Future Energy Supplies
The Big Picture

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"Available energy is the main object at stake in the struggle for existence and the evolution of the world" Ludwig Boltzmann

Some Facts & Assertions

- **The world uses a lot of energy, very unevenly**

- at a rate of 16 TW. Per person in kW:

World – 2.4, USA -10.3, UK – 4.6, China - 2.0, Bangladesh - 0.21

Note: *electricity generation only ~ 1/3 of primary energy use,* ***but*** *the % can/will rise*

- **World energy use expected to increase ~ 40% by 2030**

Increase needed to lift billions out of poverty - 1.5 billion people still lack electricity

Greater efficiency is the top priority: can curb growth, but unlikely to lead to a decrease unless development stalls in Africa, India etc

- **80% of the world's primary energy is generated by burning fossil fuels** (oil, coal, gas) – 13 TW and growing, *which is*

- causing potentially catastrophic climate change, and horrendous pollution (2 million deaths annually from air pollution: China - 650,000 + India - 530,000 + USA - 41,000 +…)

- unsustainable as they won't last forever

Will recall sources of energy, then ask:

- What is the time scale to prepare for the end of fossil fuels?
- What actions can/should we take i) to avoid climate change (assuming that we don't renounce the use of fossil fuels), ii) to replace fossil fuels when they are exhausted (or we renounce them)?

Sources of Energy

- **World's primary energy supply**:

		Approximate thermal equivalent:
81.4%	- fossil fuels*	**77.5%**
9.8%	- combustible renewables and waste	**9.3%**
5.9%	- nuclear	**5.6%**
2.2%	- hydro	**6.3%**
0.7%	- geothermal, solar, wind, .	**1.3%**

* 42% oil, 33% coal, 26% natural gas

Note: energy mix very varied

e.g. in **China:** Coal → 64% of primary energy; gas – only 3%

This explains why CO_2 per capita in China is above world average (although energy consumption per capita is below)

USA: 85% fossil; 3.5% combustible renewables etc; 9% nuclear, 3.5% hydro; 0.5% geothermal etc

Timescale for the end of fossil fuels

Saudi saying: "My father rode a camel. I drive a car. My son flies a plane. His son will ride a camel". **Is this true? Maybe:**

- **Oil** will be largely exhausted in 50 years

UKERC review - peak in production of **conventional oil** is 'likely to occur before 2030';

'significant risk' that it will occur before 2020.

Production will then fall ~ 3% (?) p.a.

'Unconventional' oil (heavy oil, oil shale, tar sands)

Could add ~ 50% to conventional oil resources,

but extraction → huge environmental damage, uses energy & produces CO_2, needs a lot of water for oil shale & tar sands, and is slow

Timescale for the end of fossil fuels (cont)

• **Gas** – *conventional gas* estimated to last ~ 130 years with current use (73 years with [IEA] 1.5% growth),

