State-of-play of fusion R&D

Carrie Pottinger, FPCC Secretary

FPCC meeting, 24-25 January 2018

State-of-play of fusion R&D and benefits

- **IEA energy technology policy analysis and guidance**

- **IEA international collaborative energy technology research**

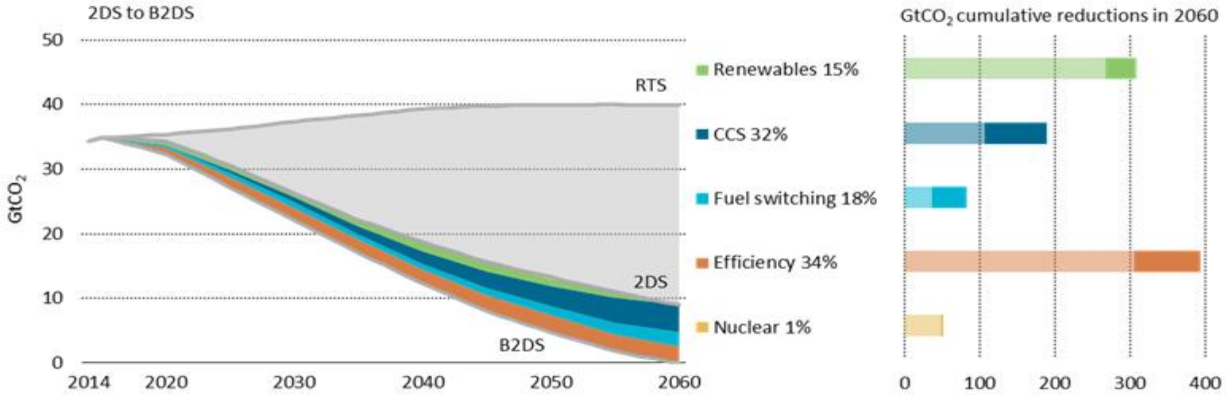
- **Fusion R&D state-of-play**

IEA energy technology policy analysis and guidance

Scenarios to understand the effectiveness of policy choices

- ***Energy Technology Perspectives 2017***
  - ***Energy scenarios to 2060***

Global CO2 emissions reductions by technology area and scenario

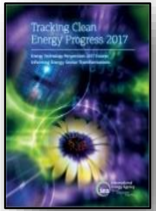


Note
RTS (Reference Technology Scenario); 2DS (- 2°C Scenario); B2DS (Beyond 2°C Scenario).
Source: IEA (2017), *Energy Technology Perspectives*. Paris.

By 2050, CO_2 emissions would need to fall to 1960 levels, yet the economy is expected to increase 20-fold.

Tracking clean energy technology progress

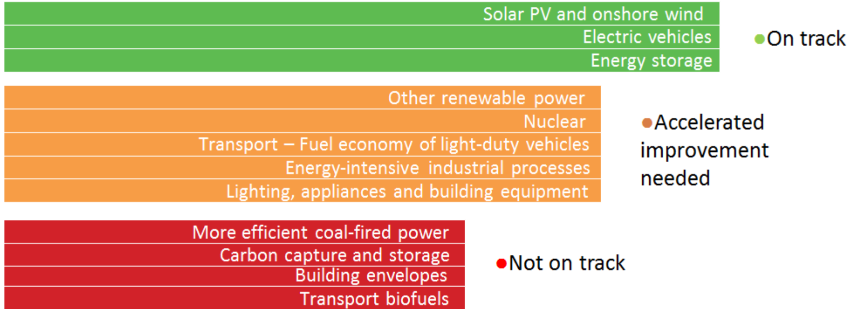
- **Energy technologies require support across all stages of R&D and innovation**
- **Tracking progress in the clean energy transition is essential to**
  - Assess collective progress toward long-term goals
  - Aid countries to identify pathways to achieving ambitions



- **Where policies have provided clear signals on the value of the technology, innovations have made substantial progress**
- **Recent progress in some clean energy areas is promising, yet many technologies still need a strong push to achieve deployment.**

Illustration of the progress in deployment of clean energy technologies compared with the rate needed to meet ambitious climate targets

Energy from fusion is not included as it is at stage of proof-of-concept



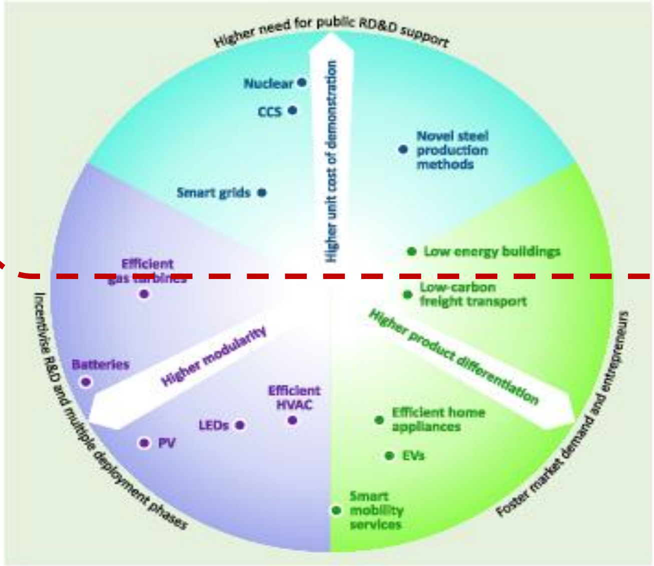
Source: IEA (2017), *Eracking Clean Energy Progress*. Paris.

