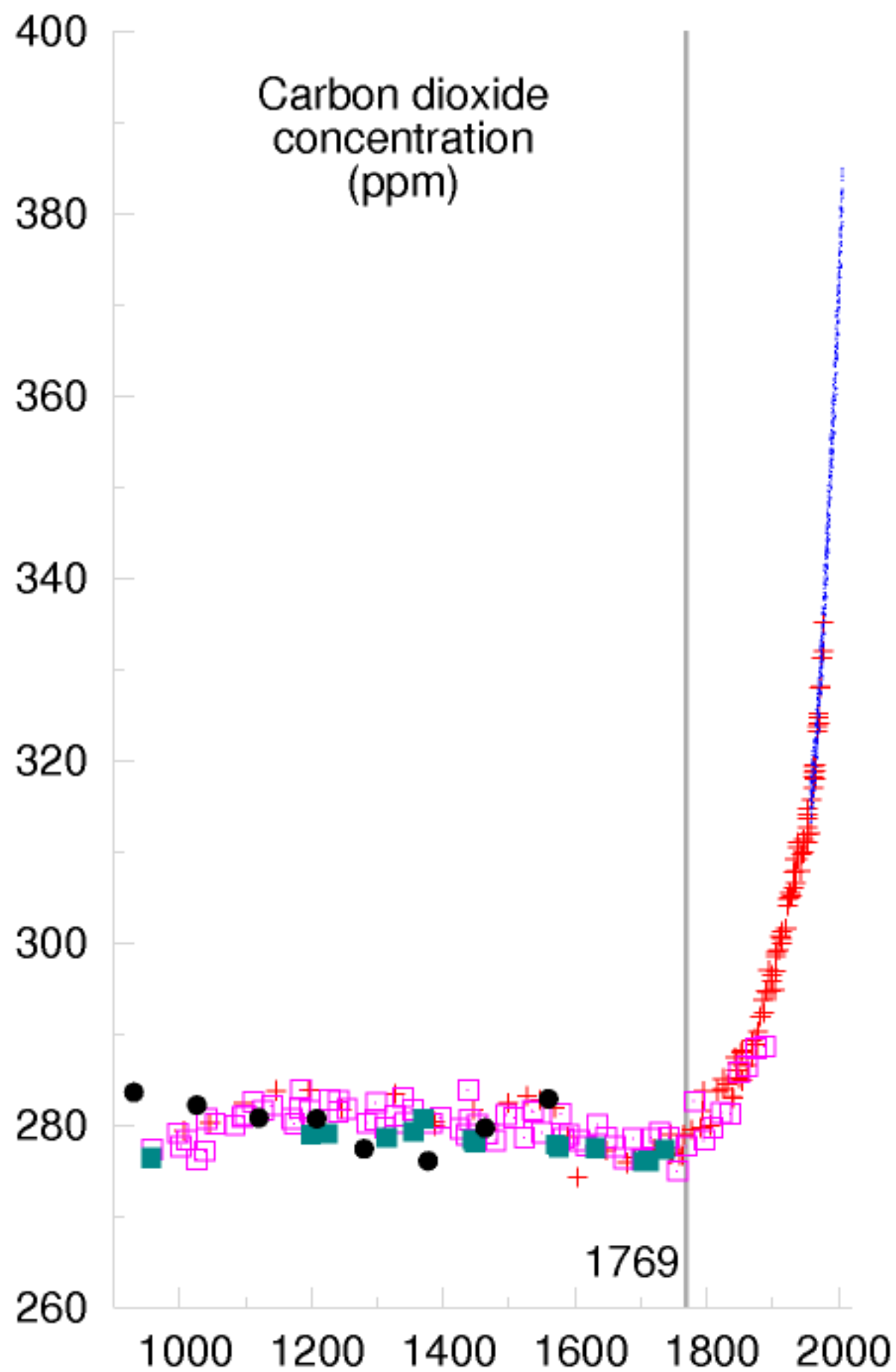
More ominously still, it assesses the concentration of carbon dioxide in the atmosphere after which the two-degree rise will become inevitable, and says it will be 400 parts per million by volume (ppm) of CO₂.



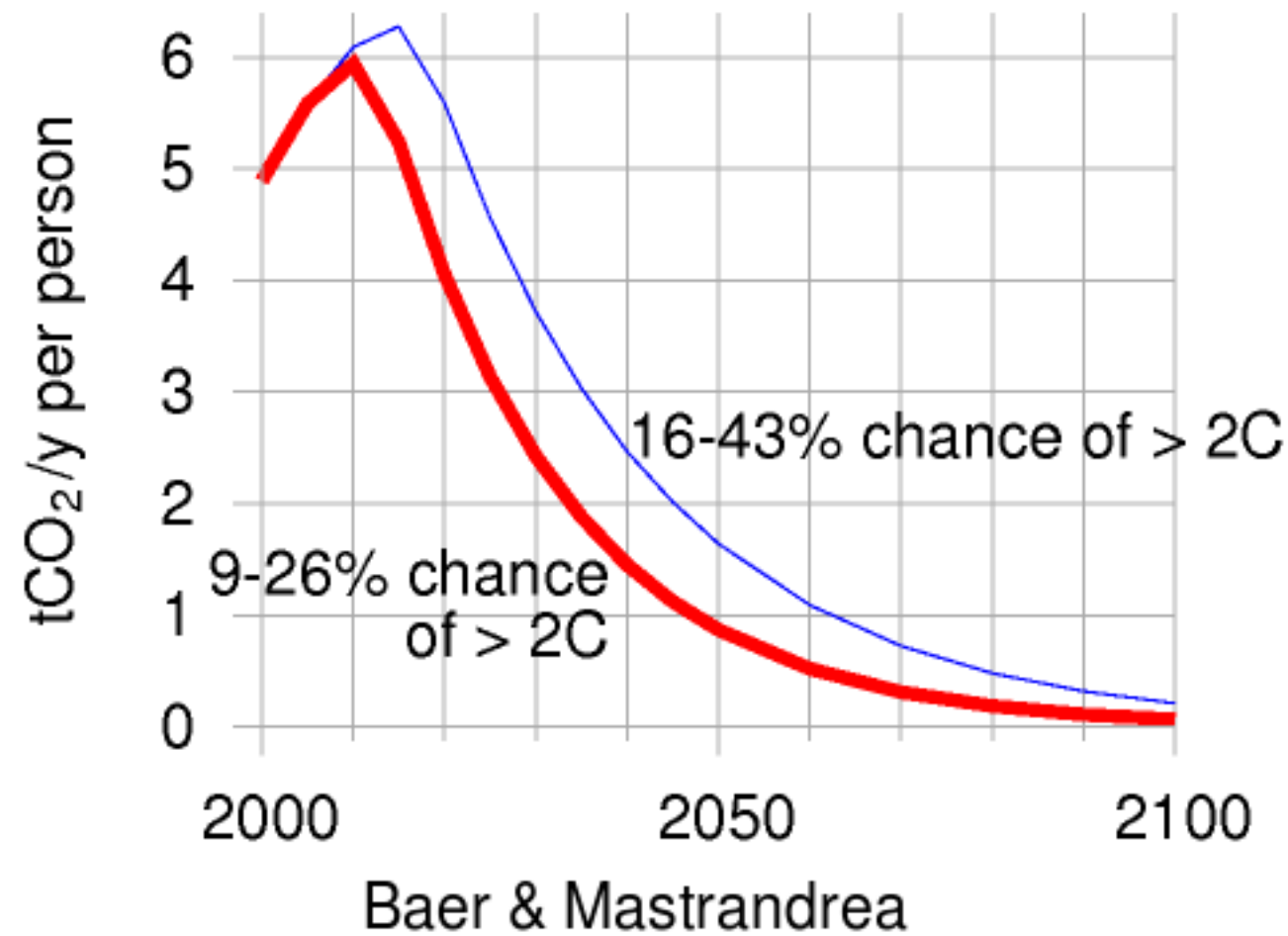




Sources: Keeling and Whorf (2005); Neftel et al (1994); Etheridge et al (1998); Siegenthaler et al (2005); Indermuhle et al (1999)

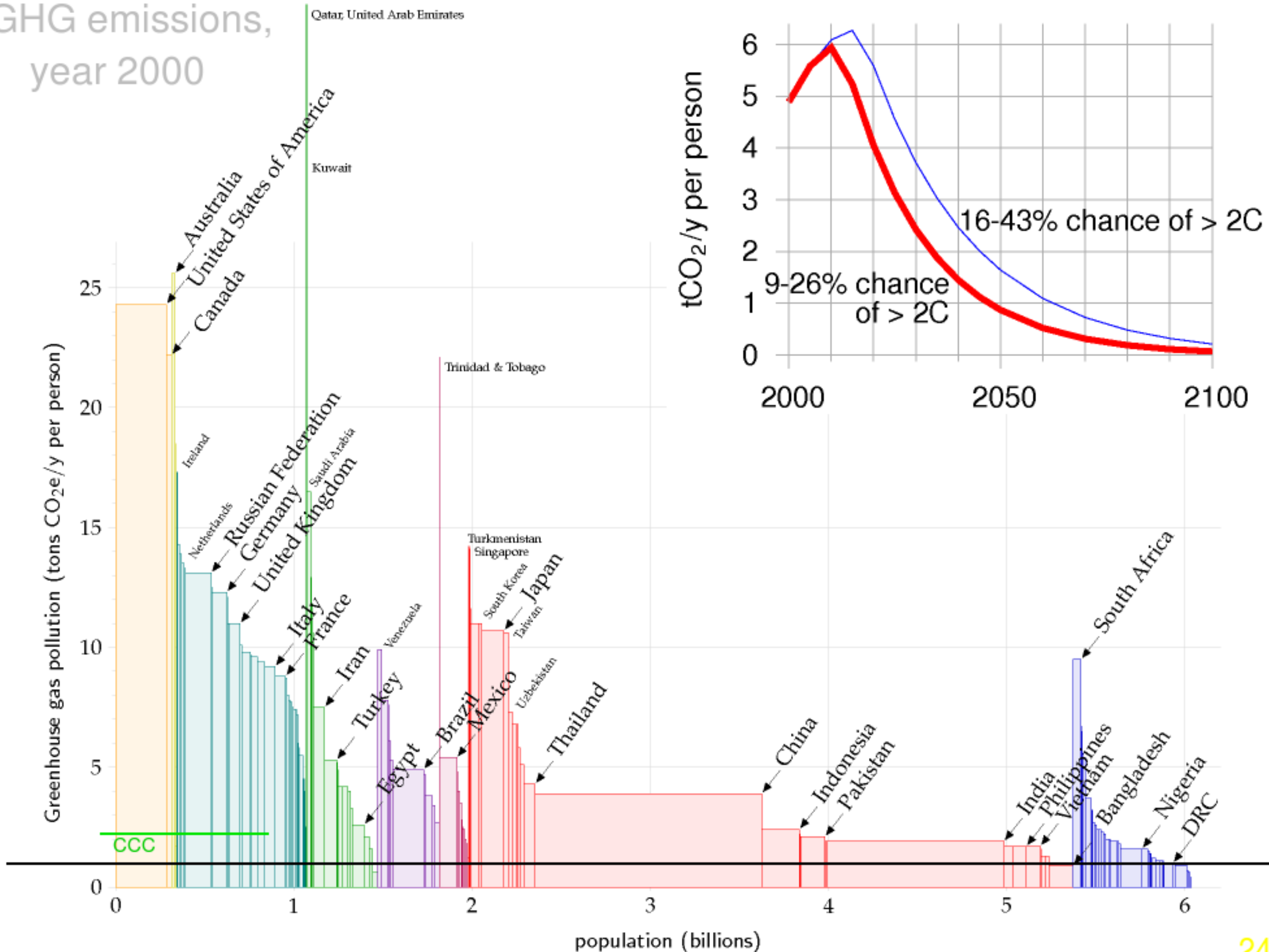


Sources: Keeling and Whorf (2005); Neftel et al (1994); Etheridge et al (1998); Siegenthaler et al (2005); Indermuhle et al (1999)



Climate scientists recommend reduction
from 5.5 t CO₂ per year per person (world average)
to ~ 1 t CO₂ per year per person by 2050

GHG emissions, year 2000



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

'Do your bit'!



