Sustainable Energy
- without the hot air

David MacKay
Department of Physics
University of Cambridge

www.withouthotair.com
About me

Cambridge University Press
Also available free online

Dasher
Information-Efficient Text Entry

Transversal
Founded 1998

Sustainable Energy -
without the hot air

www.withouthotair.com
We have an addiction to fossil fuels, and it's not sustainable
Out of Gas

The End of the Age of Oil

With a New Postscript

Conventional Fossil Fuels

- Natural Gas (Laherrère, 2007)
- Coal (Energy Watch Group, 2007)
- Oil (TheOilDrum.com, 2006)

MToe/a

Actual
Forecast

1900 1920 1940 1960 1980 2000 2020 2040 2060 2080 2100
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 document — for the average temperature prevailing in 1750 before the industrial revolution, to affect the climate. But it points out that global average temperature has already risen by 0.6 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 490 parts per million by volume (ppmv) of CO₂.
'Security of supply'

Magnus platform - delivers 5GW; 71,000 tonnes of steel

Photo by  Terry Cavner
We have an addiction to fossil fuels, and it's not sustainable
Total GHG emissions (2000) = $34 \text{ GtCO}_2^{(e)}$
Total GHG emissions (2000) = 34 GtCO$_2$(e)

Data source: Climate Analysis Indicators Tool (CAIT)
Total GHG emissions (2000) = 34 GtCO$_2$(e)

Data source: Climate Analysis Indicators Tool (CAIT)
Cumulative emissions (average for 1880–2004) – CO₂ only

1880-2004
Something must be done!
Make a world of difference
Neutralise your CO2 emissions now

We all contribute to CO2 emissions when we drive. We can all do something about it. It’s simple and doesn’t cost the earth. On average, it’s just £20 a year.

Neutralise your CO2 emissions now

Discover more about targetneutral

Reducing CO2 emissions one car at a time
'Do your bit'!

Generating a sustainable future

Positive Energy

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

Let the power of nature into your home

Click here

98% of Powergen's electricity is fossil; just 2% renewables
'Industry have done their bit'

The car industry has done its bit by making greener vehicles. Now we have to buy them, says Sean O'Grady.

34 mpg
- 219 g/km

Practically perfect: the Volvo XC90
Carbon emissions from cars

- Polo (102 g/km)

Number of cars for sale:
- Toyota Prius (104 g/km)
- Honda Civic 1.4 (109 g/km)
- Audi A3 (143 g/km)
- Jeep Cherokee 2.8 (246 g/km)
- Honda NSX 3.2 (291 g/km)
- Audi A8 (338 g/km)
- Jeep Commander 5.7 V8 (368 g/km)
- Toyota Land Cruiser Amazon 4.7 (387 g/km)
- Ferrari F430 (420 g/km)
- Ferrari Superamerica (499 g/km)

Emissions (g CO2 per km):

- Engine power (kW):
- Top speed (km/h):

- Ferrari
- Porsche
- Kadett
- Panda
Efficiency through technology

'a highly fuel-efficient aircraft'

- it burns 12 percent less fuel per passenger-km than a 747
Carbon Trust on Micro-CHP
(combined heat and power) (cogeneration)

"Micro-CHP is an emerging set of technologies with the potential to provide carbon savings in both commercial and domestic environments."

Figure 50 Annual Micro-CHP and boiler emissions for cluster scenarios
Something must be done!
Two reasons to join GREENPEACE
Nuclear versus Wind

“if we’re going to cut greenhouse gases by 60% by 2050 there is no other possible way of doing that except through renewables”.

anybody who is relying upon renewables to fill the energy gap is living in an **utter dream world** and is, in my view, **an enemy of the people.**

‘We have a **huge** amount of wave and wind’.

‘Nuclear is a **money pit**’.

Michael Meacher
former Environment Minister

Sir Bernard Ingham
former civil servant, Chief Press Secretary, Head of the Government Information Service

Ann Leslie
journalist

We need **numbers, not adjectives**
Part I: Numbers, not adjectives
  Could Britain live on its own renewables?

Part II: Energy plans that add up
  Britain without carbon
Part I: Numbers, not adjectives

Ignore economic, social, + environmental constraints

Consumption
- Heating
- Manufacturing
- Transport

Production
[Maximum conceivable sustainable production]
- Tide
- Solar
- Wind
Choose good units

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

Energy unit: kWh

Power unit: kWh per day

Fluxes: 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
Cars

Energy used per day = \frac{\text{Distance travelled per day}}{\text{Distance per unit of fuel}} \times \text{Energy per unit of fuel}

= \frac{50 \text{ km/day}}{12 \text{ km/litre}} \times 10 \text{ kWh/litre}

\Rightarrow 40 \text{ kWh/day}.

33 miles per UK gallon

40 kWh is not an average figure for UK, but a plausible value for an ordinary car-lover.
Wind
Windspeeds Cambridge 2006 (m/s) Half-hourly and daily
\[ v = 6 \text{ m/s} \text{ (force 4)} \]

Wind farm \[ 2 \text{ W/m}^2 \text{ flat ground} \]

UK: 4000 m² per person

Put wind farms on 10% of the country

- 400 square metres each

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

50 x Denmark's

7 x Germany's

Car: 40 kWh/d

Wind: 20 kWh/d
Flight

7,600 miles: one round-trip / year:

$$\frac{2 \times 240,000 \text{ litre}}{416 \text{ passengers}} \times 10 \text{ kWh/litre/year}$$

$$= 29 \text{ kWh/day}$$
Solar

Solar thermal

Cover every south-facing roof

10 m² per person:
10 kWh/day per person

Jet flights: 30 kWh/d

Car: 40 kWh/d

Solar heating: 10 kWh/d

Wind: 20 kWh/d
Solar electric (photovoltaics)
Solar electric

Data and photo by Jonathan Kimmitt

Cover *every South-facing roof*,
10 m² per person: 4 kWh/day per person

Jet flights:
30 kWh/d

Car:
40 kWh/d

PV, 10 m²:
4 kWh/d

Solar heating:
10 kWh/d

Wind:
20 kWh/d
Solar PV farming

Bavaria Solar Park: \(5 \text{ W/m}^2\); this picture shows 0.7 MW (average)
Solar PV (covering 10% - an area bigger than Wales)

- Jet flights: 30 kWh/d
- Car: 40 kWh/d

PV farm (400 m²/p): 50 kWh/d
PV, 10 m²: 4 kWh/d
Solar heating: 10 kWh/d
Wind: 20 kWh/d
Solar biomass

Best plants (1% efficient)

- cover 75% of the country;
- 1/3 lost in processing.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Daily Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet flights</td>
<td>30 kWh/d</td>
</tr>
<tr>
<td>Car</td>
<td>40 kWh/d</td>
</tr>
<tr>
<td>PV farm</td>
<td>50 kWh/d</td>
</tr>
<tr>
<td>PV, 10 m²</td>
<td>4 kWh/d</td>
</tr>
<tr>
<td>Solar heating</td>
<td>10 kWh/d</td>
</tr>
<tr>
<td>Wind</td>
<td>20 kWh/d</td>
</tr>
</tbody>
</table>

Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d

Includes sustainable waste incineration, cellulosic ethanol, methanol.
# Heating and cooling

## Hot water
- Bath: 5 kWh
- Shower: 1 kWh
- Clothes wash: 4 kWh
- Cooking, kettle, microwave, dishes

<table>
<thead>
<tr>
<th>Hot water:</th>
<th>13</th>
</tr>
</thead>
</table>

## Hot air
- Car: 40 kWh/d

<table>
<thead>
<tr>
<th>Hot air:</th>
<th>24</th>
</tr>
</thead>
</table>

## Fridge, Airconditioning
- Cooling: 1

### Heating, cooling:
- 38 kWh/d

### Jet flights:
- 30 kWh/d

### Biomass: food, biofuel, wood, waste inciner', landfill gas:
- 24 kWh/d

### PV farm (400 m²/p):
- 50 kWh/d

### PV, 10 m²:
- 4

### Solar heating:
- 10 kWh/d

### Wind:
- 20 kWh/d
1.5 kWh/d per person

(currently 0.2 kWh/d per person)

- Heating, cooling: 38 kWh/d
- Jet flights: 30 kWh/d
- Car: 40 kWh/d
- Biomass: food, biofuel, wood, waste incin' n, landfill gas: 24 kWh/d
- PV farm (400 m²/p): 50 kWh/d
- PV, 10 m²: 4 kWh/d
- Solar heating: 10 kWh/d
- Wind: 20 kWh/d

