FUSION

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Summary

- **Fusion works** [it powers the sun and stars; JET (the **J**oint **E**uropean **T**orus at Culham) has produced 16 MW of fusion power] **and has many potential attractions**

- There are **big challenges**, and more time is needed for development, **but**
  - good progress
  - no obvious barriers to rate of growth once fusion has passed threshold of viability
  - **fusion could play an important role in second half of this century**

- Role will depend on cost of fusion vs cost of carbon/cost of alternatives – models suggest it should be substantial

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FUSION ATTRACTIONS

– unlimited fuel (raw fuel = water + lithium*)

– no CO_2 or air pollution

– intrinsic safety

– no radioactive "ash" and no long-lived radioactive waste (could recycle within 100 years)

– competitive electricity generation cost, ***if*** reasonable availability (e.g 75%) can be achieved (and essentially zero "external" cost [impact on health, climate])

– would meet an urgent need

* Lithium in one lap top battery + half bath of water → 200,000 kW hrs = UK electricity production per capita for 30 years!

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Challenges I

1. **Heat a large volume of deuterium + tritium to over 100M°C –** while holding it in a "magnetic bottle" (tokamak) to prevent contact with walls
   – Done ✓ **BUT** in volume ~ 100 m^3 for ~ minutes

   Now need to scale to ~ 2000 m^3 and run round clock

   – The International Tokamak Experimental Reactor (**ITER**) (~ 800 m^3) **should definitively show this is possible**

     ITER will build on positive developments of last two decades (bootstrap current; high confinement mode)

     There is optimism that no major new problems will emerge, and that ITER and other experiments will lead to improved performance [fusion rate ~ $(\text{pressure})^2$ at fixed temperature]

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Challenges II

2. **Show that candidate materials for walls can survive in harsh fusion conditions** (several MW/m^2 of 14 MeV neutrons; large heat fluxes)
   – good candidates, encouraging results from tests in fission reactors

   BUT need tests in fusion conditions at

     – accelerator based **I**nternational **F**usion **M**aterials **I**rradiation **F**acility (IFMIF), or small driven fusion reactor

3. **Reliability** (fusion devices are complex)

