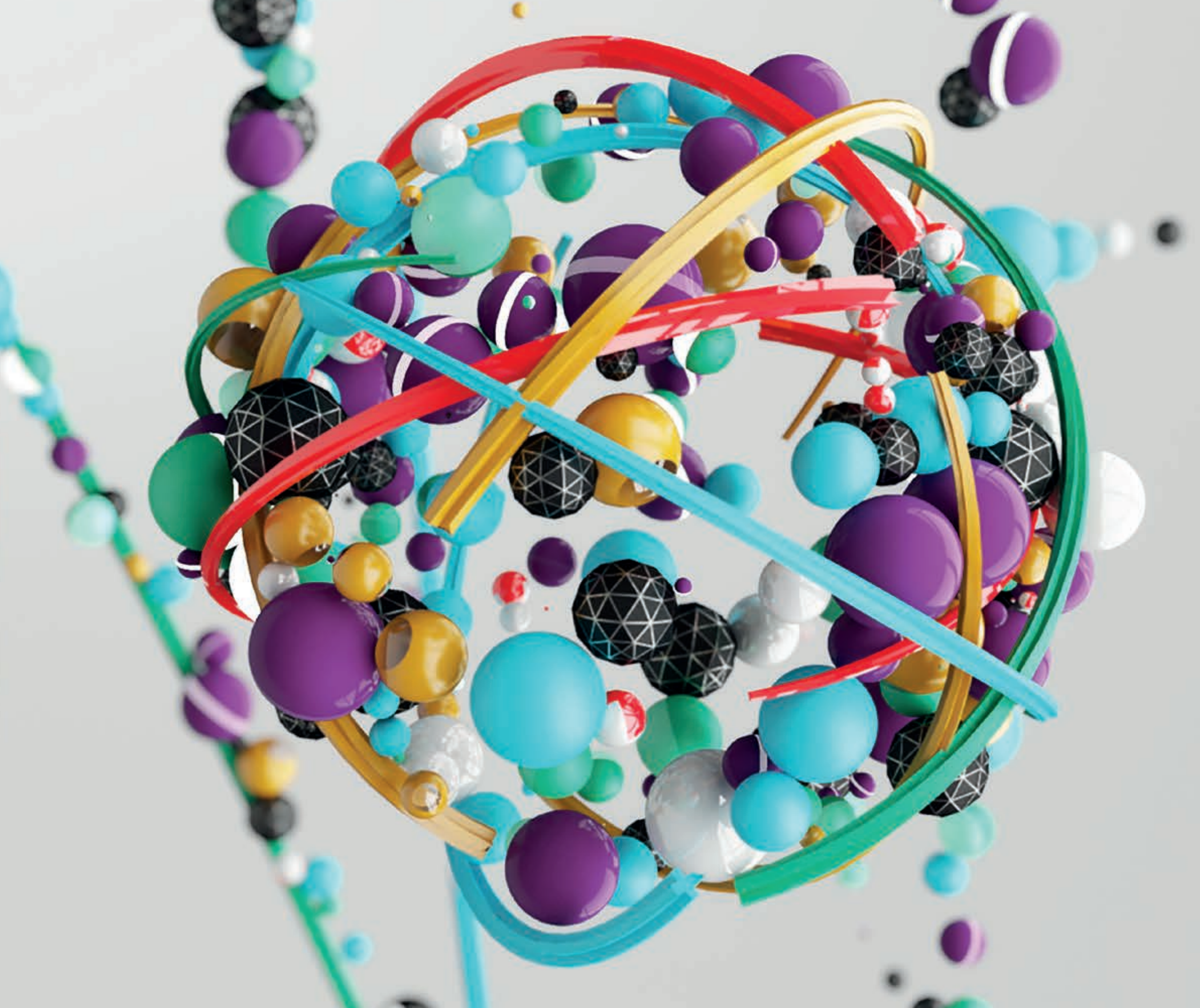
International Energy Agency
Secure
Sustainable
Together

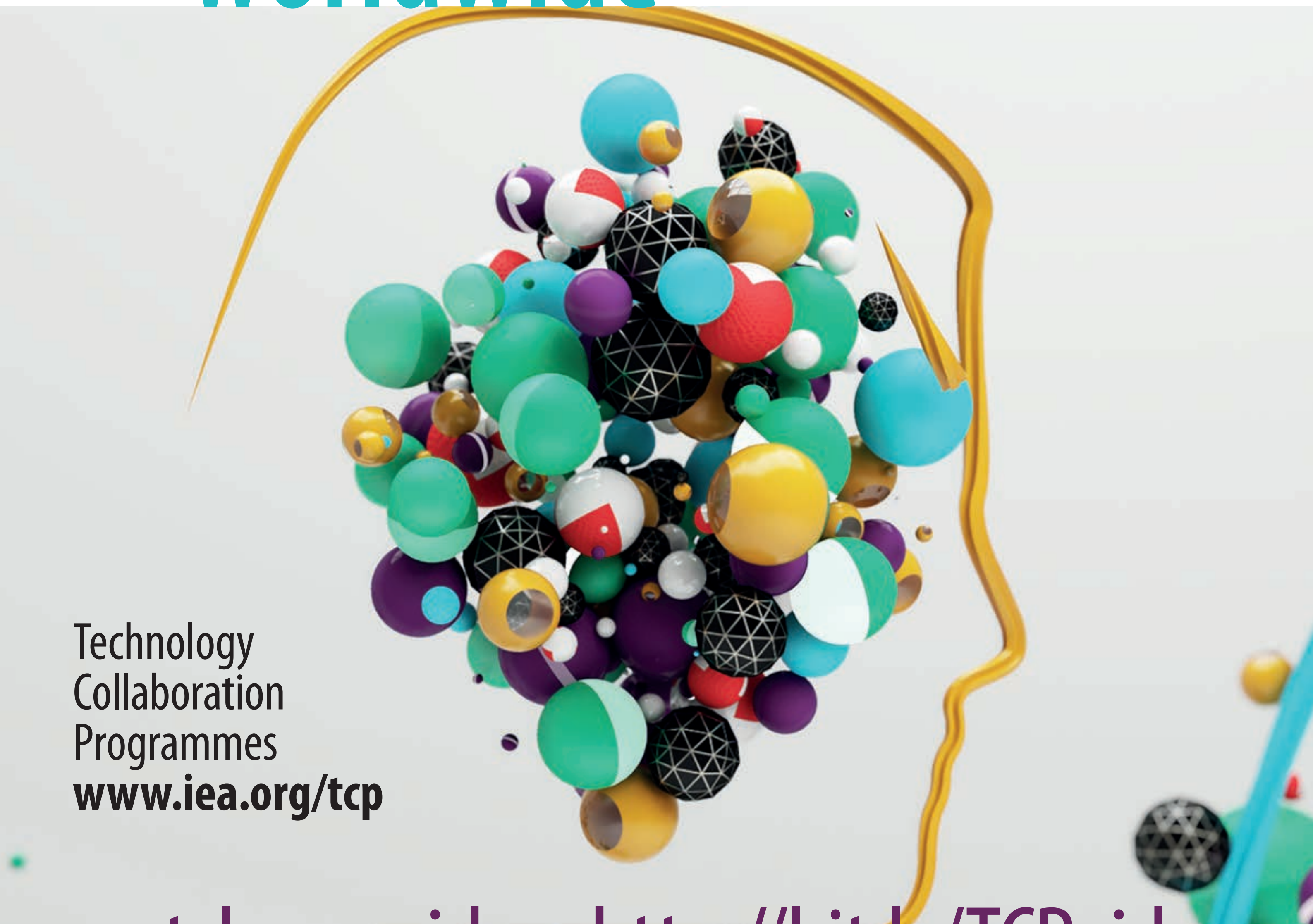
Technology Collaboration Programmes

Highlights and outcomes



iea Energy Technology Network
Technology Collaboration Programmes

Accelerating technology innovation worldwide



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Foreword

At a time when there are many calls for accelerating innovation, for a renewed approach to "technology transfer," for enhanced access to finance for clean energy technology development and deployment, it is worth highlighting the "quiet success story" that the IEA Implementing Agreement mechanism represented over the past four decades – a rarity in multilateral technology collaboration.

The year 2015 marked the 40th anniversary of these groups of experts as well as the rebranding of the Implementing Agreements as Technology Collaboration Programmes (TCPs). It also represented a critical juncture in the IEA's efforts to expand collaboration beyond current membership, to provide authoritative support to international efforts to tackle climate change, and to consolidate the IEA's role as the global clean energy hub. At the IEA 2015 Ministerial meeting, the representatives of the 29 IEA member countries and of nine IEA partner (non-member) countries recognised the critical need for increased clean energy technology research and development to achieve our shared climate goals, improve energy security, and provide access to affordable and reliable energy for everyone. In support of these objectives, the IEA members called on the Secretariat to strengthen the energy technology and innovation-related activities of the Agency, including through the TCPs.

This publication provides an overview of the activities and recent accomplishments of the TCPs. Even in the context of an increasingly complex and multi-lateralised global energy landscape, the centrality of the IEA and of the TCP mechanism to meeting the energy challenges remains uncontested. In this regard, TCPs are also testimony to the IEA's commitment to work together with countries beyond its membership and to explore synergies with industry. The first partner country joined a TCP in 1985. Entities from the People's Republic of China ("China") now participate in 18 TCPs (including one as a Chair), more than several IEA member countries. TCPs have supported – and strengthened – IEA bilateral and multilateral relations by feeding into and taking advantage of the IEA statistics, technology analysis, policy recommendations and a multitude of other tools.

The 39 TCPs operating today involve thousands of experts worldwide who represent nearly 300 public and private organisations located in 51 countries. Participants in the TCPs have examined more than 1 900 energy-related topics.

The global transition to cleaner energy is going to require teamwork on a scale the world has never seen. This argues for strong, resource-efficient, and result-orientated multi-lateral co-operation. The unrivalled breadth of TCPs' analytical expertise – on both energy technologies and markets – and their coverage of all fuel sources, including energy efficiency, are unique assets. This strength underpins the efforts of the IEA to provide support across the full spectrum of international low-carbon energy partnerships and initiatives, ranging from high-level policy fora such as the Clean Energy Ministerial, to activities under the bodies of the United Nations Framework Convention on Climate Change.

Indeed, the founders of the IEA had the foresight to create a mechanism that has withstood the test of time through four decades. Today, the TCP network is more relevant than ever in supporting energy security, economic growth, and environmental protection.

I strongly encourage those who are actively involved in energy issues, whether in government or in the private sector, to participate in and take advantage of the TCPs to accelerate innovation. This sort of global co-operation can lead to the solutions needed to address today's energy challenges.

Dr. Fatih Birol
Executive Director
International Energy Agency

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Comments and questions should be addressed to:

Ms. Carrie Pottinger

International Energy Agency

9, rue de la Fédération

75015 Paris

Email: tcp.forum@iea.org

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Building on 40 years of innovation: A new era for energy technology collaboration

1975-2015: 40 years of innovation to meet energy challenges

Through the IEA Technology Collaboration Programmes (TCPs), the IEA founders had the foresight to create a flexible collaboration mechanism for both IEA member and partner countries as well as industry that has continued to enable innovation to respond to energy challenges over four decades.

At the inception of the IEA, its members recognised the need for a flexible mechanism to respond to energy technology challenges through joint research, development and demonstration (RD&D) activities. Against this backdrop, the IEA Governing Board approved the establishment of TCPs in 1975 as the principal IEA tool for multilateral technology collaboration.

Their creation stemmed from the idea that countries had more to gain from pooling their tightening budgets for RD&D activities with other governments, industry and academia rather than carrying out separate efforts. Sharing information and experiences through a TCP accelerates outcomes on innovative energy technologies to the collective benefit of all IEA members – as well as beyond – who face similar energy challenges.

This principle of collective innovation to meet shared challenges has been at the heart of the TCPs for the last 40 years. When significant challenges to the global energy system have arisen, the TCPs have facilitated multilateral responses through co-operative RD&D efforts to spur innovation.