Nant-y-Moch by Dave Newbould
www.origins-photography.co.uk
- 10 bulbs
- 5 hours per day

<table>
<thead>
<tr>
<th>Light: 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating, cooling: 38 kWh/d</td>
</tr>
<tr>
<td>Jet flights: 30 kWh/d</td>
</tr>
<tr>
<td>Car: 40 kWh/d</td>
</tr>
</tbody>
</table>

| Hydro: 1.5 |
| Biomass: food, biofuel, wood, waste incineration, landfill gas: 24 kWh/d |
| PV farm (400 m²/p): 50 kWh/d |
| PV, 10 m²: 4 |
| Solar heating: 10 kWh/d |
| Wind: 20 kWh/d |
Offshore wind

- Shallow offshore wind: 16 kWh/d
- Hydro: 1.5 kWh/d
- Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d
- Jet flights: 30 kWh/d
- Car: 40 kWh/d
- PV farm (400 m²/p): 50 kWh/d
- PV, 10 m²: 4 kWh/d
- Solar heating: 10 kWh/d
- Wind: 20 kWh/d

Depth less than 25m (yellow); depth between 25m and 50m (magenta).
Data from DTI Atlas of Renewable Marine Resources. Crown copyright.
(c) Elsam (elsam.com). Used with permission.
Deep offshore wind

- depth less than 25m (yellow)
- depth between 25m and 50m (magenta)

Data from DTI Atlas of Renewable Marine Resources. Crown copyright.
Deep offshore wind

depth less than 25m (yellow); depth between 25m and 50m (magenta).

Data from DTI Atlas of Renewable Marine Resources. Crown copyright.
# Deep offshore wind

<table>
<thead>
<tr>
<th>Source</th>
<th>Power (kWh/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep offshore wind</td>
<td>32</td>
</tr>
<tr>
<td>Shallow offshore wind</td>
<td>16</td>
</tr>
<tr>
<td>Hydro</td>
<td>1.5</td>
</tr>
<tr>
<td>Biomass: food, biofuel, wood,</td>
<td>24</td>
</tr>
<tr>
<td>waste incin’r, landfill gas</td>
<td></td>
</tr>
<tr>
<td>PV farm (400 m²/p)</td>
<td>50</td>
</tr>
<tr>
<td>PV, 10 m²: 4</td>
<td></td>
</tr>
<tr>
<td>Solar heating: 10 kWh/d</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>20</td>
</tr>
</tbody>
</table>

- Depth less than 25m (yellow): depth between 25m and 50m (n)
- Data from DTI Atlas of Renewable Marine Resources. Crow
Gadgets

- TV
- Computer
- Cable modem
- Mobile phones
- Bedside radio
- Other gadgets

Charger left plugged in: 0.01 kWh/d
Wave

D. Mollison: Wave climate and the wave power resource (1986)
Wave

Wave Dragon, images (c) Ea

Gadgets: 5
Light: 4
Heating, cooling: 38 kWh/d

Jet flights: 30 kWh/d

Car: 40 kWh/d

PV, 10 m²: 4
Solar heating: 10 kWh/d

Wind:

Deep offshore wind: 32 kWh/d
Shallow offshore wind: 16 kWh/d
Hydro: 1.5

Biomass: food, biofuel, wood, waste incin' n, landfill gas: 24 kWh/d

'500 kW' Limpet, Islay

Predicted average power: 200kW. Actual: 21kW

Total incident power / population of UK

\[
\frac{40\text{ kW/metre} \times 1000\text{ km}}{60 \times 10^6} = 16\text{ kWh/day}
\]
### Food'n'Farming

<table>
<thead>
<tr>
<th>Category</th>
<th>Energy Use (kWh/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer</td>
<td>3</td>
</tr>
<tr>
<td>Food</td>
<td>12</td>
</tr>
<tr>
<td>Gadgets</td>
<td>5</td>
</tr>
<tr>
<td>Light</td>
<td>4</td>
</tr>
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</tr>
<tr>
<td>Car</td>
<td>40 kWh/d</td>
</tr>
<tr>
<td>Wind</td>
<td>20 kWh/d</td>
</tr>
<tr>
<td>Wave: 4</td>
<td></td>
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<td>Biomass: food, biofuel, wood, waste incin' , landfill gas:</td>
<td>24 kWh/d</td>
</tr>
<tr>
<td>PV, 10 m² solar heating:</td>
<td>4 kWh/d</td>
</tr>
</tbody>
</table>

### Energy Use Breakdown

- **Vegans:** 3 kWh/d
- **Vegetarians:** 4 kWh/d
- **Carnivores:** 16 kWh/d

*(260 kg of animal preparing to be eaten)*

*(not including energy for food delivery)*
Tide - using tide pools

<table>
<thead>
<tr>
<th>Tidal range</th>
<th>Power per unit area</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 m</td>
<td>3 W/m²</td>
</tr>
</tbody>
</table>

[Diagram of sea and tidepool with a range shown]
Tide - using tide pools

Sea | Tidepool
---|---
range

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Atlantic ocean | North Sea

Map showing North Sea, Atlantic Ocean, Faeroes, Shetland, Orkney, and North Sea.
Total incoming power in 'tidal waves'

~300 kW per metre
Total: 250 GW
(100 kWh/d per person)

Cartwright et al (1980) Phil Trans R S Series A
Tidal stream power

1kWh/d/person
(DTI figure)
Tide

- Tide farms
- Tidal lagoons

Wave: 4
Dee off shore wind: 16 kWh/d
Hydro: 1.5
PV, 10 m²: 4
Solar heating: 10 kWh/d
PV farm (400 m²/p): 50 kWh/d
Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d
Jet flights: 30 kWh/d
Light: 4
Gadgets: 5
Food: 12
Fertilizer: 3
Tide: 14 kWh/d

and barrages
0.8 kWh/d per person

Cardiff
Bristol Channel
Bristol
Severn Estuary
Weston Super-Mare
Bridgwater
Barry

M4
M5

***Stuff***

- One new computer every 2 years
  - Chips: 4
  - Aluminium: 3

- 5 cans per day

- Stuff made in China: 12 kWh/d/p

- Transporting rubbish around
  - Road freight: 7
  - Supermarkets: 0.5 kWh/d
  - Shipping: 4
  - Transports stuff: 12
  - Stuff: 48+
  - Fertilizer: 3
  - Food: 12
  - Gadgets: 5
  - Light: 4

- Tide: 14 kWh/d
- Wave: 4
- Deep offshore wind: 32 kWh/d
- Shallow offshore wind: 16 kWh/d
- Hydro: 1.5
- Biomass: food

Photo by Ian Boyle
www.simplonpc.co.uk
Geothermal

Nesjavellir, Iceland
Geothermal

Transporting stuff: 12
Geothermal: 2
  Tide: 14 kWh/d
  Stuff: 48
  Wave: 4
  Food: 12
  Deep offshore wind: 32 kWh/d
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  Jet flights: 30 kWh/d
  PV farm (400 m²/p): 50 kWh/d

5 km

'Hot dry rock'

Lithosphere

Crust
Mantle

Temperature

5 C
40 km crust
500-600 C mantle
1400 C
100-200 km

Depth
Still to come on the red stack:
- industry,
- road building,
- 'defence',
- hospitals, ...

It would be very difficult to live on our own renewables
- at least, as we currently live

www.withouthotair.com
'The quality of life of the many thousands who pass Auchencorth every day by the A701 and A702 would be diminished.'
SAY NO TO WIND TURBINES IN BENINGTON

BENINGTON NEEDS YOU

BELVOIR LOCALS OPPOSE TURBINES

MAER HILLS PROTECT

HOOK MOOR WIND FARM ACTION GROUP

YMGYRCH CEFN CROES CAMPAIGN

B.A.C.K.W.A.R.D.

STOP LOCHLUICHART

‘a windfarm too far’
Save Our Scenery - Protecting Our Heritage Coastline

BEFORE

FROM LLANDUDNO PROMENADE

AFTER

FROM COLWYN BAY PROMENADE

saveourscenery.com
News

Giant Wind Farm Off English Coast Pits Town Against Shell, E.ON

Gravestey was the site of the last battle on English soil when British forces battled a downed German bomber crew in 1940. Now the village is fighting a new enemy: the world's biggest wind farm. The local council, acting on behalf of the town's 473 residents, refused to permit a substation for the $1.5 billion London Array, which would put 271 wind turbines in the estuary of the River Thames. Royal Dutch Shell Plc and E.ON AG plan to bring power cables ashore near Gravestey. "They say this is the only place they could put it — that's rubbish," said retiree George Schneider, 73, strolling on Saxon Shore Way, a rambling route across the coastal plain. "Why use a green-field site when there are other places?"

