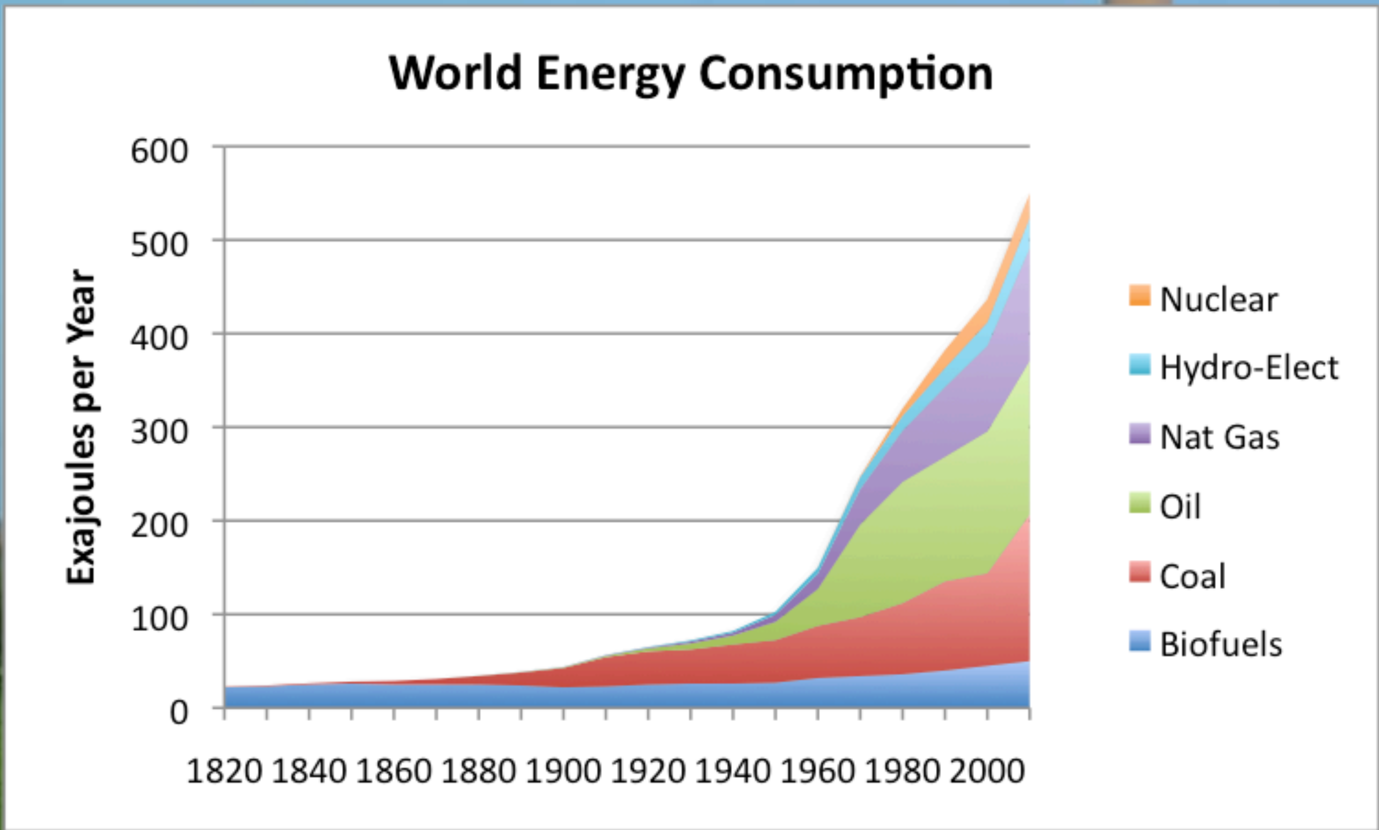
What makes the energy future problematic?

Fossil energy completely dominates..

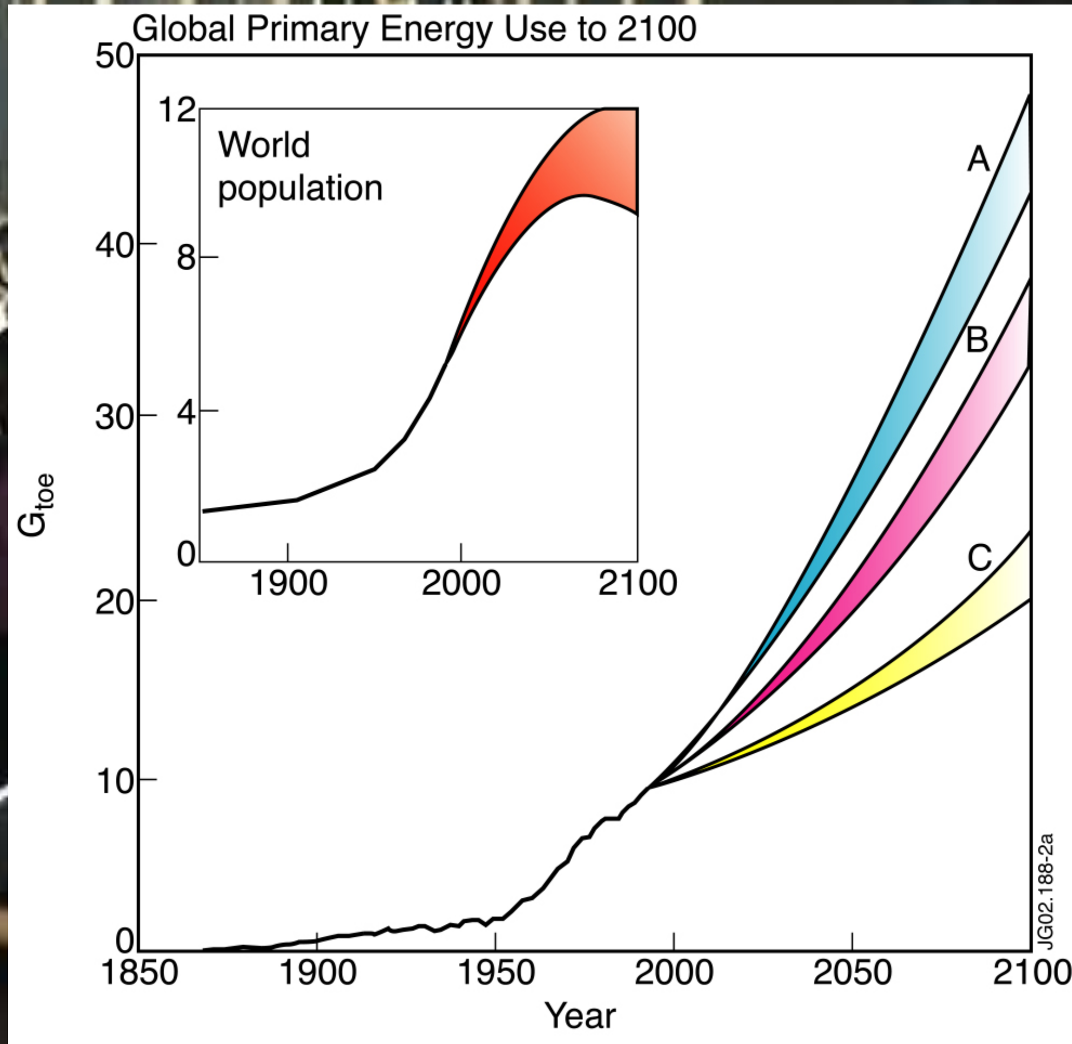


GLOBAL HEATING

Courtesy: ourfiniteworld.com

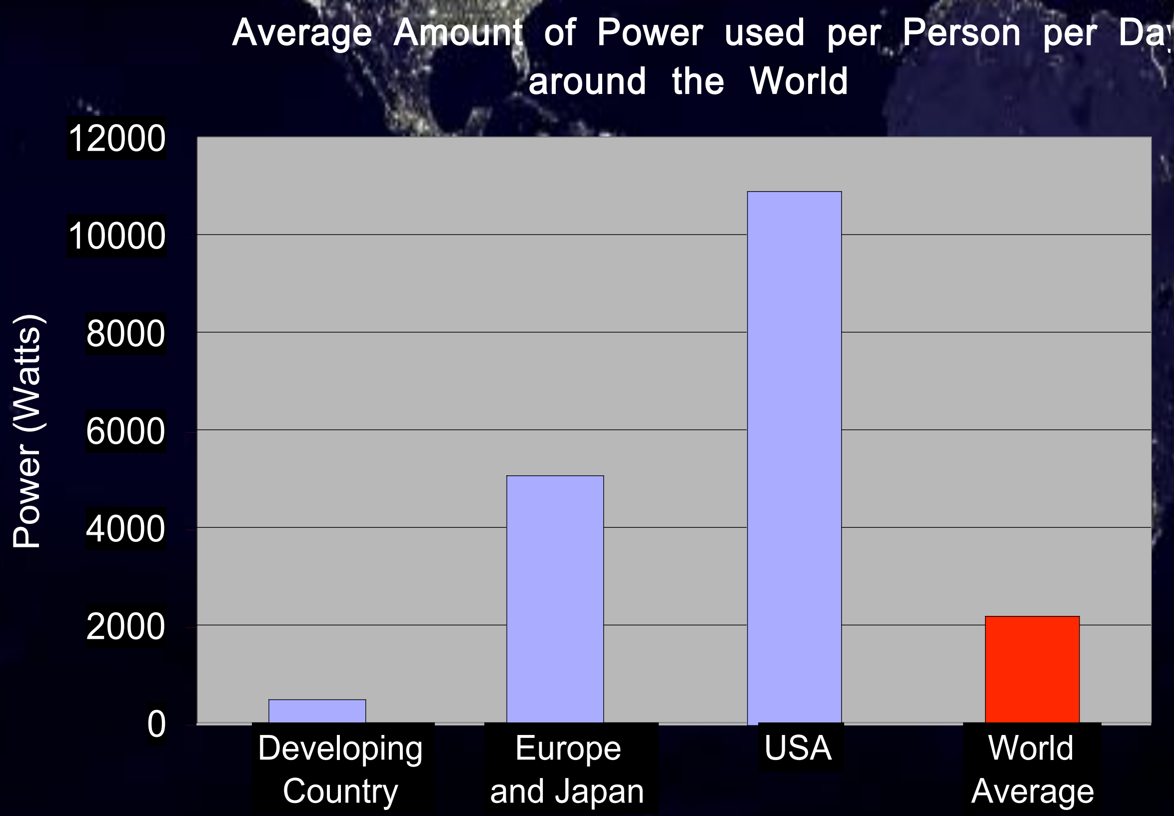
Populations increase…

Energy demands increase…



Global energy consumption

Energy use in developing countries is low, but increasing



In 50 years the global population may have doubled

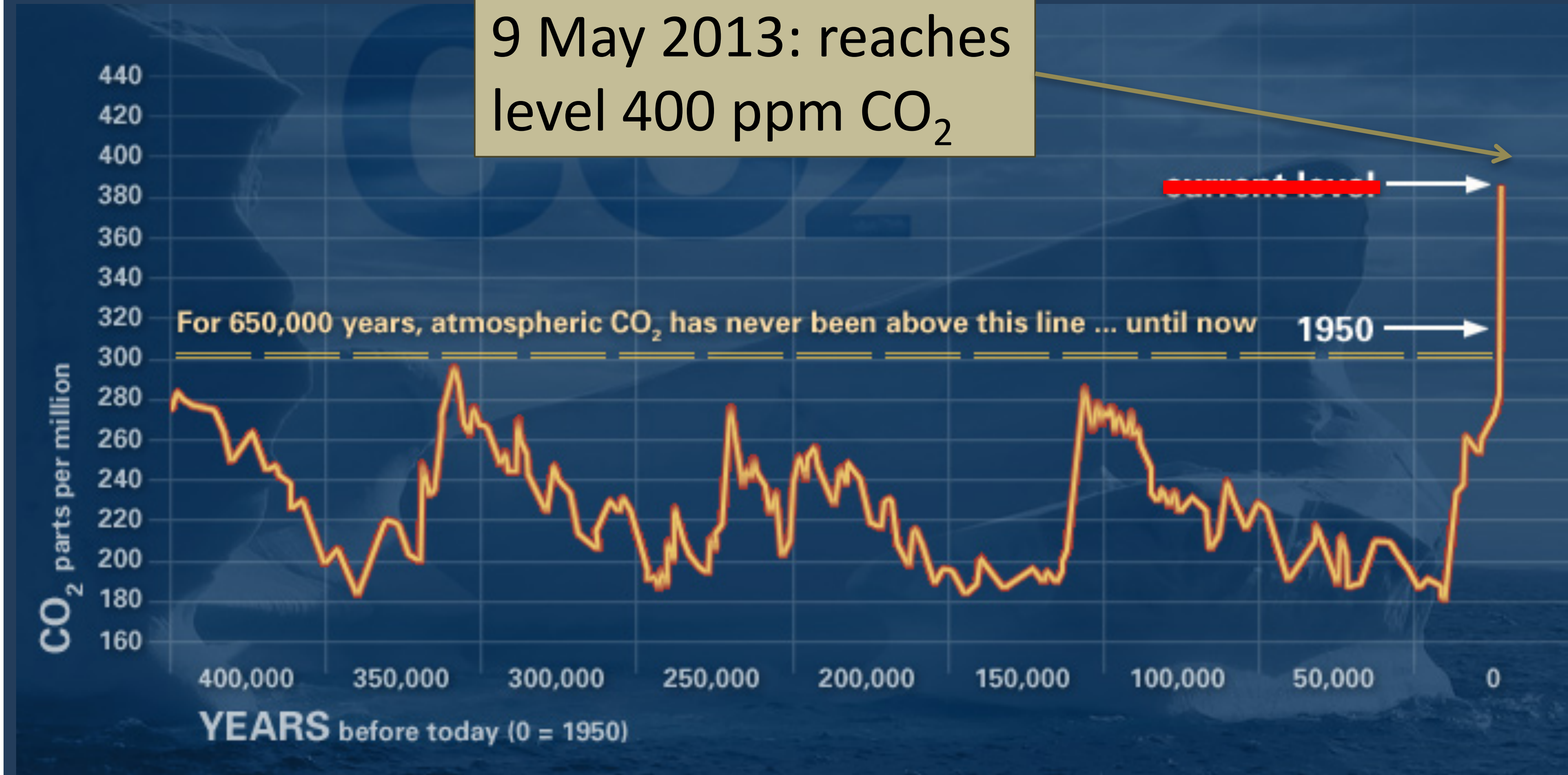
Energy use may have increased with factor 2-3

Picture courtesy of NASA/GSFC

Human impact on CO_2 in atmosphere

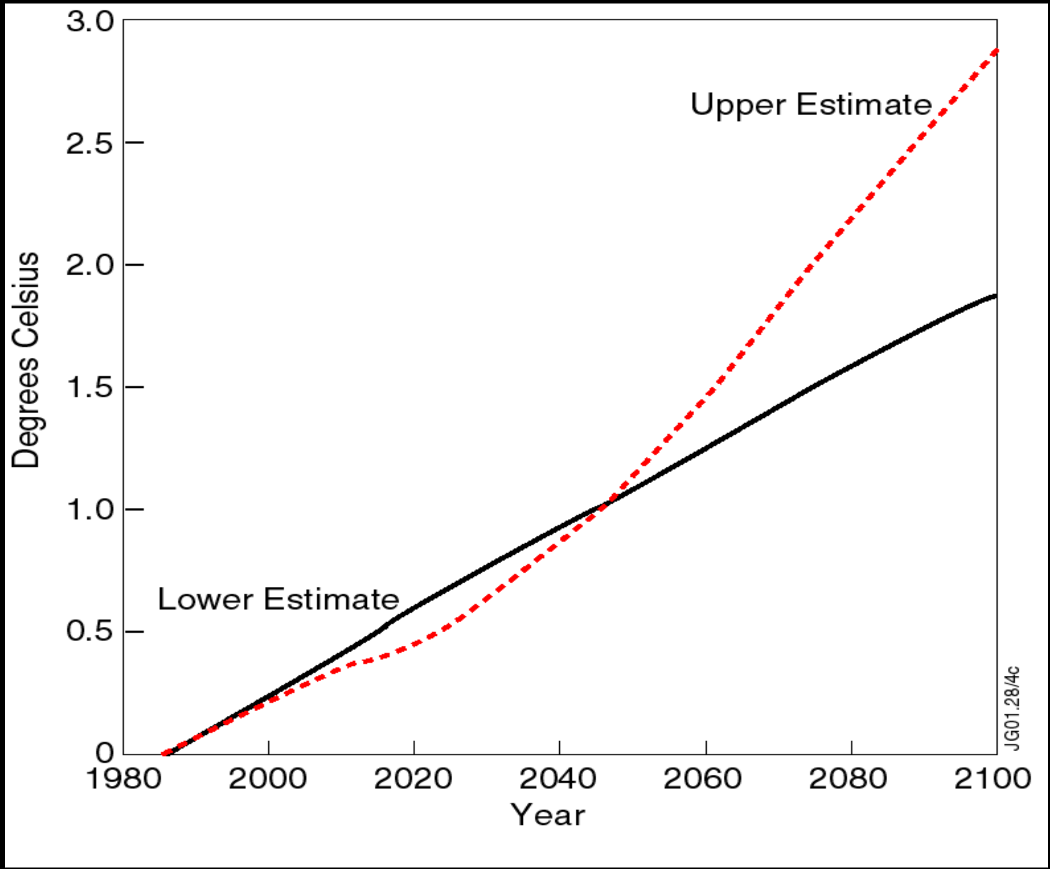
Since the industrial revolution (19th century) man has burnt enormous amounts of fossil fuel, which has changed our atmosphere

9 May 2013: reaches level 400 ppm CO_2



Fossil fuels are problematic

Fossil fuels are currently being burned and lost forever

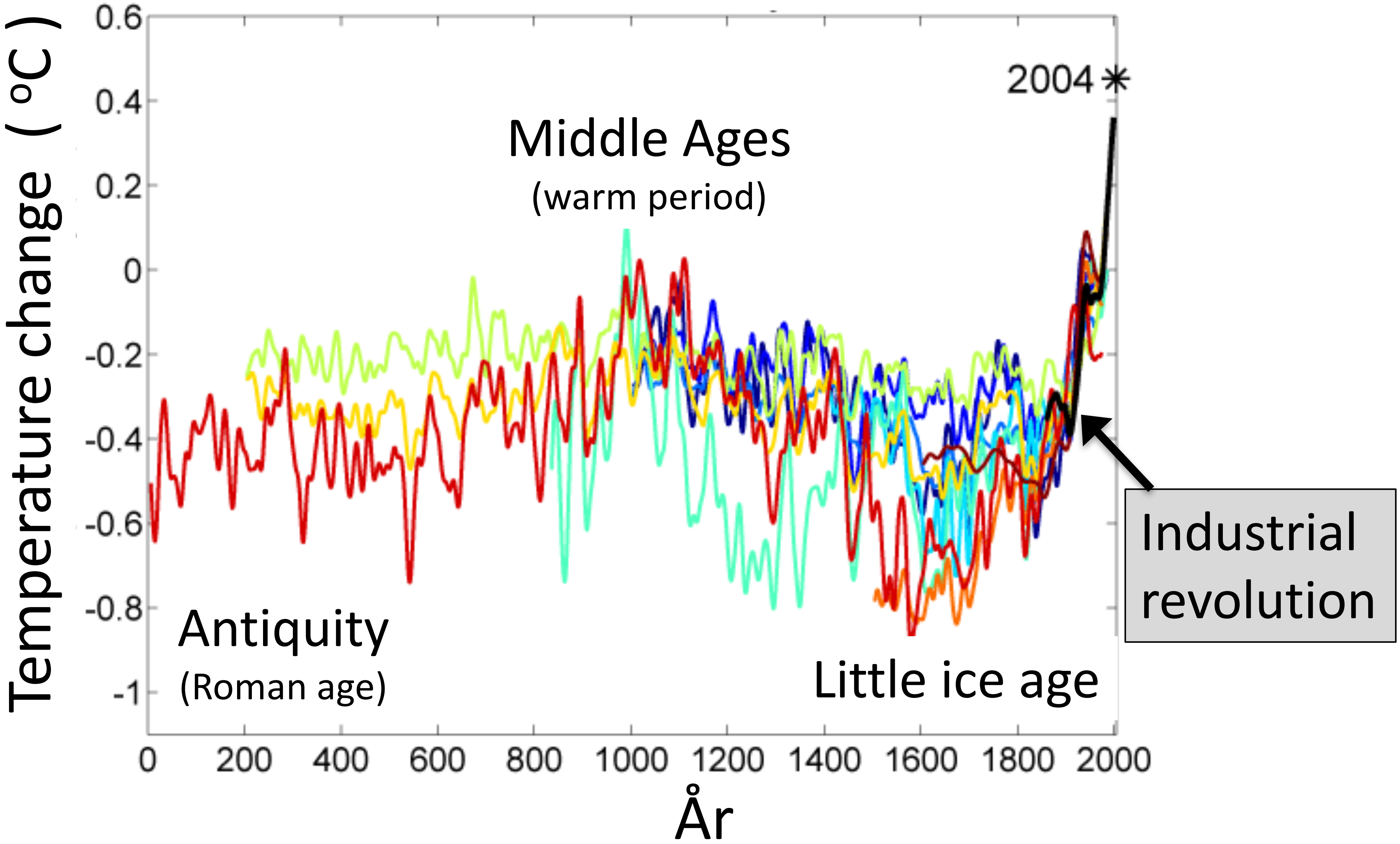


GLOBAL WARMING due to excessive production of greenhouse gases from power stations

Fossil fuels are essential in the petrochemical and pharmaceutical industries

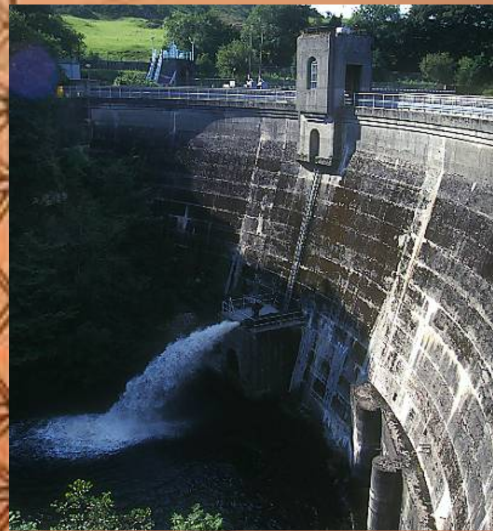
Significant economic and political impact

We have changed the global temperature



Sustainable energy sources





Renewables (bio, wind, wave, solar, geothermal, hydro)

BUT:

- **Low energy density**
- **Intermittent; need storage systems**

Renewables are not enough...

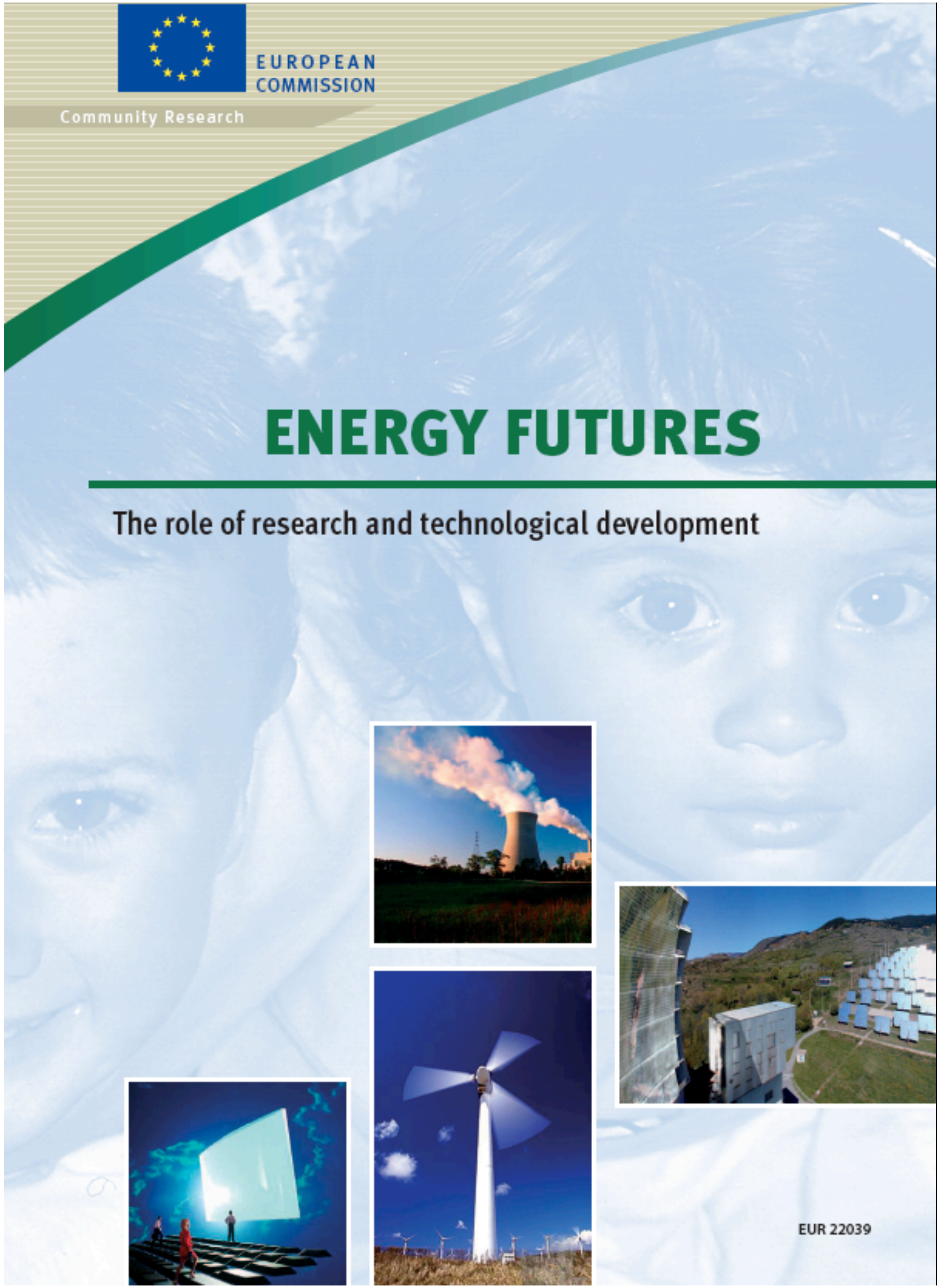
EU Commission study from 2006:
"Energy Futures -
The role of research and technological development"

Four long time scenaries for Europa were studied.

