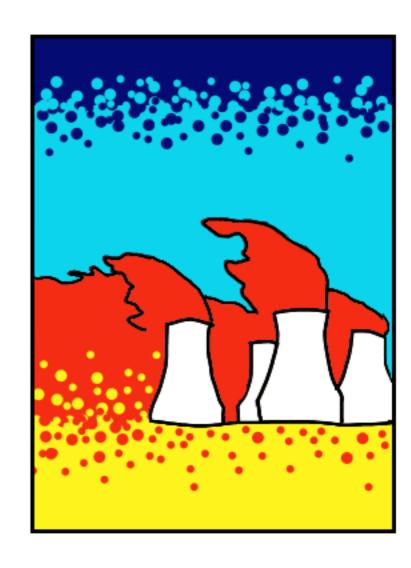
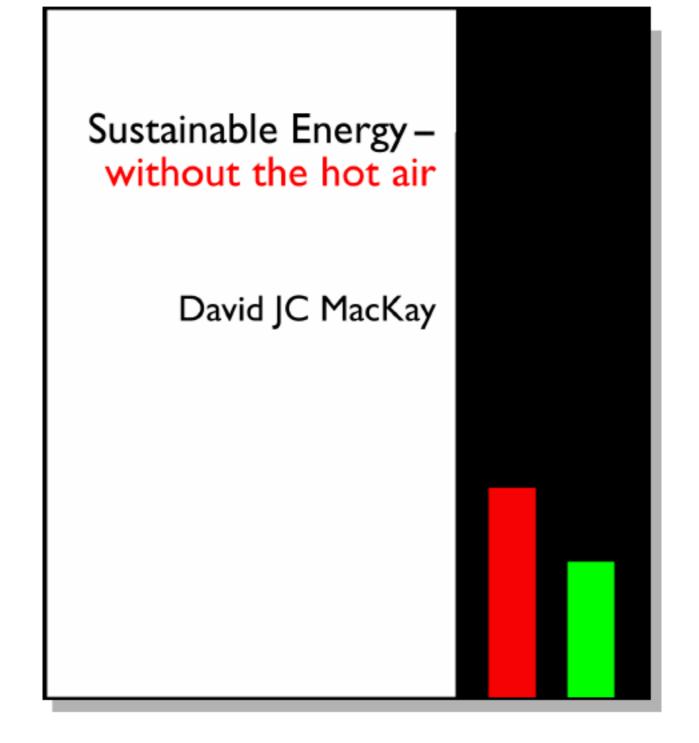
Energy plans that add up

David MacKay

Department of Physics University of Cambridge

www.withouthotair.com





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

NOW A MAJOR MOTION PICTURE

aninconvenienttruth

THE PLANETARY EMERGENCY OF GLOBAL WARMING AND WHAT WE CAN DO ABOUT IT

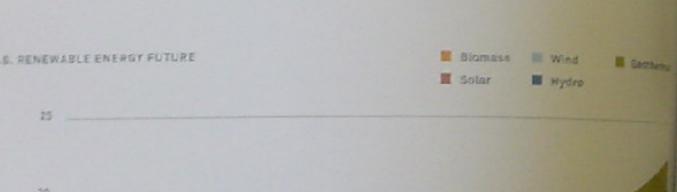
AL GORE

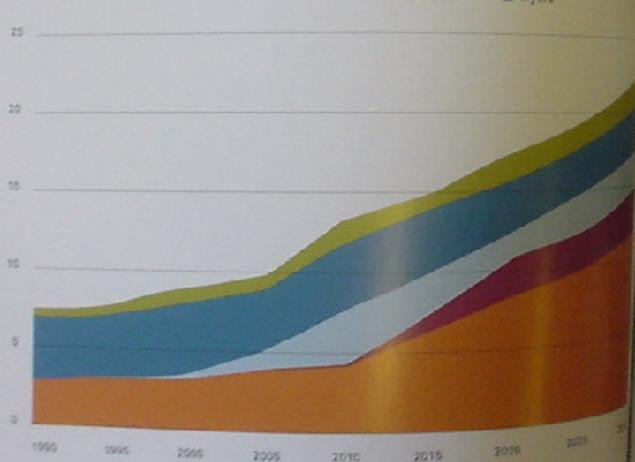
The fourth and final problem in the way some people think about global warming is the dangerous misconception that if is the dangerous misconception to the scientists saying. "We can do something about this it really is as big a threat as the scientists saying." are telling us it is, then maybe we're helpless to do anything about it so we might as well throw up our hands.

An astonishing number of people go straight from denial to despair, without pausing on the intermediate step of

and we can.









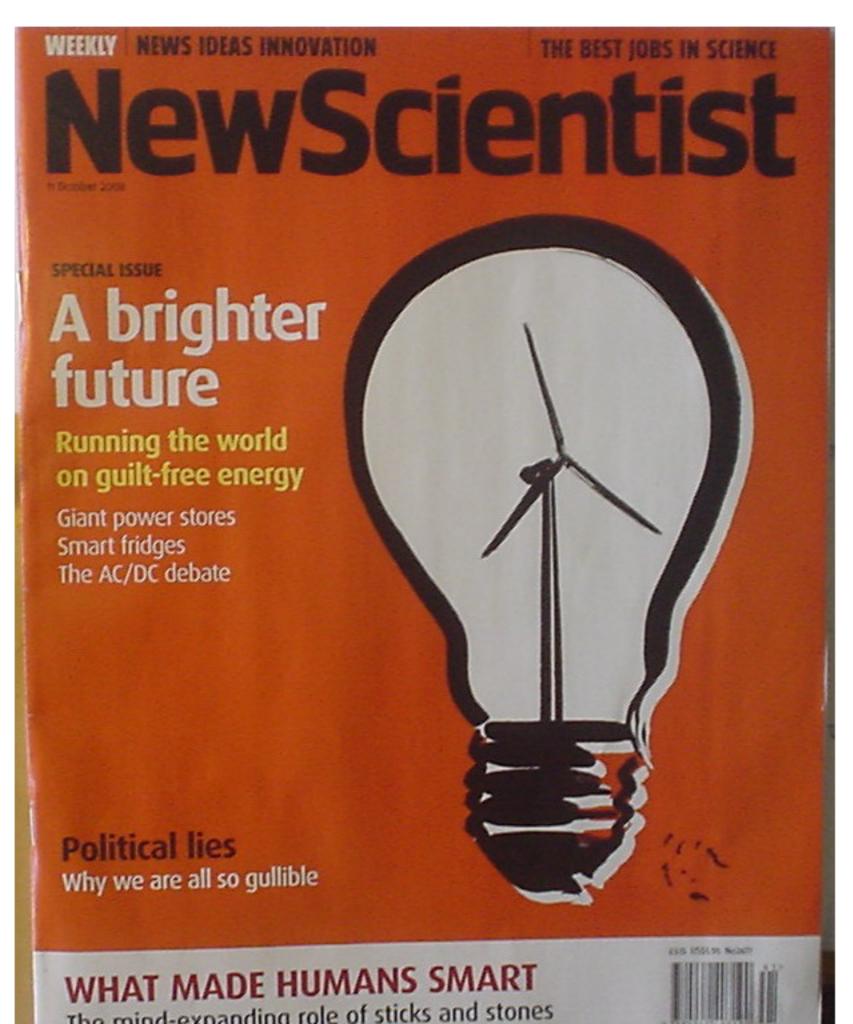


















Water Powered Car Might Be Available by 2009

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.







NATURE Vol 438 24 November 2005



"The governor is a real-life climate action hero today."

— Nancy Ryan



Arnold Schwarzenegger refuels a hydrogenpowered 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.

©2005 Nature Publishing Group

Every little helps?

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

or perhaps worse...

Solar bra brings conservation closer to the heart

Wed May 14, 2008 8:53pm IST



More Video

charge

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

guardianecostore

* Home | New | Women's Fashion | Men's Fashion | Kids | Accessories | Garden | Outdoor | Eco home | Cleaning | Health | Body | Office | Fun

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



£39.95

Quantity: 1

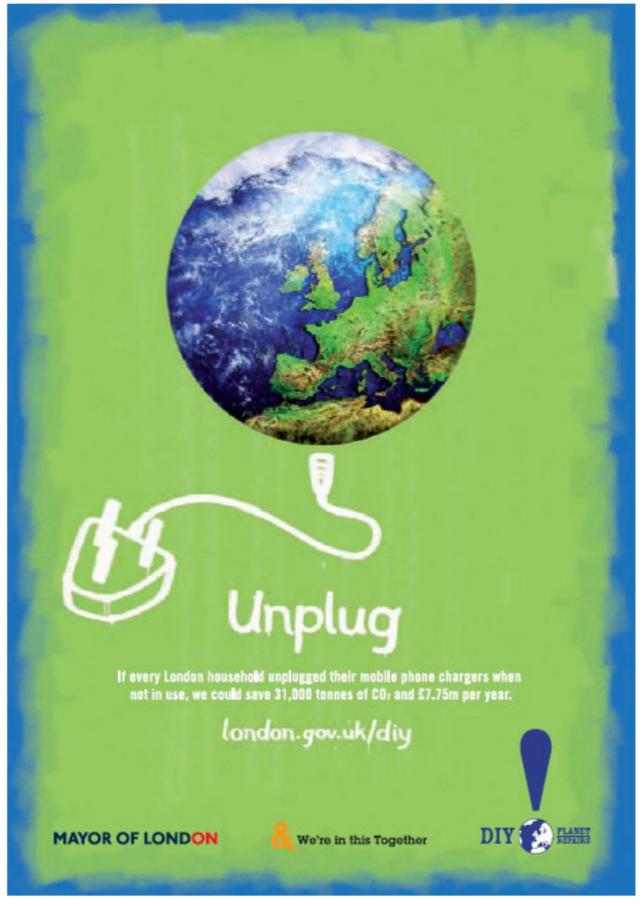
ADD TO CART

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 chargable by kinetic energy (requires minimum wind speed 9mph), but you can also charge it using an ordinary socket.

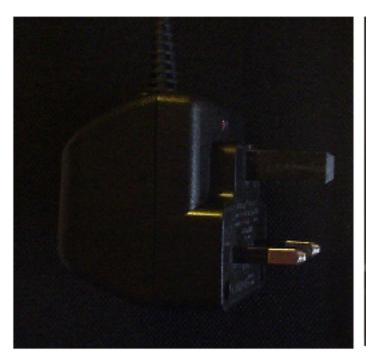
Plug in, charge up, and it becomes a power storage unit. HY-Mini is universally adaptable for your mobile devices. An AC/DC power adaptor for 3-pin wall plugs, USB transfer cable and mobile phone (Nokia / Motorola / Sony Ericsson /Samsung / LG) adaptors are included. MP3 player, iPod, PDA, digital camera,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



'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.'

Numbers







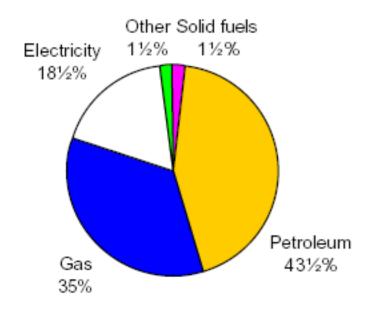
Energy saved by switching off for one day

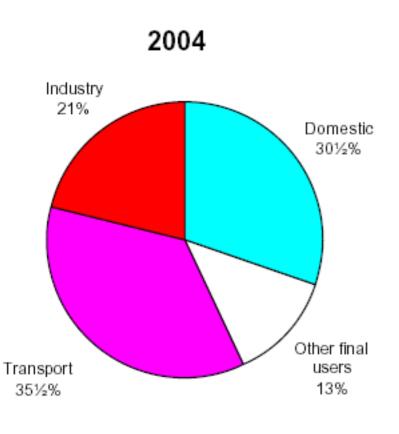
Energy used by driving an average car for one second

 $0.5 \,\mathrm{W} \times 86\,400 \,\mathrm{s} = 40\,000 \,\mathrm{W} \times 1 \,\mathrm{s}$

 $0.01\,\mathrm{kWh}$

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





www.dti.gov.uk

Transport 35%

> Hot air 26%

Hot water 8%

Lighting, appliances 6%

> Process 10%

Other 15% 'primary consumption'

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

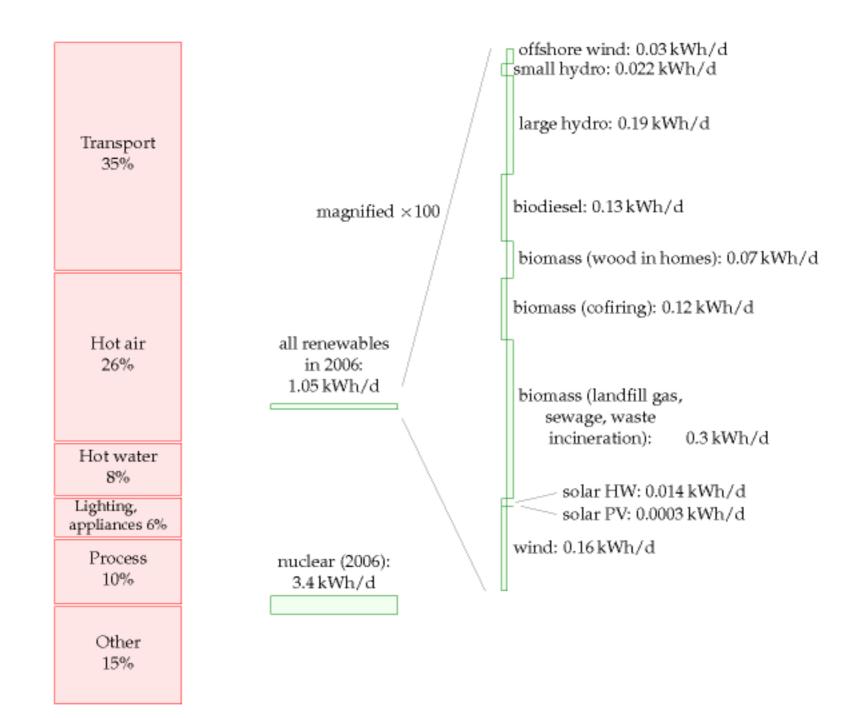
(doesn't include imports, nor solar energy in food)

