Fusion as a Future Energy Source

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Outline

- Fusion Introduction
- The Challenge
- Resource Availability
- Emissions
- Waste
- Safety
- Costs and Investment
- Conclusions

Information derived from detailed technical work around power plant and socio-economic studies. Only summary in each area is given here.

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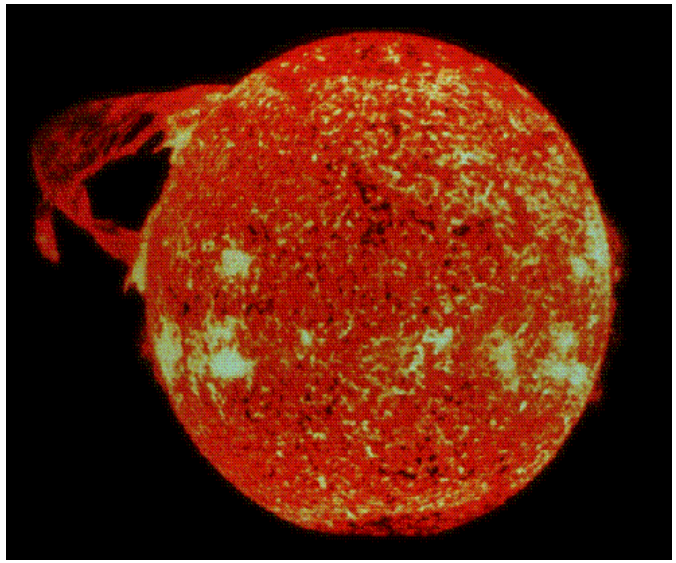
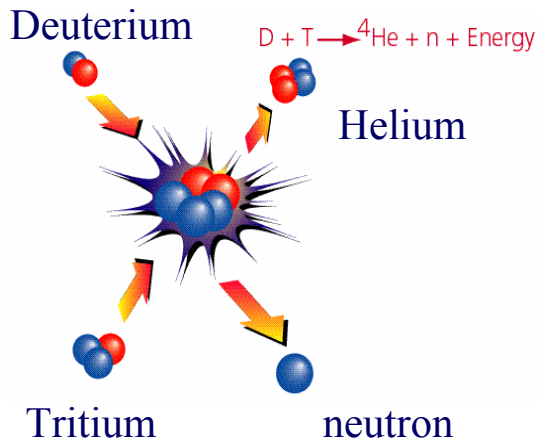
What is Fusion?



- Fusion is the process that produces energy in the core of the Sun and stars.
- The temperature of the centre of the Sun is 15 million °C. At this temperature hydrogen nuclei fuse to give Helium and Energy. The fusion of H takes billions of years.

- Fortunately isotopes of hydrogen (deuterium, tritium) can fuse much more quickly (seconds).
- We use a “magnetic bottle” called a tokamak to keep the hot plasma away from the wall, and insulate against heat loss. This allows temperatures above 100 million °C to be routinely achieved.



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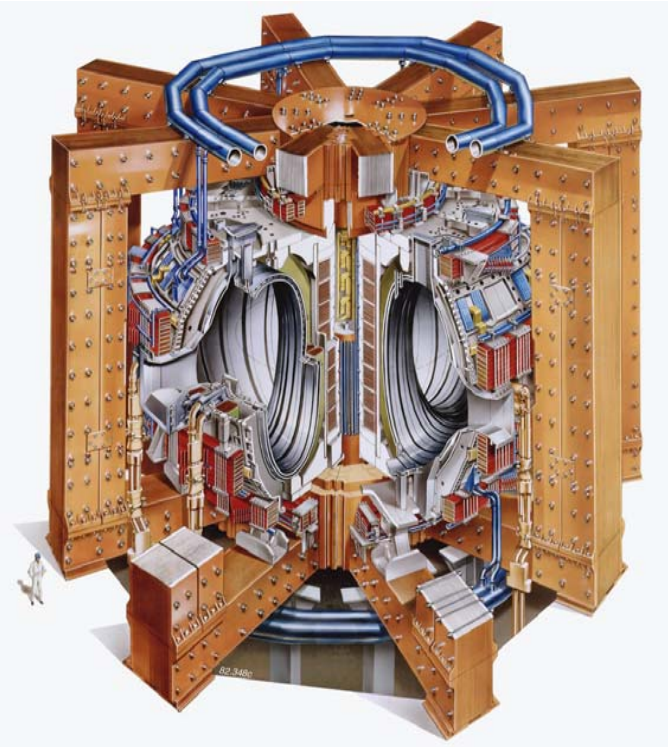
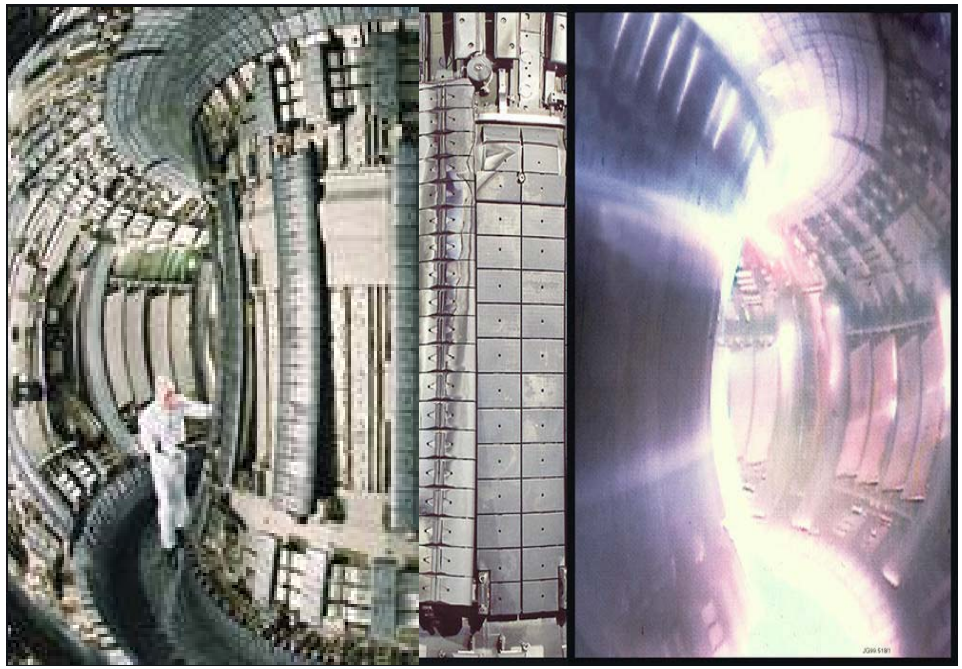
Joint European Torus (JET)

Currently the world's best fusion research facility

Operated by UKAEA as a facility for European scientists





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In JET a Fusion Plasma Lasts Around 1 Minute

Video removed from pdf version

Limited by heating of magnets since they are not superconductors in JET

JET produces up to 16 MW of fusion power

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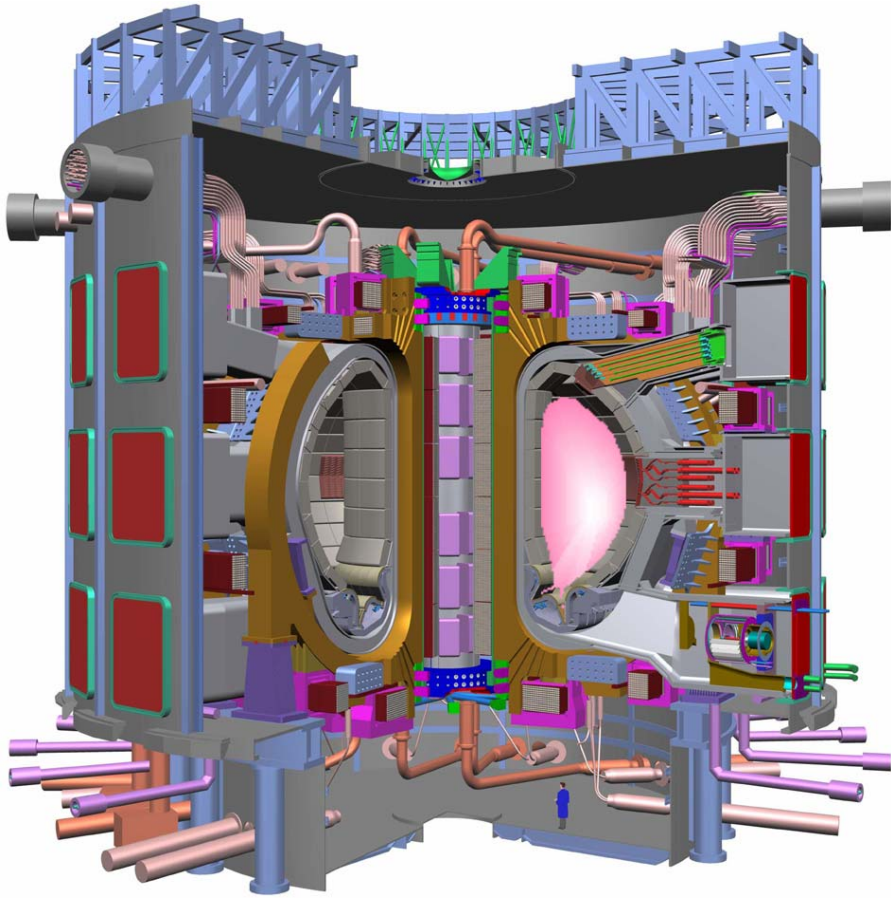
ITER