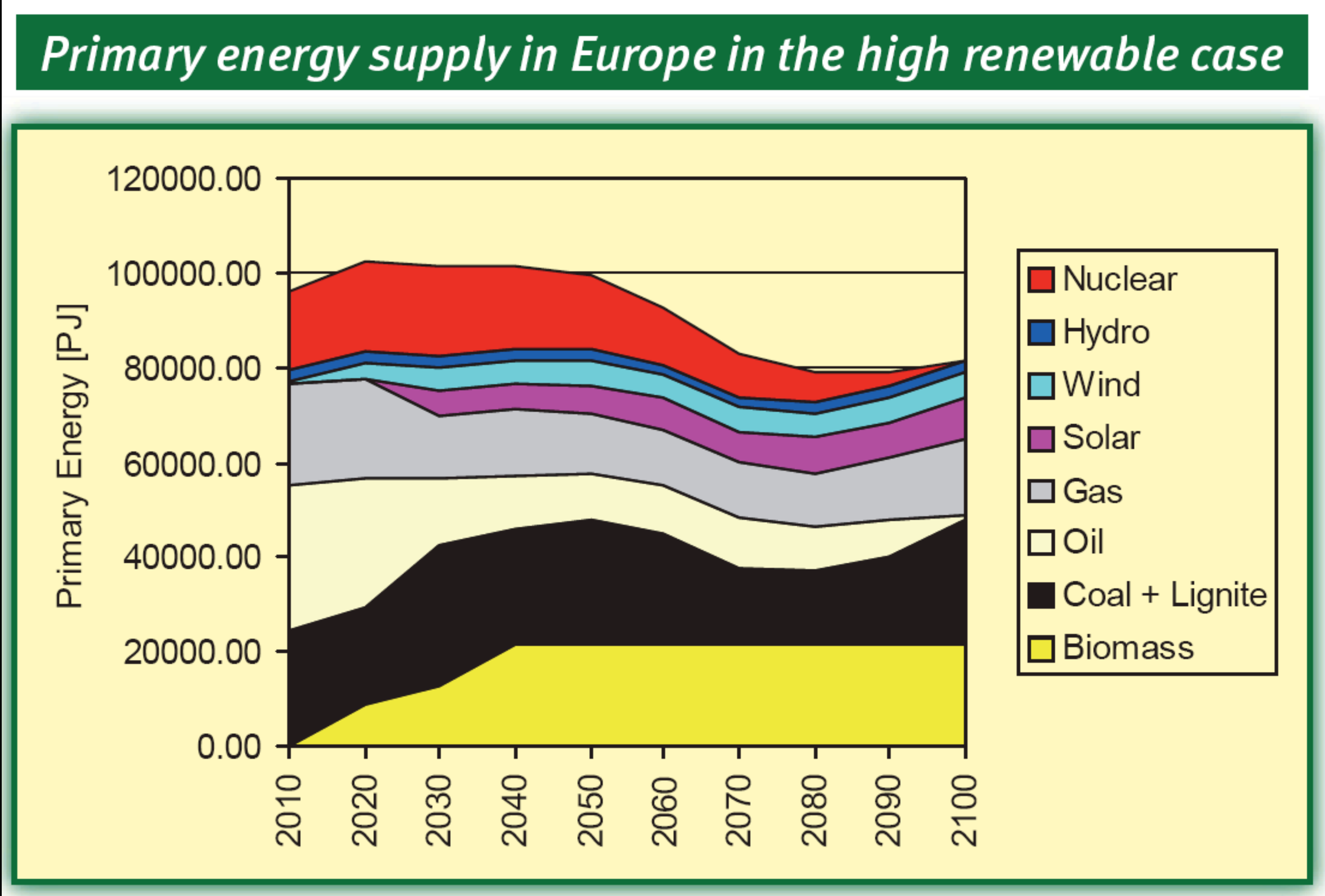
Alternative with <u>strong contribution of renewables</u>:

At most 50% of the produced energy is renewable year 2100.
biomass 25%
solar 11 %
wind 7%.

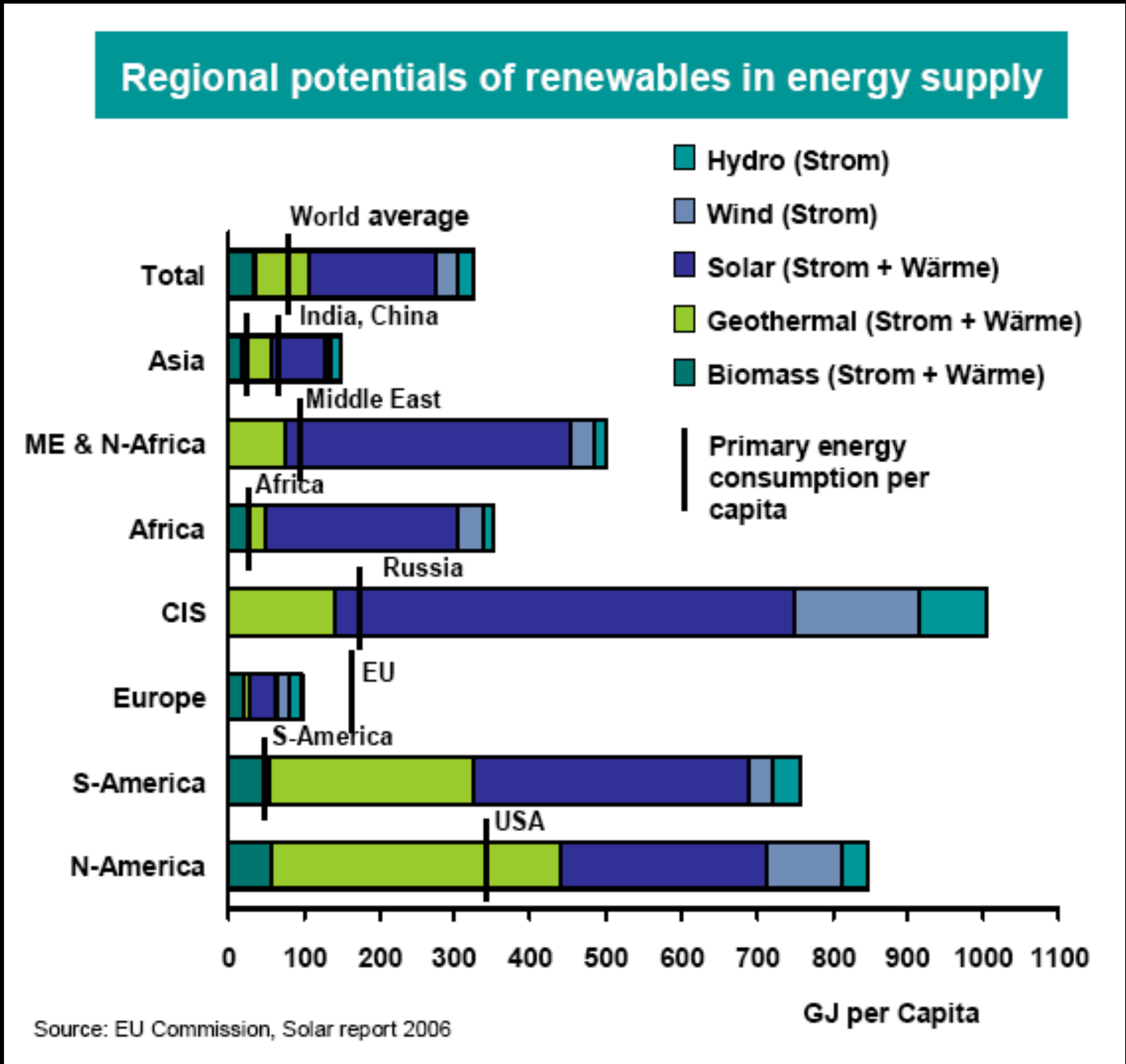
50% sustainable energy is missing!



Europe’s energy future, scenarios



Europe's energy future, scenario with maximized renewable contribution



Europe has **weak** potential for renewable energy

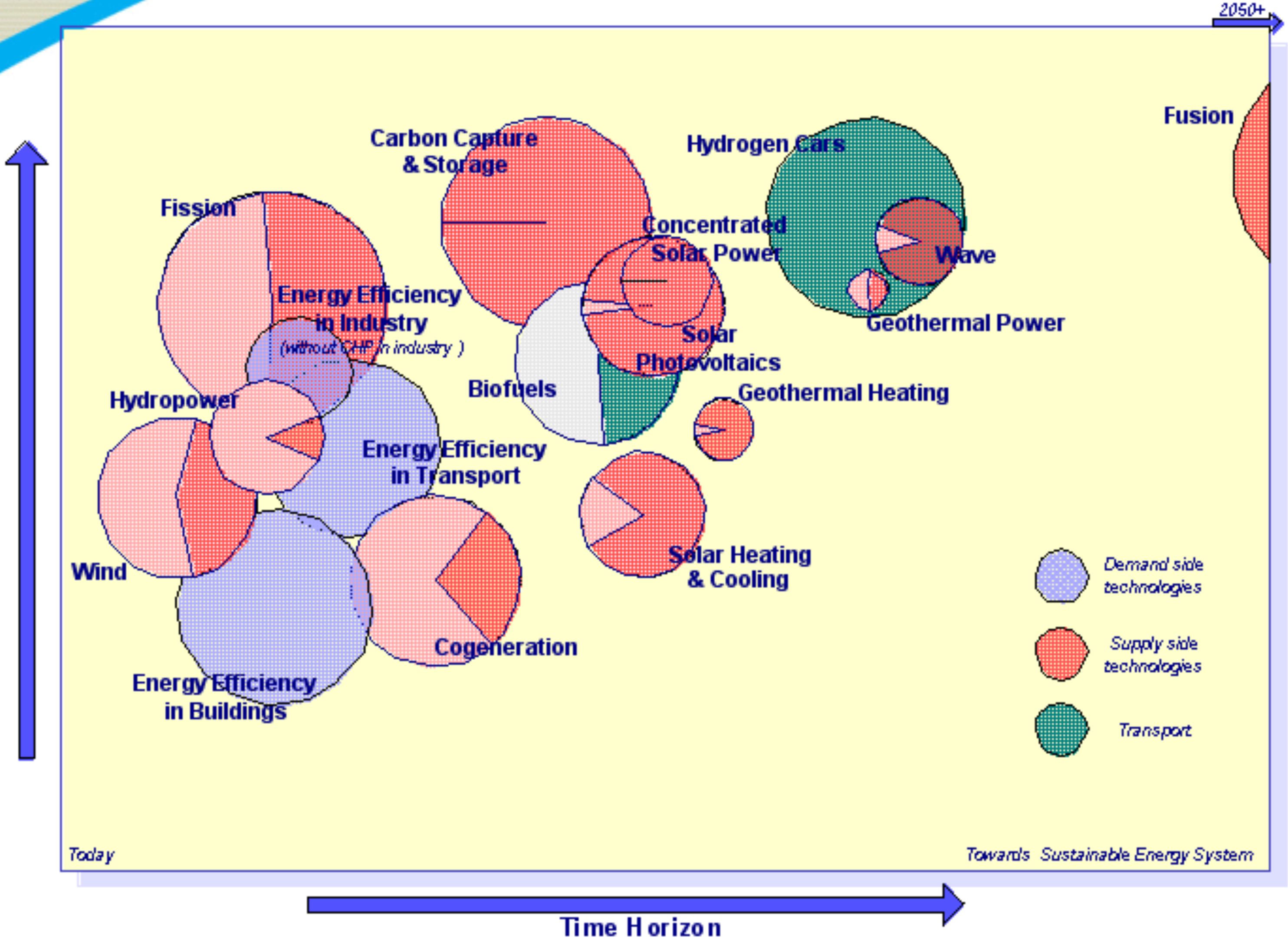
European Strategic Energy Technology Plan (SET-Plan)

European Commission

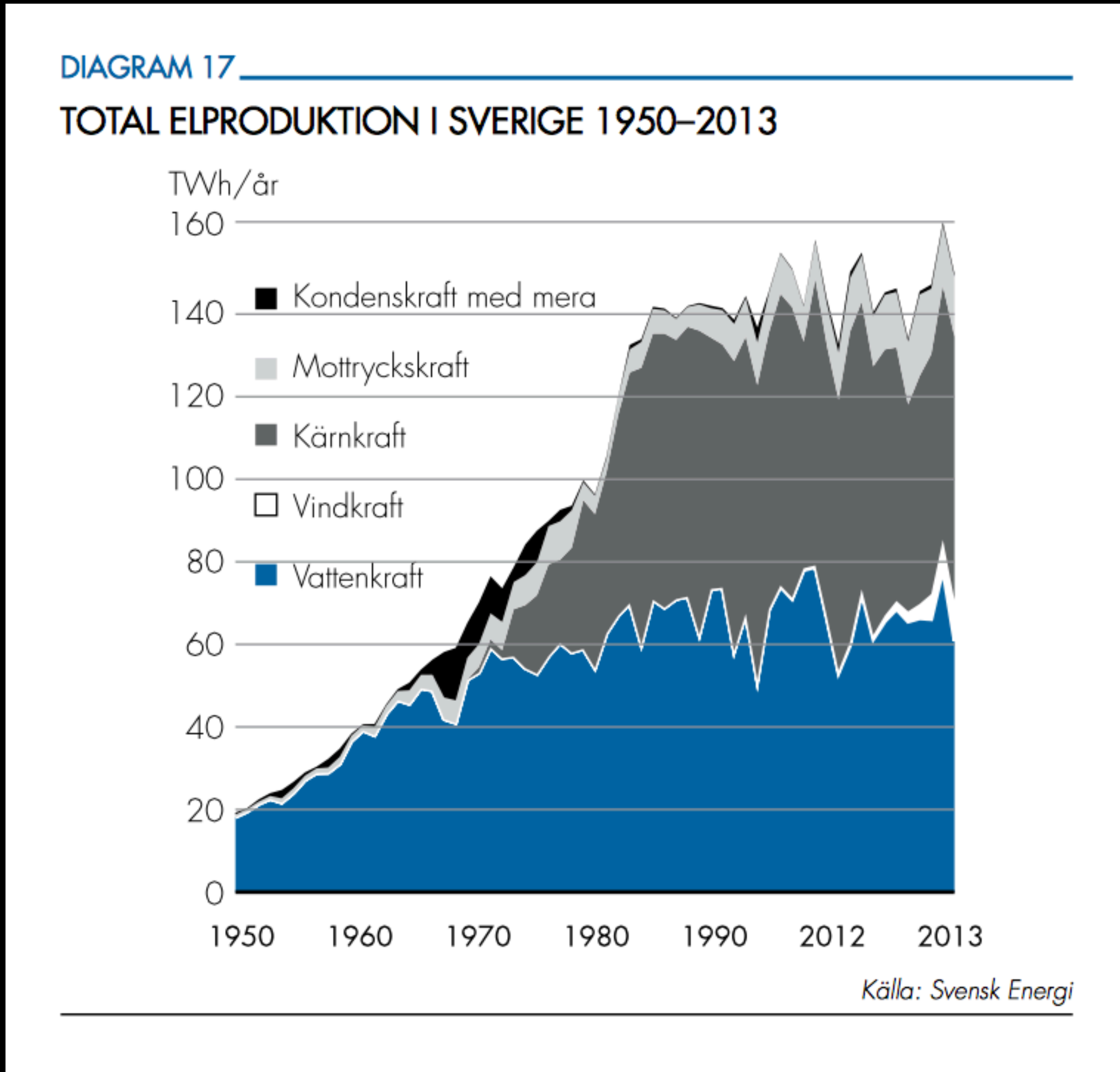
December 2007

EUROPEAN COMMISSION
Community research

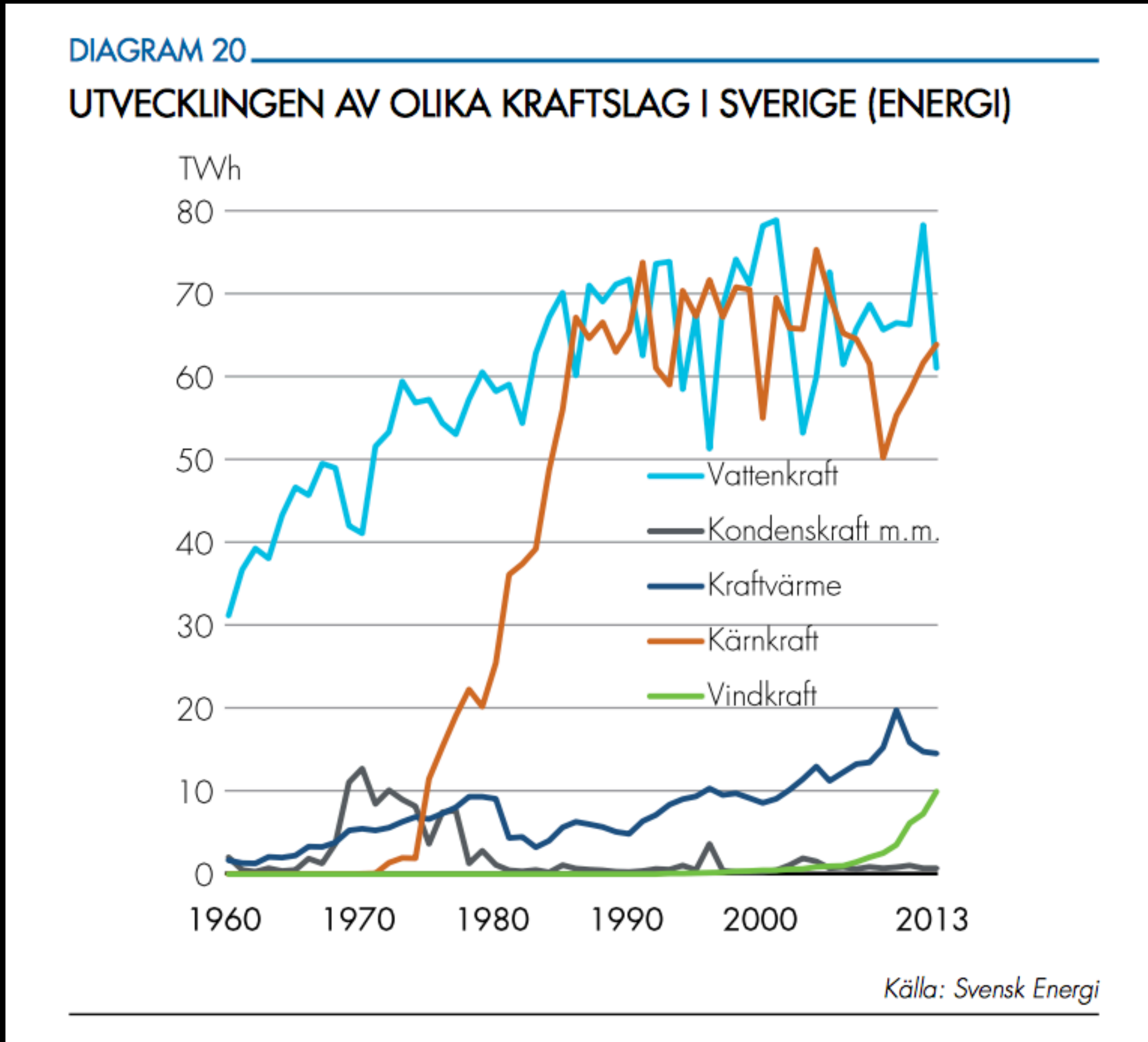
Potential of technologies



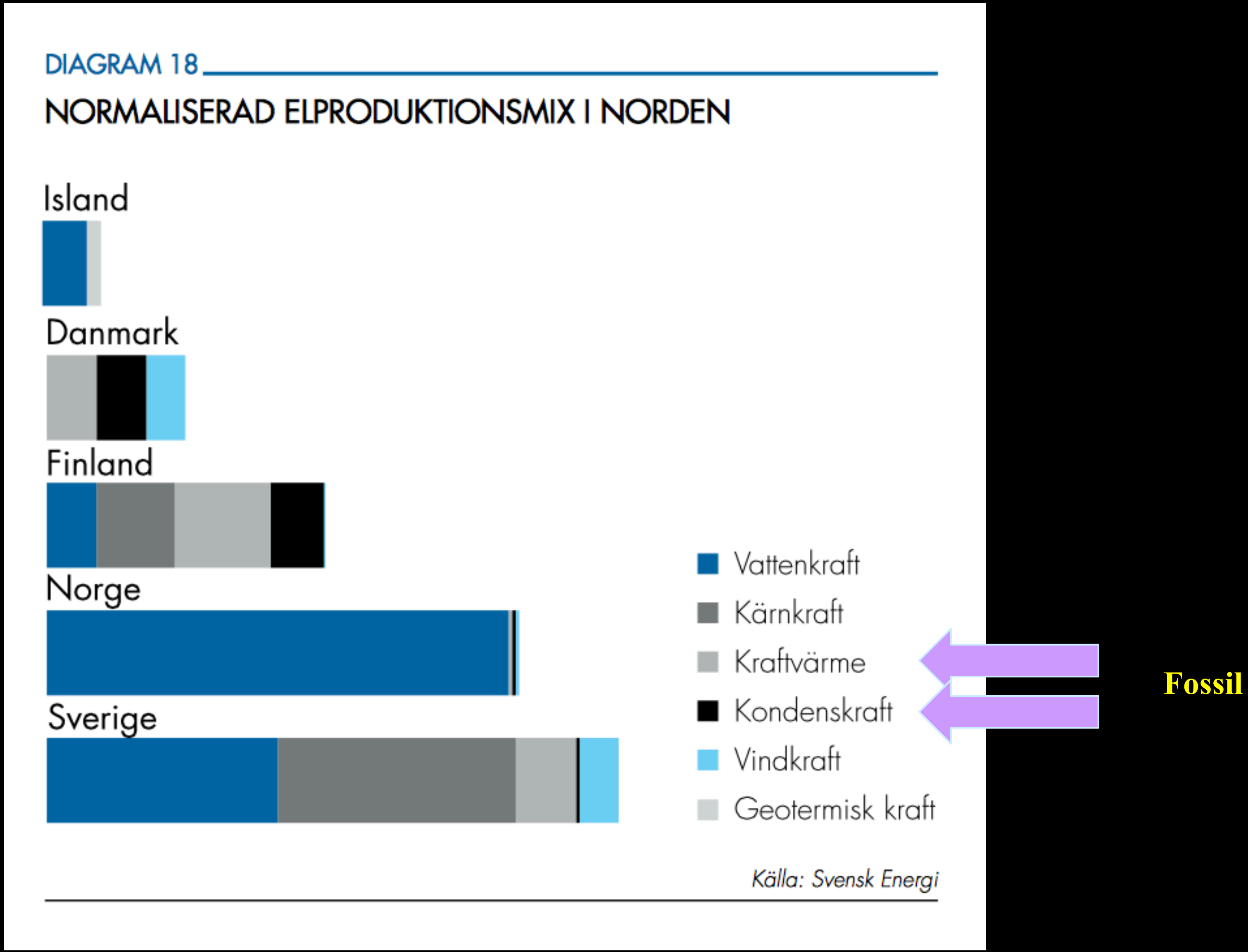
Sweden
- electricity development, total



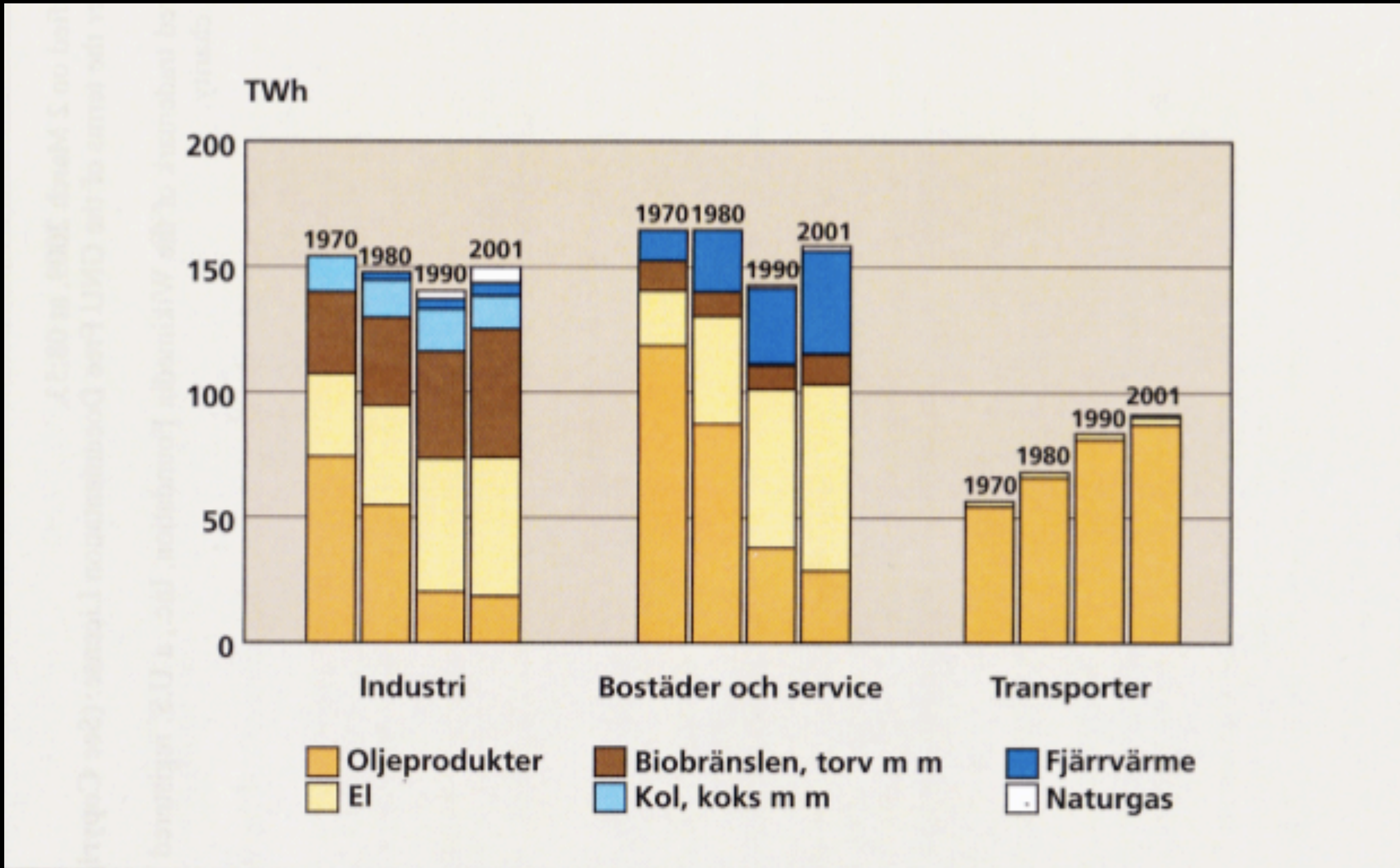
Sweden –
electricity development per source



