Sustainable Energy
- without the hot air

David MacKay
Department of Physics
University of Cambridge

www.withouthotair.com
Questions about sustainable energy

- Can we live on our own renewables?
  - What would that look like?

- How can we make a sustainable energy plan that adds up?
  - We need to get off fossil fuels
    - Numbers, not adjectives
    - Not easy; but possible
  - All renewables are diffuse
    - to make a difference, renewable facilities have to be country-sized
  - The main efficiency savings are:
    - electrify transport (electric cars)
    - electrify heating (heat pumps)
  - The supply options are:
    - our renewables
    - other countries' renewables
    - nuclear
We have an addiction to fossil fuels, and it's not sustainable
Photos by Chris Jordan
We have an addiction to fossil fuels, and it's not sustainable
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

ATMOSPHERIC CARBON DIOXIDE

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 440 parts per million by volume (ppmv) of CO₂.
Carbon dioxide concentration (ppm)

Carbon dioxide concentration (ppm)

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).
Figure 1.7  Global emissions reduction trajectories peaking in 2016
Probability of dangerous climate change / 'extreme danger'

Figure 1.11  Probabilities of exceeding a given global mean temperature increase by 2100 for emissions trajectories peaking in 2016

Note: Curves show the range of model outputs for given global temperature increase (relative to pre-industrial) in 2100, for the emissions trajectories peaking in 2016, given climate model parameters outlined in the Technical Appendix. Both 2016:3%low and 2016:3% give very similar probabilities at 2100.
Figure 1.10  CO₂-equivalent atmospheric concentrations for emissions trajectories peaking in 2016

Note: Total CO₂-equivalent atmospheric concentrations (including Kyoto GHGs, ozone and aerosols) are given in parts per million (ppm) for emissions trajectories 2016:1.5%, 2016:3%, 2016:3%low and 2016:4%low. Upper and lower thin lines show the 10th and 90th percentile bounds of model response, whilst the thick central line represents the central model estimate.
The recent past

Figure 1.1 Global carbon dioxide emissions (excluding those relating to land-use) compared to the scenarios included in the IPCC Special Report on Emissions Scenarios (2000)

Source: IPCC Special Report on Emissions Scenarios (2000) and Global Carbon Project. Errors around actual emissions are about 5%.
'Security of supply'

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

Photo by Terry Cavner
North Sea oil

The energy gap

Source: E.ON UK / House of Lords
We have an addiction to fossil fuels, and it's not sustainable
Something must be done!
'Make a difference'

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 Powegen’s Go Green tariff and do your bit for the environment

Let the power of nature into your home

Click here

98% of Powegen's electricity is fossil; just 2% renewables
Advertising watchdog receives record complaints over corporate 'greenwash'

Will Ashley-Cantello

guardian.co.uk, Thursday May 1 2008 11.30 BST
Article history

"Driving the world's first luxury hybrid SUV makes environmental, and economic, sense"

The ASA upheld complaints against Shell's 'green' advert, which Friends of the Earth claimed misrepresented the environmental impact of the oil company's activities.

The number of complaints lodged to the advertising standards board reached record numbers last year.
'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
Efficiency through technology

'a highly fuel-efficient aircraft'

- it burns 12 percent less fuel per passenger-km than a 747
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 cent of its electricity from renewable sources by 2020.
"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

<table>
<thead>
<tr>
<th>Category</th>
<th>Domestic Micro-CHP</th>
<th>Domestic boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>New build</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1920-2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre 1920</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to 90m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90m² to 110m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 110m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat demand &gt; 15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat demand &gt; 20,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Clear savings evident
Solar bra brings conservation closer to the heart

Wed May 14, 2008 8:53pm IST

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.

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

We need numbers, not adjectives
Part I: Numbers, not adjectives

Could a country like Britain live on its own renewables?

Part II: Energy plans that add up
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

EXAMPLES
- 20 mins of kettle - 1 kWh
- Food - 3 kWh / day (*)
- Bath - 5 kWh (*)
- Litre of petrol - 10 kWh
- Aluminium can - 0.6 kWh

UK: 4000 m² per person
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}

\approx 40 \text{ kWh/day}.

33 miles per UK gallon

Car: 40 kWh/d

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: \( 4000 \text{ m}^2 \) 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
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 thermal

Cover every south-facing roof

Jet flights: 30 kWh/d
Car: 40 kWh/d
Solar heating: 13 kWh/d
Wind: 20 kWh/d

10 m² per person:
13 kWh/day per person
Solar electric (photovoltaics)
Solar electric

Data and photo by Jonathan Kimmitt

Cover *every* South-facing roof,
10 m² per person: **5 kWh/day per person**
Bavaria Solar Park: 5 W/m²; this picture shows 0.7 MW (average)
Solar PV (covering 5-10% of the country)

- Jet flights: 30 kWh/d
- Car: 40 kWh/d
- PV farm (200 m²/p): 50 kWh/d
- PV, 10 m²/p: 5 kWh/d
- Solar heating: 13 kWh/d
- Wind: 20 kWh/d
Solar biomass

- Best plants (0.5% efficient)
  - cover 75% of the country;
  - 1/3 lost in processing.