The early years: Casting a wide net to strengthen energy security

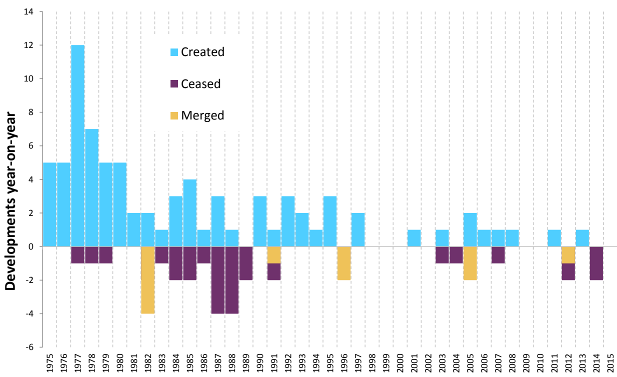
During the period 1975-80, oil supply disruptions and soaring oil prices spurred research into alternative sources of energy and technologies to improve energy efficiency. Thirty-four TCPs were created during this period, nearly one-third of which focused on coal and related technologies. For example, the participants in one former TCP agreed to build a pilot plant of a fluidized bed converter in Grimethorpe, United Kingdom, one of the first examples of research to improve the efficiency of coal-fired power. The design and construction was shared equally among the three participating organisations (Kernforschungsanlage, Germany; the National Coal Board in the United Kingdom; and the United States Department of Energy). Construction began in 1977 and tests began in 1980. At the peak of its activity the project employed 60 staff, including 26 who were seconded from 15 companies located in Germany, the United Kingdom and the United States. The total cost of the project was USD 181 million (2015 prices).

But the search for alternative energy sources to bolster energy security extended far beyond conventional fuels as pioneering research on renewable energy was also a feature of the early TCPs (the Bioenergy TCP, the Hydrogen TCP, the Hydropower TCP, the TCP on Solar Heating and Cooling [SHC TCP] and the TCP on Wind Energy).

In 1977, the Wind TCP was formed. Seven participating IEA countries agreed to each design, build and operate a 1 megawatt (MW) (or greater) wind turbine and to share their respective knowledge and experiences. By 1985, 13 large-scale wind turbines had been built in the seven countries. Following the initial construction period, applied research began on each of the pilot turbines, associated systems and performance under respective weather conditions. This TCP continues to operate today, though the focus of activities has changed to analysis of wind energy technologies and policies.

Alongside finding new sources of supply, equally important was to discover ways to reduce pressure on supply through solutions on the demand-side. Thus, the first TCPs focusing on reducing energy consumption and efficiency in the buildings sector were created. Fourteen of the initial TCPs remain active today, including the TCP on Buildings and Communities (EBC TCP); SHC TCP; TCP on Clean Coal Centre (CCC TCP); and TCP on Tokamak Programmes (CTP TCP), a technology for fusion power (Figure 1).

Figure 1. TCPs created, ceased or merged 1975-2015



Cleaner, safer energy technologies for a new century

As the 20th century drew to a close, the world's focus increasingly shifted to energy solutions that could lessen environmental impacts as well as contribute to energy security. Public awareness of the nexus between energy and the environment had been raised after incidents like the Chernobyl disaster of 1986. In response, countries sought to increase research into "safer" energy solutions.

Many of the 22 new TCPs created during the 1980s focused on increasing the energy efficiency of industry, vehicles and buildings while others examined environmental and safety aspects of new technologies, such as nuclear fusion. Nine of these TCPs remain active today.

An example of a TCP founded during this period is the TCP on District Heating and Cooling including Combined Heat and Power (DHC TCP). Established in 1983, the DHC TCP is now a prominent repository of scientific information, as it carries out applied research on district heating and cooling technologies, low-temperature heat sources, and guidelines for connecting buildings to district heating.

The adoption of the Kyoto Protocol in 1997 marked a key step for co-ordinated international action on climate change. Concurrently, the search for low-carbon technologies was accelerated through TCPs during the 1990s. Fifteen TCPs were created focusing on transport (fuel cells, hybrid and electric vehicles); carbon capture and storage (CCS); renewables (concentrating solar power, geothermal, photovoltaics, and hydropower); demand-side management of electricity; industrial processing; nuclear fusion; and information exchange.

Much of the RD&D conducted over this period is still bearing fruit today: one example of a technology benefiting from the research conducted through a TCP established in the 1980s is solar photovoltaics, which is now enjoying widespread adoption.

Meeting the challenge posed by globalisation and increases in global demand

The new millennium saw rapid technological change alongside the widespread adoption of the internet. The global energy market expanded to service the increasing appetite for electricity in both developed and developing countries. This created stress on the existing energy infrastructure and, as a result, several regions of the world experienced large-scale electricity blackouts.

The environmental impacts of delivering energy to millions of new consumers were also significant. Air quality issues proliferated and in 2004, for the first time in history, China's CO_2 emissions surpassed those of the United States (IEA, 2014a). During this period, nine TCPs were created focusing on topics such as smart grids, integrating networked devices and variable renewables into electricity networks; environmental and safety issues of gas and oil exploration; technology transfer to bridge the gap between developed and developing country energy technologies; and renewable energy technology deployment, to fast-track the adoption of clean energy technologies that had now become commercialised.

The founding of the TCP on Energy Efficient End-Use Equipment (4E TCP) in 2008 was a direct response to the growing energy use of appliances and equipment in both developed and developing countries, as rapid technological change brought a wide array of energy-using devices into the marketplace. In 2014, the 4E TCP published new research on standby power used in networked devices, which is now informing a co-ordinated policy response from G20 countries.

A diverse array of activities

Experts participating in the TCPs have carried out a broad range of activities (more than 1 900 topics covered to date).

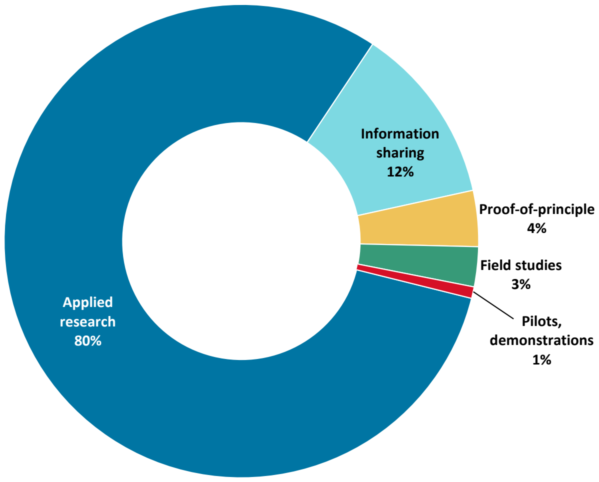
Over the past 40 years TCP activities have produced a range of noteworthy results including inventions, pilot plants, demonstration projects, databases, and development of standards. In addition to physical products, participants in the TCPs have generated substantial information and data, disseminated via scientific publications, guidebooks, databases and policy papers (amongst others). These results have often greatly contributed to the work of the IEA Secretariat by feeding into analyses and outputs.

At present, activities carried out by the TCPs can be grouped into four broad categories: proof-of-principle; pilot and demonstration projects; field studies, measurements and instrumentation; and applied research. Most TCPs also seek to raise awareness of the contribution that respective technologies and systems can make in achieving climate and energy goals.

Proof-of-principle (PoP)

Proof-of-principle (PoP) or proof of concept is the first step towards further development of a potential technology or energy solution. One of the first PoP projects under the Bioenergy TCP concerned fast-growing tree species (willow, alder, or poplars) to study genetic improvements and the development of appropriate management regimes and harvesting methods that would maximise biomass-to-energy production. Other studies investigated fungi and symbiotic nitrogen-fixing bacteria, which resulted in a catalogue of nearly 400 species as well as the cultivation and use of algae for the production of hydrogen or biofuels.

Figure 2. Focus of TCP activities 1975-2015



Pilot and demonstration projects (PDP)

Pilot and demonstration projects (PDP) are the most visible outcomes of research activities. They are costly to produce and may incur considerable risk. Multilateral co-operation enables countries to share these potential burdens and to go beyond what could have been achieved individually. Overall PDPs only represent 1% of all TCP activities to date but there have been some notable examples including the Grimethorpe pressurised, fluidized bed converter; and the design, construction, testing and operation of solar collectors and a central receiver system in Almeria, Spain from 1981-85.

More recently, a PDP on CCS assisted in the establishment of the Weyburn CO_2 monitoring and storage project, a major international endeavour (CAD 40 million) involving Canada, the United States and the European Commission (EC), 15 industrial actors and 25 research and consulting organisations from around the world.

Field studies, measurements and exchange

Field studies (on-site or *in situ* testing and surveys) enable monitoring and testing of technologies under real-life operating conditions. *In situ* tests are regularly conducted under TCPs focusing on applied research. Examples include testing of temperature gradients in existing geothermal wells; gathering methane emissions from hydropower reservoirs; study of local air flow for wind turbine siting; enhanced oil recovery techniques in existing reservoirs; small-scale reformers for on-site hydrogen supply; simulated field tests of small meters for district heating networks; thermal response tests for underground thermal energy storage containers; erosion and corrosion in test plants; and in-bed sampling and measurements of pressurised fluidized bed combustion (PFBC) devices.

Testing technology performance also requires high-quality and consistent instrumentation. Thus a range of activities involves testing measurement instruments between laboratories across the world to ensure they are calibrated to deliver consistent results. The TCP on Advanced Materials for Transportation (AMT TCP) and the 4E TCP have carried out such "round robin" testing.

In addition to direct funding of studies and measurements, a number of TCPs are funded through in-kind contributions from laboratories and research centres as well as sharing personnel, equipment – and, not least, benefits stemming from the research results. For example, participants in several of the TCPs focusing on fusion power build and maintain costly experimental reactors, sharing results of their respective experiments. The main activity of one of the fusion-related TCPs consists of scientists' exchanges among reactor sites.

Applied research

Applied research has been the focus of the greatest number of TCPs created to date (47%), and accounts for 80% of activities carried out since 1975. A large proportion of this research has been focused on energy efficiency and renewable energy technologies.

Laboratory and *in situ* testing, simulations, comparative and life-cycle analyses are carried out in order to define the reliability and durability of the technology and to set optimal operating conditions and parameters. The results of these activities are compiled into data sets that are analysed to form "benchmarks", which in turn form the basis for the industry standards that underpin regulatory instruments and commercialisation of technologies. International collaboration in applied research is beneficial to participants as it enables a broader testing base and a variety of market conditions under which the technology can be deployed.

A wide range of applied research-related activity has been conducted by TCPs over the last 40 years, including:

- **Technical analysis**, testing technology performance individually or within broader technical or distribution systems. The SHC TCP, created in 1976, has carried out more than 50 studies to date that have resulted in more than 200 research articles, publications or workshops.
- **Environment, safety and waste assessments**, to systematically examine the technology's impact on the environment, health or safety issues, as well as the potential benefits associated with its use. An example is the TCP on Advanced Motor Fuels (AMF TCP) which tested and developed the technique of blending alcohol into motor fuel as early as 1984.
- **Life-cycle and systems analysis**, to understand how the technology may integrate with systems (e.g. balance-of-plant or infrastructure) and assess its overall environmental footprint over its entire lifespan. Examples include design and optimisation of integrated systems for hydrogen (Hydrogen

TCP); urban-scale, grid-connected photovoltaic applications (PVPS TCP); and life-cycle assessment of electric vehicles (TCP on Hybrid and Electric Vehicles, or HEV TCP).

- **Barrier analysis**, examining the legal, regulatory, social or economic barriers to the uptake of a technology. The TCP on Greenhouse Gas R&D (GHG TCP) studies a range of barriers to the adoption of CCS.
- **Economic analysis** of an energy source or technology to ascertain the costs of extraction or operation, the current or potential markets for the technology, and if it is nationally or internationally traded. Examples include a cost-benefit analysis of plastic piping systems (DHC TCP); assessing business models for a more effective uptake of energy services for demand side management (DSM TCP); and calculating energy pay-back periods of crystalline silicon photovoltaic systems on a grid connected, rooftop system located in southern Europe (PVPS TCP).
- **Standards and benchmarks analysis**, to establish uniform or comparable technical criteria under which the technology may operate. Examples include analysing rating and certification procedures of solar heating and cooling installations (SHC TCP), solid biomass fuels standardisation and classification (Bioenergy TCP), and mapping and benchmarking of efficient equipment (4E TCP).
- **Forecasts** of energy demand and supply or technology use. The CCC TCP regularly produces reports on coal potentials covering topics such as prospects for clean coal technologies in partner countries.