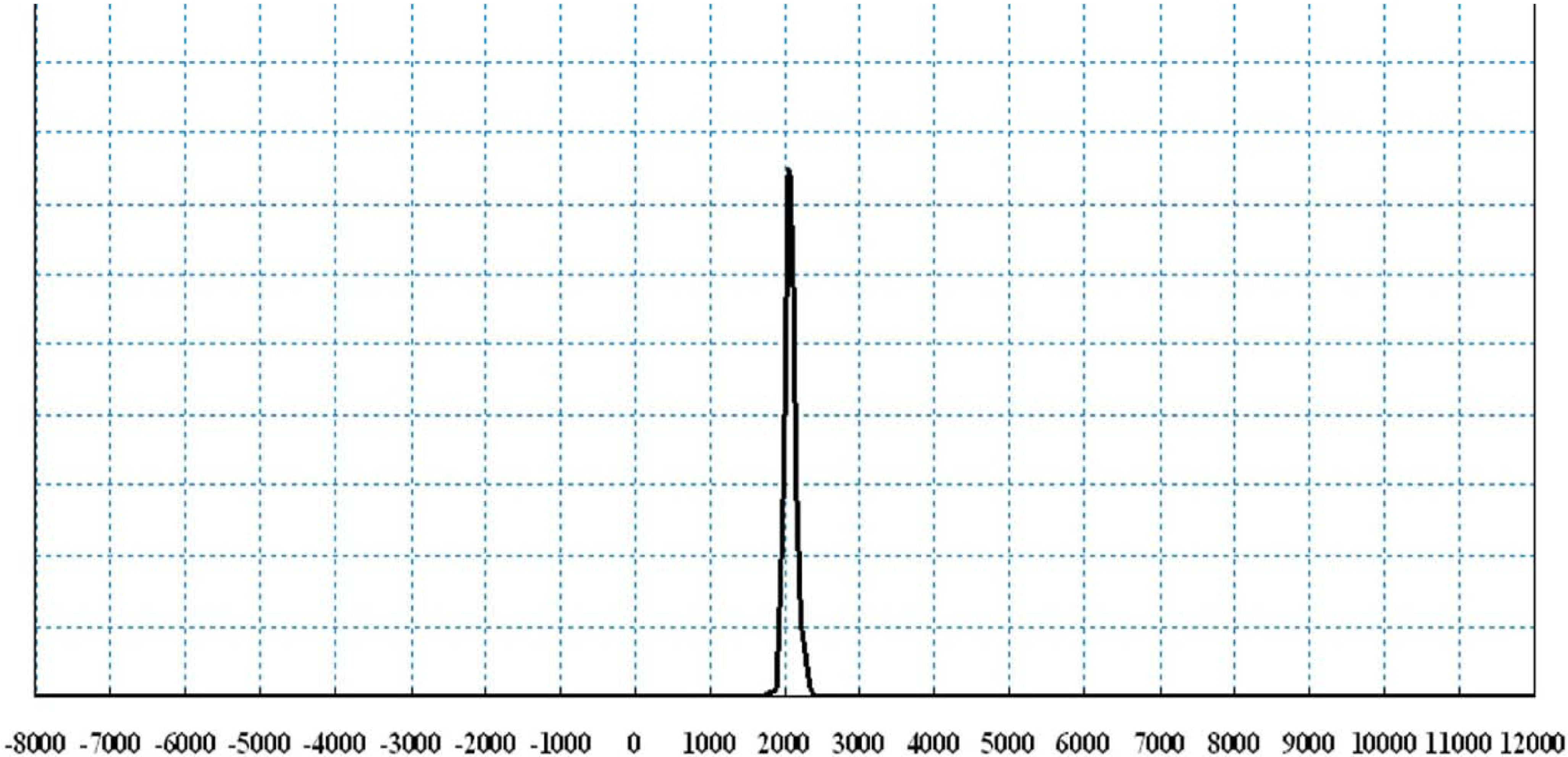
but recent huge expansion in prospects for *unconventional gas* (shale gas, tight gas, coal-bed methane) adds ~ 130 years (not including methyl hydrates)

• **Coal** – often said "enough for over 200 years" *(true? Questioned by group at Caltech)*

but that is with current use; with 1.9% p.a. growth [IEA] this becomes ~ 115 years

Note: *growth in gas and coal will increase as oil become scarce*

Need to start preparing for the post oil era now,
and thinking about the post fossil fuel era



Fossil Fuel Use

A brief episode in the world's history

If (as seems likely) we burn what remains, need to capture and bury as much of the CO2 as we can to avoid climate change

Carbon Capture and Storage (CCS)

- capture and burial of CO_2 from power stations and large industrial plants

- Given that CO_2 stays in the atmosphere for hundreds of years, we should have taken action yesterday!