- Aim is to demonstrate integrated physics and engineering on the scale of a power station (500 MW)
- Europe, Japan, Russia, US, China, South Korea, India (>3Bn people)
- Site selected, Cadarache France
- 4.5 Billion Euro construction cost (compared to ~16 Trillion predicted energy investment)
- Key ITER technologies fabricated and tested by industry



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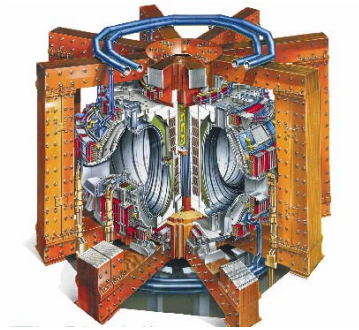
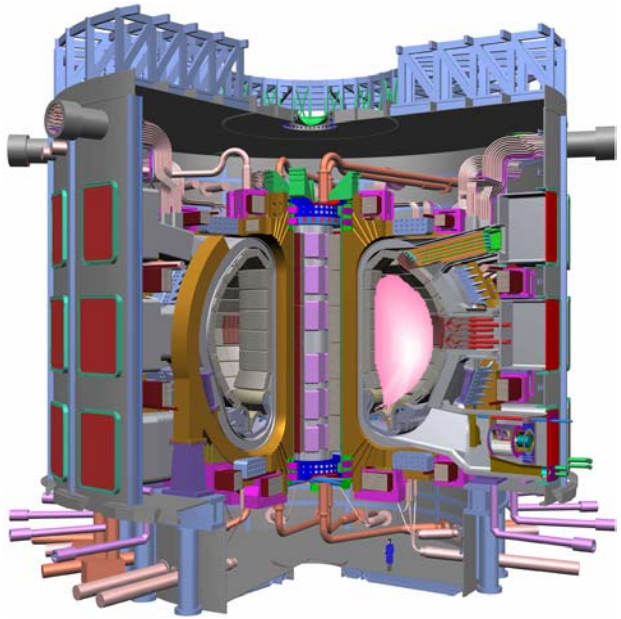
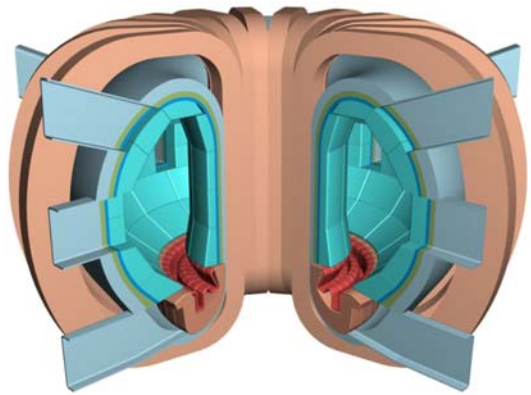
What Does the Future Hold for Fusion?



JET
(now)
EU
16MW



ITER
(next)
EU, Japan,
USA, Russia,
China, S.
Korea, India
500MW



Power Plant
(later)
3,000MW

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The Challenge

- How can the world continue to develop and poor economies grow, without excessive “cost”, whether economic, environmental or other?

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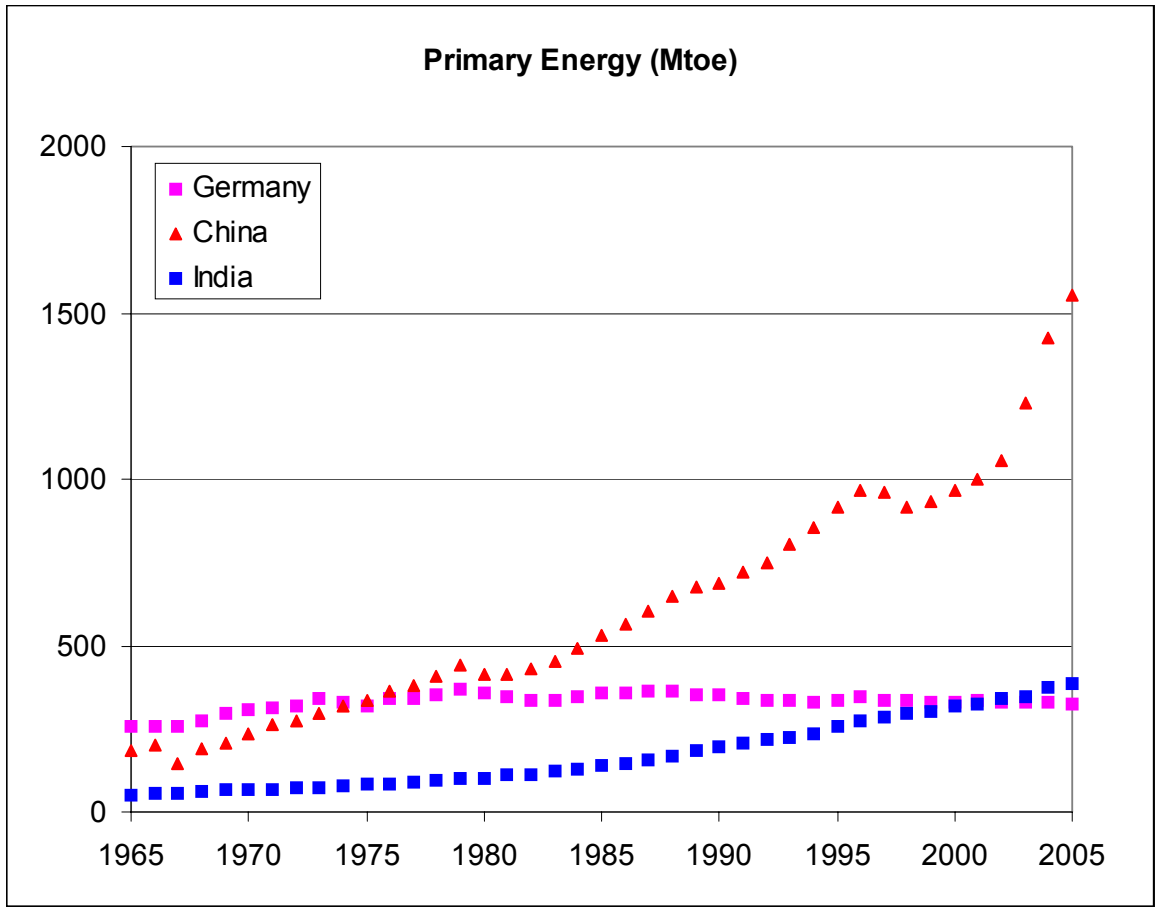
Growth in Energy Use is Enormous



In the last 2 years growth in Chinese consumption has exceeded total German consumption

- Source: BP

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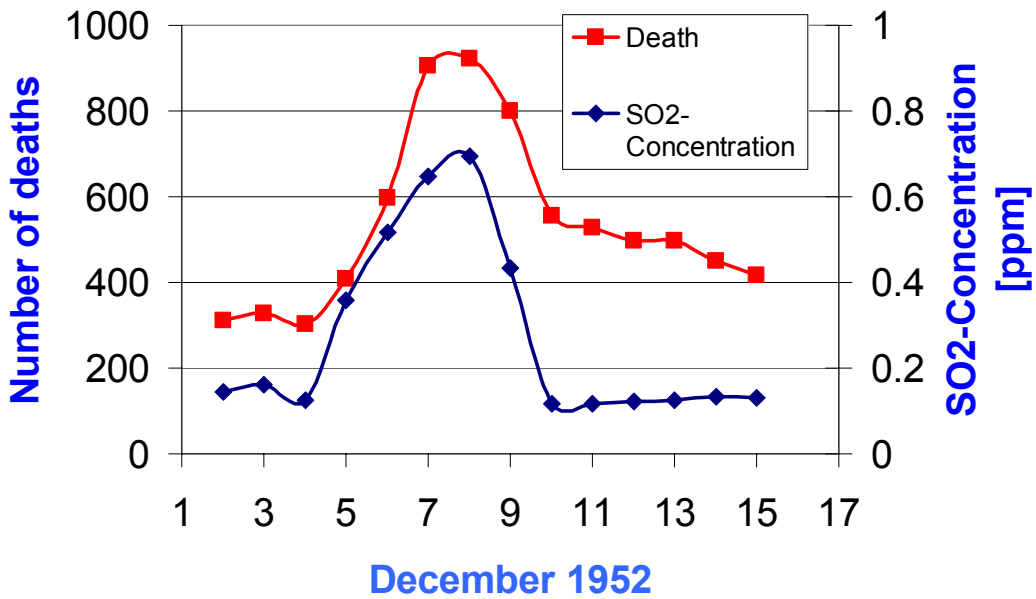
Example of Excessive Cost

- London smog (pollution event)
- Cost associated with industrialisation but overcome by regulation



Thousands die in single pollution episode.