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy output</th>
</tr>
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<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 (200 m²/p)</td>
<td>50 kWh/d</td>
</tr>
<tr>
<td>PV, 10 m²/p</td>
<td>5</td>
</tr>
<tr>
<td>Solar heating</td>
<td>13 kWh/d</td>
</tr>
<tr>
<td>Wind</td>
<td>20 kWh/d</td>
</tr>
</tbody>
</table>

*Includes sustainable waste incineration, cellulosic ethanol, methanol*
Average solar intensity, UK: 100 W per square metre

Plant power per unit area

- wood (commercial forestry)
- rape
- rape to biodiesel
- maize
- sugar beet
- short rotation coppice calorific value
- energy crops calorific value
- miscanthus to electricity
- switchgrass
- corn to ethanol
- wheat to ethanol
- jatropha
- sugarcane (Brazil, Zambia)
- tropical plantations (eucalyptus)
- tropical plantations

PV efficiencies

- amorphous silicon
- multi-crystalline silicon
- single crystal silicon
- Sunpower WHT
- Sanyo HIP
- Suntech poly-crystalline
- thin-film triple junction

Graph showing delivered power (W/sq m) vs irradiance (W/sq m)
Heating and cooling

Hot water
- Bath: 5 kWh
- Shower: 1.4 kWh
- Clothes wash: 1 kWh
- Cooking, kettle, microwave, dishes

| Hot water: 12 kWh/d |

Hot air
- 24

| Hot air: |

Fridge, Airconditioning
- Cooling: 1 kWh/d

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

| PV farm (200 m²/p): 50 kWh/d |

| PV, 10 m²/p: 5 |

| Solar heating: 13 kWh/d |

| Wind: 20 kWh/d |
1.5 kWh/d per person

(currently 0.2 kWh/d per person)
Light

- 10 bulbs
- 5 hours per day

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (kWh/d)</th>
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</thead>
<tbody>
<tr>
<td>Heating, cooling</td>
<td>37</td>
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<tr>
<td>Jet flights</td>
<td>30</td>
</tr>
<tr>
<td>Car</td>
<td>40</td>
</tr>
<tr>
<td>Hydro</td>
<td>1.5</td>
</tr>
<tr>
<td>Biomass: food, biofuel, wood, waste incineration, landfill gas</td>
<td>24</td>
</tr>
<tr>
<td>PV farm (200 m²/p)</td>
<td>50</td>
</tr>
<tr>
<td>PV, 10 m²/p</td>
<td>5</td>
</tr>
<tr>
<td>Solar heating</td>
<td>13</td>
</tr>
<tr>
<td>Wind</td>
<td>20</td>
</tr>
</tbody>
</table>
Offshore wind

- Shallow offshore wind: 16 kWh/d
- Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d
- PV farm (200 m²/p): 50 kWh/d
- PV, 10 m²/p: 5 kWh/d
- Solar heating: 13 kWh/d
- Wind: 20 kWh/d

- Light: 4 kWh/d
- Heating, cooling: 37 kWh/d
- Jet flights: 30 kWh/d
- Car: 40 kWh/d

Depth: less than 25 m (yellow); depth between 25 m and 50 m (magenta). Data from DTI Atlas of Renewable Marine Resources. Crown copyright. 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

- Deep offshore wind: 32 kWh/d
- Shallow offshore wind: 16 kWh/d
- Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d
- PV farm (200 m²/p): 50 kWh/d
- PV, 10 m²/p: 5 kWh/d
- Solar heating: 13 kWh/d
- Wind: 20 kWh/d

Light: 4 kWh/d
Heating, cooling: 37 kWh/d
Jet flights: 30 kWh/d
Car: 40 kWh/d

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

Data from DTI Atlas of Renewable Marine Resources. Crown copyright.
Gadgets

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

Charger left plugged in:
0.01 kWh/d
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.
Are they related?

Vader

Charger

'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.'
Energy saved by switching off for one day

\[ 0.5 \, \text{W} \times 86400 \, \text{s} = 40000 \, \text{W} \times 1 \, \text{s} \]

\[ 0.01 \, \text{kWh} \]

Energy used by driving an average car for one second
Wave climate and the wave power resource (1986)
Wave

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

(not including energy for food delivery)

Vegans: 3 kWh/d minimum
Vegetarians: 4 kWh/d min
Carnivores: 12 kWh/d min
(260 kg of animal preparing to be eaten)
Tide - using tide pools
Severn barrage and la Rance

La Rance (60 MW): 2.7 W/m²
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>

Atlantic ocean  North Sea

Sea  Tidepool

range

400 km

Map showing locations of Faeroes, Shetland, Orkney, North Sea, and Atlantic Ocean.
Tide

DTI
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**

## and barrages

0.8 kWh/d per person

<table>
<thead>
<tr>
<th>Source</th>
<th>kWh/d</th>
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</thead>
<tbody>
<tr>
<td>Food, farming, fertilizer</td>
<td>15</td>
</tr>
<tr>
<td>Gadgets</td>
<td>5</td>
</tr>
<tr>
<td>Light</td>
<td>4</td>
</tr>
<tr>
<td>Heating, cooling</td>
<td>37</td>
</tr>
<tr>
<td>Jet flights</td>
<td>30</td>
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<td>32</td>
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<td>16</td>
</tr>
<tr>
<td>Biomass food, biofuel, wood, waste incin’n, landfill gas</td>
<td>24</td>
</tr>
</tbody>
</table>

## Key Areas
- Cardiff
- Severn Estuary
- Bristol Channel
- Weston Super-Mare
- Bridgwater
- Barry

## Map

- Bristol
- M4
- M5

*Image credits: [Natural Resources Wales](https://www.naturalresourceswales.gov.uk)*
- One new computer every 2 years
  - Chips: 2.5 kWh/d
  - Aluminium: 3 kWh/d

- 5 cans per day

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

- Transporting rubbish around
  - Road freight: 7 kWh/d
  - Supermarkets: 0.5 kWh/d
  - Shipping: 4 kWh/d
  - Food, farming, fertilizer: 15 kWh/d
  - Gadgets: 5 kWh/d
  - Light: 4 kWh/d
  - Heating, cooling: 37 kWh/d
  - Tide: 11 kWh/d
    - Wave: 4 kWh/d
    - Deep offshore wind: 32 kWh/d
    - Shallow offshore wind: 16 kWh/d
    - Biomass: food, biofuel, wood, waste incin’r, landfill gas: 24 kWh/d