News

Wind farm 'a threat to our airport'

Southend Airport has raised serious objections to plans to build a new wind farm - even though the turbines would be nearly 15 miles to the north. Experts say the wind farm next to the defunct nuclear power station, at BilliEb air traffic control issues and might even interfere with radar. Airport manager Alistair Welch raised the concerns at a public inquiry which is being held.

June 22, 2007 in Echo

Southend Airport has raised serious objections to plans to build a new wind farm - even though the turbines would be nearly 15 miles to the north.
Protesters target wind farm plans

Local people opposing plans to build one of the UK's biggest offshore wind farms on the south Wales coast met on Friday. Residents in Porthcawl and Cefn Croes, near Bridgend, are preparing to highlight their opposition to the proposed 30-turbine wind farm at Porthcawl, which has been opposed by local groups for more than a decade. SOS Porthcawl was set up by campaigners in the town who say the wind farm will adversely affect the holiday resort, which attracts surfers and tourists from all over the UK. The demonstration coincides with a public consultation into the project by developers United Utilities Green Energy.

Four-times British surf champion, Simon Tucker said the town was a lot of feeling against the proposals within the town. "This demonstration is to ask the developers not to destroy the very environment they claim they are trying to protect," he said. Mr Tucker said the turbines, which are taller than the Statue of Liberty in New York, will destroy the panoramic views and also have an impact on the sea. "The turbines will change the shape of the sandbanks and the waves," he said. "If the waves are changed and people can't surf, it will be a disaster for the sport because of the turbines then the town is going to be destroyed.

SOS Porthcawl say the developers have a £110 million (€145 million) project to set up offshore wind turbines 8miles off the coast to supply electricity to 80,000 households.

Fishermen oppose wind farm plans

Hundreds of fishermen gathered in the Wash to protest against plans to build offshore wind turbines.

The men from Boston, Skegness and King's Lynn are unhappy at government proposals to erect 250 wind turbines in the Greater Wash.

If it goes ahead, the facility would be part of one of the largest wind farms in the world.

Planning permission has already been granted for 60 turbines on two sites off the south Lincolnshire coast.

Project 'impractical'

Andy Roper, who organised the protest, emphasised the fishermen's livelihoods are being threatened.
Winds of change will mean giant sea turbines

By Anthony Browne, Environment Editor

DOZENS of wind farms, each with hundreds of turbines up to 500ft high, are to be given the go-ahead off the coast between Scotland and Wales, around the Wash in East Anglia and in the Thames Estuary.

Yesterday's announcement was welcomed by some environmental groups; others have given warning that it will ruin views and damage sea life. Fishermen have said that they will be forced out of business.

Brian Wilson, the Energy Minister, said: "In theory, these areas could source enough electricity to power the whole of Britain, albeit intermittently. There is no doubt

Wind power 'a security risk'

02 November 2007 08:15

Defence chiefs threw the future of East Anglia's wind energy industry into confusion last night after claiming that wind turbines could be a threat to national security.

Experts say the MoD now objects to about 50pc of applications to build onshore wind turbines because of concerns they affect performance of military radar.
Transporting stuff: 12

Geothermal: 2
- Tide: 14 kWh/d
  - too expensive!
- Deep offshore wind: 32 kWh/d
  - not near my radar!
- Shallow offshore wind: 16 kWh/d
  - not near my birds!
- Biomass: food, biofuel, wood, waste, pein', landfill gas: 24 kWh/d
  - not in my valley!
- PV farm (400 kg^2/p): 50 kWh/d
  - too expensive!
- PV: 16 kWh/d
  - too expensive!
- Solar heating: 10 kWh/d
  - not on my street!
- Wind: 20 kWh/d
  - not in my back yard!

Stuff: 48+

Fertilizer: 3

Food: 12

Gadgets: 5

Light: 4

Heating, cooling: 38 kWh/d

Jet flights: 30 kWh/d

Car: 40 kWh/d
Transporting stuff: 12

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Solar heating: 10 kWh/d

Wind: 20 kWh/d

too immature!

too expensive!

not near my radar!

not near my birds!

not in my valley!

not in my countryside!

too expensive!

too expensive!

not on my street!

not in my back yard!
<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>0.3</td>
</tr>
<tr>
<td>Solar PV</td>
<td>3</td>
</tr>
<tr>
<td>Biomass</td>
<td>4</td>
</tr>
<tr>
<td>Offshore</td>
<td></td>
</tr>
<tr>
<td>Tide</td>
<td>3</td>
</tr>
<tr>
<td>Wind</td>
<td>3</td>
</tr>
</tbody>
</table>

Current consumption: 125 kWh/d per person
Average Power consumption, UK: 125 kWh/d/p

Electricity 18\%\%  
Other solid fuels 1\%\%  
Gas 35\%  
Petroleum 43\%\%  

2004

Industry 21\%  
Domestic 30\%\%  
Transport 35\%\%  
Other final users 13\%  

Transport 35\%

Hot air 26\%

Hot water 8\%
Lighting, appliances 6\%
Process 10\%
Other 15\%

'primary consumption'
125 kWh/day (Europe)
300 kWh/day (USA)

(doesn't include imports, nor solar energy in food)

For CO$_2$ pollution, divide by 10: 100 kWh/day $\sim$ 10 tonnes CO$_2$/yr

www.dti.gov.uk
We can't live on our own renewables - at least, not as we currently live.

To make a difference, renewables have to be country-sized.
### Power per unit land area

<table>
<thead>
<tr>
<th>Source</th>
<th>Power Density (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>2</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>3</td>
</tr>
<tr>
<td>Tidal pools</td>
<td>3</td>
</tr>
<tr>
<td>Tidal stream</td>
<td>8</td>
</tr>
<tr>
<td>Solar PV panels</td>
<td>5</td>
</tr>
<tr>
<td>Plants</td>
<td>0.5</td>
</tr>
<tr>
<td>Solar chimney (Spain)</td>
<td>0.1</td>
</tr>
<tr>
<td>Concentrating solar power (desert)</td>
<td>15</td>
</tr>
<tr>
<td>Ocean thermal</td>
<td>5</td>
</tr>
<tr>
<td>Rain-water (Scotland)</td>
<td>0.24</td>
</tr>
<tr>
<td>Rain-water (England)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

To make a difference, renewable facilities have to be country-sized.
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
How to make an energy plan that adds up

Demand-side
- Reduce population
- Change lifestyle
- Technology, efficiency

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

Current consumption: 125 kWh/d per person

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tide</td>
<td>3</td>
</tr>
<tr>
<td>Offshore</td>
<td>4</td>
</tr>
<tr>
<td>Biomass</td>
<td>4</td>
</tr>
<tr>
<td>Solar PV</td>
<td>3</td>
</tr>
<tr>
<td>Wind</td>
<td>3</td>
</tr>
</tbody>
</table>
Efficiency and technology

Jevons' paradox

"as technological improvements increase the efficiency with which a resource is used, total consumption of that resource may increase, rather than decrease."

For example, from 1900 to 2000, passenger transportation in the USA became 5 times more energy-efficient; but nowadays, the average person travels 50 times further.
How to make an energy plan that adds up

**Demand-side**
- Reduce population
- Change lifestyle
- Technology, efficiency

**Supply-side**
- 'Clean coal'
- Nuclear power
- Use other countries' renewables

Current consumption: 125 kWh/d per person

- Hydro: 0.3
- Tide: 3
- Offshore: 4
- Biomass: 4
- Solar PV: 3
- Wind: 3
1600 Gt of coal / 6 billion people \( \times \) 1000 years \( \times \) 8000 kWh per tonne = 6 kWh per day per person

**Carbon capture and storage**
- requires **25%** of the generated energy
- doubles the cost of building a 1GW power station

Coal: 6 kWh/d
Nuclear Fission ('sustainable' = 1000 years)

Uranium

- Once-through
  - Mined Uranium: \(0.1 \text{ kWh/d}\)
  - Fast breeder: \(5 \text{ kWh/d}\)

- Ocean Uranium: \(7 \text{ kWh/d}\)

- River Uranium: \(0.08 \text{ kWh/d}\)

Thorium

- Conventional reactor
  - Mined Thorium: \(4 \text{ kWh/d}\)

- 'Energy amplifier': \(60 \text{ kWh/d}\)

- 420 kWh/d
Nuclear Fusion

- Not a sure thing - a gamble

- DT reaction
  - requires Lithium and Deuterium

- DD reaction
  - requires Deuterium

Lithium fusion: 110 kWh/d
DD reaction

D lasts ~ 1 billion years
How to make an energy plan that adds up

- **Demand-side**
  - Reduce population
  - Change lifestyle
  - Technology, efficiency

- **Supply-side**
  - 'Clean coal'
  - Nuclear power
  - Use other countries' renewables

Current consumption: 125 kWh/d per person

<table>
<thead>
<tr>
<th>Source</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tide</td>
<td>3</td>
</tr>
<tr>
<td>Offshore</td>
<td>4</td>
</tr>
<tr>
<td>Biomass</td>
<td>4</td>
</tr>
<tr>
<td>Solar PV</td>
<td>3</td>
</tr>
<tr>
<td>Wind</td>
<td>3</td>
</tr>
<tr>
<td>Hydro</td>
<td>0.3</td>
</tr>
</tbody>
</table>
International options

Each blob: 1500 sq km; 44km diameter; 10 GW if 30% solar farm, at 20 W/sq m.