Providing guidance to policy makers

- ***Technology Roadmaps* and *How2Guides***
  - **Re-endorsed at G7 Energy Ministerial Meetings in 2016 (Japan) and 2017 (Italy)**
    - *"(G7 Ministers) welcomed the progress report on the Second Phase of IEA's Technology Roadmaps, focused on viable and high impact technologies"*
  - **Progress to date**
    - 22 *Technology Roadmaps* (global) and *How2Guides* (national or regional)
    - 33 publications (Technology Roadmaps + methodology/process + translations)

Highlighting approaches to technology deployment

- **Governments play a crucial role in shaping and influencing the marketplace for technologies**



Source: IEA (2017), *Tracking Clean Energy Progress*. Paris.

Higher unit cost of demonstration: greatest need for public support

- Highest risk
- Situational specificity
- Complexity
- Longer time to market / RoI

Commercialisation: higher modularity

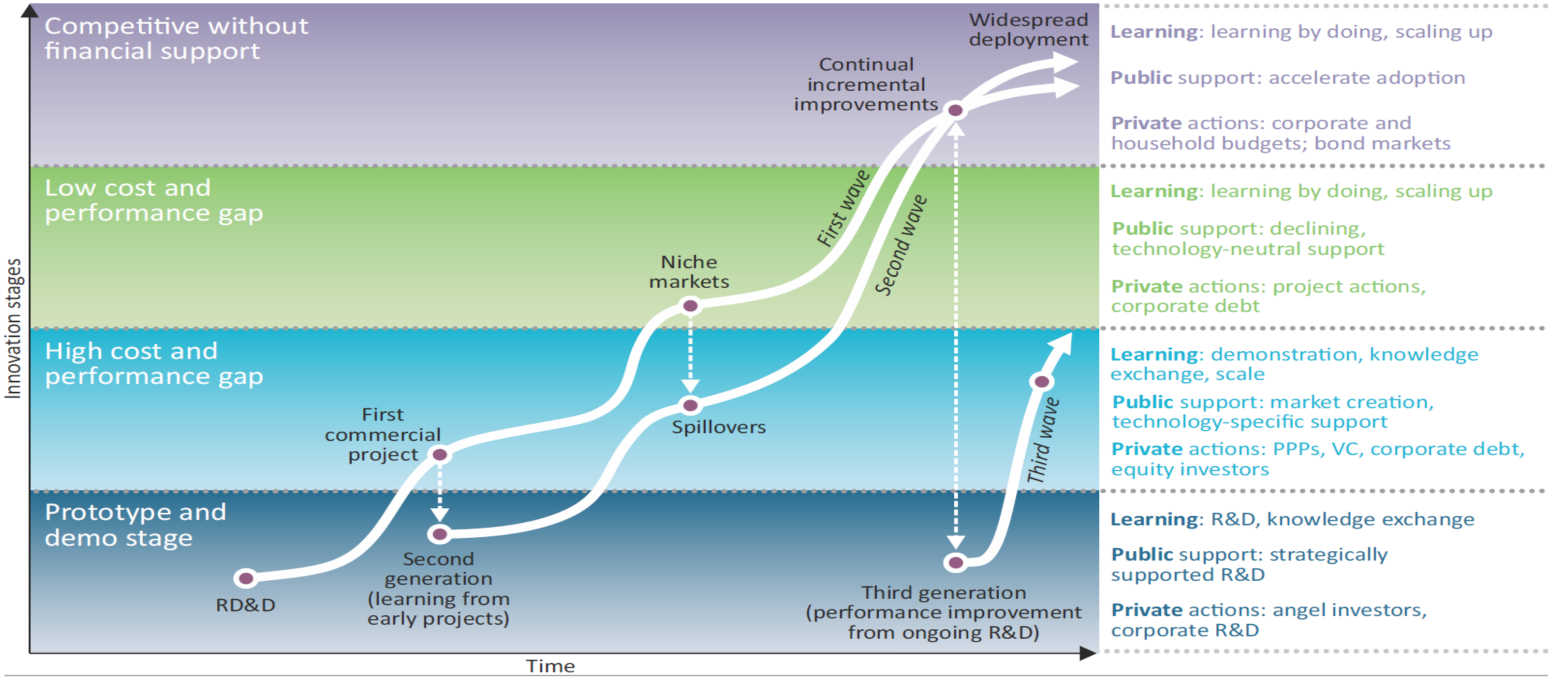
- Manufacturing improvements
- Competition
- Standards
- Consumer confidence