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

Nesjavellir, Iceland

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

Transporting stuff: 12 kWh/d
Geothermal: 1 kWh/d

Stuff: 48+ kWh/d
Tide: 11 kWh/d

Food, farming, fertilizer: 15 kWh/d
Wave: 4 kWh/d

Gadgets: 5
Deep offshore wind: 32 kWh/d

Light: 4 kWh/d
Shallow offshore wind: 16 kWh/d

Heating, cooling: 37 kWh/d
Hydro: 1 kWh/d

Jet flights: 30 kWh/d
Biomass: food, biofuel, wood, waste incin'n, landfill gas: 24 kWh/d

Car: 40 kWh/d
PV farm (200 m²/p): 50 kWh/d

PV, 10 m²/p: 5
Solar heating: 13 kWh/d

Wind: 20 kWh/d

'C Hot dry rock'

Depth:

- Crust: 5 C
- Mantle: 500-600 C
- Lithosphere:
  - 1400 C
Still to come on the red stack:
- industry,
- road building,
- 'defence',
- hospitals, ...
A consultation exercise in full swing
Save Our Scenery - Protecting Our Heritage Coastline

BEFORE

FROM LLANDUDNO PROMENADE

AFTER

FROM COLWYN BAY PROMENADE

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

Graveney was the site of the last combat 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 Graveney. “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?”

Surfers are worried about the impact of the UK proposals in the area. Surfers are worried about the impact of the UK proposals in the area.

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 a wind farm next to the defunct nuclear power station, at Bovington 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 south Wales coast met on Friday. Residents in Porthcawl were out in force to highlight their opposition to the proposed 30-turbine wind farm on Cefn Bryn Sands.

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 there 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 the sport because of the turbines then the town is going to lose a large company behind the £100m scheme say the turbines, which are 100ft above sea level, will generate enough power for 86,000 homes.

The site, which is to the west of Porthcawl, is approximately five miles south of the nearest household.

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 kWh/d

Stuff: 48+ kWh/d

Food, farming, fertilizer: 15 kWh/d

Gadgets: 5

Light: 4 kWh/d

Heating, cooling: 37 kWh/d

Jet flights: 30 kWh/d

Car: 40 kWh/d

Geothermal: 1 kWh/d

Tide: 11 kWh/d

Waste: 1 kWh/d

Deep offshore wind: 32 kWh/d

Shallow offshore wind: 16 kWh/d

Biomass: food, biofuel, wood, waste inciner’ng, landfill gas: 24 kWh/d

PV farm (200 kW/p): 50 kWh/d

PV, 10 m²/p: 5

Solar heating: 13 kWh/d

Wind: 20 kWh/d

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>Activity</th>
<th>Energy Consumption</th>
<th>Reason</th>
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</thead>
<tbody>
<tr>
<td>Transporting stuff</td>
<td>12 kWh/d</td>
<td>too immature!</td>
</tr>
<tr>
<td>Stuff</td>
<td>48+ kWh/d</td>
<td></td>
</tr>
<tr>
<td>Food, farming, fertilizer</td>
<td>15 kWh/d</td>
<td>not near my radar!</td>
</tr>
<tr>
<td>Gadgets</td>
<td>5</td>
<td>not near my birds!</td>
</tr>
<tr>
<td>Light</td>
<td>4 kWh/d</td>
<td>not in my valley!</td>
</tr>
<tr>
<td>Heating, cooling</td>
<td>37 kWh/d</td>
<td>not in my countryside!</td>
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<tr>
<td>Jet flights</td>
<td>30 kWh/d</td>
<td>too expensive!</td>
</tr>
<tr>
<td>Car</td>
<td>40 kWh/d</td>
<td>too expensive!</td>
</tr>
<tr>
<td>Solar heating</td>
<td>12 kWh/d</td>
<td>not on my street!</td>
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<tr>
<td>Wind</td>
<td>20 kWh/d</td>
<td>not in my back yard!</td>
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<tr>
<td>PV farm (200m²/p)</td>
<td>50 kWh/d</td>
<td>too expensive!</td>
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<tr>
<td>Deep offshore wind</td>
<td>32 kWh/d</td>
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<td>Shallow offshore wind</td>
<td>16 kWh/d</td>
<td></td>
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<tr>
<td>Biomass: food, biorefinery, wood, waste, incineration, landfill gas</td>
<td>24 kWh/d</td>
<td></td>
</tr>
</tbody>
</table>

**Tide: 11 kWh/d**
- too expensive!
after the great British consultation exercise...

Current consumption: 125 kWh/d per person

This would be a 15-fold increase of renewables
Average power consumption, UK: 125 kWh/d/p

2004

- Industry 21%
- Domestic 30%
- Transport 35%
- Other final users 13%
- Other 15%

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

Transport 35%

'primary consumption'

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

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

For CO₂ pollution, divide by 10:

100 kWh/day ≈ 10 tonnes CO₂/y

www.dti.gov.uk
Primary Energy
235 M Tonnes

Oil 84

Gas 91

Nuclear 15

Renewable sources 4

Coal 41

Million tonnes of oil equivalent p.a.

Final Consumption
164 M Tonnes

Non-energy use

Transport

Heat

Electricity

Appliances and Lighting

Lost in power stations & network, used by the energy industry

Numbers have been rounded, and do not balance exactly in the source

Source: BERR
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.
# Renewables are diffuse

<table>
<thead>
<tr>
<th>Power per unit land area</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>2 W/m²</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>3 W/m²</td>
</tr>
<tr>
<td>Tidal pools</td>
<td>3 W/m²</td>
</tr>
<tr>
<td>Tidal stream</td>
<td>8 W/m²</td>
</tr>
<tr>
<td>Solar PV panels</td>
<td>5–20 W/m²</td>
</tr>
<tr>
<td>Plants</td>
<td>0.5 W/m²</td>
</tr>
<tr>
<td>Solar chimney (Spain)</td>
<td>0.1 W/m²</td>
</tr>
<tr>
<td>Concentrating solar power (desert)</td>
<td>15–20 W/m²</td>
</tr>
<tr>
<td>Ocean thermal</td>
<td>5 W/m²</td>
</tr>
<tr>
<td>Rain-water (highlands)</td>
<td>0.24 W/m²</td>
</tr>
<tr>
<td>Rain-water (lowlands)</td>
<td>0.02 W/m²</td>
</tr>
</tbody>
</table>

To make a difference, renewable facilities have to be country-sized.
No green light for Severn barrage

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
Nuclear

Fission 1000 W/m²
Part II: 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
Change lifestyle?