Generating
a sustainable future

Positive Energy



Let the
power of
nature into
your home



Switch your
energy to
Powergen's
Go Green
tariff and
do your bit
for the
environment

[Click here ►](#)



98% of Powergen's electricity is fossil; just 2% renewables

Solar bra brings conservation closer to the heart

Wed May 14, 2008 8:53pm IST

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anytime soon, said Triun Masuda, as "people usually wear clothes over it."

guardianecostore

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Eco Money Savers : HY-Mini - Personal Portable Wind Power

£39.95

Quantity:

[ADD TO CART](#)



17956 HY-Mini - Personal Portable Wind Power

Attach this innovative portable and personal wind turbine to your arm, bike bars, or windowsill, and it will capture wind energy, transforming it into usable power for your mobile devices. This brilliantly clever recharger is perfect for travel and cycling holidays! With a built-in turbine, it's chargeable by kinetic energy (requires minimum wind speed 9mph), but you can also charge it using an ordinary socket.

Plug in, charge up, and it becomes a power storage unit. HY-Mini is universally adaptable for your mobile devices. An AC/DC power adaptor for 3-pin wall plugs, USB transfer cable and mobile phone (Nokia / Motorola / Sony Ericsson / Samsung / LG) adaptors are included. MP3 player, iPod, PDA, digital camera, and other 5V handheld devices can be charged with original manufacturer USB or aftermarket USB cables.

Order an Armband Kit (17958) or Bicycle Kit (17957) to attach the charger for power on-the-move.

Something must be done!



A rough guide to sustainable energy



- No millions, billions, or trillions
- Make quantities **comprehensible** and **comparable**
- Do calculations **per person**, to one significant figure

● Energy unit: **kWh**



● Power: **kWh per day**

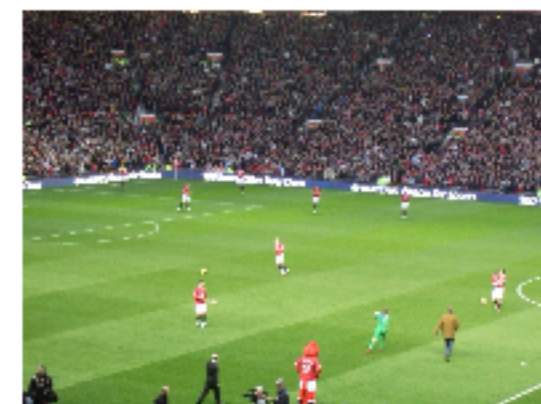
● Power per unit area: **W per square metre**

● Population density: **square metres per person**

UK: **4000 m² per person**

● Examples

- 20 mins of kettle - 1 kWh
- food - 3 kWh / day(*)
- bath - 5 kWh(*)
- litre of petrol - 10 kWh
- aluminium can - 0.6 kWh



Drive a car 100km...

80 kWh

the vehicle
anything.

HEAD

huge prob-
finding a
space and
usually re-
ing that
y like
ehi-
V3

te
vo.
arque
ed V70
he should

get a decent view out.

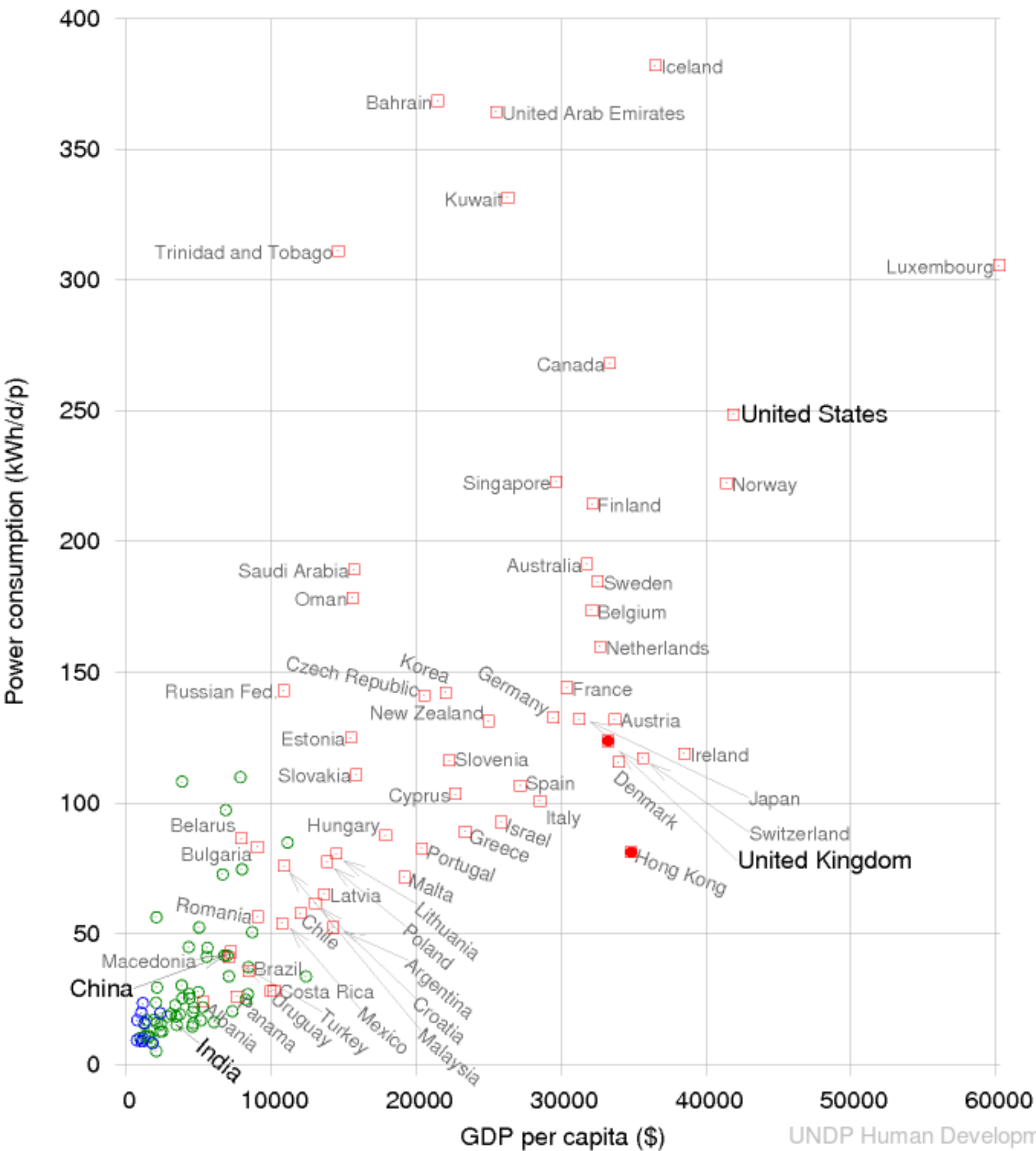
The 2.4 Diesel is efficient and probably the best all-round choice, offering 34mpg overall. During the past few years, it has

even more space inside. The trouble is, the R-Class is furiously expensive, with prices starting at more than £38,000.

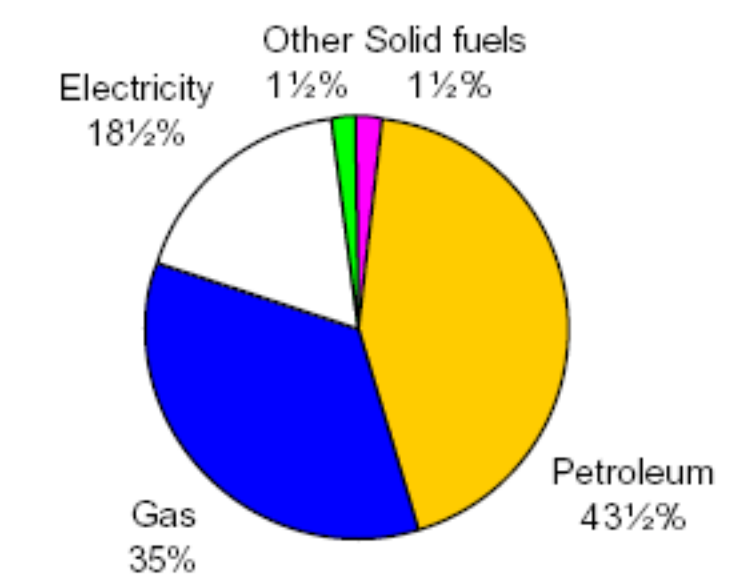


**Practically perfect:
the Volvo XC90**

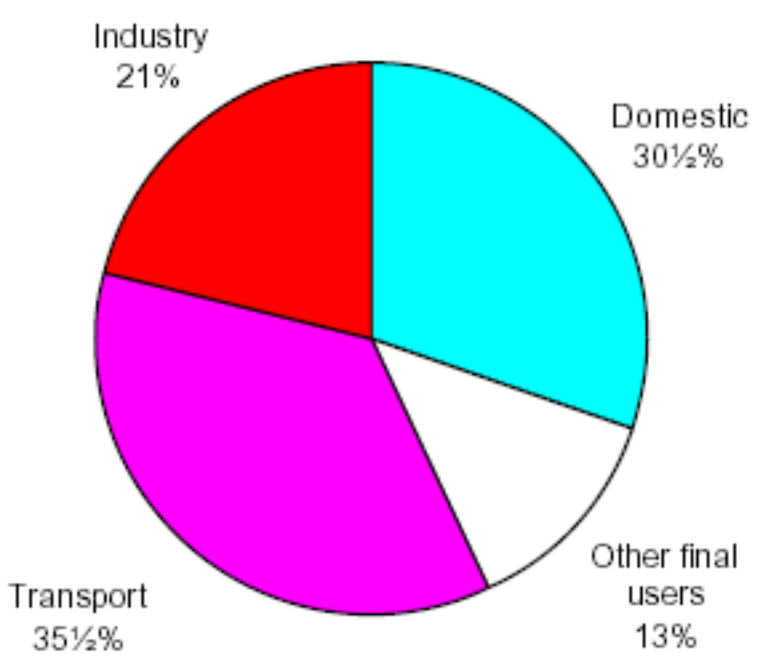
Energy use
versus GDP
- linear scale



Average power consumption, UK: 125 kWh/d/p



2004



125 kWh/day (Europe)
250 kWh/day (USA)

(Not including embodied energy in imports
nor solar energy used by agriculture)

For CO₂ pollution, divide by 10:
100 kWh/day \simeq 10 tonnes CO₂/y

Wind

Current
consumption

Current
consumption:
125 kWh/d
per person

$$v = 6 \text{ m/s (force 4)}$$

Wind farm 2 W/m^2 flat ground

UK: 4000 m^2 per person

Put wind farms on 10% of the UK

- $400 \text{ square metres}$ each

Wind:
20 kWh/d

...Twice as much windpower as the
whole world;

