Strategies for Sustainable Energy

Lecture 4. National Strategies

CBE 652

Sustainable Technology through Advanced Interdisciplinary Research (STAIR)

University of Tennessee, Knoxville

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19. Strategies: BIG

BIG Changes are required

Demand can be reduced

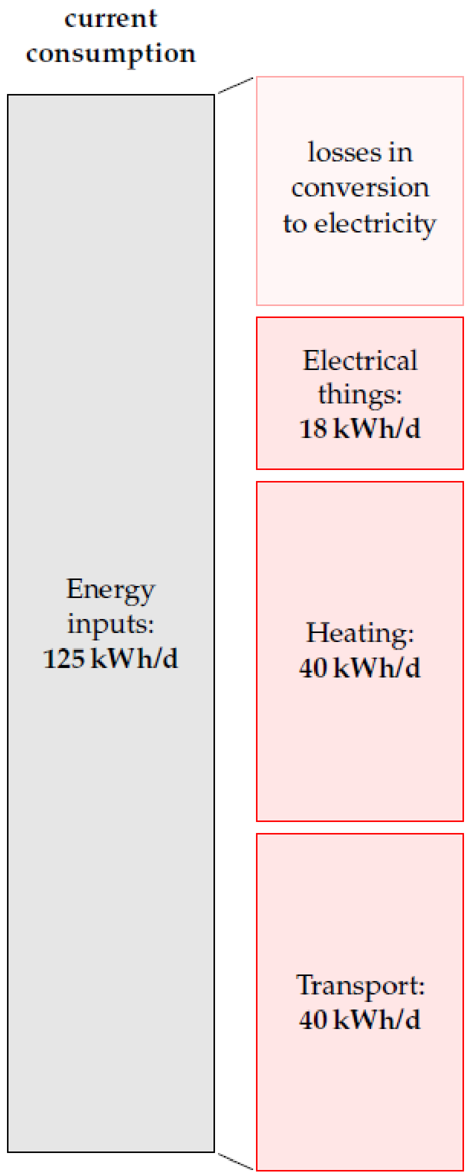
- reduce the population
- change our lifestyle
- keep population & lifestyle, reduce energy intensity through efficiency and technology

Supply can be increased

- sustainable, clean coal?
- sustainable, nuclear fission?
- buy, beg or steal renewable energy from other countries

Simplify the picture

- transport
- heating
- electricity
- conversion losses



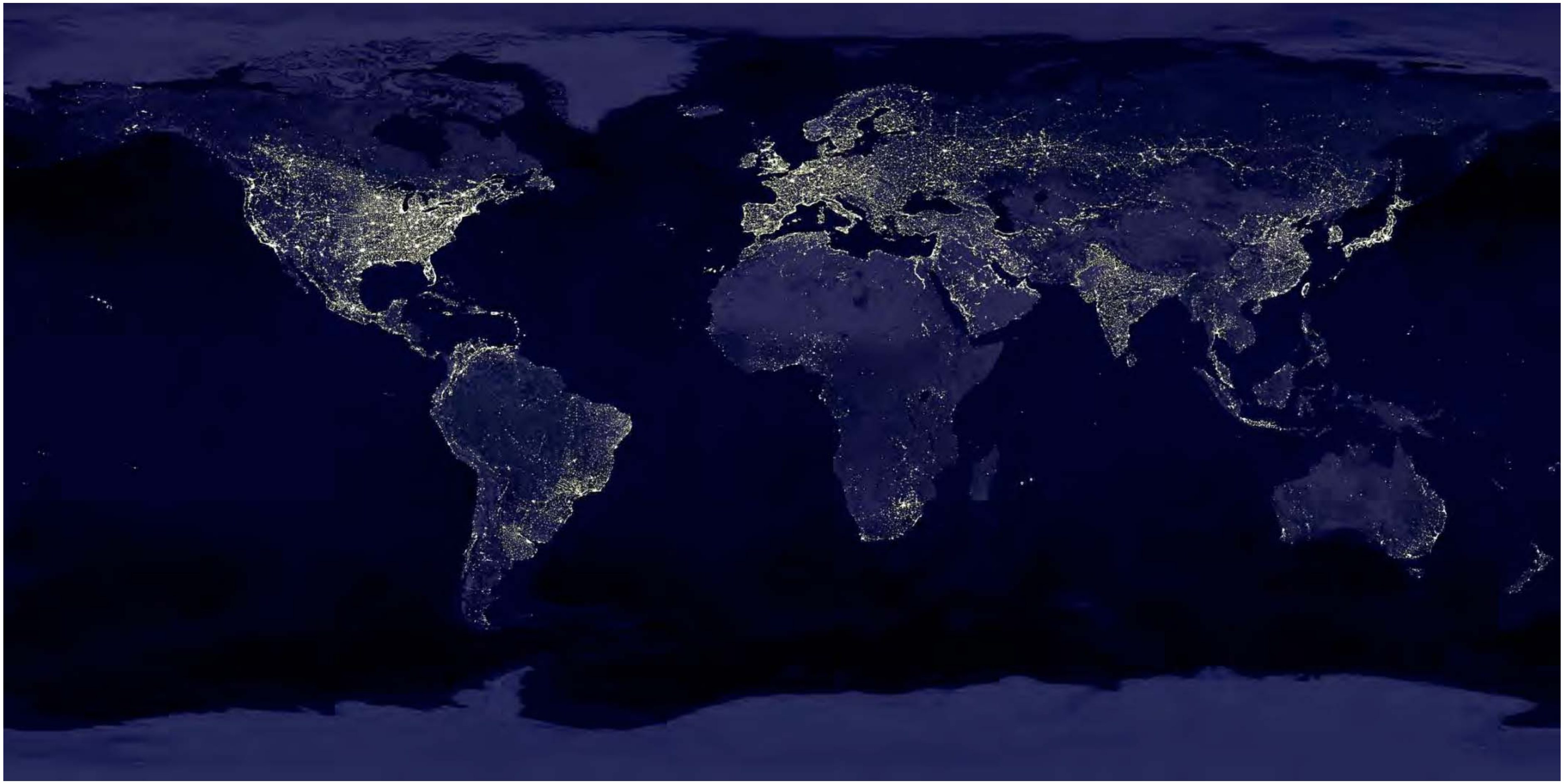
19. Strategies: BIG

Potential Directions

Better Transport (Chapter 20, discussed in Lecture Module 3)
- electrify transportation
- more mass transit
- more bicycles
- advanced design of electric cars

Smarter Heating (Chapter 21, discussed in Lecture Module 4)
- better building design
- heat pumps
- lower thermostat settings

Efficient Electricity Use (Chapter 22)
- turning off idle devices (stand by devices account for 8% of residential electricity use)
- use of energy efficient devices/bulbs
- reduce transmission losses in electrical lines



http://www.pppl.gov/colloquia_pres/WC13MAY09_JMinervini2.pdf

Reducing Transmission Losses

Transmission Losses

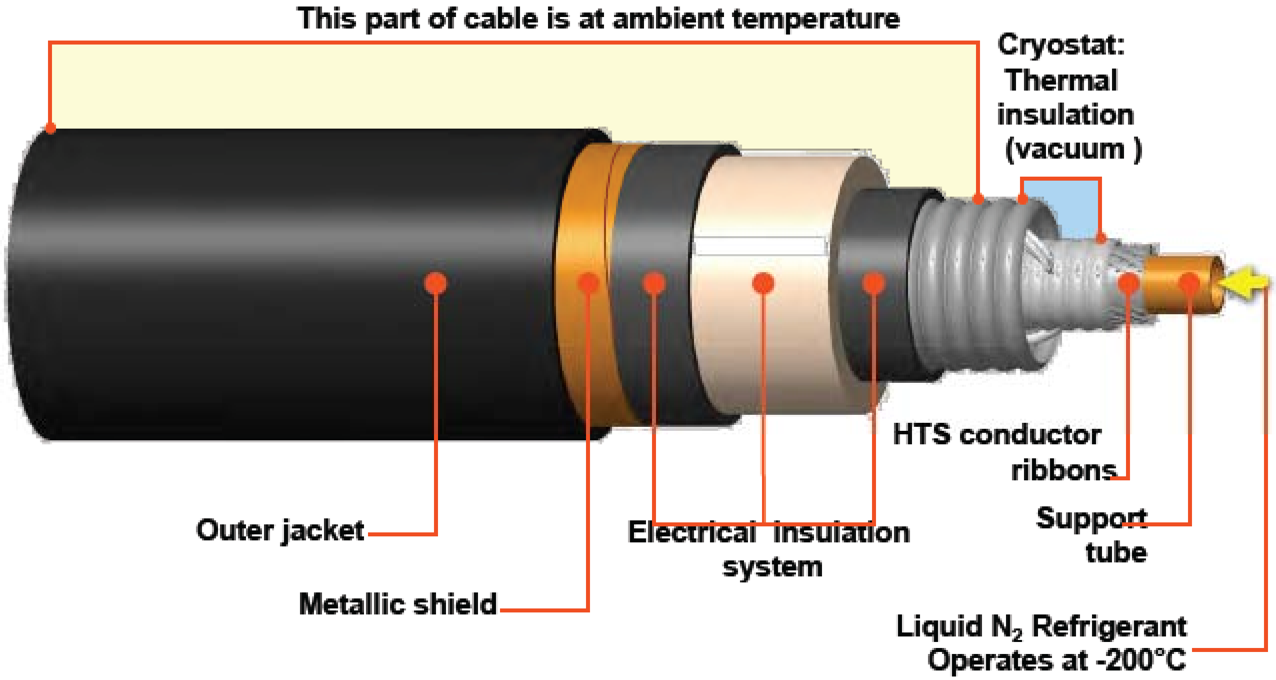
- Transmitting electricity at high voltage reduces the fraction of energy lost to resistance.
- For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor.
- At extremely high voltages, more than 2 MV between conductor and ground, corona discharge losses are so large that they can offset the lower resistance loss in the line conductors.
- Transmission and distribution losses in the USA were estimated at 6.6% in 1997[13] and 6.5% in 2007.[13]