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

10 W/m²

(c) FLAGSOL

Photo: ABB

Kramer Junction
Yellow: 125 kWh/d/p for 1 billion people; Red: 125 kWh/d/p for 60 million people
Yellow: 125 kWh/d/p for 1 billion people
- or 250 kWh/d/p for 0.5 billion people
How to make an energy plan that adds up

Demand-side
- Reduce population
- Change lifestyle
- Technology, efficiency

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

Current consumption: 125 kWh/d per person

Hydro: 0.3
Tide: 3
Offshore: 4
Biomass: 4
Solar PV: 3
Wind: 3
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
What society must do

- A plan that adds up
- Carbon tax
  - upstream, stable
- Carbon capture at all coal power stations

What individuals can do

- Read meters
- Say yes to plans that add up
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...'
What should carbon cost?

- $1000: Impact on UK car-driving
- $900: Impact on UK car-driving
- $700: Impact on air travel
- $550: Sequestration by forest in U.K.
- $500: Some impact on European lifestyle
- $400: Impact on USA car-driving
- $370: Impact on price of domestic electricity from gas
- $185: Impact on price of domestic electricity from coal
- $150: Impact on domestic heating
- $130: Sequestration from thin air theoretically possible
- $110: Impact on large-scale power-generation from renewables

Cost of 60% CO₂ reduction, 2050 ($100–150)

Stern review social cost ($85)

CO₂ sequestration at old coal power stations ($45–73)

CO₂ sequestration at gas power stations ($37–74)

CO₂ sequestration at new coal power stations ($29–51)

CO₂ pre-sequestration at IGCC coal power stations ($13–37)

$18: Price charged by c-change trust

$14: Price charged by climatecare.org

$7.5: Price charged by targetneutral
A Mitsubishi Warrior, yesterday
The current situation in Cartoon-Britain

(ignoring embodied energy in imported stuff)
Efficiency

- Improving transport efficiency
- Improving heating efficiency
Magnetic levitation

The Transrapid Superspeed Maglev System is unrivaled when it comes to noise emission, energy consumption, and land use. The innovative non-contact transportation system provides mobility without the environment falling by the wayside.

<table>
<thead>
<tr>
<th>Fast trains compared at 200 km/h (125mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
</tr>
<tr>
<td>Transrapid</td>
</tr>
</tbody>
</table>
Biofuel

'Brown Takes Ride On Green Train'

'Buyers of Jeep's newest full-sized sport utility vehicle will hit the road with a tankful of a diesel fuel blend made from soybean oil, fast-food grease or vegetable oil.'

'Green fuel to power G8 Summit vehicles'

B5 is 5% biodiesel and 95% fossil fuel

"And the funniest thing is - it's only 20% biodiesel!"
Hydrogen

Clean Urban Transport for Europe

hydrogen made from fossil fuels:

overall primary energy consumption by the hydrogen buses was between 80% and 200% greater than that of the baseline diesel bus.

GHG emissions were between 40% and 140% greater.
"Baby on board"

80 kWh per 100 person-km (1 person)
or 24 kWh per 100 person-km (3 people)

How can this consumption be reduced?

1 kWh per 100 person-km (3 people)

6 kWh per 100 person-km average
3 kWh per 100 person-km if full
1.3 kWh per 100 person-km (takes 1 teenager)
[2200 mpg]
at 15 mph

http://www.teamcrocodile.com/
Electric cars

G-Wiz

- 13 kWh per 100 km (solo)
  - equivalent to 220 miles per gallon
  - or 90 miles per gallon
  - (depending whether we say 1 kWh(e) = 2.5 kWh)

6 kWh per 100 km
Electric scooters

3 kWh per 100 km

http://www.vectrix.com/
Heat loss = Leakiness × Average temperature difference
(kWh/d)  (kWh/d/°C)  (°C)
Turn the thermostat down

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

Temperature demand, in degree-days per year

Leakiness: 8 kWh/d/°C

91 degree-days of cooling

3188 degree-days of heating

2265 degree-days of heating

1748 degree-days of heating

Average temperature difference

heating

cooling
Reduce leakiness

New leakiness: 6 kWh/d/°C
Read your meters!

**Gas**

[Graph showing gas usage with dates and numbers indicating usage in kWh/day, with annotations for condensing boiler installed and lower thermostat, more insulation, more glazing.]

**Electricity**

[Graph showing electricity usage with dates and numbers indicating usage in kWh/day.]
Read your meters!

Gas

Condensing boiler installed
Lower thermostat
More insulation
More glazing

Electricity

Electricity used (1000 kWh)

2003
50 kWh/d

2004
35 kWh/d

2005
32 kWh/d

2006
26 kWh/d

2007
13 kWh/d

2008
3 kWh/d
Heat pumps, powered by electricity

- Ground-source heat pumps

- Air-source heat pumps

4 times better than ordinary electric heating
Efficiency in the offing

Electricity

25W (0.6kWh/d)

vacuum cleaning

night

vampires off

workmen around today

70W (1.7kWh/d)

modem, wireless, and stereo on

lights, washing machine

sunday

night

monday

night

wednesday

night

thursday

night

friday
Energy inputs: 125 kWh/d

Current consumption

- Electrical things: 18 kWh/d
- Heating: 40 kWh/d
- Transport: 40 kWh/d
Five plans for Cartoon-Britain

Key ideas

- Insulation
- Heat pumps

25% of UK forests, willow, miscanthus

1 sq m per person HW

12% of UK for biofuels

Electric vehicles

50 kWh/d is 125 GW
Plan D: 'Diversity'

- Clean coal: 16 kWh/d
- Nuclear: 16 kWh/d
- Tide: 3.7
- Wave: 2
- Hydro: 0.2
- Waste: 1.1

- Pumped heat: 12
- Wood: 5
- Solar HW: 1
- Biofuels: 2
- PV: 3
- Wind: 8

40GW; triple coal imports

40GW - four-fold increase

7500 pelamis, 500km of coastline

call municipal waste incinerated, and equal agri. waste

7 sq m / p

almost all the world's windmills ('60GW')
on 2% of country and equal area offshore
Plan N: 'NIMBY'

- Solar in deserts: 20 kWh/d
- Clean coal: 16 kWh/d
- Nuclear: 10 kWh/d

- Tide: 1
- Hydro: 0.2
- Waste: 1.1

- Pumped heat: 12
- Wood: 5
- Solar HW: 1
- Biofuels: 2
- Wind: 2

- Upgrade all current sites
- All municipal waste incinerated, and equal agri. waste
- 8-fold increase in wind ('15GW')
Plan L: 'Libdem'

40GW; triple coal imports

Solar in deserts: 16 kWh/d
Clean coal: 16 kWh/d
Tide: 3.7
Wave: 2
Hydro: 0.2
Waste: 1.1
Pumped heat: 12
Wood: 5
Solar HW: 1
Biofuels: 2
PV: 3
Wind: 8

No nuclear

7500 pelamis, 500km of coastline
all municipal waste incinerated, and equal agri. waste

7 sq m / p

almost all the world's windmills ("60GW")
on 2% of country and equal area offshore
Plan G: 'Green'

No coal

- Solar in deserts: 7
- Tide: 3.7
- Wave: 3
- Hydro: 0.2
- Waste: 1.1
- Pumped heat: 12
- Wood: 5
- Solar HW: 1
- Biofuels: 2
- PV: 3

No nuclear

- 11,000 pelamis, 750km of coastline
- All municipal waste incinerated, and equal agri. waste

Pumped storage
- 400 Dinorwigs

- Loch Shin
- Loch Maree
- Loch Morar
- Loch Shiel
- Loch Awe
- Loch Sloy
- Loch Ness
- Loch Erich
- Loch Rannoch
- Loch Tay
- Loch Katrine
- Loch Leven

Wind: 32

3 x all the world's windmills ('240GW') on 8% of country & equal area offshore
Plan E: 'Economist'

- No coal - CCS more expensive than nuclear

- Nuclear: 44 kWh/d

- Tide: 0.7
- Hydro: 0.2
- Waste: 1.1
- Pumped heat: 12
- Wood: 5
- Solar HW: 1
- Biofuels: 2
- Wind: 4

- 110GW - twice France's nuclear

- All municipal waste incinerated, and equal agri. waste

- Tidal lagoons (providing storage too)

- Half the world's windmills (30GW) on 1% of country and equal area offshore

- 10-fold increase in uranium
- 15-fold increase in wind
Five plans for Cartoon-Britain

Diversity  NIMBY  Libdem  Green  Economist
What can you do?