Higher product differentiation: reduced need for public support

- Reducing public support
- Early adopters
- Niche markets

Highlighting approaches to technology deployment, cont'd

- **Case study: advances in solar photovoltaic technologies**

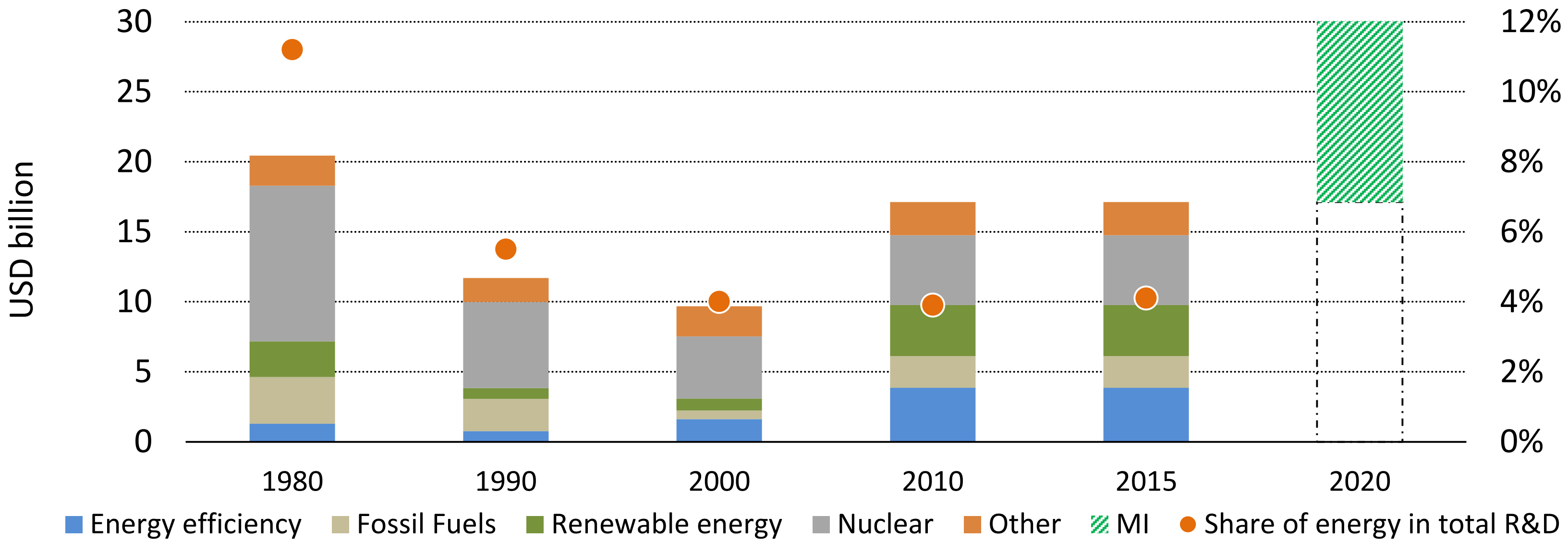


Source: IEA (2017), *Tracking Clean Energy Progress*. Paris.

Cross-fertilisation leads to spillovers which are re-injected and advances continue in a non-linear way.
<u>Information exchange through international collaboration can accelerate innovation.</u>

Collecting and sharing data

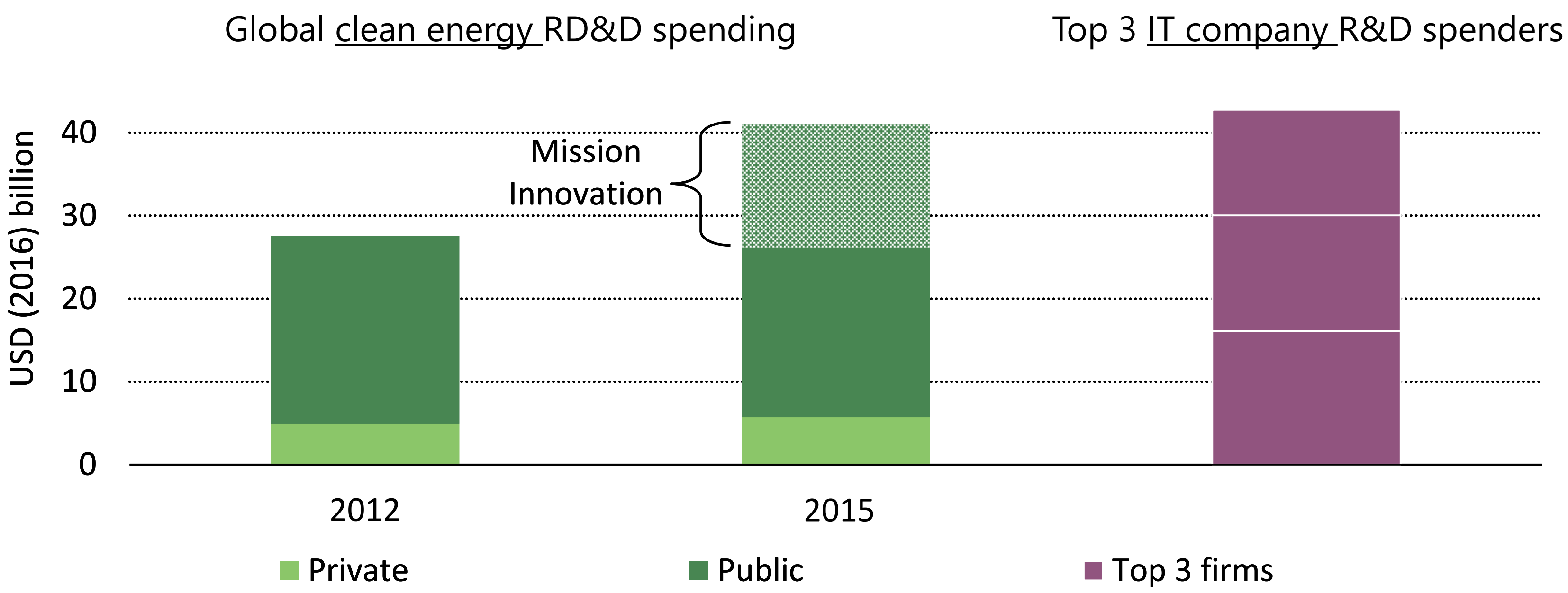
- **Public budgets for energy RD&D of IEA member countries**



Note: Includes basic research, applied research and experimental development, and demonstration (large-scale but not commercial), but excludes deployment.
Source: IEA (2017), *Energy Technology Perspectives*. Paris.