http://en.wikipedia.org/wiki/Electric_power_transmission

Reducing Transmission Losses

How much can transmission and distribution losses be reduced

High-temperature superconductors promise to revolutionize power distribution by providing lossless transmission of electrical power. The development of superconductors with transition temperatures higher than the boiling point of liquid nitrogen has made the concept of superconducting power lines commercially feasible, at least for high-load applications. It has been estimated that the waste would be halved using this method, since the necessary refrigeration equipment would consume about half the power saved by the elimination of the majority of resistive losses.



http://www.pppl.gov/colloquia_pres/WC13MAY09_JMinervini2.pdf
http://en.wikipedia.org/wiki/Electric_power_transmission

23: Sustainable Fossil Fuels?

Sustainable Coal

Target: 1000 years

- 1600 Gt of coal
- 6 billion people
- contains 6 kWh/day/person
- due to conversion losses, provides 2.2 kWh/day/person
- with clean coal technology, provides 1.6 kWh/day/person

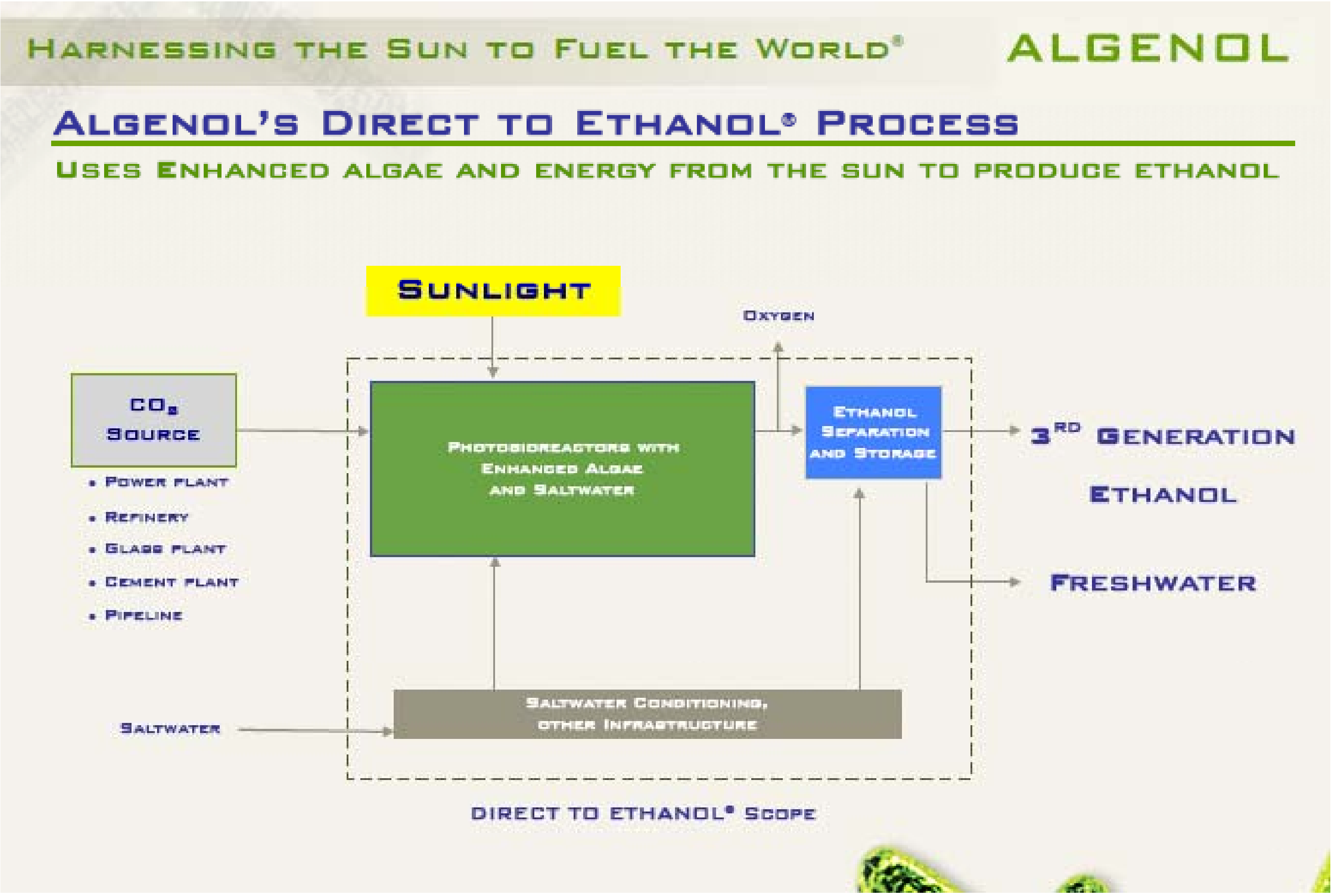
Conclusion Clean coal is only a temporary solution.

The End of Business as usual: How long will coal last?

- 1600 Gt of coal
- population increase
- coal demand increase at 3.4% per year
- 60 years of coal left ~2070
- the impact will be felt well before 2070.

If Jevons were here today, I am sure he would firmly predict that unless we steer ourselves on a course different from business as usual, there will, by 2050 or 2060, be an end to our happy progressive condition.

Example of "Clean Coal" or "Carbon Capture" Technology



http://www.algenolbiofuels.com/Algenol_Public_Presentation.pdf

23: Sustainable Nuclear?

Nuclear energy

- fission
  - make small atoms from large atoms
  - currently in use to produce energy
- fusion
  - make large atoms from small atoms
  - currently <u>not</u> in use to produce energy

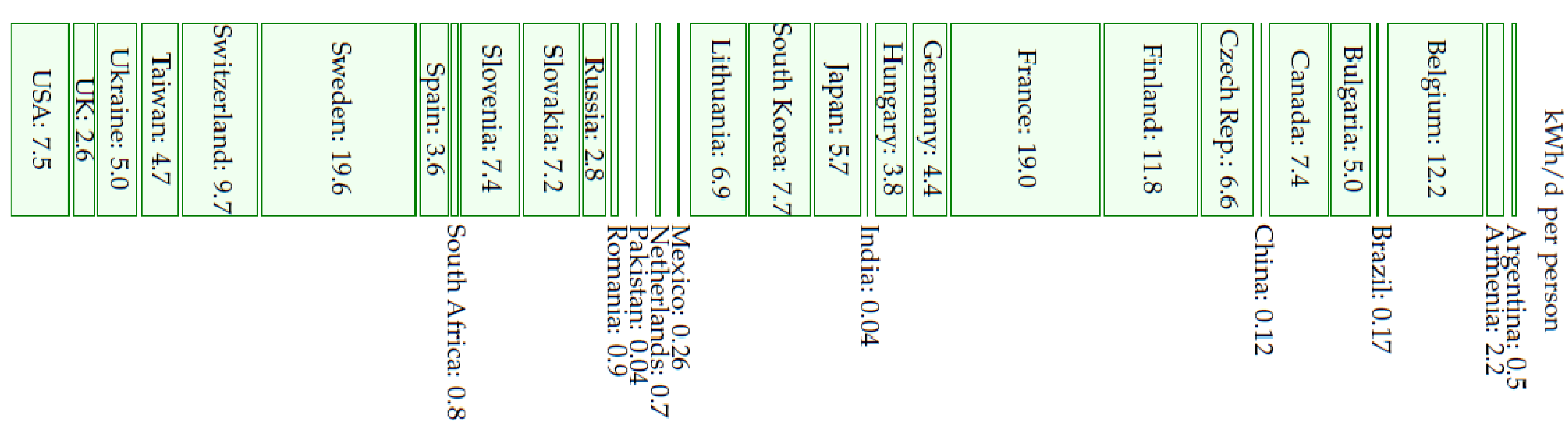


Figure 24.1. Electricity generated per capita from nuclear fission in 2007, in kWh per day per person, in each of the countries with nuclear power.