Raising awareness

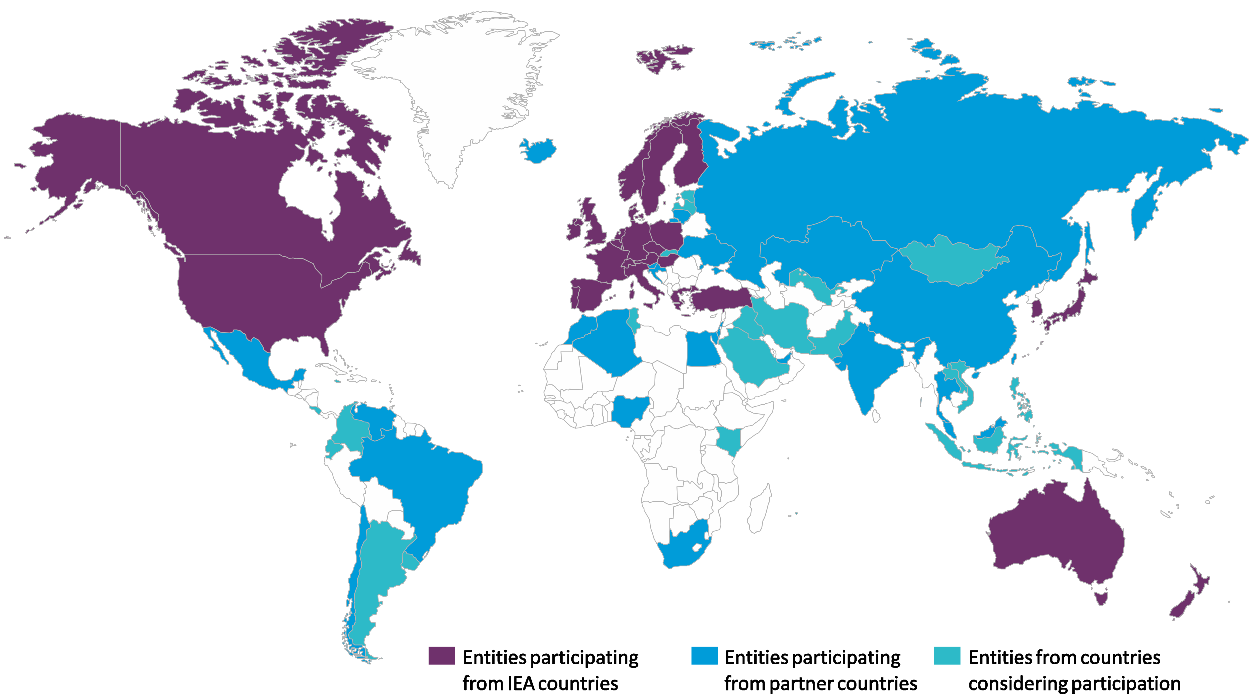
An important part of the work of TCPs has involved carrying out activities to raise awareness of new energy technologies and practices by sharing research results among broad communities of experts and non-experts. These efforts include hosting websites, distributing newsletters, development of guidebooks and manuals, training, capacity building, and stakeholder networking.

A global platform for innovation

Participation of non-IEA countries has expanded over time, with some now taking a leadership role.

As of 31 December 2015, nearly 300 entities located in 51 countries worldwide have become signatories to TCPs. From its foundations as an IEA member-driven initiative, the TCPs are increasingly becoming a global platform for energy technology co-operation.

Figure 3. Worldwide participation in TCPs (as of 31 December 2015)



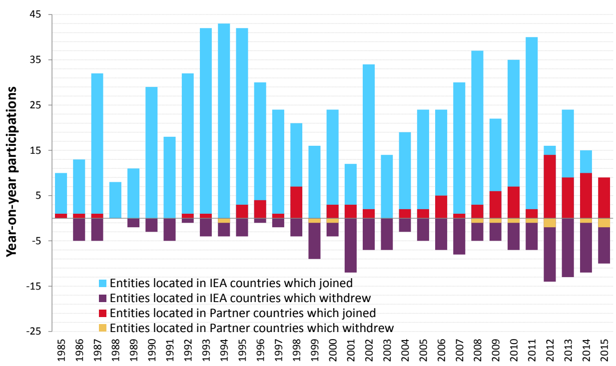
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Entities from 26 IEA member countries represent the majority (84%) of participants, led by the United States (with entities participating in 36 TCPs) and Japan (with entities participating in 31 TCPs). However, the growing involvement of participants beyond IEA member countries is a reflection of the global nature of energy and climate challenges and the IEA's commitment to working on a global scale.

The IEA Framework for International Energy Technology Co-operation (IEA Framework), introduced in 2003, was designed to provide a simplified legal mechanism for international collaboration and, in particular, to facilitate participation of partner countries and other stakeholders such as business and industry. Since then, partner country interest in TCPs has increased, with participation of partner countries more than doubling.

Today, 65 entities from 25 partner countries participate in TCPs. Meanwhile, discussions are underway with entities from a further 23 partner countries which are considering becoming a participant in one or more TCPs. Figure 4 illustrates the trend in participation of entities from IEA member and partner countries.

Figure 4. Year-on-year change in participation in TCPs



"Various Chinese institutions, through their extensive involvement in IEA Energy Technology Initiatives, have benefited a lot from exposure to the world's latest energy technologies and information. They are enthusiastic to work with international partners and keen to improve their innovation capacity through this platform. The feedback is very positive."

Wan Gang, Minister of Science and Technology, People's Republic of China

China's striking increase in participation in TCPs, from two in 1995 to 18 in 2015, is testimony to the appeal of the TCPs to fast-growing economies outside the IEA membership base. Most recently, Kazakhstan joined the TCP on Energy Technology Systems Analysis (ETSAP TCP), and Chile joined the AMF TCP.

Today, some partner countries are even leading TCP activities. China serves as the Chair of the TCP on Environmental, Safety and Economic Aspects of Fusion Power (ESEFP TCP), and India leads a project on energy efficiency labelling (DSM TCP).

Co-operation across all sectors

The IEA Framework has provided the opportunity for collaboration between government, the private-sector and international organisations.

While the participation of at least two IEA member countries is required to form a new TCP, the success of many activities would not be possible without the active involvement of the private and non-governmental sector, either through being designated by their government or through the category of Sponsor. Sponsors include industry associations, engineering and service companies, multinational enterprises, privately funded research organisations, and consultancies. In the early years of the TCPs, industry and non-governmental entities had been participating in TCP collaborations only when designated by their respective governments. For example, General Motors and Ford Motors (through the United States Department of Energy) and Daimler-Benz, Volkswagen, and the German Space Agency (through the former German Ministry for Research and Technology) carried out comprehensive exchanges of reports and materials that focused on ceramic combustion chambers for automotive gas turbine engines.

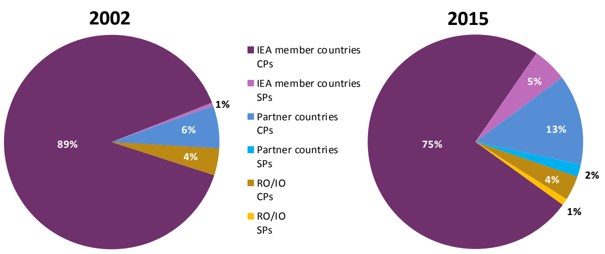
"Over the more than 13 years Chevron has been a member of the GHG TCP, my team of experts and I have benefited from the independent and authoritative assessments and access to expert networks focusing on carbon capture and storage technologies and related issues."

Arthur Lee, Chevron Fellow and Principal Advisor, Chevron

Since 2003, non-governmental entities have been encouraged to participate in the TCPs as Sponsors, which does not require designation by a government. As such, participation of non-governmental entities has gradually increased (Figure 5). A significant number of multinational enterprises and industries participate as Sponsors in two TPCs focusing on coal (CCC TCP and GHG TCP), and industry associations participate as Sponsors in several TCPs on renewables.

Several important regional and international organisations participate in the TCPs. The EC has been an active participant since 1977 and today takes part in 19 TCPs. Since 2007, the Organisation for Petroleum Exporting Countries (OPEC)[1] has participated in the GHG TCP. The United Nations Industrial Development Organisation (UNIDO)[2] has been involved in the Hydrogen TCP, and ITER[3] is part of the CTP TCP.

Figure 5. Participation in TCPs by category[4]



Note: RO/IO = regional organisation/international organisation; CP = Contracting Party; SP = Sponsor.

Most recently, two regional organisations joined the SHC TCP: the Economic Community of Western African States (ECOWAS)[5] and the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE).[6] In addition, some TCPs currently carry out joint activities with the International Renewable Energy Agency (IRENA), particularly the ETSAP TCP and the TCP on Renewable Energy Technology Deployment (RETD TCP). Further details of participation in TCPs are provided in the Statistics section.

By comparing the TCP mechanism to other initiatives, two separate studies conducted independently by the Organisation for Economic Co-operation and Development (OECD) confirmed key advantages of the TCPs: the first study highlighted the flexible governance structure; opportunities for participation by the private sector; equal sharing rights (i.e. intellectual property); the creation and strengthening of networks to increase knowledge sharing; and, the participation of partner countries (OECD, 2012a). The second study found a positive correlation for some countries between participating in a TCP and patents registered by two or more of the TCP participating countries, or co-invention (OECD, 2012b).

The next 40 years: A new era for energy technology collaboration

The critical need for enhanced collaboration and support for energy technology innovation is increasingly recognised globally. The IEA Framework can play a key role in delivering solutions for energy sector transition provided that adequate resources are committed alongside expanded engagement with business as well as emerging and developing economies.

The year 2015 marked the 40-year anniversary of the first TCPs, and provided a timely opportunity to take stock of the future role of the TCPs at a time when the world is at a critical juncture in its efforts to combat climate change. On 18 September 2015, under its new administration, the IEA Secretariat hosted a meeting led by the IEA's Executive Director, with representatives from more than 30 TCPs plus officials from the the IEA Committee on Energy Research and Technology (CERT), the Working Parties (WPs), as well as Partner countries (China, Mexico and South Africa) to identify opportunities to expand and enhance TCP activities.

Under the event's theme "Preparing the Next 40 Years of Multilateral Energy Technology Collaboration" numerous ideas emerged, and the TCPs put forward a series of suggestions for increased interactions with the Secretariat, support for broader dissemination of TCP activities and outcomes, and ideas for improving communication and awareness. This set in motion a series of reflections and discussions under the IEA Energy Technology Network as well as at high level at the IEA Ministerial meeting on 17-18 November 2015. Recognising the critical need for increased clean energy technology research and development to fully achieve IEA shared goals, the ministers provided a strong mandate for the IEA to scale up its work on energy technologies and to consolidate its role as global clean energy hub.

In this respect, TCPs provide a flexible and effective framework of collaborations to accelerate technology-related innovation that supports energy security, economic growth and environmental protection. While participants in the TCPs have produced an impressive array of results, ramping up RD&D efforts and enhancing engagement with public and private sector institutions worldwide are essential to maximising the impact of the TCPs and their potential to help meet high-level policy goals.

More resources for clean energy innovation

A key aspect of the success of the TCPs over the past decades has been their capacity to evolve and shift the focus of activities to respond to new energy challenges over time, thereby remaining highly relevant vis-à-vis advances in energy technologies, systems and policies. Much of the transformational change needed in the energy sector to meet the target of limiting the global temperature increase to 2°C (the 2DS as defined in the *Energy Technology Perspective* series) is yet to take place. TCPs can play a crucial role to bring this about by scaling-up international, national, and regional RD&D efforts according to a "solution sharing" approach.

Concerted, consistent and well-targeted global RD&D investments by both the public and private sectors will be one of the keys to making the technological breakthroughs required to bring cost-competitive low-carbon energy technologies to market. The TCP mechanism presents an effective and tested framework for co-ordinating energy RD&D efforts. Therefore, an increase in participation in and resources for TCPs targeting both supply side and end-use technologies could be part of the contribution of IEA member and partner countries to global efforts to mitigating climate change and enhance energy security.