Area

UK: $4000 \text{ m}^2 \text{ per person}$



Today's supply of renewables and nuclear



Wind

Current consumption $v = 6 \,\mathrm{m/s} \; (\mathrm{force} \; 4)$

Wind farm 2 W/m² flat ground

UK: $4000 \text{ m}^2 \text{ per person}$

Put wind farms on 10% of the country

400 square metres each



consumption: 125 kWh/d per person

Current

Wind: 20 kWh/d

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

50 x Denmark's

7 x Germany's

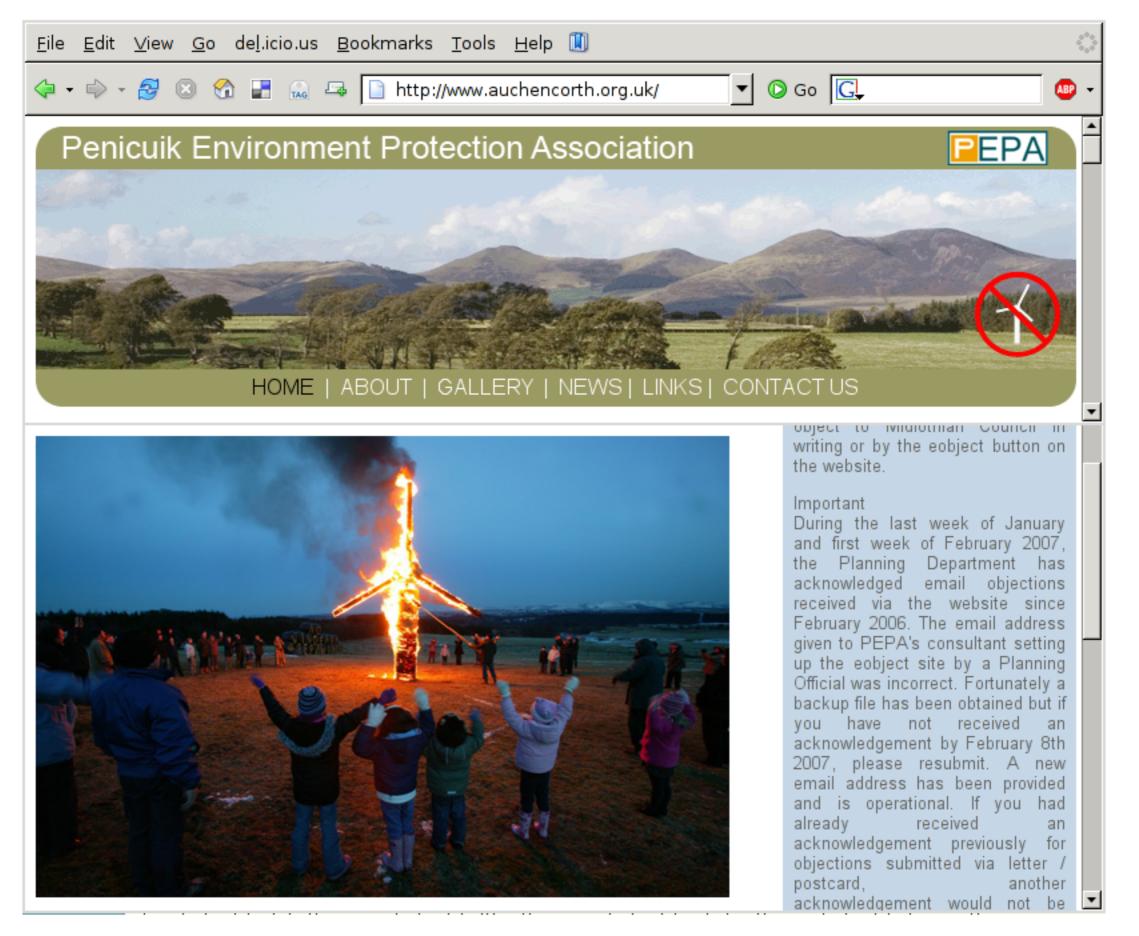


Renewables are diffuse

Power per unit land area

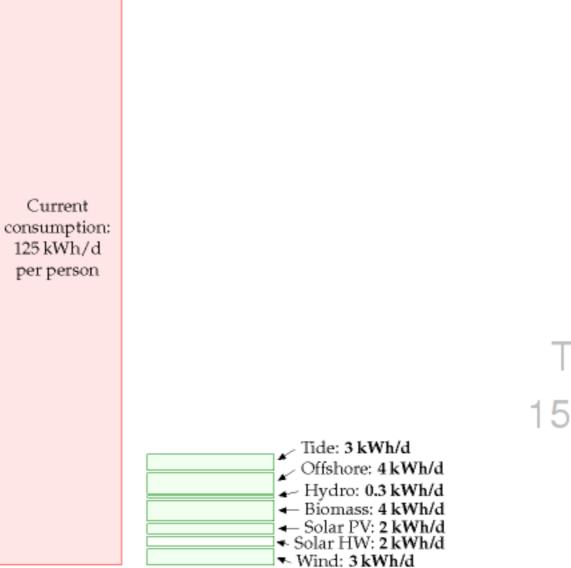
Wind	$2\mathrm{W/m^2}$
Offshore wind	$3\mathrm{W}/\mathrm{m}^2$
Tidal pools	$3\mathrm{W/m^2}$
Tidal stream	$8\mathrm{W/m^2}$
Solar PV panels	$5-20 \text{W/m}^2$
Plants	$0.5\mathrm{W/m^2}$
Solar chimney (Spain)	$0.1\mathrm{W/m^2}$
Concentrating solar power (desert)	$15-20{ m W/m^2}$
Ocean thermal	$5\mathrm{W/m^2}$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

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



A consultation exercise in full swing

after the great British consultation exercise...



This would be a

15-fold increase of
renewables

This shows 18 kWh/d/p

Conclusions - from lecture I

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

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

Current consumption: 125 kWh/d per person



How to make an energy plan that adds up

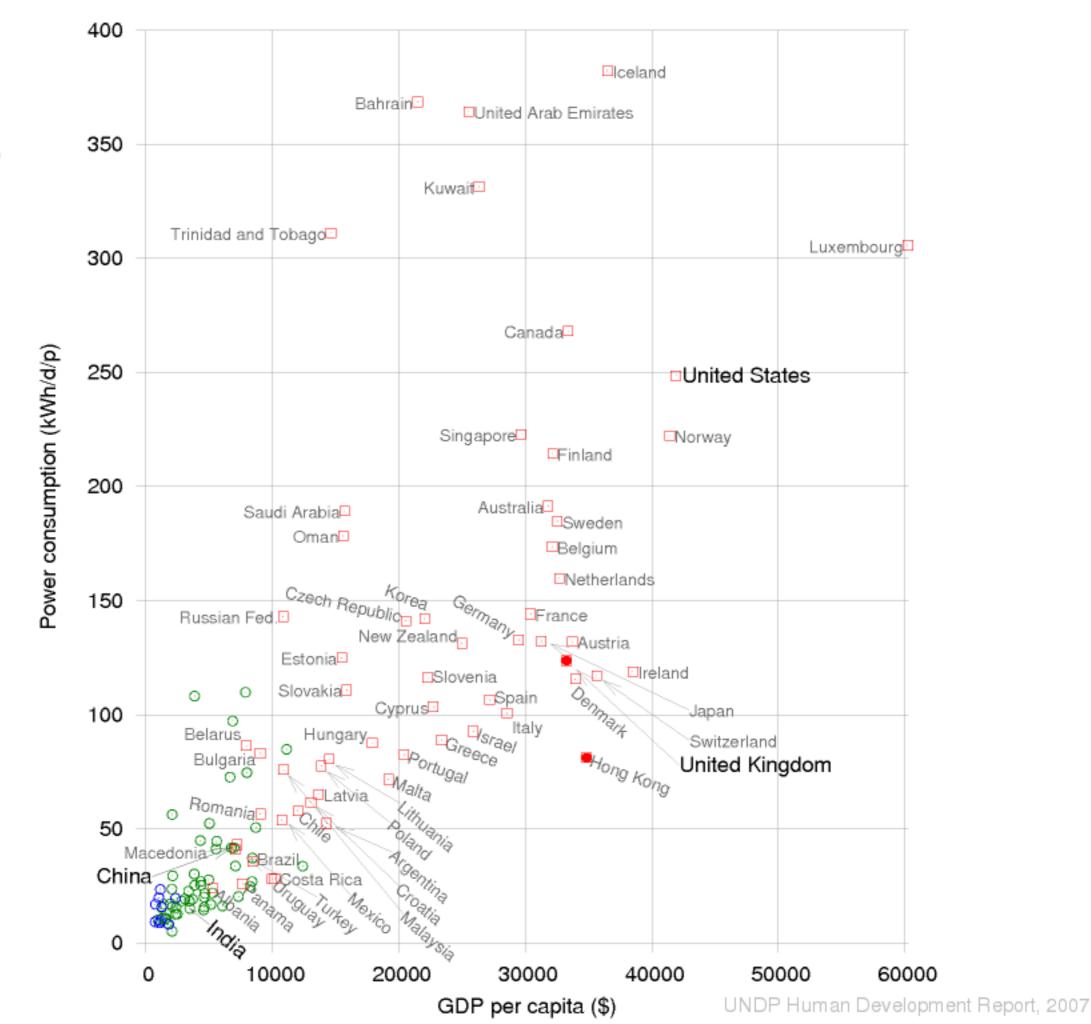
- Demand-side
 - Reduce population
 - Change lifestyle
 - Technology, efficiency

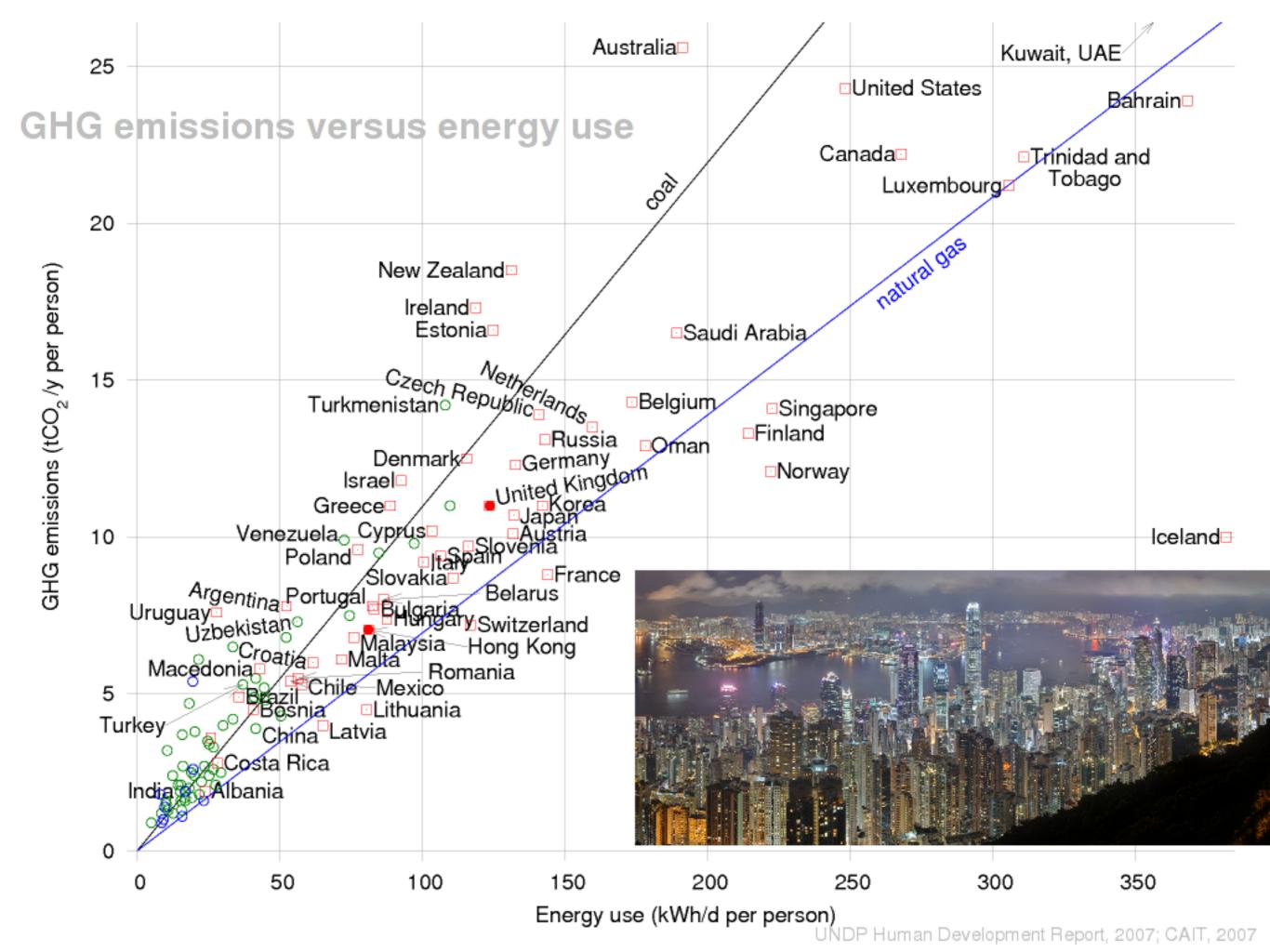
Current consumption: 125 kWh/d per person

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

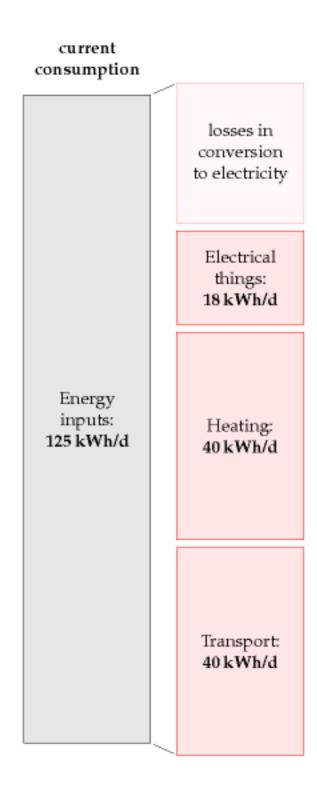
Tide: 3 kWh/d
Offshore: 4 kWh/d
Hydro: 0.3 kWh/d
Hydro: 0.3 kWh/d
Solar PV: 2 kWh/d
Solar HW: 2 kWh/d
Wind: 3 kWh/d

Energy use versus GDP - linear scale





Cartoon Britain, 2008



How to make an energy plan that adds up

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

Current consumption: 125 kWh/d per person

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Tide: 3 kWh/d
Offshore: 4 kWh/d
Hydro: 0.3 kWh/d
Hydro: 0.3 kWh/d
Solar PV: 2 kWh/d
Solar HW: 2 kWh/d
Wind: 3 kWh/d



A Mitsubishi Warrior, yesterday

Efficiency - for transport

"Baby on board"



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 3 kWh per 100 person-km 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



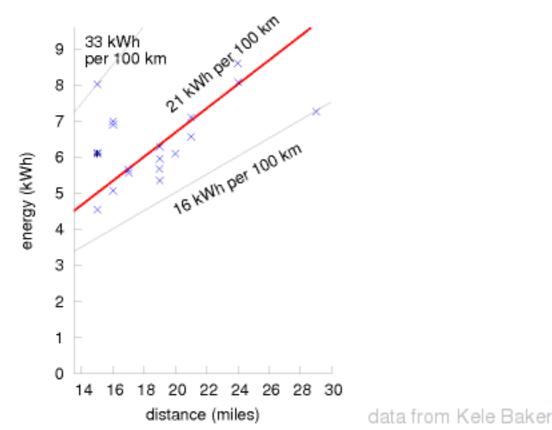






21 kWh per 100 km (solo)