Scandinavia –
total electricity mix



In Sweden the use of electricity as energy carrier increases

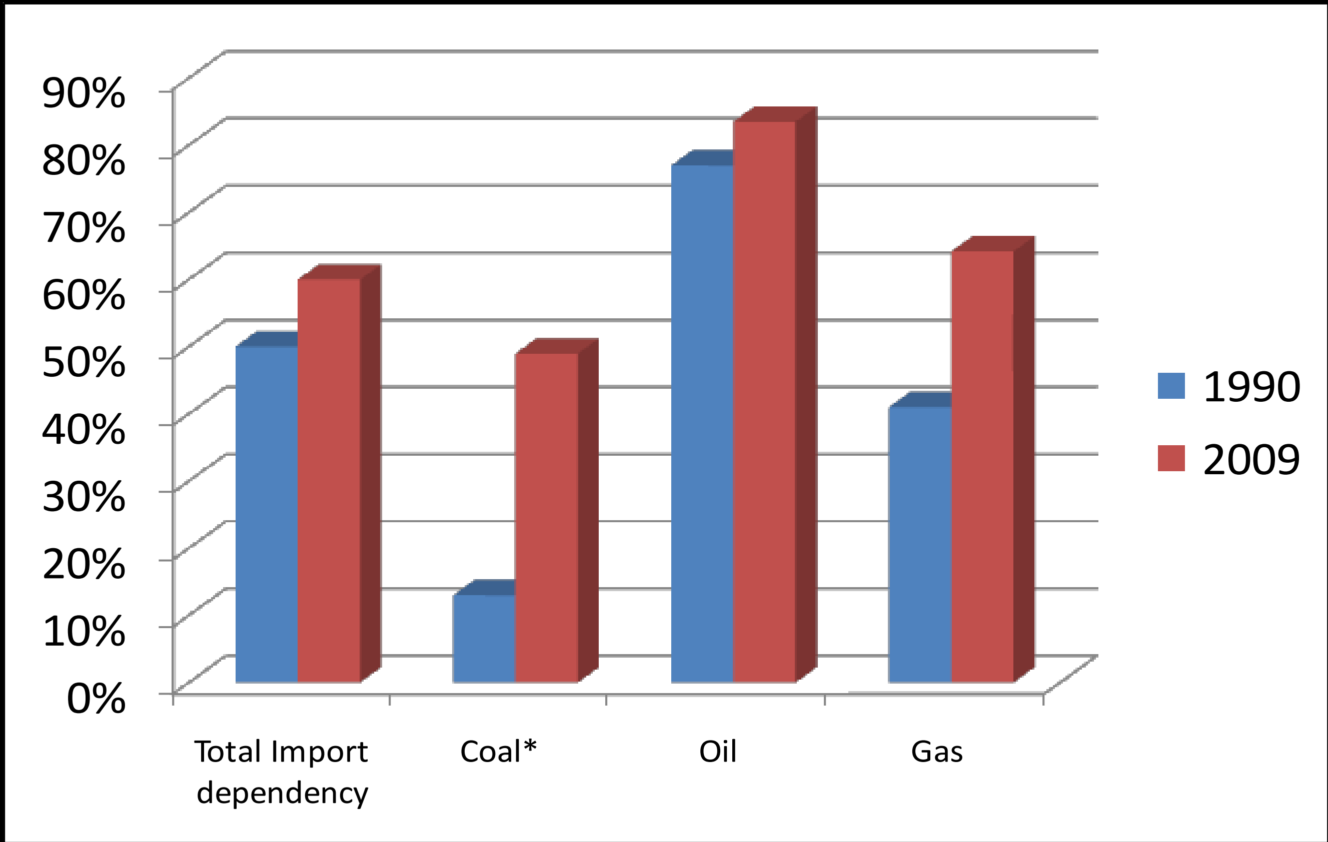


(Svensk Energi)

EU Energy Dependency

EU dependency on import is increasing for all fossil fuels...
Dependency on oil imports reached 83.5% in 2009 and 64.2% for gas.

EU-27 Energy import dependency

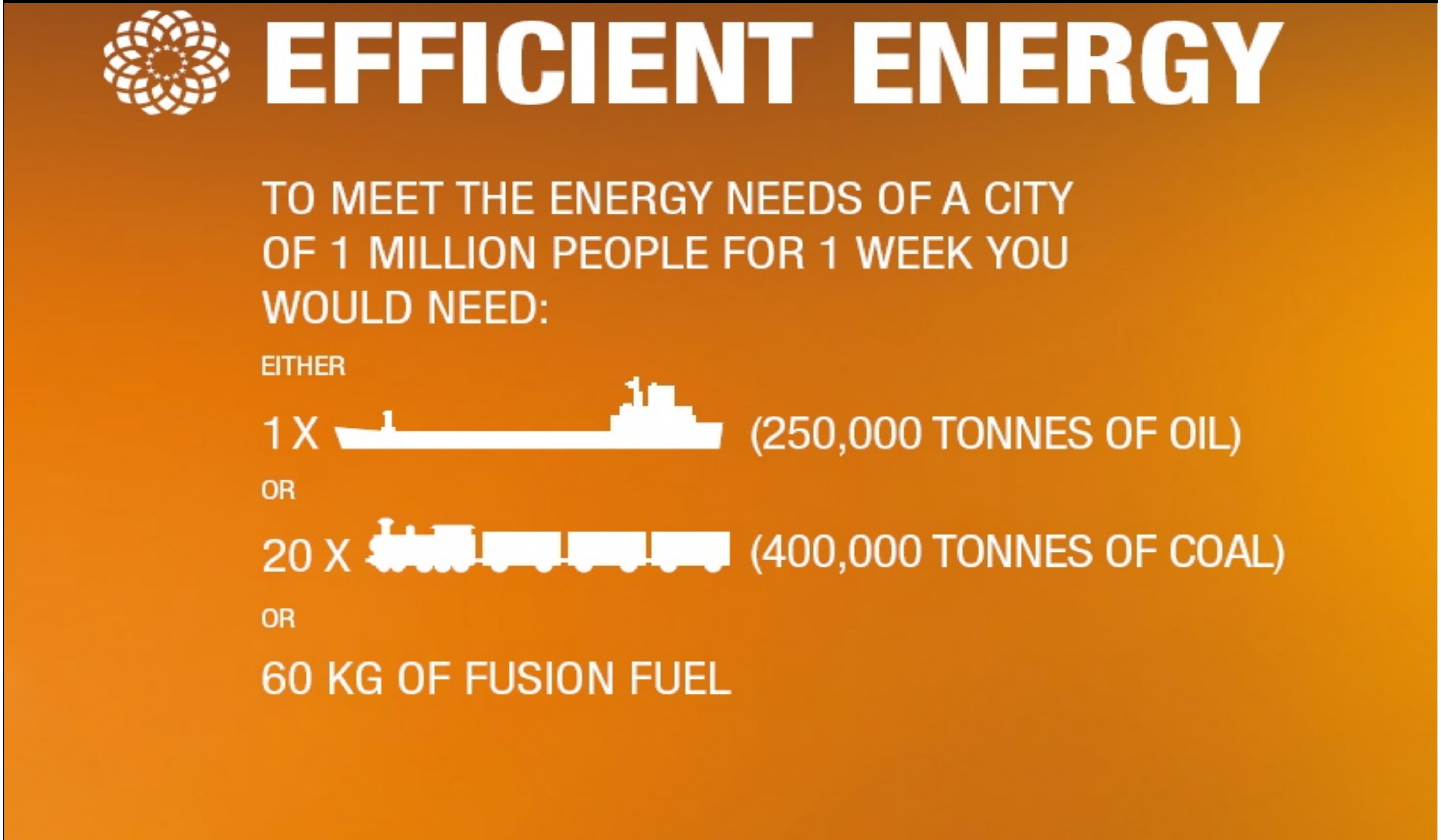


Source: Eurostat May 2011- *Coal and other solid fuels

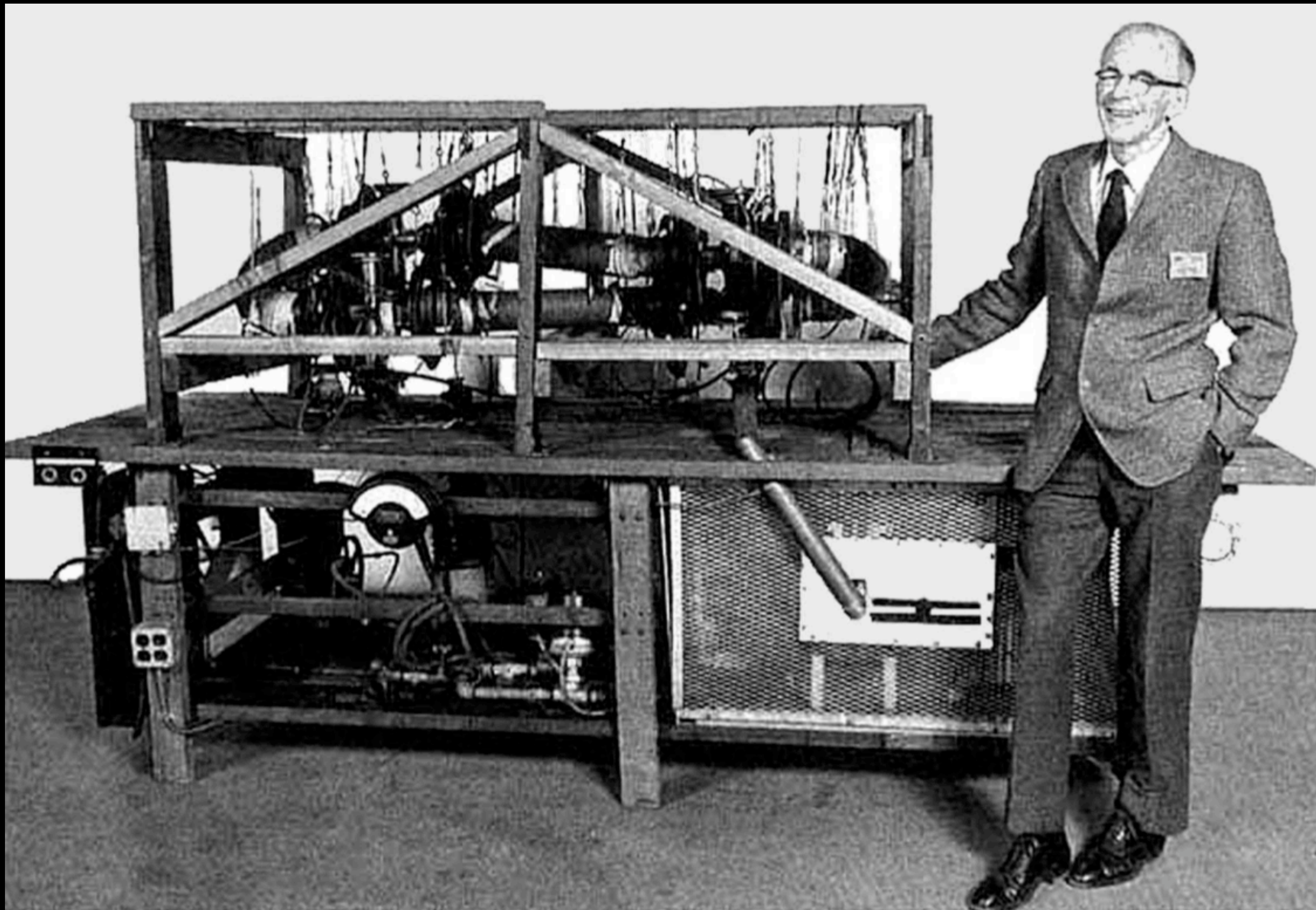
Fusion power advantages

- Negligible climate effect – no emission of greenhouse gas
- No long lived radioactive waste, no transports of waste
- No risk for nuclear meltdown
- Fusion energy is SUSTAINABLE ENERGY:
- Fuel for millions of years easily accessible in....

Did you know that…



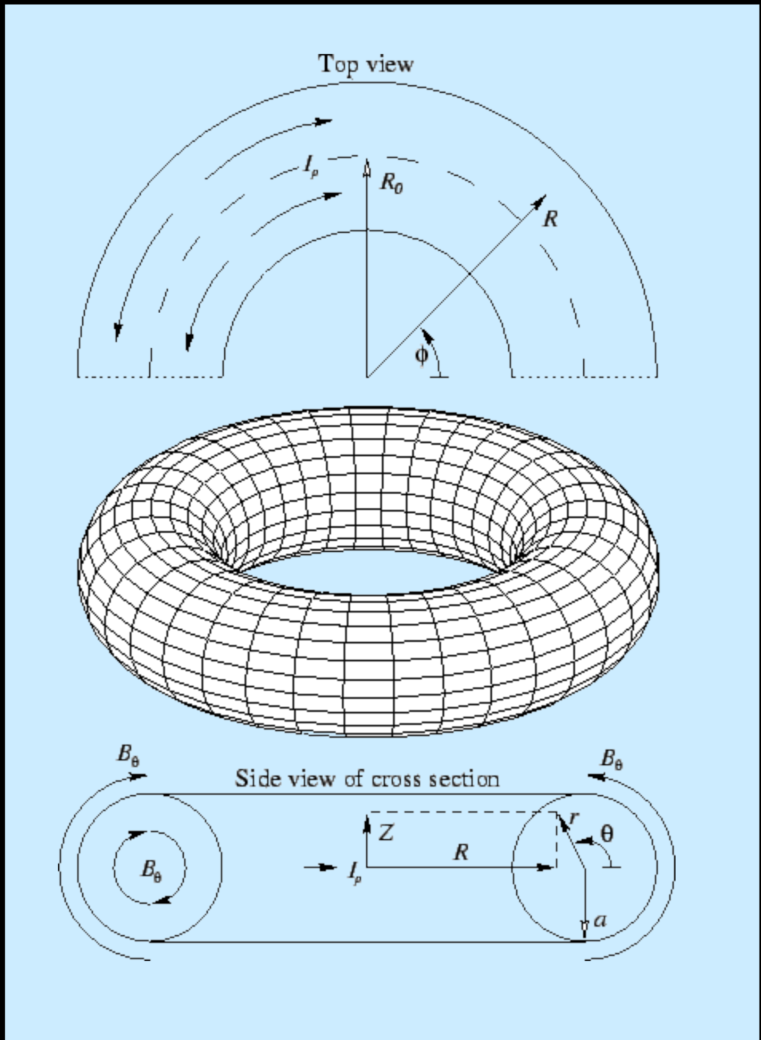
How shall we develop fusion power?



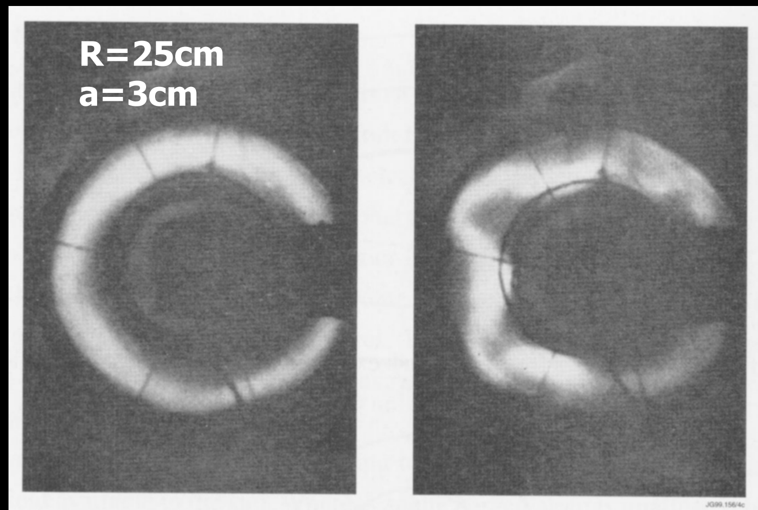
Stellarator – early 1950’s

The Pinch Effect - 1940's

Peter Thonemann and Sir George Thomson's idea

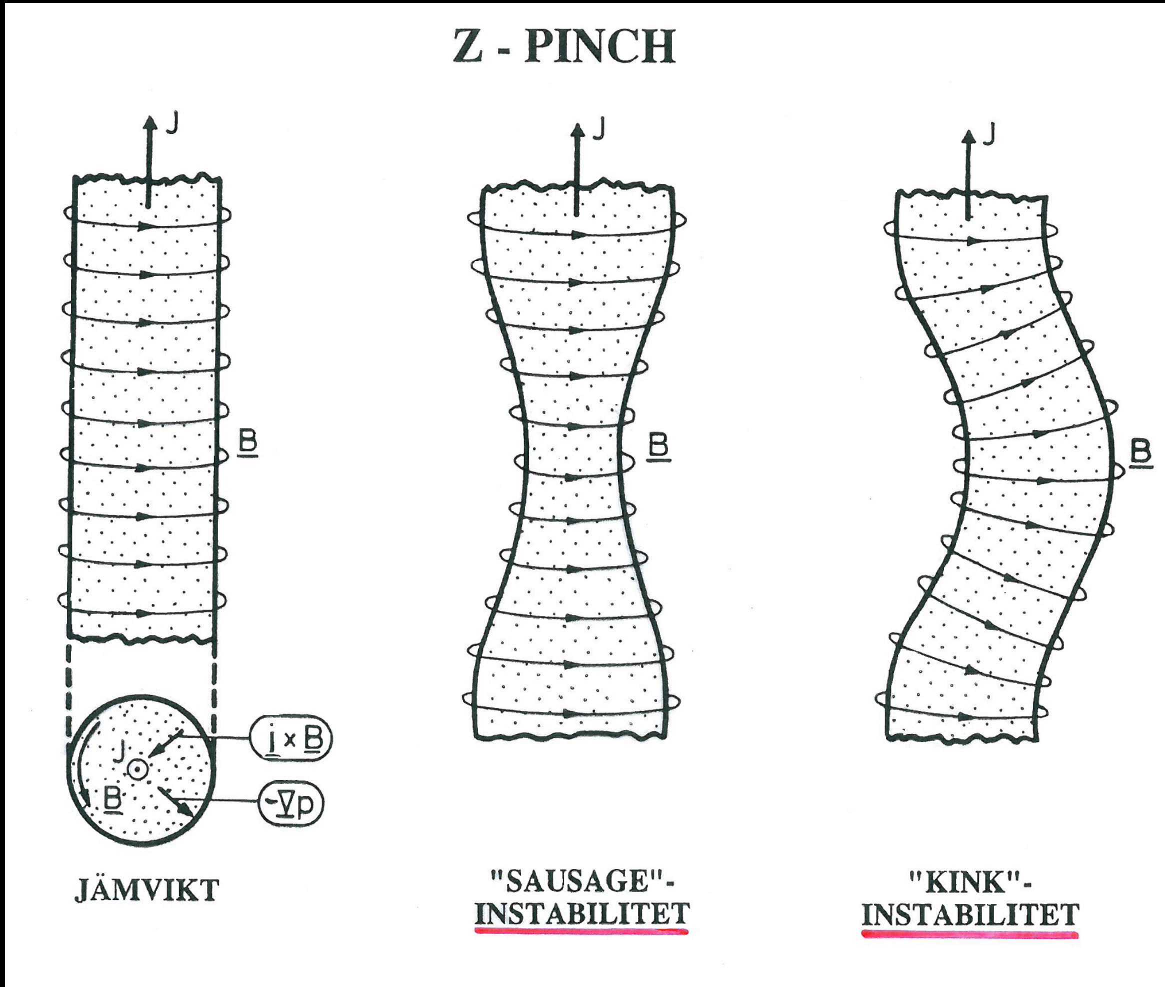


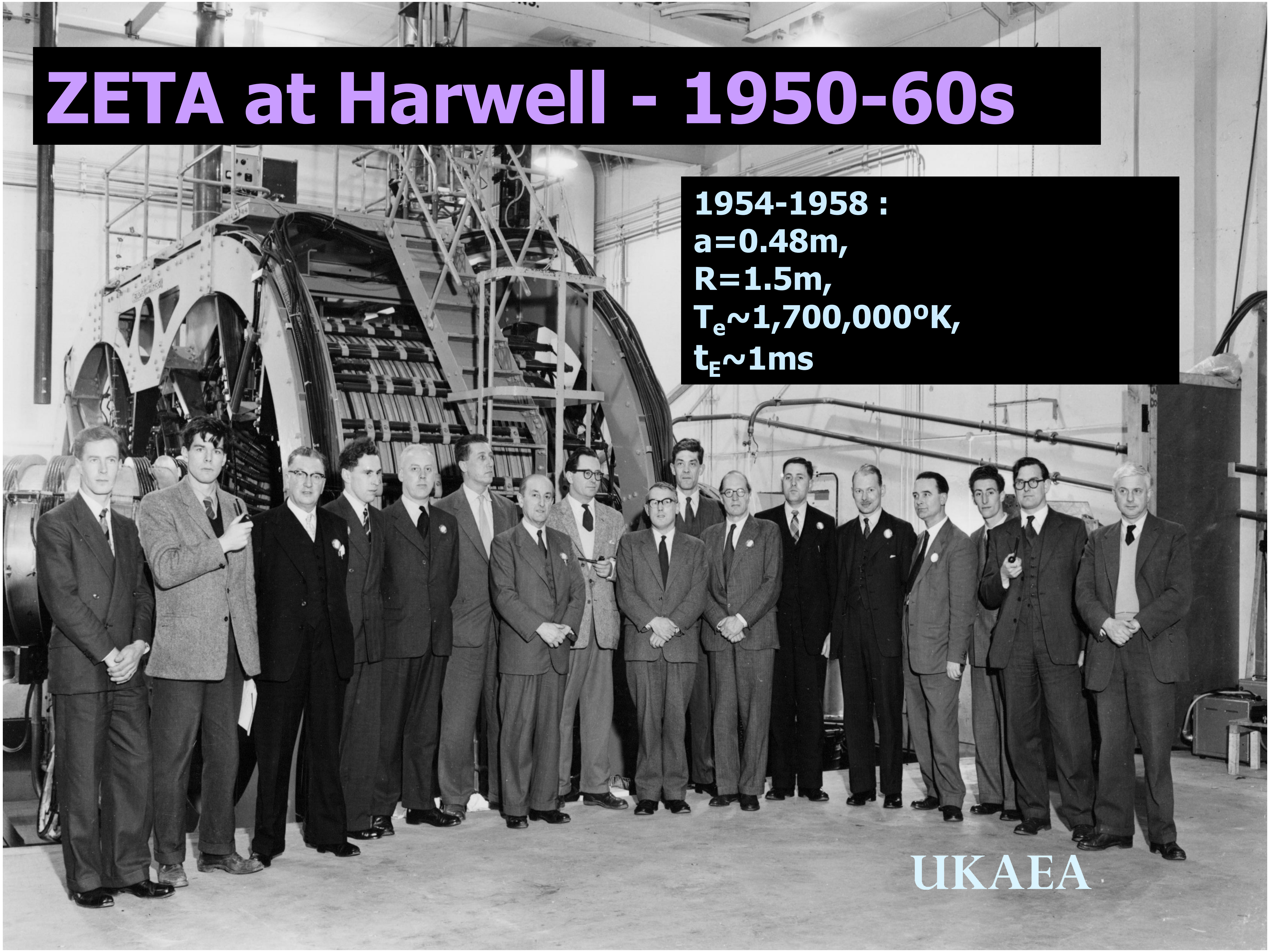
Alan Ware, Thomson Imperial College.