50 x Denmark's



7 x Germany's



Renewables are diffuse

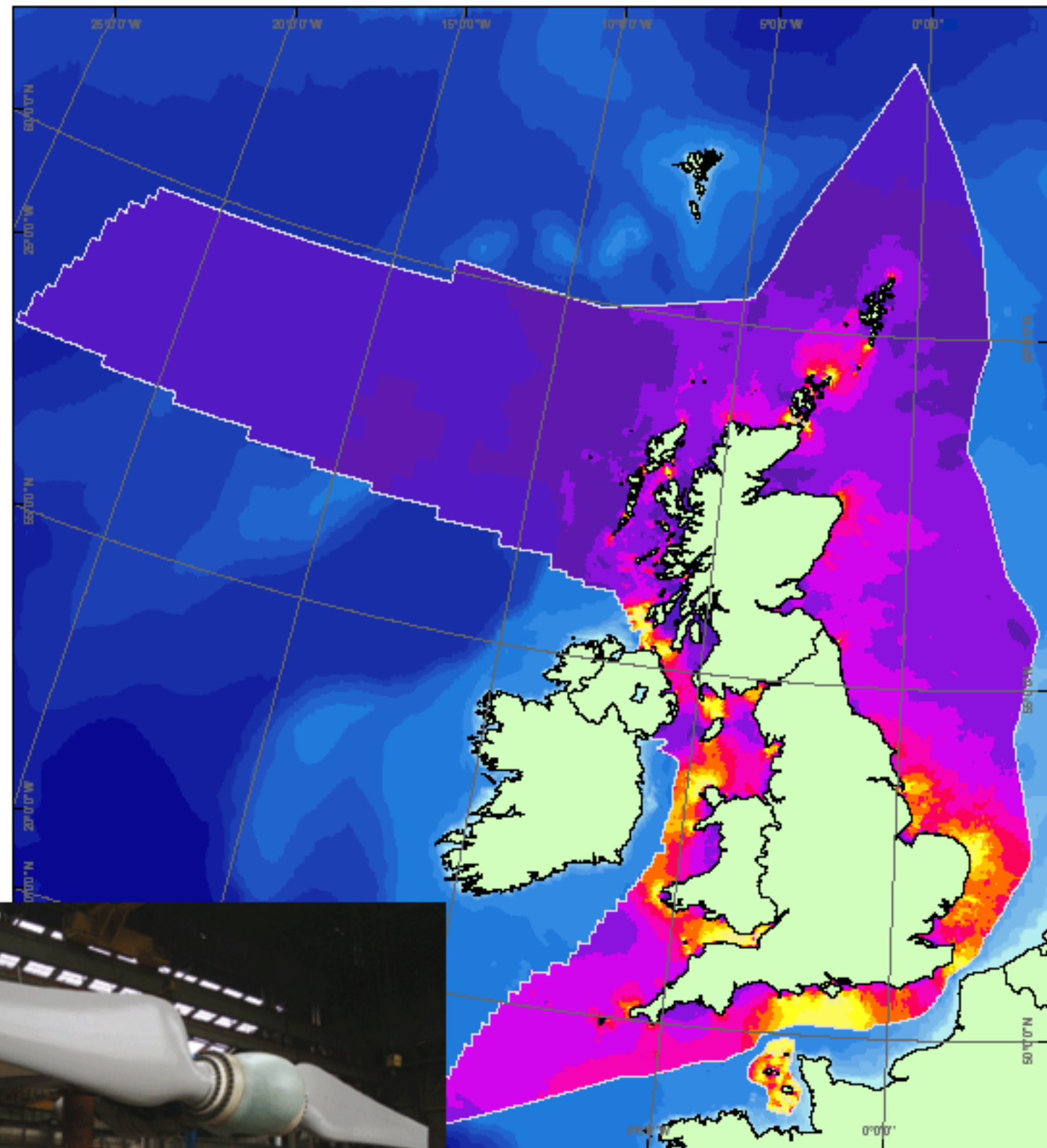
POWER PER UNIT LAND AREA

Wind	2 W/m^2
Offshore wind	3 W/m^2
Tidal pools	3 W/m^2
Tidal stream	8 W/m^2
Solar PV panels	$5\text{--}20 \text{ W/m}^2$
Plants	0.5 W/m^2
Solar chimney (Spain)	0.1 W/m^2
Concentrating solar power (desert)	$15\text{--}20 \text{ W/m}^2$
Ocean thermal	5 W/m^2
Rain-water (highlands)	0.24 W/m^2
Rain-water (lowlands)	0.02 W/m^2



(c) Elsam (elsam.com).
Used with permission.

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



marineturbines.com

All renewables are diffuse

POWER PER UNIT LAND AREA

Wind	2 W/m^2
Offshore wind	3 W/m^2
Tidal pools	3 W/m^2
Tidal stream	8 W/m^2
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Rain-water (lowlands)	0.02 W/m^2



marineturbines.com

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



Bavaria Solar Park: 5 W/m^2 ; this picture shows 0.7 MW (average)

All renewables are diffuse

POWER PER UNIT LAND

Wind
Offshore wind
Tidal pools
Tidal stream
Solar PV panels
Plants
Solar chimney (Spain)
Concentrating solar power (desert)
Ocean thermal
Rain-water (highlands)
Rain-water (lowlands)

5 W/m²

0.24 W/m²

0.02 W/m²



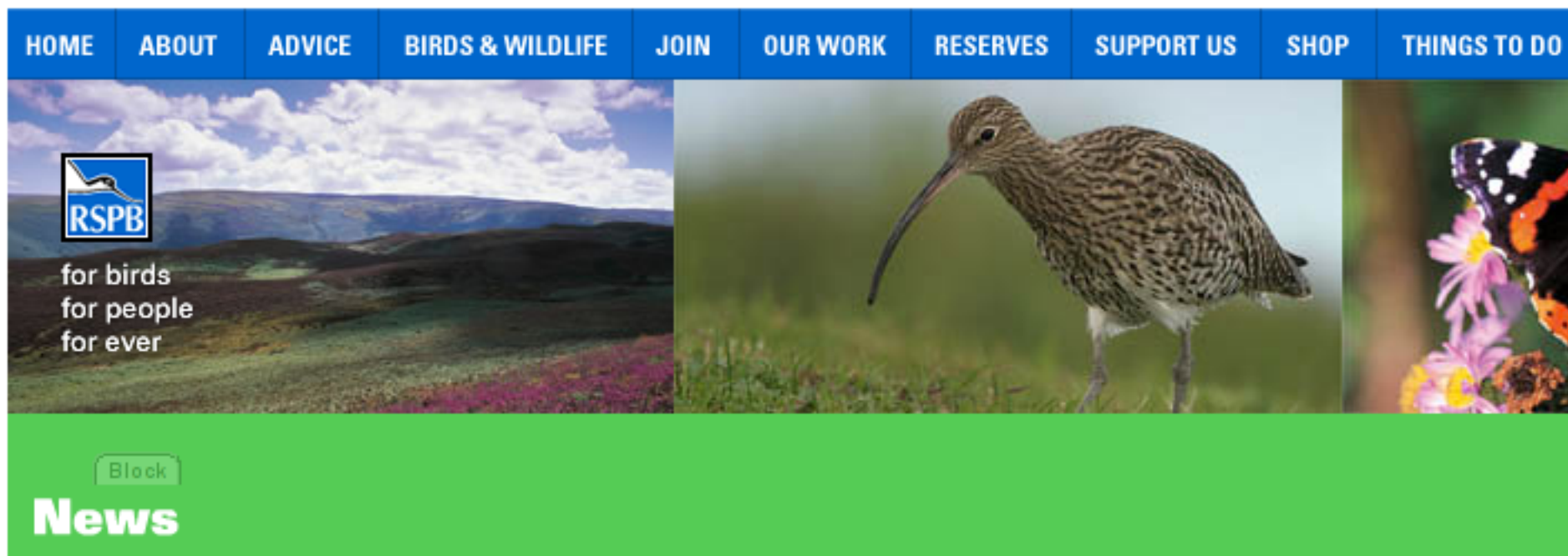
● To make a difference, renewable facilities have to be country-sized

Renewables are diffuse

POWER PER UNIT LAND AREA

Wind	2 W/m ²
Offshore wind	3 W/m ²
Tidal pools	3 W/m ²
Tidal stream	8 W/m ²
Solar PV panels	5–20 W/m ²
Plants	0.5 W/m ²
Solar chimney (Spain)	0.1 W/m ²
Concentrating solar power (desert)	15–20 W/m ²
Ocean thermal	5 W/m ²
Rain-water (highlands)	0.24 W/m ²
Rain-water (lowlands)	0.02 W/m ²

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



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No green light for Severn barrage

Last modified: 01 October 2007

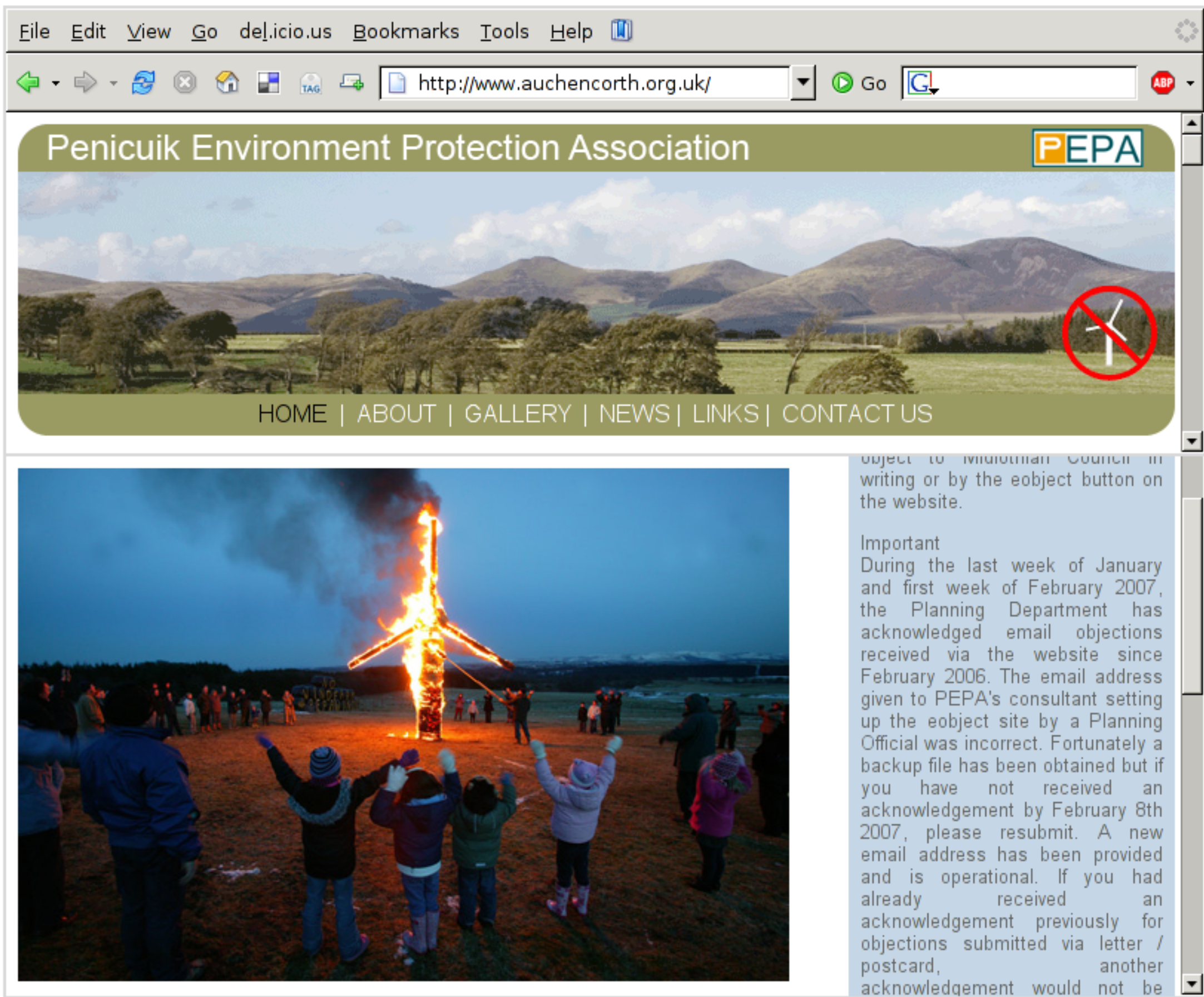
Europe's most dynamic estuary will be destroyed by the construction of a barrage across the Severn while other less striking measures would cost less and could do more to cut carbon emissions.