equivalent to 125 miles per gallon



G-Wiz



6 kWh per 100 km

Th!nk Ox



20 kWh per 100 km

Aptera

Loremo









TREV



6 kWh per 100 km

Electric scooters









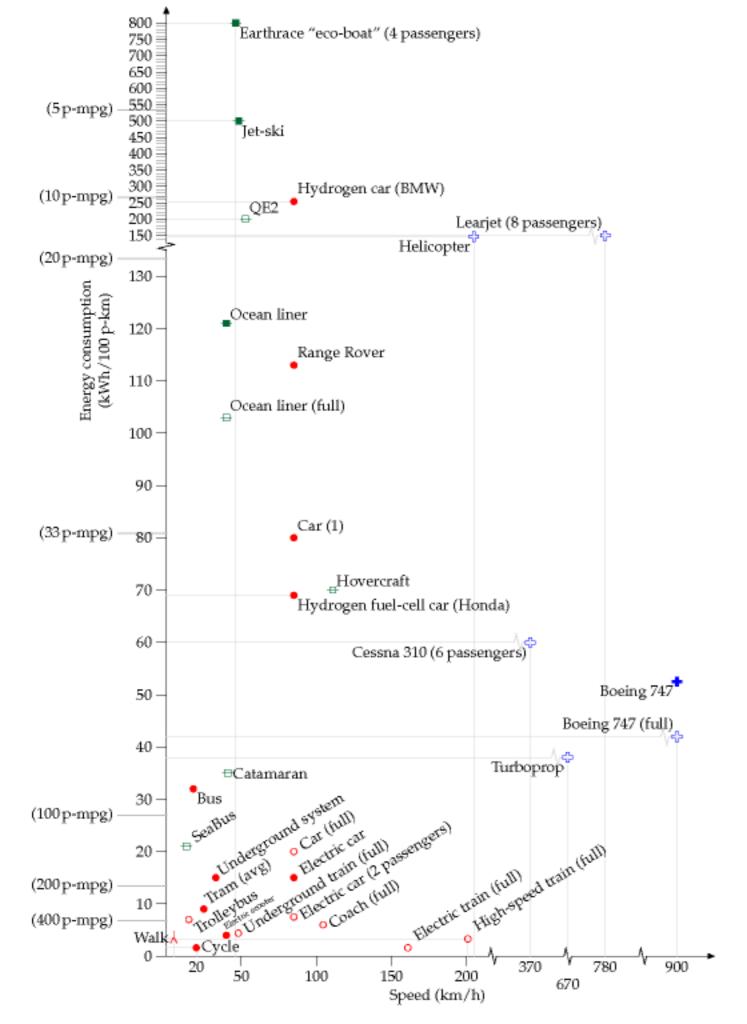


3 kWh per 100 km

http://www.vectrix.com/



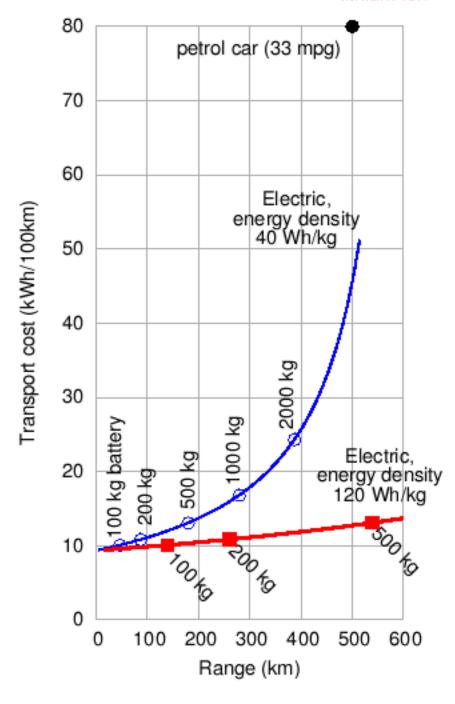




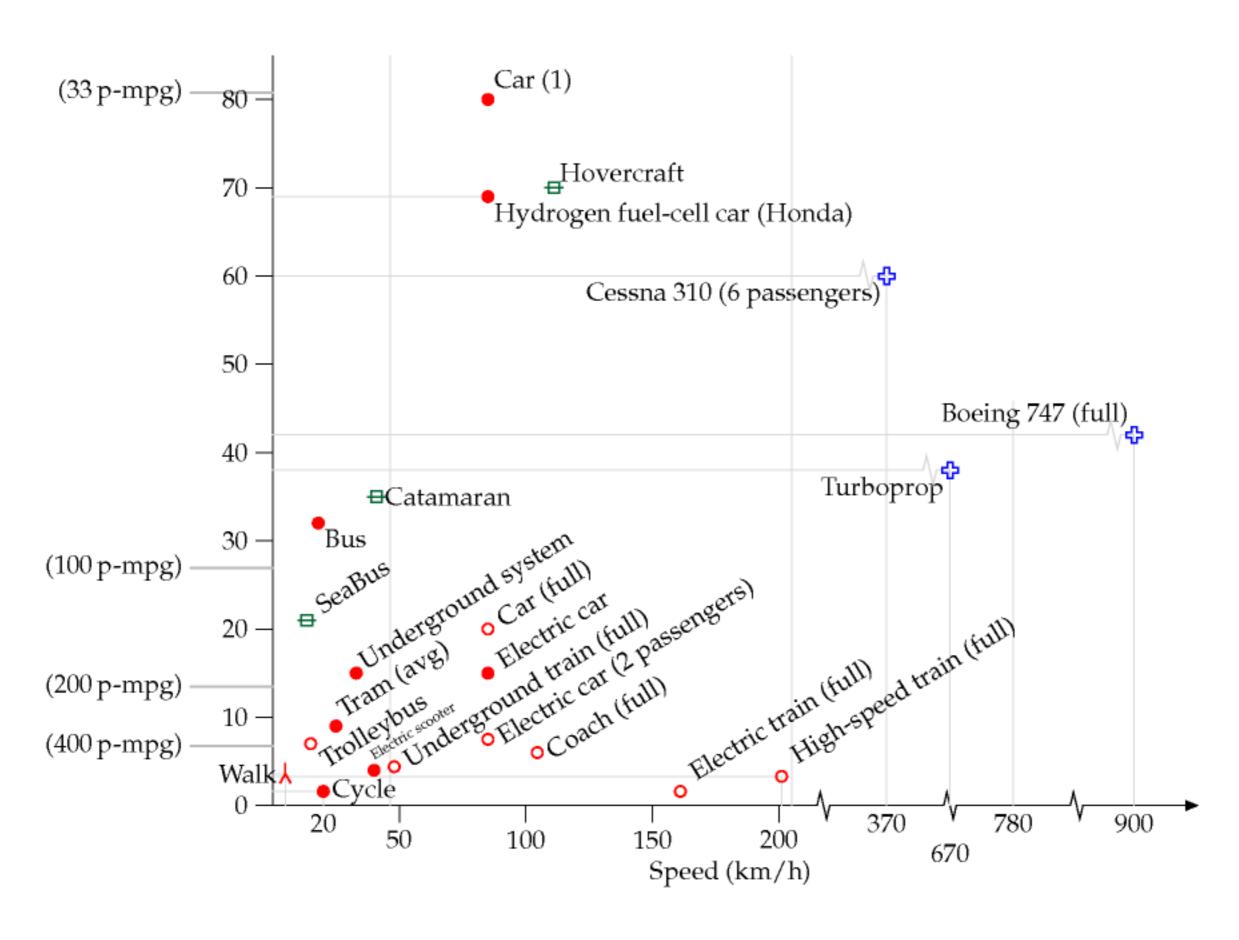
Electric car efficiency and range as a function of battery mass

lead acid -

lithium ion -



Energy consumption (kWh per 100 passenger-km)





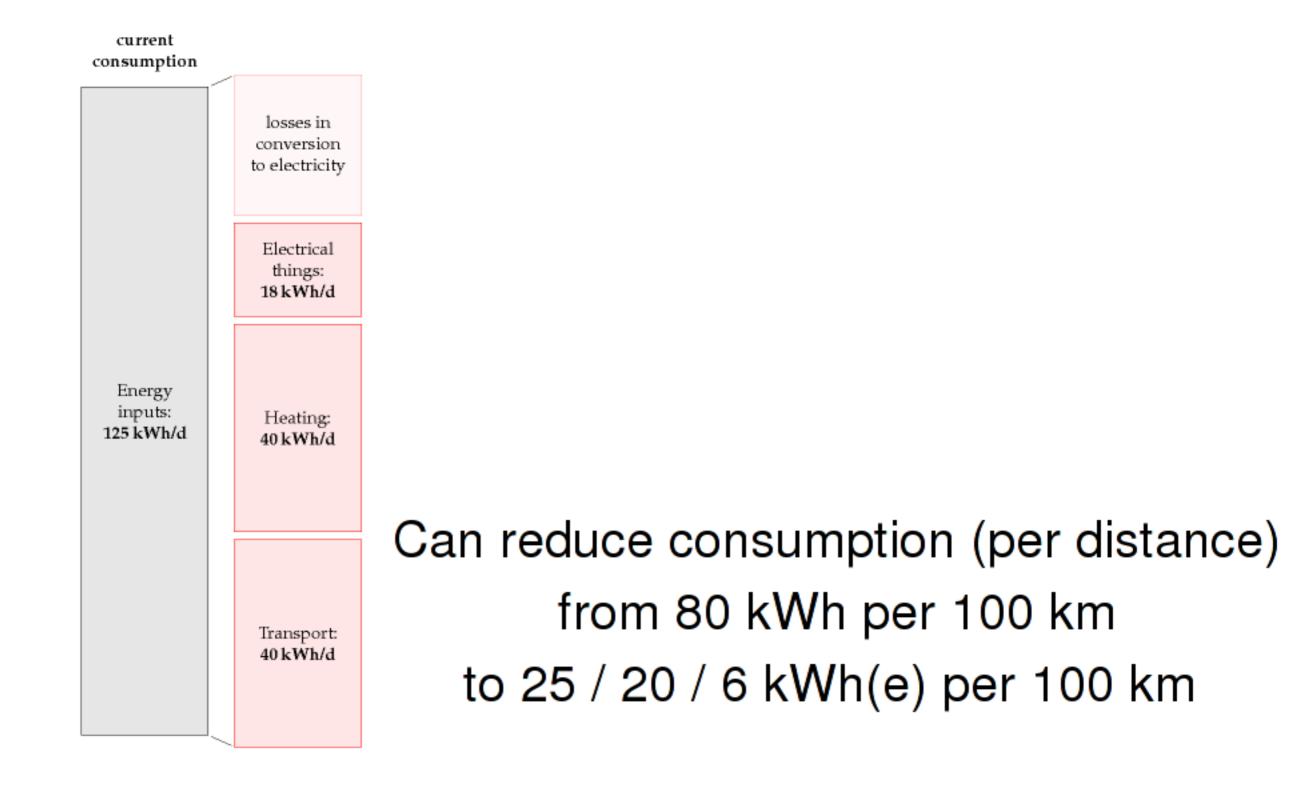
Plug-in hybrids





25 kWh per 100 km (running on electric power alone)

Electrifying transport makes it more efficient



Efficiency II

Heating



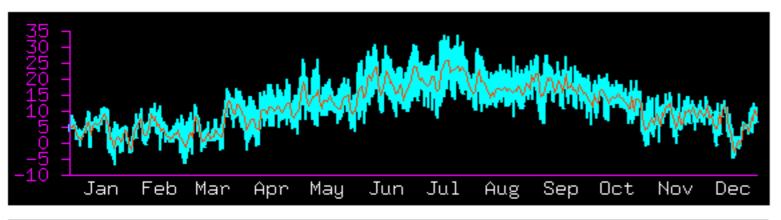
 $\begin{array}{ll} {\rm Heat~loss} & = {\rm Leakiness} & \times {\rm Average~temperature~difference} \\ {\rm (kWh/d)} & {\rm (kWh/d/^{\circ}C)} & {\rm (^{\circ}C)} \end{array}$

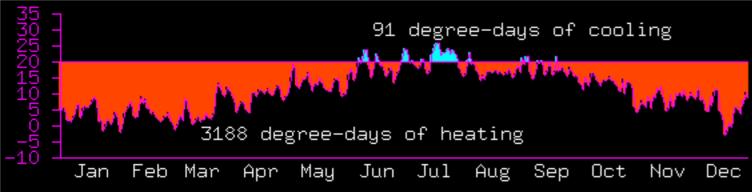
Power required = $\frac{\text{Heat loss}}{\text{of heat-creation}}$

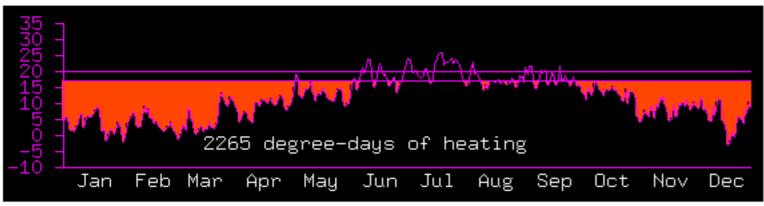
Temperature demand, in degree-days per year

Turn the thermostat down

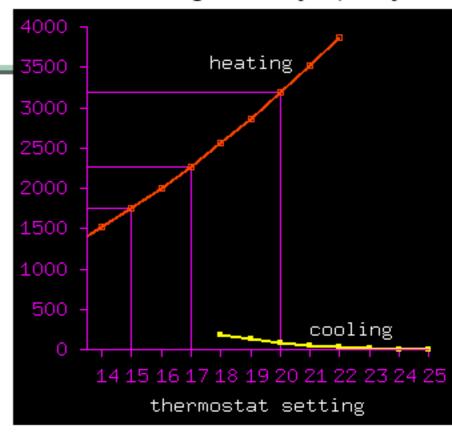




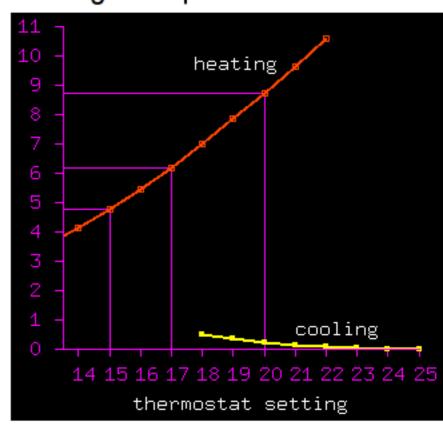






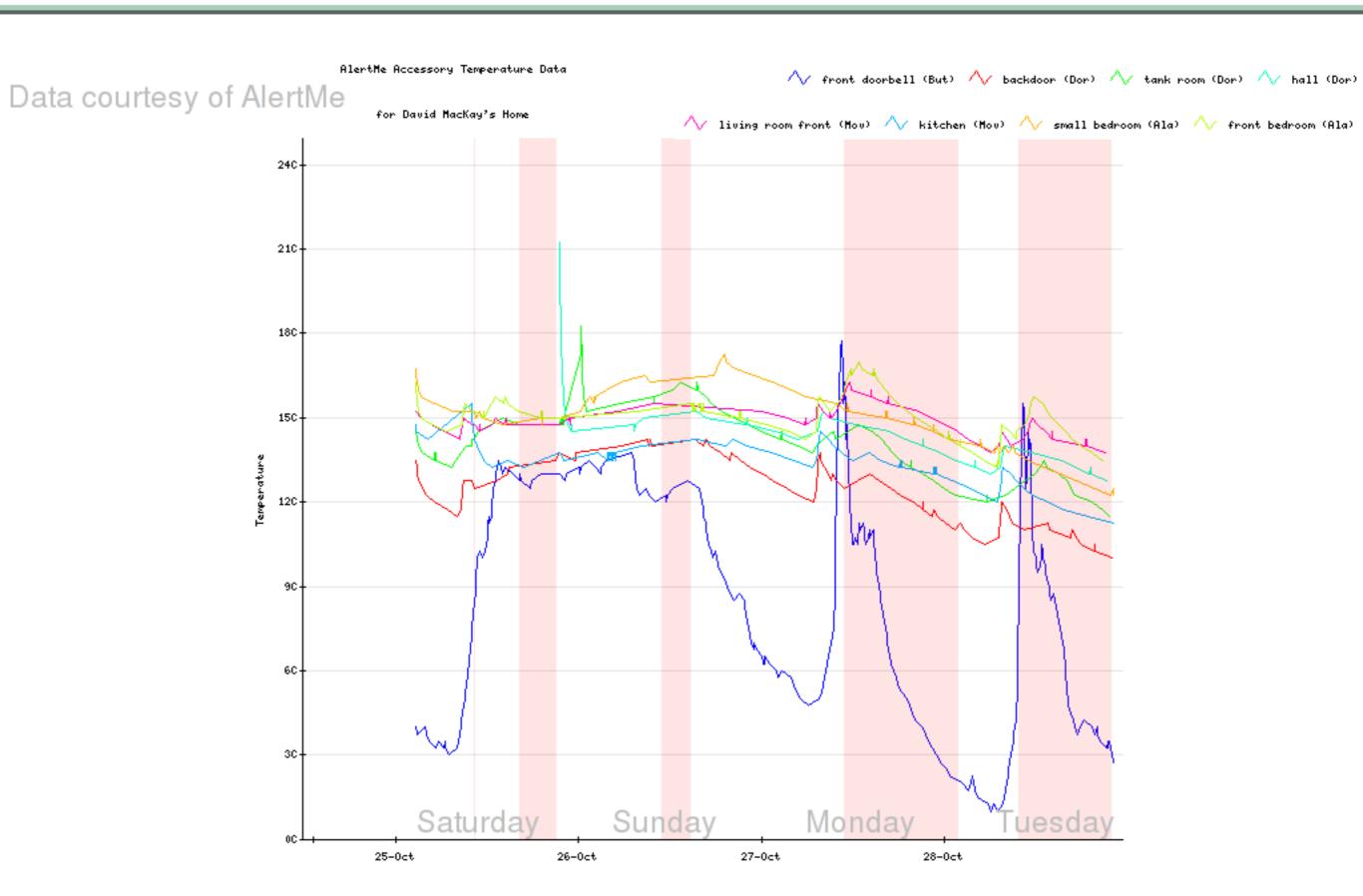


Average temperature difference



Saving: 10% per degree

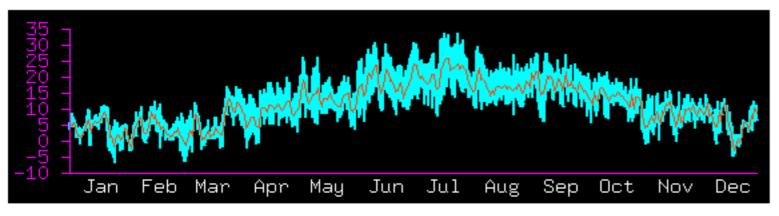
13C is fine (just turn it up when you feel cold)

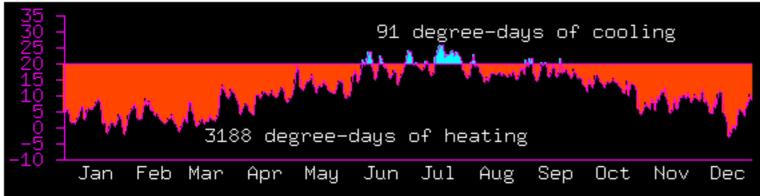


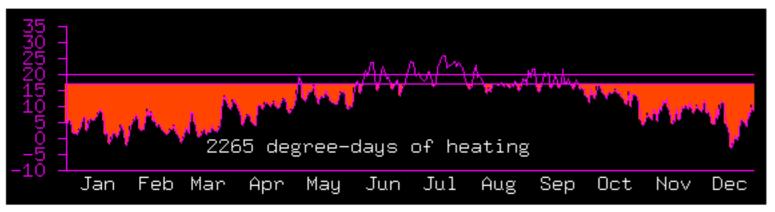
Temperature demand, in degree-days per year

Turn the thermostat down

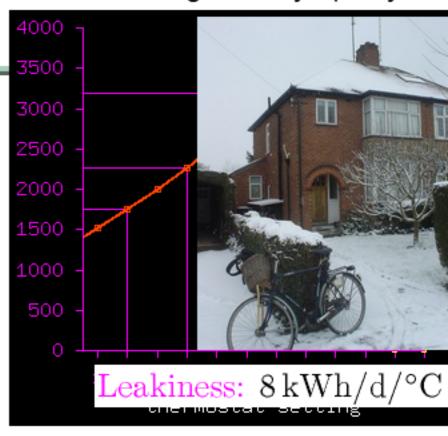




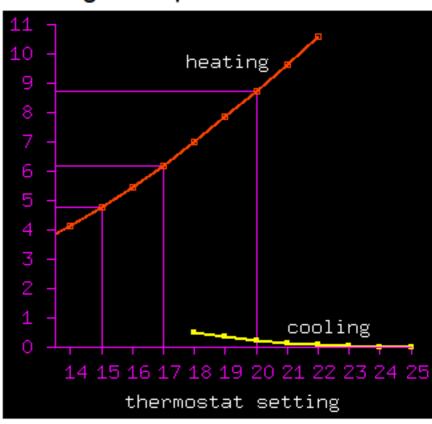








Average temperature difference





Increase coefficient of performance - use Heat pumps





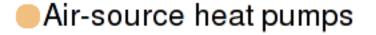
http://www.ecosystem-japan.com/

EcoCute water heater - CoP = 4.9!