Government budgets should reflect the importance of energy technology in meeting climate objectives: yet energy represents only 10% of RD&D in all sectors (defence, health, etc).
In 2015, fusion RD&D represented 7% of public energy RD&D (and only 20% of total nuclear RD&D).

Collecting and sharing data, cont'd



Global RD&D spending in efficiency, renewables, nuclear and CCS plateaued at $26 billion annually, coming mostly from governments. Mission Innovation could provide a much needed boost.

Facilitating international initiatives

- **Mission Innovation**
  - **Commitment by 22 countries (14 IEA, 8 non-IEA) and the EC at COP21**
    - Dramatically accelerate global clean energy innovation by double spending on clean energy R&D investment over 5 years
  - **Great scientific challenges in clean energy innovation**

1. Smart Grids	*China, India, Italy*
2. Off-Grid Access to Electricity	*France, India*
3. Carbon Capture	*Saudi Arabia, United States*
4. Sustainable Biofuels	*Brazil, Canada, China, India*
5. Converting Sunlight (into fuels)	*EC, Germany*
6. Clean Energy Materials	*Mexico, United States*
7. Affordable Heating and Cooling of Buildings	*EC, UAE, United Kingdom*

- **Clean Energy Ministerial (CEM), others**

Note
MI members include IEA member countries (Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Republic of Korea, Sweden, United Kingdom, United States); the European Union; Association countries (Brazil, China, India, Indonesia, and Mexico); and Saudi Arabia and the United Arab Emirates.

IEA international collaborative energy technology research

IEA support for collaborative energy technology research

- **Committee on Energy Research and Technology (CERT)**
  - **Co-ordinates and promotes the development, demonstration and deployment of technologies to meet challenges in the energy sector**
  - **Supported by experts' groups and working parties:**
    - **Experts' Group on R&D Priority-Setting and Evaluation (EGRD)**

      Examines timely, cross-cutting topics e.g. Blue Sky Research for Energy Technology (May 2017)
    - **Working Parties**

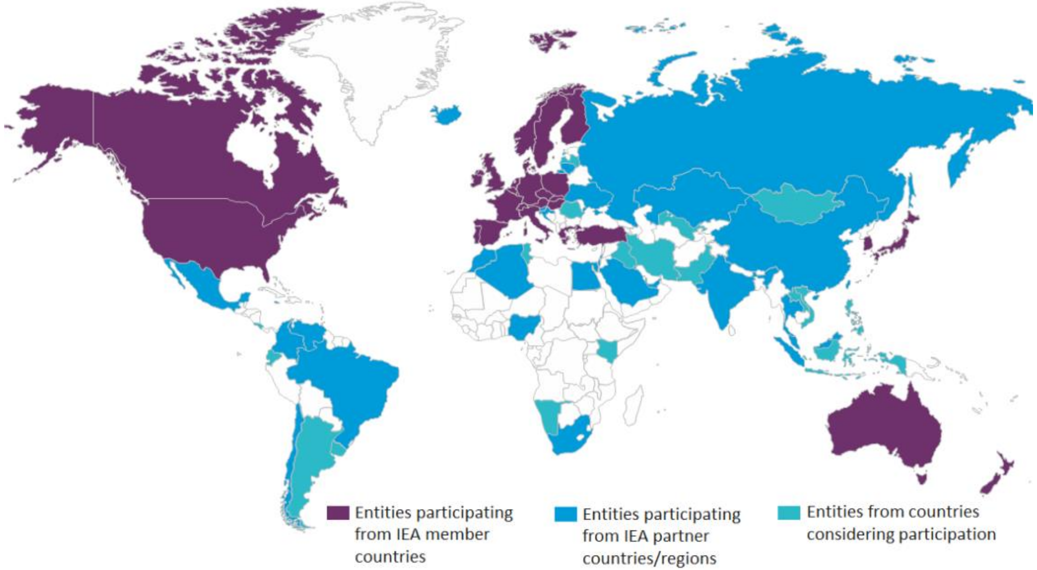
      Provide advice and coordinate activities of the Technology Collaboration Programmes (TCPs)
      - End-Use – Working Party on Energy End-use Technologies (EUWP)
      - Renewables – Working Party on Renewable Energy Technology (REWP)
      - Fossil Fuels – Working Party on Fossil Fuels (WPFF)
      - Fusion – Fusion Power Co-ordinating Committee (FPCC)
  - **Oversees international groups of experts (public, private sectors, intergovernmental orgs.)**
    - Technology Collaboration Programmes (TCPs)

Technology Collaboration Programmes (TCPs)

- **38 TCPs, five groups**
  - Cross-cutting activities (2)
  - End use and energy efficiency (14)
  - Fossil fuels (5)
  - Fusion power (8)
  - Renewable energy and hydrogen (9)
- **Focus of recent outcomes**
  - Understanding socio-economic aspects of technologies
  - Reducing greenhouse gas emissions
  - Advancing science and technology
  - Contributing to benchmarks and international standards
  - Facilitating deployment
  - Improving efficiency
- **Resources**
  - Self-financed: cost- or task-sharing
  - IEA: provides guidance and support