23: Sustainable Nuclear?

Nuclear energy

● how much uranium?
- uranium in the ground 4.7 million tons (currently used)
- uranium in phosphate deposits 22 million tons
- uranium in seawater at 3.3 ppm 4500 million tons (currently very expensive to isolate)

● what type of reactor?
- conventional once-through reactor (uses less than 1% of the Uranium)
- fast breeder reactors (obtains 60 times the energy of the conventional nuclear reactor)

● sustainable for 1000 years?
- use uranium in the ground
- use conventional once-through reactor
- 0.55 kWh/day/person
- use fast breeder reactor, 33 kWh/day/person
- use fast breeder reactor with uranium from the ocean, 420 kWh/day/person

● what about thorium?
- three times as abundant as uranium in the ground
- in "energy amplifier" reactor, 24 kWh/day/person
- don't know how to recover fissile material from irradiated fuel

http://www.iaea.org/inisnkm/nkm/aws/fnss/fulltext/te_1319_30.pdf

23: Sustainable Nuclear?

Nuclear energy safety concerns

Fatality rates in the generation of energy
This includes for example, coal miners dying in a coal mine accident.
This does not include people dying from thyroid cancer caused by enhanced mercury levels in the river fish they eat, due to mercury release from coal-fired power plants.

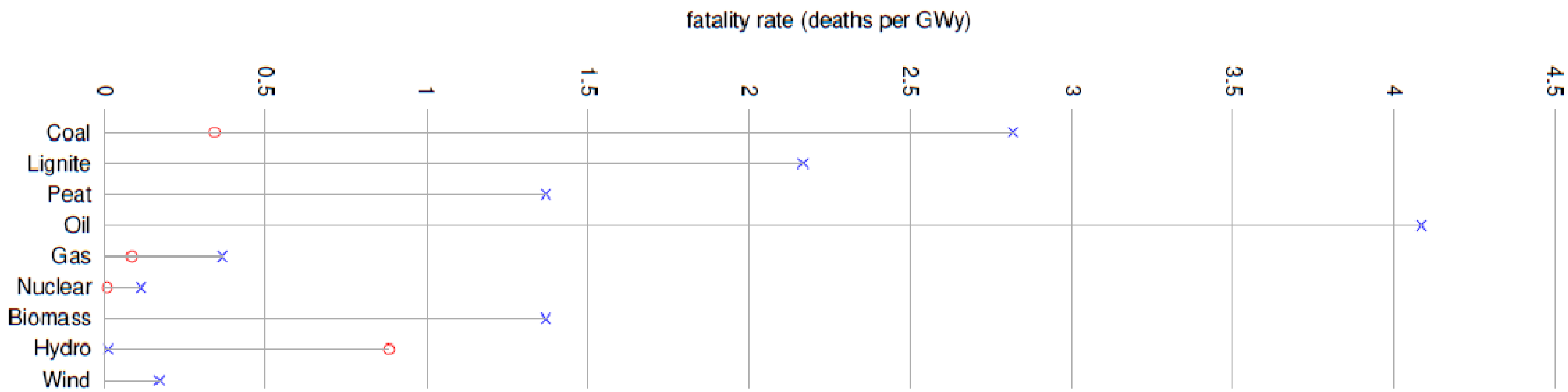


Figure 24.11. Death rates of electricity generation technologies. ×: European Union estimates by the ExternE project. ○: Paul Scherrer Institute.

23: Sustainable Nuclear?

What if fusion of deuterium became a reality?

● 33 grams of deuterium in every ton of ocean water
● 1 gram of deuterium via fusion yields 100,000 kWh
● 230 million tons of ocean water per person

● For a population of 60 billion (not six billion)
● For one million years
● 30,000 kWh/day/person

It is a worthwhile gamble to continue to pursue harnessing nuclear fusion for energy.

25: Borrowing Renewable Energy

Living on other countries' renewables?

Countries that will have renewable energy to export have
- low population density
- large area
- renewable power supply with high power density

Power per unit land or water area	
Wind	2 W/m^2
Offshore wind	3 W/m^2
Tidal pools	3 W/m^2
Tidal stream	6 W/m^2
Solar PV panels	5–20 W/m^2
Plants	0.5 W/m^2
Rain-water (highlands)	0.24 W/m^2
Hydroelectric facility	11 W/m^2
Solar chimney	0.1 W/m^2
Concentrating solar power (desert)	15 W/m^2

Table 25.1. Renewable facilities have to be country-sized because all renewables are so diffuse.

Concentrated Solar Power

What is Concentrated Solar Power?

Concentrated solar power (CSP) are systems that use lenses or mirrors to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat which drives a heat engine (usually a steam turbine) connected to an electrical power generator.
CSP should not be confused with photovoltaics, where solar power is directly converted to electricity without the use of steam turbines.

Advantages

- Uses steam turbines (conventional technology)
- No expensive solar PV cells
- 12 to 18 cents per kWh
- needs a desert

Commercial electricity ~ 9 cents/kWh (Knoxville, TN, November, 2010)

http://en.wikipedia.org/wiki/Concentrated_solar_power

Concentrated Solar Power

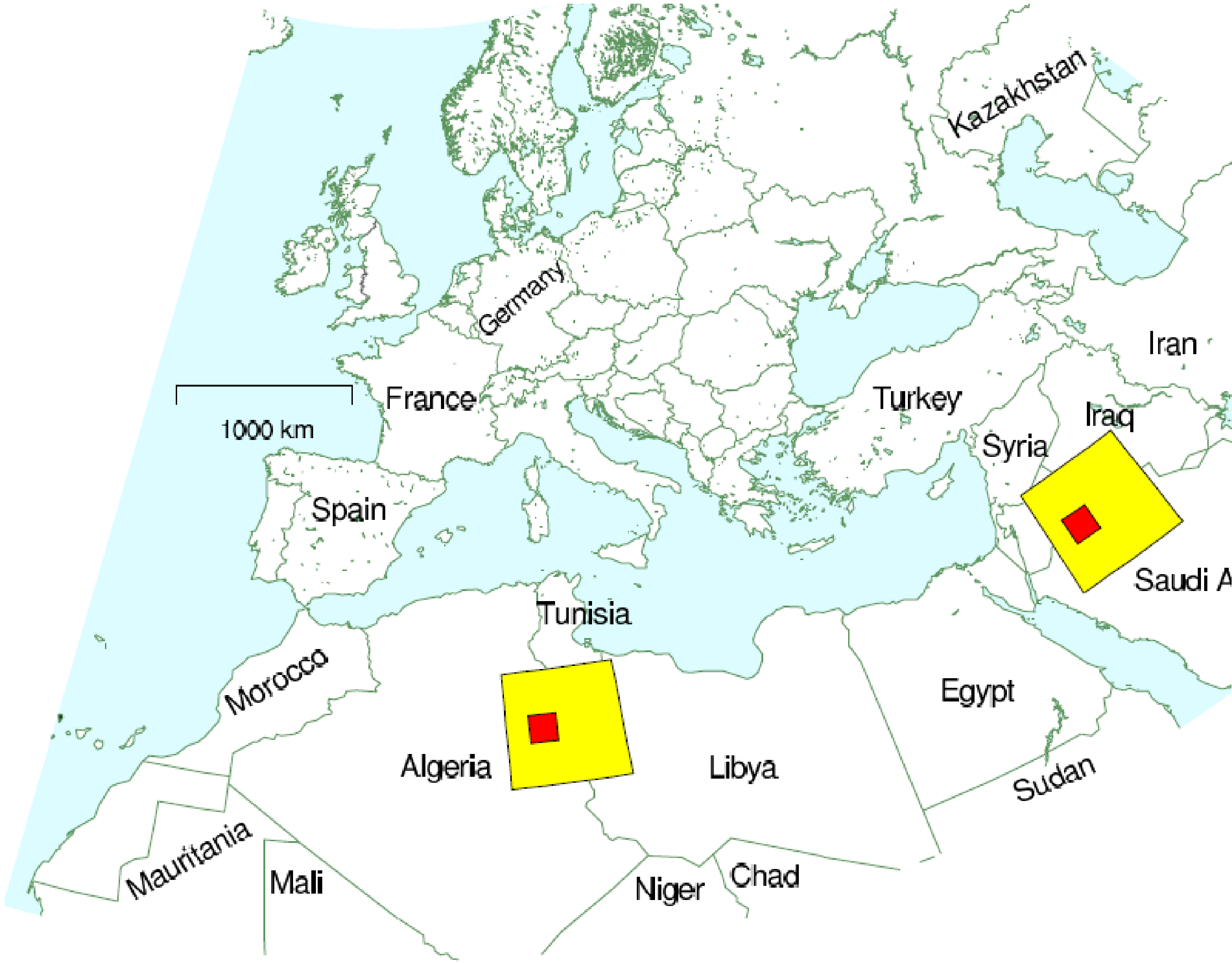


Figure 25.5. The celebrated little square. This map shows a square of size 600 km by 600 km in Africa, and another in Saudi Arabia, Jordan, and Iraq. Concentrating solar power facilities completely filling one such square would provide enough power to give 1 billion people the average European's consumption of 125 kWh/d. The area of one square is the same as the area of Germany, and 16 times the area of Wales. Within each big square is a smaller 145 km by 145 km square showing the area required in the Sahara – one Wales – to supply all British power consumption.