Power required = Heat loss / Coefficient of performance of heat-creation

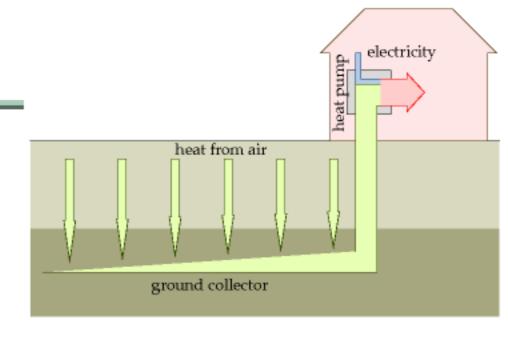
Heating without fossil fuels

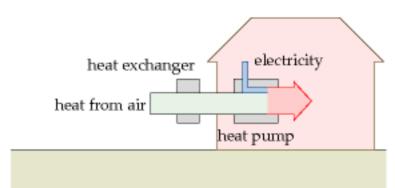
- Heat pumps, powered by electricity
 - Ground-source heat pumps





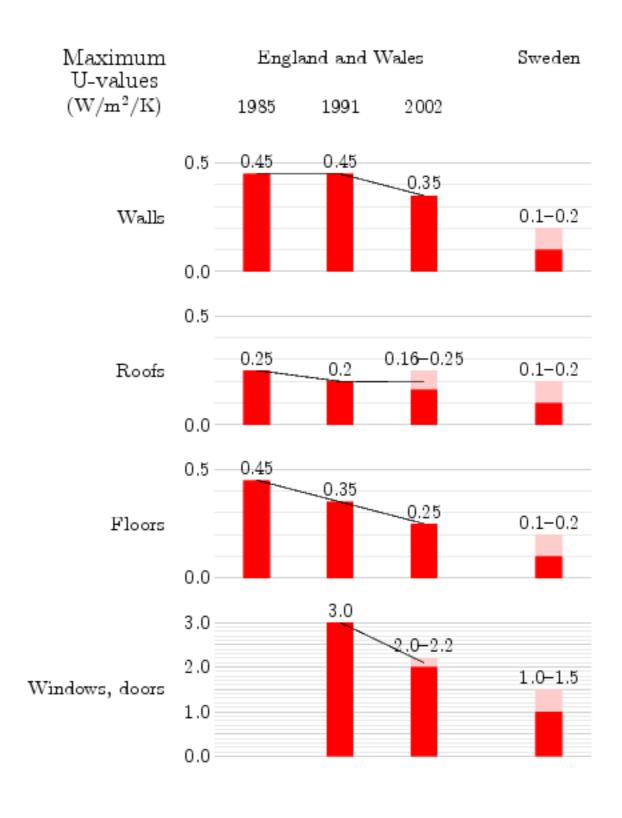
4 times more efficient than ordinary electric heating





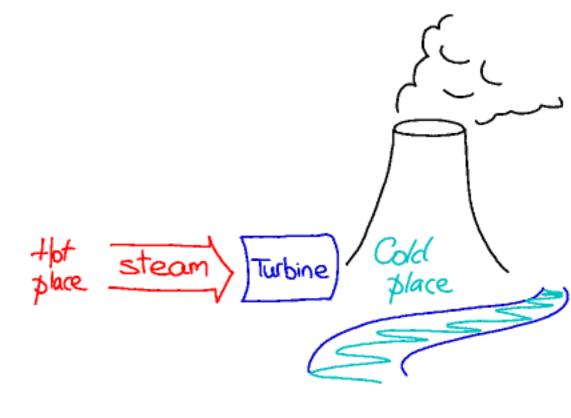


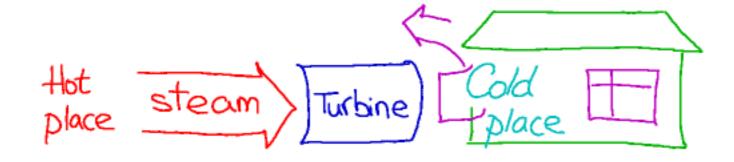
Building regulations



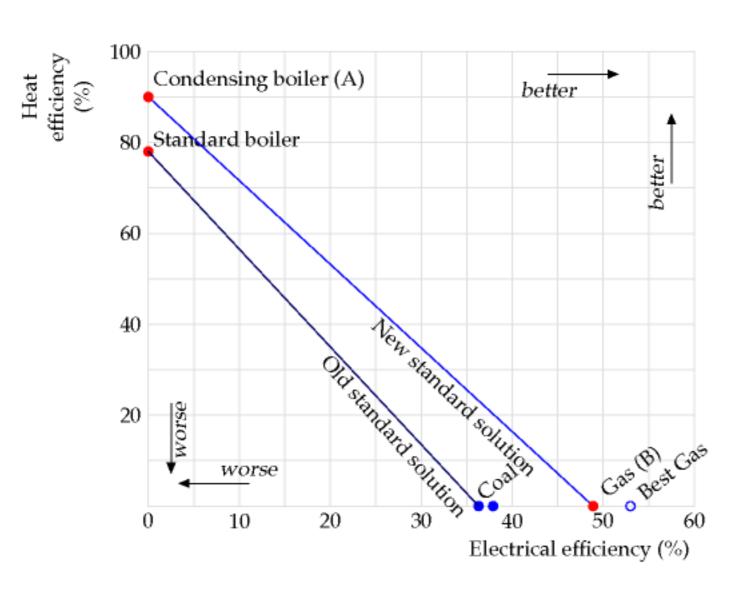
Combined heat and power?

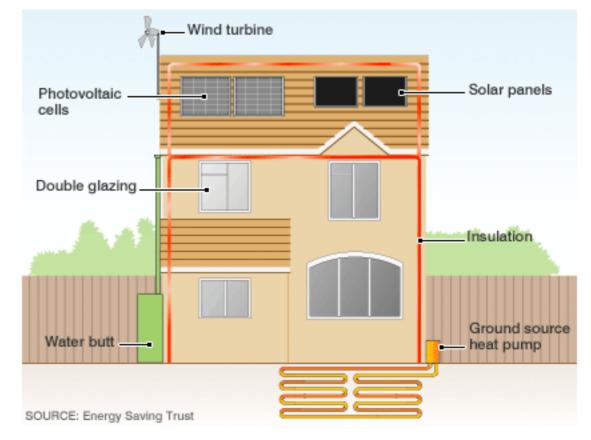






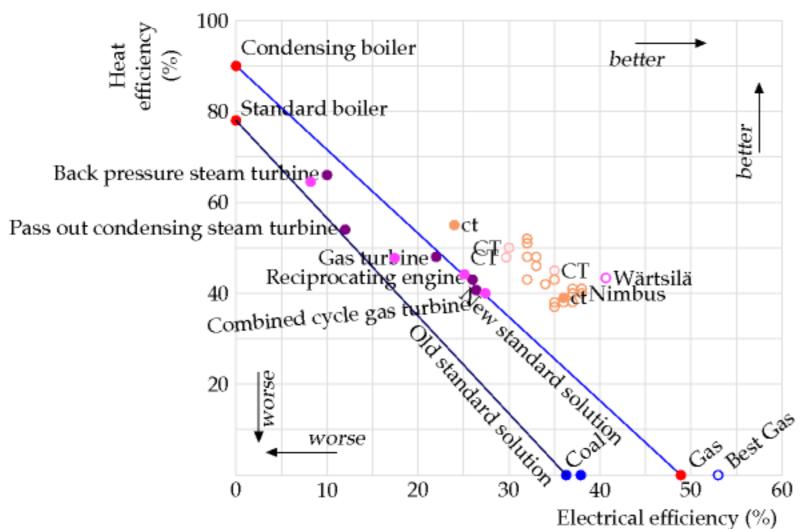
'Microgeneration', 'Decentralization'





Can we do better than Combined Heat and Power?
- Heat pumps





Can we do better than Combined Heat and Power?

- Heat pumps







About Daikin Technology **Products** Home

Domestic

Single Split Systems

- Reverse Cycle

Cool Only

Multi Split Systems

Ducted Systems

i-text

Commerical

Air Purifiers

Accessories & Options

Dealer Search

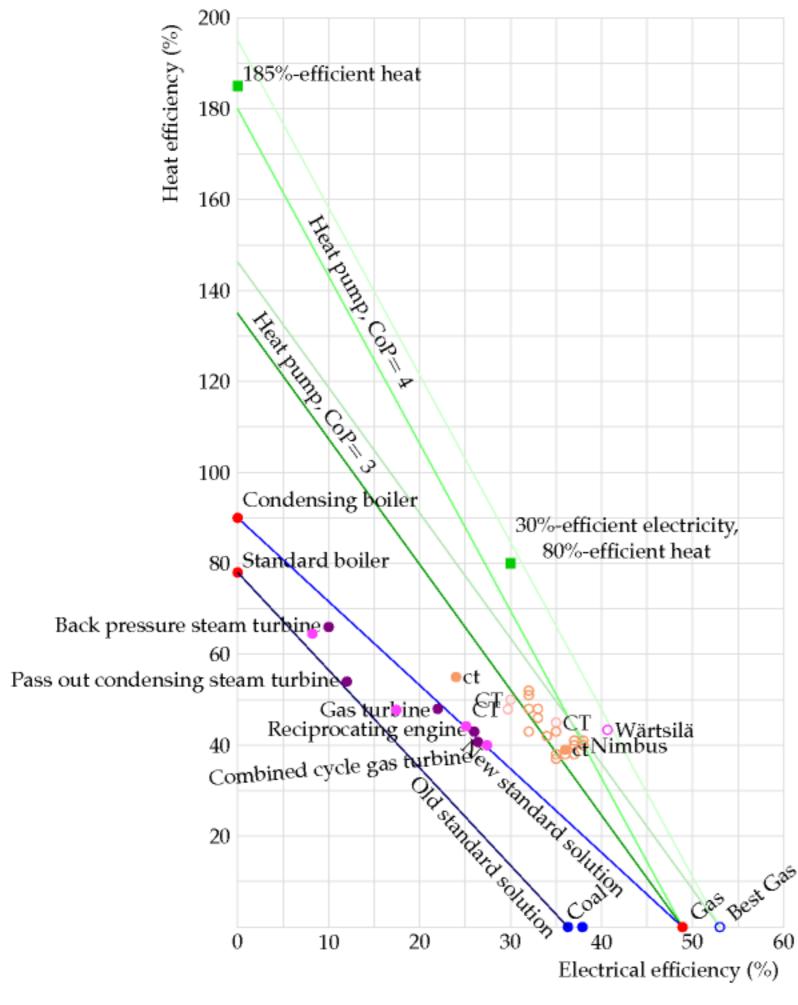
home > products > Domestic > Single Split Systems > Reverse Cycle > FTXS25E

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.

Overview	Features	Specifications	Controllers	Downloads	
Unit		ndoor Unit Outdoor Unit	FTXS25EVMA RXS25EAVMA		
Rated Capacity		Cool (KW) Heat (KW)	2.5 3.4		
Capacity Range		Cool (KW) Heat (KW)	1.2-3.0 1.2-4.5		
Indoor Air Flow		Cool (I/s) Heat (I/s)	145 157		
Indoor Fan Speeds		5 steps, quiet and automatic			
C.O.P			4.17/4.10		
Front Panel Colour			White		
Power Supply			1 phase, 220-240V, 50Hz		





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

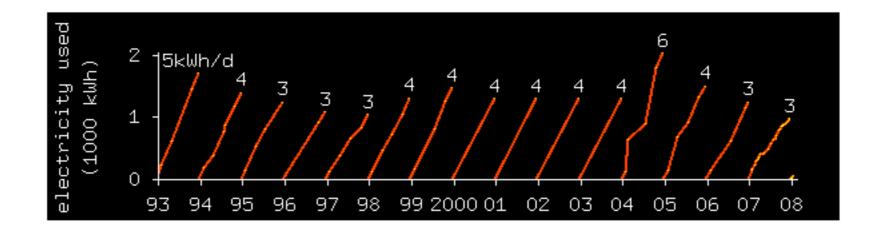
EcoCute water heater - CoP = 4.9!

Read your meters!



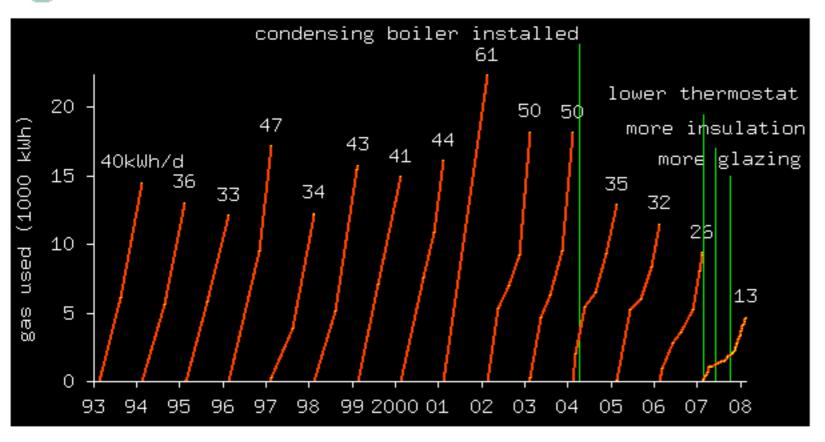


Electricity

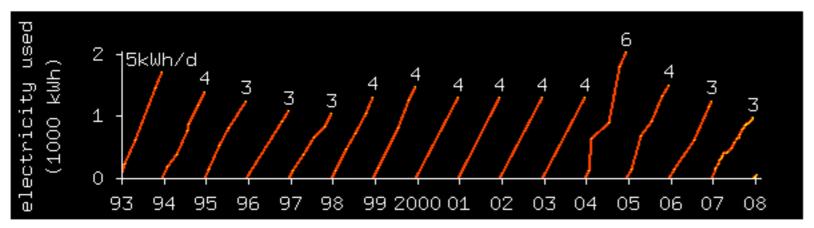


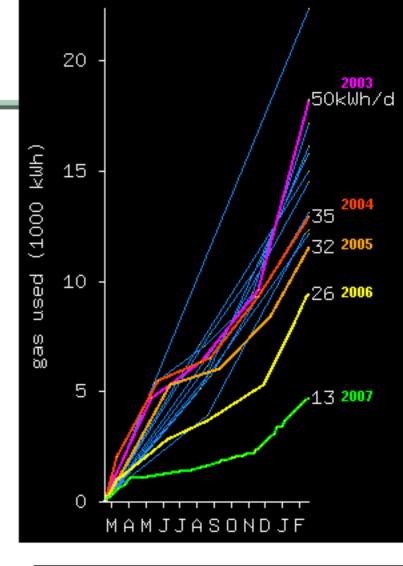
Read your meters!

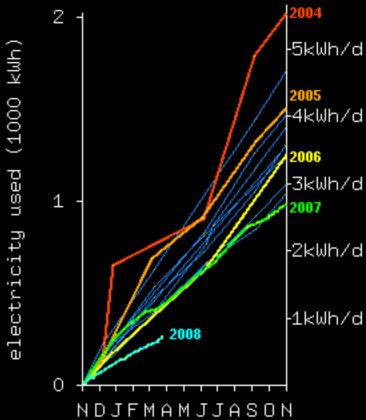
Gas



Electricity

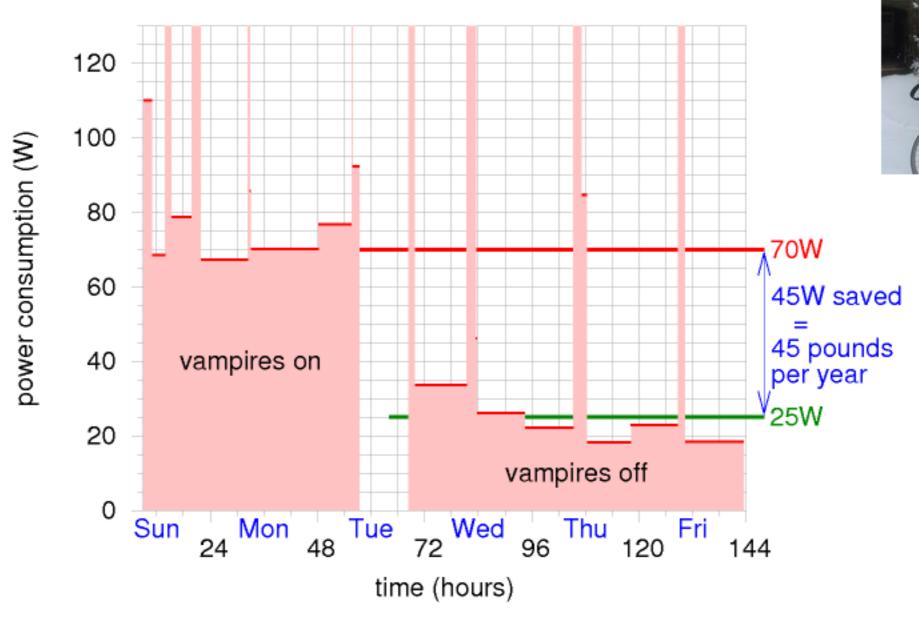






Efficiency in the offing

Electricity



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.