Source: Wilkins

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Example Where Lack of Development Imposes Excessive Cost

- Developing country biomass use generates indoor particulates.
- Approximately 1.5 million premature deaths each year, mostly women and children
- Cost associated with insufficient or inappropriate development

Source: WHO/IEA

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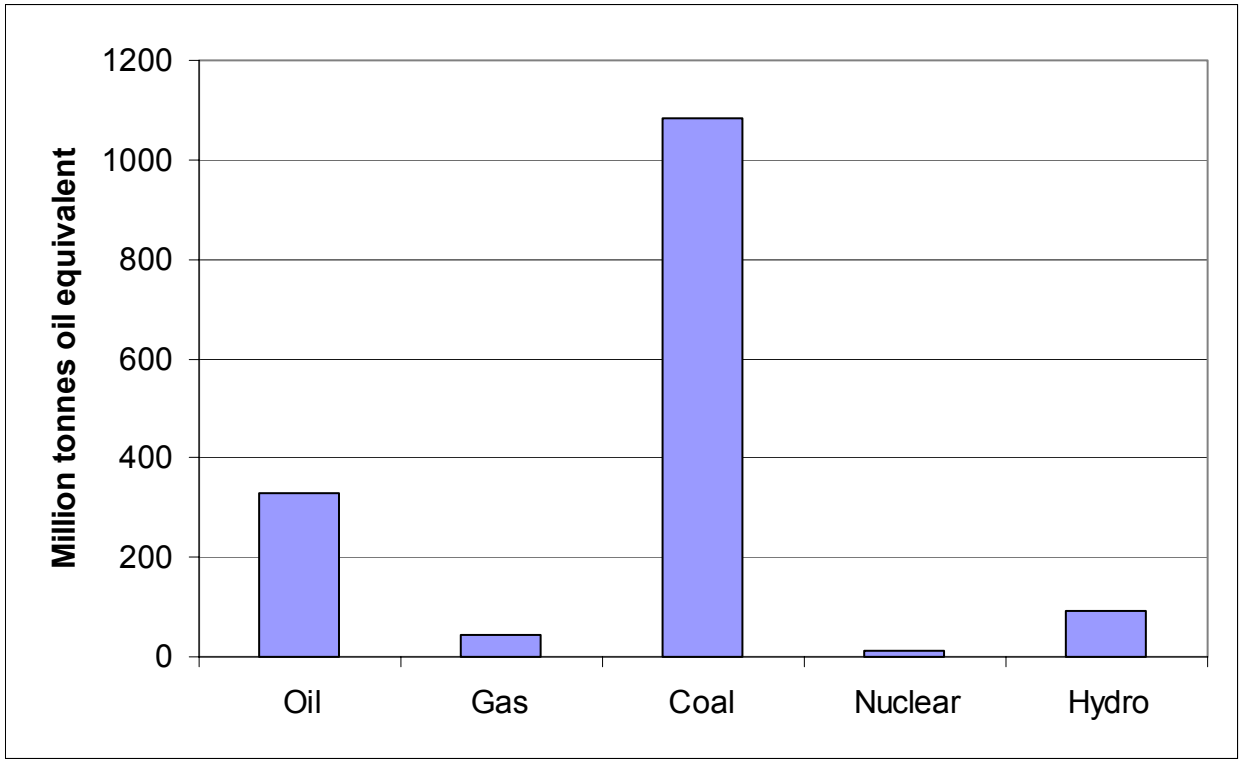
Big Questions

- How will this rising demand continue to be met?
- What is the impact of the rising demand (on health etc)
- Can fusion contribute?

China Fuel Consumption 2005



In business as usual scenarios, most world energy will be supplied by coal by 2100

Source: BP, ECN

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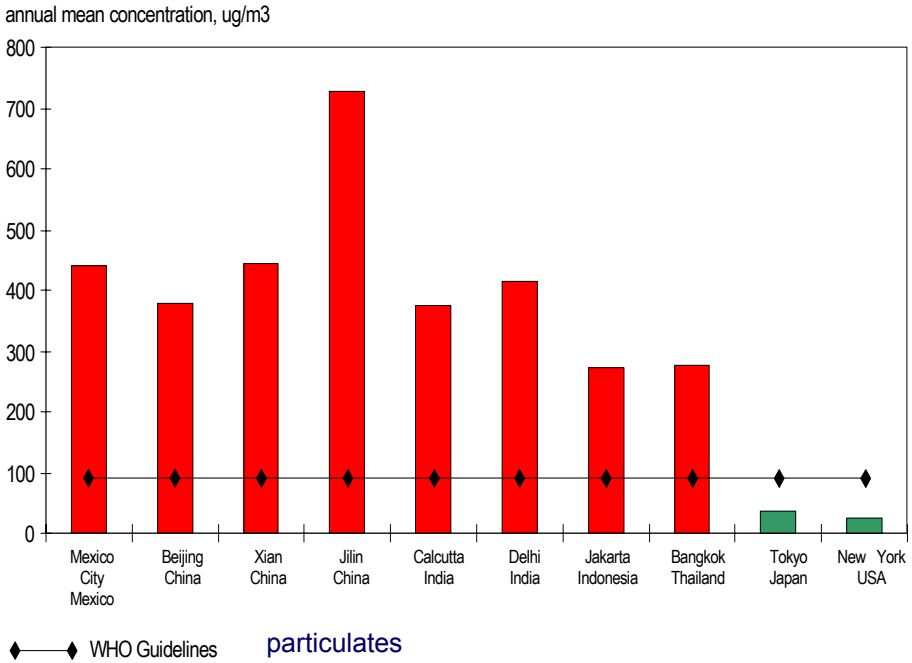
Air Pollution in Cities



Source: OECD Environmental data 1995, WRI China tables 1995, Central Pollution Control Board, Delhi. "Ambient Air Quality Status and Statistics, 1993 and 1994", Urban Air Pollution in Megacities of the World, WHO/UNEP, 1992, EPA, AIRS database.

World Bank estimates coal pollution leads to 300,000 early deaths in China each year

(Indoor air pollution levels 300-3000, WHO)

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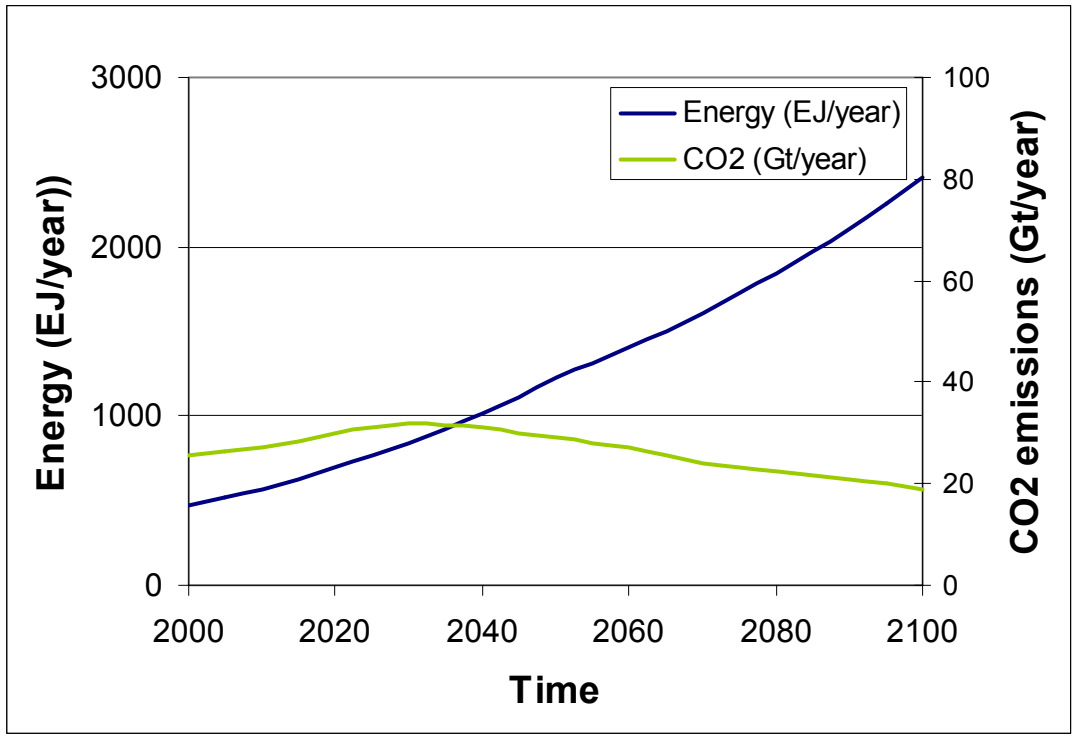
Paradox of Increasing Energy Demand but Reducing Carbon Emissions



World energy growth predicted to continue but CO_2 should plateau and decline to keep atmospheric content below e.g. 550 ppm. Decoupling energy and CO_2 will require dramatic changes in energy systems.