- Identify things that might make 1% difference (or more)
  - buildings
  - transport
- Inform politicians
  - how to add 2+2

What Would Jesus Drive?
www.WhatWouldJesusDrive.org

UK government budget: defence = 7%
10% of all industrial energy since 1940 went into making nuclear weapons
'diversity of supply'?
What can you do?

- Legislation
  - Promotion of consumption bill
  - Glorification of travel act
  - Carbon tax to replace VAT

\[2 + 2 \neq 120\]
Carbon - where is it?

Gigatonnes Carbon

- Surface waters
- Atmosphere: 600
- Vegetation: 700
- Soils: 3000
- Accessible fossil fuels: 1600
- Ocean: 40,000
Carbon - where is it going?  How to fix climate change

(A big simplification!)
(And this doesn't prevent ocean acidification)
When does it go away?
Socolow's model of CO2 emissions

Baer & Mastrandrea: Socolow's trajectory not good enough
Good books

AVOIDING DANGEROUS CLIMATE CHANGE
EDITED BY Hans Joachim Schellnhuber, Wolfgang Cramer, Nebojsa Nakicenovic, Tom Wigley and Gary Yohe

THE SCIENCE AND POLITICS OF GLOBAL CLIMATE CHANGE
A Guide to the Debate
ANDREW E. DESSLER
EDWARD A. PARSON
Carry on burning

- Sequestration
  
  (This is NOT sustainable!)

- Sequestration from thin air costs a lot of energy
  - almost as much as you get from burning the fossil

- Sequestration at the power station (costs 25%)

- Sequestration by trees...
"We plant a tree every time we fly!"
Sequestration with trees

- You pay them money
- They ‘plant trees which absorb your CO2 contribution’

What happens to the trees?

Managed forest produces

2.5 m³ of dry wood per hectare per year, i.e., 0.05 kg of Carbon per m² per year. So to balance pollution associated with 100 kWh per day, need

50 000 m² of forest

and a permanent storage place to put

12 m³ of dry wood per year.

[UK’s area is 4 000 m² per person.]

The company has a 10 acre plot. That is only 40,000 m².
Alternative model
- take barren land and produce forest on it

Mature forest contains

25 kg/m² of ‘standing phytomass’, i.e., 5 kg of Carbon per m². To balance pollution associated with 100 kWh per day, need

100 m² of new forest created per year.

[UK’s area is 4000 m² per person.]

The company has a 10 acre plot. That is only 40,000 m². So they can service 400 customers for one year in their 10 acres.
Sequestration cost per molecule (from thin air)

0.03% CO$_2$ $\longrightarrow$ Pure CO$_2$ $\longrightarrow$ Liquid CO$_2$

Ideal concentration machine

\[ kT \ln \frac{V_0}{V_1} = kT \ln 3000 = 8 \, kT \]

Ideal liquefaction machine

\[ kT \ln \frac{V_1}{V_2} = kT \ln 1000 = 7 \, kT \]

Total

\[ 15 \, kT \text{ per molecule} \]
**Ideal sequestration cost**

\[ 15kT \text{ per molecule} \]

is 0.24 kWh per kg of CO\(_2\).

Compare with energy created when emitting CO\(_2\):

\[ \frac{1}{3} \text{ kg of petrol} \rightarrow 4 \text{ kWh} + 1 \text{ kg CO}_2. \]

What’s efficiency of generator and compressor?

---

**Realistic sequestration cost**

**Production:**

1 kg of CO\(_2\) \leftrightarrow 4 kWh heat \leftrightarrow 1.3 kWh useful energy

\[ /3 \]

**Sequestration:**

1 kg of CO\(_2\) \leftrightarrow 0.24 kWh ideal cost \leftrightarrow 0.7 kWh actual cost

\[ \times 3 \]
What impact does your flight have on climate change?
Every flight you take has an impact on climate change that arises from the carbon dioxide (CO2) from burning kerosene and other effects in the upper atmosphere. British Airways supports a long-term approach to tackling this impact...

You can take responsibility for the impact of your flight
British Airways has joined forces with an organisation called Climate Care to enable you to offset the CO2 emissions created during your flight.

You can click on the calculator button to calculate your share of the emissions created during your journey and the cost of neutralising the impact of those emissions. If you decide to pay this cost, the money raised will be used by Climate Care to fund sustainable energy projects around the world on your behalf.
CO₂ Emissions calculator

From

UK London Heathrow
UK London Luton
UK Londonderry
UK Manchester
UK Newcastle
UK Southampton

To

UZBEKISTAN T'kent
VIETNAM Hanoi
ZAMBIA Livingstone
ZAMBIA Lusaka
ZIMBABWE Harare
ZIMBABWE Vic. Falls

Number of passengers: 1

Return ☑ One Way ☐

Calculate my emissions

Emissions for this flight: 1.83 Tonnes CO₂  Cost: £11.91

Add another flight

Make payment

Clicking this button will take you to WorldPay's Secure Payment Server.

Note: You can pay in £Sterling, US$ or €
There is a minimum offset of £5.00
Climate Care

When you fly, drive or heat your home, your CO₂ emissions add to global warming.

Climate Care lets you offset these emissions by funding sustainable energy and reforestation projects.

"Offsetting"

If the true cost of “neutralizing” 2 tonnes of CO₂ is £13, then our 125 kWh/day can be “neutralized” for £50/year.

which is roughly 1.5% of the 3500 per year we spend on the energy
75% of your donation will be spent on trees, land and education.
Reducing CO2 emissions

“I feel bad that using my car contributes to climate change, but now I’ve found there’s a way we can all start to redress the balance”

- Become a CO2 neutral driver at targetneutral.com

By logging on to www.targetneutral.com, drivers can calculate how much CO2 their car emits, find out how to reduce that figure and also learn more about global projects to minimise CO2. It is easy to participate, and involves a cash contribution to the programme, usually around Â£20 per year, depending on your vehicle, gas mileage and fuel consumption.

...through the scheme, all of BP's UK fuel tankers will now be CO2 neutral.

Targetneutral gives drivers an easy, affordable way to play their part in balancing the equation.
Make a world of difference
Neutralise your CO2 emissions now

We all contribute to CO2 emissions when we drive. We can all do something about it. It’s simple and doesn’t cost the earth. On average, it’s just £20 a year.

Neutralise your CO2 emissions now

Discover more about targetneutral
Karnataka, India
A wind turbine was installed at Chitradurga, Karnataka State in September, 2005. The power generated by the turbine provides renewable power to the state electricity grid that would otherwise have been generated from fossil fuel.

This renewable energy reduces CO2 emissions by 1,260 tonnes every year. That's enough to neutralise the emissions of 315 cars in the UK each year.

All your funds (excluding VAT and card transaction charges) are invested in projects that prevent or remove an equivalent amount of emissions (that you produce from driving) from the atmosphere.

This is a non-profit initiative by BP in partnership with scheme members and NGOs. Currently, for the projects we've chosen, one tonne of CO2 can be neutralised for 6 EURO. However, projects do vary in price depending on the type of project and running costs.

At this rate, UK emissions = 40 pounds each; 2.4 billion pounds - c.f. 552 billion pounds. Govt. budget 2006.
In our operations since 2001 we have been aiming to offset, through energy efficiency projects, half of the underlying Greenhouse gas emission increases that result from our growing business.

www.bp.com
What’s the best way to suck CO₂ from thin air?