Energy Technology Network
Technology Collaboration Programmes

- 6,000 experts
- 2,000 topics
- 300 public or private organisations
- 54 countries
- 70+ experts' meetings per year
- 4 intergovernmental organisations



This map is without prejudice to the status of sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Fusion at the IEA

- **Fusion energy has the potential to meet the IEA's three "E's"**
  - Energy security
  - Environmental protection
  - Economic growth

- **Consistent with the vision and mission of the IEA Medium Term Strategy for Energy Research and Technology 2018-2022 and achieves objectives**
  - **Support research and innovation activities as well as enhance and expand analysis to inform policy decisions, taking a whole-system perspective**
    - R&D for basic science / long-term solutions
  - **Further strengthen the Energy Technology Network (ETN)**
    - Fusion Power Co-ordinating Committee (FPCC) and fusion-related Technology Collaboration Programmes (TCPs)
  - **Engage with partner countries, the private sector, and relevant international partnerships and organisations**
    - Association countries and partner countries are invited to FPCC and are CPs to fusion TCPs
    - International partnerships (BA) and organisations (IAEA, ITER, NEA) share information with the FPCC

Fusion Power Co-ordinating Committee (FPCC)

- **Aims**
  - Provide advice to the Committee on Energy Research and Technology (CERT)
  - Serve as a forum for international co-operation on fusion energy R&D
  - Coordinate the activities of the fusion TCPs

- **Fusion TCPs**

Technology Collaboration Programme (TCP)	Year established	Contracting Parties (CPs) (as of 1 January 2018)
DEVICES		
Co-operation on Tokamak Programmes (CTP TCP)	2010	China, India, Japan, Korea, United States; European Commission (EC)*
Spherical Tori (ST TCP)	2007	Japan, United States, EC
Stellarator-Heliotron Concept (SH TCP)	1985	Australia, Japan, Russia, Ukraine, United States, EC
BARRIERS COMMON TO ALL DEVICES		
Socio-economic aspects		
Environmental, Safety and Economic Aspects of Fusion Power (ESEFP TCP)	1992	Canada, China, Japan, Korea, Russia, United States, EC
Plasma physics		
Reversed Field Pinches (RFP TCP)	1990	Japan, United States, EC
Interaction between the plasma and the materials		
Plasma Wall Interaction (PWI TCP)	1977	Japan, United States, EC
Technologies		
Fusion Materials (FM TCP)	1980	Canada, China, India, Japan, Korea, Russia, United States, EC
Nuclear Technology of Fusion Reactors (NTFR TCP)	1994	Canada, China, India, Japan, Korea, Russia, United States, EC

**The European Commission participates through the EURATOM Treaty.*

Fusion R&D state-of-play

Fusion R&D state-of-play

- **Survey**
  - **Qualitative questions**
    - What are barriers to successful deployment of fusion energy?
    - What are the current or planned efforts to overcome these barriers?
    - What is the added value/benefit of fusion to policy makers, the private sector and the general public?
  - **Quantitative data**
    - Current and planned activities, level of priority
    - Supply, plasma physics, materials, heating systems, magnetics, technologies, DEMO studies and engineering, systems issues, socio-economic issues, other
- **Responses**
  - **Finite data set – complemented with available information**
  - **National**
    - 14 responses
    - *Australia: Based on 2016 report to the FPCC*
  - **International**
    - Europe: EUROfusion survey + national responses (where different)
    - *Broader Approach: Based on 2017 annual report*
    - *International Atomic Energy Agency (IAEA): Based on 2015 annual report*
    - *Technology Collaboration Programmes (TCPs): Based on Annual Briefings (2016, 2017)*

Q: What are the barriers to fusion deployment?

- **The barriers to successful deployment of fusion energy are still high – fusion energy development still needs to pass a number of key milestones**
  - **Scientific:** Plasma physics.
  - **Technological:** Remote handling; tritium self-sufficiency, processing and storage; effective exhaust of heat and particles; and divertor and blanket design.
  - **Materials:** Extreme temperatures; irradiation.
  - **Systems:** Remote operations and handling; flexiblity/ability to adjust or change.
  - **Safety:** Neutronics; liquid metal loop technologies; arcing; nuclear design and safety evaluation; predicting accidents and management scenarios; radioactive waste disposal.
  - **Financial:** Uncertainty (programme funding, personnel); construction costs; investment "lock-in"; cost of de-comissioning and processing radioactive waste.
  - **Political:** Long approval processes, fusion confused with fission.

Q:What are the current or planned efforts to overcome the barriers?