- Each yellow square could provide 125 kWh/day/person for 10^9 people. Place them near water, since they can desalinate water.

Strategies for Sustainable Energy

Lecture 4. Strategies for Sustainability II

Outline

Section 1: Fluctuations and Storage
Section 2: Five Energy Plans for Britain
Section 3: Estimating Costs
Section 4: What to do now

26. Fluctuation and Storage

Energy demand fluctuates on a daily and yearly basis

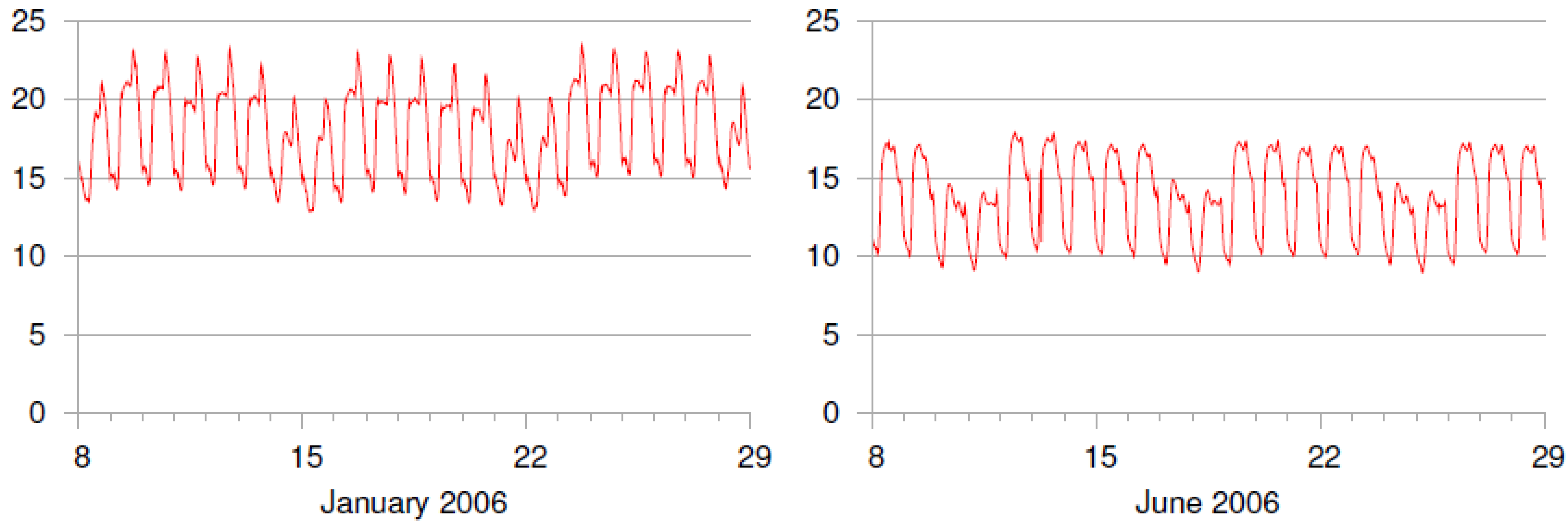


Figure 26.1. Electricity demand in Great Britain (in kWh/d per person) during two winter weeks and two summer weeks of 2006. The peaks in January are at 6pm each day. The five-day working week is evident in summer and winter. (If you'd like to obtain the national demand in GW, remember the top of the scale, 24 kWh/d per person, is the same as 60 GW per UK.)

26. Fluctuation and Storage

Energy supply from renewable sources fluctuates on a daily and yearly basis

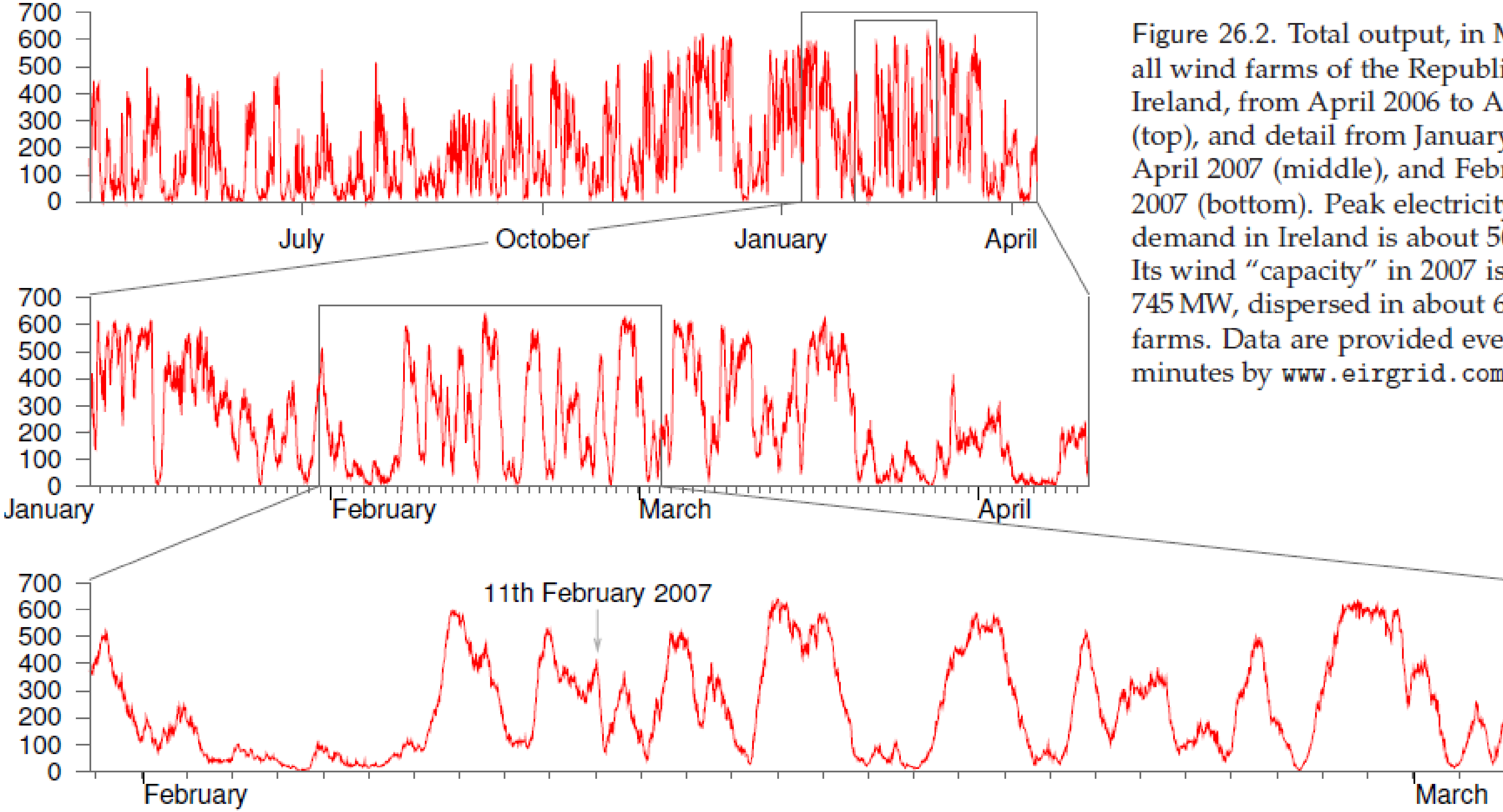


Figure 26.2. Total output, in MW, of all wind farms of the Republic of Ireland, from April 2006 to April 2007 (top), and detail from January 2007 to April 2007 (middle), and February 2007 (bottom). Peak electricity demand in Ireland is about 5000 MW. Its wind "capacity" in 2007 is 745 MW, dispersed in about 60 wind farms. Data are provided every 15 minutes by `www.eirgrid.com`.