Source: IPCC

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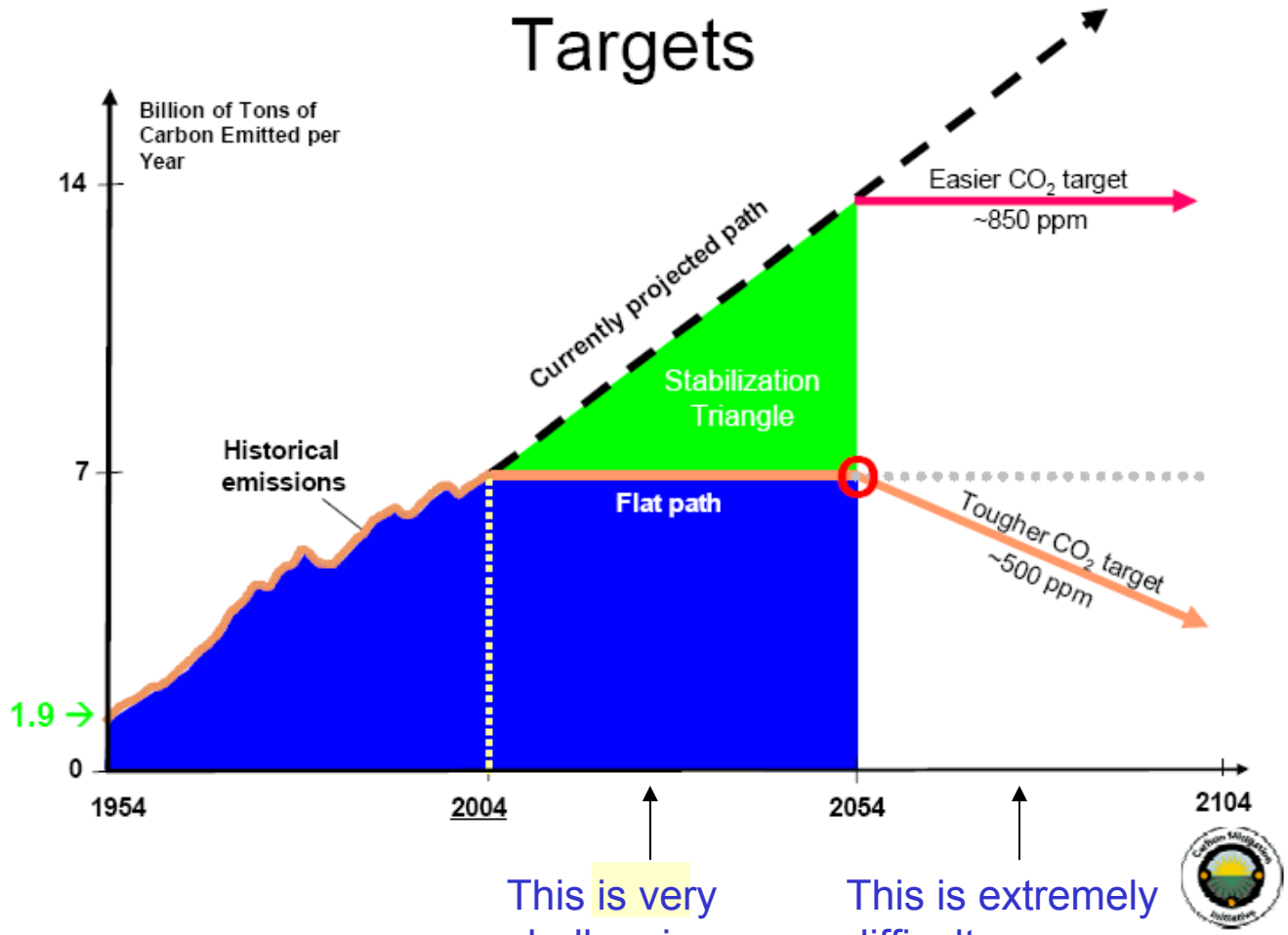
How Large is the Carbon Challenge?



This is very challenging, e.g. fission capacity x15

This is extremely difficult

Source: Sokolow

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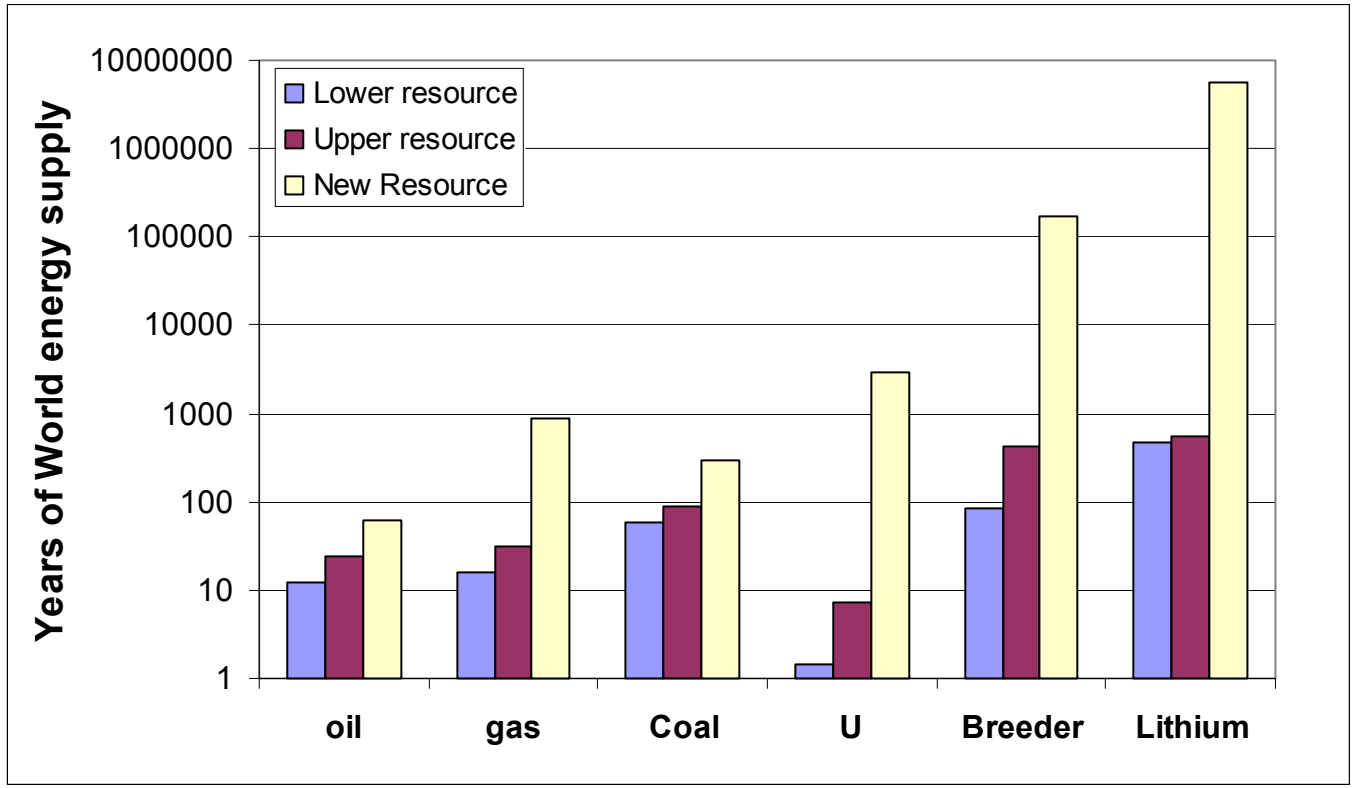
Resource Availability

Ultimate Fuel Resource for Different Energy Systems



Large resources in coal, fission breeder and fusion. Solar provides a large resource as well.

Source: WEC, BP, USGS, WNA

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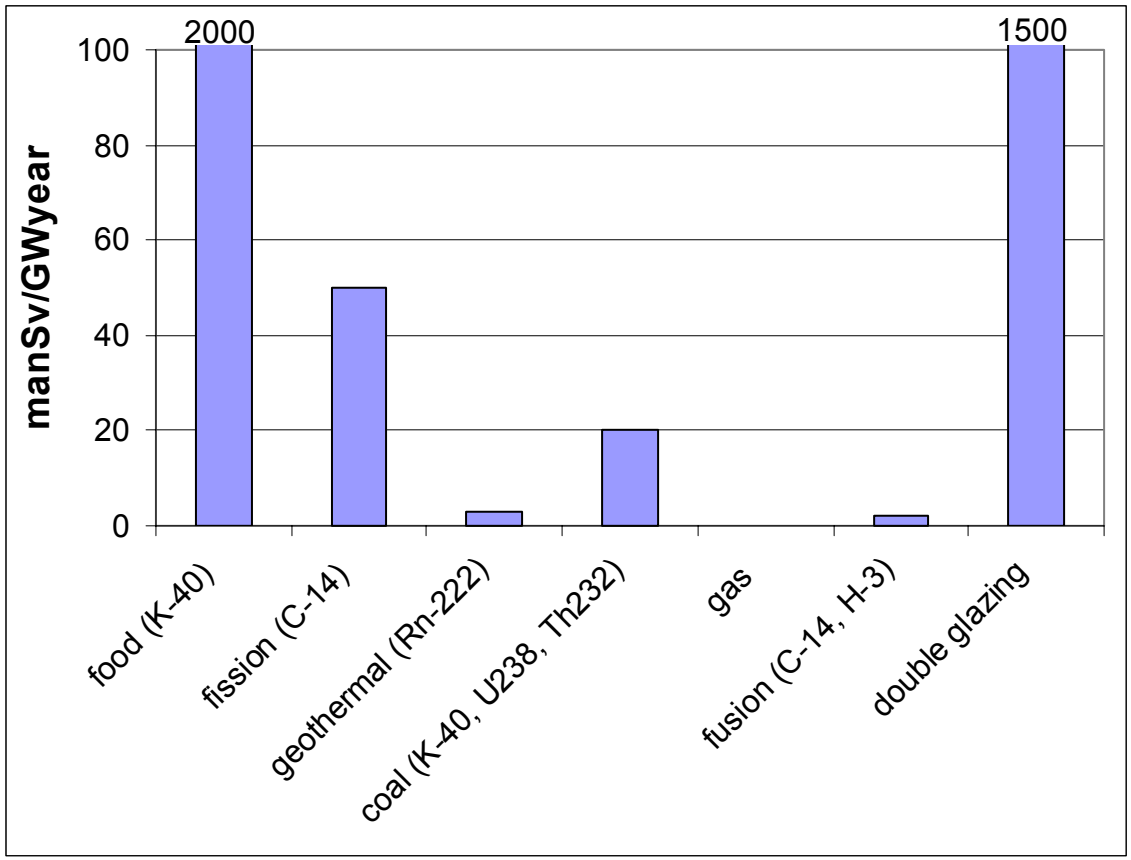
Other Materials