A Mitsubishi Warrior, yesterday

Amazing acts of testosterone-fuelled off-road driving bravery
Cartoon Britain, 2008

- Current consumption
  - Losses in conversion to electricity
  - Electrical things: 18 kWh/d
  - Heating: 40 kWh/d
  - Transport: 40 kWh/d

Energy inputs: 125 kWh/d
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

G-Wiz

6 kWh per 100 km

data from Kele Baker
Think Ox

20 kWh per 100 km
Tesla, Lightning

11 kWh per 100 km
www.lightningcarcompany.co.uk

15 kWh per 100 km
www.teslamotors.com
Lorem

TREV

Aptera

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

- Lead acid -
- Lithium ion -
Plug-in hybrids
Plug-in hybrids

25 kWh per 100 km

(running on electric power alone)
Lisbon's electric car deal leads way

By Peter Wise
Published: November 24 2008 02:00 | Last updated: November 24 2008 02:00

Portugal is to become the first European country to be supplied with electric cars by Renault and Nissan after signing an agreement to create a national network for zero-emission vehicles within three years.

The plan highlights Portugal's commitment to invest in clean energy, in spite of concerns that the global financial crisis is deterring governments from implementing ambitious European Union plans to fight global warming.

Under the agreement, finalised with the Franco-Japanese carmaking alliance over the weekend, 320 vehicle charging locations will be operational across Portugal by 2010, growing to 1,300 by the end of 2011.

Companies and motorists who buy electric cars will be exempt from road and other vehicle taxes and individuals will qualify for income tax benefits of up to €800, said José Sócrates, prime minister.

The government will also require 20 per cent of public sector vehicle purchases to be zero-emission.

Peter Wise, Lisbon

photo by Daniel Berehulak
EFFICIENCY

Cartoon Britain, 2008

- Energy inputs: 125 kWh/d
- Losses in conversion to electricity
- Electrical things: 18 kWh/d
- Heating: 40 kWh/d
- Transport: 40 kWh/d
Efficiency for heating

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

\[ \text{Leakiness}: 8 \text{kWh/d/°C} \]

\[
\text{Heat loss} = \text{Leakiness} \times \text{Average temperature difference}
\]

\[
\text{Power required} = \frac{\text{Heat loss}}{\text{Coefficient of performance of heat-creation}}
\]
Reduce leakiness

Leakiness: 8 kWh/d/°C

New leakiness: 6 kWh/d/°C
Increase coefficient of performance - use Heat pumps

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

http://www.ecosystem-japan.com/
EcoCute water heater - CoP = 4.9!
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
Cartoon Britain, 2008

Energy inputs: 125 kWh/d

- Losses in conversion to electricity
- Electrical things: 18 kWh/d
- Heating: 40 kWh/d
- Transport: 40 kWh/d
Read your meters!

**Gas**
- **condensing boiler installed**
- lower thermostat
- more insulation
- more glazing

**Electricity**
- energy usage trend for electricity usage over the years.
Efficiency in the offing

Electricity

- Power consumption (W)
- Time (hours)
- Vampires on
- Vampires off
- 70W
- 45W saved = 45 pounds per year
- 25W

ReadYourMeter.org
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.
"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"
Energy use versus GDP - log scale

UNDP Human Development Report, 2007
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
1600 Gt of coal / 6 billion people / 1000 years × 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 uranium:
  - Mined uranium: 0.55 kWh/d
  - Ocean uranium: 7 kWh/d
  - River uranium: 0.1 kWh/d

- Fast breeder uranium:
  - Mined uranium: 33 kWh/d

Assuming 27 Mt U recoverable

**Thorium**

- Conventional thorium reactor:
  - Mined thorium: 4 kWh/d

- “Energy amplifier”:
  - Mined thorium: 24 kWh/d

420 kWh/d

Assuming 1.6 Mt Th recoverable
Nuclear Fusion

- Not a sure thing
  - a gamble

- DT reaction
  - requires Lithium and Deuterium

- DD reaction
  - requires Deuterium

Lithium fusion (seawater): 105+ kWh/d
Lithium fusion: 10 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

- Tide: 3 kWh/d
- Offshore: 4 kWh/d
- Hydro: 0.3 kWh/d
- Biomass: 4 kWh/d
- Solar PV: 2 kWh/d
- Solar HW: 2 kWh/d
- Wind: 3 kWh/d
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
Yellow: 125 kWh/d/p for 1 billion people; Red: 125 kWh/d/p for 60 million people (assuming 15 W/m²)
140 kWh/d
peak 25 kW
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
Andasol, Spain

10 W/m²

(c) FLAGSOL

Kramer Junction
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
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
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

Energy inputs: 125 kWh/d

Current consumption:
- Losses in conversion to electricity
  - Electrical things: 18 kWh/d
- Future consumption
  - Heating: 40 kWh/d
  - Electrical things: 18 kWh/d
- Efficiency

Future consumption breakdowns:
- Heating: 30 kWh/d
- Pumped heat: 12 kWh/d
- Wood: 5 kWh/d
- Solar HW: 1 kWh/d
- Transport: 40 kWh/d
- Transport: 20 kWh/d
- Biofuel: 2 kWh/d
- Electricity: 18 kWh/d

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
This plan's mix

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

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

Jack-up barges cost 60M
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…'