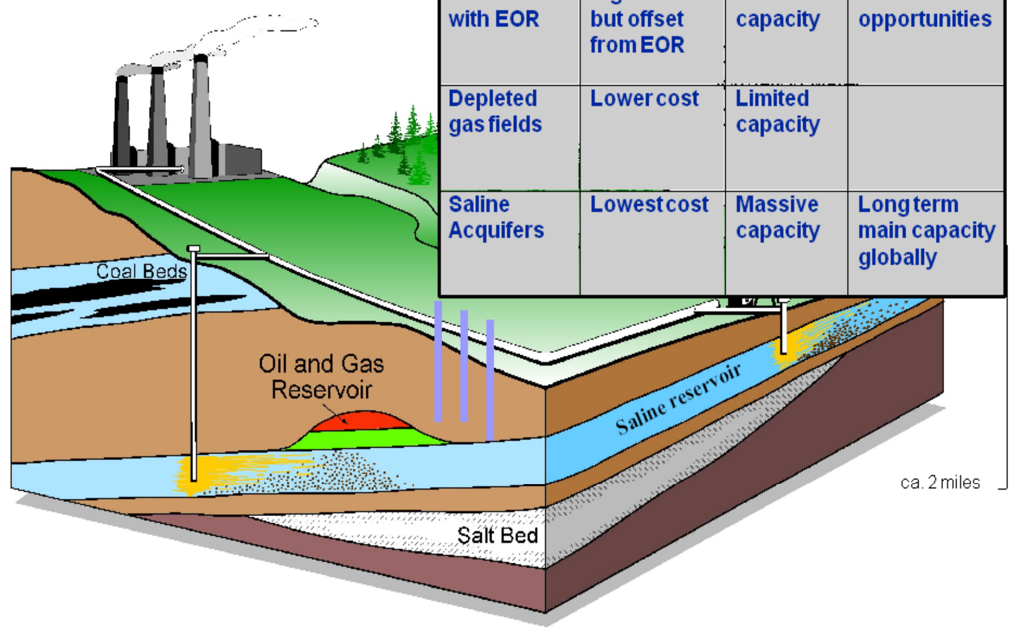
  Likely that most of the remaining fossil fuels will be burned in ~ 100 years, in which case CCS is the only action that can help

- **It should be developed as a matter of urgency and (if feasible) rolled out on the largest possible scale**

  Easy to say, but harder to do as it will put up the cost – initially will raise the production cost by ~\$100/ton of CO_2 for coal (\$50 for gas) ~ \$9c/kW-hr

CO_2 storage options

	Cost	Capacity	When
Oil – fields with EOR	Higher cost but offset from EOR	Limited capacity	Earliest opportunities
Depleted gas fields	Lower cost	Limited capacity	
Saline Acquifers	Lowest cost	Massive capacity	Long term main capacity globally



Necessary Actions in Preparation for the End of the Fossil Fuel Era

- **Reduction of energy use/efficiency**

\- can reduce the growth in world energy use, and save a lot of money, **but** unlikely to reduce total use, *assuming* continued rising in living standards in the developing world

- **Develop and expand low carbon energy sources**

\- **need everything we can sensibly get**, but without major contributions from solar and/or nuclear (fission and/or fusion) it will not be possible to replace fossil fuels without a huge drop in energy use

- **Devise economic tools and ensure the political will to make this happen**

The above steps also crucial for tackling climate change, for which carbon capture and storage is *also* vital

Use of Energy

End Use (rounded)

≈ 25% industry

≈ 25% transport

≈ 50% built environment
(private, industrial, commercial) } ≈ 30% domestic in UK

Energy Efficiency

Efficiency is a key component of the solution, but cannot meet the energy challenge on its own

Low Carbon Energy Sources

- **What can replace the 13TW** (and growing) **from fossil fuels?**

Maximum practical additional potentials ***(thermal equivalent)****:*

Wind 3TW*****, geothermal 100GW, hydro 2TW, bio 1TW, marine 100GW

which **add up to less than 7 TW**

?

Not Enough

*** Stanford claim can in principle get 72TW_e*

We should expand them as much as we reasonably can *(easy to say, but harder to do as it will put up the cost),* ***but the world will need something else, which can only be:***

Solar and/or Nuclear (fission or fusion)

Conclusions are very location dependent*: geothermal is a major player in Iceland, Kenya,…; the UK has 40% of Europe's wind potential and is well placed for tidal and waves; the US south west is much better than the UK for solar; there is big hydro potential in the Congo;…*

Solar Potential

- **Average* flux of 170 Wm^{-2} on 0.5% of the world's land surface** (50% occupied) **would, with 15% efficiency, provide 19 TW** *(equivalent to much more primary energy)*

*220 Wm^{-2} at equator, 110 Wm^{-2} at 50 degrees north

- **Photovoltaics are readily available with 15% efficiency or more, *and concentrated solar power can be significantly more efficient***

Photosynthesis:

- **Natural**: *even sugar cane is only 1% efficient at producing energy: wood ~ 1/6th efficiency of sugar cane*

Bio-fuels (2005) used 1% of agricultural land → 1% of road transport

- **Artificial**: exciting possibility of mimicking photosynthesis in an artificial catalytic system to produce hydrogen (to power fuel cells), with efficiency of possibly 10% (and no: wasted water, fertiliser, harvesting) – should be developed

Solar (non-bio)

- **Photovoltaics** (hydrogen storage?)

