

# Scientific Research - Who Benefits?

## Who Should Pay?

**Chris Lewellyn Smith**

**Director, UKAEA Culham Division  
Head EURATOM/UKAEA Fusion Association  
Chairman Consultative Committee for Euratom on Fusion**

**Director General of CERN 1994-98  
Fellow 1968-70  
Staff Member 1972-74**

**Advisor to External Review ('Abragam') Committee 1986-87  
Scientific Policy Committee 1986-92, Chairman 1990-92**

**“To invent an infallible remedy against toothache, which would take it away in a moment, might be as valuable and more than to discover a new planet.... But I do not know how to start the diary of this year with a more important topic than the news of the new planet”**

*Christof Lichtenberg, January 1782*

## Frequently (correctly) argued

- **Basic science (even if “useless”) often ⇒ very valuable**

but hard to foresee or capture/protect value ⇒ industry does not invest much, and **investment generally responsibility of governments**

- **Industry will invest if profit easily foreseeable. Hence much of applied research is/should be supported by industry.**

- **Must *not* conclude: governments ⇒ basic, industry ⇒ applied**

- **industry does some basic research (albeit declining)**

- **research (e.g.) into heart disease could ⇒ *either* to patentable drug or to need for more exercise + better diet**

- **governments have the responsibility to support basic *and* applied (mission orientated) research that is long-term or not commercial, e.g. research related to the environment, transport policy,... which is important + valuable for society, but does not lead to profit**

# OUTLINE

- Different types of science\*
- Value of basic science\*
- Why industry will not invest (enough) in basic science, and governments must do so\*
- Why it cannot be left to other countries/regions\*
- What science to fund?\*
- The changing nature (and decline) of industrial R&D laboratories
- Government funding for applied/mission oriented research
- Energy R&D as an example of (mostly applied) work that must be supported by governments

*\*'What's the Use of Basic Science?' C H Llewellyn Smith*

<http://user.web.cern.ch/public/about/what/basicscience/science.html>

## DIFFERENT TYPES OF SCIENCE

**NOTE** - use “research” in the sense understood by academic scientists

“Linear model” (basic research → applied research → industrial developments → products) is **naïve**. Sometimes the flow is reversed (☞), and **generally the relation is non-linear**.

Historical studies of successful modern research have “repeatedly shown that the interplay between initially unrelated basic knowledge, technology and products is so intense that, far from being separate and distinct, they are all portions of a single, tightly woven fabric”. **Nevertheless** a broad distinction can be made between science (~ knowledge) and technology (~ means by which knowledge is applied), and between different forms of science:

	<u>Responsibility of</u>
<b>Basic</b> (motivated by curiosity)	Governments
<b>Strategic</b>	Industry +
<b>Applied/Mission oriented</b> (designed to answer specific questions, or address specific problems)	Governments <i>in many cases</i>

**“Thermodynamics owes more to the steam engine than the steam engine owes to science”.**

**Sir George Porter**

*Warsaw 24 September 2004*

“By research in pure science I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the “utility” of this kind of research, one that has been brought into great prominence by the War - I mean the use of X-rays in surgery....

Now how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of Electricity.”

***J J Thomson***

***1916***

# BENEFITS OF BASIC SCIENCE

## ■ Contribution to culture

- our lives are enriched, and our outlook changed by (e.g. knowledge of the heliocentric system, genetic code, how sun works, why sky is blue, expansion of the Universe, etc)
- scientists are too shy about making the culture case



## ■ Possibility of discoveries of enormous economic and practical importance



## ■ Spin-offs and stimulation of industry

- devices and techniques to carry out basic research often turn out to have other uses; the demands of researchers stretch industry



## ■ Education

- excellent training; flagship role in attracting children to science and technology



**Socrates:** Shall we set down astronomy among the subjects of study?

**Glaucon:** I think so, to know something about the seasons, the months and the years is of use for military purposes, as well as for agriculture and navigation.

**Socrates:** It amuses me to see how afraid you are, lest the people should accuse you of recommending useless studies.

*Plato, the Republic*

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“I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon.

Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in and had not contributed to wave mechanics or the quantum theory of solids. It so happened that the inventors of transistors were versed in and contributed to the quantum theory of solids.

One might ask whether basic circuits in computers might have been found by people who wanted to build computers. As it happens, they were discovered in the thirties by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics.

One might ask whether there would be nuclear power because people wanted new power sources or whether the urges to have new power would have led to the discovered of the nucleus. Perhaps - only it didn't happen that way.

*Warsaw 24 September 2004*

One might ask whether an electronic industry could exist without the previous discovery of electrons by people like Thomson and H A Lorentz. Again it didn't happen that way.

One might ask even whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.

Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz who emphasised the beauty of physics and who based his work on the theoretical considerations of Maxwell. I think there is hardly an example of twentieth century innovation which is not indebted in this way to basic scientific thought."

*H G B Casimir*

*1966*

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# Particle Physics

**Direct applications of discoveries not the goal, and not expected** (but not inconceivable, e.g. magnetic monopoles, or long-lived heavy leptons, that could catalyse proton decay or fusion)

## ■ Many examples of spin-offs

### • Accelerators

- Semiconductor industry
- Sterilisation - food, medical, sewage
- Radiation processing
- Non-destructive testing
- Cancer therapy
- Incineration of nuclear waste
- Power generation (energy amplifier)?
- Source of synchrotron radiation
- Source of neutrons

} biology

} condensed matter physics...

- Particle Detectors
  - Xal detectors (BGO developed for LEP → new Xals for LHC)
    - ⇒ Medical imaging
    - ⇒ security
    - ⇒ non destructive testing
    - ⇒ research
  - MWPCs
    - ⇒ container inspection
    - ⇒ research
  - Semi conductor detectors
    - ⇒ many applications at development stage

- **Informatics**

- World Wide Web (invented at CERN)
- Simulation programmes
- Fault diagnostics
- Control systems
- Stimulation of parallel computing

- **Superconductivity**

particles physics → multifilamentary wires/cables

→ MRI scanners, NMR.....

+ Many others (cryogenics, vacuum, electrical engineering, geodesy.....)