Lowe, Private Eye
The role of nuclear power in a low carbon economy

Paper 2:
Reducing CO₂ emissions - nuclear and the alternatives

An evidence-based report by the Sustainable Development Commission
March 2006

125 kWh/d

Wave: 2.3 kWh/d
Geothermal: 10 kWh/d
Tide: 2.4 kWh/d
Energy crops: 9 kWh/d
Solar PV: 12 kWh/d
Offshore: 6.4 kWh/d
Wind: 2 kWh/d

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</th>
<th>My estimates</th>
<th>IEE</th>
<th>Tyndall</th>
<th>IAG</th>
<th>PIU</th>
<th>CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td></td>
<td>Geothermal: 10 kWh/d</td>
<td>Tide: 2.4</td>
<td>Wave: 2.3</td>
<td>Wave: 0.09</td>
<td>Tide: 3.9</td>
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<tr>
<td>Deep offshore wind</td>
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<td></td>
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<tr>
<td>Wave</td>
<td>4 kWh/d</td>
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<tr>
<td>Tide</td>
<td>11 kWh/d</td>
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<tr>
<td>Shallow offshore wind</td>
<td></td>
<td>Offshore: 6.4</td>
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</tr>
<tr>
<td>Wave</td>
<td>16 kWh/d</td>
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<tr>
<td>Hydro</td>
<td>1.3 kWh/d</td>
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<td>Biomass: food, biofuel, wood,</td>
<td></td>
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</tr>
<tr>
<td>waste incl'n, landfill gas</td>
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<td></td>
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<tr>
<td>Wave</td>
<td>24 kWh/d</td>
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<tr>
<td>Hydro</td>
<td>0.08</td>
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<tr>
<td>PV farm 200 m²/p: 50 kWh/d</td>
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<td>PV, 10 m²/p: 5</td>
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<tr>
<td>Solar heating</td>
<td>13 kWh/d</td>
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<tr>
<td>Wind</td>
<td>20 kWh/d</td>
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<tr>
<td>Offshore</td>
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<td>Offshore: 4.6</td>
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<tr>
<td>Wave</td>
<td>21 kWh/d</td>
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<td>Energy crops, waste</td>
<td></td>
<td>Energy crops: 2</td>
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<tr>
<td>landfill gas</td>
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<td>Energy crops, waste, landfill gas: 31 kWh/d</td>
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<td></td>
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<tr>
<td>Hydro</td>
<td>0.5</td>
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<td>Biomass fuel, waste</td>
<td>8</td>
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<td></td>
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<tr>
<td>PV</td>
<td>0.3</td>
<td>PV: 0.02</td>
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<tr>
<td>PV</td>
<td>12</td>
<td>PV: 1.4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Solar heating</td>
<td>1.3</td>
<td></td>
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</tr>
</tbody>
</table>
What should carbon cost?

- $1000: Impact on UK car-driving
- $900: 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
- $300: Impact on price of domestic electricity from coal
- $185: Impact on domestic heating
- $150: 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 ($35)

Cost of CO₂ permits in 2006 ($13-39)

- $50: CO₂ sequestration at old coal power stations ($45-73)
- $37-74: CO₂ sequestration at gas power stations
- $30: CO₂ sequestration at new coal power stations ($29-51)
- $18: Price charged by c-change trust
- $14: Price charged by climatecare.org
- $7.5: Price charged by targetneutral
Efficiency & technology - for Cartoon-Britain

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
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.

BMW Hydrogen 7
254 kWh per 100 km
Honda's fuel-cell car (FCX Clarity)

69 kWh per 100 km
Don't knock centralization
Energy inputs: 125 kWh/d

- Losses in conversion to electricity
- 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 kWh/d
- **Wood**: 5 kWh/d
- **Solar HW**: 1
- **Biofuels**: 2
- **PV**: 3 kWh/d
- **Wind**: 8 kWh/d

**40GW - four-fold increase**

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

**40GW; triple coal imports**

**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 kWh/d
- Hydro: 0.2 kWh/d
- Waste: 1.1 kWh/d
- Pumped heat: 12 kWh/d
- Wood: 5 kWh/d
- Solar HW: 1 kWh/d
- Biofuels: 2 kWh/d
- Wind: 2 kWh/d

40GW; triple coal imports

- 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 kWh/d
Wood: 5 kWh/d
Solar HW: 1
Biofuels: 2
PV: 3
Wind: 8

Almost all the world's windmills ('60GW') on 2% of country and equal area offshore

No nuclear

7500 pelamis, 500km of coastline

All municipal waste incinerated, and equal agri. waste
Plan G: 'Green'

No coal

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

No nuclear

- 11,000 pelamis, 750 km of coastline
- 3 x all the world's windmills ('240 GW') on 8% of country & equal area offshore
- all municipal waste incinerated, and equal agri. waste
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 kWh/d
Wood: 5 kWh/d
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
In 2006, the UK imported 28 kWh/d/p of fuel
- 23% of its primary consumption
Imports

**Value of imports**

- **EU:** £161 bn
- **Norway:** £15 bn
- **Russia:** £6 bn
- **Switzerland:** £4.5 bn
- **USA:** £26 bn
- **Canada:** £5 bn
- **China:** £16 bn
- **Japan:** £8 bn
- **Hong Kong:** £7.5 bn
- **Singapore:** £4 bn
- **Turkey:** £4 bn
- **South Africa:** £4 bn
- **other countries**

**Value of imports**

- **Bulk fuels:** £30 bn
- **Ores:** £5.5 bn
- **Agricultural products:** £27 bn
- **Wood:** £3 bn
- **Metals:** £20 bn
- **Chemicals (including plastics):** £42 bn
- **Paper, public’n:** £8 bn
- **Textiles, leather:** £20 bn
- **Machinery:** £21 bn
- **Electrical equipment:** £60 bn
- **Furniture, other stuff:** £15 bn
- **Vehicles:** £48 bn