"A reduction in growth is not an acceptable path to a lower-carbon world."



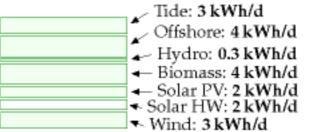
"the truth is no country is going to cut its growth or consumption substantially in light of a long-term environmental problem"

How to make an energy plan that adds up

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

Current consumption: 125 kWh/d per person

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



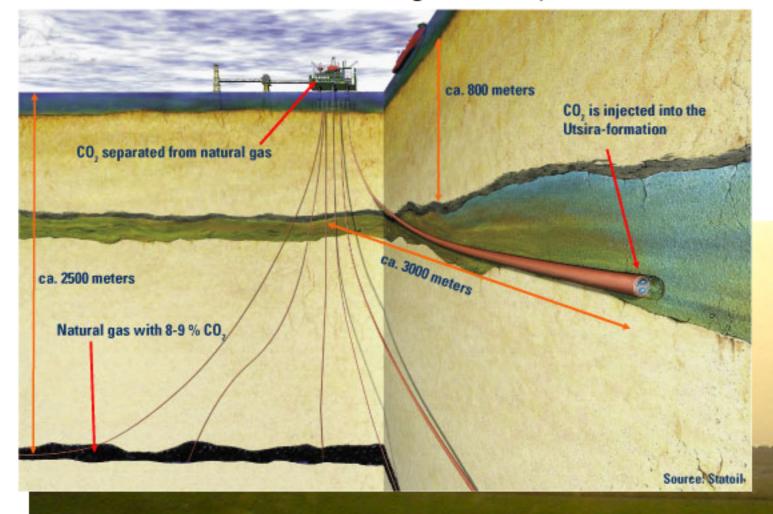
'Sustainable fossil fuels'

 $\frac{1600 \text{ Gt of coal}}{6 \text{ billion people}} / 1000 \text{ years} \times 8000 \text{ kWh per tonne} = 6 \text{ kWh per day per person}$

Coal: 6 kWh/d

Carbon capture and storage

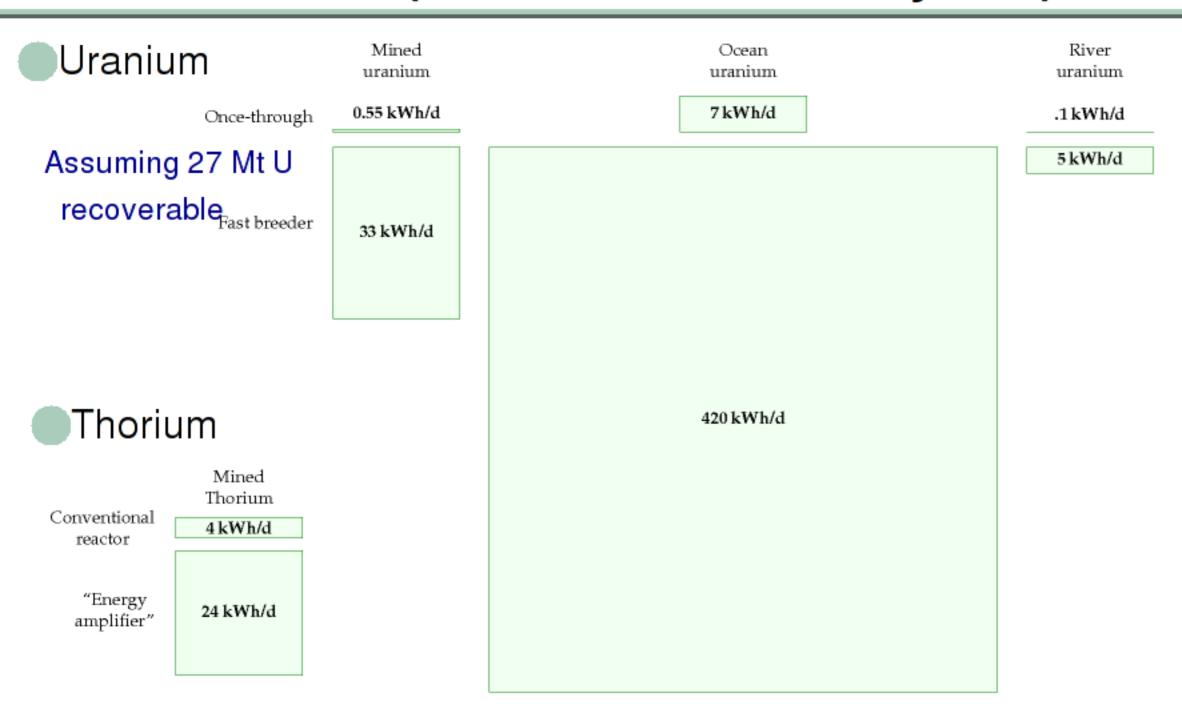
- requires 25% of the generated energy
- doubles the cost of building a 1GW power station



Sustainable Fossil Fuels The Unusual Suspect in the Quest for Clean and Enduring Energy



Nuclear Fission ('sustainable' = 1000 years)



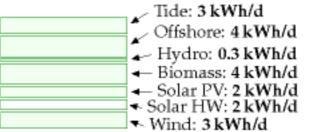
Assuming 1.6 Mt Th recoverable

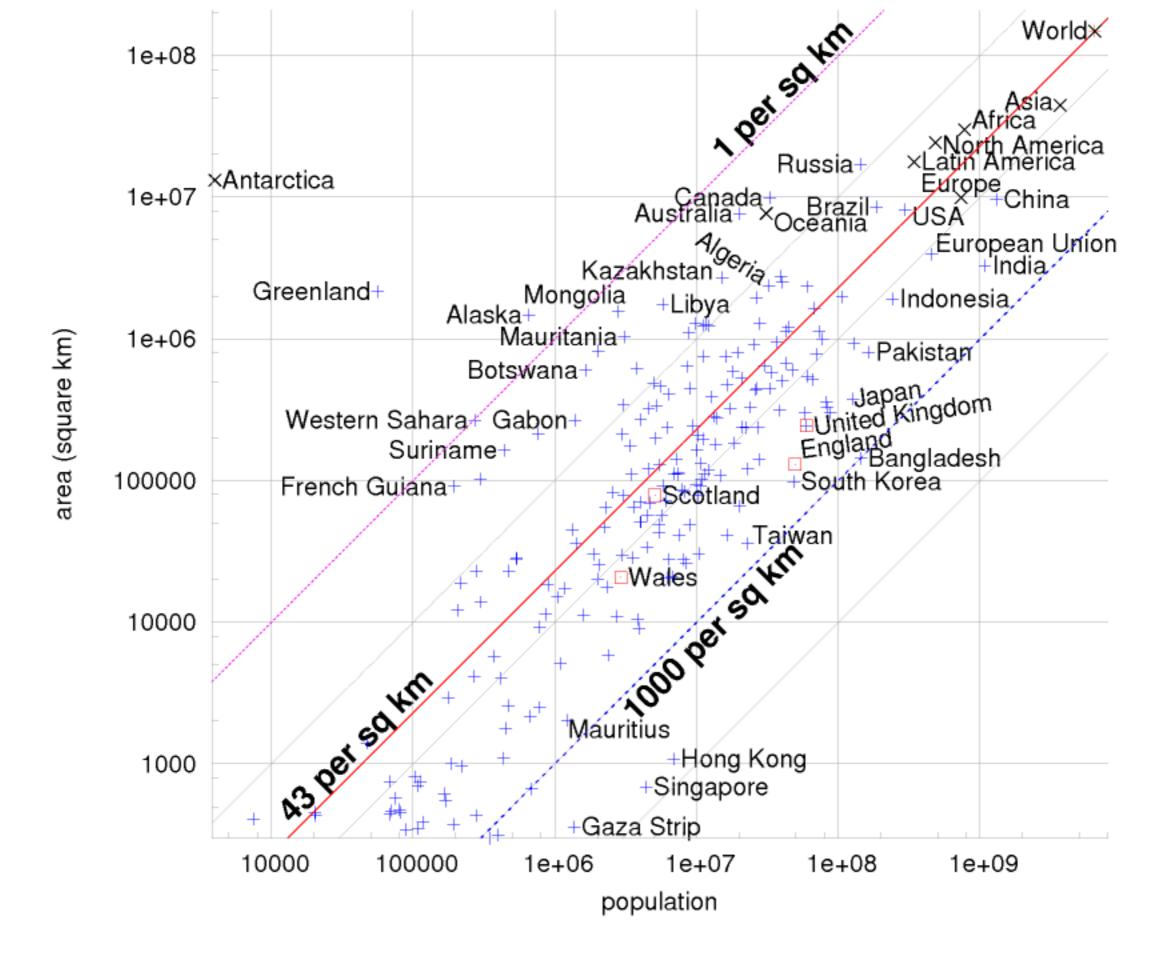
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www.stirlingenergy.com International options Iran r Turkey Iraq 1000 km Syria • Spain

Tunisia

Libya

Niger

Chad

Môrocco,

Mali

Saudi Arabia

10 GW if 30% solar farm, at 20 W/sq m.

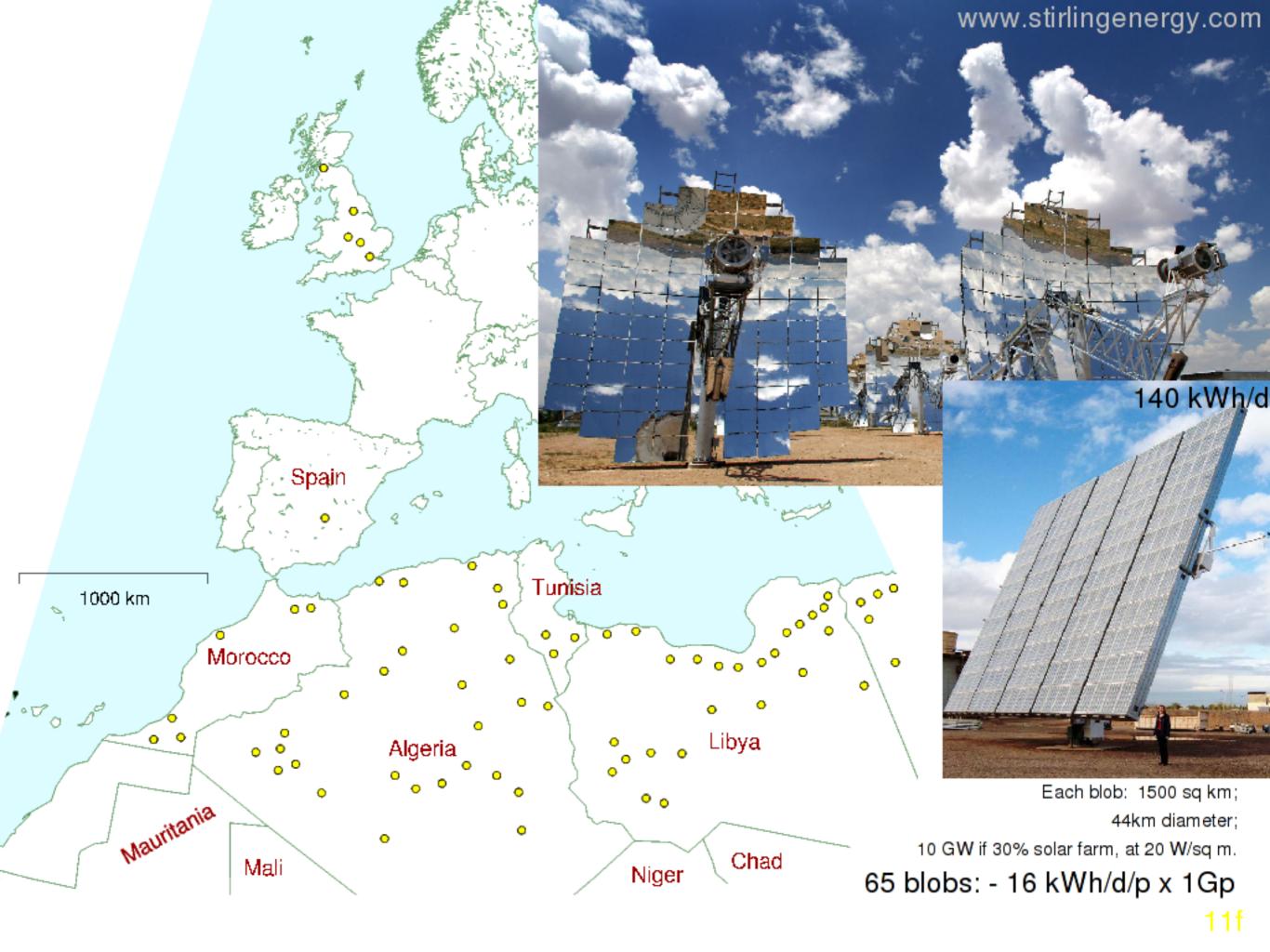
65 blobs: - 16 kWh/d/p x 1Gp

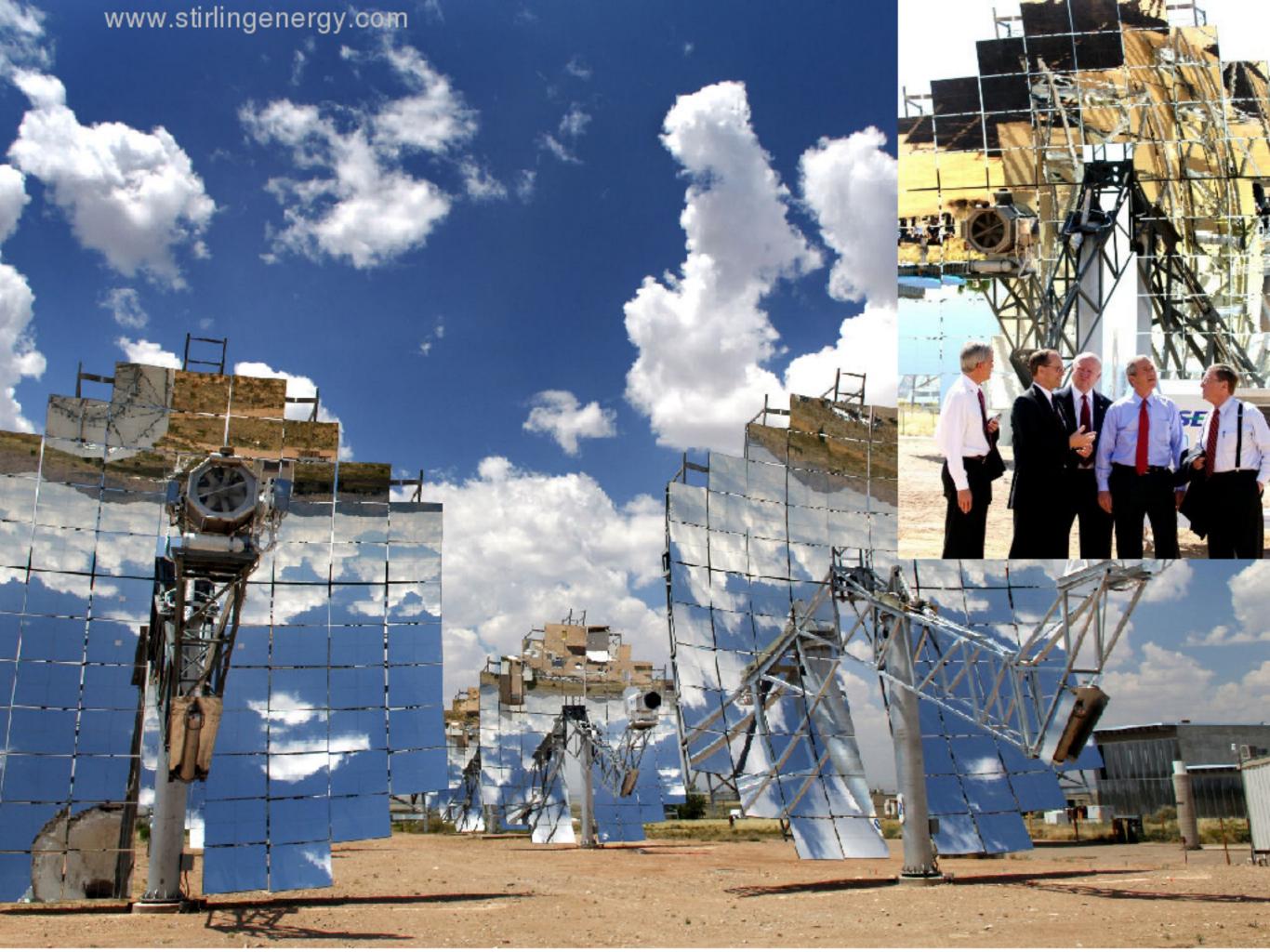
Each blob: 1500 sq km;

