The Energy Challenge

Chris Llewellyn Smith
Director of Energy Research Oxford University
President SESAME Council

Introduction 1

■ **The biggest challenge of the 21st century**

- *provide sufficient food, water, and energy to allow everyone on the planet to live decent lives, in the face of rising population**, *the threat of climate change, and declining fossil fuels*

* Today nearly 7 billion, over 50% living in big cites
Later in the century 9 to 10 billion, 80% in big cities

■ **Energy is a necessary** (but not sufficient) **means to meet this challenge**

Introduction 2
Scale of challenge

- **International Energy Agency 'new policies scenario'**

- assumes successful implementation of all agreed national policies and announced commitments designed to save energy and reduce use of fossil fuels

Projections for 2008-35:

Energy use* + 35%, fossil fuels + 24%

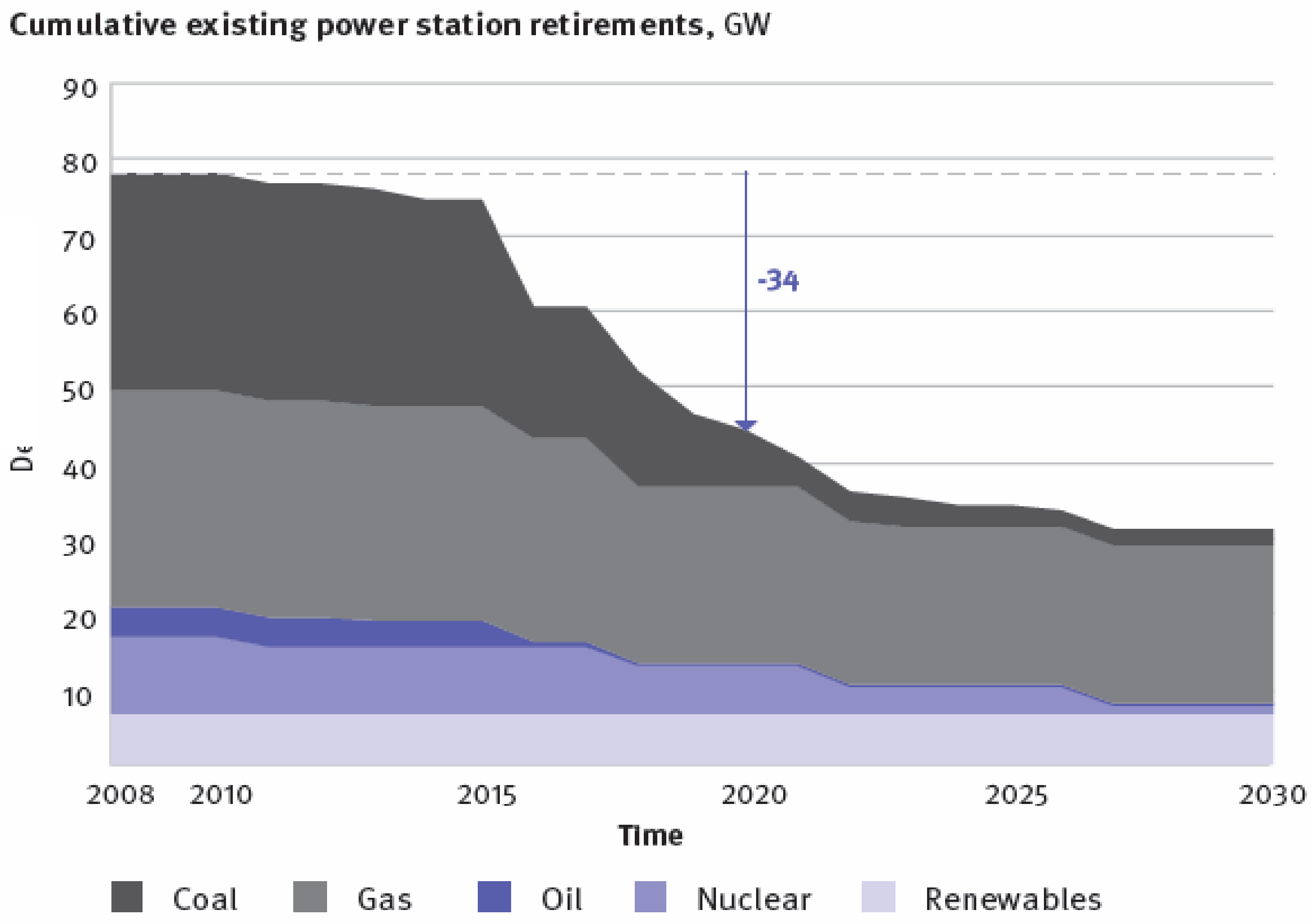
- almost all from developing countries

* nuclear + 79%, hydro + 72%, wind up 13-fold , …

- **BP** thinks **energy use will rise 40% in 2010-30**

Introduction 3

Talk addresses global situation, but note special problem in UK where 44% of current electricity generating capacity is due to close by 2020:



Note:
Graph = *capacity*
Average output ~ 44 GW

Output (2007):
Gas 42%
Coal 35%
Nuclear 16%
Hydro 2.3%
Bio 2.0%
Wind 1.3%
Oil 1.2%
Waste 0.8%

Energy Facts

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

at a rate of 16.3 TW

Per person in kW: World - 2.4

USA -10.3, UK - 4.6, China - 2.0, Bangladesh - 0.21

Note: *electricity generation only uses ~ 35% of primary power*
but *this fraction can/will rise*

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

Increase needed to lift billions out of poverty in the developing world

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

  - causing potentially catastrophic climate change, and horrendous pollution
  - unsustainable as they won't last forever

Energy Inequality

Some 1.5 billion people lack electricity

For world energy use per person to reach today's level in

- **The USA** - total world energy use would have to increase by a factor of 4.3 (5.9 when world population reaches 9 billion)
- **The UK** - total world energy use would have to increase by a factor of 1.9 (2.6 when world population reaches 9 billion)

This is not possible

There will have to be changes of expectations in both the developed and the developing world, and we must seek to use energy more efficiently and develop new clean sources

Sources of Energy

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

	Approx. thermal equivalent:	Rounded:
Fossil fuels*	77.7%	**80%**
Combustible renewables & waste	9.6%	**10%**
Nuclear	5.5%	**5%**
Hydro	6.3%	**5%**
Geothermal, solar, wind,...	0.9%	**1%**

* 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 is (part of) the explanation for the very large number of premature deaths caused by air pollution in China. Annual figures (WHO 2007):

Globally - 2 million deaths, China 650,000, India - 530,000, USA - 41,000

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?**

- Peak in production of **Conventional oil** is ‘likely to occur before 2030’ and there is a ‘significant risk’ that it will occur before 2020

Production will then fall ~ (2-4)% (?) p.a.

- ‘**Unconventional’ oil** (heavy oil, oil shale, tar sands) → 2% today → 7% (IEA) 2030 → could produce a second oil age

Extraction currently expanding too slowly to significantly mitigate a post early-peak decline in conventional – *but this could be changed by new technologies, e.g. in-situ production of hydro-carbons from shale oil*

→ serious environmental damage

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 huge expansion expected for ***unconventional*** (shale, tight, coal-bed methane) ***gas*** adds ~ 130 years, and **has transformed world gas outlook & markets**

■ **Coal** – "enough for over 200 years*" with current use (83 years with [IEA] 1.9% p.a. growth)

**being questioned (see Nature 18/11/10, page 367)*

Note: *1) Growth in gas and coal use will increase as oil become scarce, 2) Huge quantities of methyl hydrates*

Conclusions:

- Need to prepare for increasing oil price
- Fossil fuels are able (and likely) to continue to play a dominant role for many decades

Timescale to avoid climate change

■ If CO_2 emissions stop

Huge uncertainties, but some recent work → new ocean/atmosphere equilibrium at 20%-40% of peak in a few (tens of?) centuries. Then uptake as calcium carbonate (thousands of years) & by igneous rock (hundreds of thousands of years)