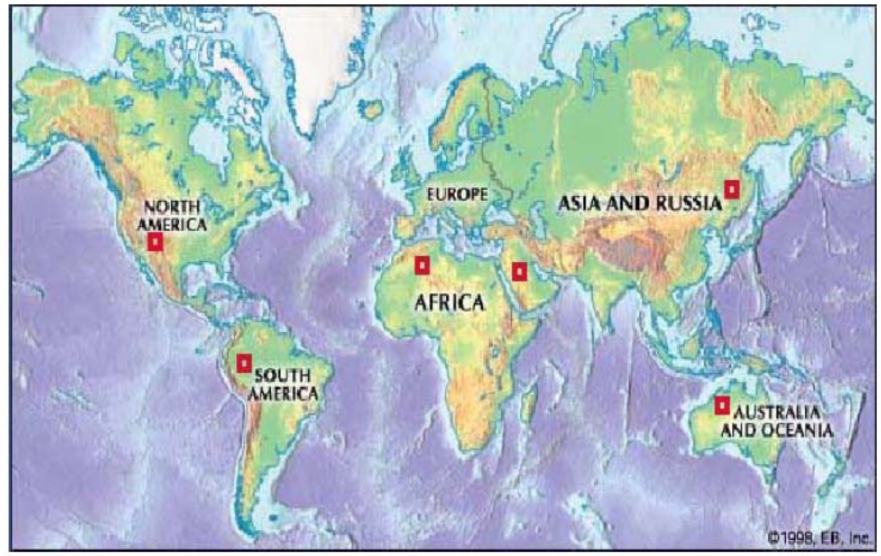
 - cost needs to come down

- **Concentration** (parabolic troughs, heliostats, towers)

→ turbines (storage: molten salts,….)

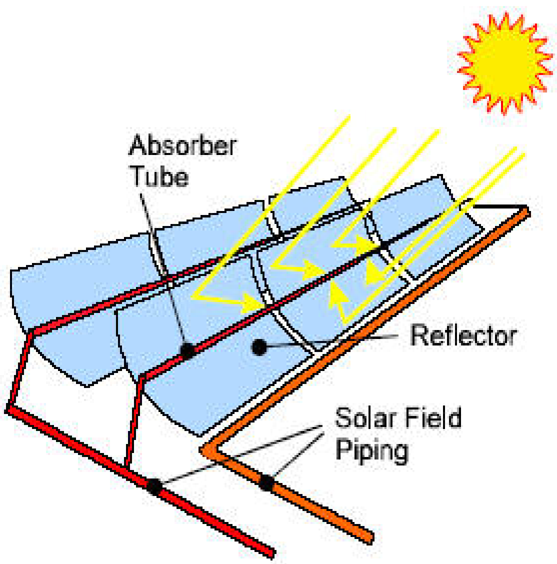
High T→ improved electrolysis (or even 'thermal cracking' of water to hydrogen? Challenges: new materials, fatigue…)

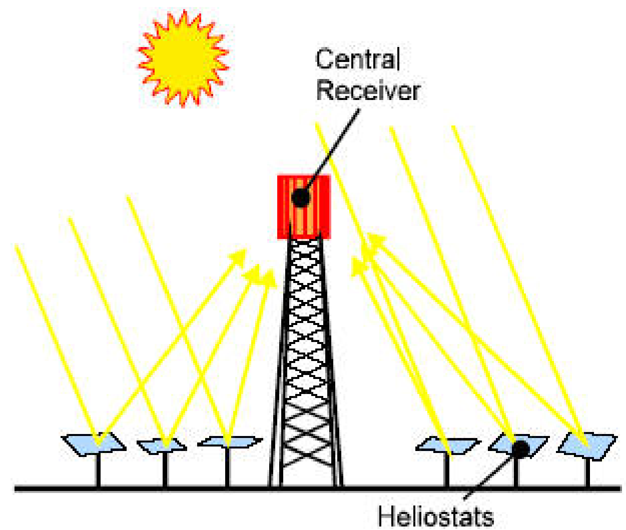
Problem – cooling water



6 boxes sized to produce 3.3TW of power each (20TW total – 630EJ)