**Won't give details of examples of spin-offs from CERN or technology transfer from CERN through people (Students, Trainees, Associates, ...) as these are well documented, but will consider technology transfer through contracts**



## Technology Transfer through Contracts

- Studies (Schmied 1975, Bianchi-Streit et al 1984) show that CERN's high-tech contracts have an 'economic utility' = increased turnover + cost savings equal to three times\* the values of the original contracts (75% of the CERN-related sales increases were in areas unrelated to particle & nuclear physics - solar energy, electrical industry, railways, computers, telecommunications)
- A similar study of ESA contracts found also a factor of three\* (but 80% of ESA-related sales increases were in the space sector; the rest mainly in aeronautics and research)

**A very interesting recent study (Autio et al, 2003) has analysed the nature of these benefits based on a survey of companies** 

*\*Normalised to the total budget the factor is 1.2 for CERN and 1.6 for ESA. Note that the factors were estimated by the industrial managers involved, not by CERN or ESA*

## Headlines on Technology Transfer and Learning through CERN's procurement

### ■ As a result of contracts:

- 38% of respondents had developed new products
- 41% said technological performance had benefited
- 60% had strengthened project management
- 52% said sales had benefited (exposure very important: 60% acquired new customers, 42% increased international exposure, 17% opened a new market)

### ■ CERN staff also benefited

## Benefits of CERN Procurement (cont)

### ■ Generally

- learning and innovation go together
- the greater the involvement (trust, access, personal relationships,....) the greater the (mutual) benefit

### ■ Implications

- Partnerships more fruitful than conventional procurement (experience in particle physics and fusion  $\Rightarrow$  partnerships highly desirable: hands-off hi-tech contracts frequently  $\rightarrow$  problems).
- Involve industry early on in R&D for hi-tech projects that will generate significant contracts.

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## WHY GOVERNMENTS MUST SUPPORT BASIC SCIENCE

- Funding of basic science is important for society as a whole, but is not in the interest of any individual investor: those who make fundamental discoveries generally do not reap the benefits - the laws of nature cannot be protected; the applications are too long-term and unpredictable, and the cultural and educational benefits do not generate direct profits  
i.e. basic science is what economists call a 'public good' which must (like lighthouses and defence) be supported by government.
  
- This leads to the questions
  - (i) if funding is not in the interest of any individual, is it in the interest of any individual country?
  - (ii) How should governments choose what basic science to fund, and at what level?

## DEVELOPED COUNTRIES SHOULD NOT LEAVE IT TO OTHERS TO SUPPORT BASIC RESEARCH

- Responsibility to contribute in the interest of society as a whole
- An active basic research base fosters and sustains technological development
  - Skills and tacit knowledge are needed to adopt, adapt and use technology
  - Important role of training scientists, who take problem solving skills to industry, and in creating networks
  - Geographical proximity to research centres → advantage in exploiting output and transferring technology\*; spin-offs and spin-off companies most likely to occur locally ( no accident that Silicon Valley is close to Stanford University).

\*cf. General tendency for linked economic activities to cluster

[Developing countries also need some basic science to underwrite and foster scientific and technological development generally (⇒ tools to address local problems& make policy choices; be an intelligent customer + adaptor of technologies developed elsewhere; be independent of strategies and priorities set elsewhere,...)...see 'Scientific collaboration – Promoting Progress, Building Bridges', C H Llewellyn Smith [weblib.cern.ch](http://weblib.cern.ch)]

## WHAT SCIENCE TO FUND?

*‘Both forecasting and innovation are highly stochastic processes, so that the probability of correctly forecasting an innovation, being the product of two low probabilities, is, in theory, close to zero...’*

Choices very difficult

- **Basic Science:** base choices on excellence of science, and people\* (money is more abundant than brain!)
- **Applied science and technology:** general principle - governments should keep ‘away from the market’, and fund areas that are ‘public goods’ because the returns are long-term, or not commercial, e.g. environment, traffic control....

But governments do not heed this advice (“Foresight”...)

\* Should we consider relative per capita costs of different sciences? *“Pourquoi irais-je payer un parapluie quinze francs quand je peux avoir un bock pour deux sous”* Courteline

## Decline of Corporate R&D Laboratories and blurring of boundaries between industry and universities

- **In the past, science based technological development** – in pharmaceuticals, aeronautics, electronics, chemicals, computers, electronics – **was carried out in big industrial laboratories**
- **The R&D often included an element of basic science** – to attract outstanding scientists and provide the right ambience
- **Today, these industries draw on a much wider (and rapidly changing) range of skills and knowledge than can reasonably be provided “in-house”**  
e.g. communication ~ not only electronic engineering + computer science, but psychology, economics, physiology,...
- **Many companies have closed their laboratories, and look for and tap into the skills they require in universities, as/when needed** [dangerous to go too far: need in-house expertise to evaluate work done elsewhere, and provide access to networks]



# Government Funding for Applied /Mission Oriented Research

**Have already concluded: Government responsibility to fund science (basic and applied) that is long-term or non-commercial, in order to**

- correct 'market failure'
- support non-commercial public goods (e.g. protection of the environment, better diet,...)
- provide basis for policy
- keep options open

**Energy research needs government support for all these reasons**

## **Energy Research as an Example of Mission Oriented Research that Needs Substantial Government Funding**

- **Looming energy crisis – can only be avoided by developing new technology**
- **Increased R&D is needed, with a large component from governments**
- **The research portfolio should be broad (including improved efficiency, development of renewables,...), but apart from burning fossil fuels, solar power, and nuclear fission (which are all problematic), only fusion is capable in principle of meeting a large fraction of need**