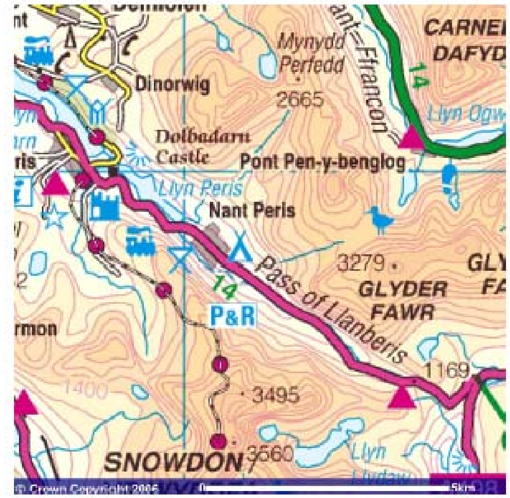
26. Fluctuation and Storage

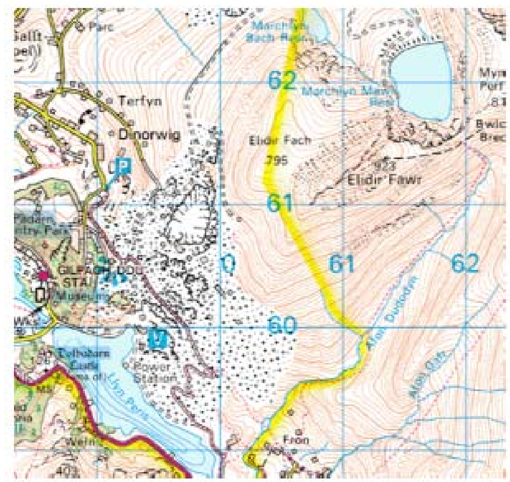
We need country-sized energy storage systems to cope with lulls in renewable energy production.

Options include

- Pumped storage
- Network of electric vehicles

Pumped storage involves using electricity to pump water from a low elevation to a high elevation, when there is excess electricity. When you need electricity and the wind turbines aren't spinning because the wind isn't blowing, you allow the water to flow back down to the lower elevation through hydroelectric turbines.





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.

26. Fluctuation and Storage

● Network of electric vehicles (Vehicle to Grid) Technology

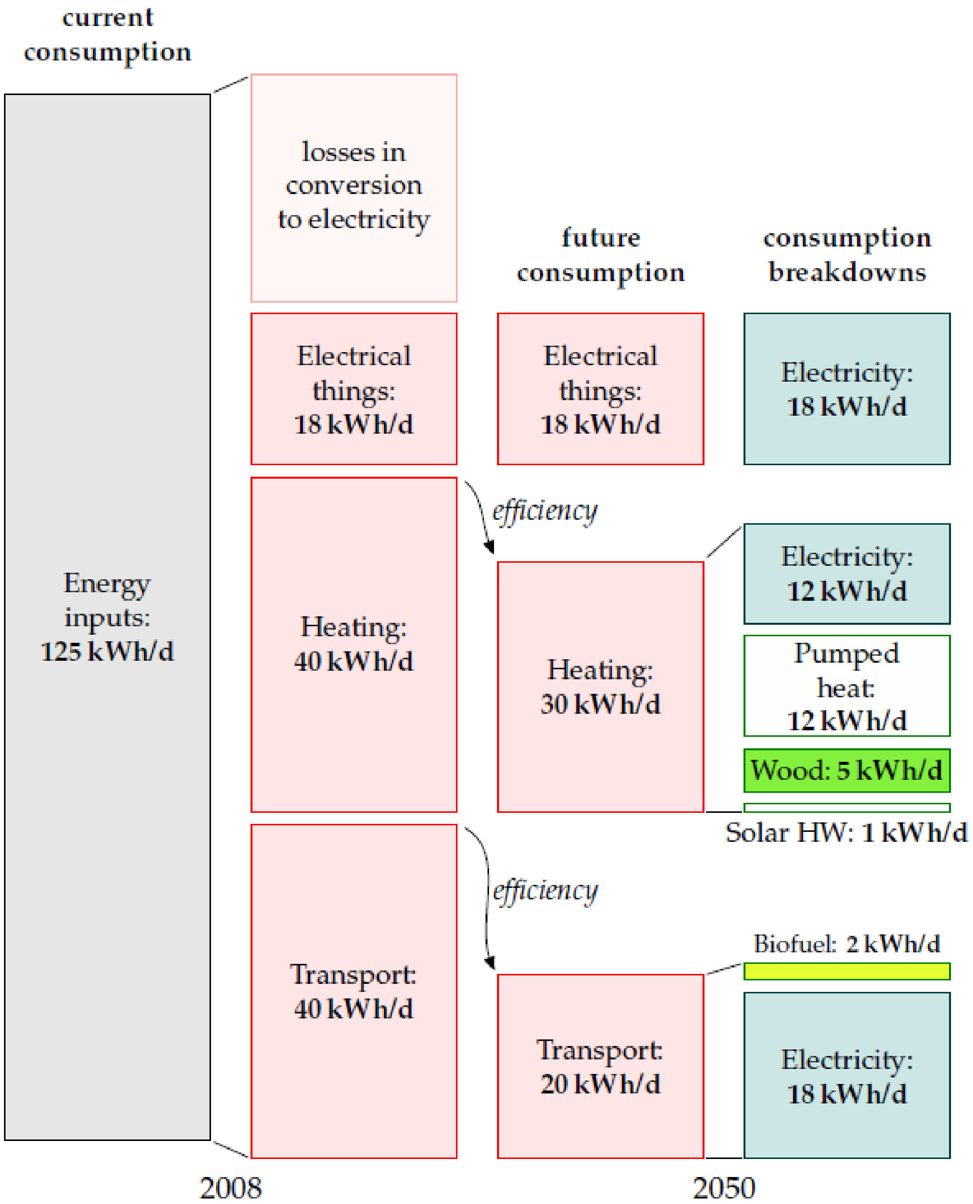
Vehicle-to-grid (**V2G**) describes a system in which plug-in electric vehicles, such as electric cars (BEVs) and plug-in hybrids (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate.[1][2]
Vehicle-to-grid can be used with such *gridable* vehicles, that is, plug-in electric vehicles (BEVs and PHEVs), with grid capacity. Since most vehicles are parked an average of 95 percent of the time, their batteries could be used to let electricity flow from the car to the power lines and back, with a value to the utilities of up to $4,000 per year per car.[3]

http://en.wikipedia.org/wiki/Vehicle-to-grid

27. 5 Plans for Britain

The Current Situation

Figure 27.1. Current consumption per person in "cartoon Britain 2008" (left two columns), and a future consumption plan, along with a possible breakdown of fuels (right two columns). This plan requires that electricity supply be increased from 18 to 48 kWh/d per person of electricity.



27. 5 Plans for Britain

Common Features of all Five Plans

transport

- transport is largely electrified.
- mass transport is more prevalent and more utilized

heating

- better insulated buildings
- heat pumps for heating

electricity

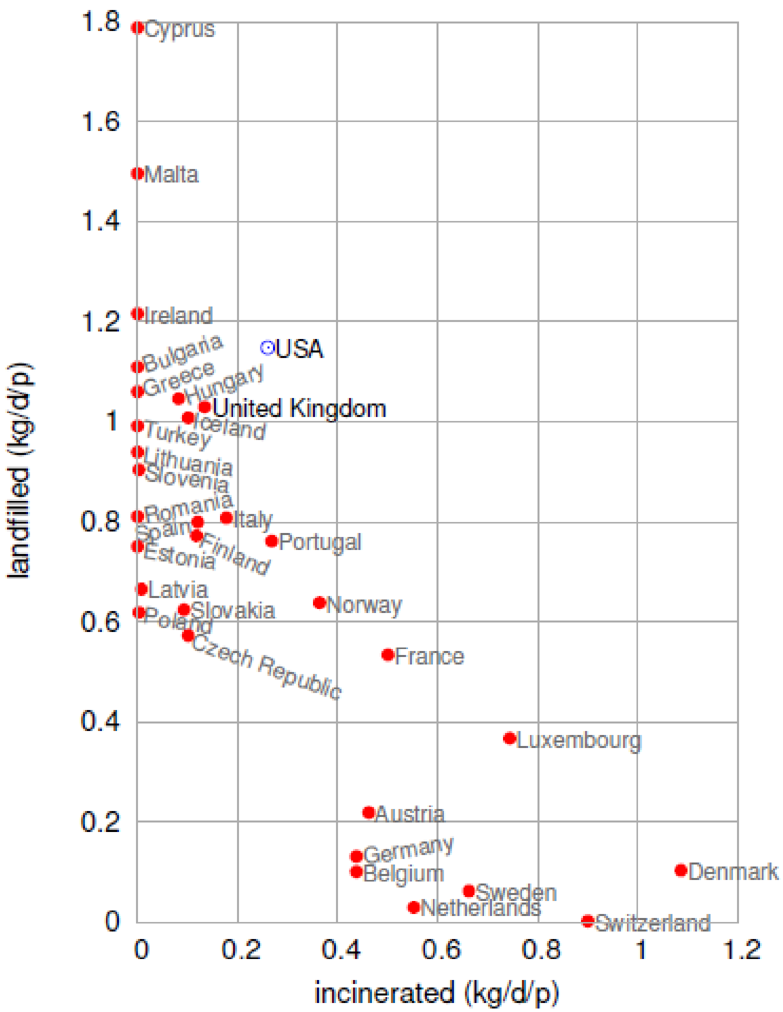
- increased from 18 kWh/d/p to 48 kWh/d/p