- Although fusion fuels appear essentially unlimited, we should take care not to be too dependent on other scarce resources. Examples often quoted are tantalum (used as an alloying element in low activation steels) and Beryllium.
- On the other hand, materials procurement is a small fraction of the cost of fusion electricity so large increases in the price of raw materials could be tolerated.

Emissions

Radiological Hazard of Different Sources of Energy



Food column is indicative of background effects – not directly comparable to others. Double glazing is due to effect of reduced ventilation on indoor radon.

Source: UNSCEAR, NRPB

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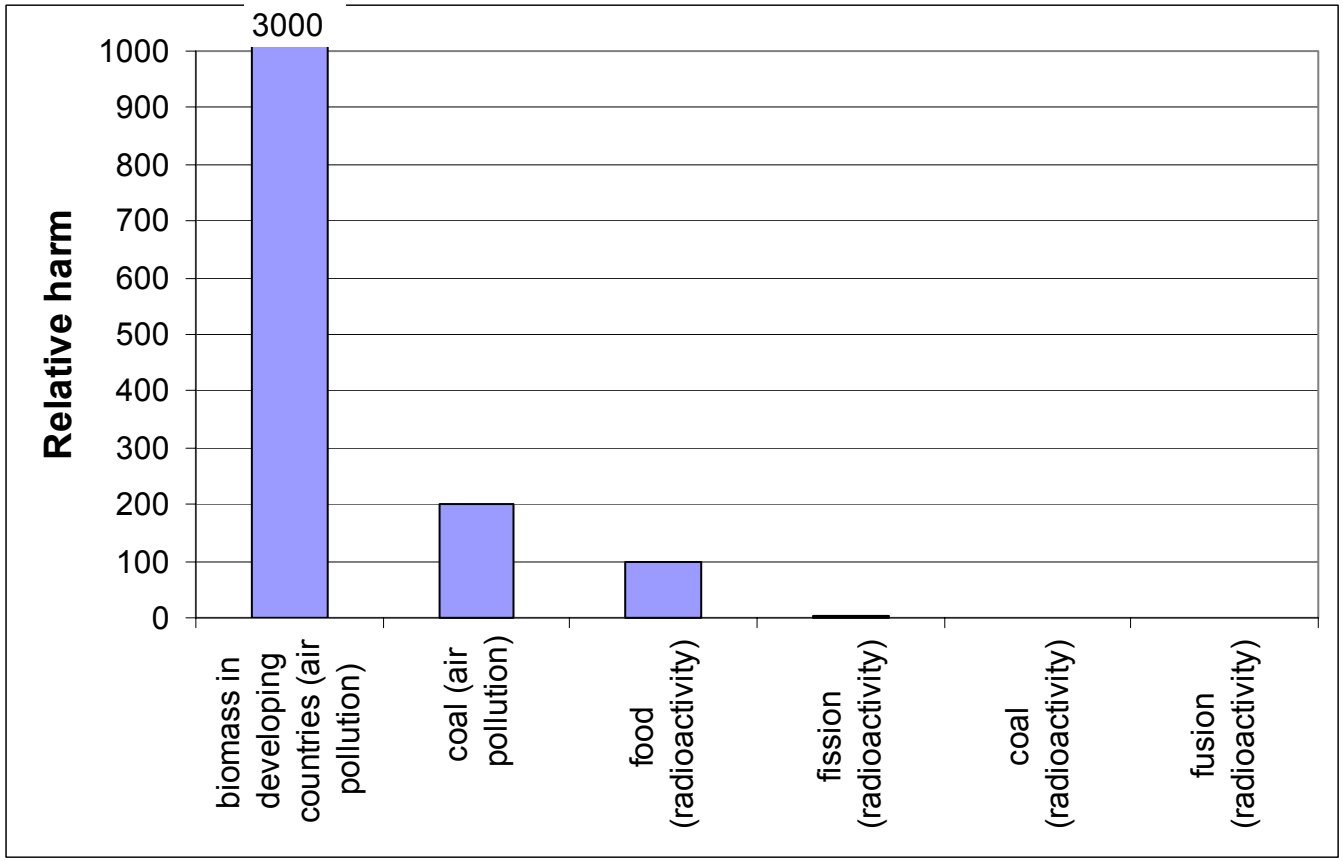
Hazard Including Other Risks



Conventional energy hazards are enormously greater than fusion hazards.

Source: WHO, UNSCEAR, NRPB, EC (ExternE)

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Waste

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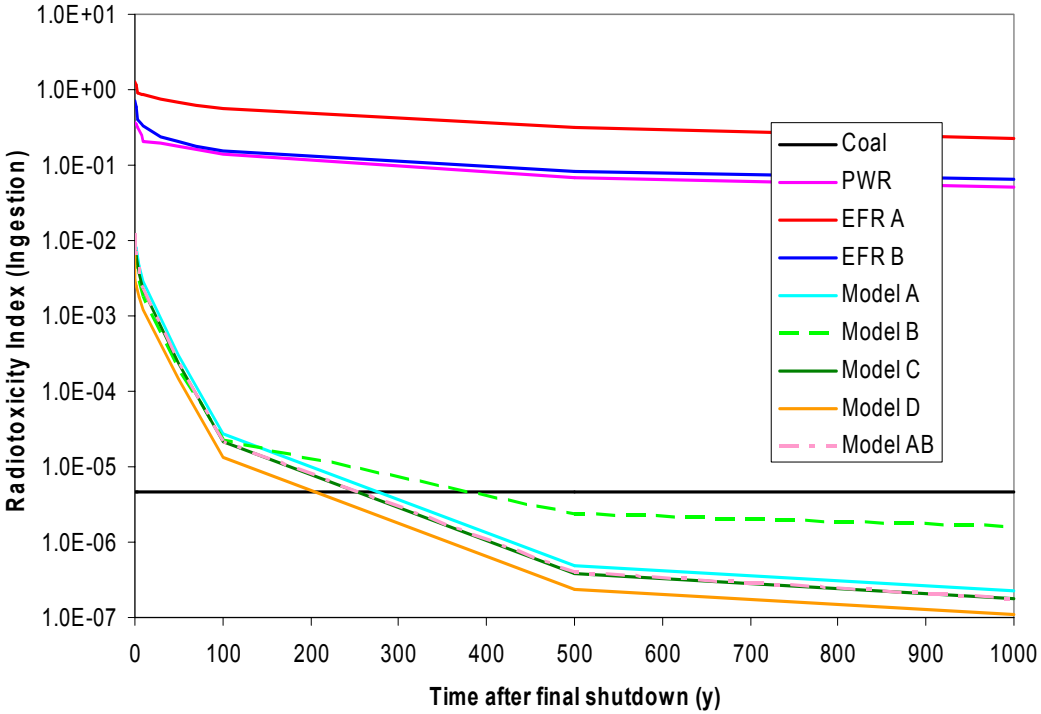
Potential Harm from Waste Materials



Initial radiological hazard from fusion materials decays rapidly, with half life of around 10 years.

Source: PPCS

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Safety

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Releases in Accident

- Bounding accident analysis, combines the worst outcome in each area.
- Releases still small and doses to the public small.