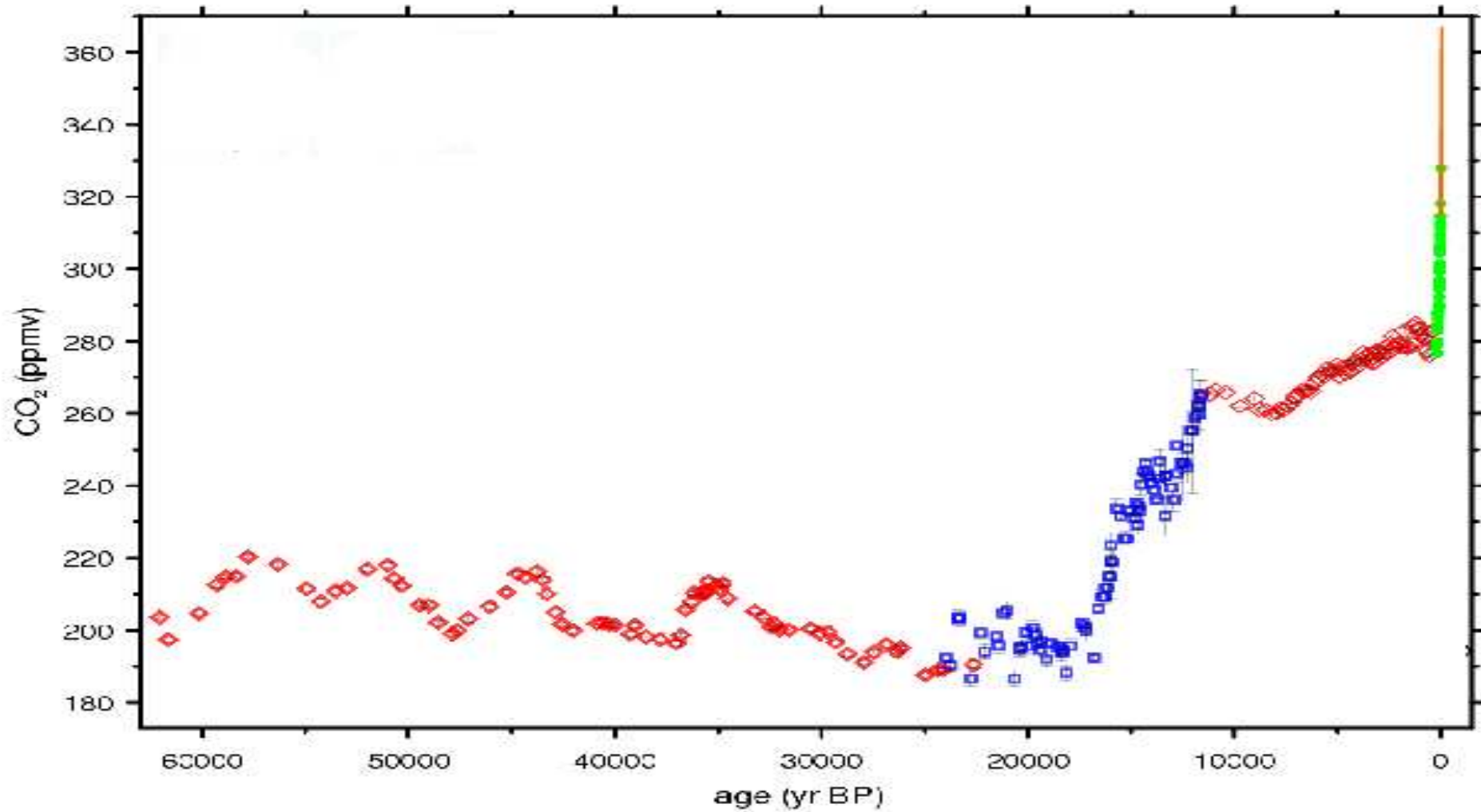
# THE LOOMING ENERGY CRISIS

- **World Energy use expected to double by 2045**  
(~ economic growth  $\Rightarrow$  growing energy use in China and India)
- **Currently 80% of primary energy supply from burning fossil fuels**
  - $\Rightarrow$  serious air pollution
  - $\Rightarrow$  CO<sub>2</sub>  $\Rightarrow$  climate change

which are running out (oil [ $\rightarrow$  95% of transport] first)

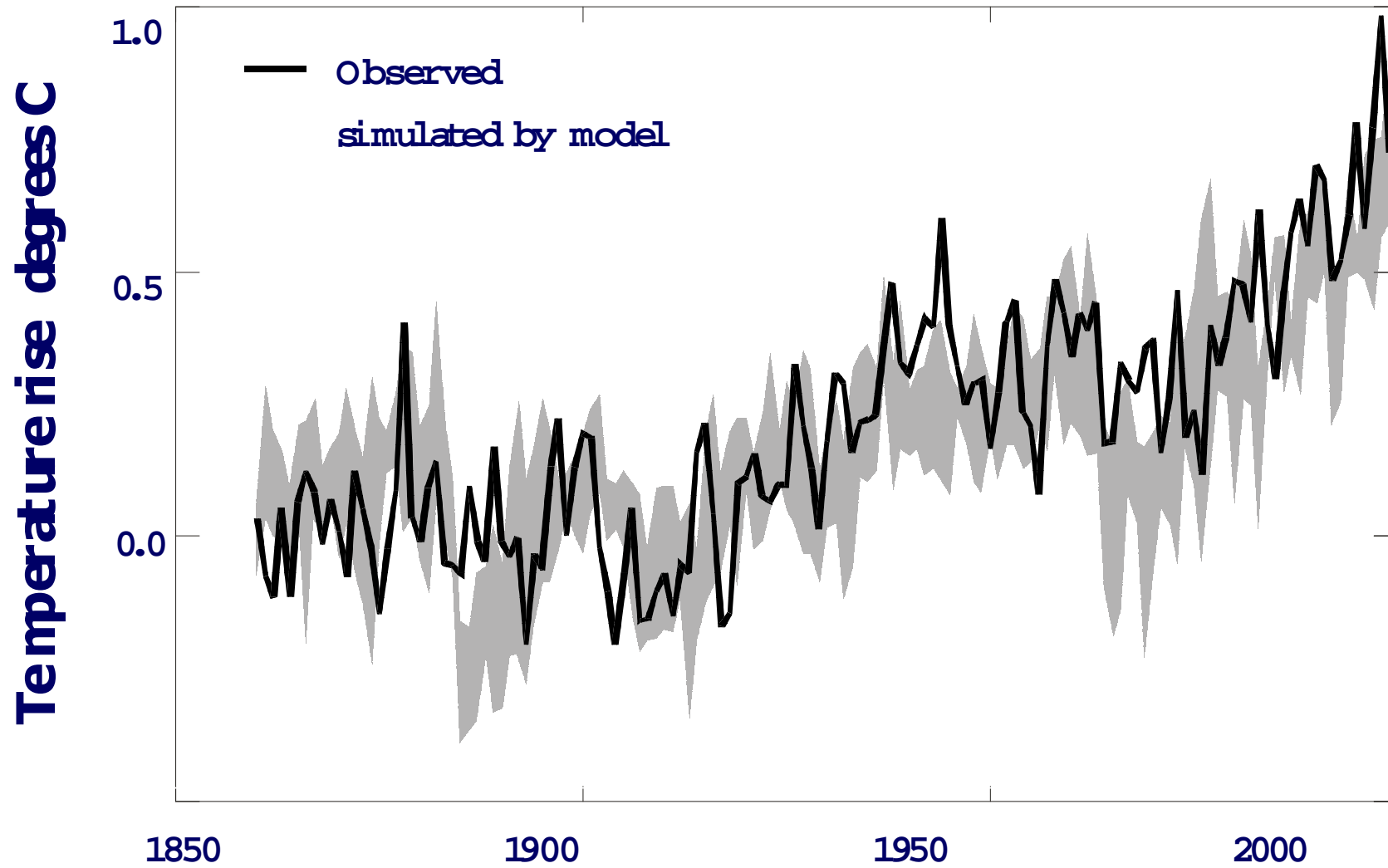
[+ 11% from burning wood, waste etc, also  $\Rightarrow$  CO<sub>2</sub>, unless wood replanted]
- **Today: only viable alternative able  $\rightarrow$  large fraction of global need is nuclear, which only  $\rightarrow$  electricity ( $\sim$  1/3 of primary energy use)**