- **Current:**
  - **National research facilities and devices (W7X)**
  - **Developing benchmarks and standards**
    - **France, United States:** Materials
    - **China:** Safety
  - **Foresight and concerted actions**
    - **Europe:** Fusion roadmap
    - **Japan:** Strategic outreach to the general public “fusion as the energy of choice”
- **Planned**
  - **Devices:** ITER, JT60A, WEST, CFETR
  - **Testing facilities**
    - **United Kingdom:** National Fusion Technology Platform (processing and storage of tritium; and thermal, mechanical, hydraulic and electromagnetic testing of prototype components)
    - **Italy:** Divertor Tokamak Test Facility (I-DTT)
    - **China:** High intensity D-T fusion neutron generator HINEG and the dual coolant thermal hydraulic experimental metal loop DRAGON-V
    - **Japan/EURATOM:** Fusion Materials Irradiation Facility/ Engineering Validation and Engineering Design Activities, DRON
  - **Data handling, modelling and scenarios**
    - **China:** SuperMC software calculates to avoid superconducting quench accidents; Fusion Neutronics book
    - **Japan/EURATOM:** International Fusion Energy Research Centre (IFERC)

Q: What is the added value/benefit of fusion to policy makers, the private sector and the general public?

- ***Policy makers***
  - Fusion will provide **self-sustaining supply for countries with few natural resources**
  - Fusion will **protect the environment – extremely low radioactive waste and no carbon emissions**
  - Fusion is **inherently safe – the plasma deflates when disrupted**
- ***Private sector/industry***
  - Fusion enables industries to **develop new manufacturing capabilities – in fusion or beyond**
    - Engineering, welding, thermal insulation, superconductors, radio-frequency sources, power supplies, non-destructive testing, diagnostics, imaging, remote maintenance, gas handling, precision measurements, testing capabilities
  - Fusion enables industries to **sell skills and knowledge gained to others**
  - **Public/private co-operation reduces development risks and costs**

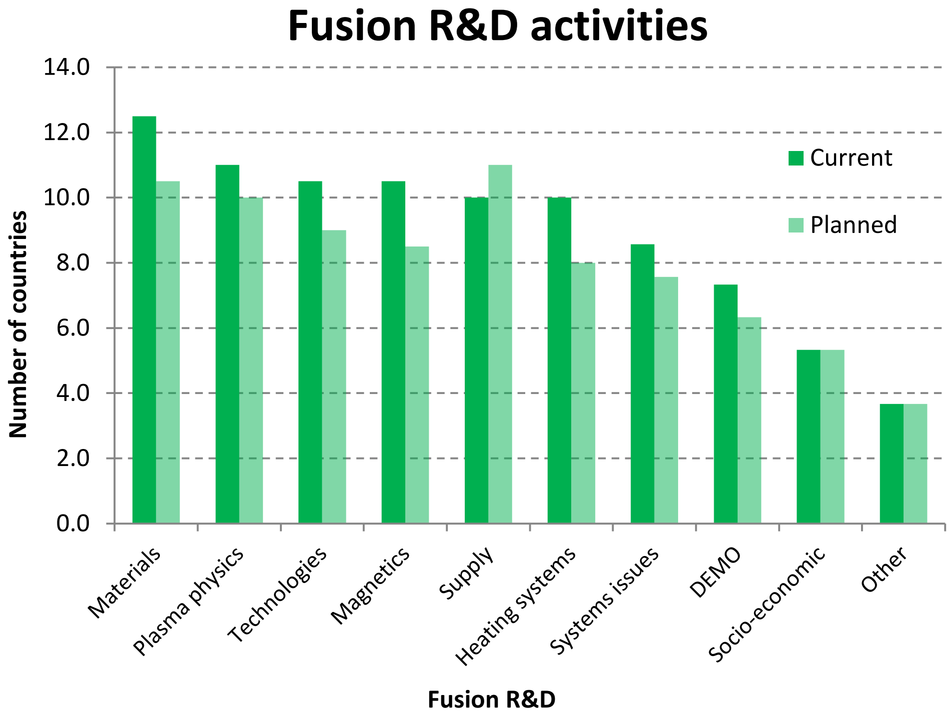
Developing fusion fosters job creation

- ***General public***
  - Fusion research has **significantly expanded our collective understanding of science**
    - Understanding plasma behaviour, understanding astrophyics, testing the physical limits of materials
  - Fusion research has **enabled a rapid development in a wide range of research fields**
    - Plasma physics, superconducting magnet technologies, and development of materials
  - Fusion research has **resulted in a number of important spin-offs and practical applications**
    - Magnetic resonance imaging (MRI), nanomaterials, artificial diamond synthesis, micro- and opto-electronics, energy efficient lighting, water sterilisation, tissue healing, combustion enhancement, satellite communication, and aerospace propulsion; waste disposal; improving textiles