**Weight of imports in Mt**

- **Bulk fuels:** 131 (not to scale)
- **Ores:** 18
- **Agricultural products:** 9
- **Forestry products:** 8
- **Iron, steel products:** 6
- **Liquid bulk products:** 7
- **Dry bulk products:** 11
- **Containerized freight:** 31
- **Other freight:** 50
- **Vehicles:** 3.2
Independence for Scotland
Plan S: zero-carbon Scotland

Tidal stream: 15+
Wave: 3
Hydro: 2
Waste: 1.1
Pumped heat: 12 kWh/d
Wood: 5 kWh/d
Solar HW: 1
Biofuels: 1
PV: 3
Wind: 28

Tidal stream
1,000 pelamis, 65km of coastline

Biofuels
all municipal waste incinerated, and equal agri. waste

Energy crops: 1200 sq m per person

4% of country
30 windfarms, each 100 sq km
- 6 times as much wind hardware as Denmark

Wood/Miscanthus

Pumped storage - 30 Cruachans
Upgrade Anglo-Scottish interconnector
Plan S: zero-carbon Scotland

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]
Nuclear-powered ships

NS Savannah

Ice-breaker Yamal
Electric plane

Range: 50 km
Passenger transport efficiency: 11 kWh per 100 p-km
Road planning
What can you do?

Legislation

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

\[2 + 2 \neq 100\]
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
Petrol and diesel

The graph shows the relationship between energy consumption (kWh per 100 km) and emissions (g per km) for different fuel efficiencies. The lines represent different fuel types: petrol and diesel.

- **Petrol** lines are represented by blue dots and red crosses.
- **Diesel** lines are represented by red dots and blue crosses.

The x-axis represents emissions in grams per kilometer, while the y-axis represents energy consumption in kWh per 100 kilometers.

Key points:
- At 20 mpg, petrol and diesel lines converge, indicating similar energy consumption and emissions at this efficiency level.
- As efficiency increases, the difference in energy consumption and emissions between petrol and diesel becomes more pronounced.

This graph highlights the trade-offs between fuel efficiency and emission reduction for petrol and diesel vehicles.
Carbon emissions from cars

VW Polo blue motion (99 g/km)
Toyota Prius (104 g/km)
Honda Civic 1.4 (109 g/km)
Audi A3 (143 g/km)
Average new car, UK (168 g/km)
Lexus RX 400h (192 g/km)
Jeep Cherokee 2.8 (246 g/km)
Average new car, USA (255 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)
Building regulations

<table>
<thead>
<tr>
<th>Maximum U-values (W/m²/K)</th>
<th>England and Wales</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Roofs</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>Floors</td>
<td>0.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Windows, doors</td>
<td>3.0</td>
<td>2.0-2.2</td>
</tr>
</tbody>
</table>
Energy-efficient, award-winning buildings?

Energy rating bands

Homes
- European average: 33 W/m²
- my house, before: 7.1 W/m²
- my house, after the Heatkeeper house: 6.6 W/m²

Offices
- UK service sector: 30 W/m²
- DFID: 43 W/m²
- Home Office: 167 kWh/y/m²
- NEF office: 265 kWh/y/m²
- Elizabeth Fry bldg, UEA: 11 W/m²
- Cambridge University: 37 W/m²
- Old Schools: 34 W/m²
- Rutherford building: 36 W/m²
- Law Faculty: 22 W/m²
- Gates Building: 25 W/m²

112 kWh/y/m² benchmark for offices
167 kWh/y/m² university arts benchmark
265 kWh/y/m² science lab benchmark

Power per unit floor area (W/m²)

Old Schools
Rutherford building
Law faculty
Gates building
Turn the thermostat down

Heat loss = Leakiness × Average temperature difference

(kWh/d) (kWh/d/°C) (°C)

Graphs showing 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
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>Overview</th>
<th>Features</th>
<th>Specifications</th>
<th>Controllers</th>
<th>Downloads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
<td>Indoor Unit</td>
<td>FTXS25EVMA</td>
<td>RXS25EAVMA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outdoor Unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rated Capacity</strong></td>
<td>Cool (kW)</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat (kW)</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capacity Range</strong></td>
<td>Cool (kW)</td>
<td>1.2-3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat (kW)</td>
<td>1.2-4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indoor Air Flow</strong></td>
<td>Cool (l/s)</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat (l/s)</td>
<td>157</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indoor Fan Speeds</strong></td>
<td></td>
<td>5 steps, quiet and automatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C.O.P</strong></td>
<td></td>
<td>4.17/4.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front Panel Colour</strong></td>
<td></td>
<td>White</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Supply</strong></td>
<td></td>
<td>1 phase, 220-240V, 50Hz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Heat pumps

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

EcoCute water heater - CoP = 4.9!
Carbon Trust on Micro-CHP

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.

**Annual emissions (kgCO₂)**

- **Domestic Micro-CHP**
- **Domestic boiler**

Cluster scenarios include:
- New build
- 1920-2005
- Pre 1920
- Up to 90m²
- 90m² to 110m²
- Over 110m²
- Heat demand > 15,000
- Heat demand > 20,000
If they used 0.43 kg CO$_2$/kWh instead...
Micro-wind (one per person?)

David Cameron's chimney ->

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

2000 pounds for that!
How to make a difference?

"We were going to have a wind turbine but they're not very efficient"

From Private Eye, April 2007
Micro-wind and mini-wind

Ampair '600 W' micro-turbine
Leamington Spa
0.04 kWh per day

Iskra '5 kW'
Hertfordshire
11 kWh per day
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 wind farms. 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 - 10 GWh energy; 2 GW maximum power
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.
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

The diagram compares various energy storage technologies based on energy density, cycles, and efficiency. Technologies such as hydrogen, propane, petrol, ethanol, coal, methanol, firewood, alkaline, lithium ion, Ni-MH, Ni-Cd, lead acid, vanadium, supercapacitor, and pumped storage are plotted on the graph.
Altitudes in the UK

Figure 7.1. Altitudes of land in Britain. The rectangles show how much land area there is at each height.