# Carbon dioxide levels over the last 60,000 years

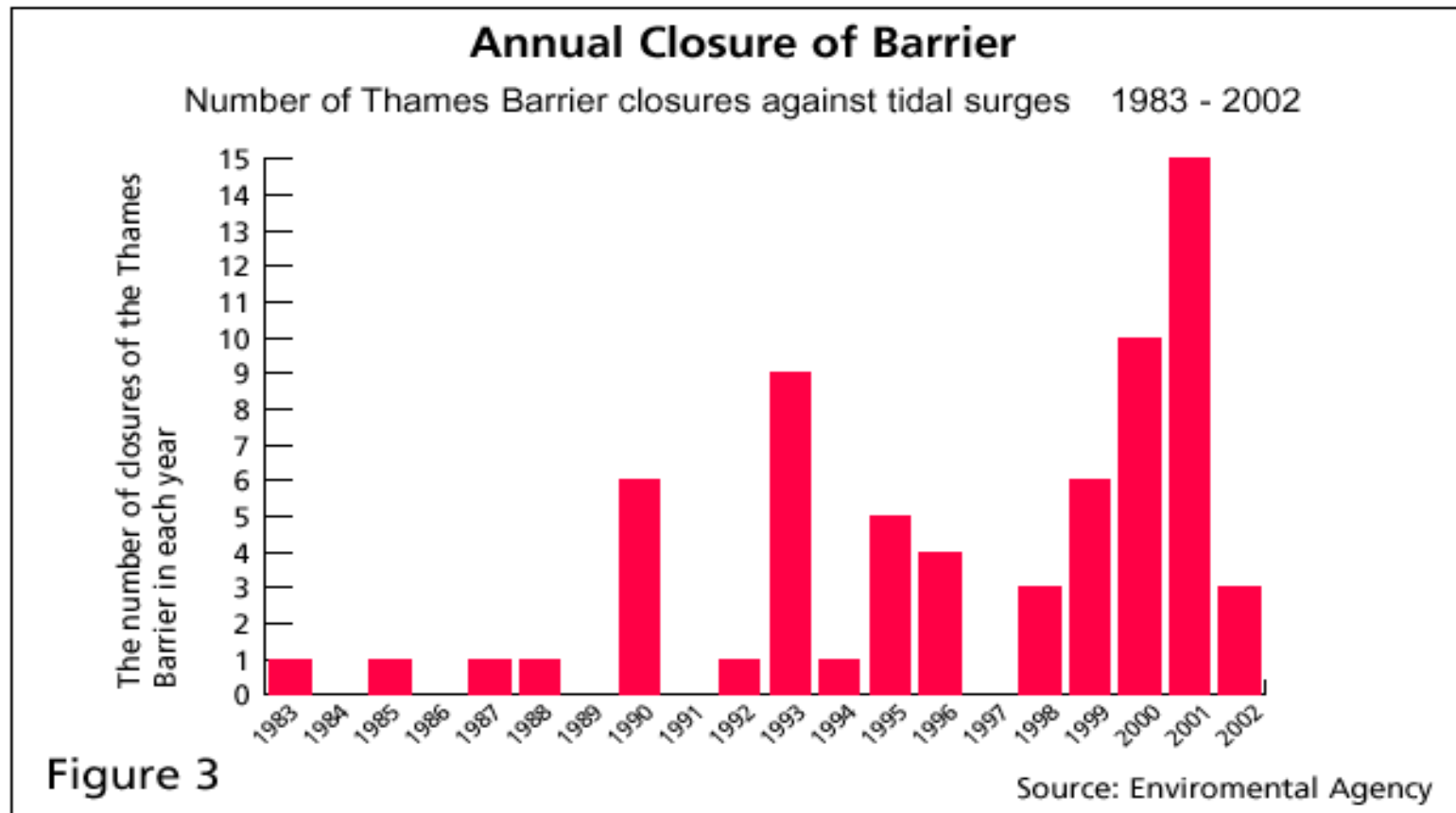


Source University of Berne and National Oceanic, and Atmospheric Administration

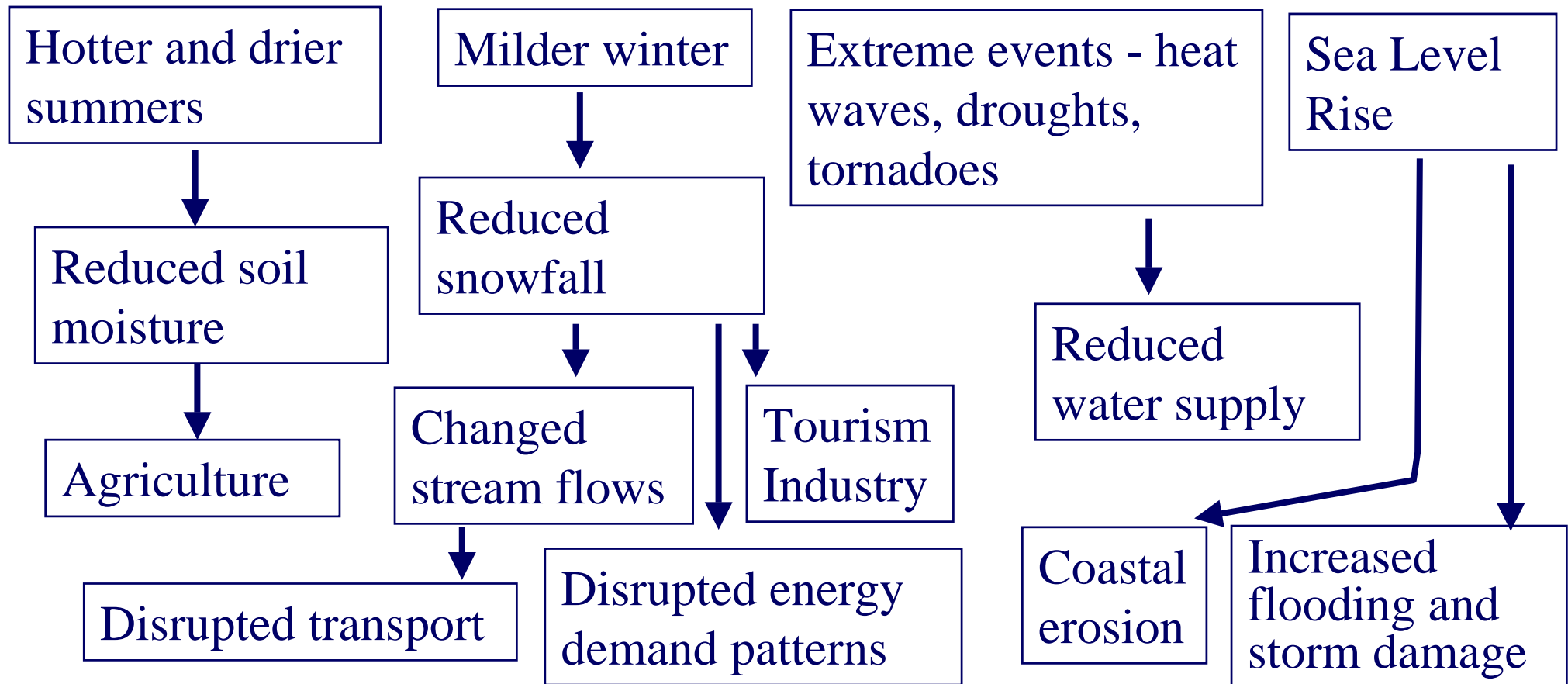
# Modelling global warming



# Thames Barrier Now Closed Frequently to Counteract Increasing Flood Risk



# The Effects Of Climate Change



**Ambitious goal for 2050** (when total world power market predicted to be 30TW)

- limit CO<sub>2</sub> to twice pre-industrial level

Will need 20 TW of CO<sub>2</sub>-free power (compared to today's world total power market of 13 TW)

**US DoE "The technology to generate this amount of emission-free power does not exist"**

**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?**

■ Estimates of world’s total endowment of accessible conventional oil ~ stable and consistent for 50 years, *except* for recently upgraded estimate (assumes 40% improvement in extraction) by

**US Geological Survey** which is the largest available

This (optimistic?) estimate  $\Rightarrow$  remaining oil will last 60 years\* *with current use*  $\Rightarrow$  40 years if use doubles\* in forty years

\*ignores price $\uparrow$   $\Rightarrow$  consumption $\downarrow$  as end approaches

■ **Production will peak much sooner**

many believe production  $\Rightarrow$  peak in 5-10 years, then fall ~ 3% pa

( $\Rightarrow$  “prices up, inflation, recession, international tension”)

Even USGS estimate  $\Rightarrow$  peak cannot be much more than 20 years away