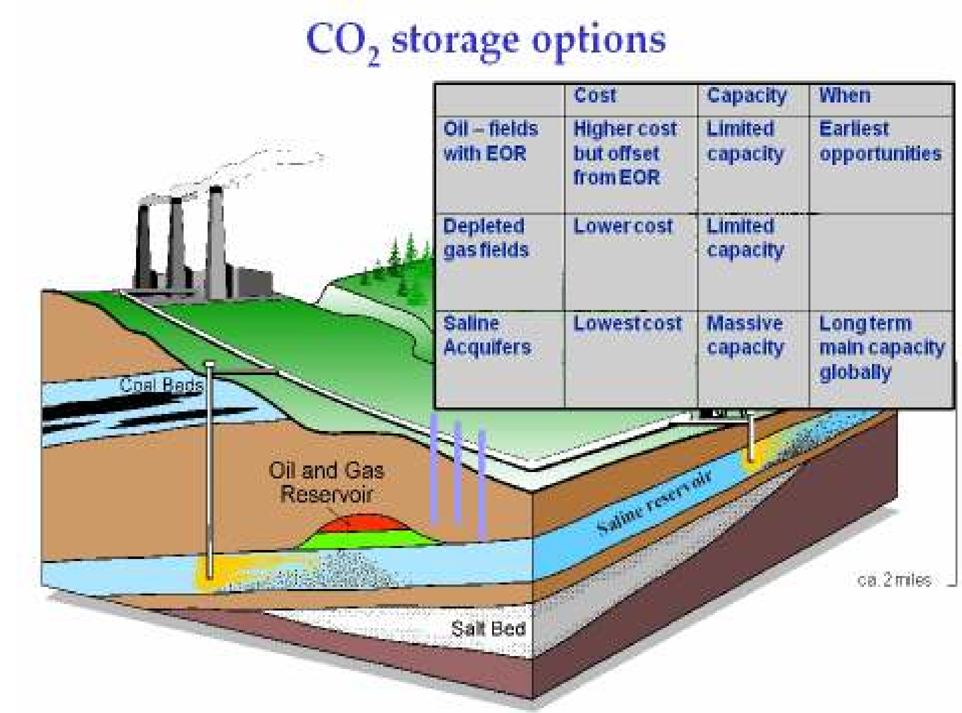
Most of the remaining fossil fuels will be burned in ~ 100 years *unless we can develop large-scale cost-competitive alternatives*

Meanwhile the only action we can take to avoid climate change:

■ Carbon Capture and Storage*

*capture and burial of CO_2 from power stations and large industrial plants, *which must stay buried for thousands of years!*

should be developed as a matter of urgency and ***(if feasible and safe)*** **rolled out on the largest possible scale** *(easy to say, but harder to do as it will put up the cost)*



	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

- **Carbon Capture and Storage** *(if feasible and safe)*

- **Reduce energy use/improve efficiency**

- can reduce the growth in world energy use, and save a lot of money, **but** unlikely to reduce total use, *assuming* continued rise 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 the 13.3 TW currently provided by fossil fuels

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

Use of Energy, Demand Reduction & Energy Efficiency

- **End Use** (rounded)
  - ≈ 25% industry
  - ≈ 25% transport
  - ≈ 50% built environment (private, industrial, commercial) } ≈ 30% domestic in UK

- **Demand reduction** - better design & planning, changes of lifestyle

- **Substantial efficiency gains possible, and would save money, e.g.**

- raise world average thermal power plant efficiency from ~ 33% to 45%
- better insulated buildings
- more efficient lighting
- more efficient internal combustion engines → hybrids → batteries → fuel cells

Huge scope & considerable progress but demand is rising faster

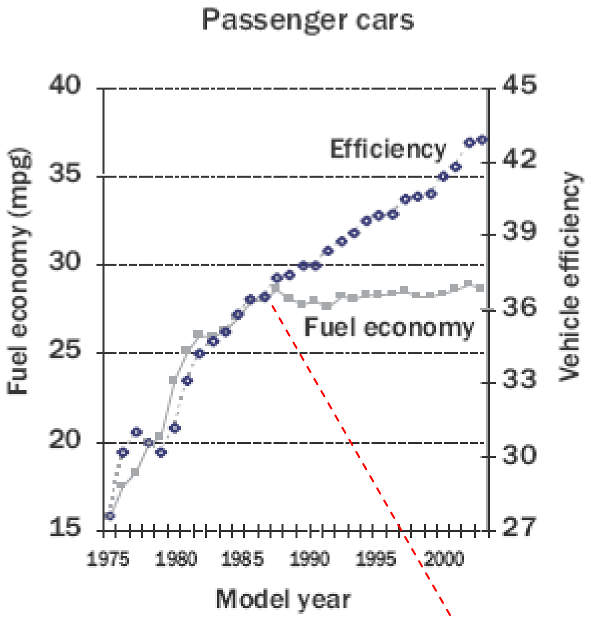
Efficiency is a key component of the solution, but cannot meet the energy challenge on its own

Key Role of Regulation

Figure 6

U.S. fuel economy vs. fuel efficiency

Fuel economy and fuel efficiency for cars and light trucks in the United States for the period 1975 to 2004. (The unit of efficiency in this figure only is ton-miles per gallon. This is the fuel efficiency mentioned in the text multiplied by the weight of the vehicle.)