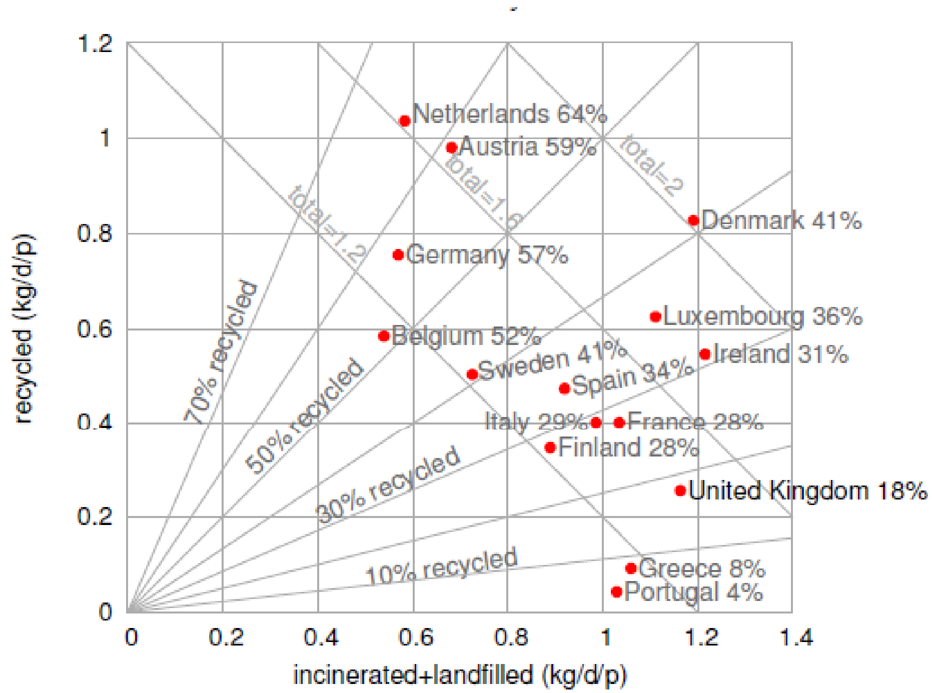
Waste incineration

- all waste that cannot be recycled is burned for energy

27. 5 Plans for Britain

Waste Incineration



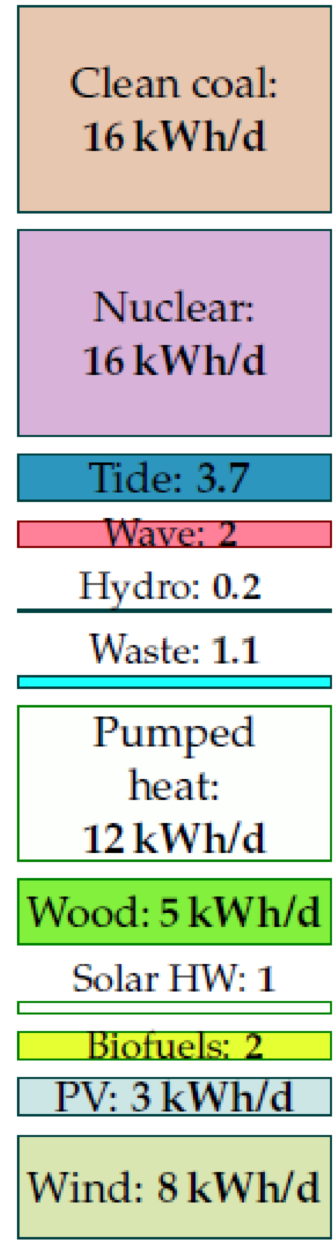


27. 5 Plans for Britain

Plan D: Domestic Diversity

Make as much energy as possible domestically.

- 30 fold increase in wind power
- 6 m^2 of 20% efficient PV cells per person in England
- Waste incineration 2 kg/d/person
- Wave power 16,000 pelamis wave devices
- Tidal stream installation, a barrage & tidal lagoons
- 4 fold increase in nuclear
- Increase coal-fired power plant capacity
- Use imported coal
- 32% of the energy from other countries (coal)

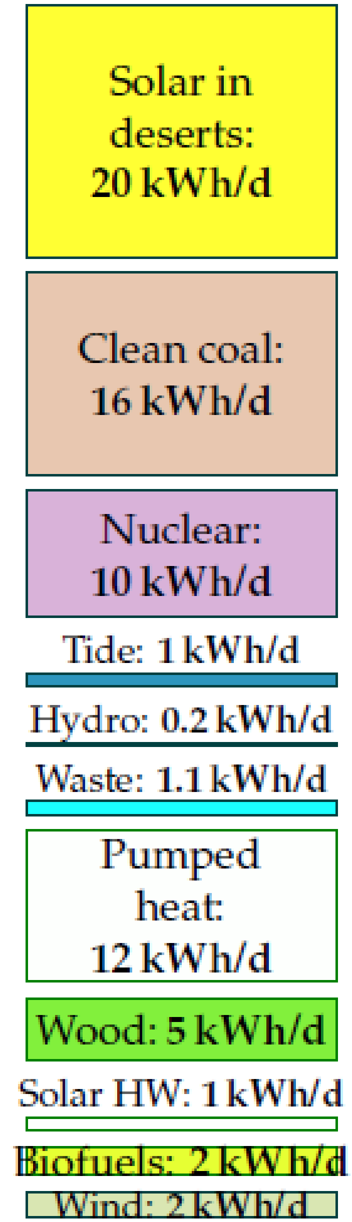


27. 5 Plans for Britain

Plan N: NIMBY: Not In My Back Yard

Don't industrialize the countryside.
Minimize nuclear.

- 8 fold increase in wind power
- No solar PV cells per person
- Waste incineration 2 kg/d/person
- No Wave power
- modest increase in nuclear (no new plants)
- Increase coal-fired power plant capacity
- Use imported coal
- solar power stations in North African deserts
- 72% of the energy from other countries



27. 5 Plans for Britain

Plan L: Liberal Democrats

No nuclear

- Same as plan D, but swap nuclear for solar.
- Solar power farms in North African deserts
- 64% of the energy from other countries

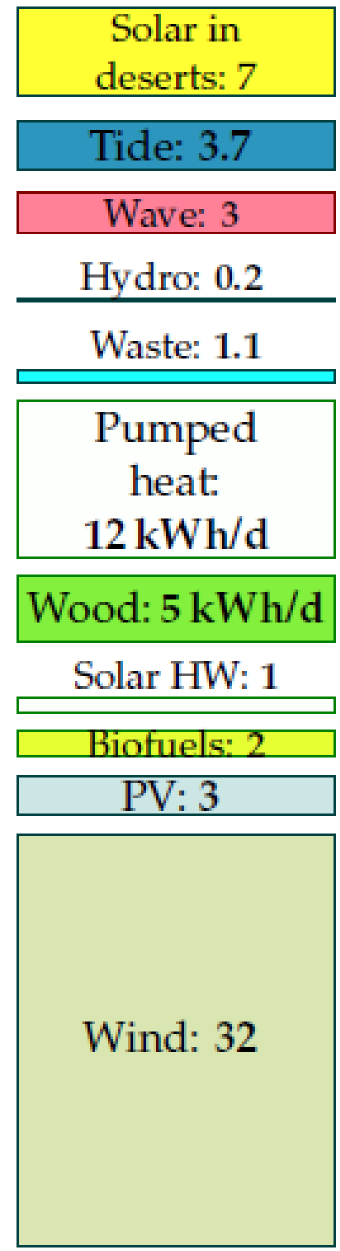
- 30 fold increase in wind power
- 6 m^2 of 20% efficient PV cells per person
- Waste incineration 2 kg/d/person
- Wave power 16,000 pelamis wave devices
- Tidal stream installation, a barrage & tidal lagoons
- Increase coal-fired power plant capacity
- Use imported coal

27. 5 Plans for Britain

Plan G: Green Party

No nuclear
No coal.