■ **20 years is not long to develop and deploy alternatives for transport**

[hydrogen - whence?;...] **or** introduce large scale coal and/or unconventional oil  $\Rightarrow$  oil [+CO<sub>2</sub>] conversion

■ **Gas will last longer; coal *much* longer**



# WHAT MUST BE DONE?

- **Recognise the problem, and that**
    - only new/improved technology can → solution (although fiscal measures ⇒ change behaviour of consumers + stimulate work by industry also essential)
    - increased investment in energy research essential\*.  
Note: energy market ~ \$3 trillion p.a., so 10% cost increase → \$300 bn p.a.
    - global co-ordination and collaboration (→ necessary funding and expertise; prevent duplication) and co-operation essential: results should be openly available (as far as practical)
- \* public funding down 50% globally since 1980 in real terms; private funding also down, by (e.g.) 67% in USA in 1985-98*

## Over Co-ordination : A Cautionary Tale

- In 1405-33 seven Chinese treasure fleets (of ships up to 120m long: three times the size of Columbus's Santa Maria) explored as far as East Africa.

*Why did the Chinese not discover West America, West Africa, Europe?*

Power struggle → new faction in Beijing which

- forbade ocean shipping
  - closed shipyards
- } In all China

- 1480s - Columbus sought support/ships from
    - King of Portugal
    - Duke of Medina-Sedonia
    - Duke of Medina-Celia
    - King and Queen of Spain
- } All said no

but in 1492 the King and Queen of Spain finally agreed.