44km diameter;

Egypt









ausra.com

Andasol, Spain

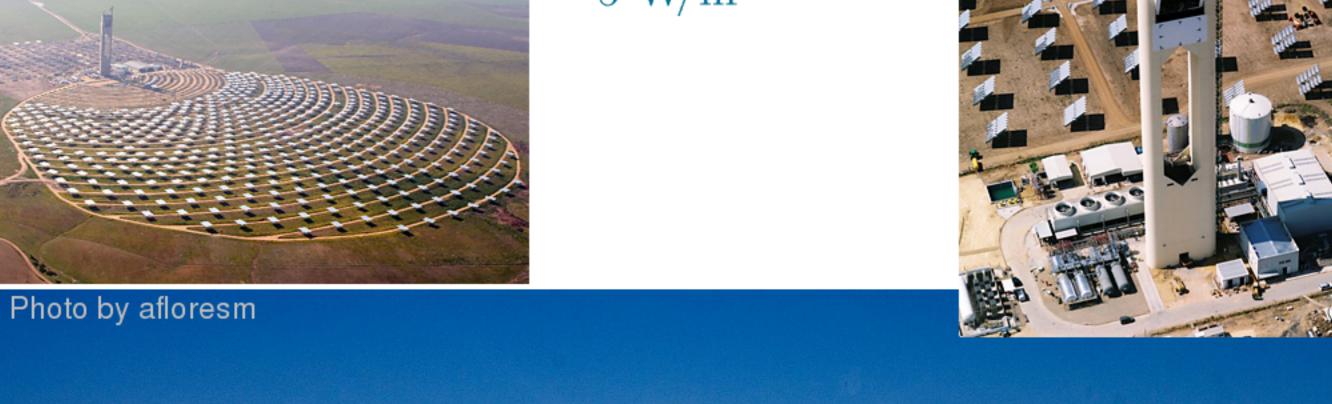


Photo: ABB

PS10, Solucar



 5 W/m^2





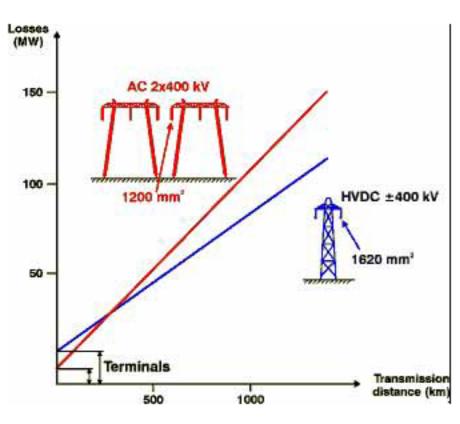


140 kWh/d peak 25 kW



Yellow: 125 kWh/d/p for 1 billion people; Red: 125 kWh/d/p for 60 million people

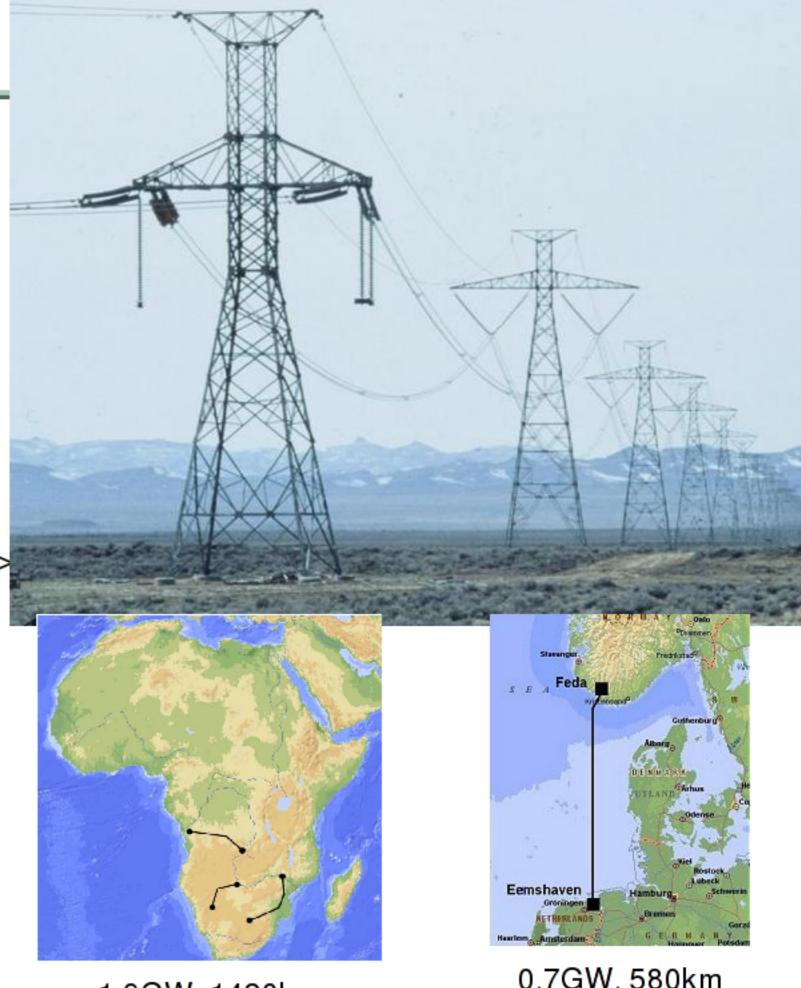
HVDC transmission



Photos and diagrams: ABB 2GW --:



3.1GW, 1360km



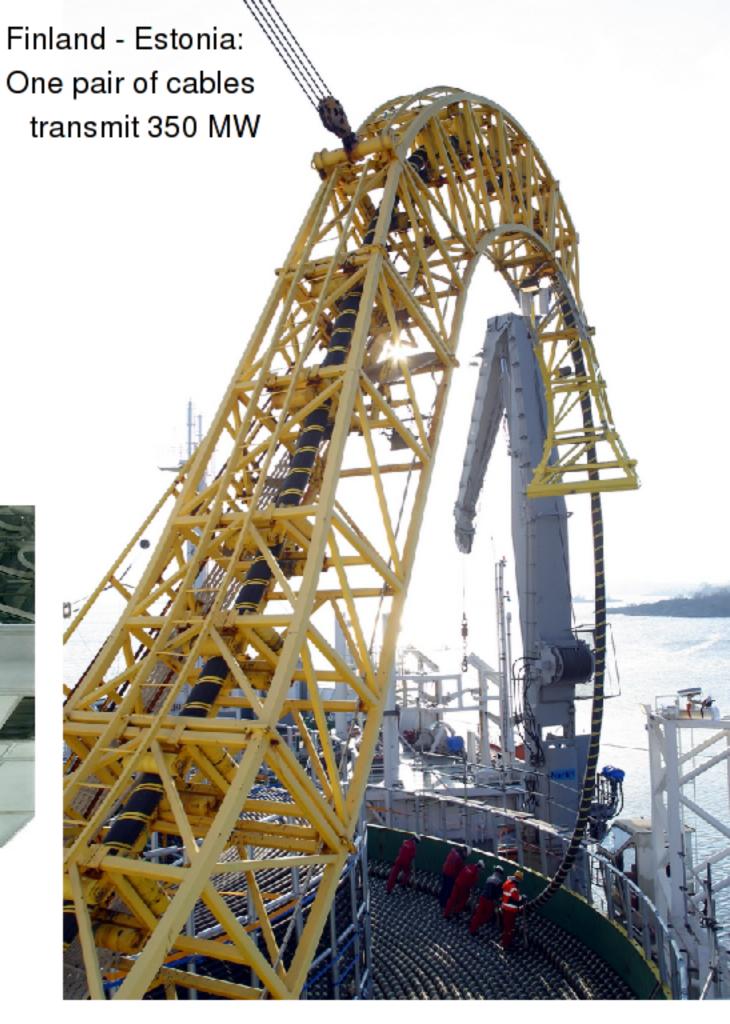
1.9GW, 1420km

0.7GW, 580km



Photos: ABB



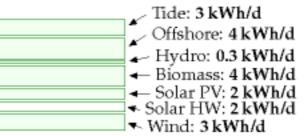


How to make an energy plan that adds up

- Demand-side
 - Reduce population
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Current consumption: 125 kWh/d per person

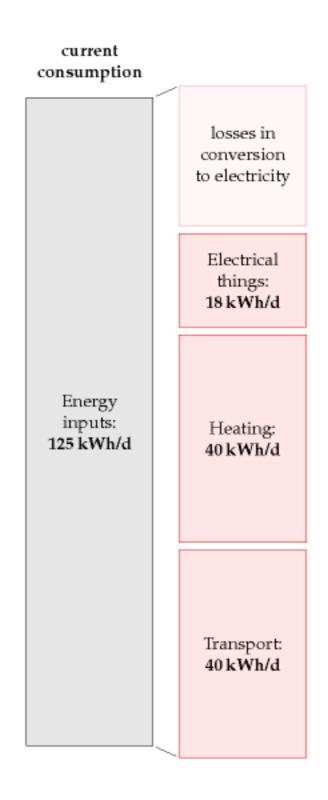
- Supply-side
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Efficiency & technology - for Cartoon-Britain

The current situation in Cartoon-Britain

(ignoring embodied energy in imported stuff)



Efficiency

Improving transport efficiency

Improving heating efficiency

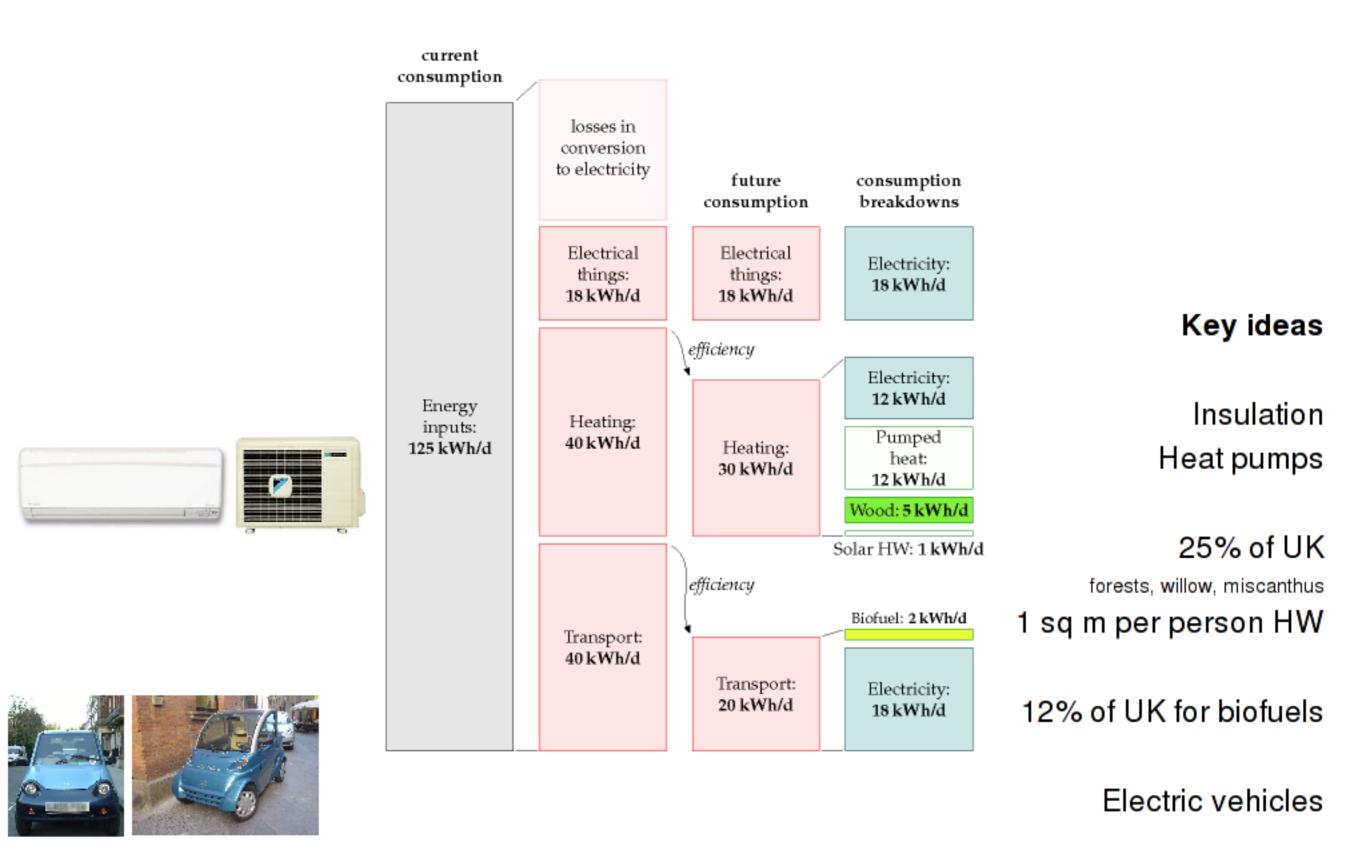
Reducing electricity

Growth

Growth

Growth

Five plans for Cartoon-Britain



Plan D: 'Diversity'



40GW; triple coal imports



7 sq m / p

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: 8kWh/d

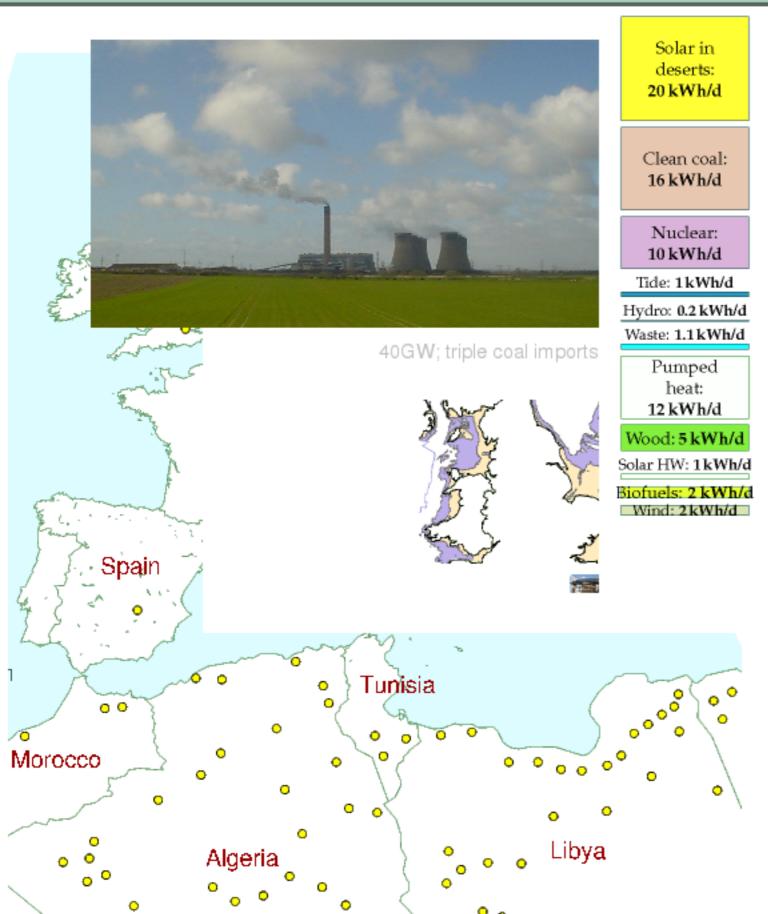
40GW - four-fold increase

7500 pelamis, 500km of coastline



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

Plan N: 'NIMBY'







upgrade all current sites







8-fold increase in wind ('15GW')

Plan L: 'Libdem'



40GW; triple coal imports



7 sq m / p

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





7500 pelamis, 500km of coastline





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

Plan G: 'Green'

7 sq m / p pumped storage 400 Dingrwigs Loch Ness och Æricht. Toch Rannoch Loch Tay pen Slov

Solar in deserts: 7

No coal

Loch Leven

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

Wind: 32





11,000 pelamis, 750km of coastline







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

Tide: 0.7

Hydro: 0.2

Waste: 1.1

Pumped heat: 12 kWh/d

Wood:5 kWh/d

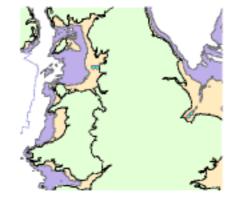
Solar HW: 1

Biofuels: 2 Wind: 4

Nuclear: 44 kWh/d



110GW - twice France's nuclear



Tidal lagoons (providing storage too)