- 120 fold increase in wind power
- Solar power farms in North African deserts
- Waste incineration 2 kg/d/person
- Wave power 16,000 pelamis wave devices
- Tidal stream installation, a barrage & tidal lagoons
- Increase coal-fired power plant capacity
- Use imported coal
- 14% of the energy from other countries

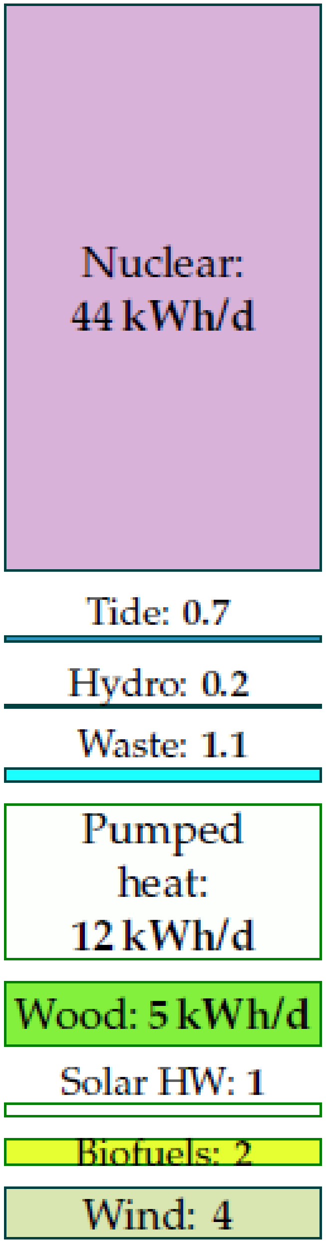


27. 5 Plans for Britain

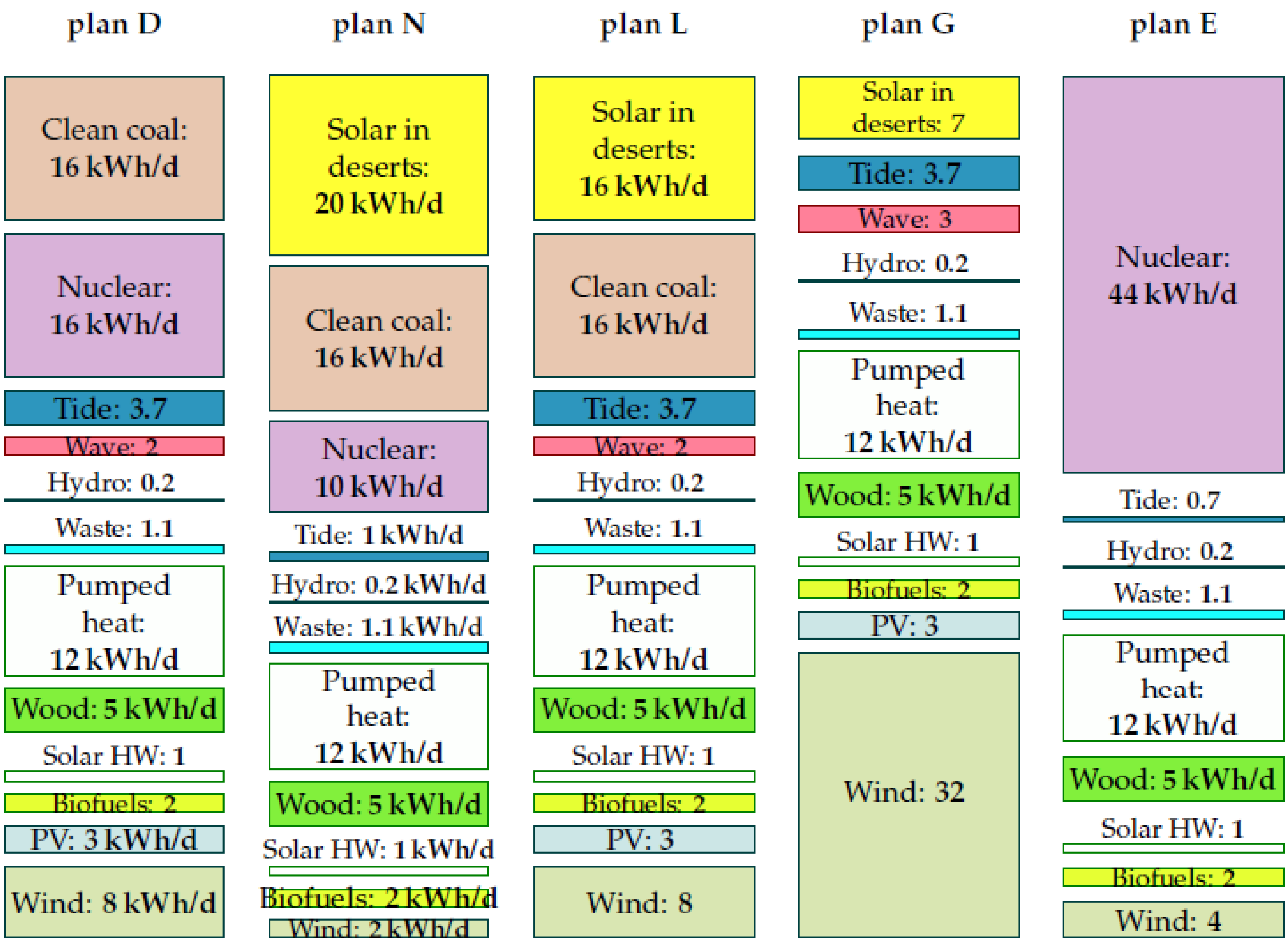
Plan E: Economics

Energy market with a strong carbon price.
Cheapest solution wins.
Nuclear is cheaper than "clean coal".

- 15 fold increase in wind power
- Waste incineration 2 kg/d/person
- 0% of the energy from other countries, if you don't count uranium



27. 5 Plans for Britain



All these plans are absurd. If so, think of a better one.