**If there had been a unified European exploration policy, Columbus might never have set sail!**

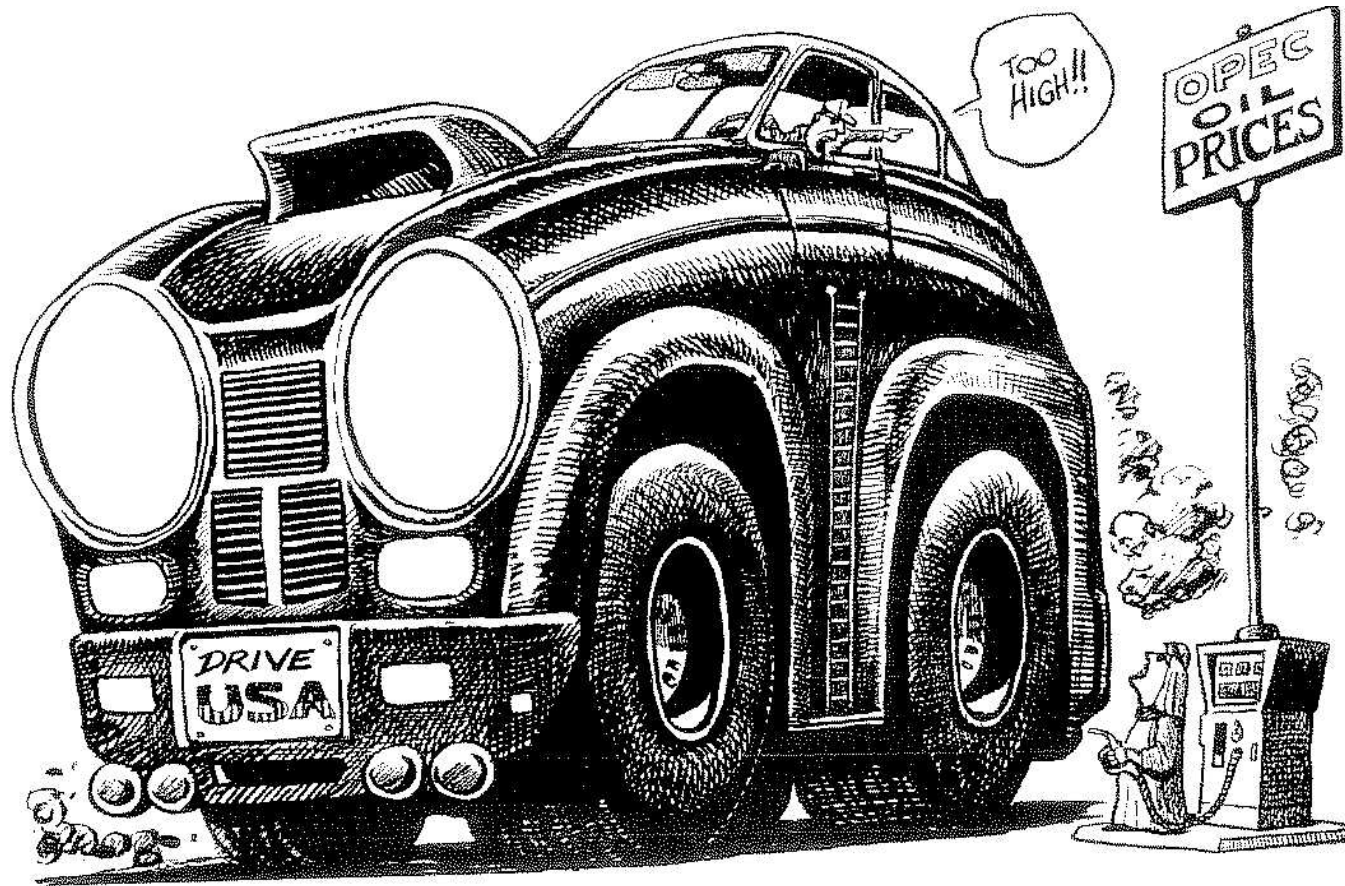
# FOCUS FOR RESEARCH

**Must explore all avenues (solution = cocktail).** Note - highly interdisciplinary: socio-economic, biological and physical sciences

- **Energy efficiency - yes** (will ameliorate but not solve problem)
- **CO<sub>2</sub> capture and sequestration - yes** (but big challenges, risks, and will add costs)
- **Renewables - yes** (but, apart from solar, do not have potential to meet large fraction of global demand). **Solar - yes** (enough in principle, but currently very expensive and mostly not where needed)
- **Energy storage\*** - **yes** (essential for large scale use of intermittent sources)
- **Nuclear fission - yes** (at least until fusion available)

\* energy storage/retrieval inevitably  $\Rightarrow$  significant losses

Warsaw 24 September 2004



*The Economist 29/5/04*

## ■ Fusion - yes

**Apart from fossil fuels** (as long as they last), **solar** (not [yet?] viable/economical except for niche uses) and **nuclear** (→ fast breeders in the future), ***fusion is the only known technology capable in principle of producing a large fraction of world's electricity***

**With so few options, I believe we must develop fusion as fast as possible - although success is not certain**

**The Joint European Torus (JET) at Culham in the UK has produced 16 MW and shown that fusion can work**

**The big question is whether/when we can develop the technology → robust, reliable (⇒ economic) fusion power stations**

## WHAT IS FUSION ?

**Fusion** is the process that produces energy in the core of the sun and stars

It involves fusing light nuclei (while fission  $\Rightarrow$  splitting heavy nuclei)

The most effective fusion process involves deuterium (heavy hydrogen) and tritium (super heavy hydrogen) heated to above **100 million  $^{\circ}\text{C}$**  :

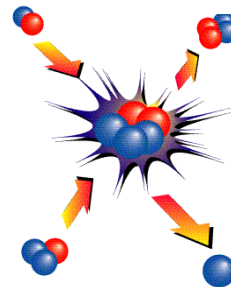
**Deuterium**

**Helium**

**Tritium**

**+ energy**

**Neutron**



A “magnetic bottle” called a **tokamak** keeps the hot gas away from the wall

**Challenge:** make an effective “magnetic bottle” (now done (?))

**and a robust container**

## FUSION ADVANTAGES

- unlimited fuel (raw fuel = water + lithium: lithium in one lap-top battery + 40 litres of water  $\Rightarrow$  200,000 kw-hours, same as 40 tonnes of coal)
  - no CO<sub>2</sub> or air pollution
  - major accidents impossible\*
  - no radioactive “ash” and no long-lived radioactive waste
  - potentially (depending on reliability) competitive “internal” cost, and essentially zero “external” cost [impact on health, climate]
- \* 100 tonne core of uranium, plutonium etc in nuclear reactor replaced by 1/10 gram of deuterium and tritium

## DISADVANTAGES

- Development not complete or certain
- Container  $\Rightarrow$  radioactive: but not long-lived - could recycle after 100 years

## STATUS OF FUSION

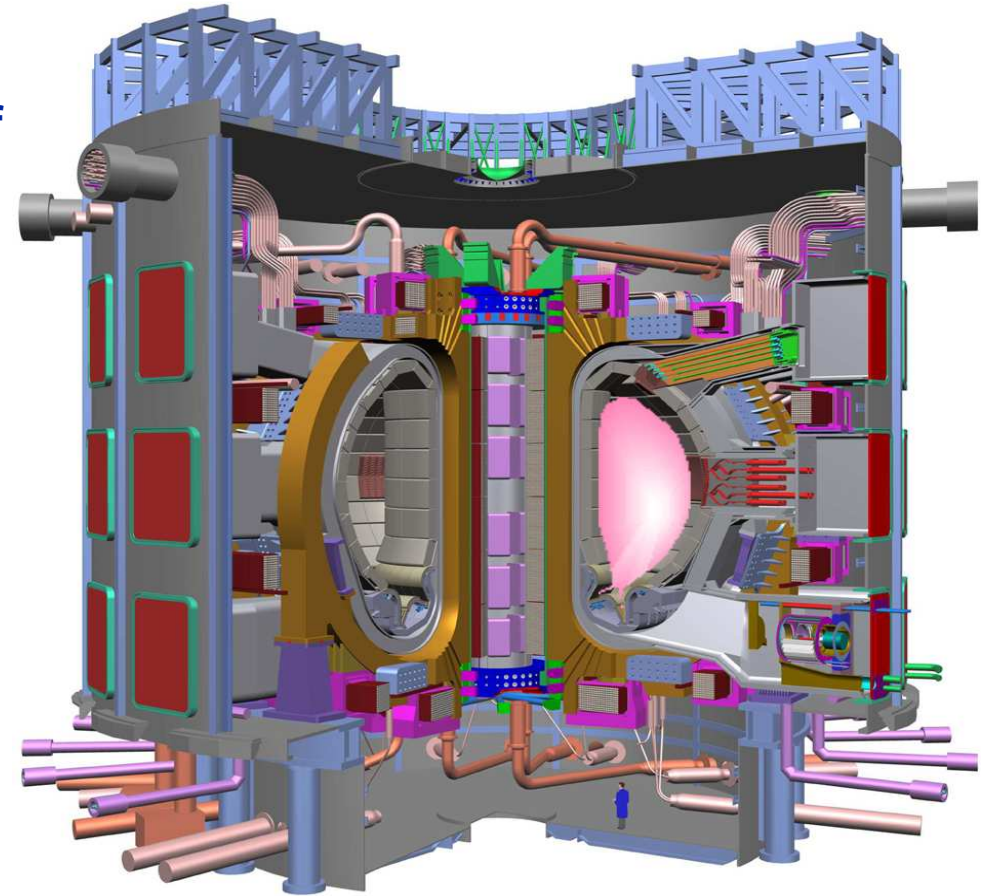
- JET has produced 16 MW
- ITER (~2 x linear dimensions of JET) designed  $\Rightarrow$  at least 500MW and should confirm that it is possible to build a fusion power station.
- **Big Question:** when will it be possible to build a robust reliable (economically viable) fusion power station?