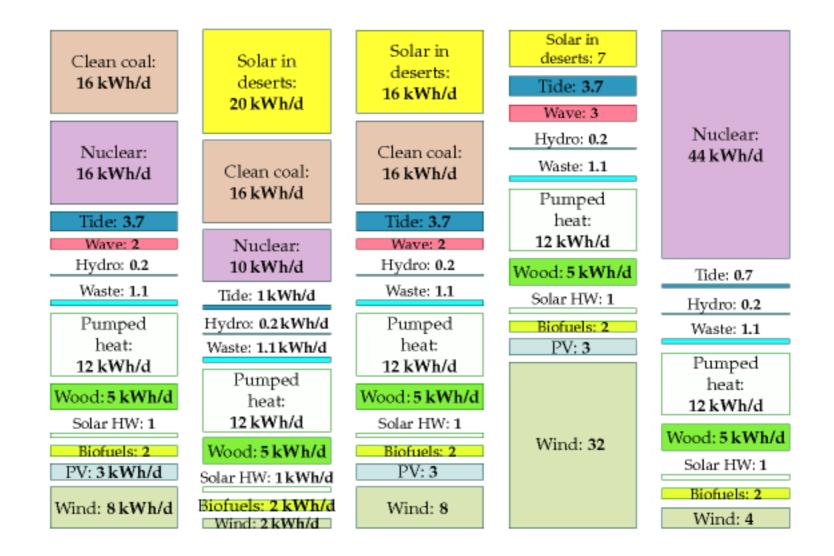
all municipal waste incinerated, and equal agri. waste



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

Current imports of energy

In 2006, the UK imported 28 kWh/d/p of fuel - 23% of its primary consumption

Plan M

Solar in Solar in deserts: 7 Clean coal: Solar in deserts: 16 kWh/d deserts: Tide: 3.7 16 kWh/d 20 kWh/d Wave: 3 Nuclear: Hydro: 0.2 Nuclear: Clean coal: 44 kWh/d Waste: 1.1 Clean coal: 16 kWh/d 16 kWh/d 16 kWh/d Pumped heat: Tide: 3.7 Tide: 3.7 12 kWh/d Wave: 2 Wave: 2 Nuclear: Hydro: 0.2 Hydro: 0.2 10 kWh/d Wood: 5 kWh/d Tide: 0.7 Waste: 1.1 Waste: 1.1 Tide: 1kWh/d Solar HW: 1 Hydro: 0.2 Pumped Hydro: 0.2 kWh/d Pumped Biofuels: 2 Waste: 1.1 heat: heat: PV: 3 Waste: 1.1 kWh/d Pumped 12 kWh/d 12 kWh/d Pumped heat: Wood: 5 kWh/d Wood:5 kWh/d heat: 12 kWh/d 12 kWh/d Solar HW: 1 Solar HW: 1 Wood: 5 kWh/d Wind: 32 Wood: 5 kWh/d Biofuels: 2 Biofuels: 2 Solar HW: 1 PV: 3 kWh/d PV: 3 Solar HW: 1kWh/d Biofuels: 2 Biofuels: 2 kWh/d Wind: 8kWh/d Wind: 8 Wind: 4 Wind: 2 kWh/d

Diversity NIMBY Libdem Green Economist

"Middle"

Solar in

deserts:

16 kWh/d

Clean coal: 3

Nuclear:

16 kWh/d

Tide: 3.7

Wave: 0.3

Hydro: 0.2

Waste: 1.1

Pumped

heat:

12 kWh/d

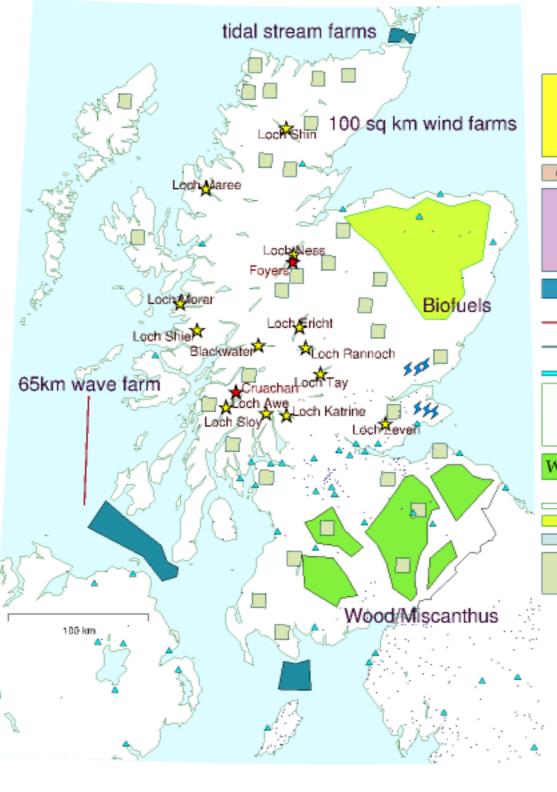
Wood:5 kWh/d

Solar HW: 1

Biofuels: 2

PV: 2

Wind: 8



Solar in deserts: 16 kWh/d

Clean coal: 3

Nuclear: 16 kWh/d

Tide: 3.7

Wave: 0.3

Hydro: 0.2

Waste: 1.1

Pumped heat: 12 kWh/d

Wood:5 kWh/d

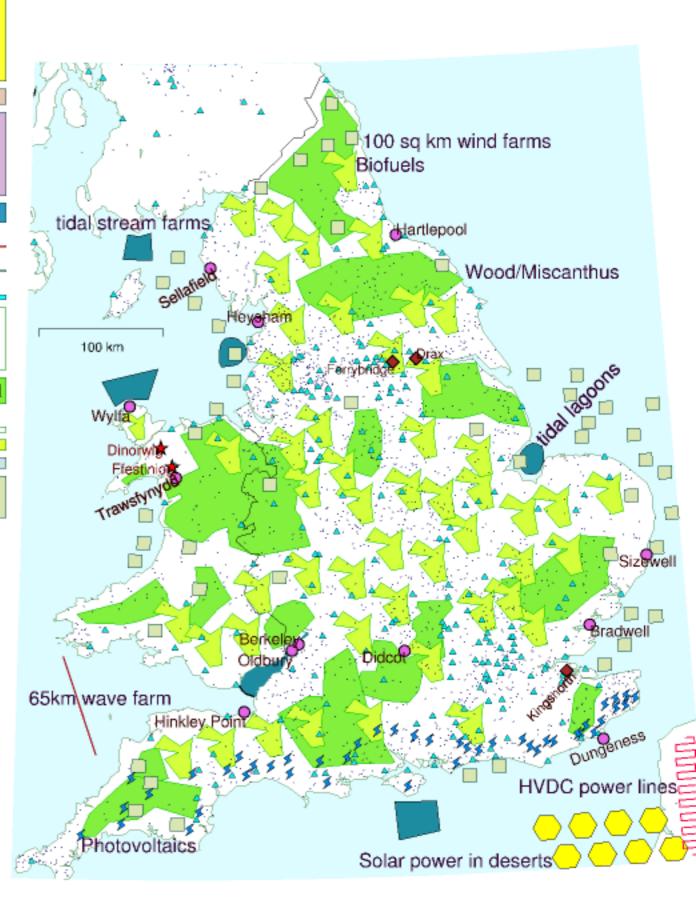
Solar HW: 1

Biofuels: 2

1 7 - 2

Wind: 8





This plan's mix

Jack-up barges cost 60M

Solar in deserts: 16 kWh/d

Clean coal: 3

Nuclear: 16 kWh/d

Tide: 3.7

Wave: 0.3

Hydro: 0.2 Waste: 1.1

Pumped heat: 12 kWh/d

Wood:5 kWh/d

Solar HW: 1

Biofuels: 2

Wind: 8

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]

Micro-wind (one per person?)

David Cameron's chimney ->



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

2000 pounds for that!

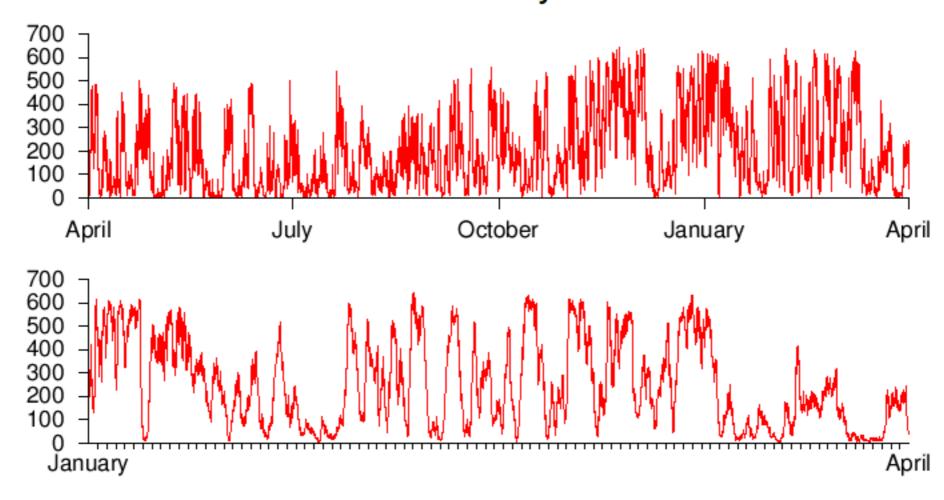


"We were going to have a wind turbine but they're not very efficient"

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'





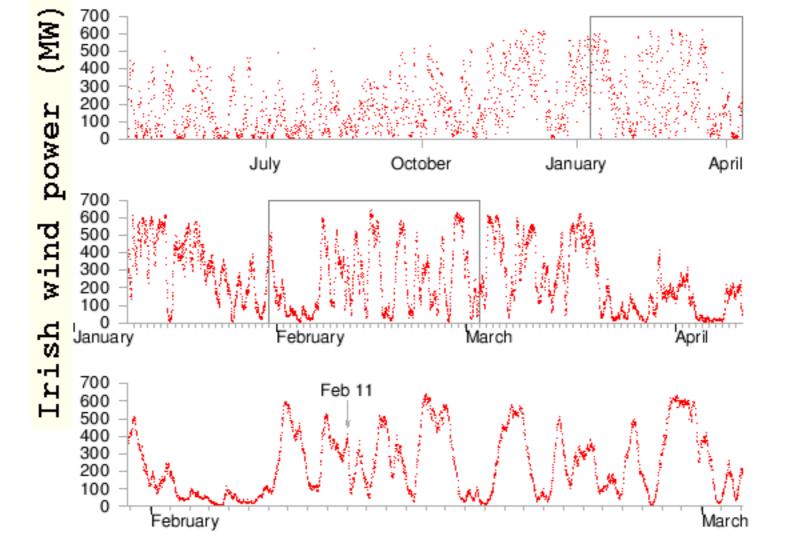
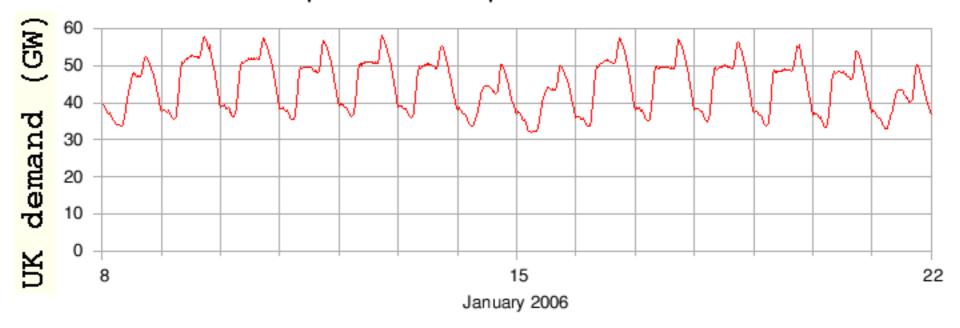


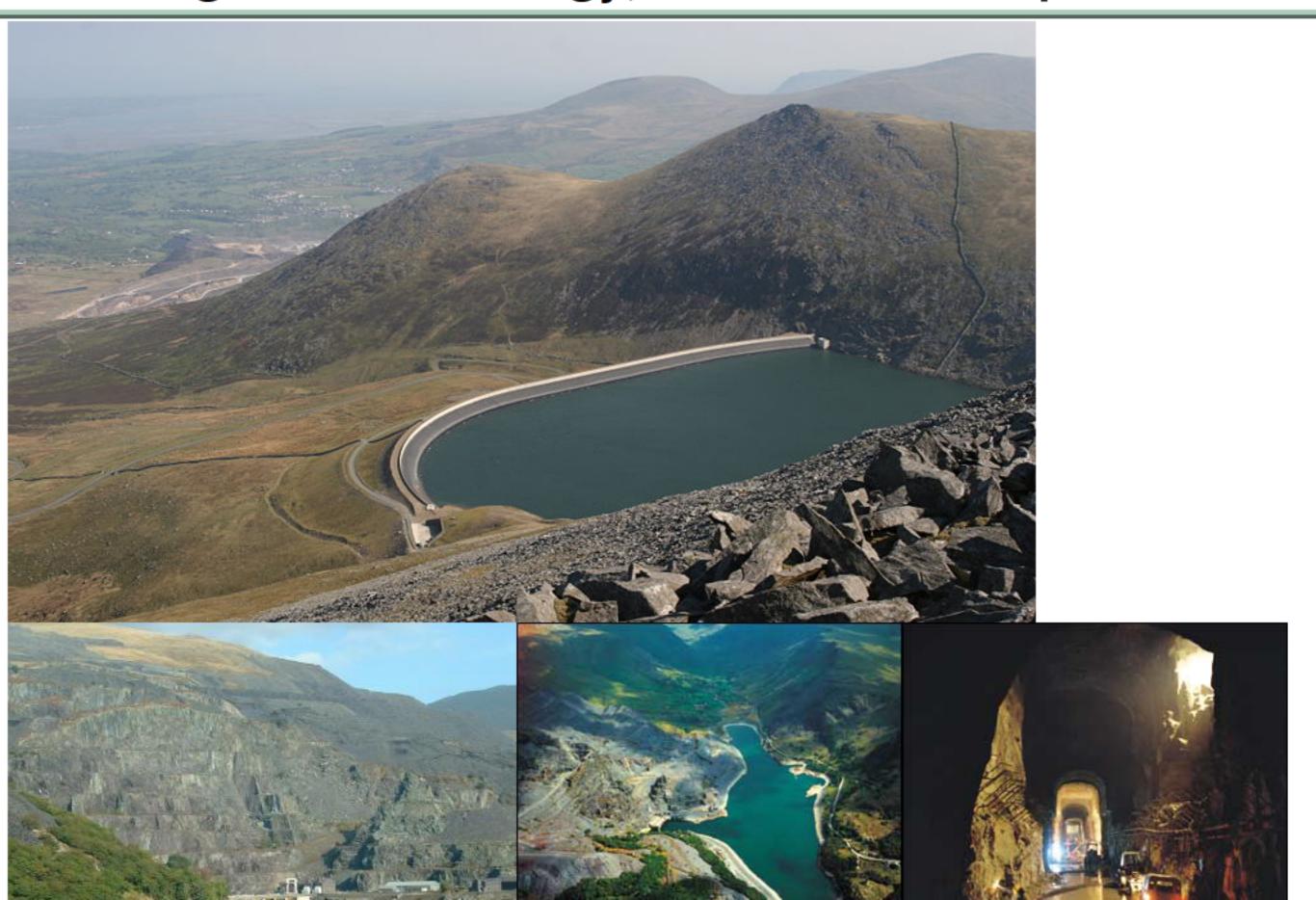
Figure 26.2. Total output, in MW, of all windfarms of the Republic of Ireland, from April 2006 to April 2007 (top), and detail from January 2007 to April 2007 (middle), and February 2007 (bottom). Peak electricity demand in Ireland is about 5000 MW. Its wind 'capacity' in 2007 is 745 MW, dispersed in about 60 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

Dinorwig - 10 GWh energy; 2 GW maximum power



Storage - more Dinorwigs

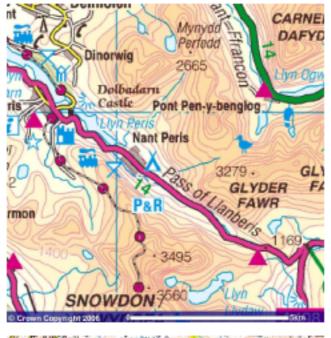
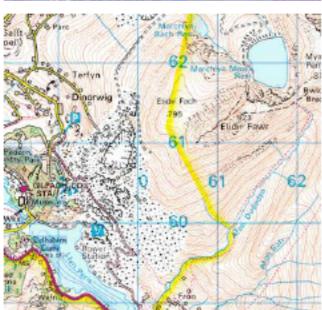