"other less striking measures"?



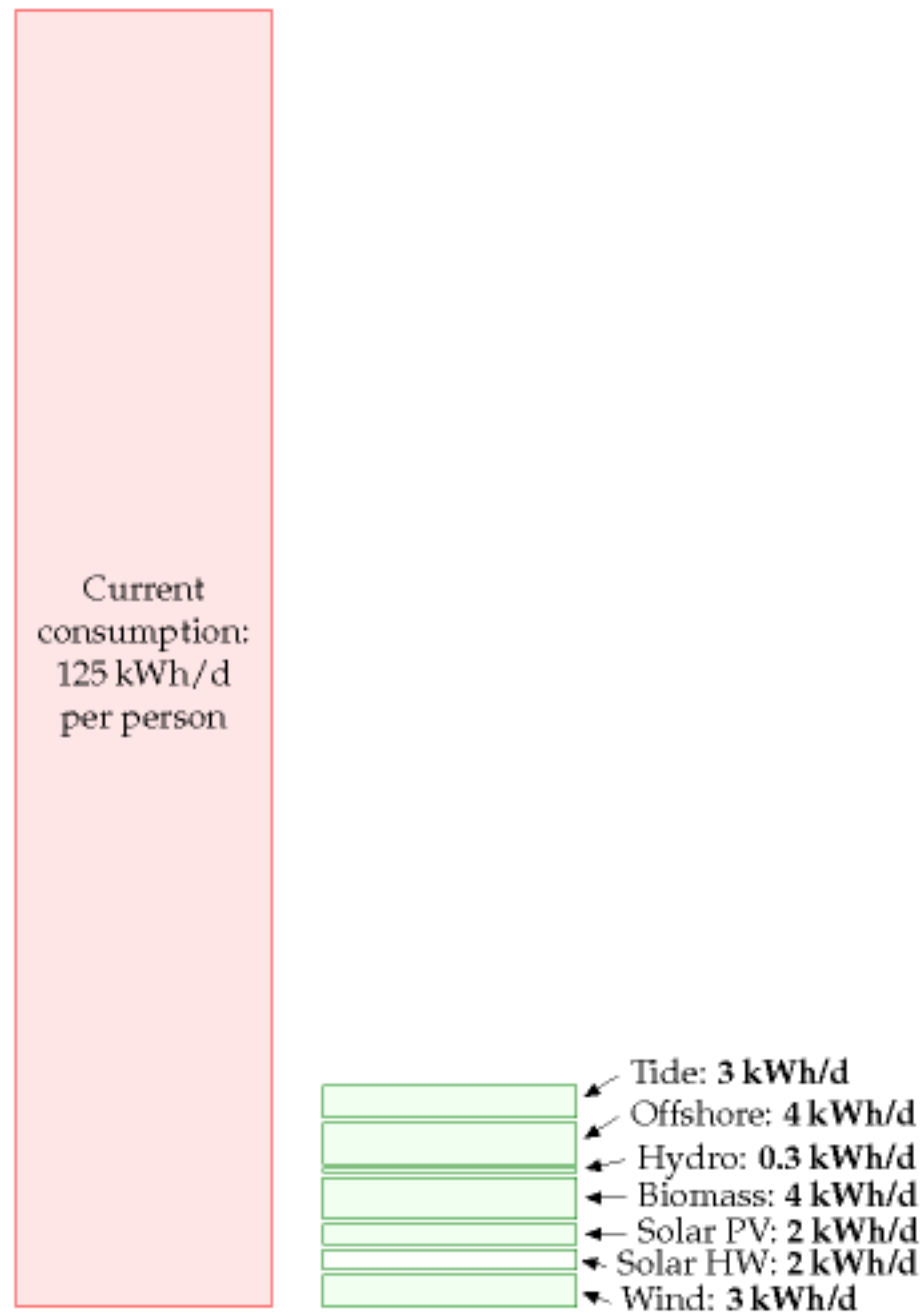
● To make a difference, renewable facilities have to be country-sized



A consultation exercise in full swing

jokes/87g

after the great British consultation exercise...

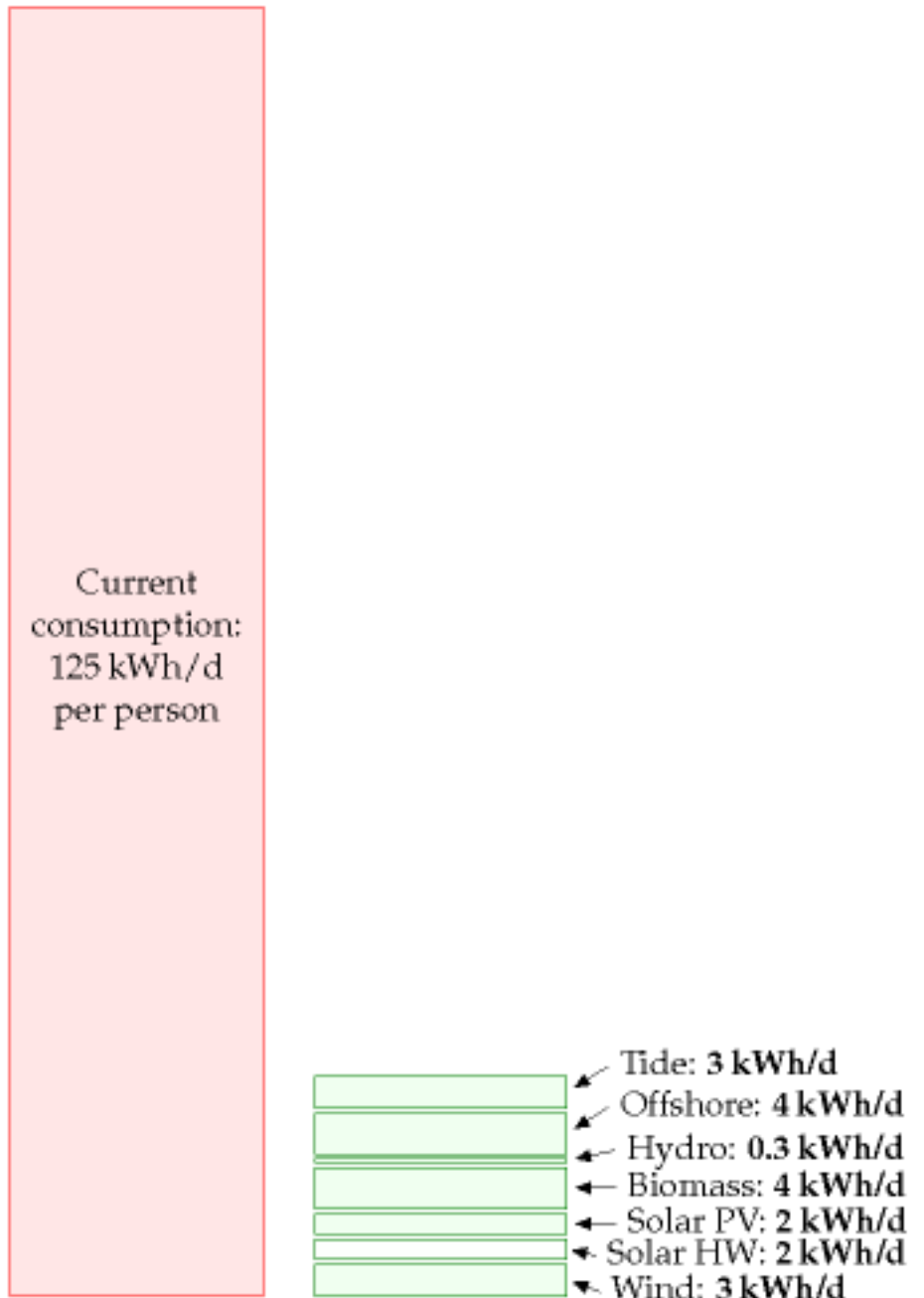


This would be a
15-fold increase
of renewables

Conclusions - part I

**A country like Britain
can't live on
its own renewables
- at least,
not as we currently live**

**To make a difference,
renewables have to be
country-sized**



Part II: How to make an energy plan that adds up

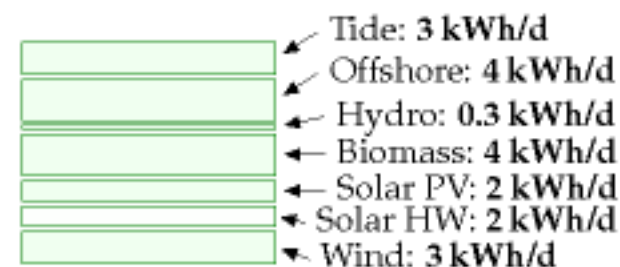
● Demand-side

- Reduce population
- Change lifestyle
- Technology, efficiency

Current
consumption:
125 kWh/d
per person

● Supply-side

- 'Clean coal'
- Nuclear power
- Use other countries' renewables



Change lifestyle?

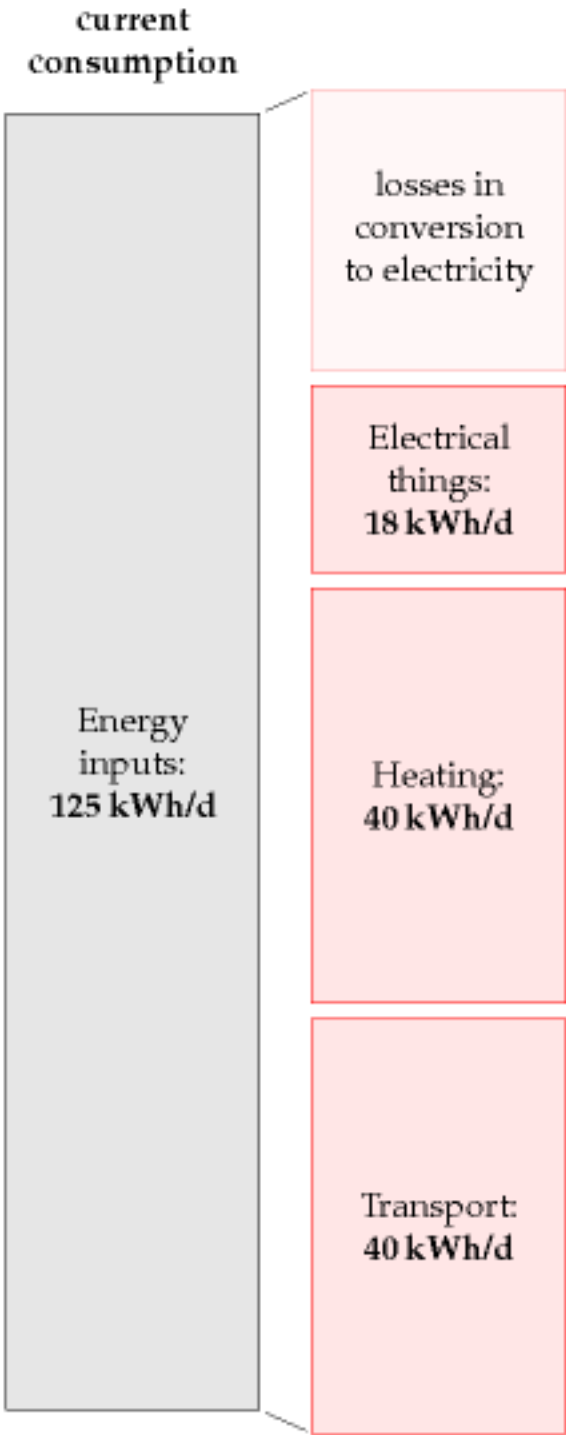


A Mitsubishi Warrior, yesterday

Some people demand the right to commit Amazingly brave acts of off-road driving

EFFICIENCY

● Cartoon Britain, 2008



Efficient transport

Have small frontal area per person

Have small weight per person

Convert energy efficiently

Go slowly

Go steadily





Average UK car uses
80 kWh per 100 person-km (1 person)

How can this consumption be reduced?