Model	Dose
A	1.2 mSv
B	18.1 mSv

Compared with approximately 4 mSv average annual background in EU

Source: PPCS

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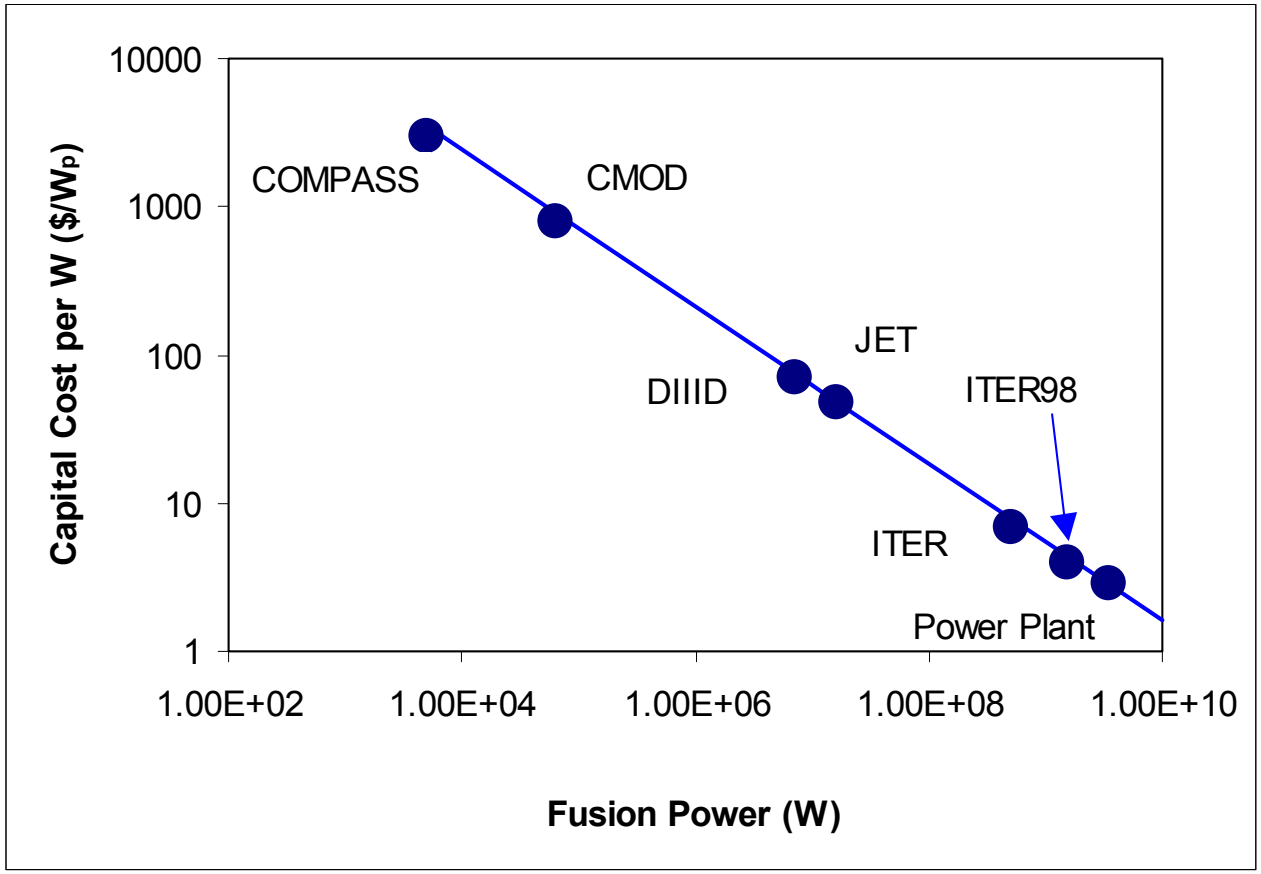
Tritium

- One of the main hazards in an accident
- Maximum possible releases from an internal accident are a few 10's of grammes.
- Doses to local population are, in the worst case, too low for evacuation to be considered.
- An external accident, e.g. enormous earthquake, could potentially release more but the consequences of the event itself would be much more serious than any releases from the plant.

Source: PPCS, SEAFP

Costs and Investment

Costs Reduce Through R&D and Scale



GW scale devices projected to be in few $/W range

Power which would be produced if non-DT devices were to use DT

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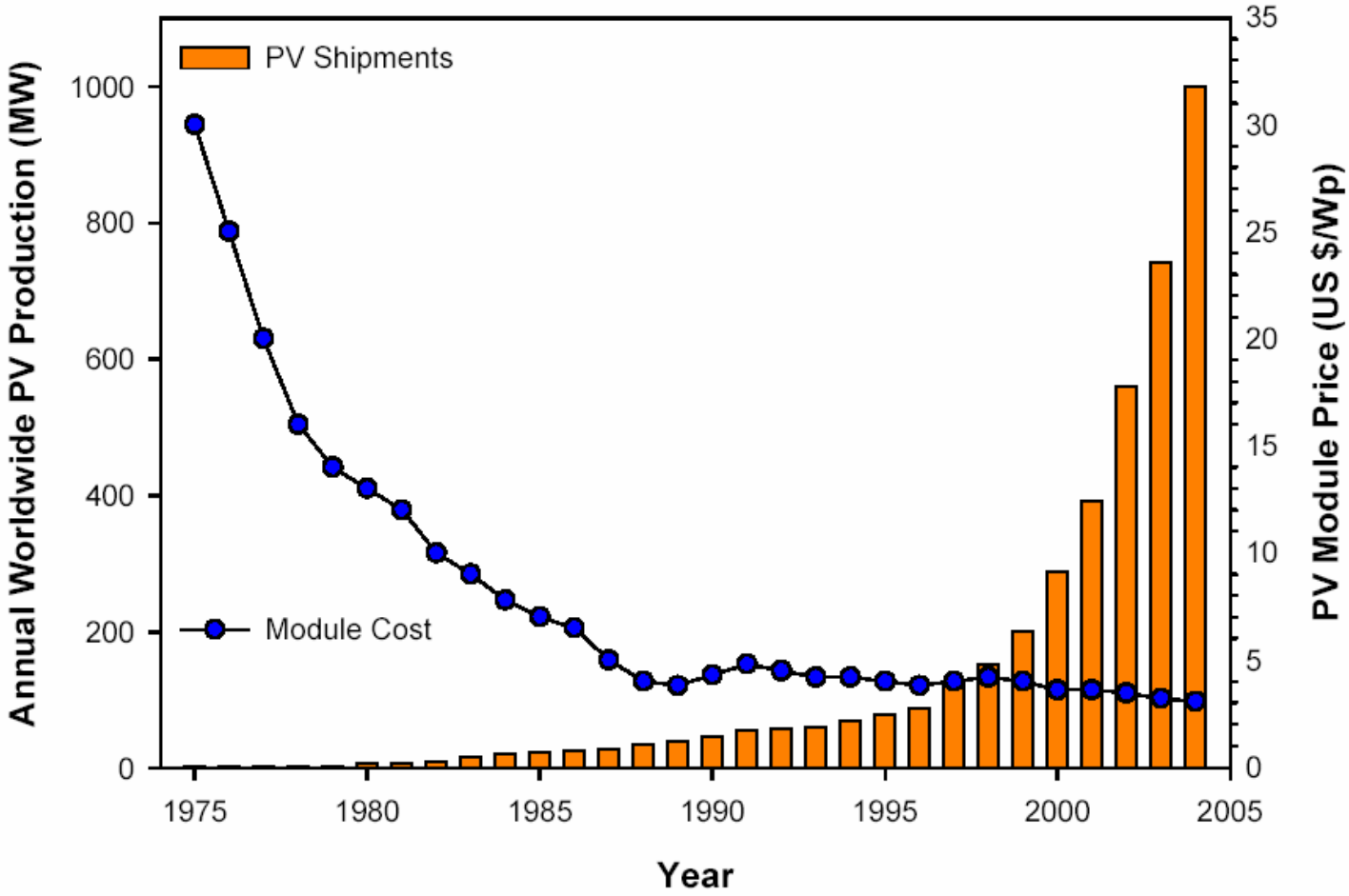
Technological Learning Reduces Costs Through Experience



Source: Solarbuzz

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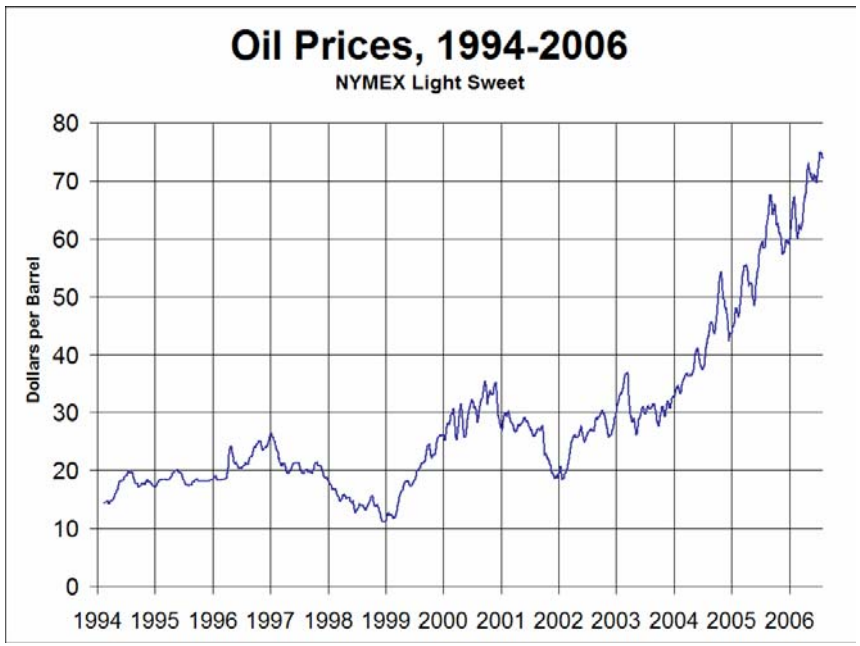
Large Volatility in Energy Markets

EU ETS Carbon price
€/tonne CO_2

Factor of 3 in 1 week

Now 1€/tonne (March 07)
Factor of 30 in 1 year



World oil price

Factor of 7 in 7 years

The target for a future energy price is very uncertain.