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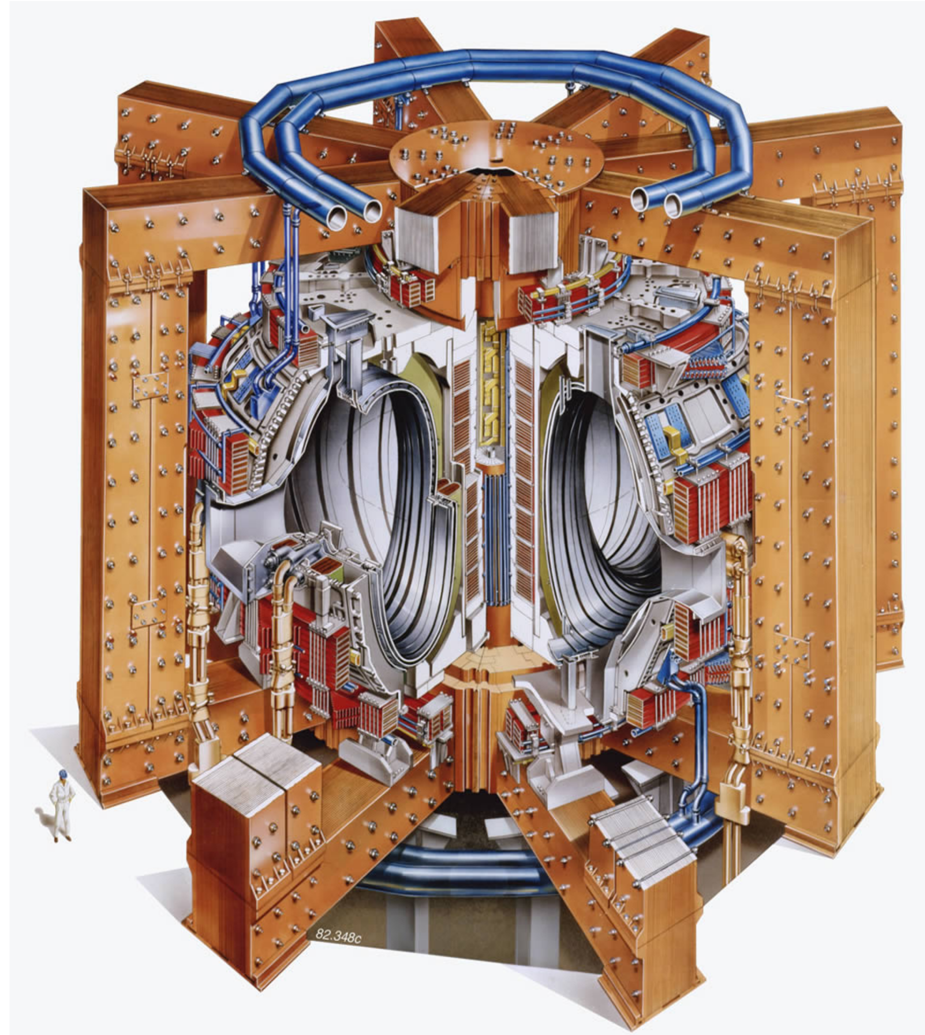
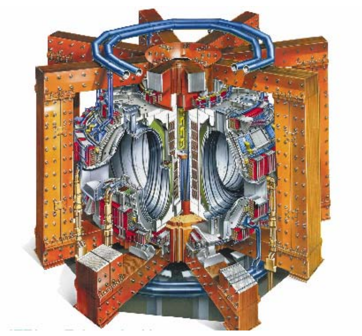
Progress in Fusion

T3: Vol ~1 m^3
established tokamak as best configuration (1969): temperature ~ 3 M ^{0}C

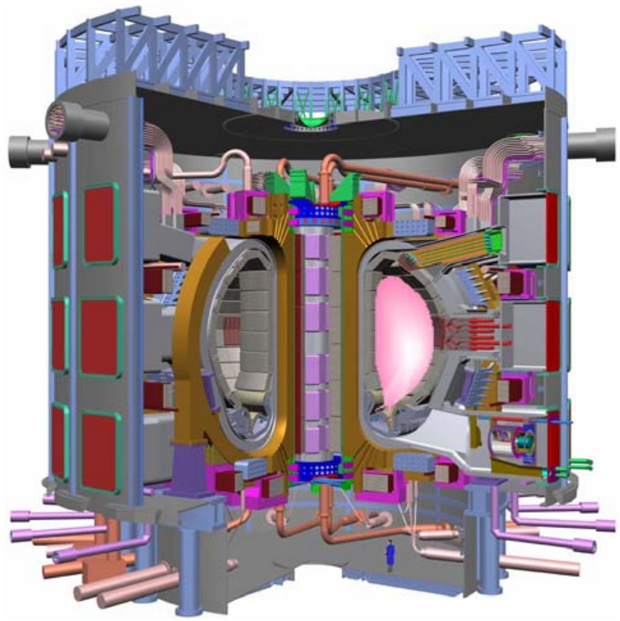


JET: Vol ~100 m^3: temperature ~ 150 M ^{0}C; world record (16 MW) for fusion power (1997)