If ITER and IFMIF (\$900M International Fusion Materials Irradiation Facility ~ two 40 MeV, 5 MW deuteron accelerators) started in parallel in near future, a prototype fusion power station could  $\Rightarrow$  power into grid within 30 years



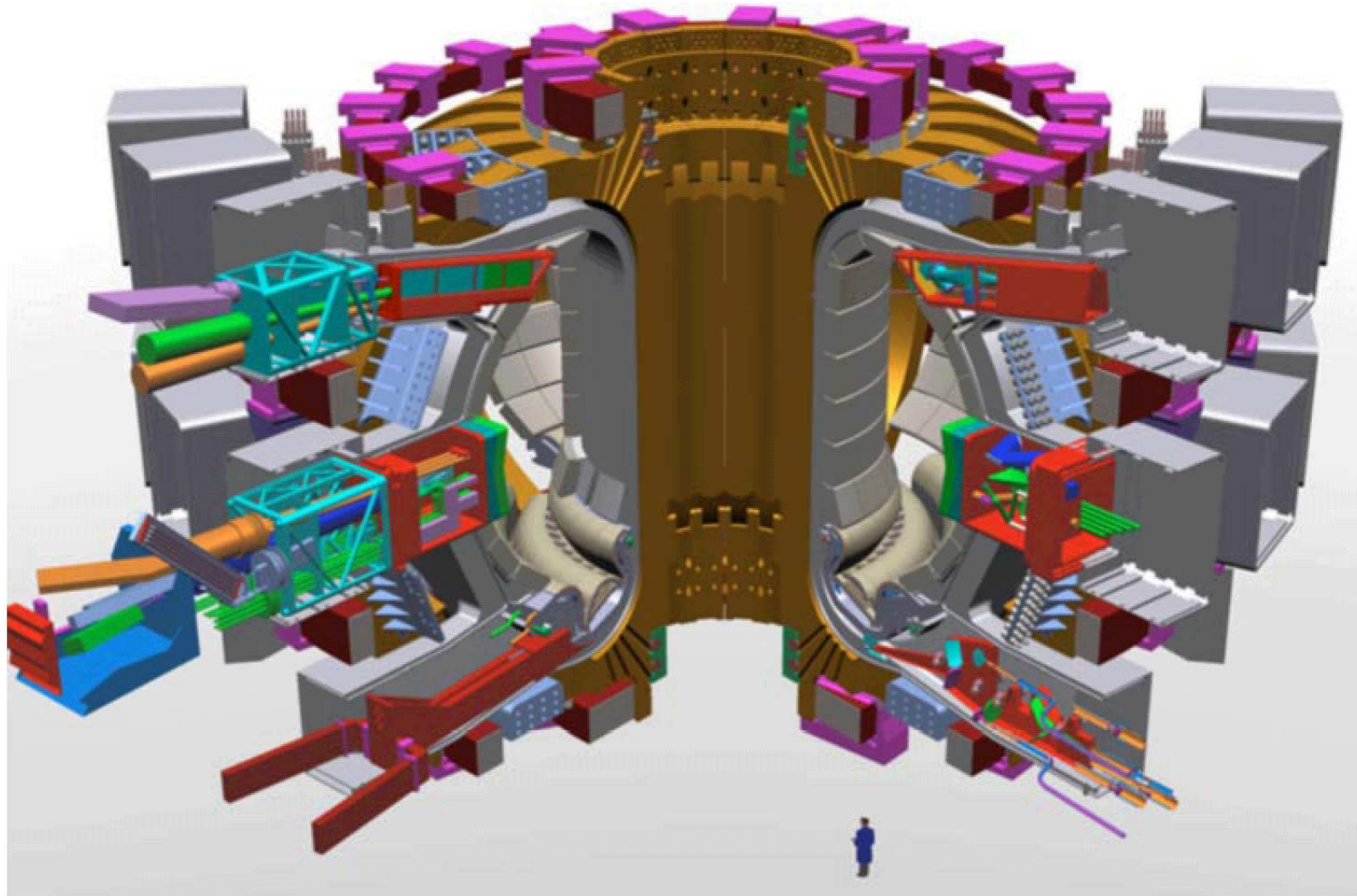
# ITER

- Aim is to demonstrate integrated physics and engineering on the scale of a power station
- Key ITER technologies fabricated and tested by industry.
- 4.5 Billion Euro construction cost
- Europe, Japan, Russia, US, China, South Korea.
- Candidate sites in France and Japan
- Decision hoped for in near future