Greater industry involvement in TCPs

As the private sector will be responsible for making the bulk of future energy investment, governments and industry must work hand-in-hand to develop the energy solutions and capacities that would benefit the whole sector but are too risky or expensive to be handled by a single country, company or research institute. The TCPs provide an excellent platform for public-private partnerships, where participation of non-governmental entities improves the understanding of the commercial aspects that are important to accelerate deployment of a technology. While industry representation in the TCPs has increased in recent years, significant potential remains to expand private sector participation and interactions.

Broadening the scope of global engagement

Several factors warrant encouraging further participation of IEA partner countries in the TCPs. Collaboration through TCPs provides mutual benefits for emerging economies and for the IEA: it can support policy and decision makers' efforts to set priorities for low-carbon technologies, strengthening national capabilities, aligning RD&D budgets, and attracting the required investments in clean technologies. In turn, TCPs can serve as "ambassadors" of IEA energy technology work to policy makers in all parts of the world, broadening the portfolio of what the IEA can offer under its activities of bilateral and multi-lateral engagement.

The participation of countries at the forefront of efforts to improve energy access could help with adapting and deploying a generation of technological solutions that are suited for application in a developing country context. Distributed generation technologies are just one example of a research topic that would benefit with greater engagement from the countries in which such technologies are likely to be applied.

Future activities under the TCPs ought to expand far beyond the IEA member countries, to widen the breadth of countries engaged through this framework to overcome the twin challenges of climate change mitigation and energy access in an inclusive manner. China's increased participation and central role in many of the TCPs has been lauded as one of the successes over the recent years – and rightly so.

> "The main benefit derived from our participation in the PVPS TCP is the knowledge gained for policy making. In this connection, the PVPS TCP has confirmed to be a valuable global platform to exchange information, data and views on the photovoltaics sector with high-level experts."
>
> *Dr. Fabio Belloni*
> *European Commission*
> *Directorate-General for Research & Innovation*

Enhanced communication of TCP achievements

In December 2015, at the 21st Conference of the Parties of the United Nations Framework for a Climate Change Convention (COP21) the IEA Secretariat organised in collaboration with the French Presidency and other partners under the Lima-Paris Action Agenda (LPAA) Innovation focus, an event entitled "Accelerating Innovation through Multilateral Energy Technology Collaboration". The event drew from experiences under the TCPs and highlighted how these groups provided the set-up for augmenting national research efforts, avoiding unproductive duplication in some areas, sharing knowledge and pooling resources to deliver cost-effective solutions to common challenges.

Looking ahead, the IEA Secretariat will continue its efforts to ensure the results of TCP activities are communicated to policy makers. On the occasion of the IEA Ministerial, a short promotional film on the TCPs was released that can be accessed from the IEA website. This publication aims to make a further contribution to the efforts to raise awareness of the policy implications of significant TCP activities and outcomes.

The global transition to cleaner energy will require a push towards more co-ordination and support for low-carbon energy innovation worldwide to increase confidence in the effectiveness of collective efforts and attract renewed public and private participation across all phases of energy technology RD&D. TCPs are uniquely poised to play a key role in this new era of technology collaboration.

Part 1

Technology Collaboration Programmes (TCPs)

TECHNOLOGY COLLABORATION PROGRAMMES (TCPS)

Highlights and outcomes

Accelerating research, development and deployment (RD&D) of energy technologies and systems is a crucial component of resolving key global challenges, such as promoting efficient production and use of energy, ensuring energy security, and providing global access.

The TCPs provide a flexible mechanism for IEA member and partner countries (IEA non-member country) governments, industries, businesses, and regional or international organisations (RO/IO) to leverage resources and multiply the results of research and transfer these into energy technologies and related issues.

As of 31 December 2015, there were 39 TCPs working in the following areas:

Cross-cutting: two TCPs carry out cross-cutting activities, such as modelling and technology transfer, that are of relevance to a wide range of sectors and energy sources.

End use: Improving end-use energy efficiency, whether in buildings and commercial services, electricity, industry or transport sectors, is crucial for the environment, economic development and energy security. Fourteen TCPs currently research various aspects of each end-use sector.

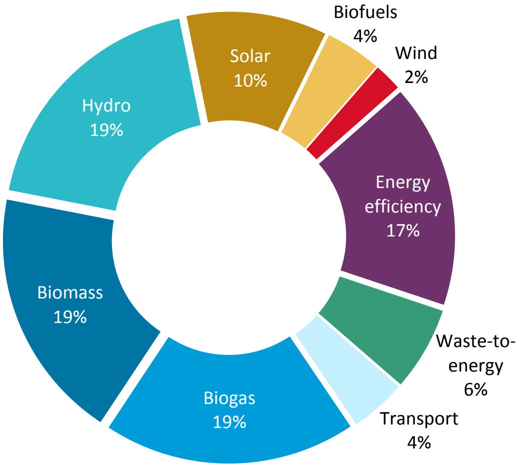
Fossil fuels: Fossil fuels lie at the core of energy supply in the transport and electricity generation sectors and will likely continue to play a key role for years to come. At the same time it is important to minimise greenhouse gas emissions along the production-utilisation chain from every barrel of oil, cubic metre of gas or tonne of coal while reducing costs and improving efficiency. Five TCPs carry out activities focused on fossil fuels.

Fusion power: Fusion power has the potential to supply baseload electricity with minimal environmental impact. Significant research is ongoing to demonstrate the safety and economic viability of fusion power technologies, as well as on fusion materials, reactors, superconductors, plasmas, and a range of devices and concepts relating to fusion science. Eight TCPs relate to fusion power.

Renewable energy and hydrogen: Renewable energy technologies have expanded rapidly in recent years and provide clean, sustainable, and cost-effective applications for electricity generation, heating or cooling services as well as for the transport sector. Ten TCPs pertain to renewable energy and hydrogen technologies.

CLIMATE TECHNOLOGY INITIATIVE (CTI TCP)

Focus of CTI clean technology projects having reached financial closure during 2013-14.



Source: Adapted from data provided by the CTI TCP.

Highlight

Enabling global green growth through project financing

The CTI TCP provides a framework to bridge the gap between investors and clean energy projects in need of financing. In 2013-14 it saw 19 project deals completed (190 MW capacity) which could result in CO_2 emissions reduction of 302 000 tonnes/year.

Non-OECD countries are expected to account for 97% of the growth in global energy demand from 2012-40 (IEA, 2014b). As a result, developing and emerging economies will increasingly share the burden of building an environmentally sound future. Sharing best practices, knowledge, tools and financing options are important steps to accelerating development and diffusion of clean technologies.

For these reasons the CTI TCP developed the Private Financing Advisory Network (PFAN), a multilateral activity dedicated to reducing greenhouse gas (GHG) emissions by bridging the gap between investors and clean energy projects in need of financing. Promising projects are identified at an early stage of development, professional assistance provided through preparation of a financially sound business plan and investors are introduced to mature projects.

PFAN mitigation activities have expanded significantly: 19 projects reached financial closure, representing 190 MW of clean generation capacity and the potential to reduce 302 000 tonnes of CO_2 emissions per year. PFAN projects being considered increased by 52% compared to end-2012, representing an additional USD 6 billion of total value. The total amount of financing raised amounted to USD 578 million, at a leveraging rate of 1:100 (public funds to private financing).

The large majority of PFAN mitigation projects (70%) reaching financial closure focused on renewables (biomass, biogas, hydropower, solar, biofuels and wind), energy efficiency (17%), waste-to-energy (6%) and transport (4%). There are similar trends for projects in the pipeline at end-2014, with the addition of projects focusing on geothermal energy. The majority of these projects were located in Asia (54% of which 16% in China); sub-Saharan Africa (30%); and Latin America and the Caribbean (4%). In 2015 PFAN anticipated to scale up climate adaptation related projects across Sub-Saharan Africa.

Membership in the PFAN network grew by 30% compared to end-2012, comprising 130 government agencies, investment banks, regional development banks, small power producer collectives, competency centres and green initiatives.

PFAN activities receive direct or indirect support from participants in the CTI TCP, national agencies such as the United States Agency for International Development, the Renewable Energy and Energy Efficiency Partnership, the Energy and Climate Partnership of the Americas, the International Development Research Centre, and the International Centre for Energy Technology Transfer.

Activities

- Application of clean energy technologies
- Assessing developing country technology needs
- Clean technology business network
- Capacity building
- Collaboration with climate-related international fora
- Exchange of experts
- Facilitation of private financing for technology transfer
- Financing adaptation-related projects
- Market mechanisms for climate action – urban level
- Private financing advisory network (PFAN)
- Regional clean energy financing forums
- Technology needs assessments

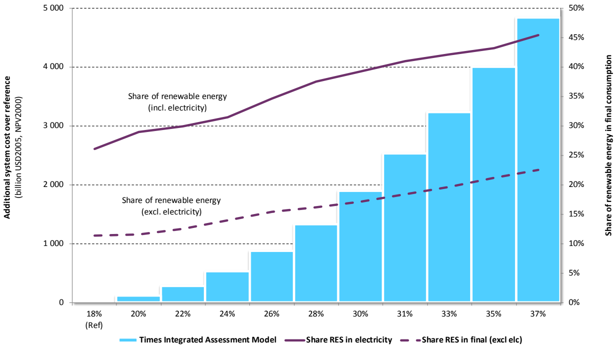
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	8	–	–
Sponsors	–	–	–

www.iea.org/tcp/cross-cutting/cti/

ENERGY TECHNOLOGY SYSTEMS ANALYSIS (ETSAP TCP)

The step-by-step approach to modelling shows pathways to doubling the share of renewable energy in final consumption by 2030.



Source: Adapted from data provided by the ETSAP TCP.

Highlight

Pathways to step-up the share of renewables by 2030

The ETSAP TCP assists decision makers to assess the current energy technologies and markets that will meet the future challenges of energy supply, economic development and environmental protection. Activities carried out included support for comparing pathways to double the share of renewables by end-use sectors by 2030.

As the share of renewable energy is expected to grow only from 14% to 19% in the global energy mix by 2040 under current and planned policies, developing pathways to assist policy makers in identifying technology deployment, investment and policy needs on a national and international level is a priority (IEA, 2014b).

To support the *Renewable Energy Roadmap (REmap 2030)* of the International Renewable Energy Agency (IRENA), the ETSAP TCP and IRENA collaborated on a comparative analysis of their pathways to achieving a doubling of the share of renewables in end-use sectors by 2030.

The two approaches quantify the expected impacts of increased renewable energy sources (RES) by identifying technology deployment, investment and policy needs on a national and global level by creating comparable cost-supply curves across countries.

REmap 2030 provides detailed information on each of the renewable energy sources, technologies and their deployment potentials in the different energy sectors in a simple, replicable and transparent format based on national data in order to explore pathways to reach the 2030 targets.

The ETSAP TCP approach incorporates energy efficiency measures to achieve incremental increases in the share of renewable energy in the end-use sectors. For each increase, systems costs (i.e. grid integration and capital stock turnover) required to increase RE at the lowest cost are calculated. This incremental, integrated approach enables policy makers to gain understanding of the long-term costs – and benefits – associated with strategic choices concerning RES and technologies.

For example, in the first incremental increase, natural gas for electricity generation is displaced by onshore wind, photovoltaics and, depending on the resources, geothermal, while oil is displaced by biofuels in the industry sector, and diesel is displaced by ethanol in the transport sector. As the demand for low-carbon electricity generation will continue to increase, a share of 36-44% for RES in end-use sectors was feasible by 2030. These steps also highlight benchmarks that may be integrated into national plans and targets.

On the other hand, the IRENA approach explores strategies to increase the amount of provision from RES, leaving out possible further contribution from energy efficiency measures, to increase the share of renewables in final energy use. Understanding different approaches provides for more accurate energy planning. Information on the two approaches has been integrated into IRENA's REmap 2030 publication.