Quantitative responses: preliminary results

B. QUANTITATIVE QUESTIONS				
For each of the areas below, please indicate whether the activity is currently carried out within the national programme or whether it is planned.				
	Currently	**Planned**	**Priority level***	**Explanatory notes**
FUSION RESEARCH STRATEGY				
	Year established	Y/N	H/M/L	*Title, and if available, the web page link.*
FUSION RESEARCH ACTIVITIES				
Supply				
Tritium self-sufficiency	Y/N	Y/N	H/M/L	
Plasma physics				
Steady state or pulsed	Y/N	Y/N	H/M/L	
Density, shape, impurities	Y/N	Y/N	H/M/L	
Confinement scaling laws	Y/N	Y/N	H/M/L	
High beta stability limits	Y/N	Y/N	H/M/L	
Materials				
Plasma-facing components	Y/N	Y/N	H/M/L	
Plasma wall interaction	Y/N	Y/N	H/M/L	
Heating systems				
Electron Cyclotron	Y/N	Y/N	H/M/L	
Ion Cyclotron	Y/N	Y/N	H/M/L	
Neutral Beams	Y/N	Y/N	H/M/L	
Magnetics				
Coils (indicate technology type)	Y/N	Y/N	H/M/L	
Protection systems for anomalies (e. g. quenches, arcing)	Y/N	Y/N	H/M/L	
Technologies				
Divertor	Y/N	Y/N	H/M/L	
Reactor design technologies	Y/N	Y/N	H/M/L	
Demo studies and engineering preparations				
Steady state stellarator or tokamak design?	Y/N	Y/N	H/M/L	
Pulsed tokamak design?	Y/N	Y/N	H/M/L	
Net electrical power and efficiency	Y/N	Y/N	H/M/L	
Systems issues				
Balance of plant	Y/N	Y/N	H/M/L	
Heat and particle exhaust	Y/N	Y/N	H/M/L	
Current drive	Y/N	Y/N	H/M/L	
Cryo-genics	Y/N	Y/N	H/M/L	
Vaccuum pumps	Y/N	Y/N	H/M/L	
Diagnostics	Y/N	Y/N	H/M/L	
Remote handling	Y/N	Y/N	H/M/L	
Socio-economic issues				
Environmental impact	Y/N	Y/N	H/M/L	
Grid integration	Y/N	Y/N	H/M/L	
Safety	Y/N	Y/N	H/M/L	
Other areas of high relevance to the fusion research programme				
	Y/N	Y/N	H/M/L	
	Y/N	Y/N	H/M/L	

Quantitative responses: preliminary results, cont'd

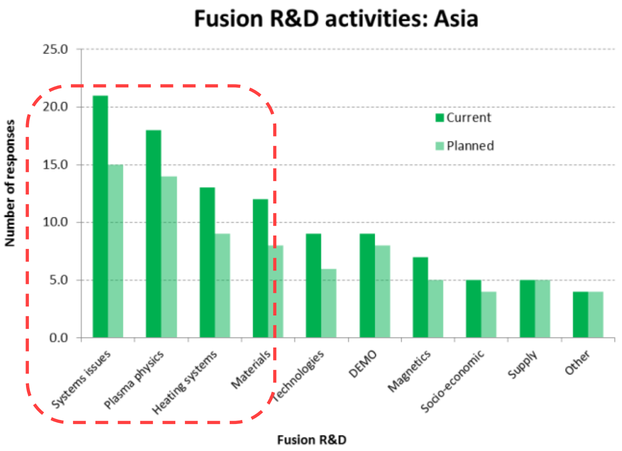


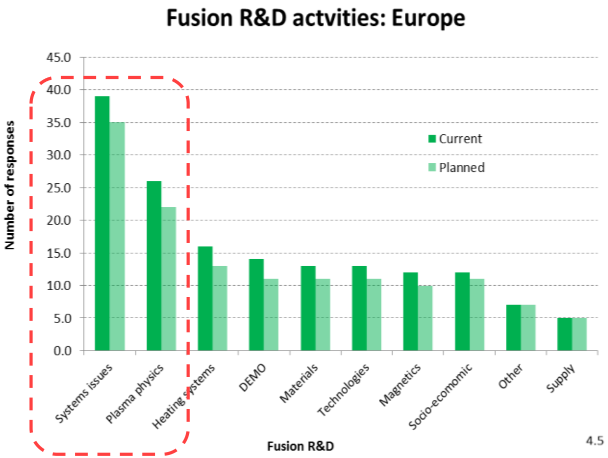
Notes:
Other includes education and training; in-situ cleaning of PFCs; compact fusion devices; modelling, codes, scenarios and numerical simulations; measurement systems; disruptions and plasma edge stability; materials for breeder blankets; materials and engineering.

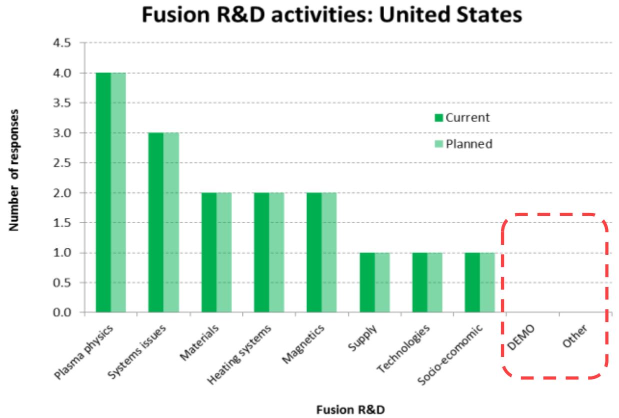
Source: Replies to the survey from IEA member government agencies or research facilities, as well as China, India and the Ukraine. Data for Australia were estimated.