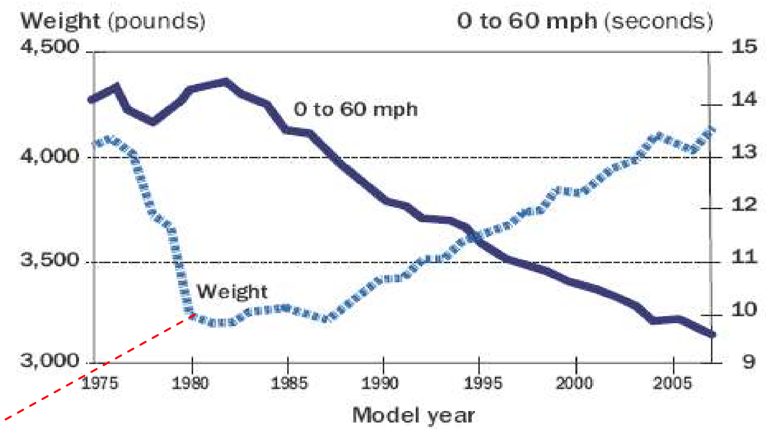


Source: Lutsey and Sperling, 2005

Figure 7

Vehicle weight and acceleration, 1975-2007

Vehicle weight initially decreased to help meet the new standards, but has increased ever since.



Source: Environmental Protection Agency, 2007

End of mandatory Corporate Average Fuel Economy standards

Low Carbon Energy Sources

What can replace the 13.3 TW (rising) from fossil fuels?

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

- Wind 3 TW **(50 x today)**
- Hydro 2 TW (2x today)
- Bio 1 TW (2/3 of today)
- 'Enhanced' geothermal 0.9 TW (70 x today)
- Marine 0.1 TW (500 x today)

?

Not Enough

We should expand these sources as much as we reasonably can *- hard as they are more expensive than fossil fuels,* and wind & marine will have to be supported by large scale storage – *needs to be developed!*

But they cannot provide enough to replace fossil fuel

Will need major contributions from *solar, nuclear fission or fusion*

* ***very location dependent****: the UK has 40% of Europe's wind potential and is well placed for tidal and waves; there is big hydro potential in the Congo;…*

Solar - today → 0.54 GW_e out of 2,270 GW_e total

Enormous potential, but needs cost reduction, storage, and transmission in order to be a big player

- **Photovoltaics** (hydrogen storage?)

Currently* $25c/kW-hr

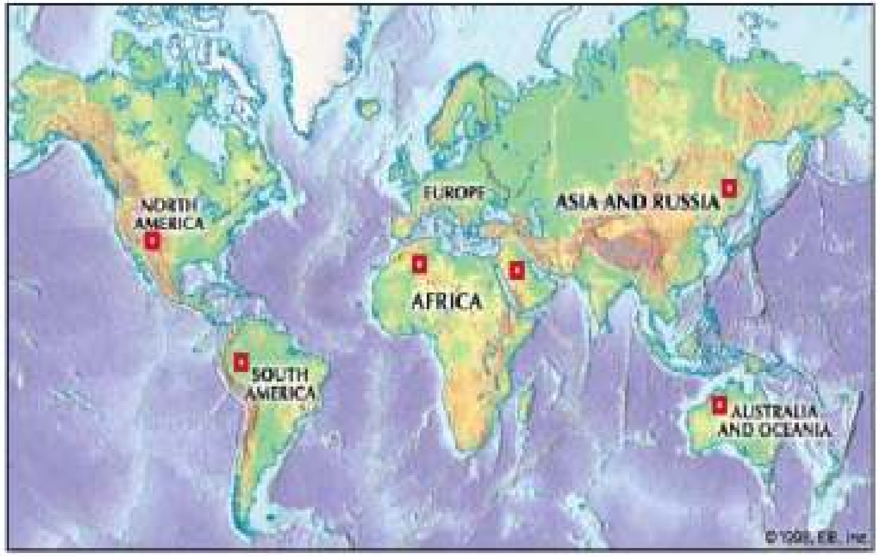
→ 5 in 2050 (IEA)???