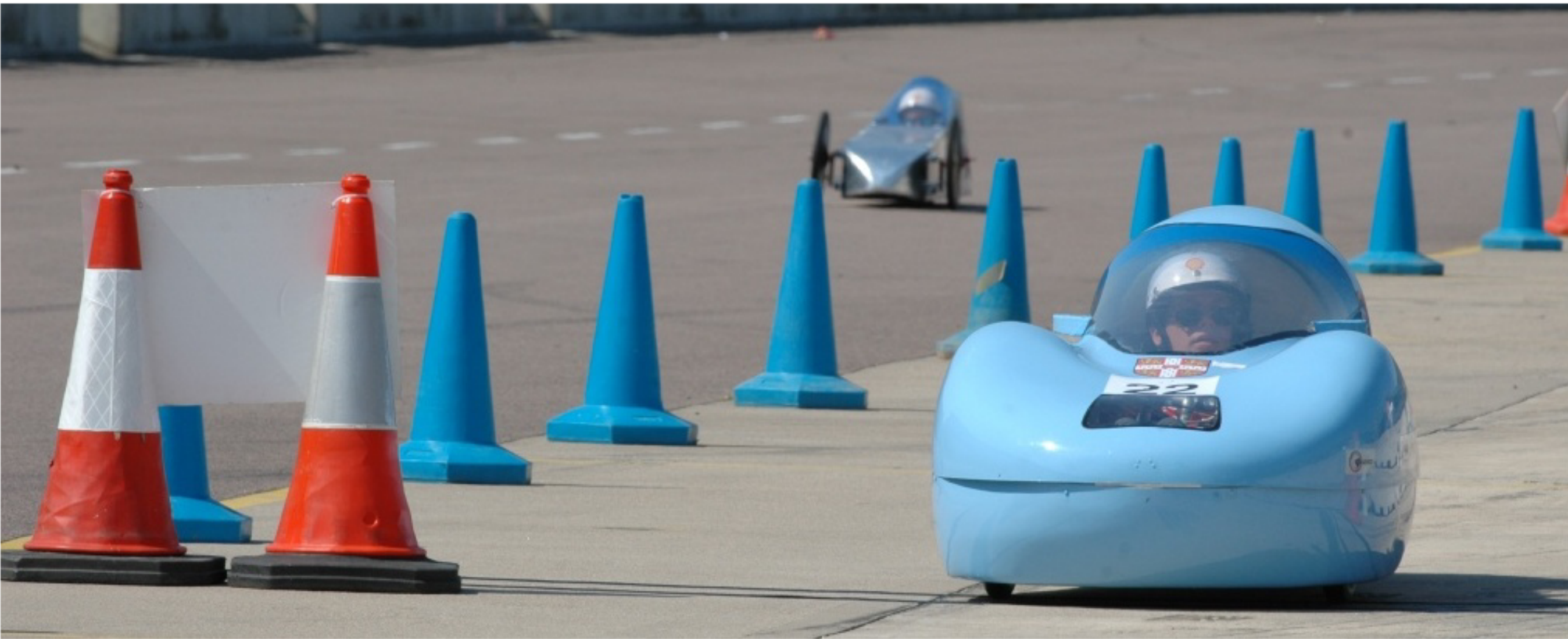


1 kWh per 100 person-km (3 people)



6 kWh per 100 person-km average (electric)
3 kWh per 100 person-km (electric) if full

Eco-car



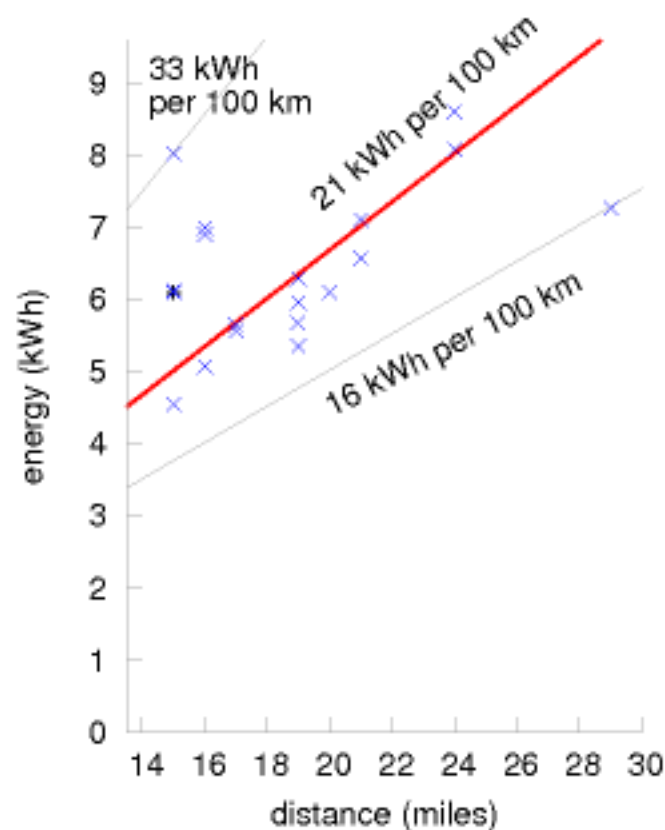
1.3 kWh per 100 person-km (takes 1 teenager)
[2200 mpg]
at 15 mph