- 670 km$^2$ between 800m and 1344m
- 20000 km$^2$ between 400m and 800m
- 40000 km$^2$ between 200m and 400m
- 63000 km$^2$ between 100m and 200m
- 72000 km$^2$ between 50m and 100m
- 50000 km$^2$ between 0m and 50m
Pumped storage and tide combined

Sea

High

Low

Pump at high tide

Generate on demand (lower conditions)

Pump at low tide

Generate on demand (higher conditions)
Seagen

marineturbines.com
'Tidal power slows down the earth's rotation'

Natural rotational energy loss is already 3 TW.
Natural slowing rate of the earth's rotation is 2.3 ms/day per century.

World power consumption is 15 TW.
If extra tidal power doubled the slowing rate, then in two million years, the length of a day would be longer by two minutes instead of one minute.
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
Waste incinerators

1 kg of waste - 0.5 kWh of electricity
Municipal solid waste

The diagram illustrates the recycling, incineration, and landfilling of solid waste in different countries. Each point on the graph represents a country, with the axes indicating the landfilled and incinerated waste per capita (kg/d/p). The percentage of recycled waste is also shown on the graph.

Key countries and their waste management percentages include:
- Netherlands: 64%
- Austria: 59%
- Germany: 57%
- Denmark: 41%
- Luxembourg: 36%
- Ireland: 31%
- United Kingdom: 18%
- Belgium: 52%
- Sweden: 41%
- Spain: 34%
- Italy: 29%
- France: 28%
- Finland: 28%
- Greece: 8%
- Portugal: 4%

This visual representation helps in understanding the distribution and management of municipal solid waste across various European countries.
British nuclear waste

Figure 24.13. British nuclear waste, per person, per year, has a volume just a little larger than one wine bottle.

<table>
<thead>
<tr>
<th>waste</th>
<th>mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>0.0015 g per kWh</td>
</tr>
<tr>
<td>spent fuel from npower’s reactors</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>1000 g per kWh</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>ash</td>
<td>30 g per kWh</td>
</tr>
<tr>
<td>U₃O₈ in Chinese ash</td>
<td>0.0060 g per kWh</td>
</tr>
</tbody>
</table>
"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.

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
Ocean Uranium
Desalination

8 kWh/m³

Jersey Water
Sunniness

and its effect on PV

Dependence on irradiance

PV efficiencies

Cambridge

Delivered power (W/sq m)
Solar chimney

No mirrors!
Yellow: 125 kWh/d/p for 1 billion people
- or 250 kWh/d/p for 0.5 billion people
Numbers

24 MW at Guernsey electricity

20 MW
1 kW (24 kWh/d)
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
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): N701iEKO
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)
KiWiGen CAROUSEL: the circular base, tensor-structure and the tandem kite arrays

280 000 m²
300 W/m²
84 MW

Comparison between a large scale KiWiGen and a 1 MW 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>
</tr>
</tbody>
</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

![Graph showing the relationship between Power (MW) and Diameter (m) for SA, NREL, and DWIA models.](image)
Energy use versus GDP - linear scale
Energy use versus GDP - log scale

GDP per capita ($)

Power consumption (kWh/d/p)

UNDP Human Development Report, 2007
Carbon - where is it?

Gigatonnes Carbon

- Atmosphere: 600
- Vegetation: 700
- Soils: 3000
- Accessible fossil fuels: 1600
- Ocean: 40 000
Carbon - where is it going?

- Atmosphere: 600 GtC/y
- Vegetation: 700 GtC/y
- Soils: 3000 GtC/y
- Accessible fossil fuels: 1600 GtC/y
- Ocean: 40000 GtC/y

Fluxes:
- 2 GtC/y from Vegetation to Atmosphere
- 7 GtC/y from Soils to Atmosphere
When does it go away?
Socolow's model of CO2 emissions

Baer & Mastrandrea: Socolow's trajectory not good enough
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.]
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.]
Sequestration cost per molecule (from thin air)

0.03% CO$_2$ $\rightarrow$ Pure CO$_2$ $\rightarrow$ Liquid CO$_2$ (100–200 bar)

Ideal concentration machine

$$kT \ln \frac{V_0}{V_1} = kT \ln 3000 = 8 \ kT$$

Ideal liquefaction machine

$$4 \ kT$$

Total

$$12 \ kT \text{ per molecule}$$
Ideal sequestration cost

$12kT$ per molecule is $0.2$ 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

Sequestration:

1 kg of CO$_2$ $\leftrightarrow$ 0.2 kWh ideal cost $\leftrightarrow$ 0.6 kWh actual cost
Lackner’s method (June 2007): \(1.3 \text{kWh}^{(e)}\) per kg of CO\(_2\):

To capture 30 kg per day per person, need \(40 \text{kWh}^{(e)}\) per day.
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

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
"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.
make a donation
Every £10 buys 1 tree and offsets 1 tonne of CO₂

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 £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

Reducing CO2 emissions one car at a time

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Glossary
FAQ
Contact us
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 CO$_2$ from thin air?

Energy cost $\geq$ 600 kWh per tonne
Gasoline from thin air

Federal Lab Says It Can Harvest Fuel From Air (With a Catch)

By ANDREW C. REVKIN

February 13, 2008, 3:06 pm

Fill 'er up from the sky? (Photo: Marilynn K. Yee/The New York Times)

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:**

\[
1 \text{ kg of CO}_2 \leftrightarrow 4 \text{ kWh heat } \leftrightarrow 1.3 \text{ kWh useful energy} /3
\]

**Reversal:**

\[
1 \text{ kg of CO}_2 \leftrightarrow 4 \text{ kWh ideal cost } \leftrightarrow 12 \text{ kWh actual cost} \times 3
\]

At 5p per kWh, that costs £600 per ton of CO₂.