Energy cost ≥ 700 kWh per tonne
Scientists Would Turn Greenhouse Gas Into Gasoline

By KENNETH CHANG
Published: February 19, 2008

Two scientists are introducing a concept, which they have patriotically named Green Freedom, for removing carbon dioxide from the air and turning it back into gasoline.
Gasoline from thin air

Energy cost is dominated by the cost of reversing the reaction
\[
\frac{1}{3} \text{ kg of petrol} \rightarrow 4 \text{kWh} + 1 \text{ kg CO}_2.
\]

Realistically

**Production:**
1 kg of CO\(_2\) \leftrightarrow 4 kWh heat \leftrightarrow 1.3 kWh useful energy

**Reversal:**
1 kg of CO\(_2\) \leftrightarrow 4 kWh ideal cost \leftrightarrow 12 kWh actual cost

\[\times 3\]

At 5p per kWh, that costs £600 per ton of CO\(_2\).

Under these assumptions, every litre of gasoline (10 kWh) would cost 30 kWh of nuclear.
Carbon tax
Lifestyle change?

Welcome to a Great Time!!
Changing energy consumption
"A reduction in growth is not an acceptable path to a lower-carbon world."

"the truth is no country is going to cut its growth or consumption substantially in light of a long-term environmental problem"
Combined heat and power?

'Microgeneration', 'Decentralization'
Can we do better than Combined Heat and Power?  
- Heat pumps
Can we do better than Combined Heat and Power?

- Heat pumps
FTXS25E

A DAIKIN Split System will air condition one room or an area of your home. Discreet wall-mounted models, compact floor consoles and versatile floor and ceiling units are all part of the DAIKIN range.

Create perfect conditions all year round with DAIKIN reverse cycle split system air conditioners.

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
<td></td>
</tr>
<tr>
<td>Indoor Unit</td>
<td>FTXS25EVMA</td>
</tr>
<tr>
<td>Outdoor Unit</td>
<td>RXS25EAVMA</td>
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<tr>
<td><strong>Rated Capacity</strong></td>
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<tr>
<td>Cool (kW)</td>
<td>2.5</td>
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<tr>
<td>Heat (kW)</td>
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<td><strong>Capacity Range</strong></td>
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<tr>
<td>Cool (kW)</td>
<td>1.2-3.0</td>
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<tr>
<td>Heat (kW)</td>
<td>1.2-4.5</td>
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<tr>
<td><strong>Indoor Air Flow</strong></td>
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<td>Cool (l/s)</td>
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<tr>
<td>Heat (l/s)</td>
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<tr>
<td><strong>Indoor Fan Speeds</strong></td>
<td></td>
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<td></td>
<td>5 steps, quiet and automatic</td>
</tr>
<tr>
<td><strong>C.O.P</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.17/4.10</td>
</tr>
<tr>
<td><strong>Front Panel Colour</strong></td>
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</tr>
<tr>
<td></td>
<td>White</td>
</tr>
<tr>
<td><strong>Power Supply</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 phase, 220-240V, 50Hz</td>
</tr>
</tbody>
</table>
Heat pumps

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

EcoCute water heater - CoP = 4.9!
Executive summary

Micro-CHP is an emerging set of technologies with the potential to provide carbon savings in both commercial and domestic environments. Combined Heat and Power (CHP) systems provide potential reductions in carbon emissions and costs by generating both heat and electricity locally with efficient use of fuel and by offsetting the use of centrally-generated electricity from the grid.

Range of carbon savings expected for domestic and commercial Micro-CHP (relative to a typical A-rated condensing system boiler and based on carbon emissions factor of 0.568kgCO₂/kWh for displaced electricity)
Figure 50 Annual Micro-CHP and boiler emissions for cluster scenarios

Clear savings evident

- Domestic Micro-CHP
- Domestic boiler

Annual emissions (kgCO₂)

- New build
- 1920-2005
- Pre 1920
- Up to 90m²
- 90m² to 110m²
- Over 110m²
- Heat demand > 15,000
- Heat demand > 20,000
Carbon Trust on Micro-CHP

If they used 0.43 kgCO₂/kWh instead...

Figure 53 Range of carbon savings expected for domestic and commercial Micro-CHP (based on carbon emissions factor of 0.43 kgCO₂/kWh for displaced electricity)

Key:
- Potential range
- Average
- Likely range

Electricity carbon factor: **0.430 kgCO₂/kWh**

Carbon savings (%)

- Domestic Micro-CHP (all house types): -5%, 0%, 5%
- Domestic Micro-CHP (target market): 0%, 2.5%, 5%
- Commercial Micro-CHP: 6%, 8.5%, 11%
Ocean thermal

- Not available in the UK
- Theoretical limit: $5 \text{W/m}^2$
- Spin-offs:
  - Uranium extraction
  - Desalinated water
  - Air-conditioning
- Fantasy:
  - Cover 10% of all tropical oceans with heat engines
  - 120 kWh per person per day
Paper 2: Reducing CO$_2$ emissions - nuclear and the alternatives

An evidence-based report by the Sustainable Development Commission

March 2006

IEE’s ‘technical potential’ is 'an upper limit that is unlikely ever to be exceeded even with quite dramatic changes in the structure of our society and economy'.
Estimates of theoretical / practical resources

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>My estimates</th>
<th>IEE</th>
<th>Tyndall</th>
<th>IAG</th>
<th>PIU</th>
<th>CAT</th>
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<tbody>
<tr>
<td>Geothermal</td>
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<td>3.4</td>
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<tr>
<td>Tide: 14 kWh/d</td>
<td></td>
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<td>Wave: 4</td>
<td></td>
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<tr>
<td>Deep offshore wind: 32 kWh/d</td>
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<tr>
<td>Shallow offshore wind: 16 kWh/d</td>
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<tr>
<td>Hydro: 1.5</td>
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<tr>
<td>Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d</td>
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<td>Energy crops, waste: 2</td>
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<td>Hydro: 0.08</td>
<td></td>
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<tr>
<td>Offshore: 21</td>
<td></td>
<td></td>
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<tr>
<td>Energy crops, waste incin’n, landfill gas: 31 kWh/d</td>
<td></td>
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<tr>
<td>PV farm (400 m²/p): 50 kWh/d</td>
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<tr>
<td>PV, 10 m²: 4</td>
<td>0.3</td>
<td></td>
<td>0.02</td>
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<tr>
<td>Solar heating: 10 kWh/d</td>
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<td>Wind: 20 kWh/d</td>
<td>2</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Wind: 2</td>
<td></td>
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<tr>
<td>Solar heating: 1.3 kWh/d</td>
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<td></td>
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<tr>
<td>Wind: 1</td>
<td></td>
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</tbody>
</table>
Don't knock centralization
Cars

- Engine inefficiency
  - Internal combustion is 25% efficient

- Drag

  \[ \text{Drag} \sim \rho A v^2 \]

  No viscosity!

- Acceleration/deceleration

  \[ \text{Power} = \frac{1}{2} \rho A v^3 c_d + \frac{1}{2} \frac{mv^3}{D} \]

Car: 40 kWh/d
Micro-wind (one per person?)

David Cameron's chimney ->

1.6 kWh/d if wind speed is 6 m/s

2000 pounds for that!
"We were going to have a wind turbine but they're not very efficient"

From Private Eye, April 2007
Wind fluctuates

Even when added over a whole country

Total output (in MW) of all windfarms in Eire, April 2006 - April 2007

www.eirgrid.com
'Wind is intermittent, so requires fossil-fuel back-up'
Figure 26.2. Total output, in MW, of all windfarms of the Republic of Ireland, from April 2006 to April 2007 (top), and detail from January 2007 to April 2007 (middle), and February 2007 (bottom). Peak electricity demand in Ireland is about 5000 MW. Its wind ‘capacity’ in 2007 is 745 MW, dispersed in about 60 windfarms. Data are provided every 15 minutes by www.eirgrid.com.

Scale this up: with 33 GW of capacity, expect slew rate of 3.7 GW per hour - an unprecedented problem for Britain?

Every morning, demand rises at a slew rate of 6.5 GW per hour.
Annual windmill- and car-caused deaths in Denmark; and deaths caused in the UK by cats.
Dinorwig is the home of a 9 GWh storage system, using Marchlyn Mawr (615E, 620N) and Llyn Peris (590E, 598N) as its upper and lower reservoirs.

Loch Sloy illustrates the sort of location where a 40 GWh storage system could be created.