<http://www.teamcrocodile.com/>

Electric cars



- 21 kWh per 100 km (solo)
- equivalent to 125 miles per gallon



data from Kele Baker

G-Wiz



6 kWh per 100 km

Loremo



Aptera



TREV



6 kWh per
100 km

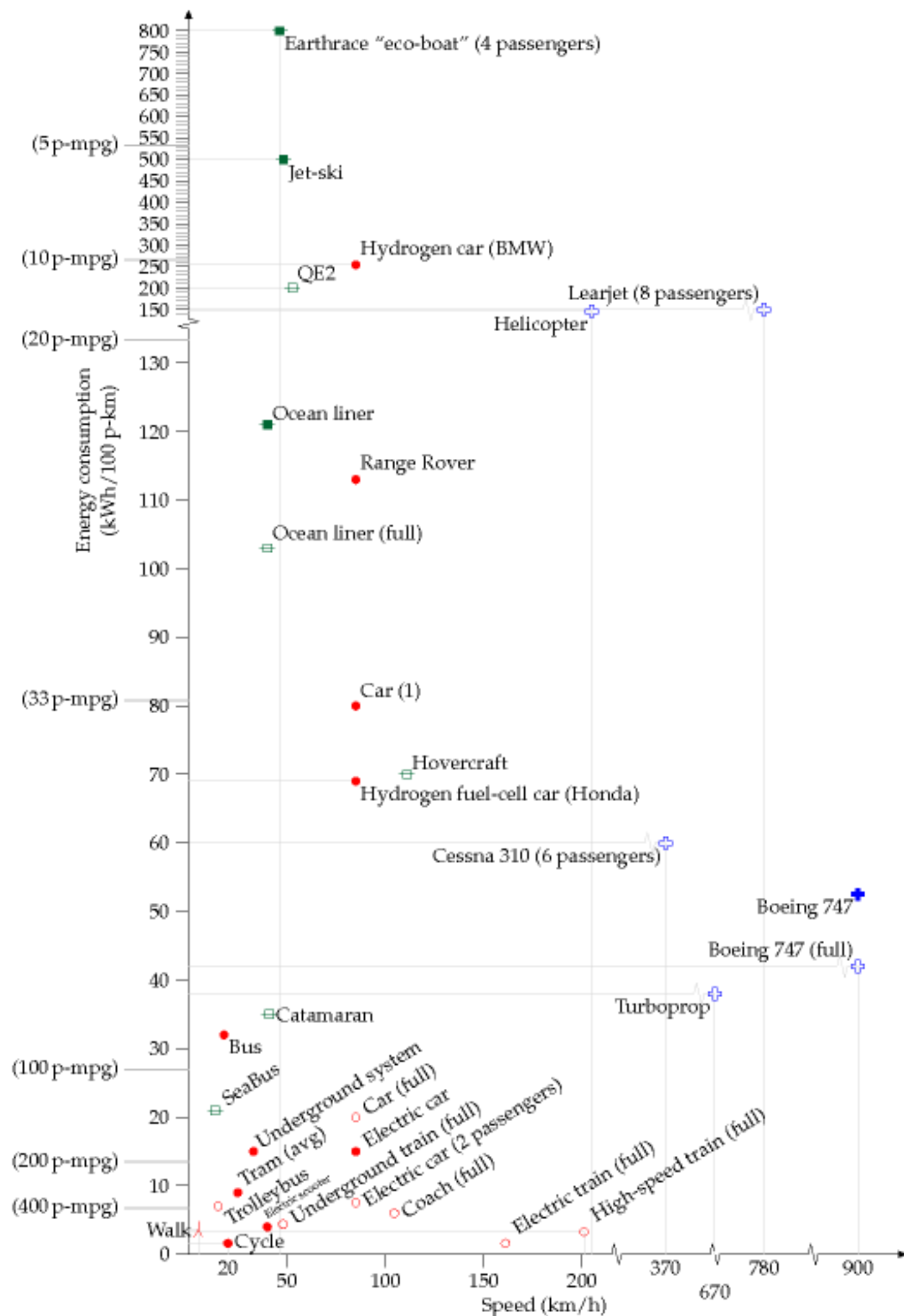
Electric scooters



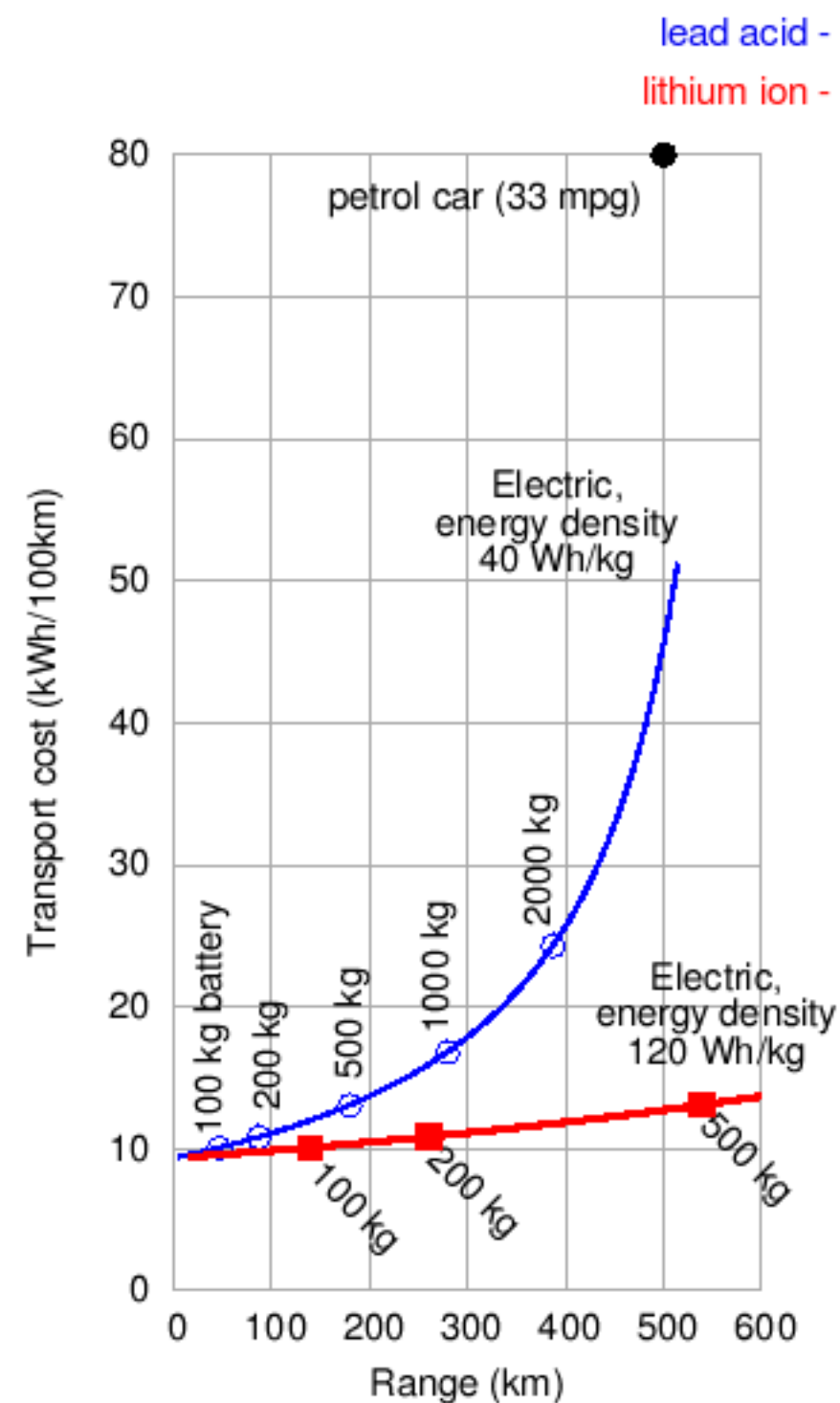
3 kWh per 100 km

<http://www.vectrix.com/>

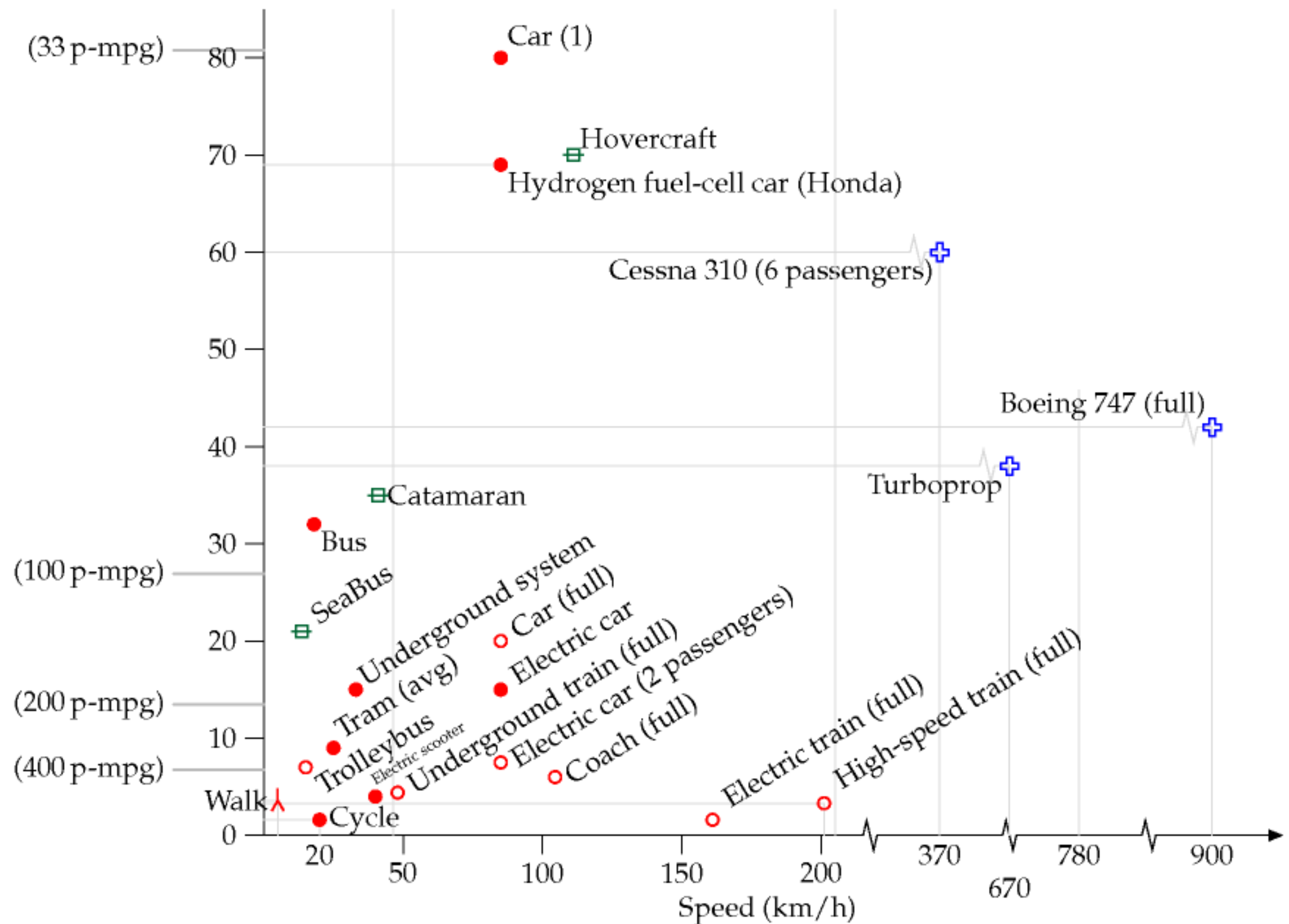




Electric car efficiency and range as a function of battery mass

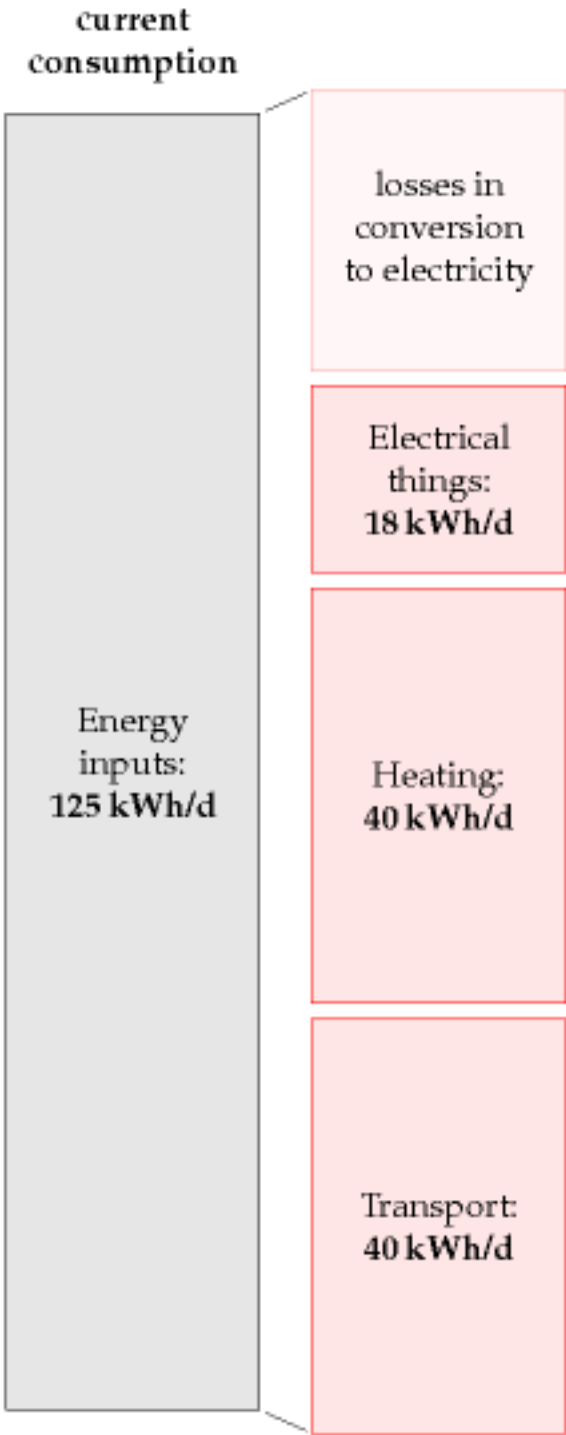


Energy consumption (kWh per 100 passenger-km)