Activities

- Advances in modelling, tools and training modules
- Building and improving a global multi-regional model
- Contributing to the World Bank Climate Smart Planning Platform
- Energy technology briefs
- Linking energy systems and macroeconomic models
- Modelling behaviour in energy systems models

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	20	2	1
Sponsors	1	–	–

www.iea.org/tcp/cross-cutting/etsap/

BUILDINGS AND COMMUNITIES (EBC TCP)

An example of integrated energy and urban planning (Rieselfeld district, Freiburg, Germany).

Highlight

Guiding successful urban energy planning

The EBC TCP provides high-quality scientific reports and summary information for policy makers on integrated planning and building design; building energy systems; building envelopes; community- scale methods; and real building energy use. Given national emissions targets, local decision makers must define strategies and implement programmes to integrate energy planning into urban and economic planning.

To achieve national GHG-reduction targets, urban decision makers and planning departments are at the forefront of implementing the programmes necessary to deploy clean energy technologies and energy efficiency measures. Yet there is often a gap between urban planning and energy planning. There may also be a lack of co-ordination between municipalities, communities and neighbourhoods.

For these reasons, the EBC TCP set out to analyse barriers to integrated energy and urban planning and to identify possible solutions. The project builds on investigative discussions with 20 municipal planning departments in the 11 countries participating in the project. These discussions led to an in-depth understanding of the specific concerns faced by municipalities in linking climate and energy issues to urban planning.

The case studies revealed a number of barriers, including most importantly a lack of access to relevant knowledge (energy systems analysis, process management), a lack of municipal management structures and resources, a low level of understanding of the importance of such structures and a lack of sustained commitment on the part of important local stakeholders. A lack of specialised monitoring equipment and qualified personnel for commissioning and optimal operation of the systems was also identified. Lastly, poor performance of the installed technologies resulted in inadequate integration of the various system components.

To overcome these barriers, policy strategies, planning tools and implementation instruments were identified to help local decision makers, project developers and urban planners. For example, standard "design, build and operate" contracts, which combine public ownership and financing of projects with private-sector funded design, building and operation, were identified as a means of mitigating the performance risk that is passed to the contractor. Close co-operation with experienced contractors in the design, operation and implementation phases were found to reduce performance risk as well as costs.

Furthermore, enhanced co-ordination between local planners and private investors was found to increase a municipality's understanding of the management requirements. By developing a comprehensive long-term local energy strategy, municipalities could guide market participants to make the right decisions at the right time – and lower costs. The conclusions and lessons learned from the case studies are compiled in the report, *Energy Efficient Communities: Case Studies and Strategic Guidance for Urban Decision Makers* (EBC TCP, 2014).

Activities

- Adaptive thermal comfort in low-energy buildings
- Air infiltration and ventilation centre
- Cooling with ventilation
- Deep energy retrofits of public buildings
- Embodied energy and emissions with construction
- Energy efficient retrofitting
- Energy flexible buildings
- Energy strategies in communities
- High-temperature cooling, low-temperature heating
- Indoor air quality in low-energy buildings
- Long-term performance of super-insulating materials
- New generation computational tools
- Occupant behaviour simulation
- Optimised renovation for energy and CO_2 emissions
- Reliable energy performance characterisation

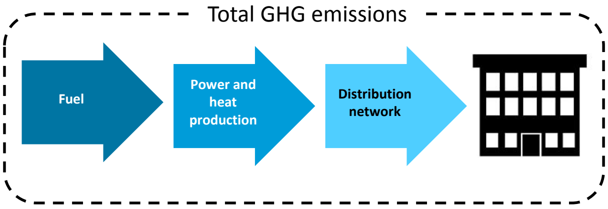
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	24	2	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-buildings/ebc/

DISTRICT HEATING AND COOLING INCLUDING COMBINED HEAT AND POWER (DHC TCP)

Methods to account for emissions from DHC systems need to be accurate and comprehensive.



Source: Adapted from information provided by the DHC TCP.

Highlight

Assessing emissions from district heating and cooling

The DHC TCP conducts unique international research that covers all areas of district heating and cooling (DHC) networks and combined heat and power (CHP). Accounting for national GHG emissions requires tools to calculate emissions from the various energy systems. The Universal Calculation Model enables decision makers to accurately assess energy consumption and emissions from DHC systems.

In 2013, energy consumption in the buildings sector accounted for 39% of the European Union's total energy consumption (IEA, 2015b). In support of the European objectives on energy efficiency, the EU Directive 2010/31/EU states that member states shall adopt, either at national or regional level, a methodology for calculating the energy performance of buildings. A number of methodologies have been derived to calculate the energy consumption in buildings.

However, the evaluation becomes more complex when energy for heating and cooling is produced offsite and delivered by a complex DHC network. Defining, allocating and calculating the energy use in district heating and cooling systems can have a significant impact on the GHG emissions that are reported. Other current evaluation methods follow a more general approach which does not enable precise results for each individual DHC network.

For these reasons, the DHC TCP funded the development of a transparent method for precisely calculating primary energy factors, primary energy use and CO_2 emissions from complex DHC systems including those integrating CHP, the universal calculation model (UCM). UCM users enter the annual heat and/or cooling need and the type of fuel that will be used. The energy consumed, the electricity produced and the resulting GHG emissions and energy indicators of the DHC systems are then calculated automatically for each process in the DHC distribution system. Special characteristics of the UCM are that it enables calculation of the total emissions and comparison of different assessment methodologies (allocation method). The choice of the allocation method can have a major impact on the results of energy and emissions calculations.

At national level, the total GHG emissions and energy consumption reflect the different systems in the country including DHC and CHP. UCM enables decision makers to make better informed decisions on the method used based on accurate calculations.

For example, for a given CHP plant, the GHG emissions and the primary energy demand of heat from district heating can vary by more than a factor of two, depending on the allocation method. In addition, if all elements of a system are not accounted for, the emissions will not be representative of the DHC system. Therefore the potential impact of the allocation method used can be significant. In addition, if all elements of a system are not accounted for, the emissions will not be representative. UCM enables its users to perform a comprehensive assessment and quickly visualise the effects of system parameter choices.

In summary, the UCM enables decision-makers to accurately assess the energy consumption and GHG emissions from DHC systems and to compare the impact of different allocation methods. This information is important in building accurate national GHG accountings. Some of these conclusions have been compiled in the UCM final summary report *Universal Calculation Model Tool* (Alonso et al., 2014). The software and the report are available for free after registration and login on the DHC TCP website.

Activities

- Optimising urban forms of district energy
- Roadmap: high- to low-temperature DH systems
- Strategic decision-making processes for DH
- User-centred approaches to DH management

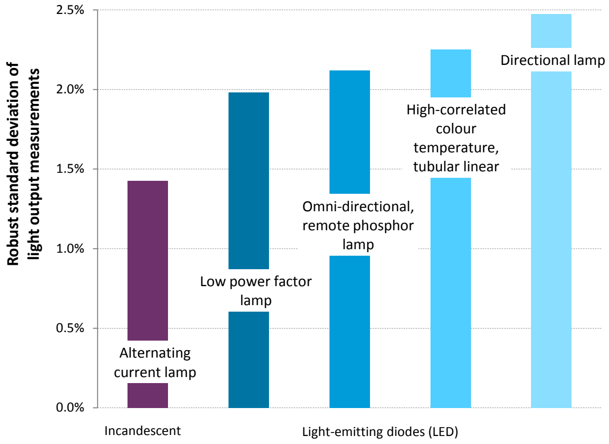
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	9	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-buildings/dhc/

ENERGY EFFICIENT END-USE EQUIPMENT (4E TCP)

Compared to incandescent lamp testing, test results of the perceived power of LED lamps vary significantly.



Source: Adapted from data provided by the 4E TCP.

Highlight

Testing lamps to support international standards

The 4E TCP supports sound policy development in the field of energy efficient end-use equipment by providing a forum for governments and other stakeholders to understand effective approaches to policy making. A comparison of results from 110 LED testing laboratories around the world has helped to improve the reliability of data for lighting products.

Lighting constitutes approximately 15% of electricity consumption worldwide. It is estimated that wide scale deployment of energy efficient lighting products, in particular light emitting diodes (LED), could significantly reduce electricity consumption for lighting. Yet due to the wide variation in the quality and reliability of LED products available to consumers, ensuring consistent measurements among laboratories would increase market growth of LED products worldwide.

For these reasons, the 4E TCP set out to assist governments to monitor and verify the quality of LED products by conducting a comparison of LED testing laboratories. The project was carried out in compliance with the joint international standard of the International Organization for Standards (ISO) and the International Electrotechnical Commission (IEC) (ISO/IEC 17043:2010, Conformity Assessment – General Requirements for Proficiency Testing), involving 110 laboratories located in 18 countries which contributed 123 data sets.

The products tested varied slightly taking into account popular models available in each of the three regional markets (Asia, North and South America and Europe). For each LED product tested, the laboratories measured the efficacy, brightness, light colour metrics and electrical properties.

While the results were relatively uniform across most of the participating laboratories, a few extreme measurements were observed which may have been caused by the participating laboratories' inability to meet the requirements of the test method. After identifying the differences, the laboratories were able to refine their testing methods. In addition, the uncertainties reported by the laboratories were found to have a very large range: some significantly under estimated light colour metrics while others did not report uncertainties in the equipment used to measure the LEDs.

A key finding of the study is that accurately measuring LED qualities, in particular colour metrics, remains a challenge for the lighting industry. While data from these tests are now being used by participating laboratories to verify calibration of the equipment and to improve measurement practices, the wide variations demonstrate that the LED industry urgently needs practical methods and instruments as well as further education and training on evaluating uncertainty of the measuring equipment.

The results of the 4E TCP study contributed to the international test method for LED products published by the International Commission on Illumination, CIE International Standard S 025/E:2015. All of the results and conclusions of the 4E TCP project have been compiled in the final report, *Solid State Lighting Annex: 2013 Inter Laboratory Comparison* (4E TCP, 2014).

Activities

- Electronic devices and networks
- Engagement with intl. standardisation organisations
- G20 energy efficiency action plan: networked devices
- International mapping and benchmarking
- Monitoring verification and enforcement
- Motor systems
- Policy-driven innovation
- Smart metering infrastructure
- Solid-state lighting
- Technology forcing standards for energy efficiency

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	12	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-buildings/4e/

ENERGY STORAGE (ECES TCP)

Testing the efficiency gains and CO_2 reductions from phase-change materials in building walls (Lleida, Spain).

Highlight

Improving efficiency, lowering costs and reducing CO_2

The ECES TCP develops and demonstrates advanced thermal and electrical energy storage technologies and encourages their use as standard engineering design options. Innovative energy storage materials were found to increase energy efficiency and reduce CO_2 emissions in a wide range of applications.

During conversion (electricity generation, refineries, combustion engines), nearly 50% of the world's primary energy supply is lost due to low efficiencies of the mechanisms. Therefore, increasing the efficiency of energy conversion processes is crucial to reducing CO_2 emissions.

Further emissions reductions are possible by recuperating the surplus heat created from the combustion process to be re-used, either within the plant or by transferring the heat to a nearby industrial complex or heat distribution system.

For these reasons the ECES TCP sought to measure the CO_2 mitigation potential of thermal energy storage (TES) technologies in industry, power generation, appliances, and vehicles. The project conducted 20 case studies of new TES materials and applications in eight countries representing Europe, North America and Asia. The project findings show that TES materials can increase energy efficiency and reduce CO_2 emissions by reducing heat loss and recuperating surplus heat for other applications.

One case study examined commercial concentrated solar power (CSP) plants. CSP plants use molten salts to store the heat which can then be used at night or overcast days. Yet molten salts are expensive (from USD 630/tonne to USD 945/tonne), sources are scarce and the maximal temperature is limited to approximately 600°C. To resolve these issues, the molten salts were replaced with a low-cost (USD 10/tonne) ceramic material recycled from industrial waste, capable of withstanding temperatures close to 1 100°C. This innovative approach presented no health hazards, no environmental impact and has the potential to increase the economic viability of CSP plants.

Another case study sought to reduce the temperature loss from opening freezer doors and electrical power failure. Participants found that the use of phase change materials (such as paraffin, fatty acids, salt hydrates and specialised salt mixtures) maintained the freezer temperature 4°C to 6°C lower than conventional freezers during three hours of power failure. The use of PCM was shown to maintain freezer temperatures relatively constant (from -12°C to -14°C) for more than three hours of power loss which protected the food quality.