Source: NYMEX

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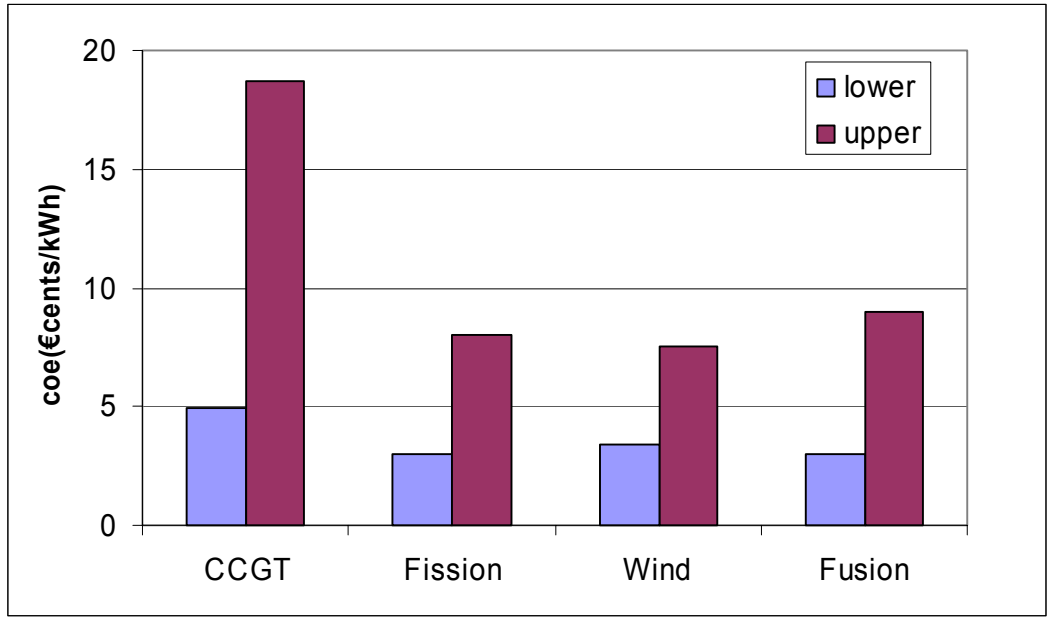
Direct Cost Comparison with Other Future Projections



Large uncertainty inherent in projections. Include projected fuel price increases but no carbon tax. Wind is near term technology but no standby or storage costs.

Source: “Projected Costs of Generating Electricity” IEA, 1998 Update, PPCS

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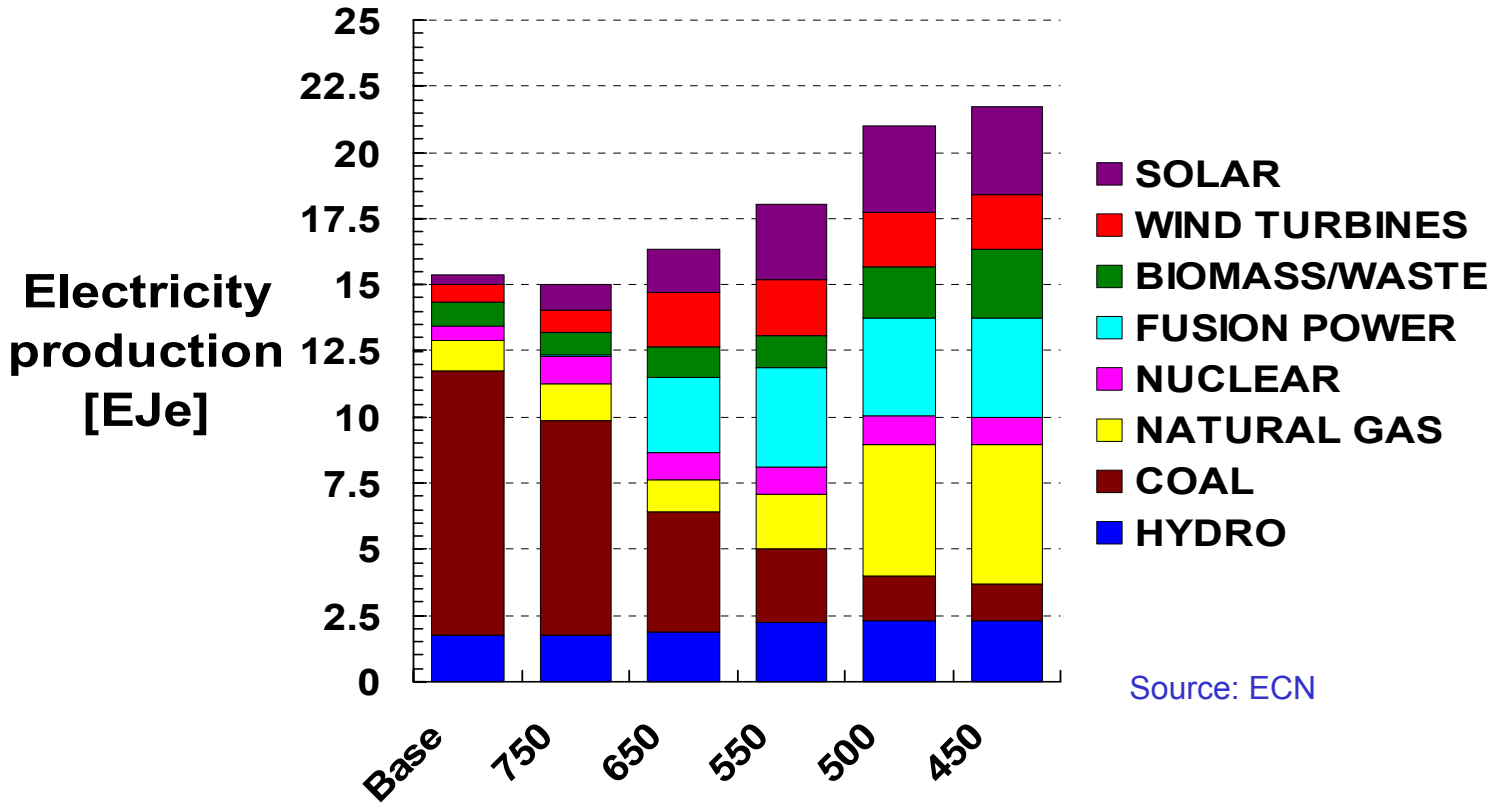
How Can Fusion Contribute to a Future Energy Market?



Source: ECN

In a CO_2 constrained scenario, fusion can enter the Western Europe energy market as coal is progressively excluded. Situation for the world is more stringent as shown by initial results of new model – EFDA/TIMES.

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What Approach Should be Taken to Bring New Energy Systems to Market?

- Introduction of new energy sources is essential.
- This requires effort at all points in the chain - Research, Development, Demonstration and Deployment is essential.
- Fusion (if successful) is a good option for large-scale deployment globally, because of its enormous fuel resource and favourable safety and environmental characteristics.