- **Concentration** (thermal storage + fossil- or bio- fuelled furnace)

Currently* $20c/kW-hr

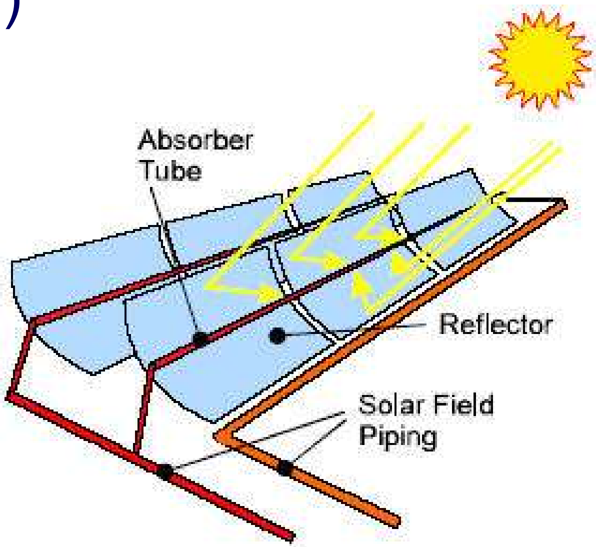
→ 5 in 2030 (IEA)??

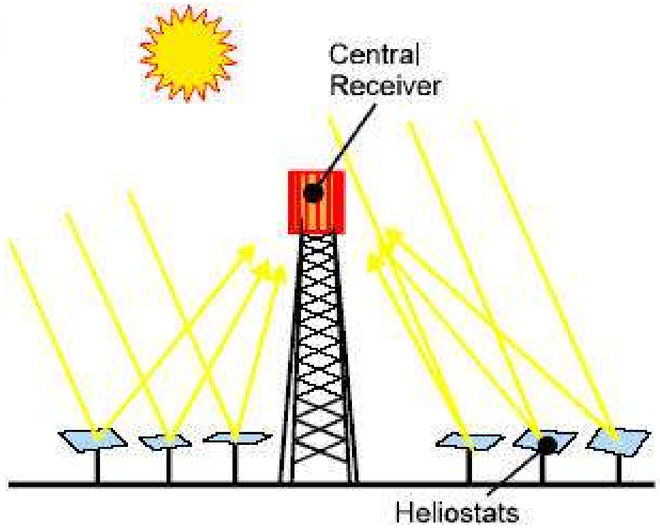
*large scale in very good conditions



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

- **Looking to the future, need to consider**

- **Problems/limitations**

  - proliferation: mainly a political issue
  - safety: mainly a problem of perception
  - waste: problem technically solved – issue is volume
  - uranium resources: think (?) enough for 475 years with current use + today's reactors: 80 years if nuclear → 100% of today's electricity

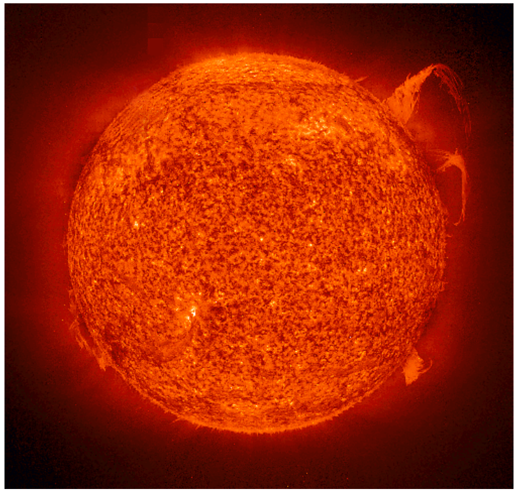
- **Options** **(Aims:** less waste, prolong nuclear age, greater proliferation resistance,...)

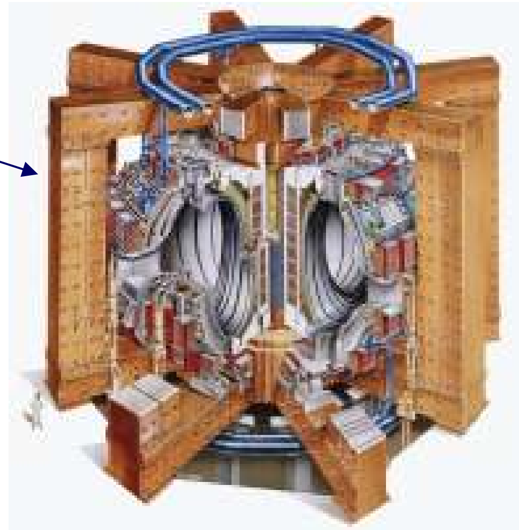
  - re-cycle fuel (20% more energy, less waste)
  - fast breeders (100xenergy, less waste, but more expensive) – need development
  - thorium (lots of it;less waste) – needs development
  - fusion

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 (briefly) produced 16 MW of fusion power





so it works

The big question is

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

First: why is it taking so long?