Source: Lewis et al 2003c





Nuclear

Should be expanded dramatically now

■ New generation of reactors

- Fewer components, passive safety, less waste, more proliferation resistant, lower down time and lower costs
- On large scale: several options - AP1000, EPR, CANDU, ESBWR,…

• Looking to the future, need to consider

- Problems and limitations (snails pace of planning permission in some countries, safety*, waste, proliferation, uranium resources**)

  * biggest problem is perception; modern 1 GW coal power station with W European population density causes ~ 300 premature deaths (~ 10 years loss of life) per year → 9,000 in 30 years: more than Chernobyl

  ** 5mt conventional reserves → 38 mt including undiscovered conventional + U in phosphates = enough for 476 years at present use, but….

- Options

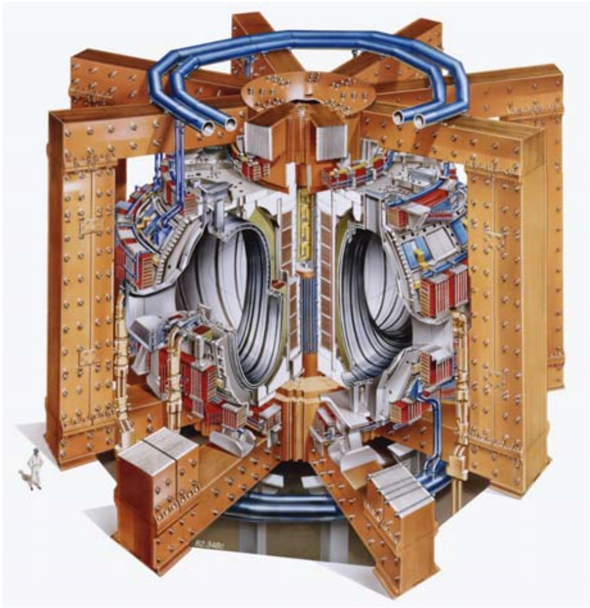
  Advanced fuel cycles, Uranium/plutonium fast breeders, Thorium reactors, Fusion - *will need some/all of these in longer term*

FUSION

powers the sun and stars

and a controlled 'magnetic confinement' fusion experiment at the **J**oint **E**uropean **T**orus (JET) (in the UK) has produced 16 MW of fusion power

so it works



The big question is

- when/whether it can be made to work reliably and economically, on the scale of a power station?

- **Raw fuels are water and lithium**

The lithium in one laptop battery + half a bath of water would produce 200,000 kW-hours of electricity = EU per-capita electricity production for 30 years

→ essentially unlimited fuel, no CO_2 or air pollution, intrinsic safety, no radioactive ash or long-lived nuclear waste (walls become activated but with right choice of materials can recycle in ~ 100 years), cost will be reasonable ***if*** we can get it to work reliably

sufficient reasons to develop fusion as a matter of urgency

Could what is available add up to a 'solution'?

Known technologies could *in principle* meet demand with constrained CO_2 *(but > 500 ppm inevitable?)* **until the middle of the century**

but

it will be very difficult (*much* harder than implied by the IEA's 2010 World Energy Outlook)

and will only be possible with

- technology development, e.g. for carbon capture and storage - *essential*

- increased efficiency: *most obvious steps save money (see next slide)*

why's it not happening?