A further case study evaluated the cooling effect of walls with PCMs (paraffin and salt hydrates). The PCMs delayed the rise of the temperature inside the building during the day, reducing the need for air conditioning. At night, when temperatures were lower, the PCMs released the stored heat to indoor and outdoor ambient air, keeping the room temperature comfortable. Findings confirmed energy savings of 15% to 17% compared to cubicles without PCMs. Further research on PCMs is needed before the technology is widely commercialised. These and other results were assembled in the final report, *Surplus Heat Management using Advanced TES for CO_2 Mitigation* (ECES TCP, 2014).

Activities

- Distributed energy storage for renewable energy
- Future electric energy storage demand
- Materials research and development for improved systems (a joint activity with the SHC TCP)
- Optimisation and automation for net zero energy buildings
- Thermal energy storage for cost-effective energy management and CO_2 mitigation

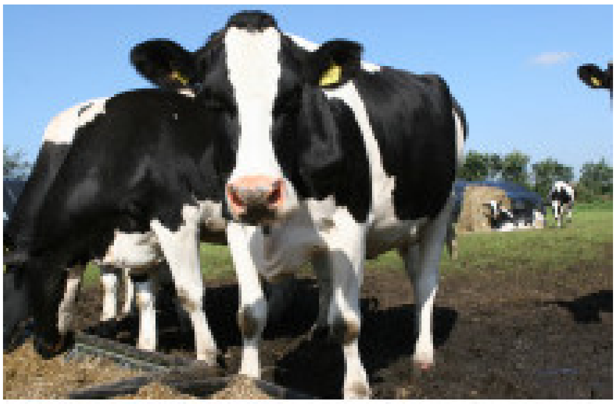
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	15	2	1
Sponsors	2	–	–

www.iea.org/tcp/end-use-buildings/eces/

HEAT PUMPING TECHNOLOGIES (HPT TCP)

Saving energy on a dairy farm (Götene, Sweden).



Highlight

Saving costs and CO_2 with industrial heat pumps

The HPT TCP supports deployment of heat pumps by quantifying the energy savings and emissions reduction potentials of heat pumps in different applications. By recuperating waste heat with heat pumps and combining processes, energy savings of 20% per year were possible in some industries.

In 2014, energy use in industry accounted for close to 29% of world final energy consumption (IEA, 2015c). Heat pump technologies are an effective means of reducing demand for primary energy to create the heat – and the resulting CO_2 emissions. While impressive efficiency gains have been achieved in other end-use sectors, there remains significant further potential to improve efficiency in the industrial sector.

For these reasons the HPT TCP carried out an extensive survey of the commercial entities in the industrial sector, reviewing the processes in order to identify potential energy savings and emissions reductions through implementation of heat pumps. Fifteen organisations in Europe and Asia took part in the four-year study, which resulted in 33 projects and 76 case studies.

One advantage of heat pumps in industrial applications is the potential to achieve significant energy savings by upgrading low-temperature, surplus heat at higher temperatures. An example of this is the case study of a dairy farm in Sweden.

The dairy processes 270 000 tonnes of milk per year using high-temperature steam purchased from a neighbouring industry for the pasteurisation process and for cleaning, equivalent to 30 000 megawatt hours (MWh).

The dairy was found to have significant capacity variations during the day, week and year, resulting in heat that was simply "lost". It was found that by recuperating the surplus heat from the pasteurisation process and reusing it for cleaning, it was possible to achieve annual energy savings of 6 200 MWh and cost savings of EUR 158 000.

In addition, the demand for high-temperature steam was significantly reduced by implementing a heat pump to increase the temperature of the surplus heat from 30°C to 80°C, an increase that would enable the dairy to be self-sufficient in high-temperature steam. It was estimated that the initial investment cost of the heat pump (EUR 380 000) could be paid back within less than four years. Taken together, energy savings of 20% per year were possible.

Case studies of efficiency improvements with heat pumps in the report include a chocolate factory, an automobile manufacturer, a biomass combined heat and power plant, and a metal processing plant. Four main barriers were identified: lack of knowledge of the heat losses for each commercial application; lack of knowledge of the advantage and uses of heat pumps; the initial investment costs; and the need for high-temperatures. Technical and socio-economic solutions were identified for each barrier.

The case studies and findings have been compiled in the final report, *Applications of Industrial Heat Pumps (HPT TCP*, 2014).

Activities

- Cold climate heat pumps
- Energy efficient supermarket buildings pumps
- Field measurements of building heat pump systems
- Fuel-driven sorption heat pumps
- Industrial heat pumps
- Near zero-energy buildings heat pump concepts
- Quality installation and maintenance
- Smart grids and heat pumps
- Solar thermal energy systems and heat pumps
- Testing and rating residential heat pumps

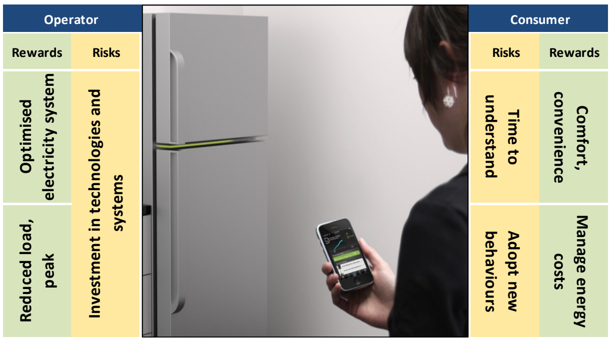
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	16	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-buildings/hpt/

DEMAND-SIDE MANAGEMENT (DSM TCP)

An informed and motivated consumer is central to successful implementation of smart grids.



Source: Adapted from information provided by the DSM TCP.

Highlight

Enabling demand-side flexibility in smarter power systems

The DSM TCP focuses on strategies for modifying the demand of energy from end users using technological solutions, regulatory or financial incentives, and other means of encouraging behavioral change. By reducing or shifting demand according to a power system's needs, investment in power generation and grid capacity can be deferred or avoided, with benefits in both fast-growing economies where much power infrastructure is yet to be built, and in established systems where ageing infrastructure needs to be replaced.

A more responsive demand-side is necessary to provide the flexibility that is needed for integrating higher shares of variable renewable electricity and distributed generation, or for rolling out electric vehicles in a cost-efficient manner.

While significant research is being carried out on the technological platform that could facilitate demand-side flexibility (c.f. ISGAN, page 35), the degree to which consumers and markets will respond remains a fundamental knowledge gap for innovation in this area.

For these reasons, the DSM TCP set out to identify the risks and rewards to consumers, and to explore the interaction between policies, markets and guidance. Five countries from Europe and Asia participated in the extensive study, which comprised 38 case studies of smart grid pilot programmes or trials, 22 consumer surveys and the analysis of market research of 1 000 households.

Defining the market's "readiness" was found to be an element of successful programmes, more easily visualised through a market analysis ("map"). A deregulated electricity market, combined with a competitive business environment, efficient value chains and preferential tariff rates were seen to be the optimal conditions. Effective tools to facilitate market readiness included appliance standards, settlement arrangements and billing arrangements or simply supplying households with the meters at little or no cost.

Regarding consumers, simply stating that the benefits (improved autonomy, control, comfort; lower costs; or environmental benefits) outweigh the costs (time, money) did not fully reflect consumers' views. Other reasons expressed included a lack of understanding of the benefits of smart grids, scepticism as to how the data would be used, the opportunity to choose, and, in some cases, reluctance to make an effort.

Indeed, with smart grid technologies consumers actively participate in how much energy is used, for which applications, and at what times. Enabling choice, providing tangible benefits to the consumers (and the local community), consumer awareness campaigns and financial incentives were found to address these concerns. These and other findings have been synthesised into the final report*, The Role of the Demand Side in Delivering Effective Smart Grids* (DSM TCP, 2014).

Activities

- Behaviour change: theory, policies, practice
- Business models for energy services
- Competitive energy services (phase 3)
- Demand side management, energy efficiency, distributed generation and renewables (phase 3)
- Effective smart grids
- Multiple benefits

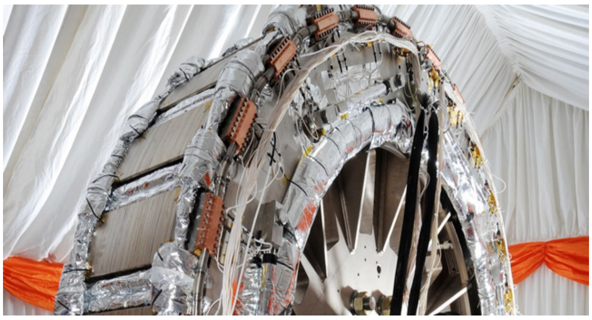
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	13	1	–
Sponsors	1	–	1

www.iea.org/tcp/end-use-electricity/dsm/

High-Temperature Superconductivity (HTS TCP)

One of the newer applications for high-temperature superconducting cables – a generator for ultra-large wind turbines (Rugby, United Kingdom).



Highlight

Enabling high capacity wind with superconductivity

The HTS TCP aims to analyse superconductivity technology, monitor developments in industry standards, and assess the benefits and existing barriers to deployment. It brings together manufacturers, cryogenics research, laboratories and trade organisations to enable significant improvements in the generation, transmission, distribution and use of electric power. The recent roadmap for the widespread integration of high-temperature superconductors into the electricity supply network highlights both traditional and innovative applications.

Between 1973-2013 electricity demand worldwide increased nearly four times, from 440 TWh to 1 677 TWh (IEA, 2015c). In some world regions, electricity network infrastructure is ageing and in need of significant improvements. Incorporating superconducting cable technologies into electrical generators and equipment increases system efficiency, reliability and safety. As a result, CO_2 emissions are reduced and energy security is improved.

Losses in electricity transmission may result from the resistance of the wires and cables as well as from the transformation of the high voltages needed for transmission lines into the lower voltage needed for end users. Because high-temperature superconducting cables transport current with essentially no or very low electrical resistance they can transmit up to ten times more power than conventional copper cables (or can carry equivalent power at much lower voltages). In addition these cables require reduced space in urban environments since they may be installed underground and they do not produce a magnetic field or heat.

Through a number of pilot projects in the countries participating in the HTS as well as through others from around the world, cable technology is moving from the pre-commercial to the commercial stage for electricity transmission; as such, it is increasingly being considered for a variety of applications, including in the transport, industry, medical, and defence sectors.

For these reasons in 2014 the HTS TCP held a workshop to examine the state of the art and to discuss the most promising HTS applications beyond 2020. The information collected at the workshop laid the groundwork for developing a roadmap setting out the steps necessary for the widespread integration of cables into the electricity supply network. Policy needs, and consumer awareness are considered. In messages, market considerations (e.g. value chains), research addition the roadmap explores the potential for other applications, including high-capacity (>10 MW) wind turbines.

As superconducting cable technologies would enable smaller and lighter generators than is possible with conventional materials, this could essentially eliminate the need for a gearbox. The roadmap highlighted the need for prototype generators for high-capacity wind turbines in order to test materials, components, and performance. Three wind turbine companies have begun to lay the groundwork for slow-turning, high-torque generators. In addition superconducting cables are particularly suited to integrating variable, high-capacity sources of power as they operate at higher current levels with much lower losses and a reduced need for voltage transformation steps. These recommendations are compiled in the roadmap, *HTS from Pre-Commercial to Commercial: A Roadmap to Future Use of HTS by the Power Sector* (Wolsky, 2013).

Activities

- Efficient and resilient power networks
- Fault current limiters, cables, rotating machines for large wind turbines
- Low-cost, high-current, superconductors
- Roadmap

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	12	1	–
Sponsors	2	–	–

www.iea.org/tcp/end-use-electricity/hts/

SMART GRIDS (ISGAN TCP)

The inaugural Award of Excellence, presented at the fifth annual Clean Energy Ministerial (Seoul, Korea).