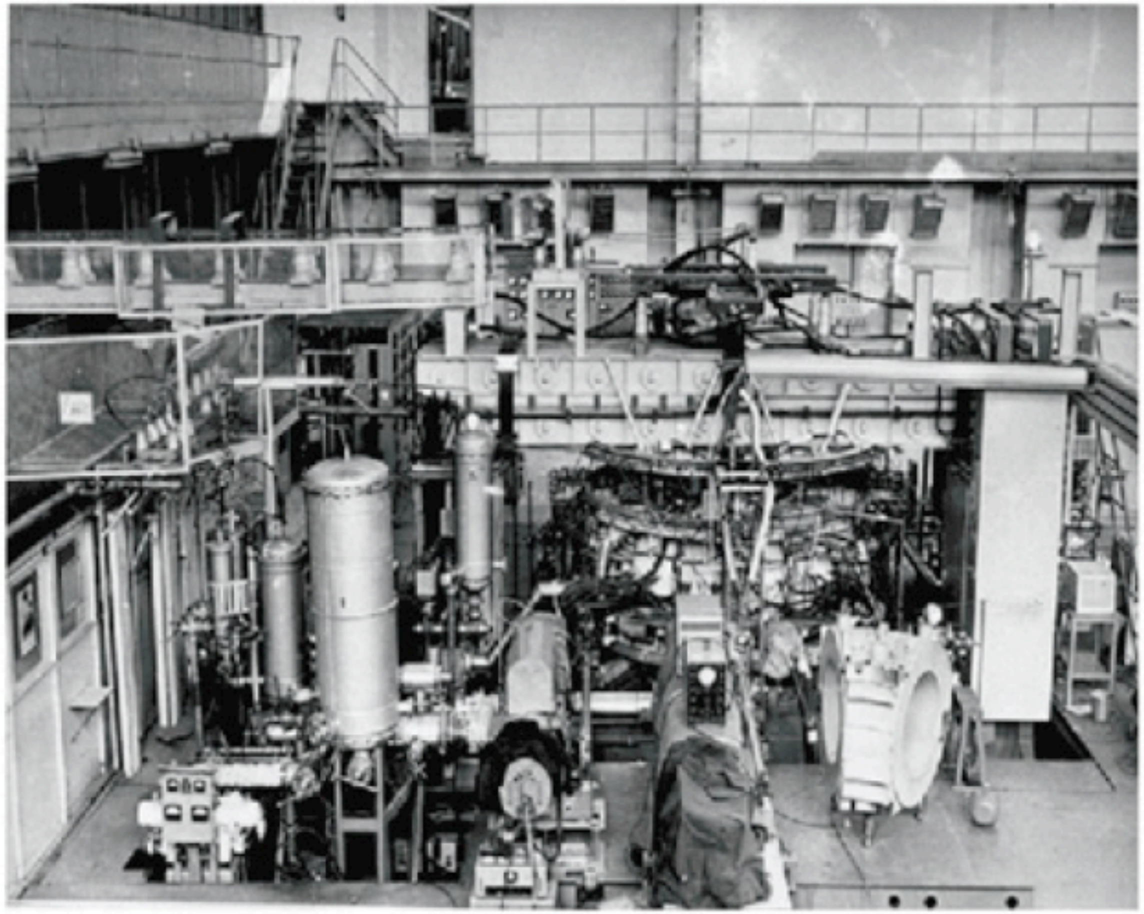
UKAEA

z-pinch instabilities




ZETA at Harwell - 1950-60s
1954-1958 :
a=0.48m,
R=1.5m,
T_e~1,700,000ºK,
t_E~1ms
UKAEA

The Tokamak- a Soviet invention



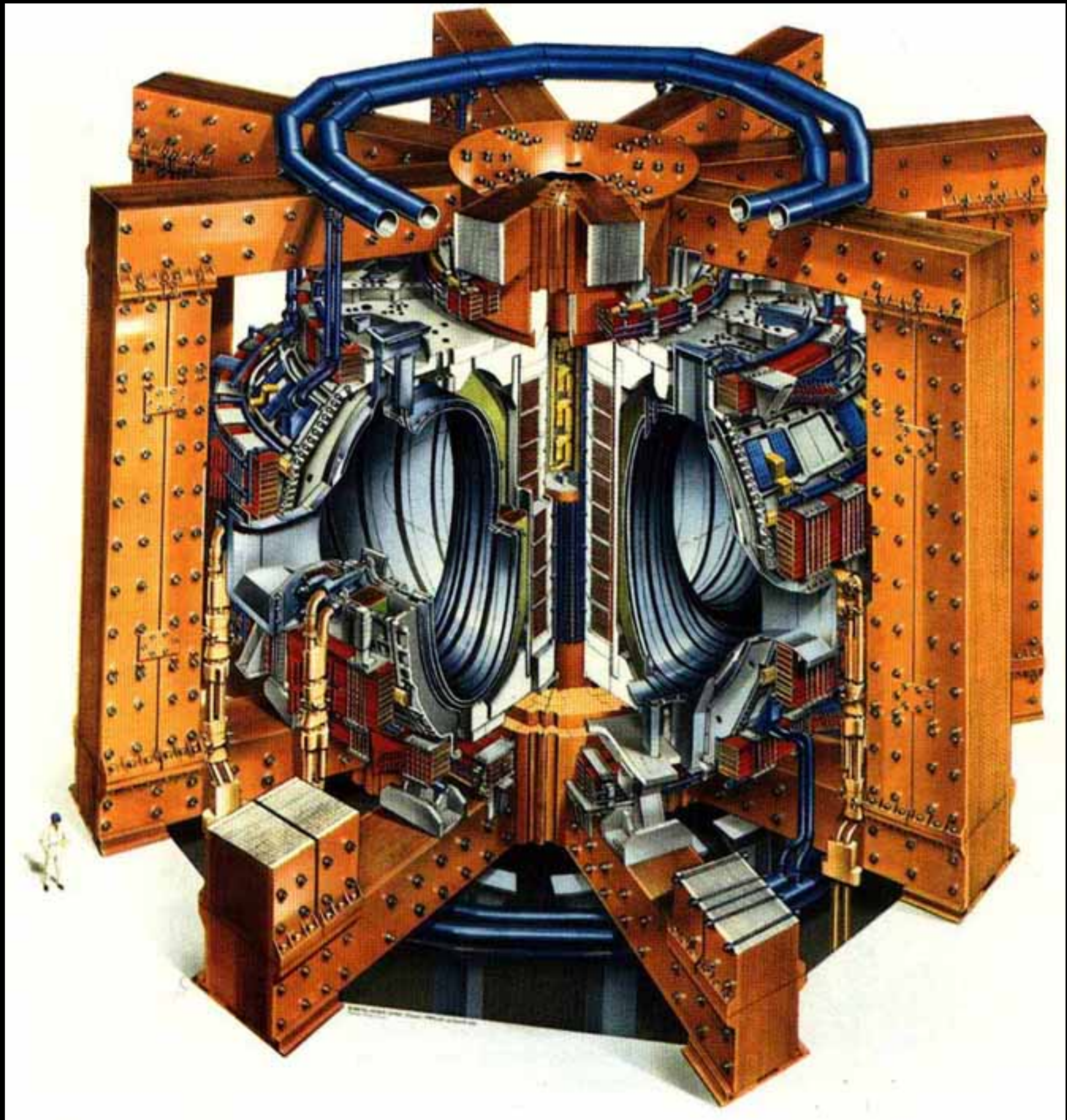
Tokamak T-3 (1962)
R = 1 m, a = 0,15 m, B = 3,8 T, I = 150 kA

Time:
1950-60

Place:
Moscow

Characteristic:
Strong magnetic field

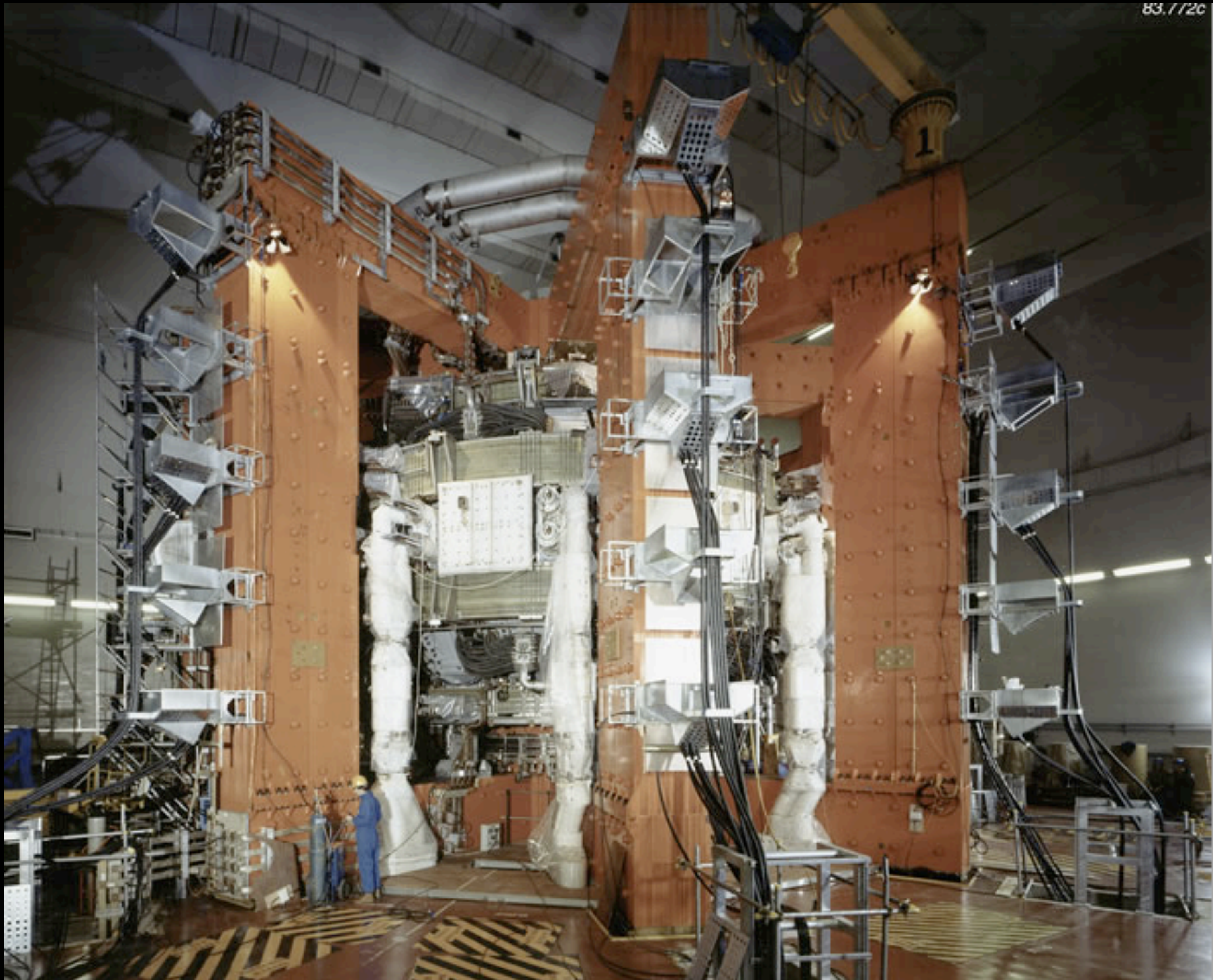
JET – the world's largest fusion experiment



Location:
Culham, England

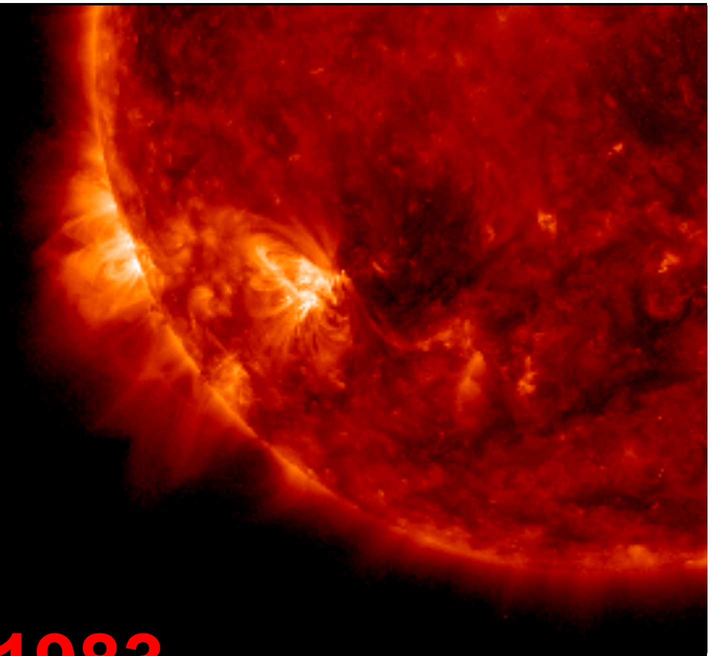
European project

JET – the world's largest fusion experiment



JET
Tokamak

Question

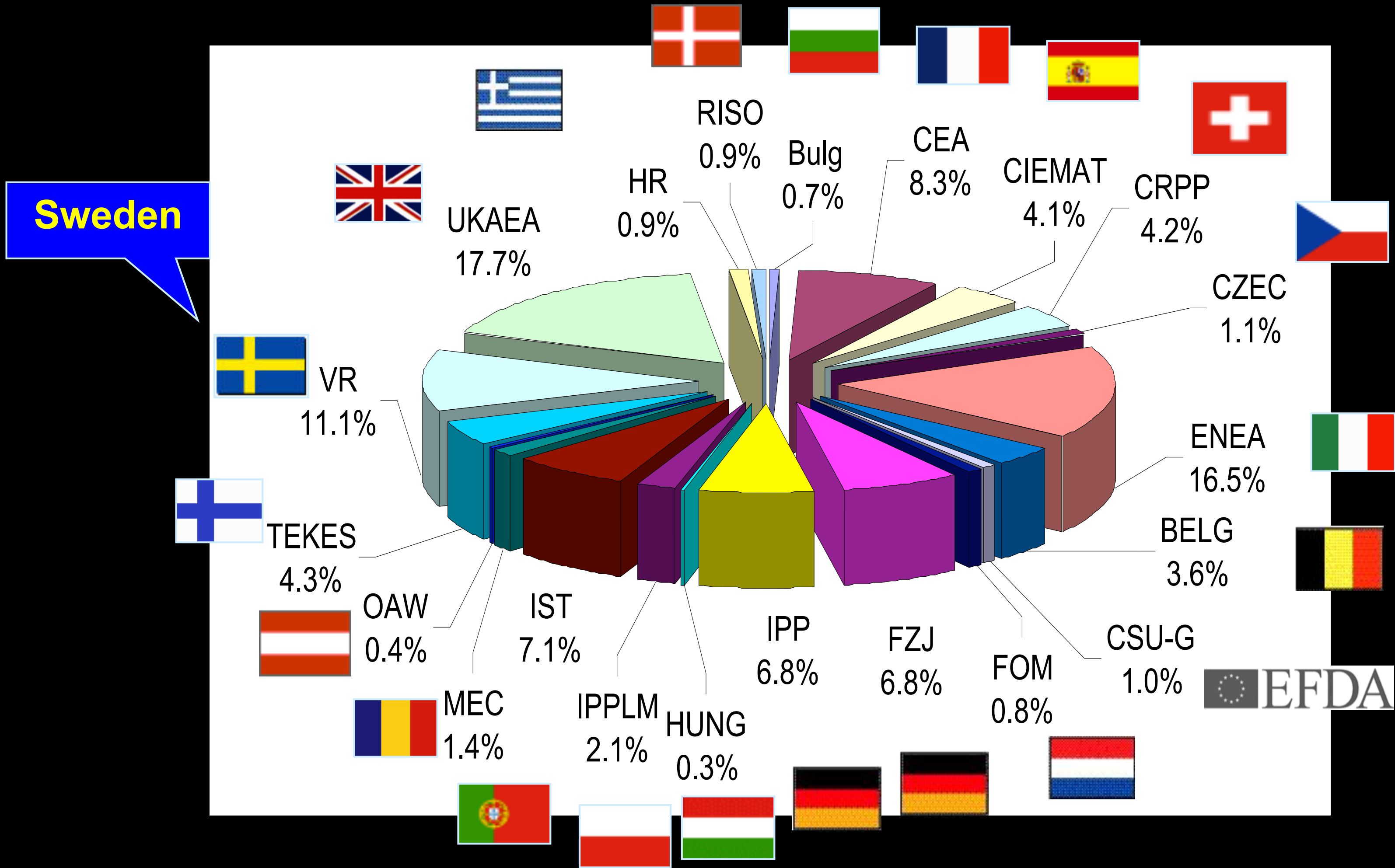


Which alternative is true?

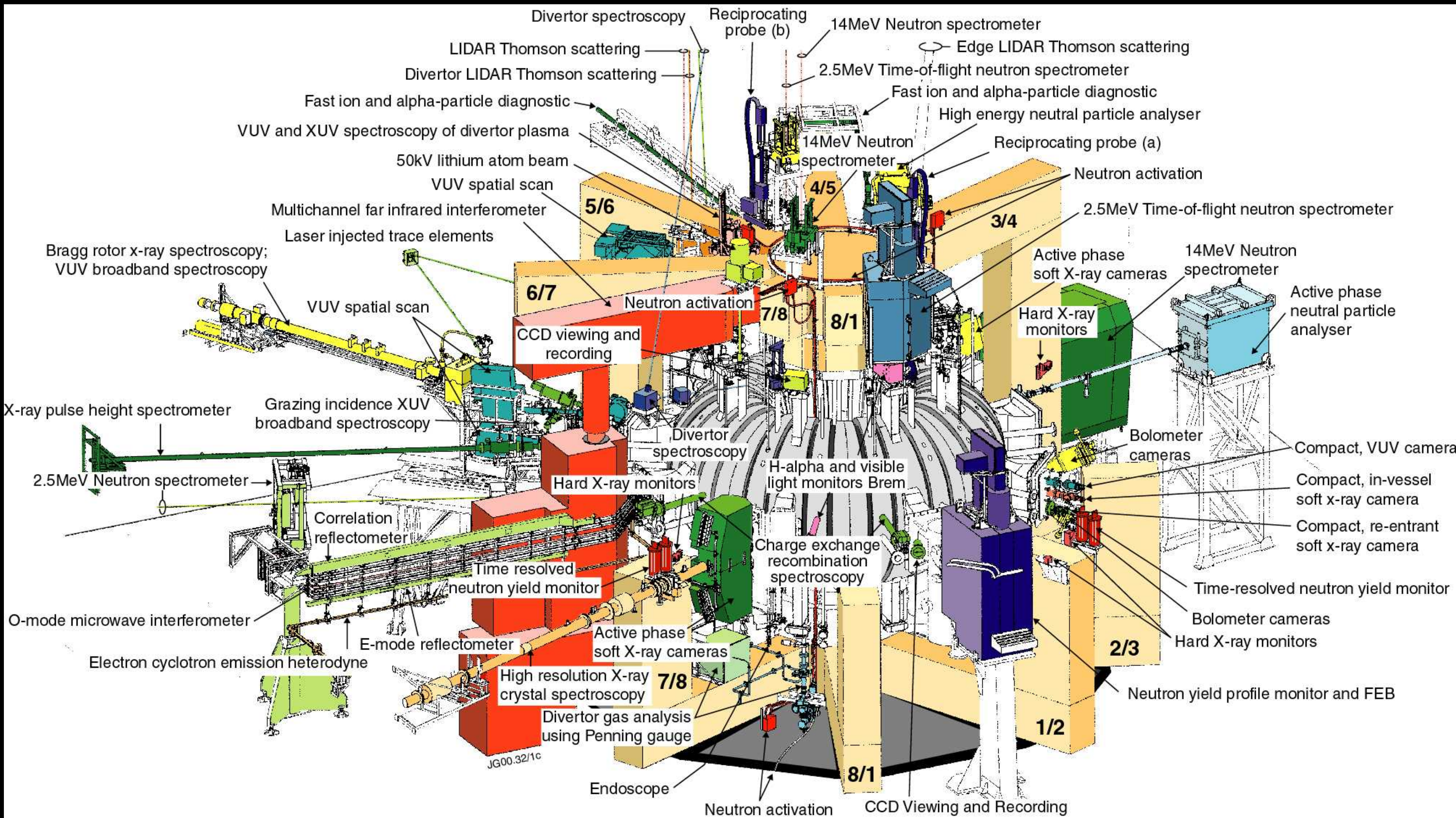
- First plasma at JET was in 1983
- JET has reached ignition
- JET routinely uses D-T plasma
- JET has superconducting coils