EFFICIENCY

● Cartoon Britain, 2008



Efficiency for heating



- Reduce **temperature difference**

 - Turn the thermostat down

- Reduce **leakiness**

- Increase **CoP of heat-creation**

← **Leakiness:** 8 kWh/d/°C

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

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

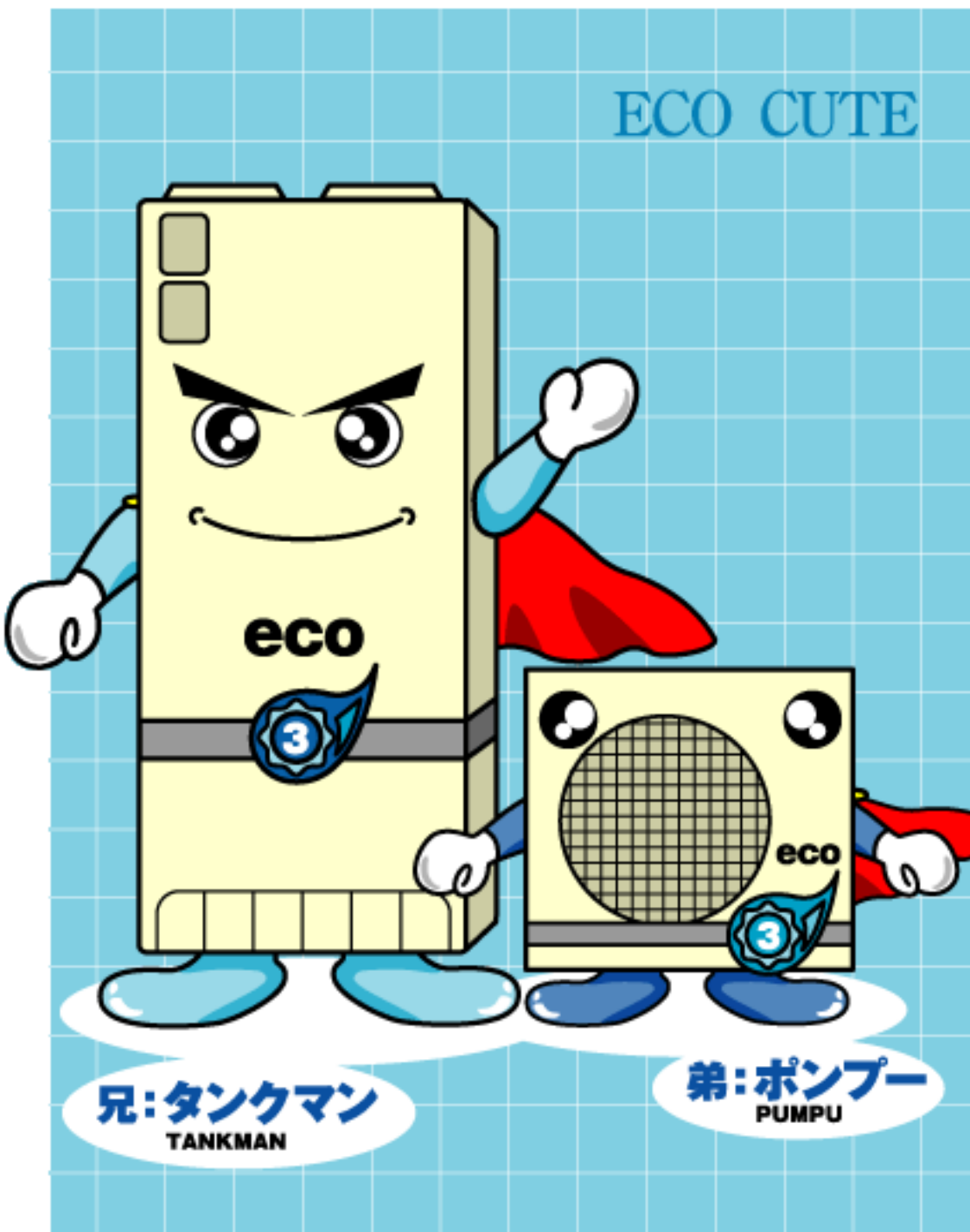
Reduce leakiness

← Leakiness: $8 \text{ kWh/d/}^{\circ}\text{C}$



New leakiness: $6 \text{ kWh/d/}^{\circ}\text{C}$

Increase coefficient of performance - use Heat pumps



<http://www.ecosystem-japan.com/>

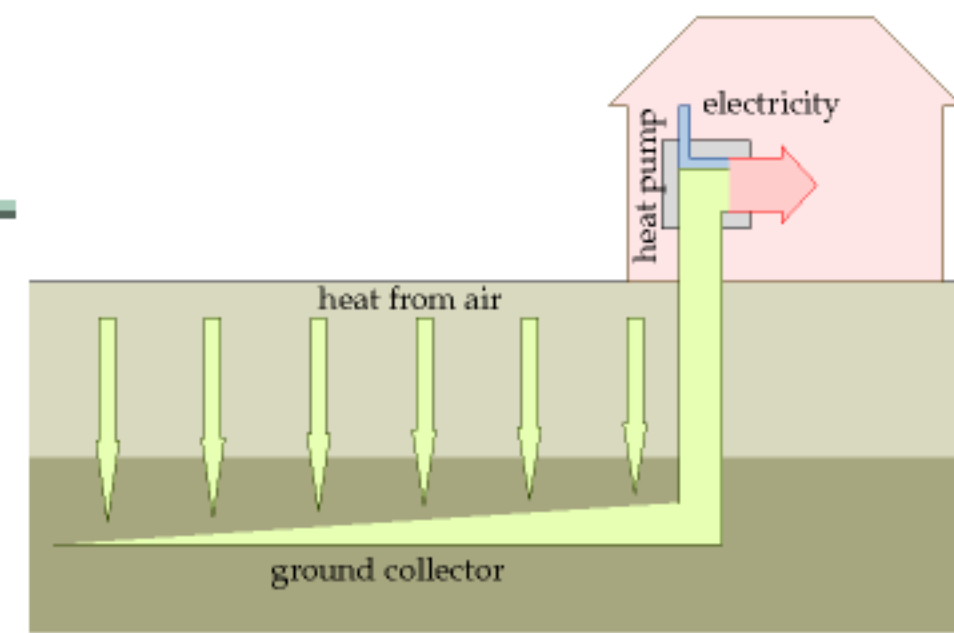
EcoCute water heater - CoP = 4.9!

$$\text{Power required} = \frac{\text{Heat loss}}{\text{Coefficient of performance of heat-creation}}$$

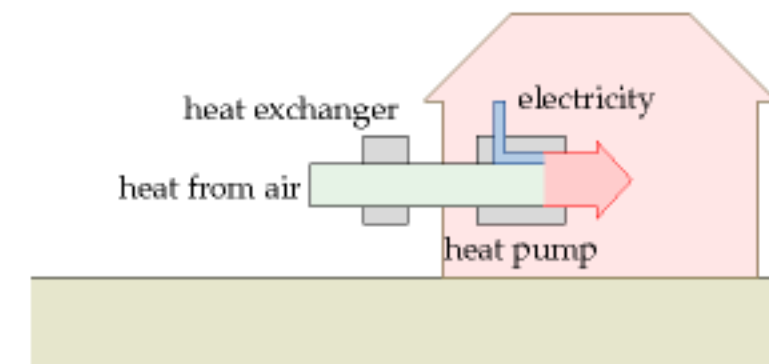
Heating without fossil fuels

- Heat pumps, powered by electricity

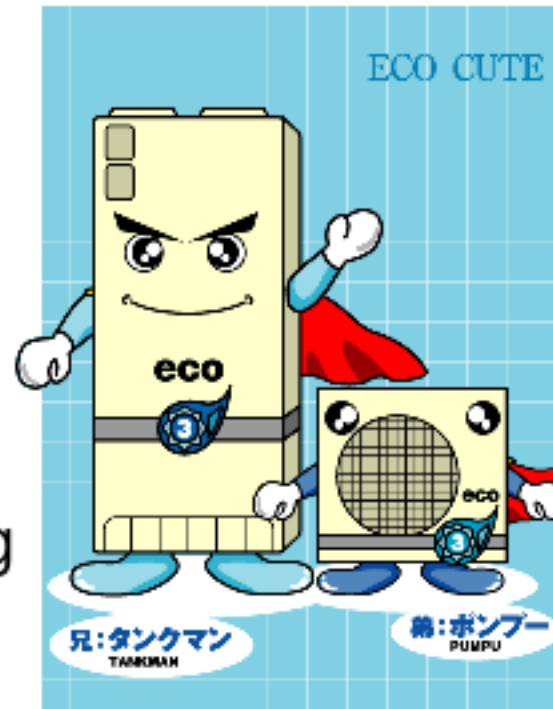
- Ground-source heat pumps



- Air-source heat pumps



4 times more efficient than ordinary electric heating



How to make an energy plan that adds up

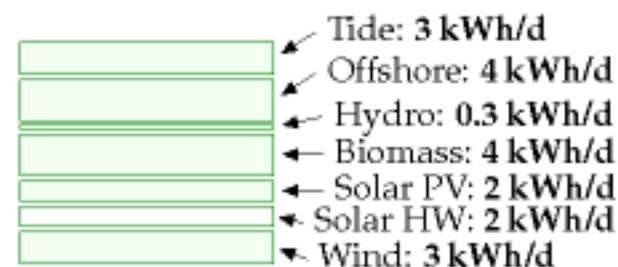
● Demand-side

- Reduce population
- Change lifestyle
- Technology, efficiency

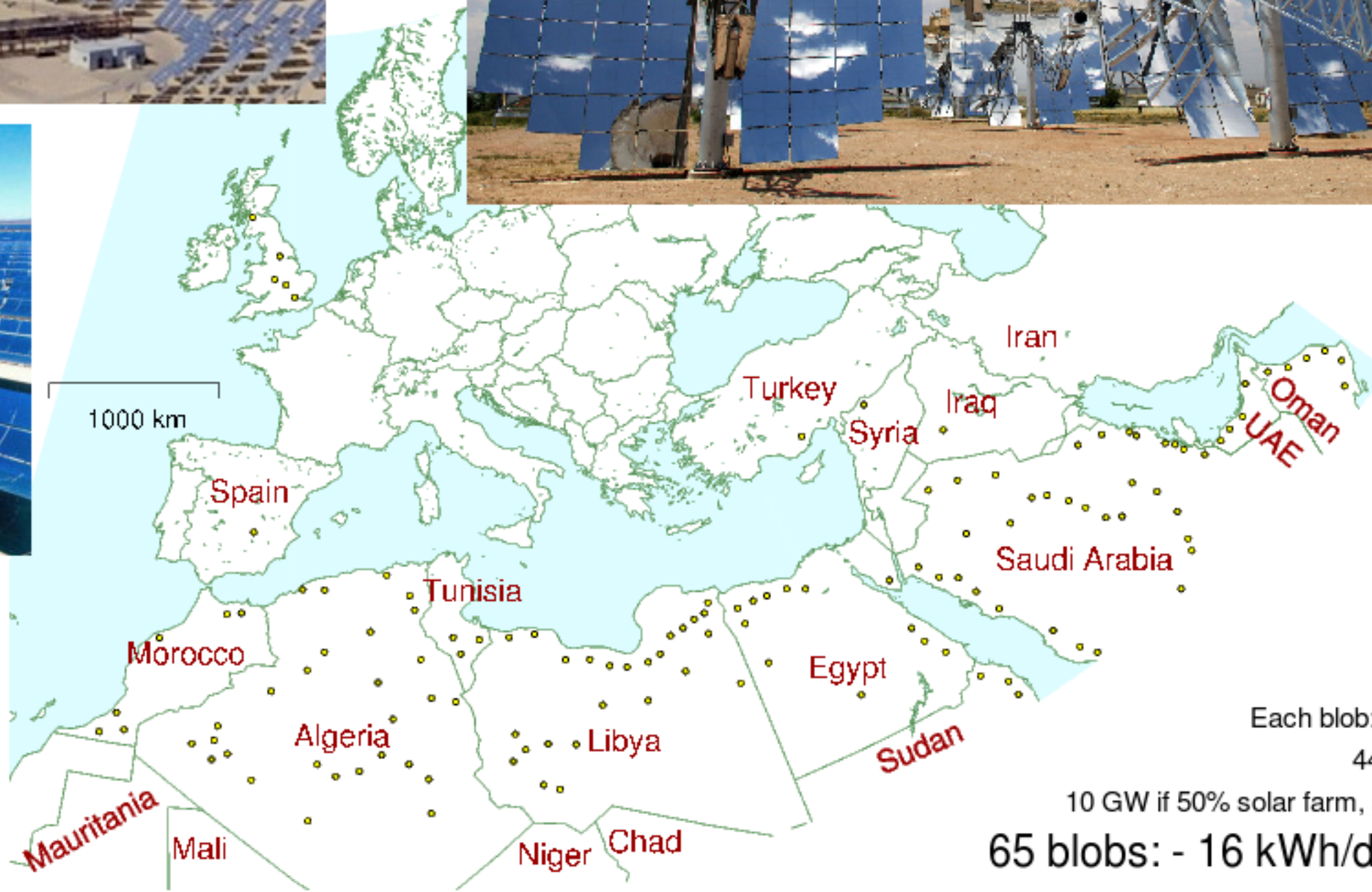
Current
consumption:
125 kWh/d
per person

● Supply-side

- 'Clean coal'
- Nuclear power
- Use other countries' renewables



International options



Each blob: 1500 sq km;
44km diameter;