Highlight

Rewarding smart grid best practice

The ISGAN TCP aims to advance policy, technology and related standards for smart grids by raising awareness of their benefits, developing tools for implementation, and co-ordinating joint projects. The annual ISGAN TCP Award of Excellence[7] *has become a global mark for outstanding projects and best practices on smart grids development and deployment.*

Electricity networks are under increasing stress as the sources of power supply and demand become progressively more varied and complex. To address this, the ISGAN TCP examines ways to enhance the resilience of electricity networks with a range of advanced information, sensing, communications, control, and energy management technologies that are collectively referred to as the "smart grid".

Each country has a unique set of drivers and approaches to adapting smart grid technologies and systems. These include improving operational efficiency and system reliability; improving electricity market function; reducing losses; differentiating electricity services for consumers; and integrating a range of energy supply and end-use technologies, such as solar photovoltaics, plug-in electric vehicles and energy storage.

Sharing best practices among countries promotes replication or adaptation of proven concepts in other markets, countries, and regions.

For these reasons, the ISGAN TCP rewards leadership and innovation in smart grid projects through an annual "Award of Excellence". Submitted projects are reviewed by an independent, international jury drawn industry, the Global Smart Grid Federation (GSGF). The winning project is chosen based on several criteria covering the potential impact, benefits, economic rationale, potential for replication, and level of innovation, and alignment with the mission of the ISGAN TCP. Projects and programmes considered may be at the pilot, demonstration or deployment phases of smart grid technologies.

The 2015 ISGAN TCP Award of Excellence was bestowed on the project entitled "Grid4EU: Large-Scale Demonstration of European Smart Distribution Networks", led by France in collaboration with five European countries. The project demonstrated excellence in many areas and it was particularly fitting to the 2014 theme of renewable energy integration. Two projects, "EcoGridDS3 – Delivering a Secure, Sustainable, Electricity System" (Ireland) and "Smart Grid Station of Korea Electric Power Corporation" (Korea) each received an honourable mention.

Recognising that the active participation of consumers is one of the most vital attributes of successful SG implementation, the theme of the inaugural, 2014 Award was "consumer engagement and empowerment". The winner that year was the "SmartView" pilot project on advanced metering infrastructure (United States). The project entitled "EcoGrid: Consumer Engagement" (Denmark) received an honourable mention, while eight other projects from Europe, Asia and North America were listed as finalists. Case studies of all the finalists are expected to be collected, synthesised and published.

Activities

- Knowledge exchange, briefs, case studies and trainings on transmission on a range of smart grid topics, including distribution systems, advanced metering infrastructure, demand side management, consumer engagement and empowerment
- Pre-standardisation evaluation of testing protocols
- Smart grids drivers and technology priorities
- Standardised methods for cost-benefit analysis

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	18	6	1
Sponsors	–	–	–

www.iea.org/tcp/end-use-electricity/isgan/

INDUSTRIAL TECHNOLOGIES AND SYSTEMS (IETS TCP)

The panel discussion during the 2013 International Process Integration Jubilee Conference (Gothenburg, Sweden).

Highlight

Designing efficiency improvements in industrial processes

The IETS TCP aims to support the research and to promote the results of cost-effective new industrial technologies and system configurations that increase productivity and product quality while improving energy efficiency and sustainability. One key message stemming from activities of the IETS TCP is that by integrating process analysis into small- and large-scale industrial processes it is possible to achieve energy savings and to reduce CO_2 *emissions.*

Today the industry sector represents 29% of the world's energy consumption (IEA, 2015c). Therefore, improving energy efficiency in industries such as aluminium, cement, chemicals, food processing, iron and steel, petrochemicals, and pulp and paper could offer considerable benefits.

Energy efficiency improvements include integrating individual processes to whole systems related to heat, power, chemicals or equipment, to reduce costs of the energy and mitigate environmental effects. These improvements – referred to as "process integration" (PI) – have the potential to achieve cost reductions for industries as well as emissions reduction and waste reduction.

For example, PI methodologies enable industries to identify and quantify opportunities for GHG emissions reduction at every point in the process. PI also enables industries to transition from a continuous, linear production process to a flexible "batch" production. Enhancements to each batch could be made at a lower cost than revising the entire system. For these reasons, PI is the focus of one of the ongoing activities of the IETS TCP – the international PI conferences.

In March 2013, 110 participants from 24 countries attended the International Process Integration Jubilee Conference (Gothenburg, Sweden), the 20th such event held since 1992.

The conference presented an overview of developments in PI since 1992, highlighted best practice, and identified a number of remaining barriers. First, there appears to be a lack of analytical tools that were simple in presentation to be understood by a layperson yet complex in their implementation so as to provide real benefit. Moreover, existing energy efficient tools and methods are designed for strategic analysis, and not developed for the day-to-day optimisation of the production sites. The development of a guidance system to optimise energy use thus requires further model development both in real-time and in the future. Additionally, a lack of dedicated personnel in commercial plants to carry out the PI analysis and implementation was noted.

As PI integrates a number of traditional disciplines (chemistry, mechanical engineering, energy, modelling, and management) with few programmes integrating industrial considerations, there is a gap in academic degrees covering all aspects of PI. Cross-disciplinary academic programmes are one way to address this issue, resulting in a benefit for industries. In spite of these barriers, PI is applied successfully today in many industries worldwide, and tools are available to facilitate further implementation.

Nevertheless, case studies of best practice are rare, and data from case studies are lacking. Case studies for large, multi-disciplinary projects highlighted during the conference will be synthesised into a summary report.

Activities

- Energy efficiency in small and medium enterprises
- Energy-efficient separation systems
- Industrial excess heat recovery
- Industrial heat pumps
- Industry-based bio-refineries
- Membrane technologies
- Process integration in the iron and steel industry

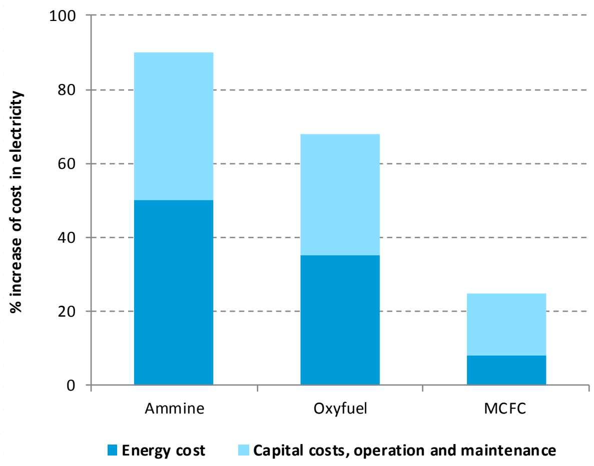
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	9	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-industry/iets/

ADVANCED FUEL CELLS (AFC TCP)

The cost of reducing CO_2 emissions from coal-fired power plants using molten carbonate fuel cells (MCFC) is lower than traditional methods.



Source: Adapted from data provided by the AFC TCP.

Highlight

Reducing emissions from power plants with fuel cells

The AFC TCP advances understanding of fuel cells through co-ordinated research, technology development and systems analysis. Promising, cost-effective new applications for fuel cells are emerging, including separating the CO_2 from the exhaust gas of a coal-fired power plant.

Fuel cells use a chemical reaction to generate electricity from fuels. This process does not cause greenhouse gas emissions that are associated with fuel combustion. Fuel cells provide electricity at the point of consumption, reducing losses and costs associated with the electricity distribution network. Generating hydrogen from biomass and other renewable energy sources leads to very low greenhouse gas emissions, and certain processes may even sequester carbon on net.

Molten carbonate fuel cells (MCFC) operate on a variety of fuel sources such as hydrogen, ammonia, gases (such as methane, syngas, ethanol, propane or liquefied petroleum gas), diesel or CO_2. MCFCs are primarily used for stationary applications, enabling a decentralised, stable energy supply.

For these reasons, the AFC TCP studied the status of MCFC technology and deployment. The aims were to gather information in order to improve the performance, endurance, and cost-effectiveness of fuel cell technologies. Five case studies of commercial applications (including market perspectives) are featured as well as nine pilot or demonstration projects in participating countries. Investment and operating costs and promising new applications are also considered.

After several years of research programmes and extensive demonstrations, MCFC-based power systems are reaching the full commercial stage. Dedicated applications include industrial processes (food processing, manufacturing); high-density buildings requiring critical power requirements (hospitals, prisons, universities, and hotels); and utilities. Since MCFCs operate at 600°C and above, they produce both electricity and heat, thereby serving as stand-alone combined heat and power plants. MCFC power stations or “fuel cells parks” are also on the rise. Following 2013 construction of the 11.2 MW fuel cell park in Daegu City, Korea, further facilities offering capacities of 14.9 MW (Connecticut, United States) and 59 MW (Hwasung City, Korea) were completed and began operating in 2013 and 2014, respectively. Experiences gained from these systems demonstrate that lifetime enhancement and cost reductions are still needed.

Yet promising new applications for MCFCs are emerging, including separation of the CO_2 from the exhaust gas of a coal-fired power plant. The MCFC uses CO_2 as a fuel to produce electricity, increasing the overall efficiency of the plant. After the CO_2 is consumed, 70% less CO_2 is emitted. In addition, more MCFCs may be added depending on the flue gas exhaust of each plant. Thus the costs of CO_2 separation using MCFCs (initial investment, operations and maintenance, fuel) may be considerably lower than those in traditional processes. These and other findings are synthesised in the report, *International Status of Molten Carbonate Fuel Cell Technology* (AFC TCP, 2015).

Activities

- Electrolysis
- Modelling
- Molten carbonate fuel cells
- Polymer electrolyte fuel cells
- Portable applications
- Solid oxide fuel cells
- Stationary applications
- System analysis
- Transportation

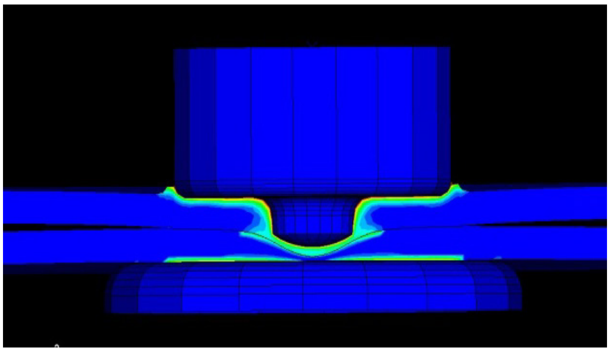
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	11	2	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-transport/afc/

ADVANCED MATERIALS FOR TRANSPORTATION (AMT TCP)

Computer image of a strong, solid-state metallurgical bond between different types of materials.



Highlight

Building lighter vehicles with multiple materials

Activities of the AMT TCP are focused on improving vehicle energy efficiency without compromising safety, durability, performance or comfort. While promising lighter-weight materials could reduce consumption, studies of welding methods must be performed to ensure vehicle safety, integrity and durability.

In 2013 the transport sector accounted for 65% of world oil consumption (IEA, 2015c). Replacing vehicle chassis with lighter weight materials is an efficient way to reduce fuel consumption. Combining high-strength steels with lighter materials reduces consumption while maintaining safety standards and vehicle performance. Yet permanently and effectively joining these different materials into vehicle structures and systems is a very complex task.

The AMT TCP set out to examine the technical challenges in processing and joining multiple, dissimilar materials, as well as the testing and inspection techniques that would enable assembly and production of vehicles composed of multiple materials, while maintaining or increasing their structural integrity.

The AMT TCP examined the most efficient welding methods to join dissimilar materials. While fusion spot welding processes are commonly used in vehicle production today for mild steels, and corrosion-resistant galvanised steels are used for unibody vehicle structures, friction-stir spot welds (FSSW) were shown to hold greater promise in joining multiple, dissimilar materials.

FSSW is used to join traditional steels with high-strength steels, or high-strength steels with lightweight materials such as aluminium, magnesium, polymers or carbon fibre reinforced plastics. Thus development of the FSSW technique for multi-materials was chosen for initial study.

Vehicle design relies on detailed knowledge of, and guidelines for, the performance of materials and the processes for manufacturing and assembling components. Of particular interest in the study of FSSW was the recession caused when the welding tool is inserted into the material substrates and the metal mixes with the components being joined. By using a refill technique the recession could be eliminated, resulting in improved joint strength and resistance to fatigue. Experiments evaluated the effects of tool rotation speed, tool plunge depth and weld time on the tensile properties of three combinations of materials: aluminium-aluminium, aluminium-steel and magnesium-steel.