Figure 29.2. Dinorwig, in the Snowdonia National Park, compared with Loch Sloy and Loch Lomond. The upper maps show 10 km by 10 km areas. In the lower maps the blue grid is made of 1 km squares. Images produced from Ordnance Survey’s Get-a-map service www.ordnancesurvey.co.uk/getamap. Images reproduced with permission of Ordnance Survey. © Crown Copyright 2006
Pumped storage

Okinawa Seawater Pumped Storage Power Plant (0.2 GWh)
www.ieahydro.org
Output - 30 MW

Kannagawa Power Plant (29 GWh)
www.ieahydro.org

Electric vehicles - another huge easily-switch-off-and-on-able load
Energy storage
Altitudes in the UK

Figure 7.1. Altitudes of land in Britain. The rectangles show how much land area there is at each height.
Pumped storage and tide combined

Sea

Pump at high tide

Generate on demand (lower conditions)

High

Low

Pump at low tide

Generate on demand (higher conditions)
Waste incinerators

1 kg of waste - 0.8 kWh of electricity
"For nuclear power to make a significant contribution to a reduction in global carbon emissions in the next two generations, the industry would have to construct nearly 3000 new reactors [over 60 years] ... [This is] a pipe dream and completely infeasible. The highest historic rate of build is 3.4 new reactors a year."

(Guardian, citing an Oxford Research Group report, 4th July 2007)
Huge expansion for wind turbines

There could be more than two offshore wind turbines per mile of UK coastline under plans being set out by ministers.

Business Secretary John Hutton says he wants to open up British seas to allow enough new turbines - up to 7,000 - to power all UK homes by the year 2020.

The aim is for 20% of EU energy to come from renewables by 2020.

John Sauven, the executive director of Greenpeace, said that the plans amounted to a "wind energy revolution". "And Labour needs to drop its obsession with nuclear power, which could only ever reduce emissions by about 4% at some time in the distant future."

How does nuclear's pathetic 4% compare with the proposed offshore wind?

'33GW' of offshore wind would deliver on average 10GW, which is 4kWh/d per person

4%!

4 kWh/d

4 kWh/d

4 kWh/d

'all homes'

10 GW nuclear

33 GW wind
Ocean Uranium
Sunniness

and its effect on PV
Solar chimney

No mirrors!
HVDC transmission

Photos and diagrams: ABB 2GW -->

3.1GW, 1360km

1.9GW, 1420km

0.7GW, 580km
Finland - Estonia:
One pair of cables transmit 350 MW

Photos: ABB
Carbon translation chart

<table>
<thead>
<tr>
<th>kWh/d each</th>
<th>kWh(e)/d each</th>
<th>t CO₂/y each</th>
<th>Mt CO₂/y / UK</th>
<th>MtC/y / UK</th>
<th>GtC/y / World</th>
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<tbody>
<tr>
<td>120</td>
<td></td>
<td>11</td>
<td>180</td>
<td></td>
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<td>110</td>
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<td>40</td>
<td>UK Electricity</td>
<td>3</td>
<td>100</td>
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<td>30</td>
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<td>10</td>
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<td>0</td>
<td>70</td>
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<td>7</td>
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- UK (1990) 170 GtC/y
- UK (2005) 180 GtC/y
- World (2005) 18 GtC/y

- ‘Safe and fair’ 100 MtCO₂/y
- ‘Safe’ 20 MtCO₂/y
- 90% target 30 MtCO₂/y
- 90% target 40 MtCO₂/y
<table>
<thead>
<tr>
<th>kWh/d each</th>
<th>GW / UK</th>
<th>TWh/y / UK</th>
<th>Mtoe/y / UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
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<tr>
<td>1000</td>
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</tbody>
</table>

1 kWh/d the same as 1/24 kW
GW often used for ‘capacity’ (peak output)
TWh/y often used for average output
1 Mtoe ‘one million tonnes of oil equivalent’

‘UK’ = 60 million people

USA: 300 kWh/d each
Europe: 120 kWh/d each
Numbers

24 MW at Guernsey electricity

20 MW
Desalination

8 kWh/m³

Jersey Water
Something must be done!

'Making a difference'
- Corporate poppycock
- Media poppycock
- Consumer scams & ripoffs

Make a world of difference
Neutralise your CO2 emissions now

We all contribute to CO2 emissions when we drive. We can all do something about it. It’s simple and doesn’t cost the earth. On average, it’s just £20 a year.

Neutralise your CO2 emissions now
Discover more about targetneutral

Reducing CO2 emissions one car at a time
Britain tops energy waste league

British people are Europe's worst energy wasters, with bad habits such as leaving appliances on stand-by likely to waste £11bn by 2010, a study claims.

If current levels of wastage continue, an extra 43m tonnes of carbon dioxide will be pumped into the atmosphere in that time, it added.

Leaving mobile phone chargers plugged in and lights on were among the most common energy-wasting habits.

The Energy Saving Trust surveyed 5,000 people in five countries for the study.

Figures in the Habits of a Lifetime report, commissioned to mark the start of Energy Saving Week, said 71% of UK consumers admit to leaving stand-by buttons on once a week.

Meanwhile, 65% of UK consumers leave chargers on once a week and 63% forget to switch the lights off when leaving the room.

ENERGY WASTERS LEAGUE

- 1. UK
- 2. Italy
- 3. France
- 4. Spain
- 5. Germany
'If every London household unplugged their mobile phone chargers when not in use, we could save 31,000 tonnes of CO2 and 7.75m per year.'
'If every London household unplugged their mobile phone chargers when not in use, we could save 31,000 tonnes of CO2 and 7.75m per year.'
Forget cars fuelled by alcohol and vegetable oil. Before long, you might be able to run your car with nothing more than water in its fuel tank. It would be the ultimate zero-emissions vehicle.

While water is not at first sight an obvious power source, it has a key virtue: it is an abundant source of hydrogen, the element widely touted as the green fuel of the future.
Arnold Schwarzenegger refuels a hydrogen-powered car (top). His vision is to see vehicles like this replace the polluting models on the road.

Once again, Rosenfeld says, the message for California on saving energy is simple: every little bit helps.

Charles Petit is a freelance writer in California.

Every little helps?
reminds me of friend who drove 20 miles in order to take one milk bottle to recycling centre
### Example Call Savings

<table>
<thead>
<tr>
<th></th>
<th>Peak</th>
<th>Off-Peak</th>
<th>Savings vs BT</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK national</td>
<td>3.1</td>
<td>2.1</td>
<td>38 - 54%</td>
</tr>
<tr>
<td>UK local</td>
<td>2.5</td>
<td>0.85</td>
<td>0 - 26%</td>
</tr>
<tr>
<td>Australia</td>
<td>6.5</td>
<td>0.85</td>
<td>83%</td>
</tr>
<tr>
<td>France / Germany</td>
<td>5.5</td>
<td>5.5</td>
<td>76%</td>
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<tr>
<td>Ireland</td>
<td>5.5</td>
<td>5.5</td>
<td>70%</td>
</tr>
<tr>
<td>USA</td>
<td>3.9</td>
<td>3.9</td>
<td>80%</td>
</tr>
</tbody>
</table>

All prices exclude VAT. Comparison against BT standard prices. Prices to other destinations can be found on our website.

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**Yorkshire CND** has joined up with **The Phone Co-op** (www.thephone.coop), an ethical and environmentally responsible telephone service provider, to offer our supporters a great deal on phone calls. We chose **The Phone Co-op** because as well as offering great value for money, they share our values and are extremely green - for instance they neutralise all CO2 emissions generated by your phone calls through their partnership with **Climate Care** (www.climatecare.org). **As well as being able to make big savings on your bill whilst being green,**
Every little helps

If everyone does a little, you'll get a little

or perhaps worse...
Every little helps

Recyclable mobile (NEC): N701iECO
Every little helps

'Latest in ecological and environmental design'

By just adding **water** you are providing your product with an endless source of energy.

The new H2O Desktop Calculator from Tango Group is the latest in ecological and environmental design. Incorporating the revolutionary and patented, H2O **water** powered battery, together with conventional digital technology; the H2O Desktop Calculator offers the user an environmental design solution for a product that is used in every day home or office life.

This has all been made possible by groundbreaking developments in portable power technology operated by an inexhaustible resource - "**water**". The patented technology utilises two electrodes consisting of specially formulated alloys, one positive, and the other negative. When immersed in **water** an electrochemical reaction takes place resulting in the production of electrical energy.

As all the components of the H2O **water** battery are recyclable, the benefits over traditional batteries are countless. Every year billions of conventional dry cell batteries are used, and the recycling of such waste is not only expensive but often incomplete, resulting in hazardous pollution and damage to our environment.