Technically very challenging → why bother?

Cannot demonstrate on a small scale. Inadequate funding

Why bother?

- Raw fuels are lithium and water

Enough lithium for millions of years *(water for billions)*

- *Lithium in one laptop battery + 40 litres of water*

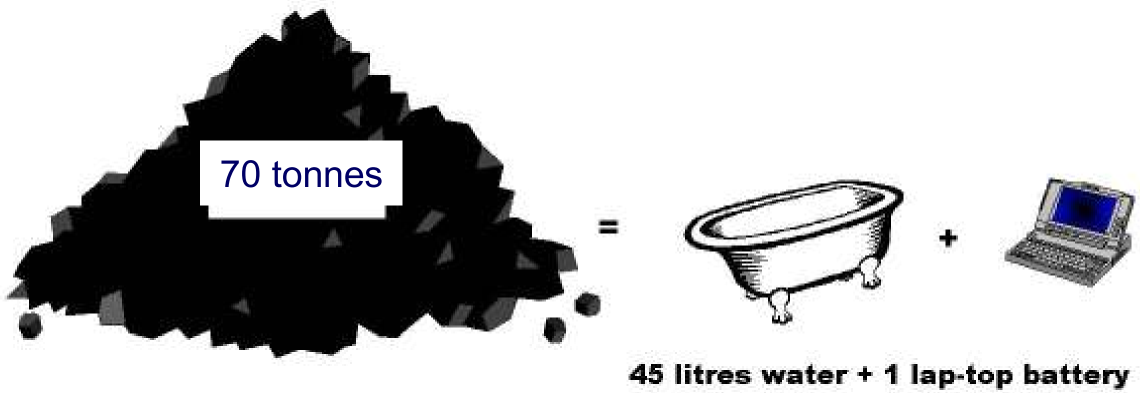
used to fuel a fusion power station

would provide 200,000 kW-hours =

per capita electricity production in the UK for 30 years

in an intrinsically safe manner with no CO_2 or long-lived waste,

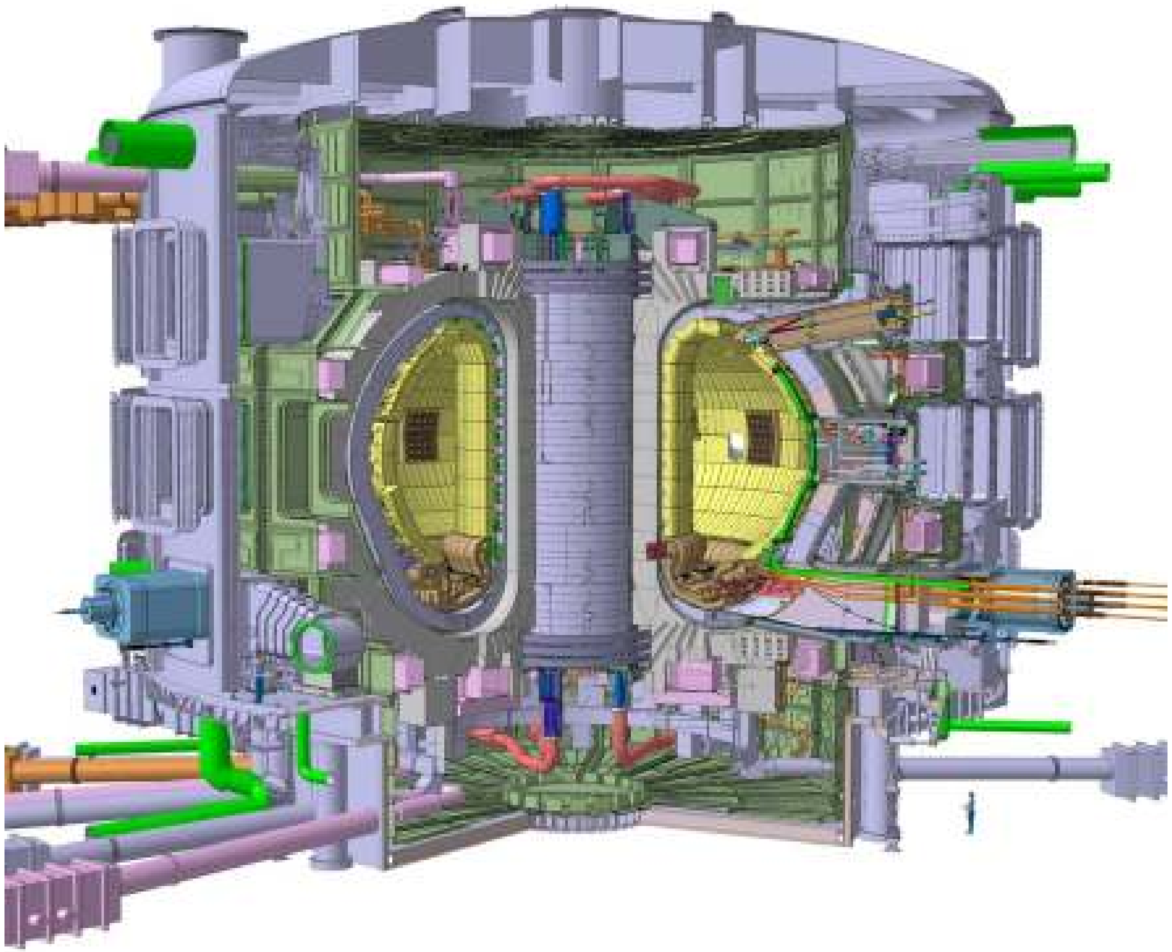
at what appears will be a reasonable cost