JET,
Culham,
England

Participation in the JET campaigns of late 2005 - 2006

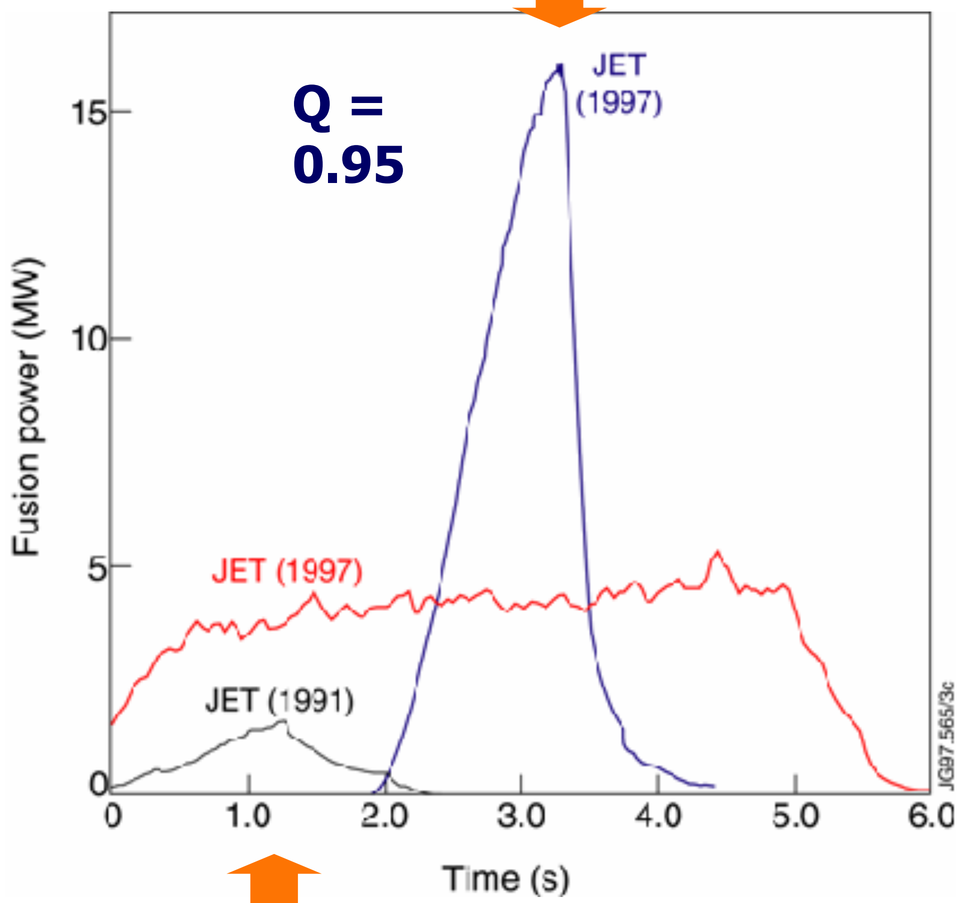


Diagnostics at JET



Demonstration in JET: production of fusion energy

16.2 MW
(World Record)



1.7 MW
(World First)

Heating

25 MW

2 s, Q=0.6

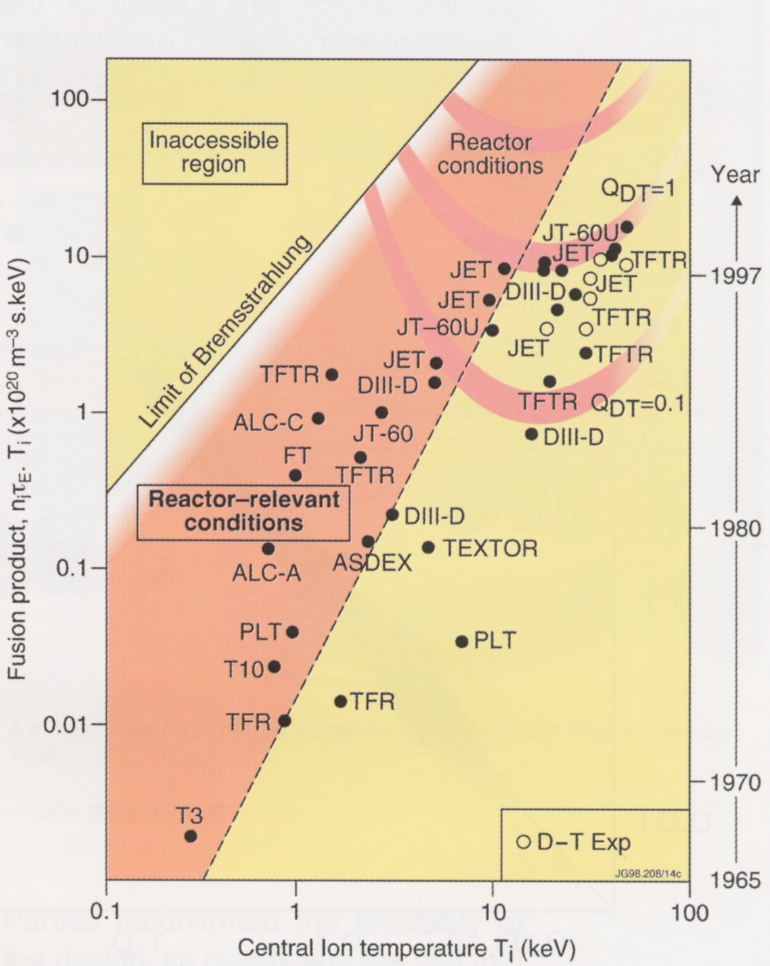
16 MW

Fusion Energy

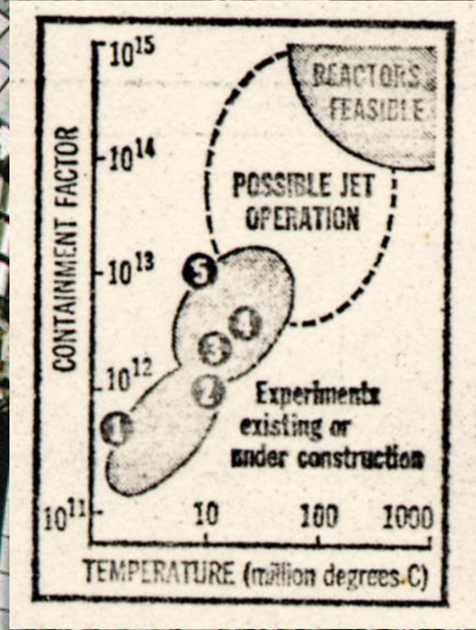
Success at JET

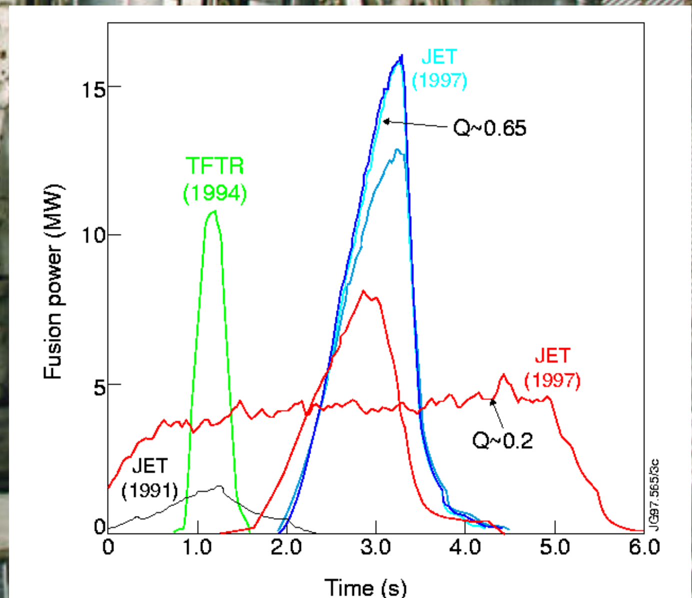
J94.43c

UKAEA



This plot shows how, over several decades of research, the key performance parameters of fusion devices (the plasma ion temperature and the fusion triple product) have moved towards the conditions required for a reactor.

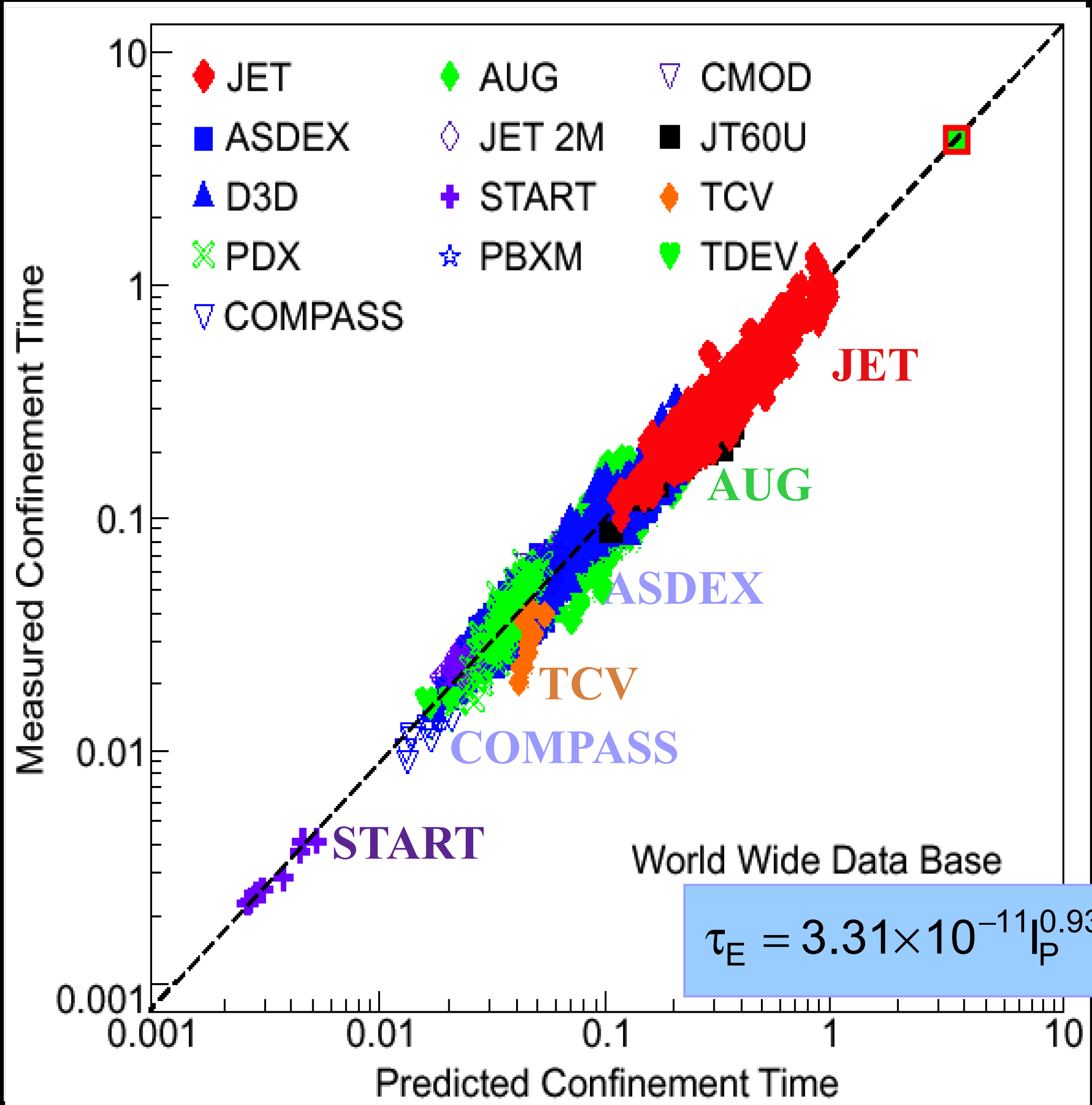




EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

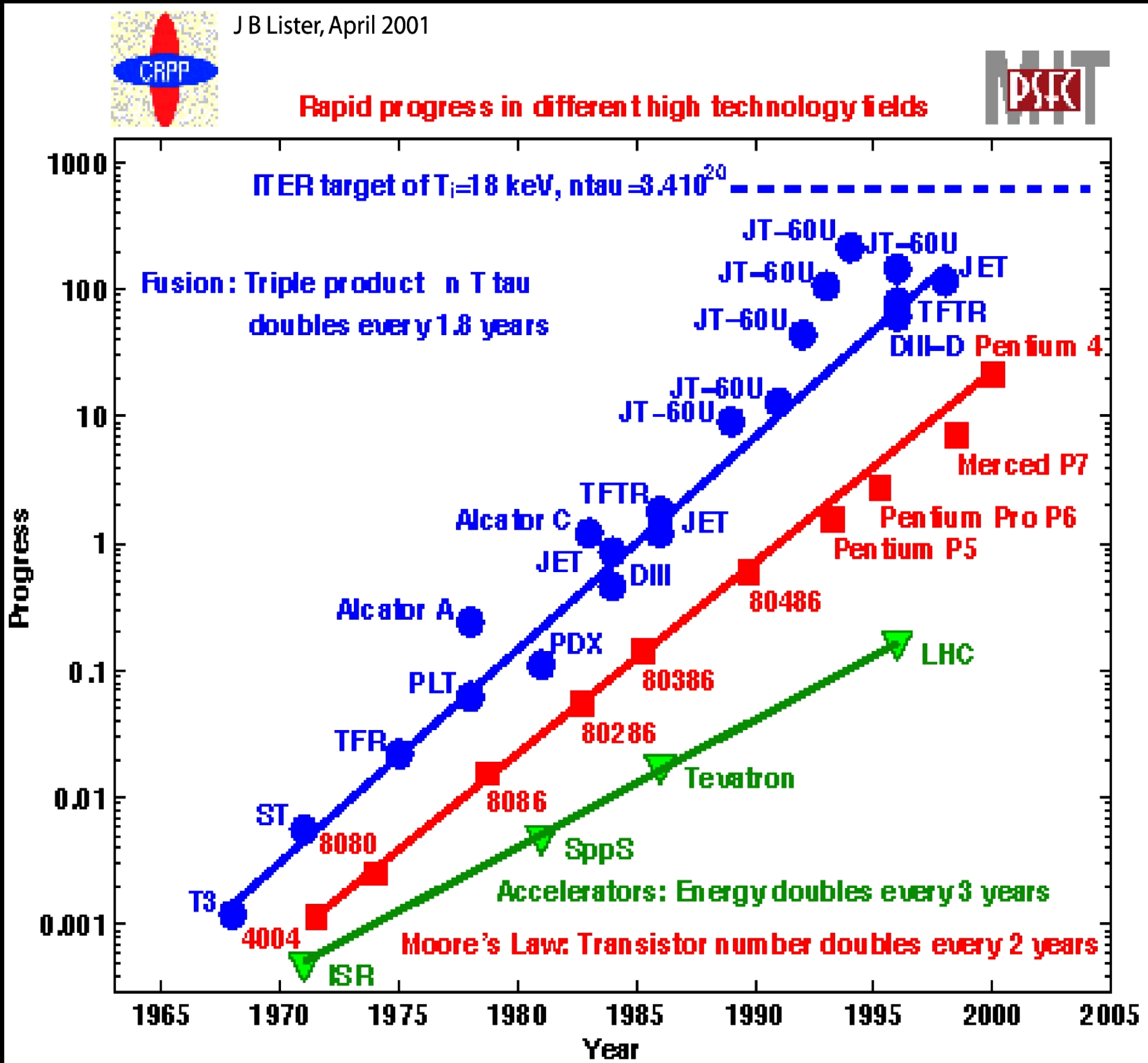
Progress in ITER like Scenario



$$\tau_E = 3.31\times10^{-11} I_P^{0.93} B^{0.15} P^{-0.69} R^{1.97} n^{0.41} M^{0.19} \varepsilon^{0.58} \kappa^{0.78}$$

Fusion devices in the EU make a major contribution to the databases for ITER

Fusion progress is comparable with other fields

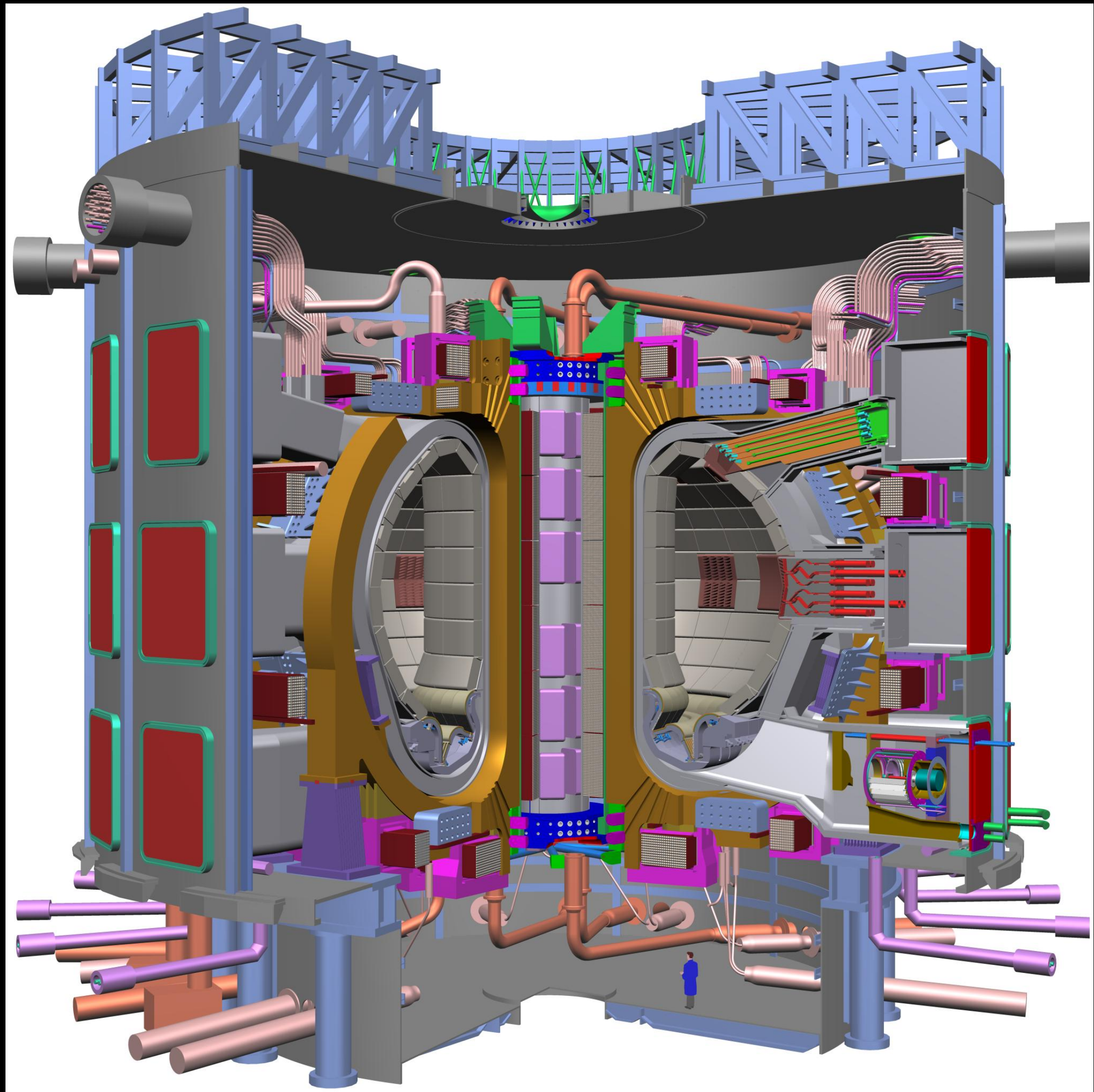


n = Density
a measure of the number of reactions we can have

T = Temperature
a measure of the energy given to the fuel particles

τ = Confinement time
a measure of the thermal insulation of the fuel

ITER – nest step towards fusion



Location:
Cadarache, France

Collaboration:
EU
China
Japan
Russia
South Korea
India
USA

History of ITER

"For the benefit of mankind"

The idea for ITER originated from the Geneva Superpower Summit in 1985 where Gorbachev and Reagan proposed international effort
to develop fusion energy…

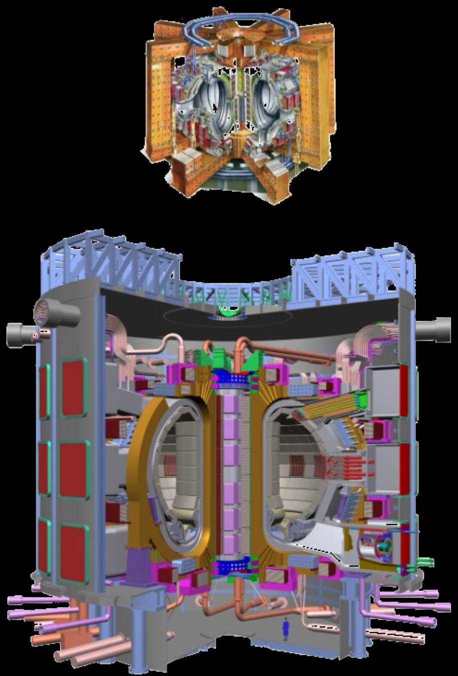
…"as an inexhaustible source of energy for the benefit of mankind".

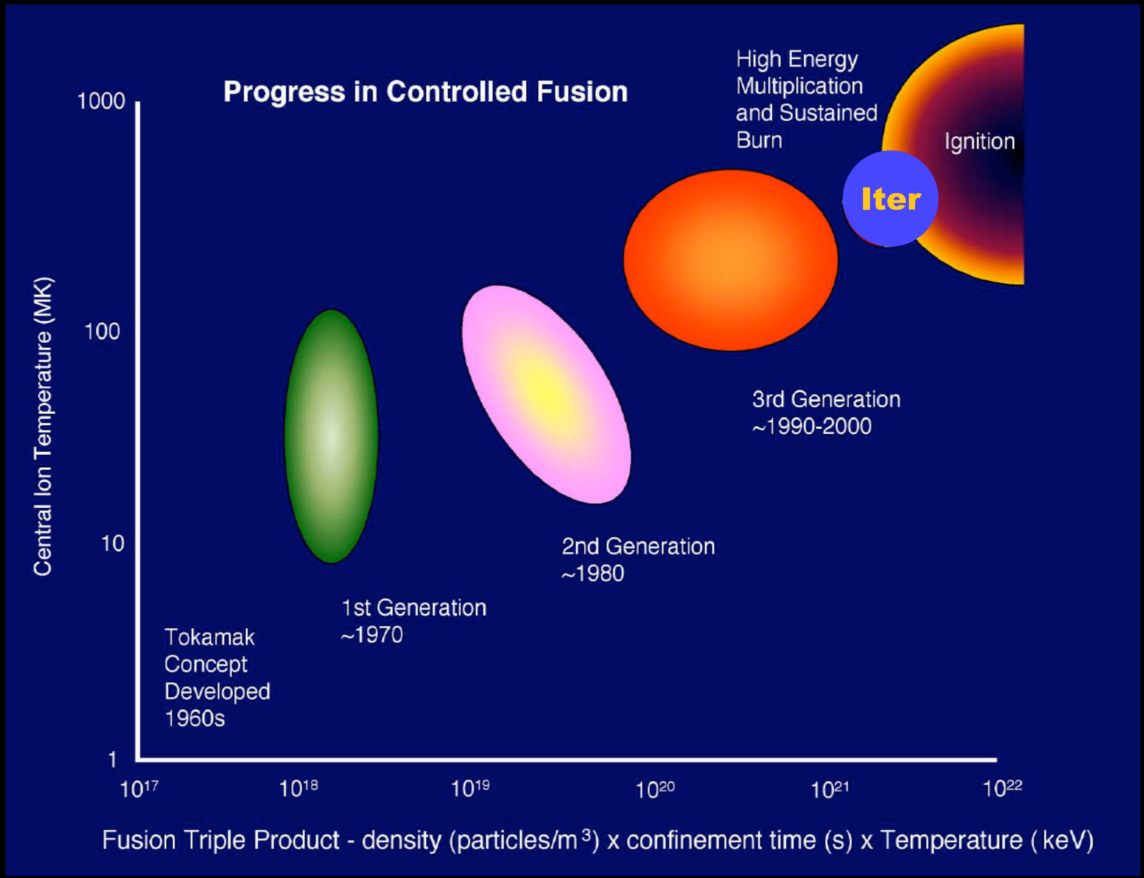
November 21, 2006: China, Europe, India, Japan, Korea, the Russian Federation and the United States of America sign the ITER Agreement

ITER progress

ITER represents a big step in fusion research but is in line with the continuous progress over the years