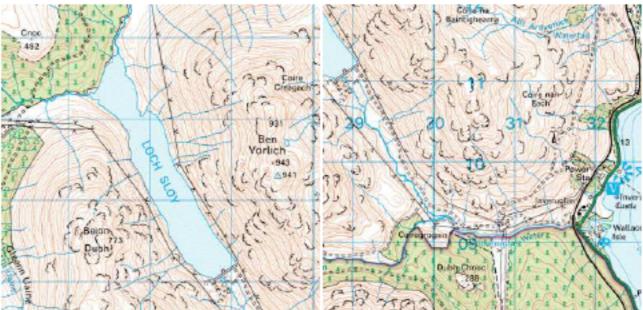


Figure 29.2. Dinorwig, in the Snowdonia National Park, compared with Loch Sloy and Loch Lomond. The upper maps show 10 km by 10 km areas. In the lower maps the blue grid is made of 1 km squares. Images produced from Ordnance Survey's Get-a-map service

www.ordnancesurvey.co.uk/getamap. Images reproduced with permission of Ordnance Survey. © Crown Copyright 2006



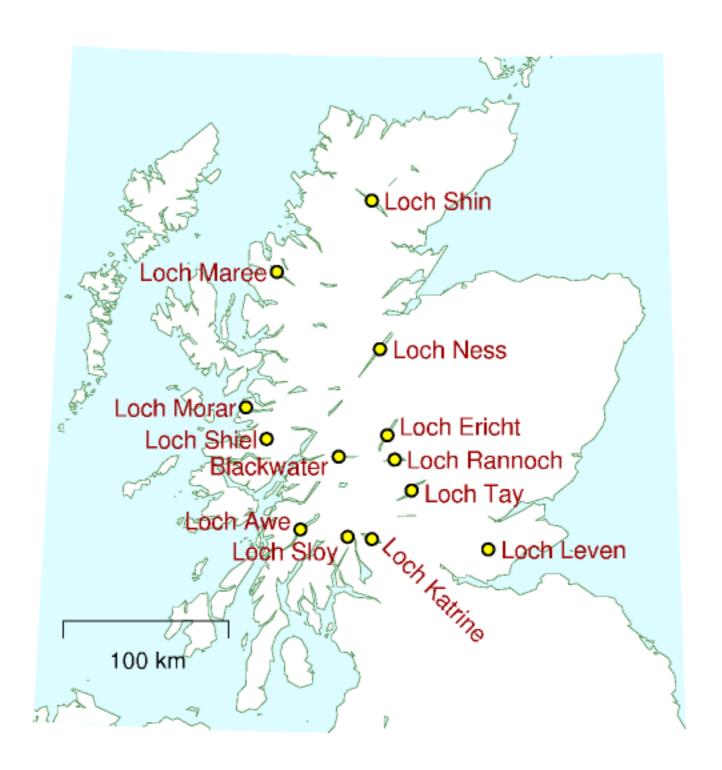
Dinorwig is the home of a 9 GWh storage system, using Marchlyn Mawr (615E,620N) and Llyn Peris (590E,598N) as its upper and lower reservoirs.



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

or smart storage ('net-energy')

Roughly 40 GWh at each hydro facility



About 420 GWh total (7 kWh per person)

Pumped storage





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

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

Electric vehicles - another huge easily-switch-off-and-on-able load

30 million electric vehicles

10 million connected, 2 kW each - 20 GW of dynamic demand

30 million cars, 40 kWh each - 1200 GWh

Exchangeable batteries:

30 million batteries, 10 kWh each - 300 GWh

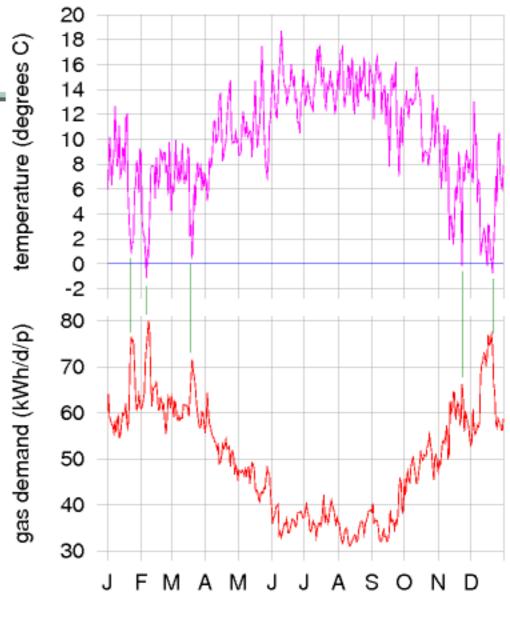
3000 new vehicles for every 3-MW wind turbine

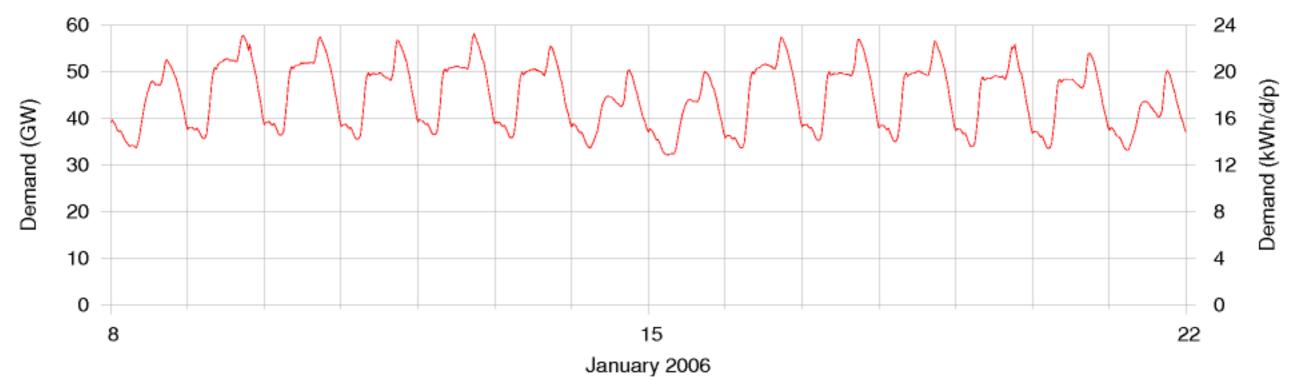






Demand variations





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

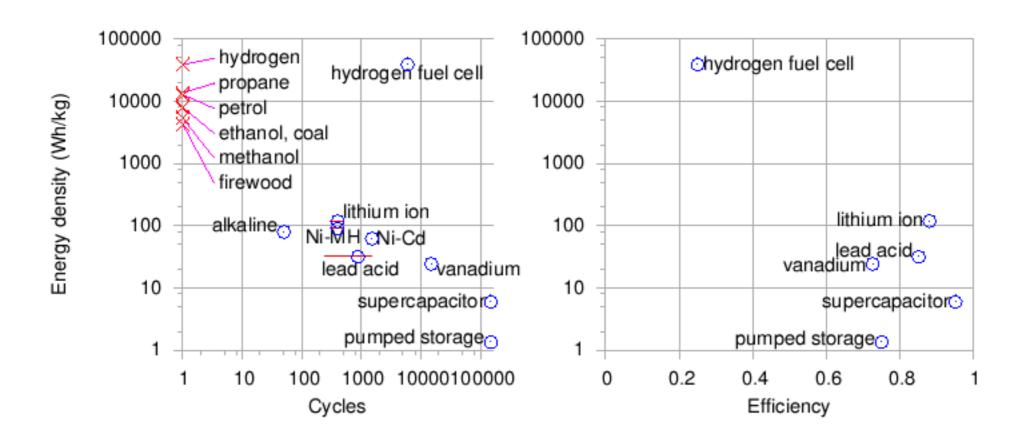
And efficiency too of course





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

Energy storage



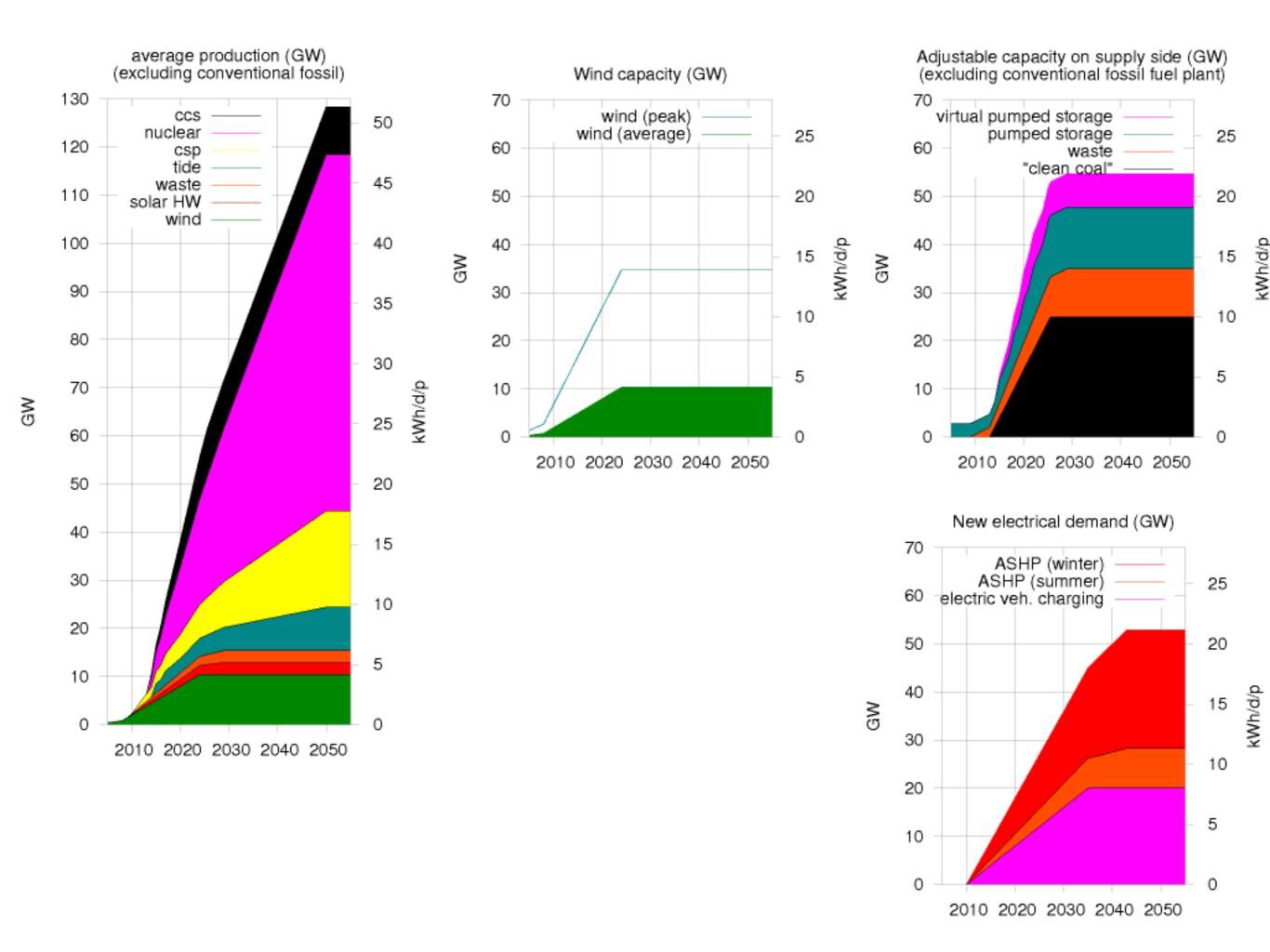
PLANS

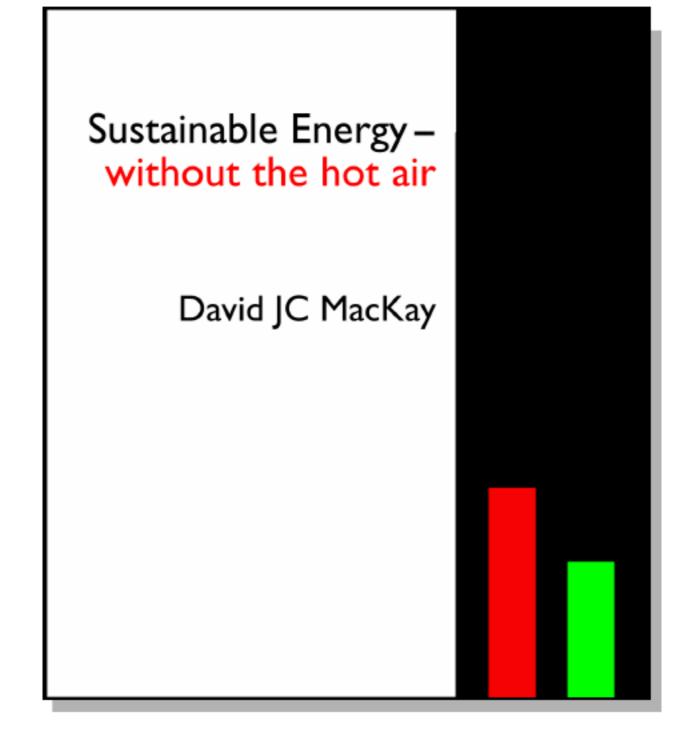
Rules

- Cover all these forms of energy consumption:
 - transport, heating and electricity
- 90% reduction in GHG emissions by 2050
- The plan must add up
 - Energy production = energy consumption

Plan 7

A plan with trajectories





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

Publisher: UIT Cambridge

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www.withouthotair.com

Hydrogen



SUSTAINABL TRANSPORT ENERGY



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

Transport

Transport 35%

> Hot air 26%

Hot water 8%

Lighting, appliances 6%

> Process 10%

Other 15%



Today: 40 kWh/d/p of liquid fuels

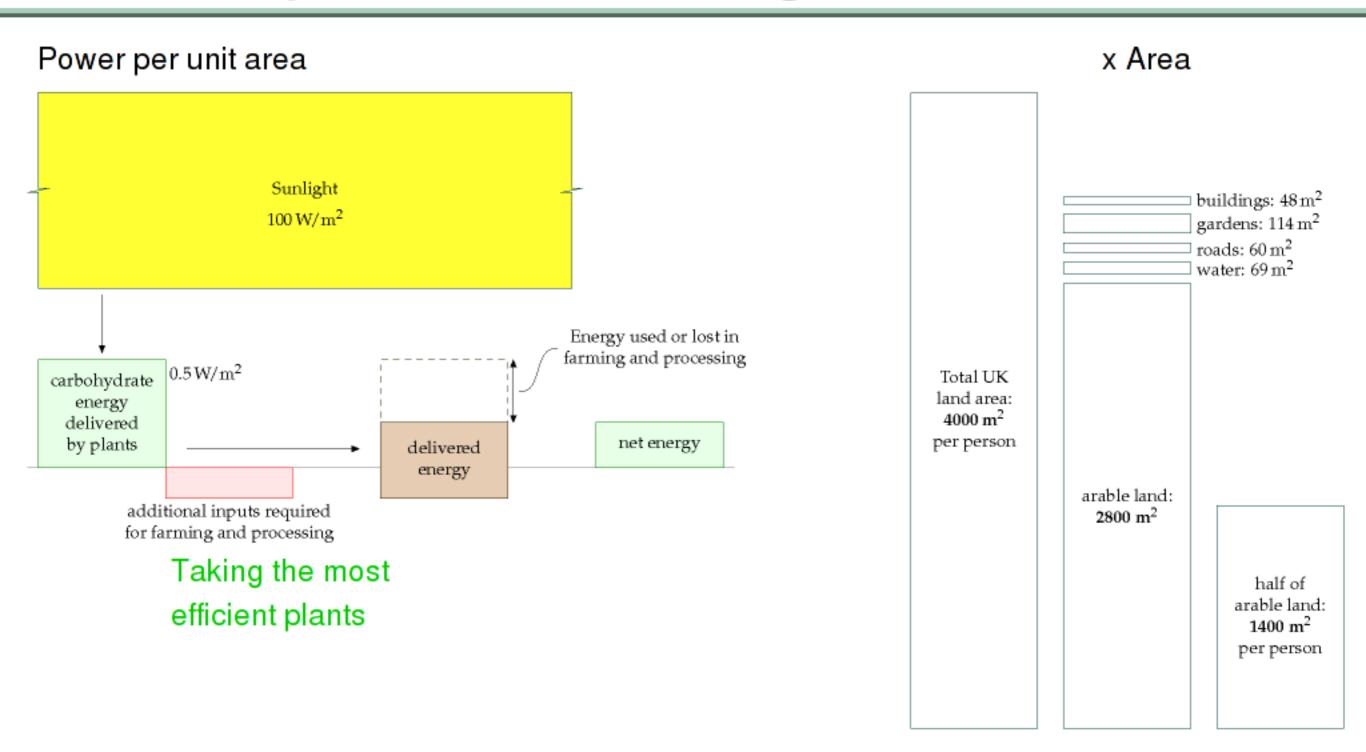
Plants





0.5 W/m2 25% of country 12 kWh/d/p

How much power could Britain get from biofuels?



How much power could Britain get from biofuels?