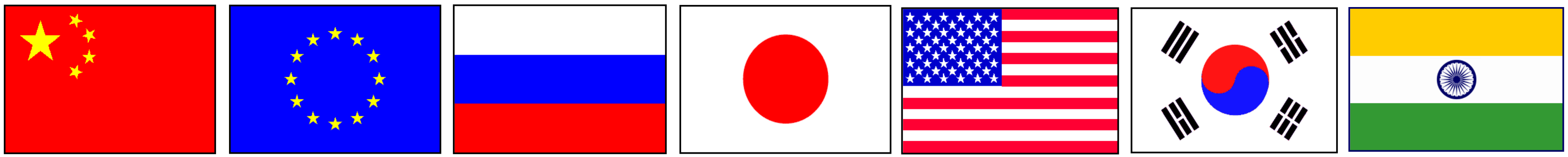


Sufficient reason to develop fusion power, unless/until we find a barrier

Next Step: Build ITER (2xsize of JET)

- **Aim –** demonstrate/test integrated physics and engineering (tritium generation, power conversion,…) in a burning plasma on the scale of a power station, with **energy out *at least* ½ GW = 10x energy in**
- **Construction beginning**
- **Operation should start in 2019. Burning plasma ~ 2027**





Timetable to a Demonstrator Power Plant (DEMO)

- **Build ITER ~ 10 years + Operate ~ 10 years**
- **In parallel*intensified work on materials work for walls + further development of fusion technologies + design work on DEMO:**
- **Assuming no major adverse surprises, ready to stat building DEMO in ~ 20 years**
- **Power from DEMO to the grid in ~ 30 years**
- **'Commercial' fusion power** (cost projections look OK) **~ middle of the century**

This work is currently not being funded adequately so, like previous timetables, this one looks set to be wrong – for the same reason

Conclusions on fusion

- I believe it will be possible to make a fusion power station, ***although*** I'm not sure when/whether it will be possible to make it reliable and competitive (with what?)
- **I am *absolutely certain* that the world must pursue fusion development as rapidly and effectively as reasonably possible** (no point doing it badly)

    - the potential is enormous

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

All sensible measures: more wind, hydro, biofuels, marine, and

particularly: demand reduction, increased efficiency, more nuclear, CCS[?]

and in longer term: much more **solar, advanced nuclear fission**, and **fusion** [?]

- Huge R&D agenda - needs more resources (to be judged on the ~ $5 trillion p.a. scale of the world energy market + $400 billion p.a. subsidies for fossil fuels)
- Need financial incentives - carbon price, and regulation
- Political will (globally) - targets no use on their own

The time for action is now

Malthusian "solution" if we fail?