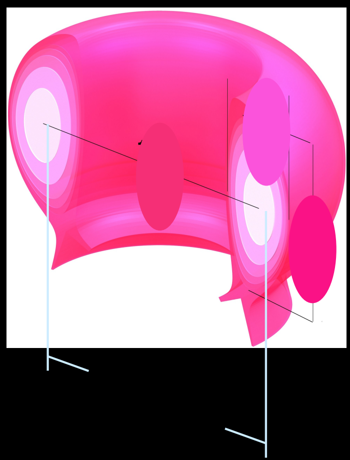
More than double the size of JET



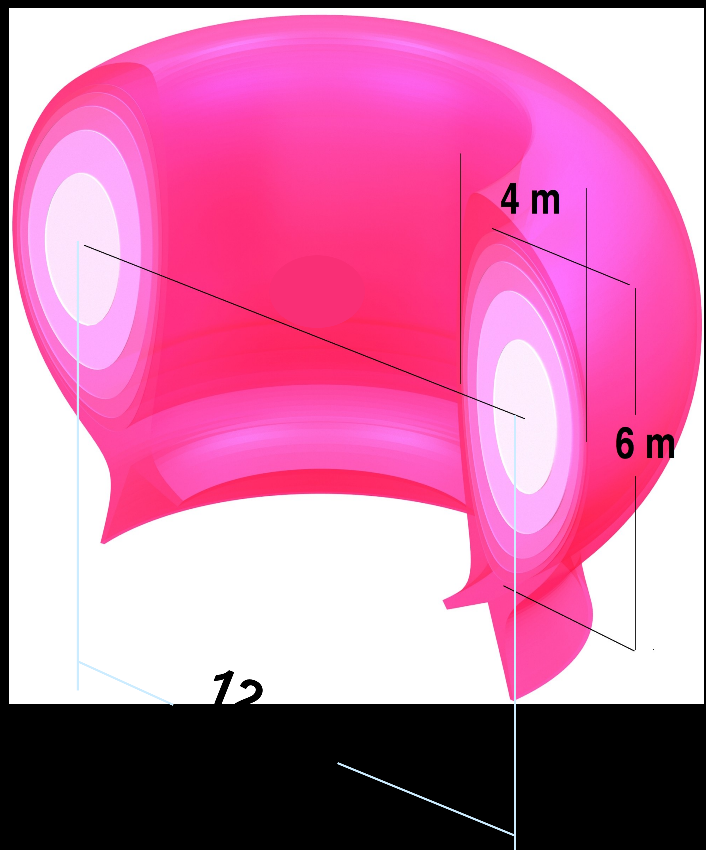


Comparison JET - ITER

JET



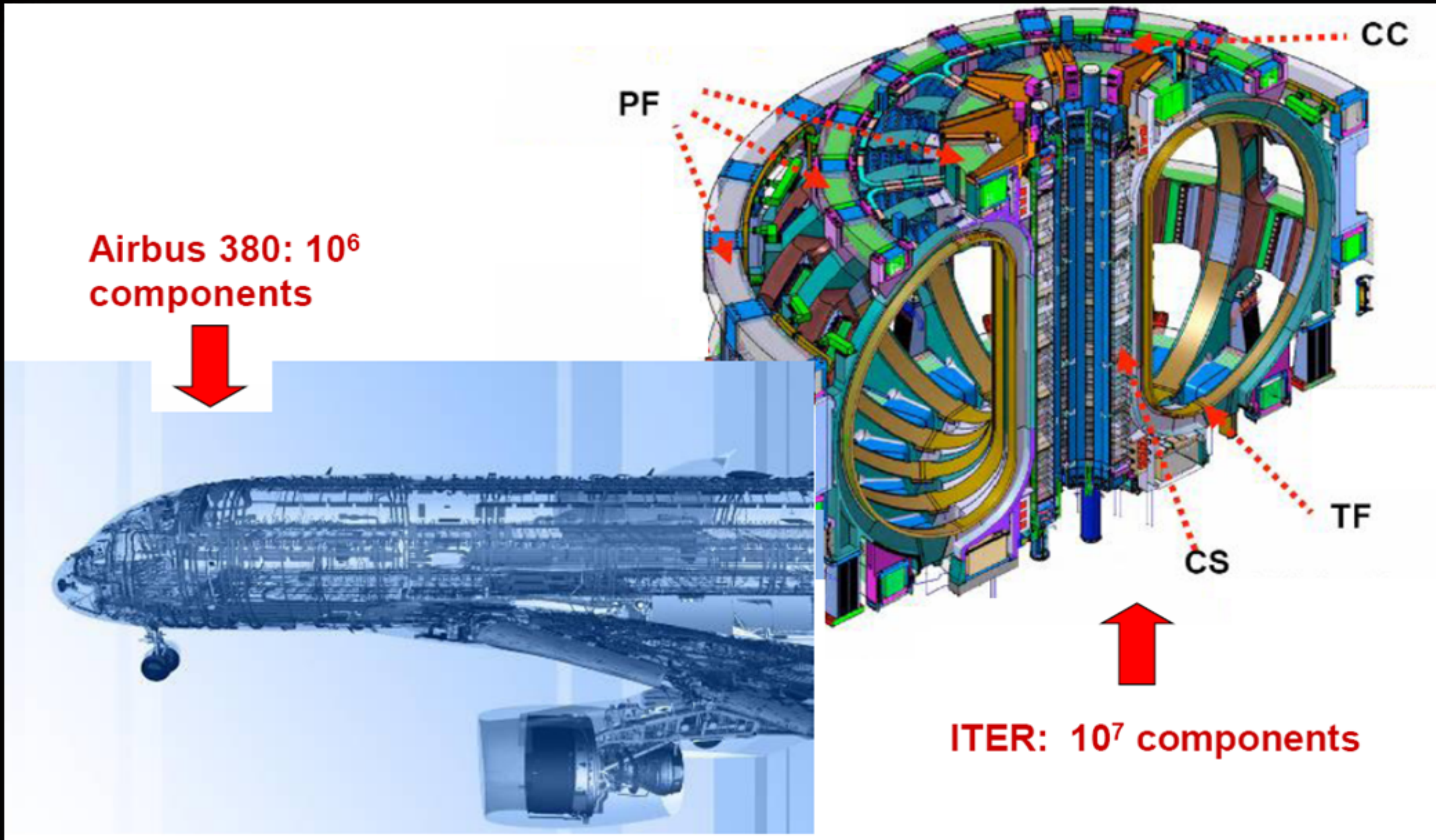
ITER



ITER - Goals

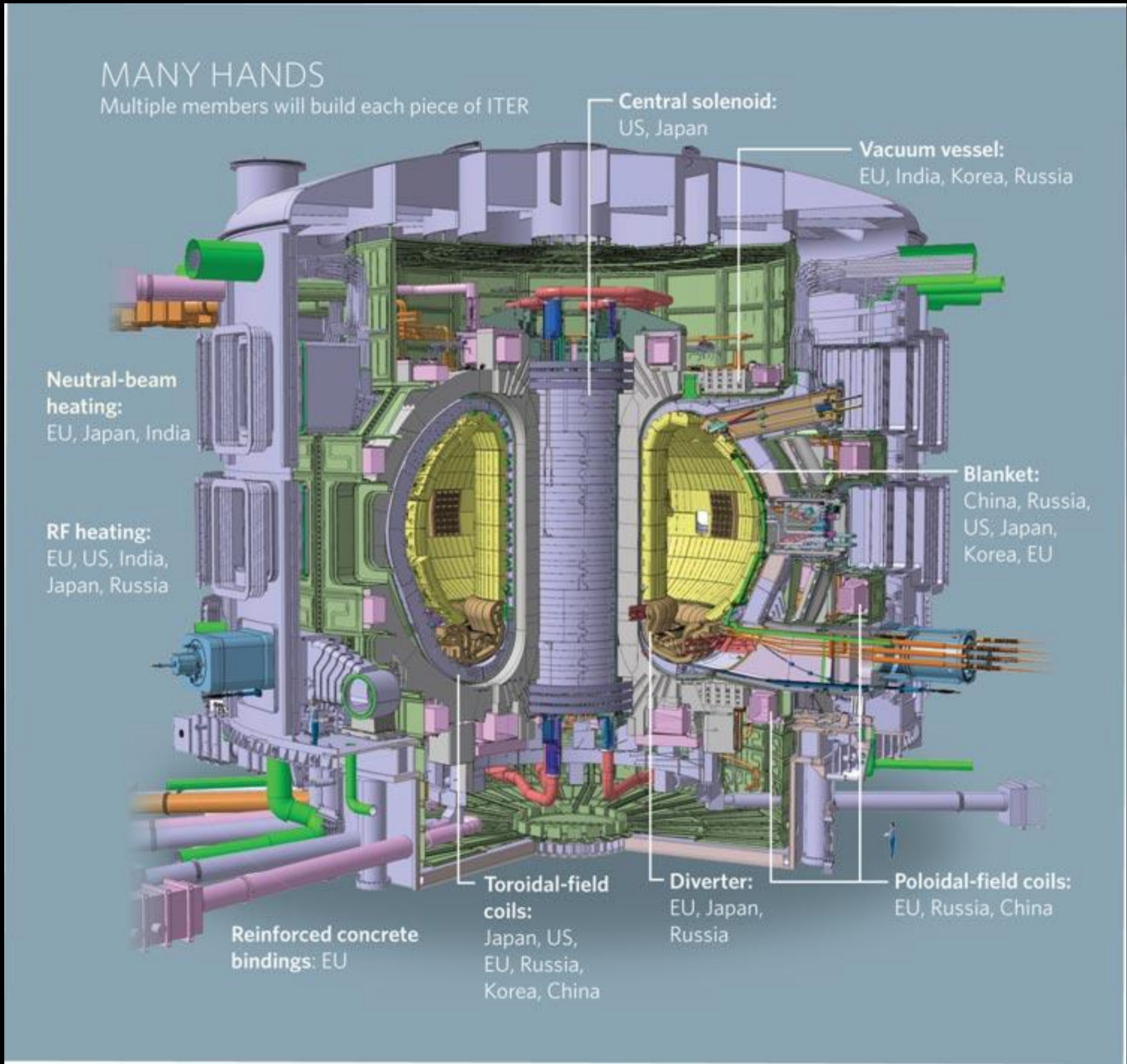
- Produce 500 MW fusion power.
  (10 times more power than what is needed to run the experiment).
- Smaller than a power station but big enough to prove principle.
- Optimize plasma physics.
- Test technology that is needed for a power station (*exception: materials*).
- In operation: for 20 years.

Integration - Engineering



Courtesy CIEMAT

ITER – next step towards fusion



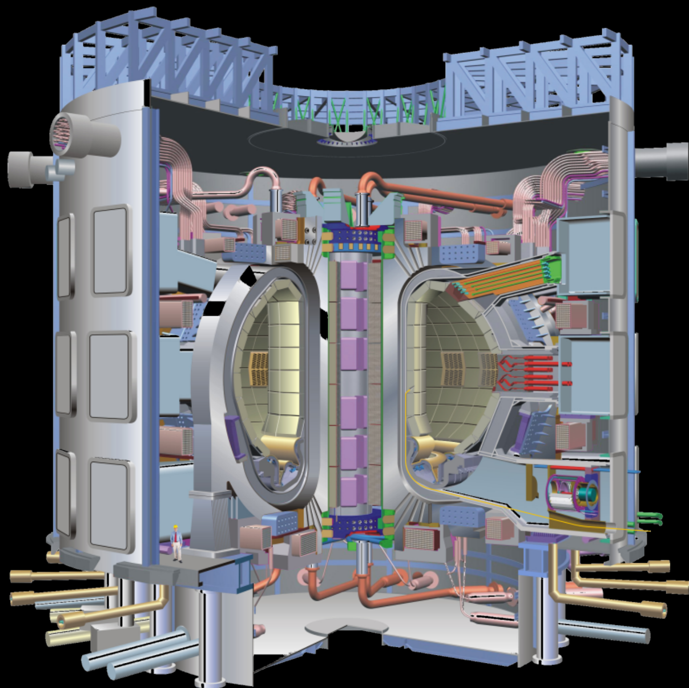
Location:
Cadarache, France

Collaboration:
EU
China
Japan
Russia
South Korea
India
USA

ITER

-A drone's view, January 2017

https://www.youtube.com/watch?v=1-xejqkjf_c



Europe provides through
Fusion For Energy (http://fusionforenergy.europa.eu)

45 % of ITER construction costs

34 % of operation, deactivation, decommissioning

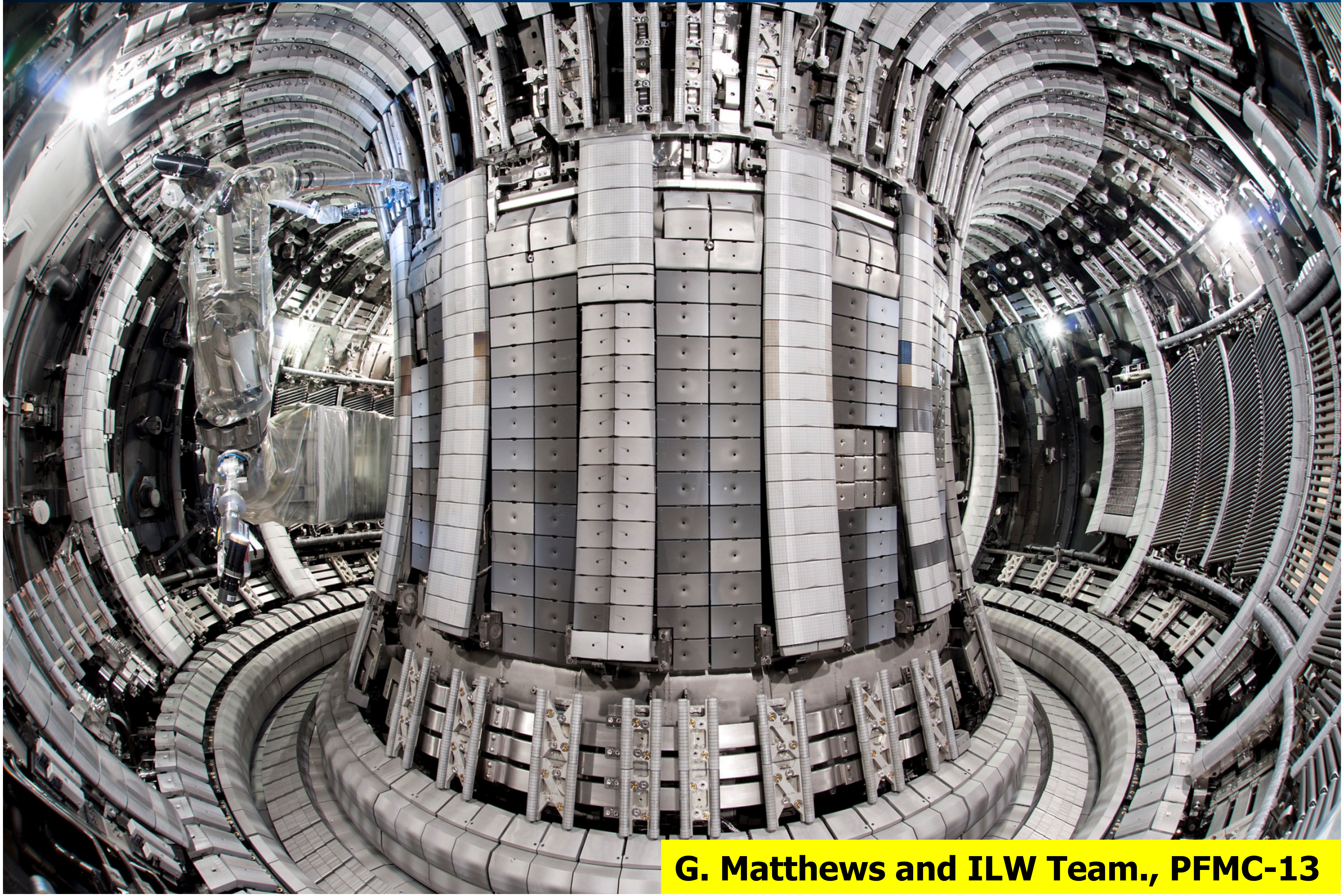
EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

ITER
Wall sector

Experiments at JET prepare for ITER

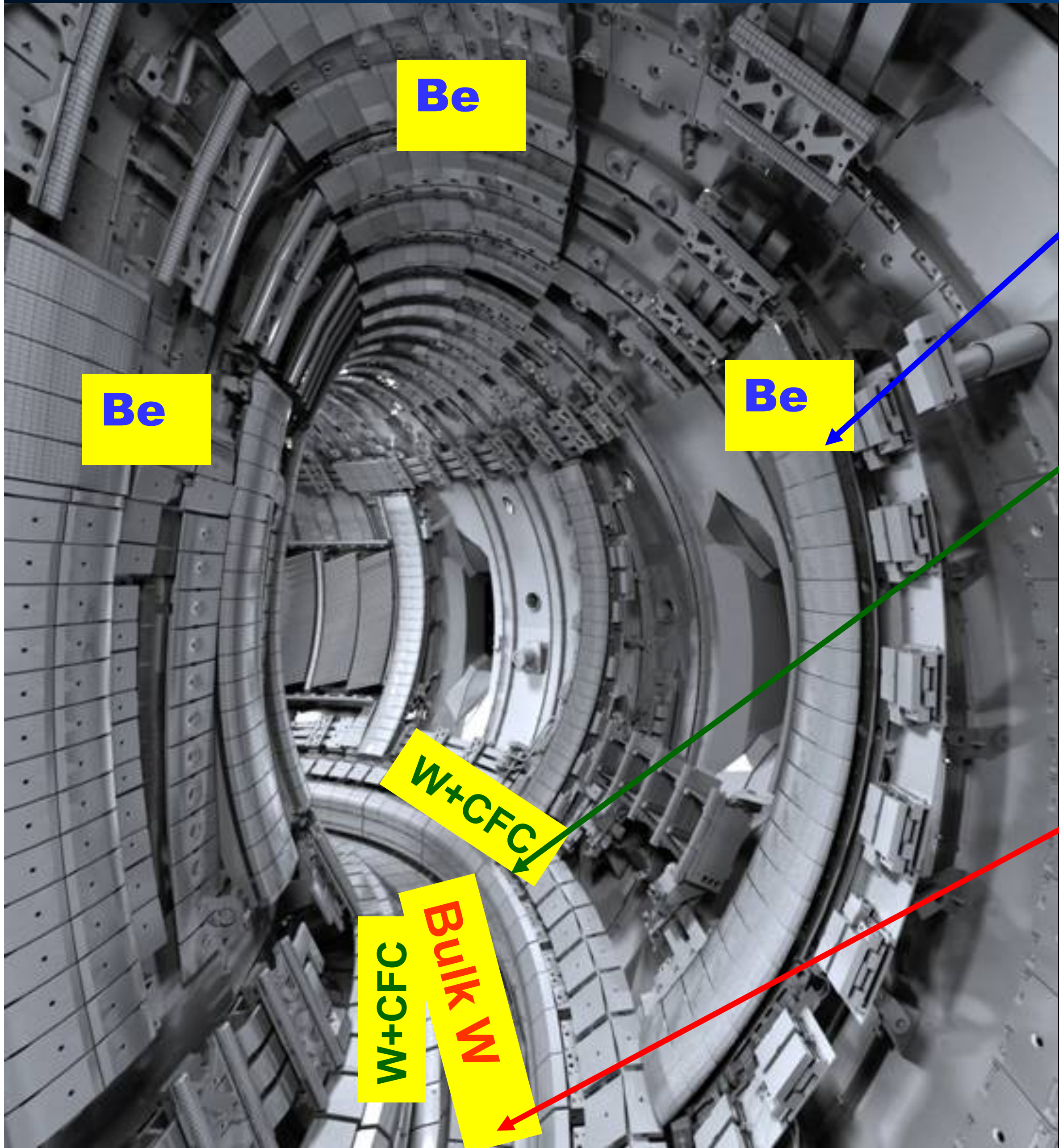
ITER – like wall
has been installed

The ITER-Like Wall: May 8, 2011



G. Matthews and ILW Team., PFMC-13

The ITER-Like Wall: Operation limits



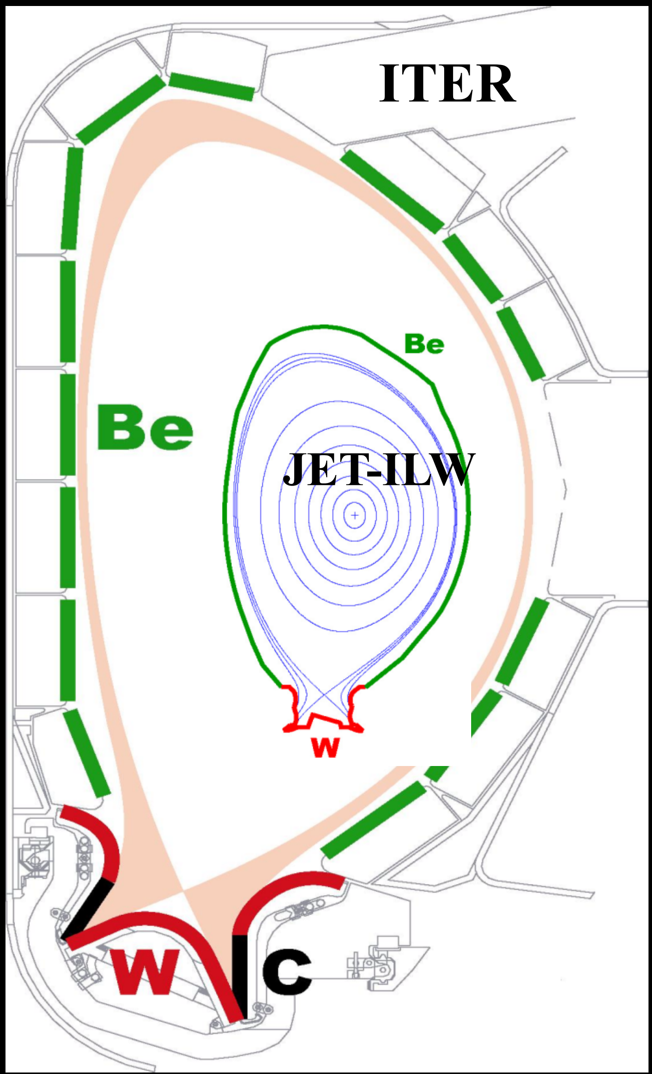
Solid Be
Surface temperature < 900°C

W-coated CFC
Temperature <1200°C

W stacks
Surface temperature limit
<1200°C-2200°C

G. Matthews and ILW Team

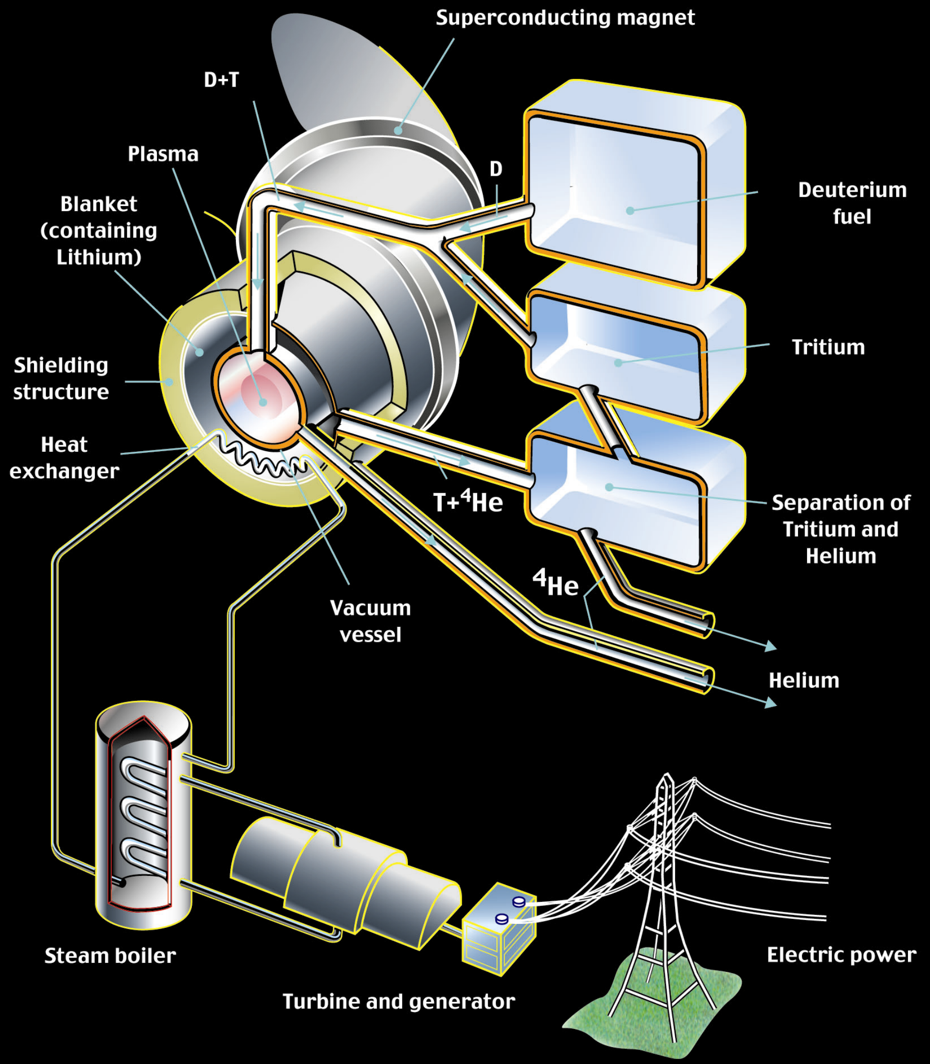
ITER-Like Wall at JET



All W divertor & Be wall

- Minimises risk of contamination by carbon.
- Compatibility of JET with beryllium and tritium.

Fusion power station

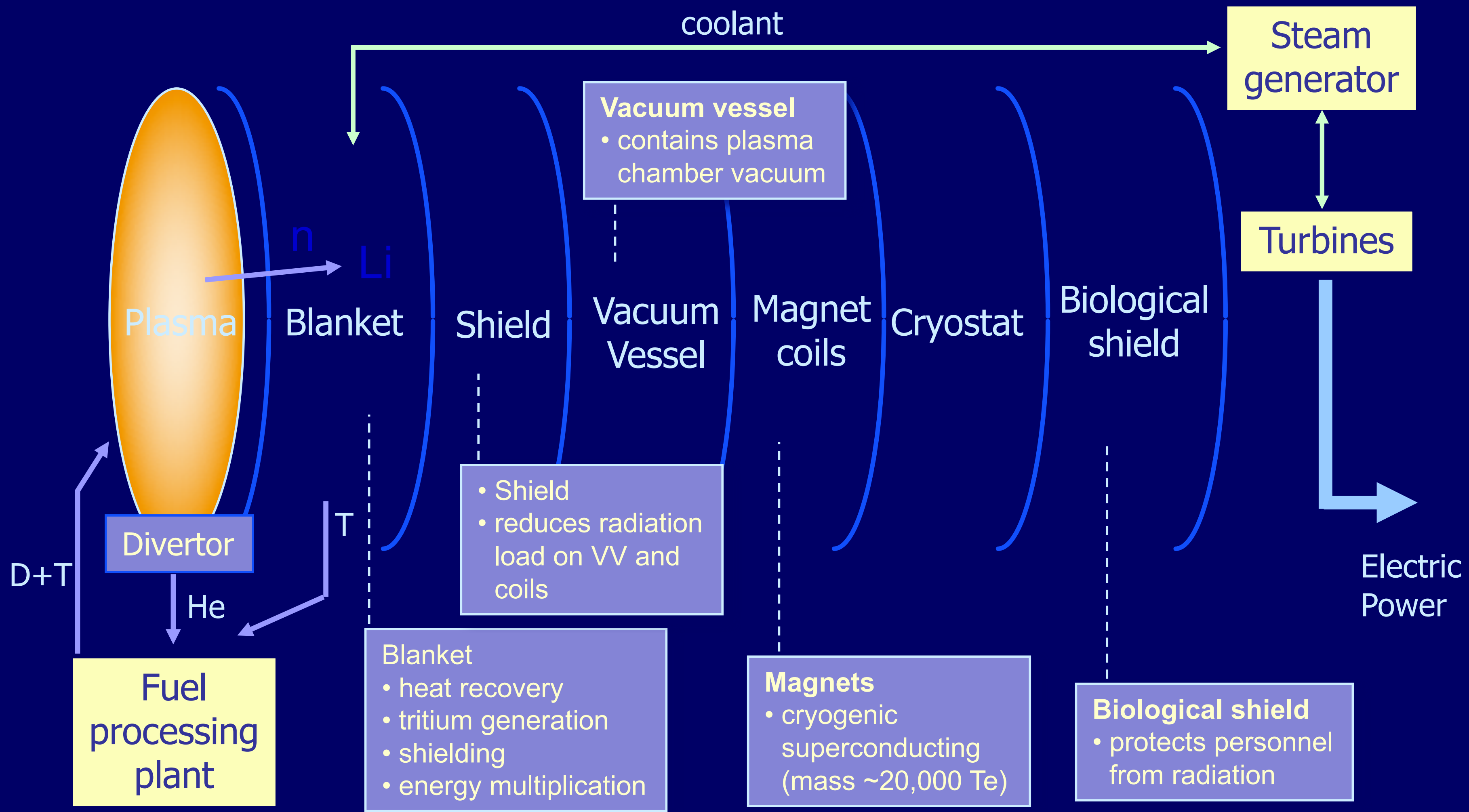


Blanket, containing lithium, captures energetic neutrons from the fusion reactions.