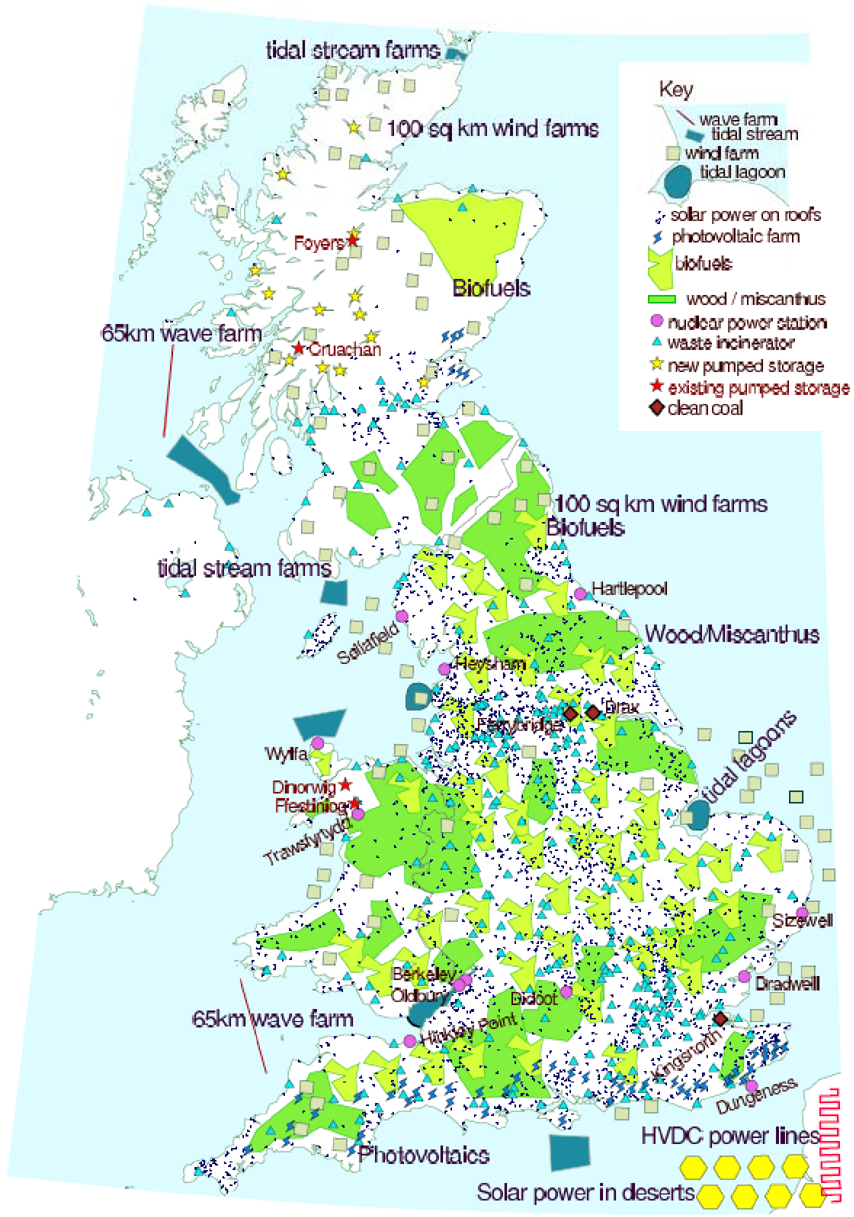
28. Putting Costs in Perspective

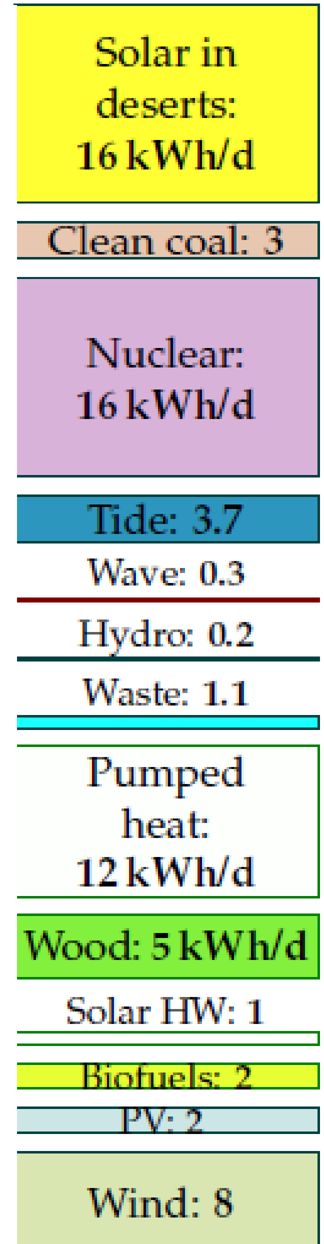
Plan M: the Middle plan

Combine elements of the five previous plans.

This model contains all technologies.

It is physically feasible. There is enough area around England for each of the technologies.





28. Putting Costs in

Plan M: the Middle plan

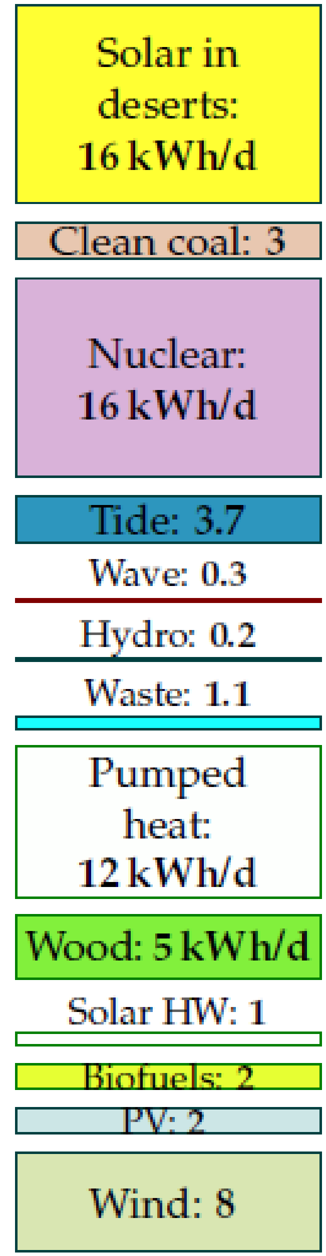
	Capacity	Rough cost total	Rough cost per person	Average power delivered
52 onshore wind farms: 5200 km^2	35 GW	£27bn – based on Lewis wind farm	£450	4.2 kWh/d/p
29 offshore wind farms: 2900 km^2	29 GW	£36bn – based on Kentish Flats, & including £3bn investment in jack-up barges.	£650	3.5 kWh/d/p
Pumped storage: 15 facilities similar to Dinorwig	30 GW	£15bn	£250	
Photovoltaic farms: 1000 km^2	48 GW	£190bn – based on Solarpark in Bavaria	£3200	2 kWh/d/p
Solar hot water panels: 1 m^2 of roof-mounted panel per person. (60 km^2 total)	2.5 GW(th) average	£72bn	£1200	1 kWh/d/p
Waste incinerators: 100 new 30 MW incinerators	3 GW	£8.5bn – based on SELCHP	£140	1.1 kWh/d/p
Heat pumps	210 GW(th)	£60bn	£1000	12 kWh/d/p
Wave farms – 2500 Pelamis, 130 km of sea	1.9 GW (0.76 GW average)	£6bn?	£100	0.3 kWh/d/p
Severn barrage: 550 km^2	8 GW (2 GW average)	£15bn	£250	0.8 kWh/d/p
Tidal lagoons: 800 km^2	1.75 GW average	£2.6bn?	£45	0.7 kWh/d/p
Tidal stream: 15 000 turbines – 2000 km^2	18 GW (5.5 GW average)	£21bn?	£350	2.2 kWh/d/p
Nuclear power: 40 stations	45 GW	£60bn – based on Olkiluoto, Finland	£1000	16 kWh/d/p
Clean coal	8 GW	£16bn	£270	3 kWh/d/p
Concentrating solar power in deserts: 2700 km^2	40 GW average	£340bn – based on Solúcar	£5700	16 kWh/d/p
Land in Europe for 1600 km of HVDC power lines: 1200 km^2	50 GW	£1bn – assuming land costs £7500 per ha	£15	
2000 km of HVDC power lines	50 GW	£1bn – based on German Aerospace Center estimates	£15	
Biofuels: 30 000 km^2		(cost not estimated)		2 kWh/d/p
Wood/Miscanthus: 31 000 km^2		(cost not estimated)		5 kWh/d/p

28. Putting Costs in Perspective

Plan M: the Middle plan

Installation cost per kWh/day/person.

	cost (billion pounds)	power kWh/d/p	cost/power (billion pounds/kWh/d/p)
onshore wind	27	4.2	6.428571
offshore wind	36	3.5	10.28571
photovoltaic farms	190	2	95
solar hot water	72	1	72
waste incinerators	8.5	1.1	7.727273
heat pumps	60	12	5
wave farms	6	0.3	20
tidal barrage	15	0.8	18.75
tidal lagoons	2.6	0.7	3.714286
tidal farm	21	2.2	9.545455
nuclear power	60	16	3.75
clean coal	16	3	5.333333
concentrating solar power in deserts	340	16	21.25



28. Putting Costs in Perspective

Other things that cost a billion

$46 billion/year – US war on drugs
$700 billion/year – US expenditure on foreign oil
$120 billion/year – US wars in Iraq and Afghanistan
$40 billion/year – US federal highway maintenance
£10 billion/year – UK spent on food that is not eaten
$40 billion/year – Exxon profits (2006)

The global cost of averting dangerous climate change (if we act now) is $440 billion/year

£ 0.012 billion/per year: UK government investment in renewable energy research and development

There is money out there.
We spend it on short-sighted endeavors.

29. What to do now?

Carbon Pollution
The price of carbon dioxide must be set sufficiently high that people stop burning coal without capture.

Energy Supply
We cannot rely on the free market to drive energy sustainability.
The free market makes short-term decisions for short-term investments.
We need government legislation and green taxes.

Greening the tax system
It is cheaper to buy a new microwave or dvd player than it is to have the old one repaired. In part because labor is taxed higher than material goods. If the tax on goods was higher, the option of repairing a device would be more economically attractive.

Investment in Research and Development
Energy technologies take decades to develop. An increase in research money is needed immediately.

29. What to do now?

Simple action	possible saving
Put on a woolly jumper and turn down your heating's thermostat (to 15 or 17 °C, say). Put individual thermostats on all radiators. Make sure the heating's off when no-one's at home. Do the same at work.	20 kWh/d
Read all your meters (gas, electricity, water) every week, and identify easy changes to reduce consumption (e.g., switching things off). Compare competitively with a friend. Read the meters at your place of work too, creating a perpetual live energy audit.	4 kWh/d
Stop flying.	35 kWh/d
Drive less, drive more slowly, drive more gently, carpool, use an electric car, join a car club, cycle, walk, use trains and buses.	20 kWh/d
Keep using old gadgets (e.g. computers); don't replace them early.	4 kWh/d
Change lights to fluorescent or LED.	4 kWh/d
Don't buy clutter. Avoid packaging.	20 kWh/d
Eat vegetarian, six days out of seven.	10 kWh/d

32 Saying yes

Because Britain currently gets 90% of its energy from fossil fuels, it's no surprise that getting off fossil fuels requires big, big changes – a total change in the transport fleet; a complete change of most building heating systems; and a 10- or 20-fold increase in green power.

Given the general tendency of the public to say "no" to wind farms, "no" to nuclear power, "no" to tidal barrages – "no" to anything other than fossil fuel power systems – I am worried that we won't actually get off fossil fuels when we need to. Instead, we'll settle for half-measures: slightly-more-efficient fossil-fuel power stations, cars, and home heating systems; a fig-leaf of a carbon trading system; a sprinkling of wind turbines; an inadequate number of nuclear power stations.

We need to choose a plan that adds up. It *is* possible to make a plan that adds up, but it's not going to be easy.

We need to stop saying no and start saying yes. We need to stop the Punch and Judy show and get building.

If you would like an honest, realistic energy policy that adds up, please tell all your political representatives and prospective political candidates.