Under these assumptions, every litre of gasoline (10kWh) would cost 30kWh of nuclear.
'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.'
The plastics we use are made from one hundred percent by-product of the refinement of oil to petroleum and are, therefore, totally environmentally friendly as long as society has a petroleum (petrol) requirement.
Sustainable Energy
- without the hot air

Biofuels

David MacKay
Department of Physics
University of Cambridge

www.withouthisair.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 delivered by plants

delivered energy

additional inputs required for farming and processing

Energy used or lost in farming and processing

net energy

x Area

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/p

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

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

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

- all renewables in 2006: 1.05 kWh/d
  - offshore wind: 0.03 kWh/d
  - small hydro: 0.022 kWh/d
  - large hydro: 0.19 kWh/d
  - biodiesel: 0.13 kWh/d
  - biomass (wood in homes): 0.07 kWh/d
  - biomass (cofiring): 0.12 kWh/d
  - biomass (landfill gas, sewage, waste incineration): 0.3 kWh/d
  - solar HW: 0.014 kWh/d
  - solar PV: 0.0003 kWh/d
  - wind: 0.16 kWh/d

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

Power per unit area

- Sunlight: 100 W/m²
- Carbohydrate energy delivered by plants: 0.5 W/m²
- Additional inputs required for farming and processing
- Energy used or lost in farming and processing

Net energy

Taking the most efficient plants

Total UK land area: 4000 m² per person

- Buildings: 48 m²
- Gardens: 114 m²
- Roads: 60 m²
- Water: 69 m²

Arable land: 2800 m²

Half of arable land: 1400 m² per person
How much power could Britain get from biofuels?

Power per unit area

- Sunlight: 100 W/m² × 1400 m²
- Carbohydrate energy delivered by plants: 17 kWh/d
- Energy used or lost in farming and processing
- Delivered energy
- Net energy

Additional inputs required for farming and processing

Total UK land area: 4000 m² per person
- Arable land: 2800 m²
- Half of arable land: 1400 m² per person
- Buildings: 48 m²
- Gardens: 114 m²
- Roads: 60 m²
- Water: 69 m²
Even if all the other issues were resolved

Biofuels could make only a small contribution

Sunlight
100 W/m² × 1400 m²

Carbohydrate energy delivered by plants
17 kWh/d

Additional inputs required for farming and processing

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://lfee.mit.edu/metadot/index.pl?id=2234

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

Britain

Total UK land area: 4000 m² per person

- buildings: 48 m²
- gardens: 114 m²
- roads: 60 m²
- water: 69 m²

arable land: 2800 m²
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

**Examples**
- 20 mins of kettle - 1 kWh
- Food - 3 kWh / day (*)
- Bath - 5 kWh (*)
- Litre of petrol - 10 kWh
- Aluminium can - 0.6 kWh

**UK:** 4000 m² per person
Drive a car 100km...

80 kWh

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

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 ≈ 10 tonnes CO₂/y

www.dti.gov.uk
\[ v = 6 \text{ m/s (force 4)} \]

\[
\begin{array}{ll}
\text{Wind farm} & 2 \text{W/m}^2 \text{ flat ground}
\end{array}
\]

**UK:** 4000 m\(^2\) 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
Renewables are diffuse

<table>
<thead>
<tr>
<th>Power per Unit Land Area</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>2 W/m²</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>3 W/m²</td>
</tr>
<tr>
<td>Tidal pools</td>
<td>3 W/m²</td>
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<td>5–20 W/m²</td>
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<tr>
<td>Plants</td>
<td>0.5 W/m²</td>
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</tr>
<tr>
<td>Concentrating solar power (desert)</td>
<td>15–20 W/m²</td>
</tr>
<tr>
<td>Ocean thermal</td>
<td>5 W/m²</td>
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<tr>
<td>Rain-water (highlands)</td>
<td>0.24 W/m²</td>
</tr>
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<td>Rain-water (lowlands)</td>
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To make a difference, renewable facilities have to be country-sized.
All renewables are diffuse

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To make a difference, renewable facilities have to be country-sized
Bavaria Solar Park: $5 \text{ W/m}^2$; this picture shows $0.7 \text{ MW}$ (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)

- 3 W/m²
- 0.24 W/m²
- 0.02 W/m²

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

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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
<table>
<thead>
<tr>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fission</td>
</tr>
<tr>
<td>1000 W/m²</td>
</tr>
</tbody>
</table>
We can't live on our own renewables - at least, not as we currently live

Current consumption: 125 kWh/d per person

- Tide: 11 kWh/d
- Wave: 4 kWh/d
- Shallow offshore wind: 16 kWh/d
- Hydro: 15 kWh/d
- Biomass: food, biofuel, wood, waste incin’n, landfill gas: 24 kWh/d
- PV, 10 m²/p: 5
- Solar heating: 13 kWh/d
- Wind: 20 kWh/d

www.withouthotair.com
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'.
A consultation exercise in full swing

Penicuik Environment Protection Association
http://www.auchencorth.org.uk/
13C is fine (just turn it up when you feel cold)
Carbon dioxide concentration (ppm)

World greenhouse gas emissions: 34 GtCO$_2$e/y

Total GHG emissions (2000) = 34 GtCO$_2$e
What's required:

Baer & Mastrandrea

World greenhouse gas emissions: 34 GtCO$_2$e/y

Total GHG emissions (2000) = 34 GtCO$_2$e
Total GHG emissions (2000) = 34 GtCO$_2$e
1880-2004

Data source: Climate Analysis Indicators Tool (CAIT)
Sustainable Energy – without the hot air

David JC MacKay

Publication date: December 1, 2008
ISBN: 978-0-9544529-3-3
384 pages, full colour throughout.
Price (provisional): £24.95

Publisher: UIT Cambridge

get it free online www.withouthotair.com