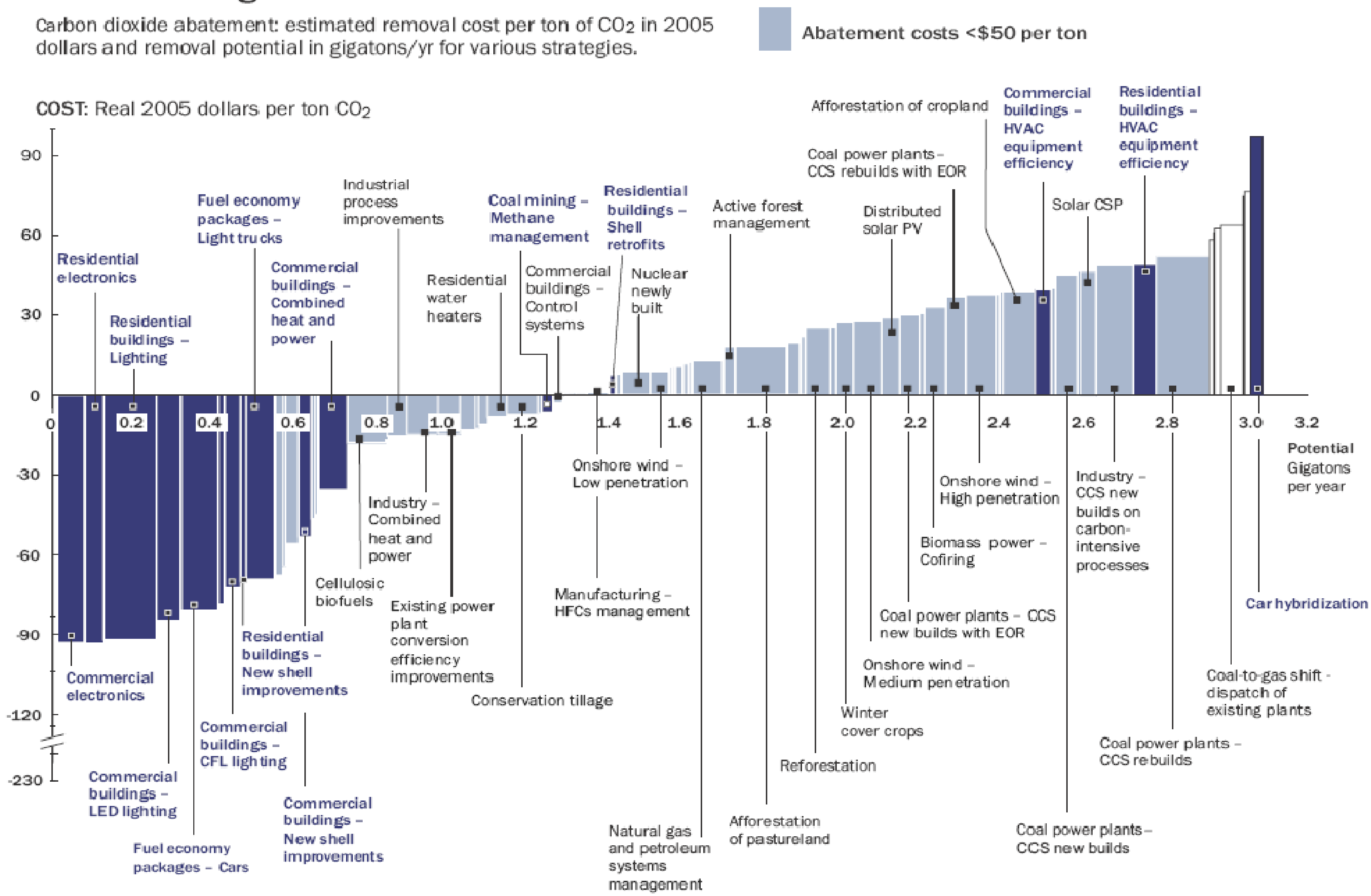
- all known low carbon sources pushed to the limit *(including much more nuclear)*

- **public willingness to pay more *before* the lights to out** in order to reduce CO_2 and prevent lights going out**,**

and/or political will *globally* to *force* the public to do so → cost up through Carbon tax (best) or credits (more likely) + strong regulations

U.S. mid-range abatement curve - 2030

Carbon dioxide abatement: estimated removal cost per ton of CO_2 in 2005 dollars and removal potential in gigatons/yr for various strategies.



Source: *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*, Executive Report, McKinsey & Company, December 2007

Final Conclusions

- Huge increase in energy use expected; large increase needed to lift world out of poverty
- Challenge of meeting demand in an environmentally responsible manner is enormous
- No silver bullet - need a portfolio approach

Need all sensible measures: more wind, hydro, biofuels, marine, and **particularly: CCS** (essential to reduce climate change) and **increased efficiency**, and in longer term: more **solar** and **nuclear fission**, and **fusion** [we hope]

- Huge R&D agenda - needs more resources (to be judged on the ~ $5 trillion p.a. scale of the world energy market)
- Need fiscal incentives - carbon price, regulation
- Political will (globally) - targets no use on their own

The time for action is now

Malthusian "solution" if we fail?