10 GW if 50% solar farm, at 15 W/sq m.

65 blobs: - 16 kWh/d/p x 1Gp

How to get the UK off fossil fuels

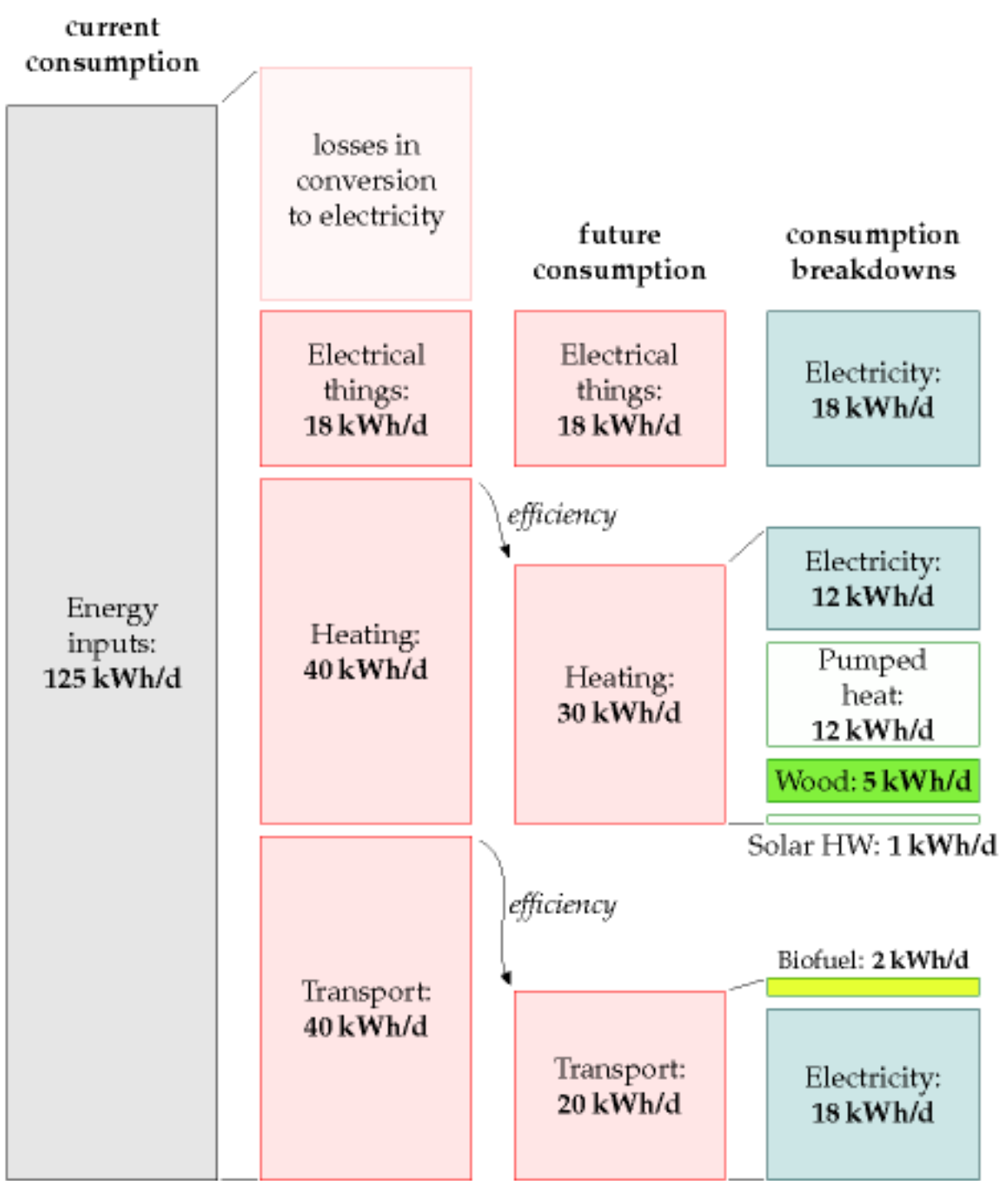
● Transport, Heating, Electricity

- Electrify all transport
- Insulate all buildings; read all meters
- Electrify all building-heating
 - ▶ air-source or ground-source heat pumps
 - ▶ (not combined heat and power)

- Our renewables
- Nuclear? (stop-gap?)
- 'Clean coal'? (stop-gap)
- Other people's renewables



One cartoon plan



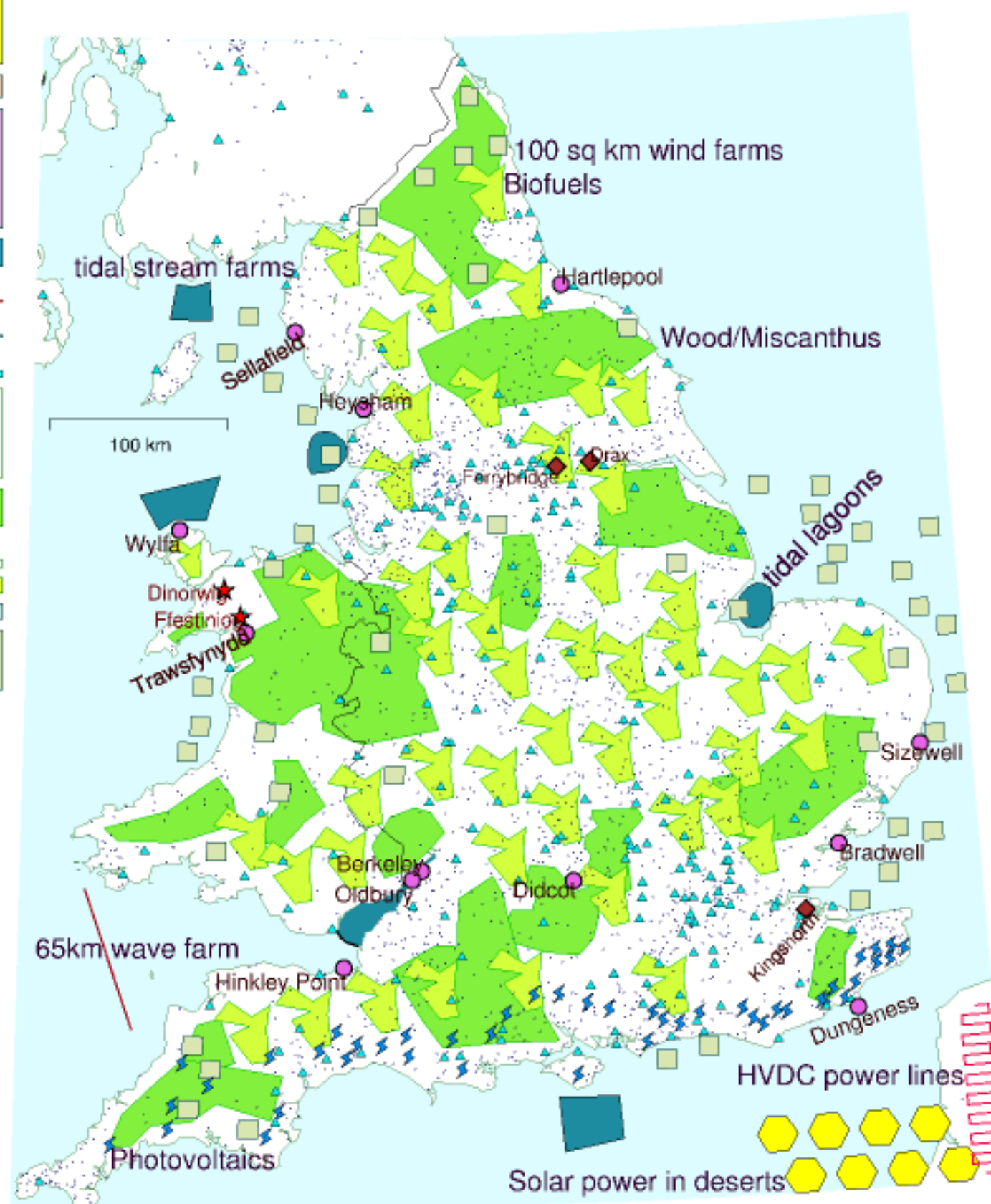
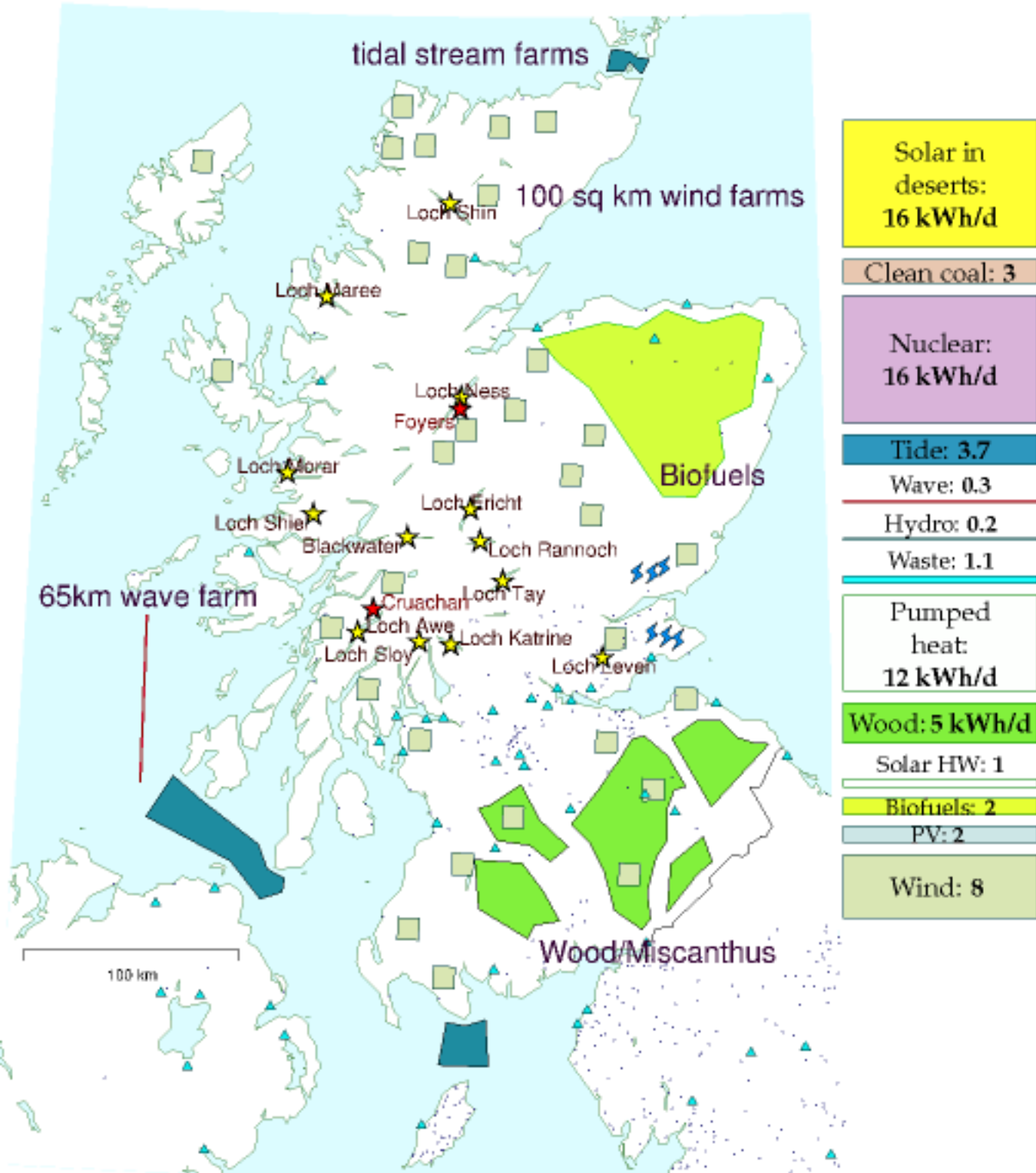
Key ideas

Insulation
Heat pumps

25% of UK
forests, willow, miscanthus
1 sq m per person HW

12% of UK for biofuels

Electric vehicles



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 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