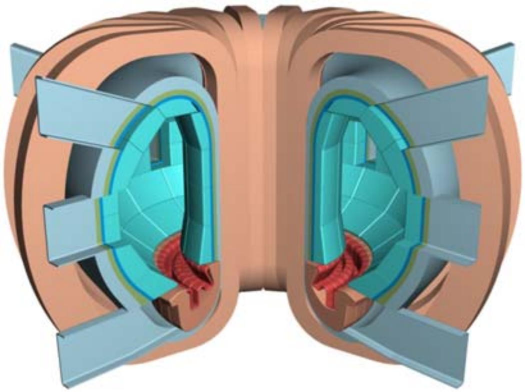
Next steps for Fusion



JET (now)
~ 100 m^3
16 MW



ITER ~ 800 m^3
(2016)
Should produce at least 500 MW

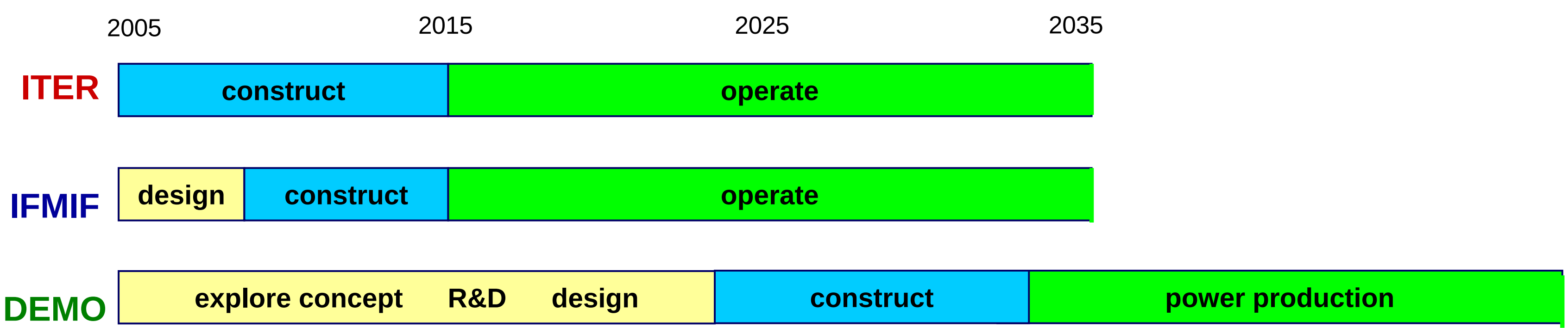


Proto-type Power Plant
('DEMO')
3,000 MW fusion power < 2035?
(This model assumes big advances: first models could be somewhat bigger)

Timetable for Next Steps

- **During ITER construction**
  - operate existing devices → speed up/improve ITER operation
- **In parallel intensify materials work, approve and build IFMIF**
- **Then**, having assimilated results from ITER and IFMIF,

  build a Prototype Power Plant ('DEMO'):



Commercial fusion power could follow ~ 10/15 years after first DEMO operation

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European Power Plant Conceptual Study

Results (used as input to timetable study reported above)

- Confirm good safety and environmental features of fusion
- **Give encouraging range for the expected cost of fusion generated electricity**

9 €-cents/kW-hour for early near-term (water cooled steel) model

5 €-cents/kW-hour for early advanced (Li-Pb cooled SiC composite) model

– *costs will fall with maturity*

Note

- Economics favours large fusion power plants → major centres of population (complementary to renewables)
- Capital intensive; very low operating cost – lots of cheap off peak power → hydrogen?

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Conclusions

■ **DEMO could be putting power into the grid within 30 years**, given i) adequate funding*****, and ii) no major adverse surprises

***** energy R&D funding generally is minute on scale of world energy [electricity] market ~ $4.5 [1.5] trillion p.a.*

Commercial fusion power on a significant scale could follow (say) 15 years later

■ **With any serious constraints on carbon** (e.g. tax of €30/tonne) **fusion power should play a significant role** (it will be very hard to meet demand with carbon constrained) **provided cost is similar to that of other major low carbon energy sources**

■ Meeting demand in an environmentally responsible manner will be an enormous challenge. It will require a **'portfolio' approach.**

Fusion is one of very few options for large scale provision of base-load power and should be developed as fast as reasonably possible