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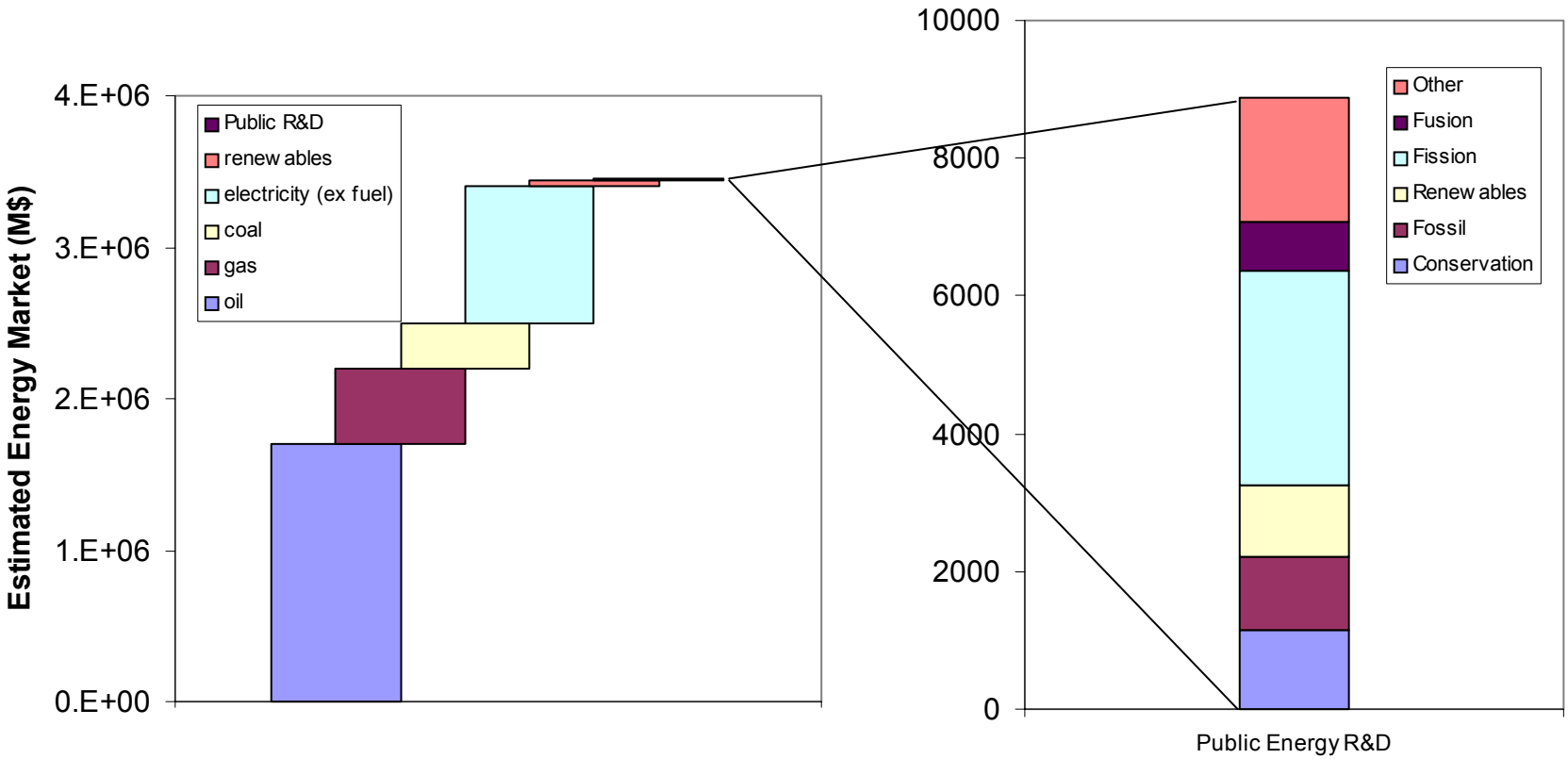
Is Enough Being Done?



Public Sector Energy R&D is a negligible fraction of the world energy spend. Fusion is a small part of that negligible fraction.

Source: IEA, BP

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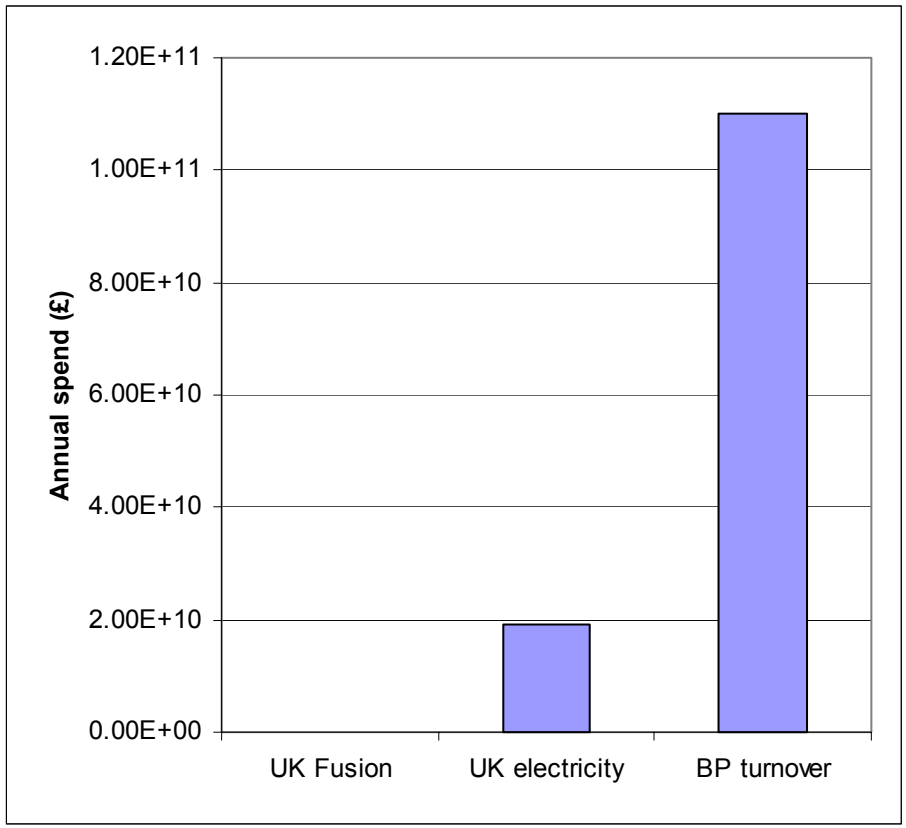
Is Enough Being Done - UK?



- Overall energy R&D is far too low - less than 0.3% of market – to achieve a transformation in the energy markets.
- UK Parliament Science and Technology Committee 2003 "expenditure on energy research has been pitiful"

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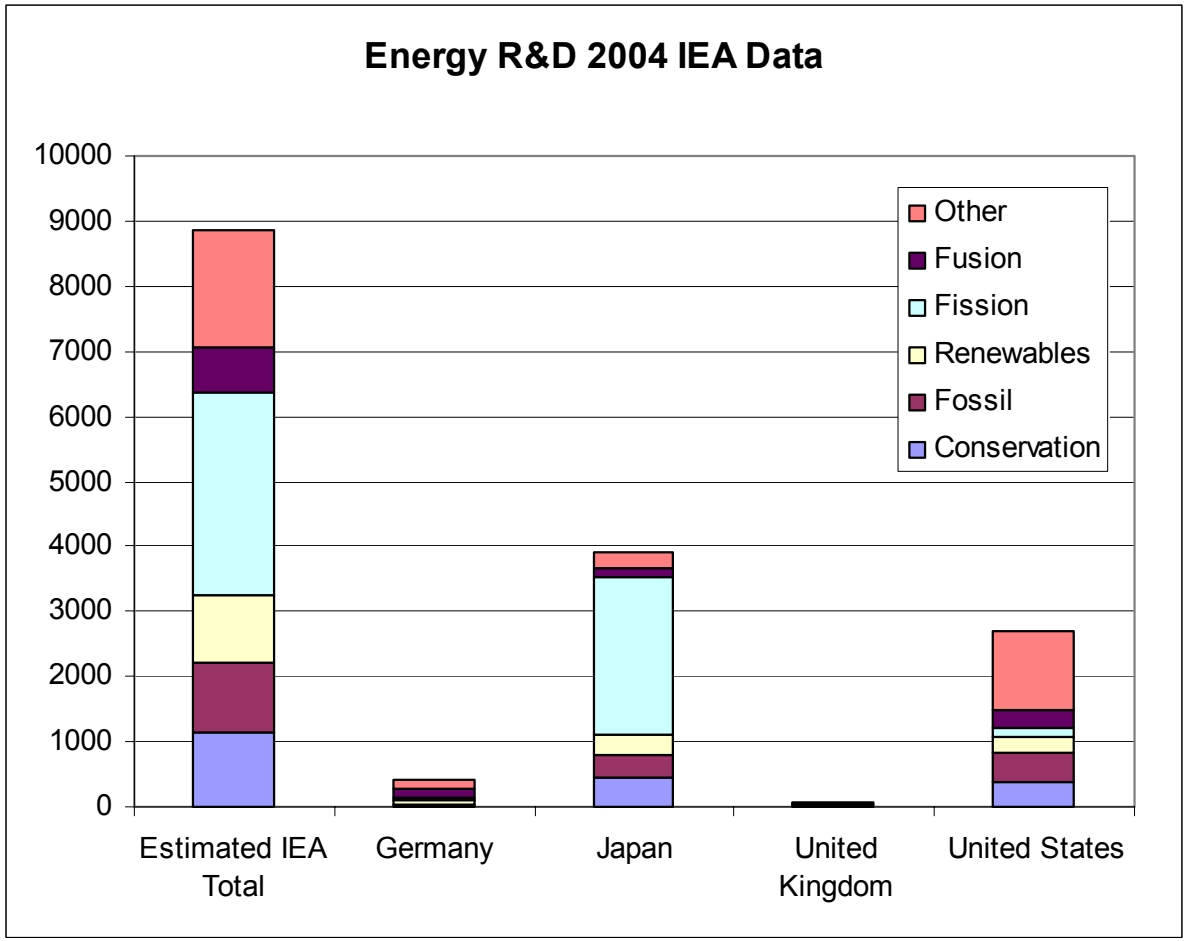
Where is the R&D being Carried Out?



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Conclusions

- World energy consumption is likely to more than double even if OECD countries cap their energy consumption.
- Continuing business as usual implies a large increase in CO_2 emissions and other pollutants globally.
- There is an enormous potential market for low pollution, low carbon energy sources, such as fusion.
- Fusion has very large benefits in terms of resources, environmental impact, safety and waste materials.
- We must focus on demonstrating fusion as a power source, ensuring these benefits are optimised, at the same time ensuring costs are reasonable.
- The world is not putting sufficient effort into energy R&D if we are to achieve the transformation in energy markets that is needed.