Blanket serves two purposes:

- **Hot cooling water provides steam for turbines and generators**
- **Neutrons and lithium combine to tritium which, together with deuterium, is the fuel**

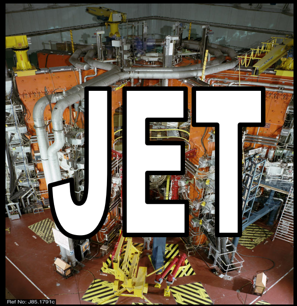
Fusion Power Plant operation



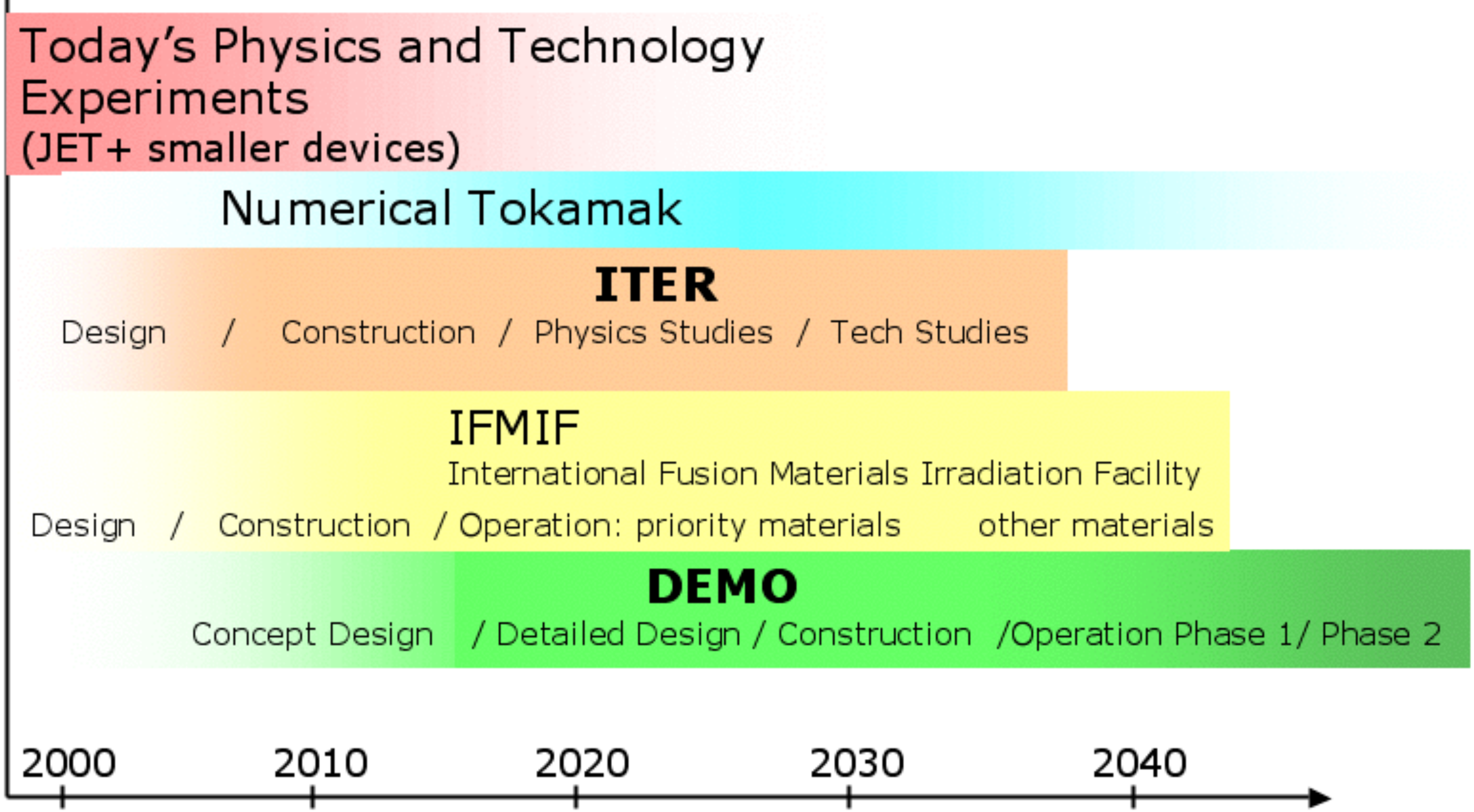
UKAEA

Fusion Working with Europe

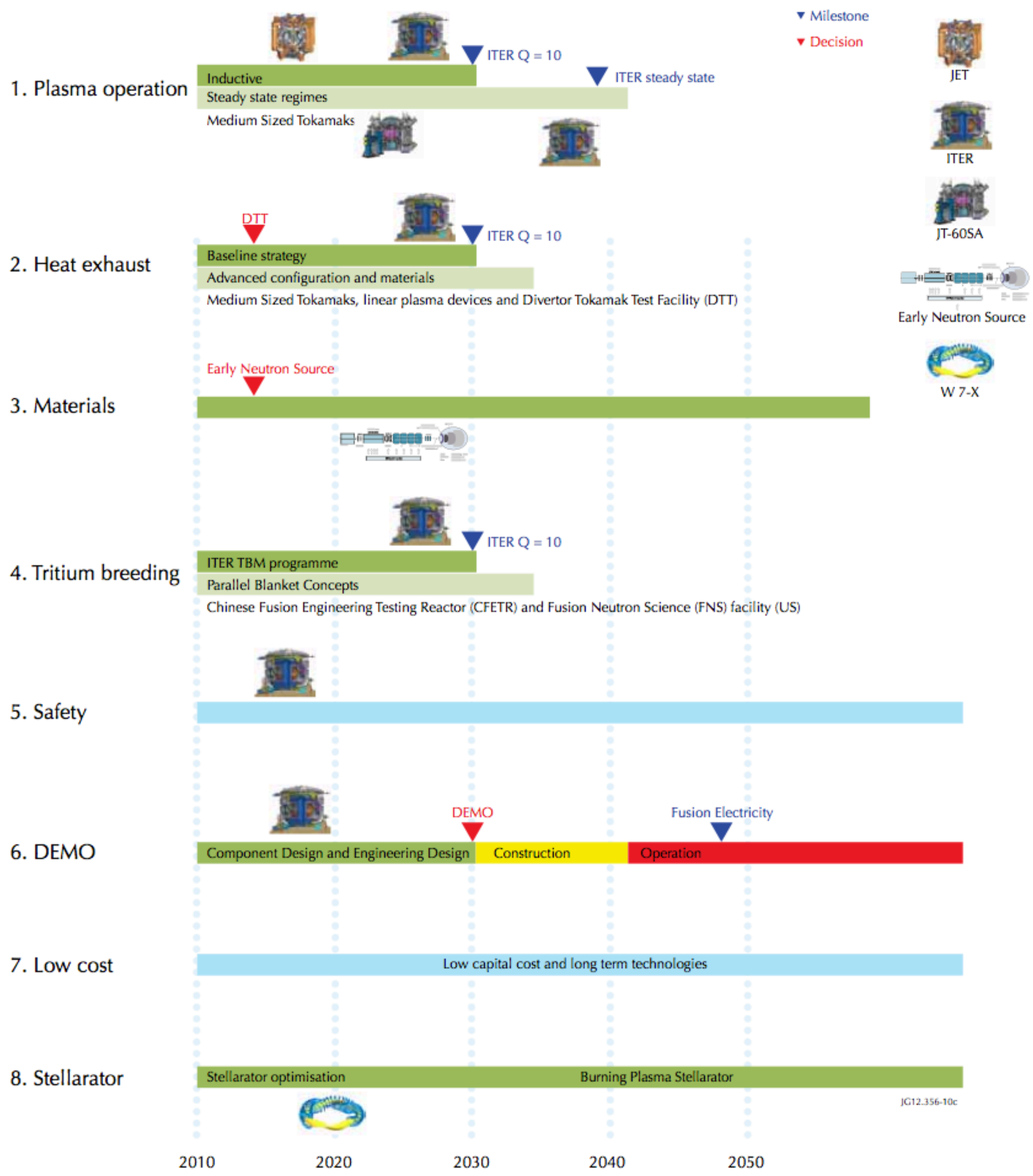
Development of fusion energy

	When?	Fusion power	Pulse length	Q
	1997	16MW	10 seconds	0.65
	2017-2020	500-700MW	30 minutes	10
	2030/40	1.5-2GW	days/stationary	30

Roadmap – Fast Track

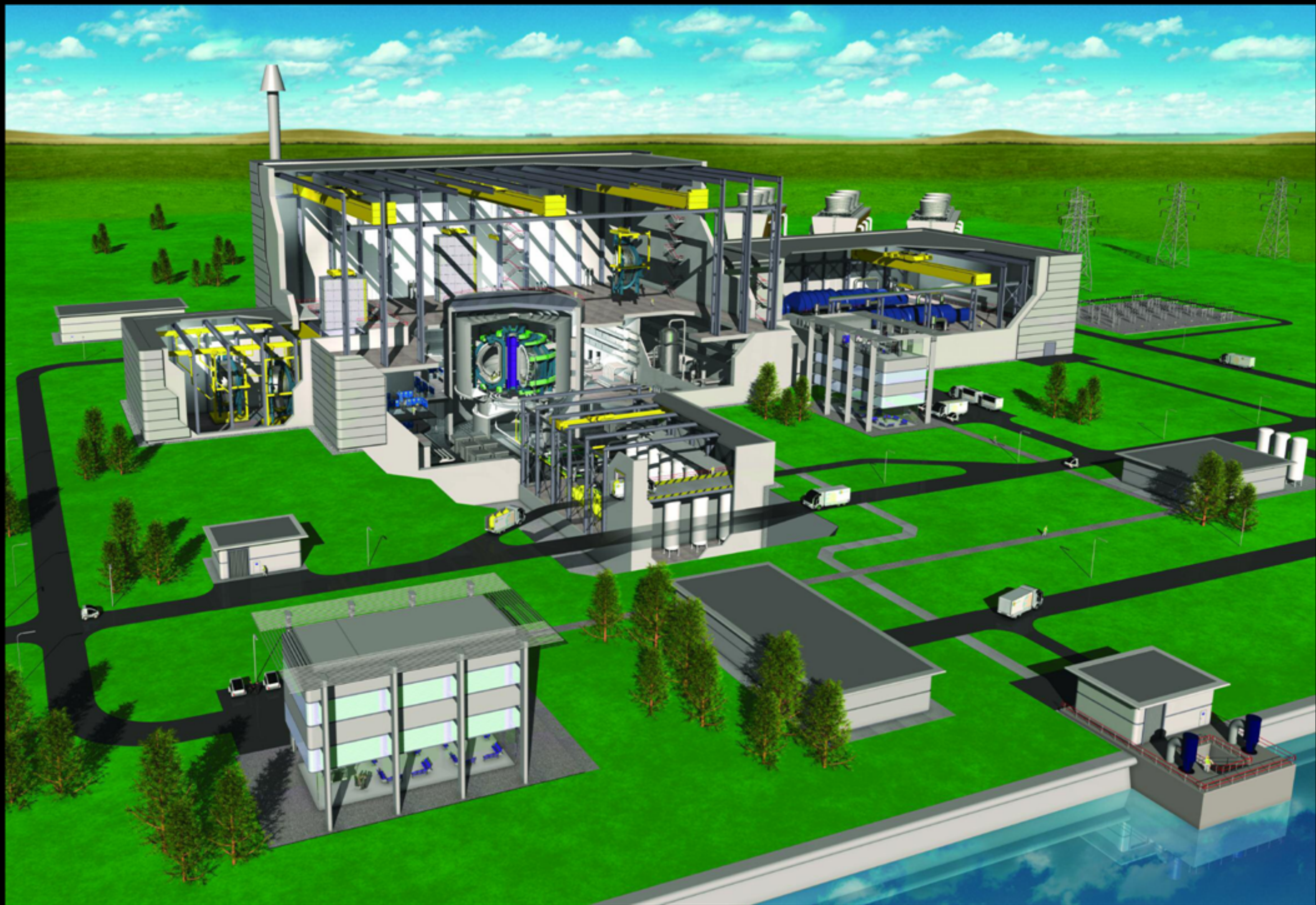


Fusion Roadmap



The missions to the realisation of fusion electricity

A fusion power station of the future



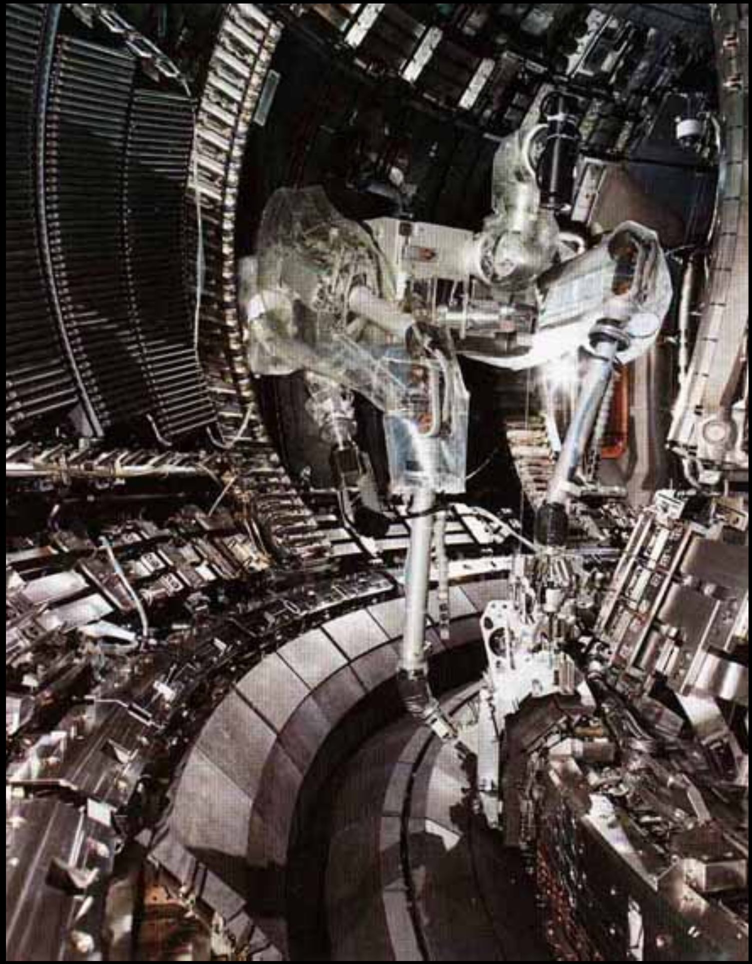
Fusion: safety and environmental issues

- **T-fuel is radioactive** (beta decay, 12 y halftime, extremely unlikely loss of 1 kg T causes however only 50 mSv 1 km away; evacuation not needed)

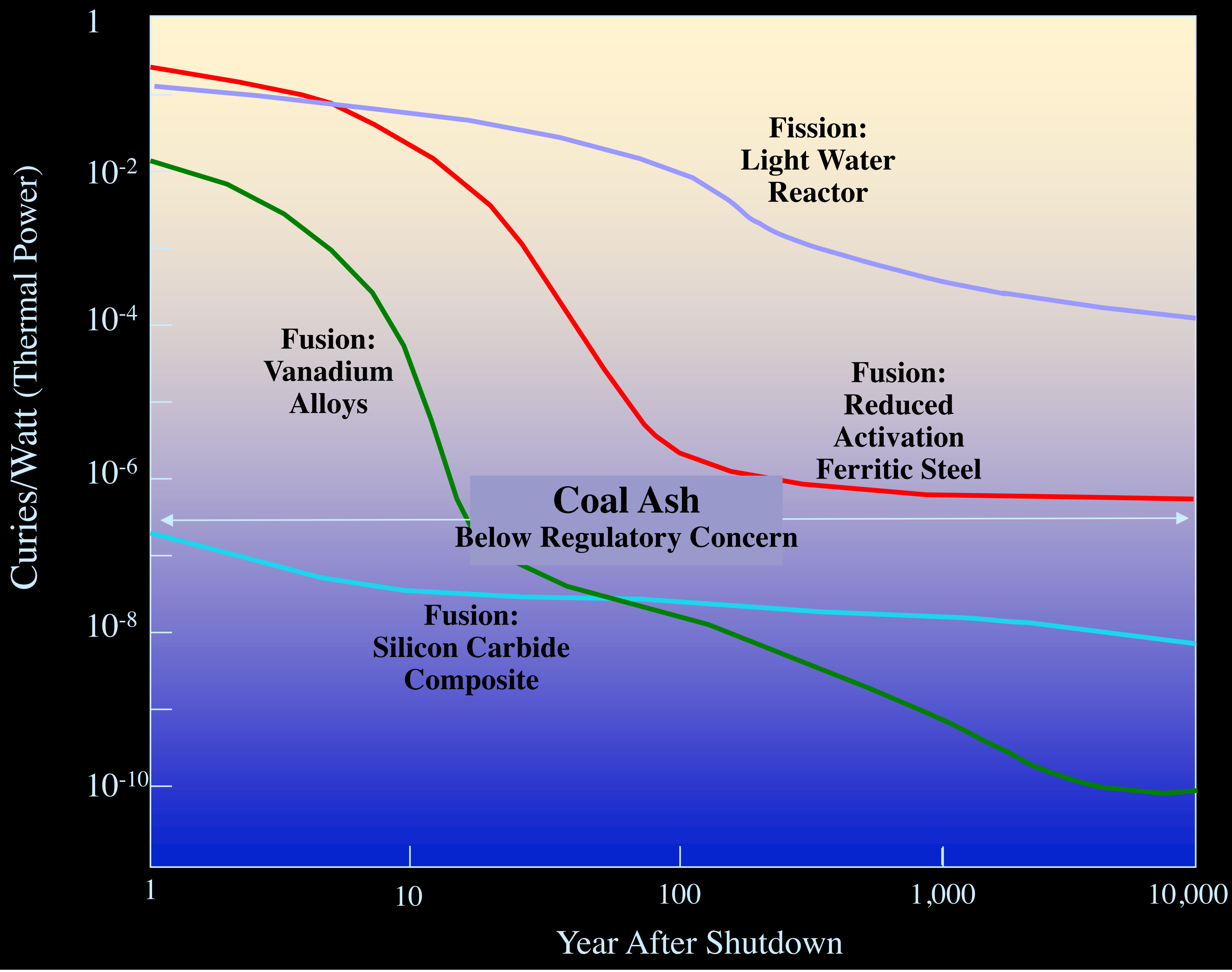
- **Reactor walls activated** (initial activity as for fission, but within 10-100 y the activity is 4-5 orders of magnitude lower than that of fission)

- **Disruptions** can cause wall damage or harm supraconducting magnets

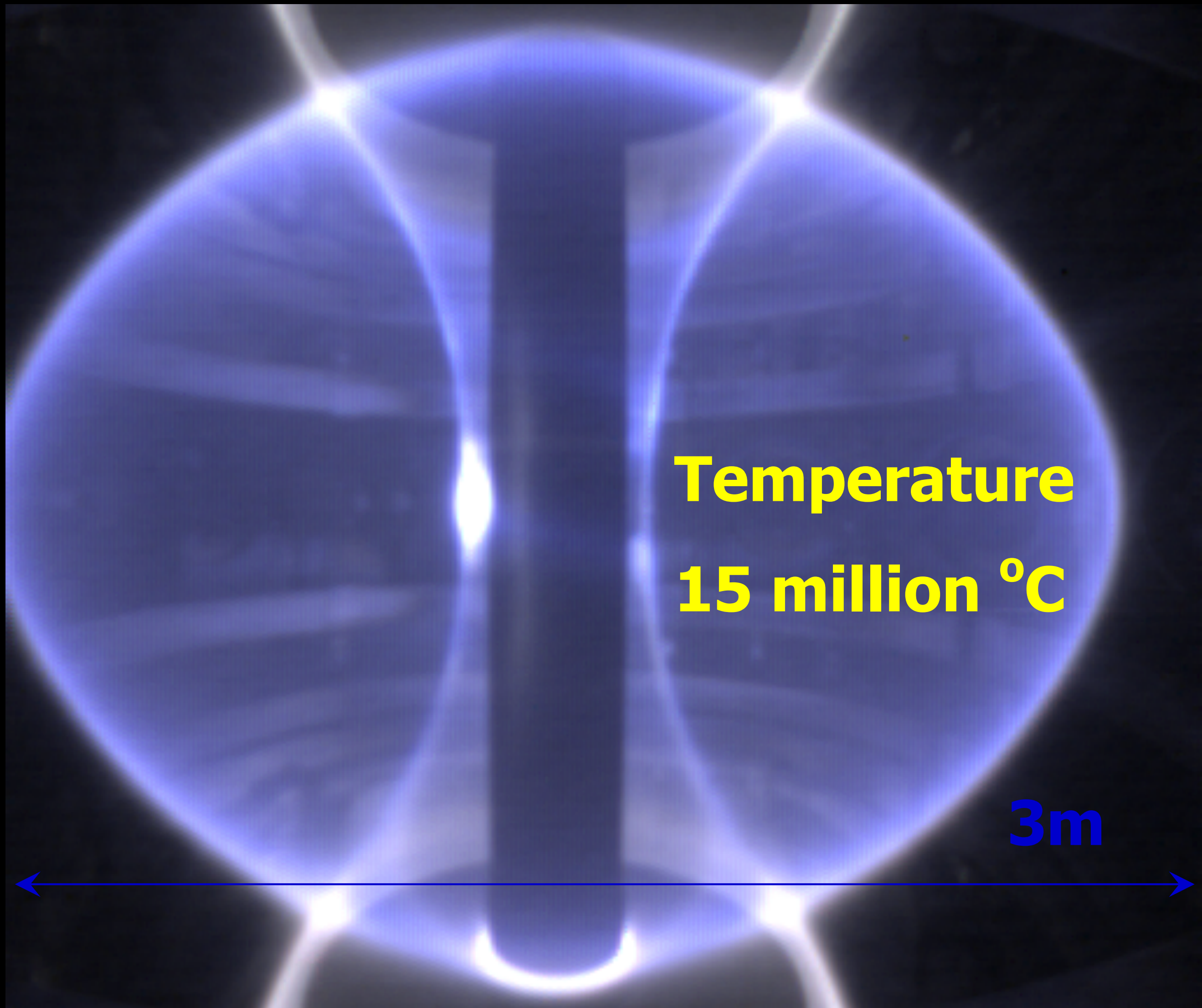
- **Liquid lithium**, if used as coolant, is highly reactive