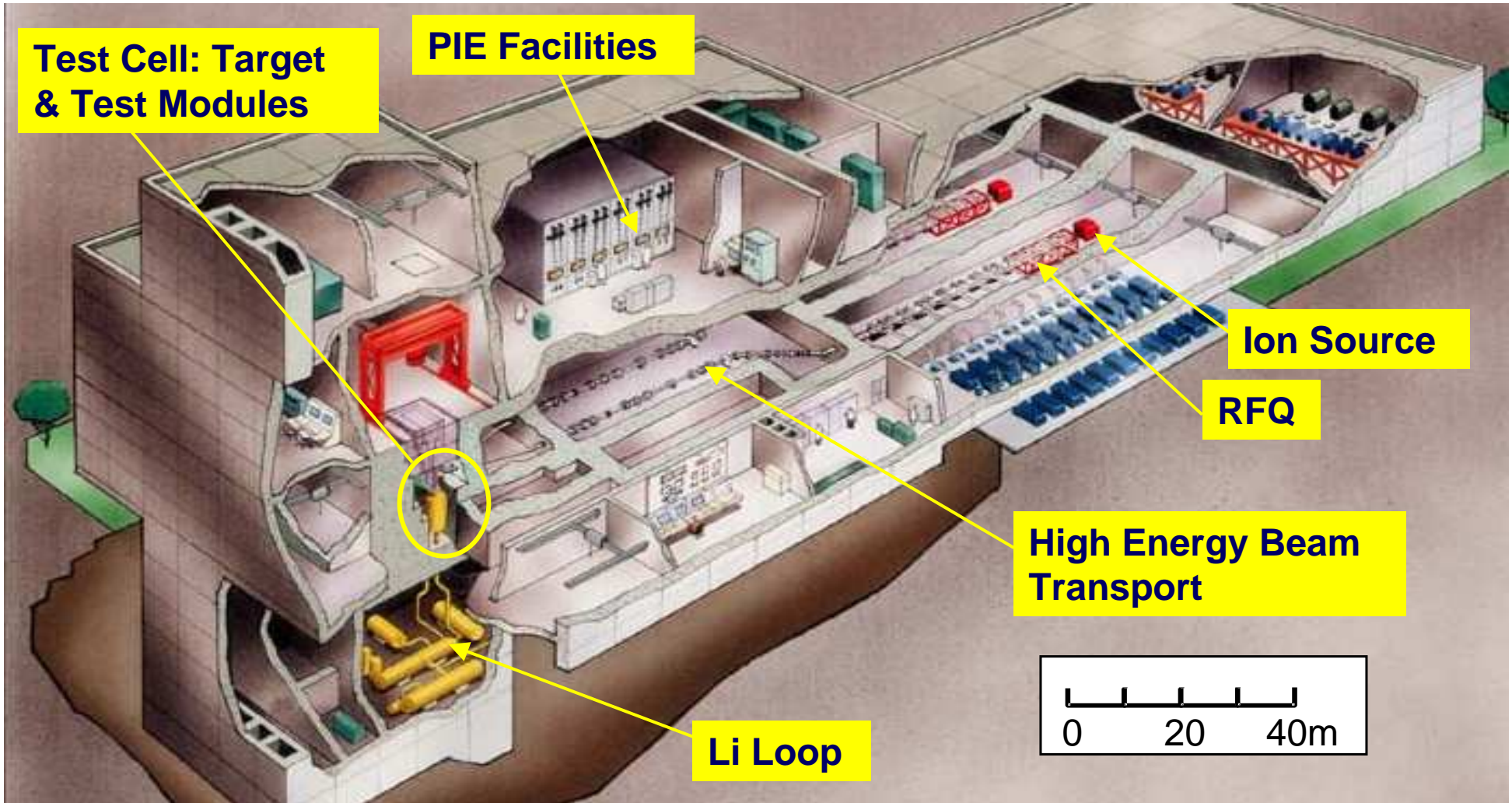
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## ITER systems are big...



**IFMIF**

# System Design



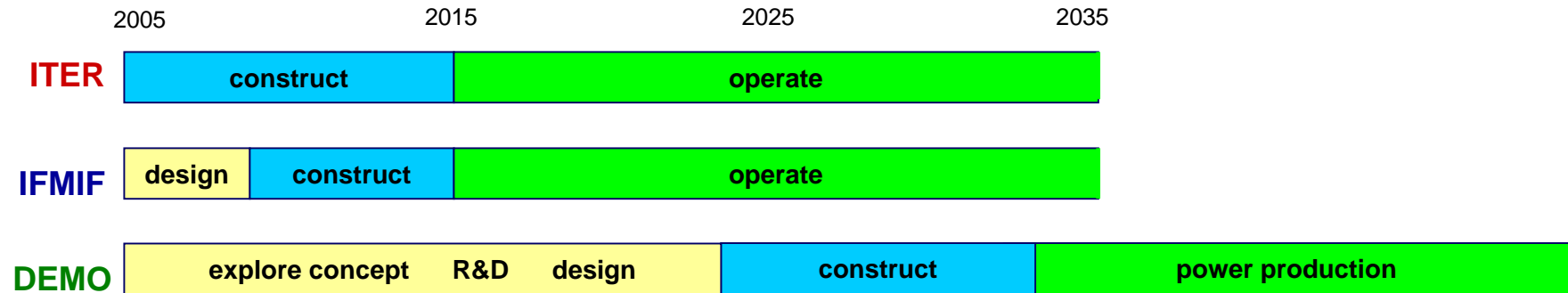
## FUSION FAST TRACK: WHAT IS NEEDED

- **Approve ITER now**
  - during ITER construction → operate JET → speed up/improve ITER operation
  - continue configuration optimisation (MAST, . . .)
- **In parallel intensify materials work, approve and build IFMIF**
- **Then move from ITER directly to Prototype Power Plant**

[generally → project-oriented approach]

⇒ **Fusion a reality in our lifetimes**

## THE BROADER/FAST-TRACK APPROACH TO FUSION



This aggressive timetable can in principle be met given

- **Funding\*** to begin IFMIF in parallel with ITER, and also to maintain a strong accompanying programme\*\*, including continued operation of JET, technology development, start on design of DEMO

- **No major surprises!**

*\* cf world electricity market ~ \$1 trillion p.a. : meanwhile fossil fuels (⇒ carbon-dioxide, pollution) are running out, while fission faces problems*

*\*\* ITER construction budget mainly to industry, not to fusion R&D*

## CONCLUSIONS (I)

### Science – who benefits, who should pay?

- “Useless” science is often surprisingly valuable
- When companies foresee benefit (profit + occasionally image) they will invest
- When the benefits are long-term or non-commercial, investment is the responsibility of governments – true for basic science and applied/mission orientated research

## CONCLUSIONS (II)

- The choice of what to support is difficult – but “*under pressure for immediate results, and unless deliberate policies are set up to guard against it, applied science invariably drives out pure\**”

*\*Vannevar Bush “Science the Endless Frontier” (1945)*

and mission oriented R&D with short-term goals drives out research with long-term goals

### - be on guard\*

\* Be on guard also in case emphasis on capturing/protecting the *direct* results of basic research leads to protective policies that could slow down scientific progress. ‘Open Science’ (hallmark = disclosure) cannot be taken for granted: only in the 17/18th century did it supersede an earlier protectionist tradition (technologies guarded by guilds; geographical discoveries kept secret; mathematical proofs hidden)