The H2O Desktop Calculator is designed and manufactured for both professional and home use in mind. By just adding **water** you are providing your product with an endless source of energy. At the end of the H2O **water** battery’s life (indicated by dimming of the display) simply replace the battery and start all over again. (Replacement water powered batteries are readily available from Tango Group Limited).
Kite power - 'a single installation could replace 5 nuclear power stations'

The 50 MW KiteGen as a free interpretation of an illustrator

Sequoia Automation S.r.l. (movie)

WREC 2006

1f/movie
Kite power - 'a single installation could replace 5 nuclear power stations'
KiWiGen CAROUSEL: the circular base, tensor-structure and the tandem kite arrays

280000 m²
300 W/m²
84 MW

Comparison between a large scale KiWiGen and a 1MW class windmill. The red area represents the engaged wind front, considering a similar weight for the two systems (2000 tons)
Scalability of the system

The KITE WIND GENERATOR is an installation that produces energy in proportion to its size. As its diameter is increased, the amount of energy captured grows exponentially. This amount is further augmented by the higher altitude of the kites, thus the stronger winds that they are in contact with. Some examples of these values, can be:

<table>
<thead>
<tr>
<th>a diameter of</th>
<th>is equivalent to a generator of</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m</td>
<td>0.5 MW</td>
</tr>
<tr>
<td>200 m</td>
<td>3 MW</td>
</tr>
<tr>
<td>300 m</td>
<td>7 MW</td>
</tr>
<tr>
<td>1.000 m</td>
<td>250 MW</td>
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</table>

The maximum possible diameter of a KITE WIND GENERATOR is one of the objects of study of this project, but from the initial evaluations, it appears possible to exceed 5,000MW (5 Gigawatts) without great structural risks, with a diameter of slightly more than 2000 metres.
Theoretical limits
'Global warming has stopped'

Looking at 8-year trends makes as much sense as analysing the temperature observations from 10-17 April to check whether it really gets warmer during spring.'
PM outlines climate action plan

Mr Brown said there were hard choices ahead. Prime Minister Gordon Brown has said there will be a "green hotline" to advise people on what they can do to cut their impact on the environment.

Mr Brown, who said the UK's emission target of a 60% cut by 2050 could be increased to 80%, said he would also seek the end of one-use plastic bags.

In his first speech on the environment as PM he said there would be "hard choices and tough decisions".

But he said Britain could lead the world and gain thousands of jobs.

From The Times
November 20, 2007

Gordon Brown's bid to seal fate of carrier bags

Francis Elliott, Deputy Political Editor

The plastic bag's status as a symbol of waste was confirmed yesterday as Gordon Brown pledged to help to eliminate its use in Britain.

He threw his weight behind the growing campaign against disposable carriers in his first big speech on the environment since becoming Prime Minister. Speaking before an international climate change summit in Bali next month, Mr Brown confirmed that the Government's target of a 60 per cent reduction in Britain's greenhouse gas emissions by 2050 may be extended to 80 per cent.

Environmentalists also welcomed his statement that Britain was committed to meeting its share of an EU target to generate 20 per
Sustainable Energy
- without the hot air

Biofuels

David MacKay
Department of Physics
University of Cambridge

www.withouthotair.com
It is a crime against humanity to convert food crops to fuel

Jean Ziegler,
UN Special Rapporteur on the Right to Food.

The world should wake up to the dangers of the mass production of biofuels

Professor Sir Peter Crane,
Director, Royal Botanic Gardens, Kew.
Biofuel boom ‘to raise beer price’

BEER drinkers could face a rise in the price of a pint because farmers are planting crops for green fuels instead of barley. Rising demand for corn, soya beans and rapeseed for use in biofuels is making farmers move away from barley, a key ingredient in brewing. The price of barley has soared in the past year. Heineken chief executive Jean-François van Boxmeer said a long-term rise in beer prices was likely as a result.
Biofuels worsen global warming

- Borneo - peat-burning
- Rape-seed - nitrous oxide
How much power could Britain get from biofuels?

Power per unit area

Sunlight

Carbohydrate energy captured by plants

Energy used or lost in farming and processing

Delivered energy

Net energy

Attention is sometimes focussed on the comparison of the other inputs with the delivered energy. For corn-ethanol, the required inputs and losses are so big, it's difficult to make the Net Energy positive!
Average Power consumption, UK: 125 kWh/d each

'primary consumption'
125 kWh/day (Europe)
300 kWh/day (USA)

(doesn't include imports, nor solar energy in food)

Area
UK: 4000 m² per person

www.dti.gov.uk
Today's supply of renewables

- Offshore wind: 0.03
- Small hydro: 0.022
- Large hydro: 0.19
- Biodiesel: 0.13
- Biomass (wood in homes): 0.07
- Biomass (cofiring): 0.12
- Biomass (landfill gas, sewage, waste incineration): 0.3

All renewables in 2006: 1.05 kWh/d

Solar HW: 0.014
Solar PV: 0.0003
Wind: 0.16

Nuclear (2006): 3.4 kWh/d
How much power could Britain get from biofuels?

Power per unit area

Sunlight
50W/m²

Taking the most efficient plants
Carbohydrate energy captured by plants 0.5W/m²

Energy used or lost in farming and processing
Delivered energy
Net energy

x Area

Total UK land area: 4000 m² per person
arable land: 2800 m² per person
half of arable land: 1400 m² per person

other inputs required for farming and processing
How much power could Britain get from biofuels?

Power per unit area

Sunlight

$50 \text{W/m}^2 \times 1400 \text{ m}^2$

Carbohydrate energy captured by plants

17 kWh/d

energy used or lost in farming and processing

Delivered energy

Net energy

Total UK land area: 4000 m$^2$ per person

Arable land: 2800 m$^2$ per person

Half of arable land: 1400 m$^2$ per person
Even if all the other issues were resolved

Biofuels could make only a small contribution

Sunlight
50 W/m² × 1400 m²

Carbohydrate energy captured by plants 17 kWh/d

Delivered energy

Energy used or lost in farming and processing

Net energy

Transport 35%
Hot air 26%
Hot water 8%
Lighting, appliances 6%
Process 10%
Other 15%

www.withouthotair.com
"Even if the USA's entire corn and soya harvests were used to produce agrofuels, they would satisfy only 12 per cent of the USA's current thirst for petrol and 6 per cent of its need for diesel. The situation in Europe is even worse: the UK, for example, could not grow enough agrofuels to run all its cars even if it put the whole country under the plough."

MIT lifecycle analysis (Groode and Heywood):
http://ifee.mit.edu/metadot/index.pl?id=2234

Alex Farrell, Science, DOI:10.1126/science.1121416

Total UK land area: 4000 m² per person

arable land: 2800 m² per person
Population densities

[Graph showing population densities of different regions with coordinates for population and area (square km).]
Plan S: zero-carbon Scotland

- Tidal stream farms
- 100 sq km wind farms
- 65km wave farm
- Biofuels
- Wood/Miscanthus

**Tide:** 15+
- Wave: 3
- Hydro: 2
- Waste: 1.1

**Pumped heat:** 12

**Wood:** 5

**Solar HW:** 1

**Biofuels:** 1

**PV:** 3

**Wind:** 28

- Tidal stream (20b?)
- 1,000 pelamis, 65km of coastline (4b?)
- All municipal waste incinerated, and equal agri. waste
- Energy crops: 1200 sq m per person
- 4% of country (20b)
- 30 windfarms, each 100 sq km
  - 6 times as much wind hardware as Denmark

Pumped storage - 30 Cruachans (30b)
Upgrade Anglo-Scottish interconnector (1b)

Total ballpark cost: 75b
[Scottish Government budget: 30b/y]
[10 GW nuclear: 10b]
Plan S: zero-carbon Scotland

- **Tide**: 15+
- **Wave**: 3
- **Hydro**: 2
- **Waste**: 1.1
- **Pumped heat**: 12
- **Wood**: 5
- **Solar HW**: 1
- **Biofuels**: 1
- **PV**: 3

- **Wind**: 28

- **Tidal stream farms**: 100 sq km wind farms
- **65km wave farm**:
- **1,000 pelamis, 65km of coastline**
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- **4% of country**
  - 30 windfarms, each 100 sq km
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- **Pumped storage**: 30 Cruachans
- **Upgrade Anglo-Scottish interconnector**
Independence for Scotland
Four Londons' worth

Use for cofiring biomass with CCS

40GW - four-fold increase

25% of UK - forests, willow, miscanthus
1 sq m per person HW
12% of UK for biofuels
Half of all roofs
33-fold increase in wind capacity, mainly offshore.

[Jet flights: 5kWh/d/p, while oil lasts]