Comparison - radioactivity from fission and fusion after shutdown



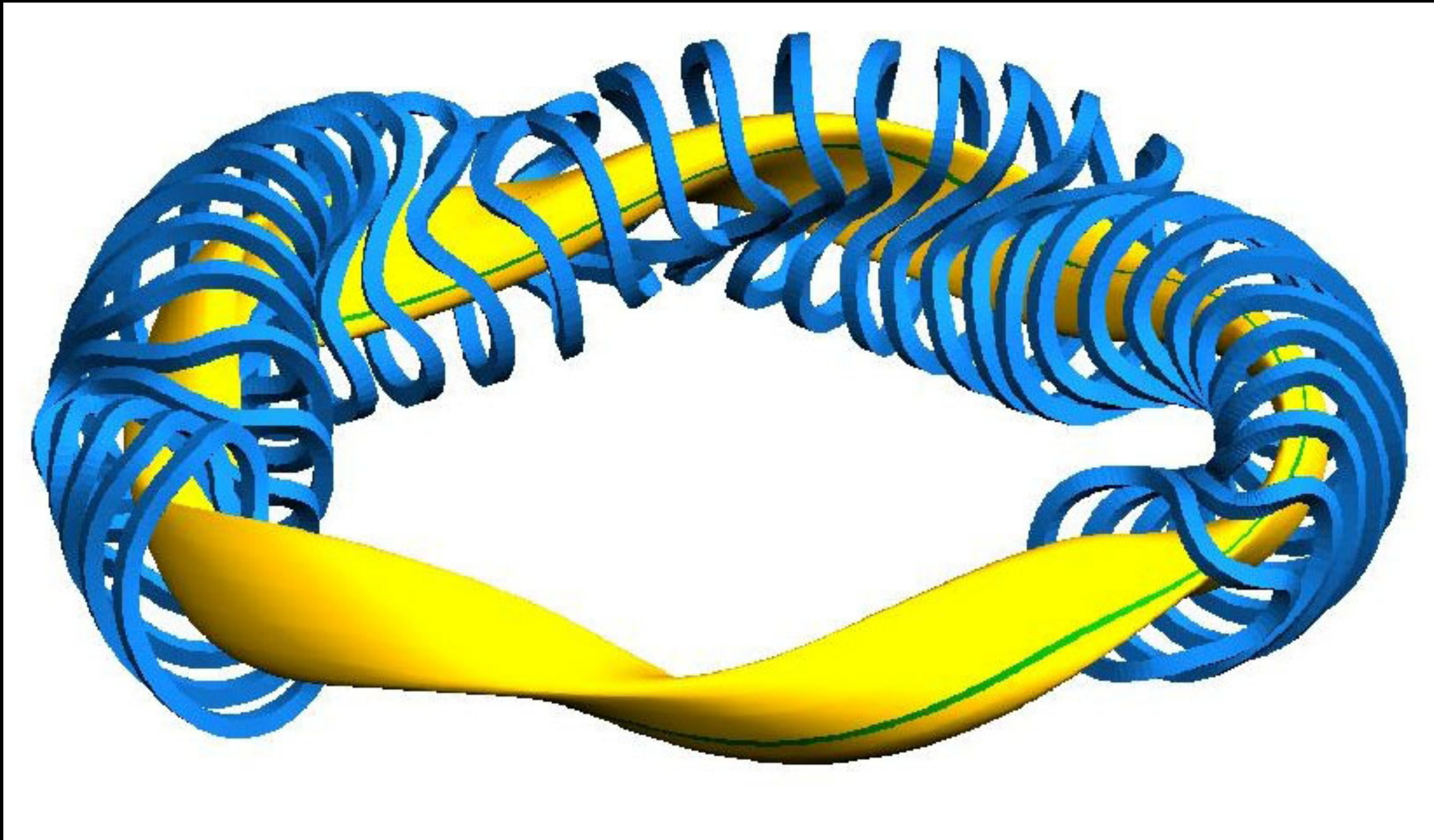
A MAST plasma



MAST - Culham, England

Stellarator – Wendelstein 7-X

Max-Planck-Institut für Plasmaphysik
EURATOM Assoziation

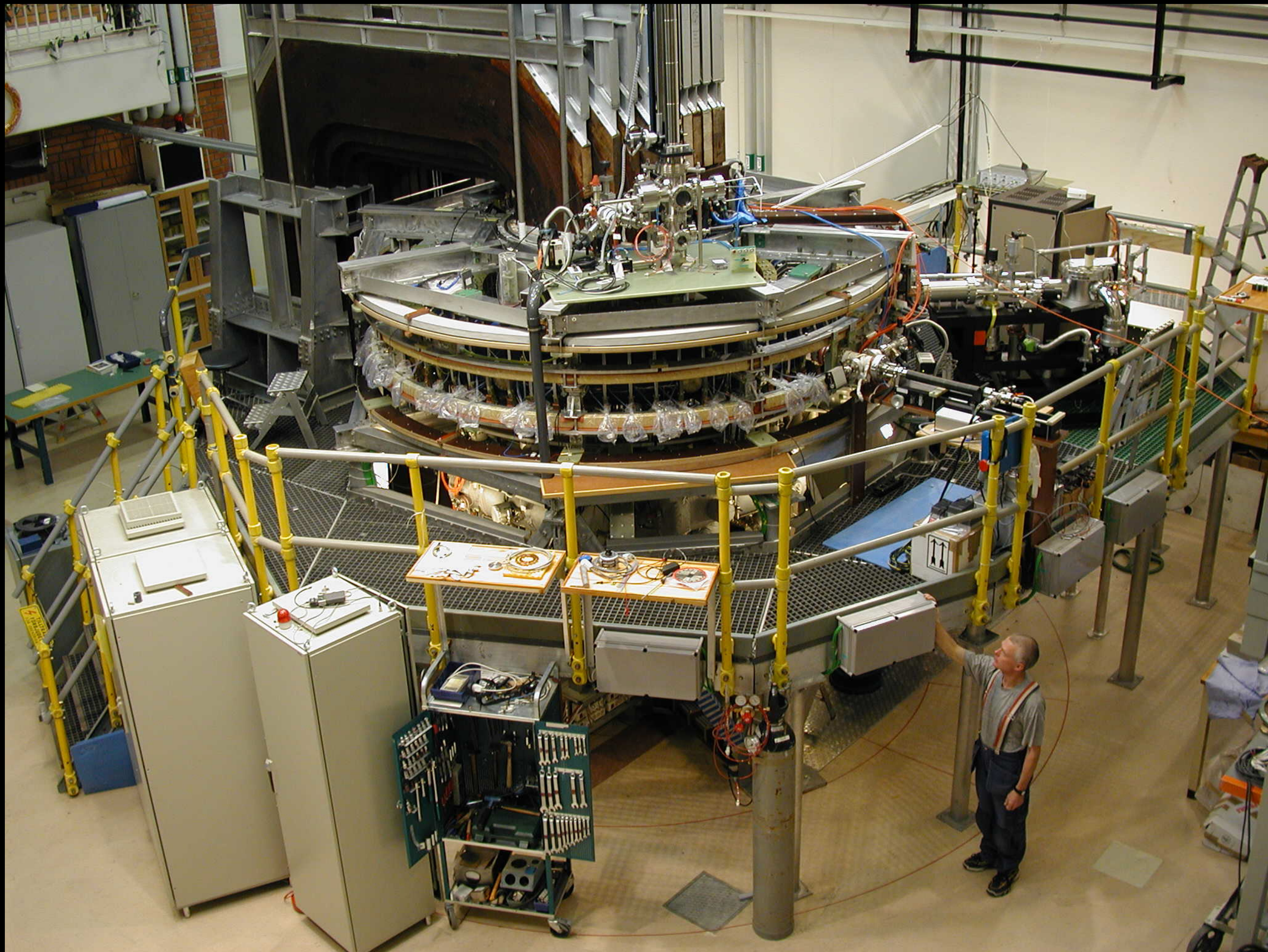


Stellarator – Wendelstein 7-X

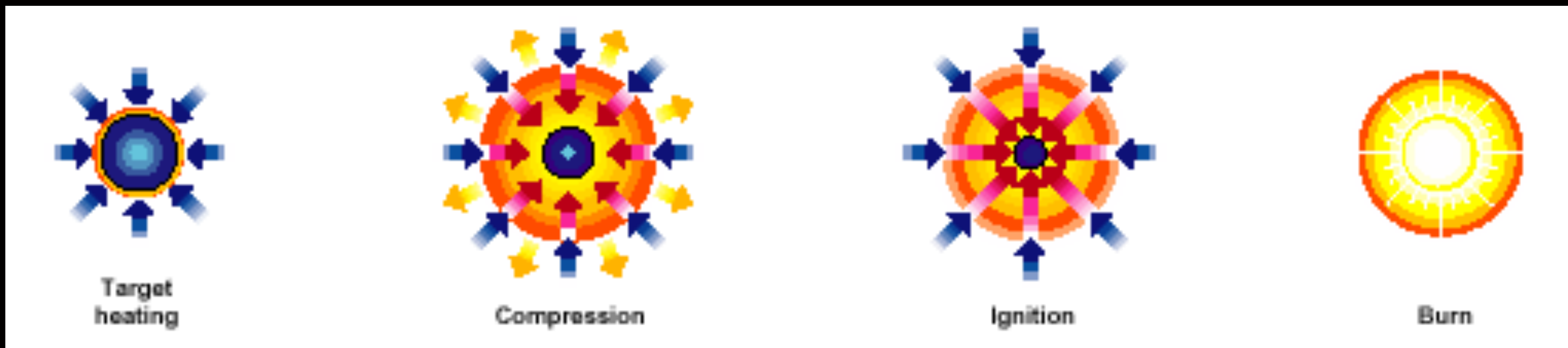
Max-Planck-Institut für Plasmaphysik
EURATOM Assoziation

EXTRAP T2R, Alfvénlaboratoriet, KTH

Scandinavia's only fusion experiment – a Reversed-field Pinch (RFP)



Inertial confinement (laser fusion)



National Ignition Facility (NIF), Livermore, CA (inertial fusion)

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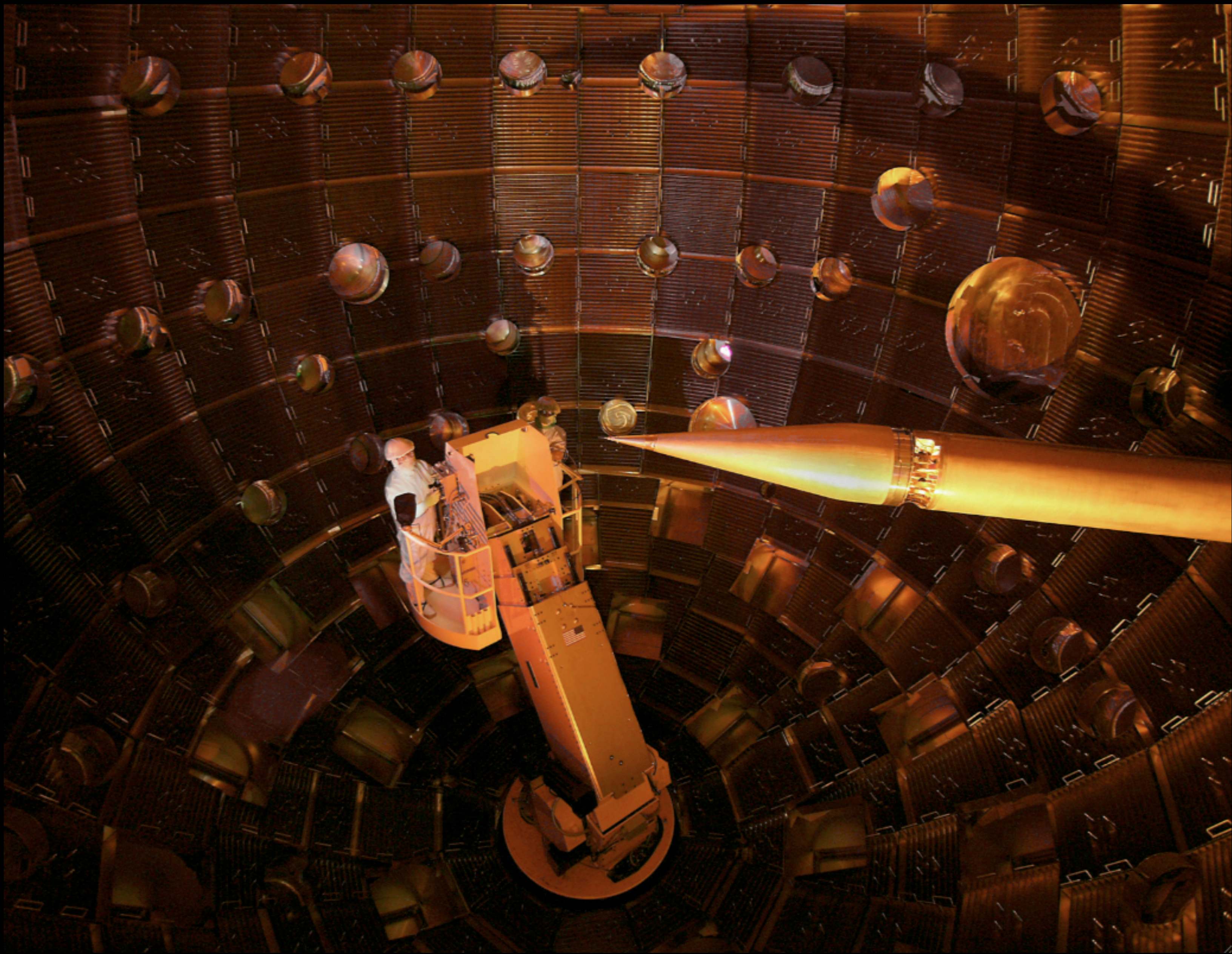
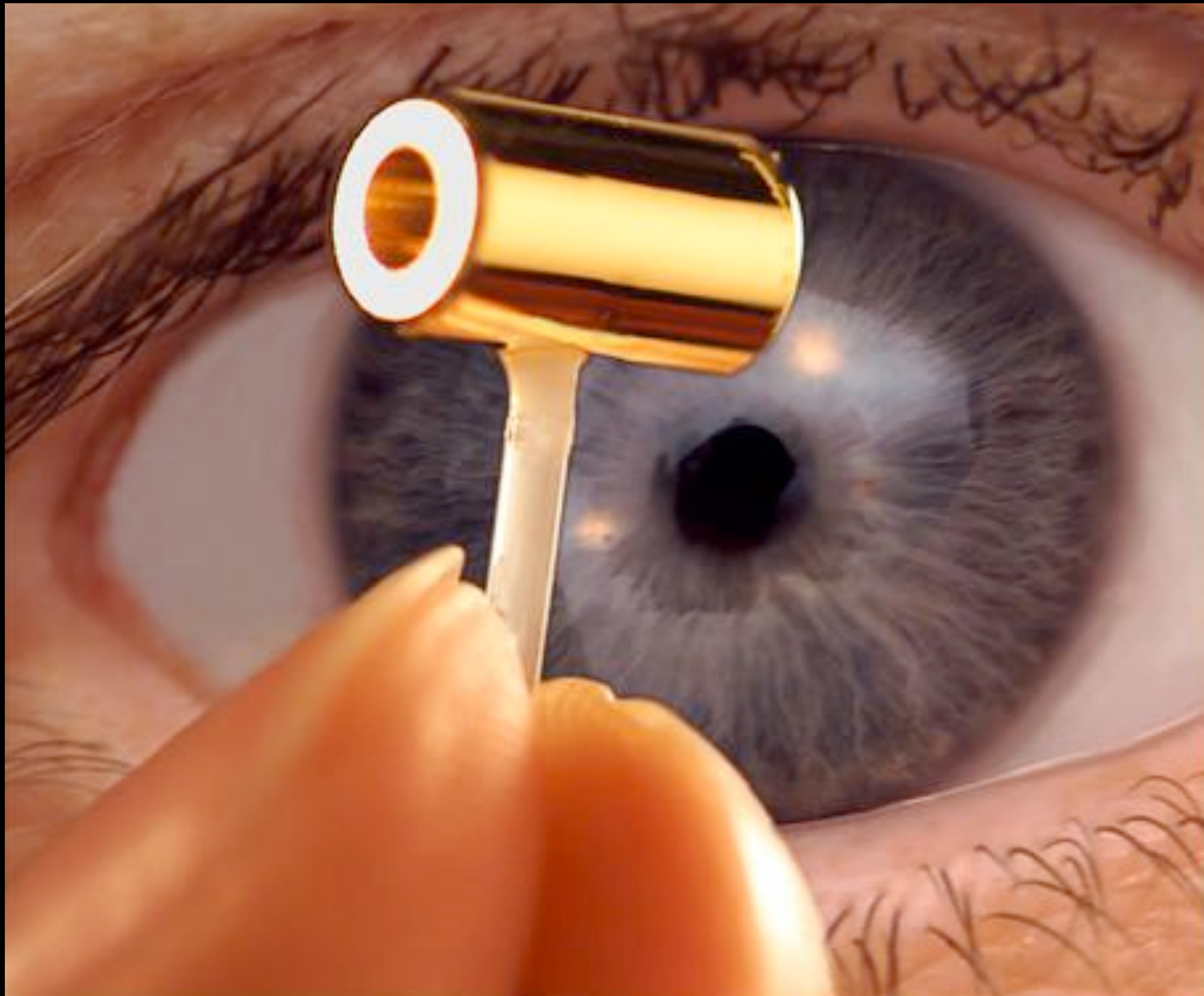


National Ignition Facility (NIF), Livermore, CA (inertial fusion)



Distributed R&D 26 Associations in an Integrated Programme

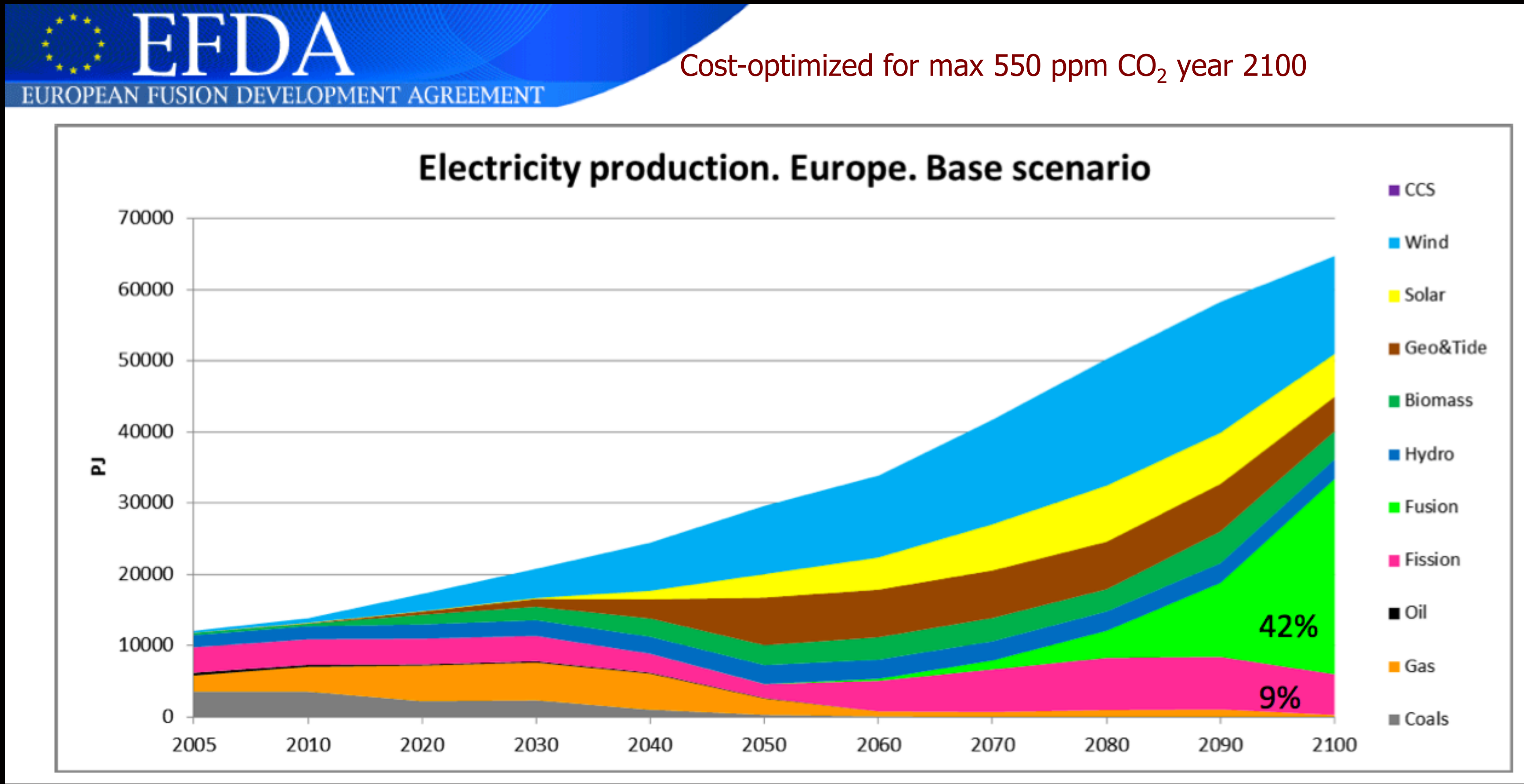
- Euratom - CEA (1958) France
- Euratom – ENEA (1960) Italy (incl. Malta)
- Euratom - IPP (1961) Germany
- Euratom - FOM (1962) The Netherlands
- Euratom - FZJ (1962) Germany
- Euratom - Belgian State Belgium (1969) (incl. Luxembourg)
- Euratom - RISØ (1973) Denmark
- Euratom – UKAEA (1973) United Kingdom
- Euratom - VR (1976) Sweden
- Euratom - Conf. Suisse Switzerland (1979)

- Euratom - FZK (1982) Germany
- Euratom –CIEMAT (1986) Spain
- Euratom – IST (1990) Portugal

- Euratom - TEKES (1995) Finland (incl. Estonia)
- Euratom - DCU (1996) Ireland
- Euratom - ÖAW (1996) Austria
- Eur - Hellenic Rep (1999) Greece (incl. Cyprus)
- Euratom - IPP.CR (1999) Czech Rep.
- Euratom - HAS (1999) Hungary
- Euratom – MEdC (1999) Romania
- Euratom – Univ. Latvia Latvia (2002)

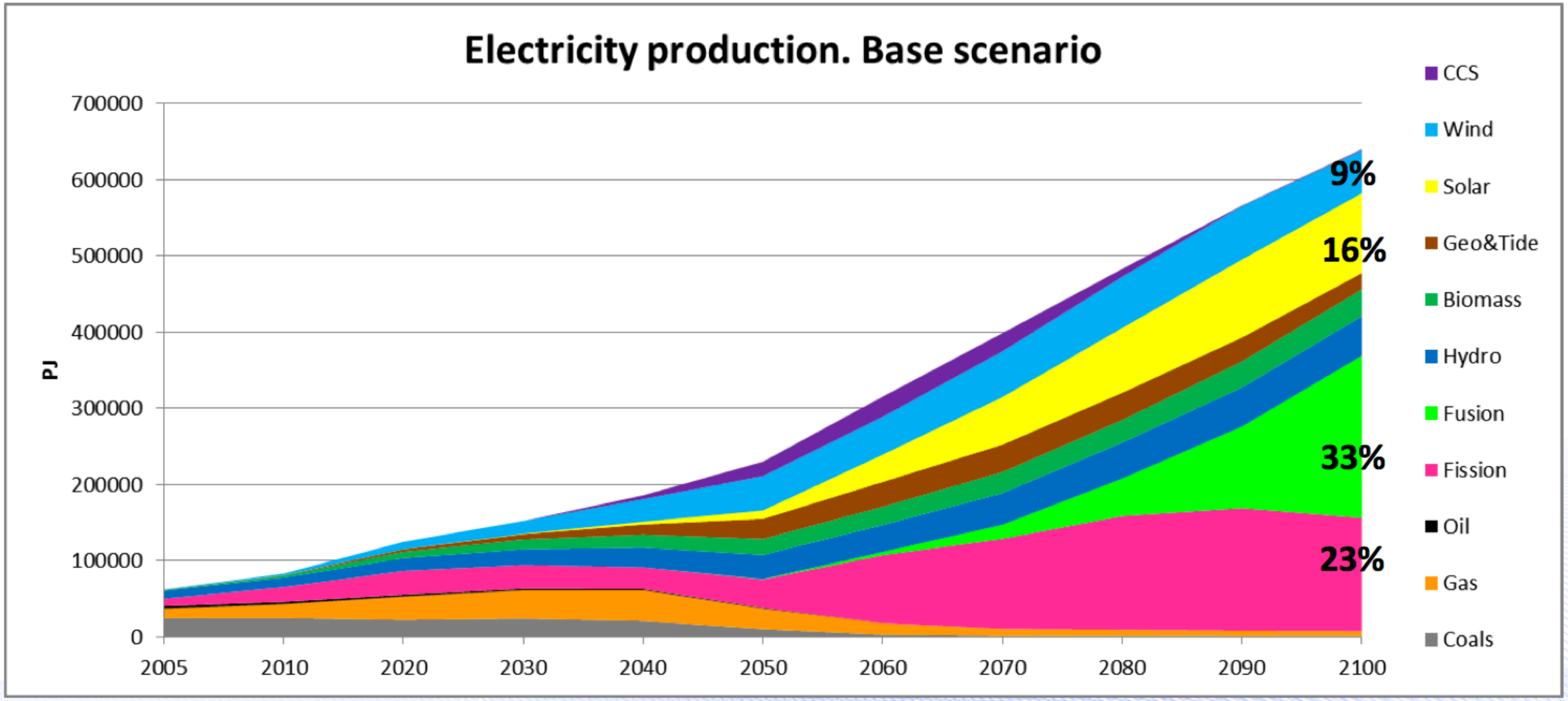
- Euratom - IPPLM (2005) Poland
- Euratom - MHEST (2005) Slovenia
- Euratom – CU (2007) Slovakia
- Euratom – INRNE (2007) Bulgaria
- Euratom – LEI (2007) Lithuania

Fusion energy is needed
- and is on its way



EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

Base scenario results



33% of fusion electricity in 2100. 42% of renewables. 23% of fission . 1% gas.
Coal phases out around 2060 and gas technologies reduce their share
CCS techs play a role in the mid of the century

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