Quantitative responses: preliminary results, cont'd

- **Regional focus**



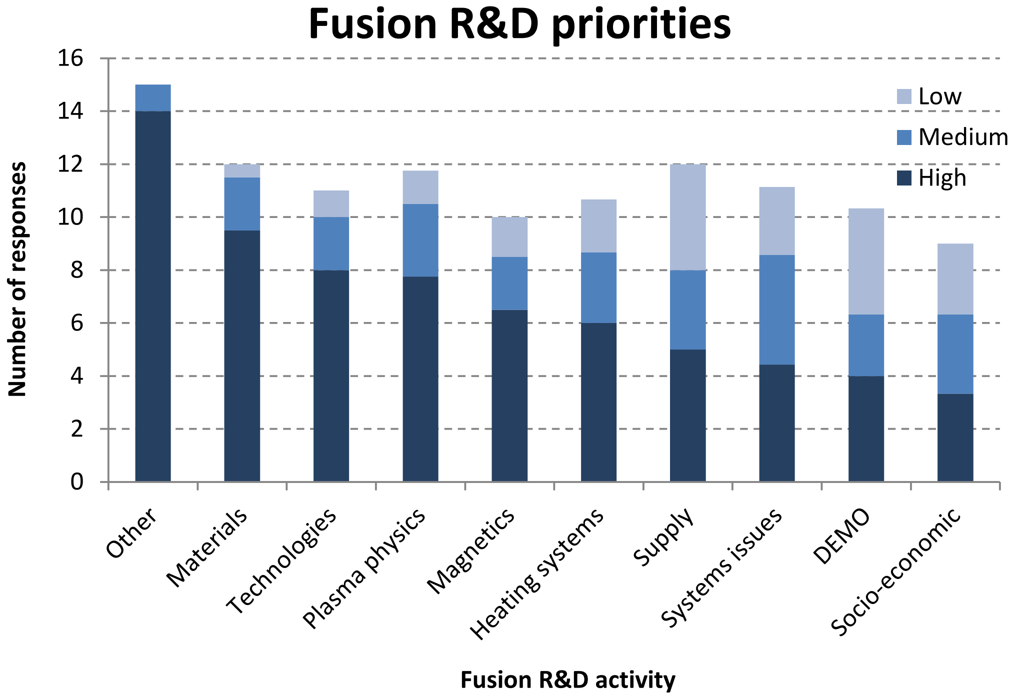




- **All regions:** Most current activities cover systems issues, plasma physics, heating systems, materials and technologies
- **Asia:** Relatively homogenous levels of activity across a range of areas.
- **Europe:** The majority of activities focus on systems and plasma physics.
- **United States:** no activities focusing on DEMO

Notes:
Asia comprises replies to the survey for Japan, Korea, China, and India. Data for Australia were estimated.
Europe comprises replies to the survey: France, Germany (IPP), Italy, Spain, Switzerland , the United Kingdom and the Ukraine.

Quantitative responses: preliminary results, cont'd



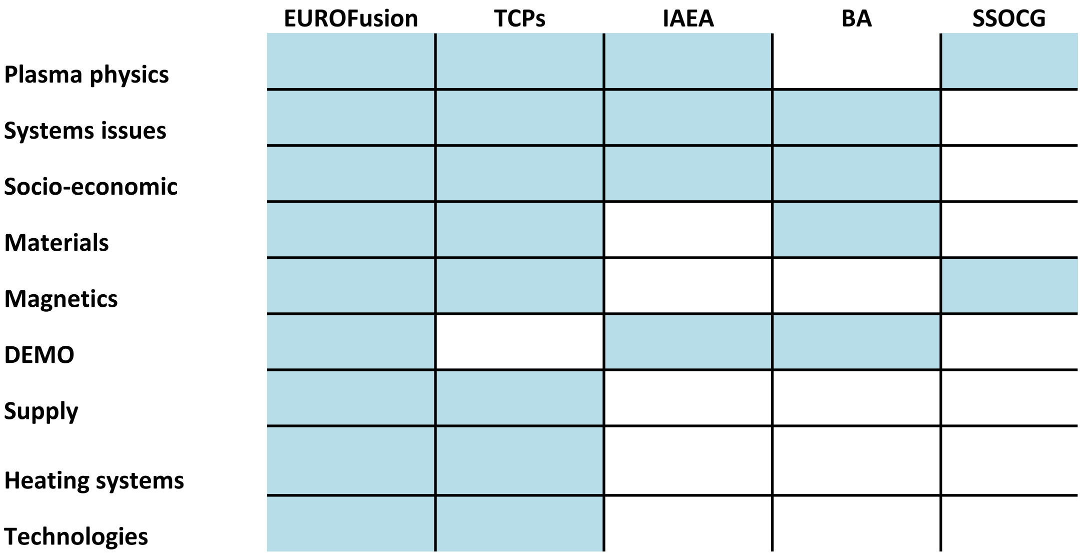
<u>*Notes*</u>

Other includes education and training; in-situ cleaning of PFCs; compact fusion devices; modelling, codes, scenarios and numerical simulations; measurement systems; disruptions and plasma edge stability; materials for breeder blankets; materials and engineering.

Source: Replies to the survey from IEA member government agencies or research facilities, as well as China, India and the Ukraine. Data for Australia were estimated.

Quantitative responses: preliminary results, cont'd

International co-operation on fusion research



Notes
International co-operation includes information exchange and joint experiments aimed at transferring knowledge across national research facilities and university programmes.
Source: Replies to the survey (Eurofusion) and Secretariat estimates based on annual reports (others).

Summary

- **Barriers to fusion development are known - and steps are being taken to overcome them**
  - Creating new capabilities: components, facilities, devices, modelling/scenarios
  - Concerted actions (roadmaps)
  - Enhanced international co-operation
- **Survey results**
  - Basis for first discussion
  - More detailed efforts needed to fully capture worldwide efforts – regional strengths
- **There are many benefits to fusion as an energy source**
  - Communicating scientific outcomes is sometimes challenging
  - Targeting communications to the audience significantly increases understanding