The results show that it is possible to fabricate sound joints with all three material combinations using FSSW. In particular, no brittle intermetallic compound layers were detected at the interface between aluminium-aluminium and aluminium-steel, signalling a high level of joint strength. Further work will be done to enhance the joint properties.

The AMT TCP study will continue to expand, including activities on joining technologies which may include mechanical joints based on advanced riveting techniques and adhesives and fusion processes such as hybrid welding brazing. In the near term, the AMT TCP plans to further examine the performance of metal joints and detecting damage accumulation in polymers.

Activities

- International standards and testing for low-cost carbon fibres
- Integrated surface technology to reduce engine friction
- Model-based design of coating systems
- Multiple-material joining for lightweight vehicles
- Technology assessment and policy implications
- Thermoelectric materials for waste heat recovery

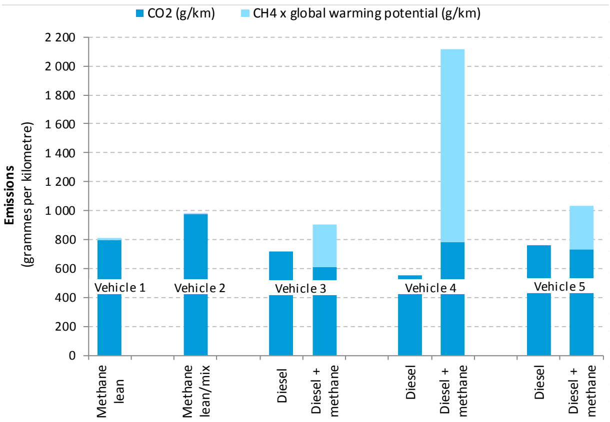
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	7	3	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-transport/amt/

ADVANCED MOTOR FUELS (AMF TCP)

Emissions from heavy duty vehicle engines operated with diesel or diesel in combination with methane.



Source: Adapted from data provided by the AMF TCP.

Highlight

Analysing heavy duty vehicle efficiencies and emissions

The primary goal of the AMF TCP is to facilitate the market introduction of advanced motor fuels and related vehicle technologies. This TCP provides an effective platform for fuel analyses and reporting of GHG emissions tested and measured in engines.

Reducing the environmental impact of fossil fuels usage for transport, the largest contributor to CO_2 emissions, is a policy priority for a growing number of countries worldwide. Alternative motor fuels can provide an effective solution to improve the fuel economy.

Alternates include substituting diesel fuel with a synthetic fuel or hydro-treated vegetable oils, or by modifying heavy duty vehicle (HDV) engines to operate on other fuels such as natural gas or plant-based natural gas (bio-methane). While fuel efficiencies of passenger vehicles continues to increase, and alternative fuels comprise an increasing share of fuels consumed, improved efficiencies of HDVs is lagging and few alternatives to diesel are currently available.

For these reasons one study of the AMF investigated the current status of the fuel efficiency and emission performance for commercially available (new or retrofit) diesel dual-fuel (DDF) engines of HDVs, including benchmarking of the emissions performance and certification schemes. HDV testing was carried out in Canada, Finland and Sweden (and with contributions from Japan, Germany and the EC) under a variety of driving conditions on the road as well as in laboratories on chassis dynamometers under well specified conditions. CO_2 and CO_2-equivalent emissions (CO_2 plus methane emissions multiplied by its global warming potential) were measured on different types of HDV engines fuelled by diesel alone or diesel "dual-fuel" (diesel combined with methane).

Even if the carbon content per unit energy of methane is lower than in diesel fuel, tests on five different vehicles showed that CO_2 equivalent emissions were lower for dual-fuel engines operating solely on diesel compared to when operated on a mix of diesel and methane (vehicles 3, 4 and 5 in graph). This was found to be due to a combination of lower fuel efficiency and the occurrence of "methane slip", i.e. the emission of methane that is not combusted in the engine from the tailpipe. Engines fuelled solely with methane (vehicles 1 and 2) had a lower fuel efficiency than diesel engines, which led to higher CO_2 emissions, but with minor methane slip. The vehicle manufacturers of the HDVs tested in the study were informed of the results. This analysis shows that further development is needed for dual-fuel engines to reach adequate on-road performance regarding fuel efficiency and/or exhaust emissions.

These and other findings, compiled in the AMF TCP final report, *Enhanced Emissions Performance and Fuel Efficiency for Heavy-Duty Methane-Fuelled Engines*, have contributed to development of a certification scheme for diesel dual-fuel engines (AMF TCP, 2014).

Activities

- Alcohol: application in compression-ignition engines
- Alcohol fuels: unregulated pollutants
- Commercial vehicles: fuel and technology alternatives
- Dimethyl ether specifications
- Ethanol and butanol: direct-injection, spark ignition engines
- Hydro treated oils and fats for engines
- Internal combustion engines: exhaust gas and particles
- Methane emissions control
- On-road vehicles: natural gas pathways
- Off-road engines: fuel and technology alternatives
- Passenger cars: fuel performance evaluation

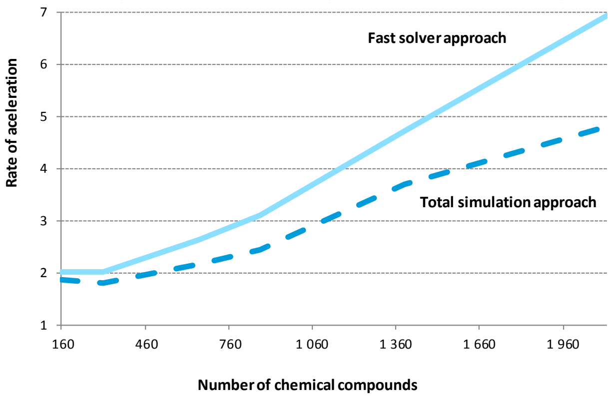
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	14	4	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-transport/amf/

EMISSIONS REDUCTION IN COMBUSTION (COMBUSTION TCP)

Comparison of modelling approaches simulating the chemical reactions in the combustion process.



Source: Adapted from data provided by the Combustion TCP.

Highlight

Simulating combustion to reduce CO_2

The Combustion TCP carries out experimental and computational research projects related to internal combustion in engines and gas turbines, and furnace combustion. A new, more accurate model of the chemical reaction in combustion engines enables accelerated analysis of efficiencies and CO_2 emissions reductions.

Reducing fossil fuel consumption and CO_2 emissions in the transport sector are challenging priorities for policy makers. While increased consumption of low-carbon fuels and deployment of hybrid or electric vehicles present viable alternatives, the majority of vehicles operating today still use conventional fuels associated with the internal combustion (IC) engine. Further understanding of the physics and chemistry of the combustion process is fundamental to achieving improvements in fuel efficiency, reducing greenhouse gas emissions and pollutants, and transitioning to alternative fuels.

For these reasons, the Combustion TCP set out to study the chemistry of the combustion process in order to model development and analysis of clean and efficient engine combustion. The main focus of this collaborative study is to extend and to improve the understanding of kinetics and fluid dynamics through computation in order to reduce formation of pollutants and to enable reductions in GHG.

In order to develop more accurate fuel chemistry models to improve engine designs, analytical tools capable of simulating chemical reactions in engines were elaborated. Based on the "fast solver" principle, which provides information on the degrees and rates of reactants conversion, the formation of pollutants, and the effects of additives, participants designed an improved fast solver approach.

This was undertaken in co-operation with automobile and equipment manufacturers, national research laboratories, universities and industry associations. The improved version includes preconditioning the model with specific parameters (e.g. flame speed, one-dimensional diffusion, piston and other models), creating a mechanism to debug tools, and leveraging the analysis which accelerates the calculations of the combustion effects. Participants derived an improved simulation performance and efficiency through more accurate calculations, a new computing architecture and improved physical models.

The debugging and diagnostics have enabled fuel researchers to create more robust and accurate models. In addition, the updated fast solvers have accelerated results from days (and in some cases weeks) to less than an hour. The new fast solvers and fuel model are able to deliver more predictive engine simulations that will facilitate the design and development of highly efficient, cleaner combustion engines worldwide. The new solvers have been licensed to Convergent Sciences Inc. (CSI) for use in their calculations, widely used by engine manufacturers.

These and other findings are available in the final presentation, *Improved Solvers for Advanced Engine Combustion Simulation* (McNenly et al., 2014).

Activities

- Combustion of alternative fuels
- Combustion chemistry
- Gas engines
- Hydrogen gas turbines
- Low-temperature combustion
- Nanoparticle diagnostics
- Single contributor tasks
- Sprays in combustion

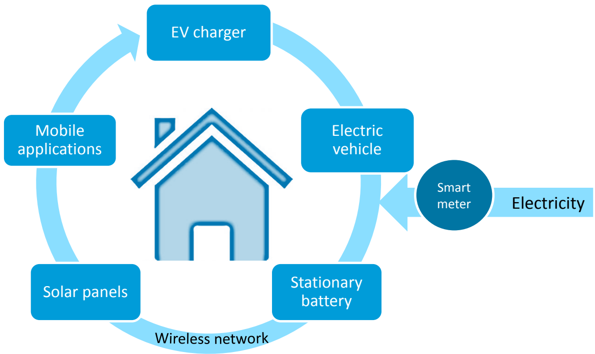
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	13	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-transport/combustion

HYBRID AND ELECTRIC VEHICLES (HEV TCP)

Illustration of the value chain of electric vehicles.



Source: Adapted from information provided by the HEV TCP.

Highlight

Assessing the economics of hybrid and electric vehicles

The HEV TCP aims to produce and disseminate balanced, objective information about advanced electric, hybrid, and fuel cell vehicles for governments and local authorities. Hybrid and electric vehicles (HEV) hold great potential to contribute to reducing energy consumption and emissions from road transport.

Reducing dependence on fossil fuels in the transport sector is a priority. Annual world sales of electric vehicles (EV) increased from less than 10 000 vehicles in 2010 to close to 1.1 million vehicles in 2015. Despite this increase, in 2015 they represented less than 1% of all passenger vehicles on the road (IEA, 2016). While manufacturing costs have significantly decreased since the first HEVs were commercialised, price remains a barrier for large-scale deployment. Other barriers include a lack of infrastructure and the lack of cross-border harmonisation of recharging mechanisms, and reducing these barriers incurs additional costs.

The HEV TCP set out to examine the economic and business models that would further deployment of HEVs. Successful deployment requires optimum policy and market conditions as well as concerted actions among a wide range of stakeholders. Given this complex landscape, a business model for EV deployment may be successful under some conditions but not others. Therefore, the HEV TCP compared case studies to identify the elements of successful vehicle deployment business models.

Further, the HEV TCP is examining the potential economic impact of the introduction of HEVs, contributing to the so-called "green economy" by stimulating environmentally sustainable economic growth through new value chains that may result in new business and employment opportunities. Electricity networks, smart grids, charging infrastructure, financing services, and electric vehicles sharing systems are some examples of the elements in the value chain.

A common methodology has been developed for economic impact assessment, including key indicators such as production volume, employment, export volume, innovations and patents. Yet national, regional and local socio-economic (e.g. policy frameworks, manufacturing capacities, or transport modalities) and geographic conditions are also considered. For example, while automobiles comprise the majority of data, some participating countries may also consider electric bicycles, scooters, trucks, buses, and boats.

Preliminary results show that patents of the HEV system components are on the rise both in Europe as well as internationally. While not a direct indicator of economic impact, the patents provide one indication of potential follow-on business and employment opportunities.

Insights from policy makers, economists, the business community, engineers, technology managers, and researchers worldwide have been collected in two HEV TCP reports, *Electric Vehicle Business Models: Global Perspectives* (HEV TCP, 2015a), and *Hybrid and Electric Vehicles: the Electric Drive Delivers* (HEV TCP, 2015b).

Activities

- Economic impact assessment of E-mobility
- Electrochemical systems
- Electrification of transport logistic vehicles
- Electric vehicle business models
- Home grids and V2X technologies
- Life-cycle assessment of electric vehicles
- Light electric vehicle parking and charging infrastructure
- Plug-in electric vehicles
- Quick charging technology
- System optimisation and vehicle integration
- Testing the lifetime of lithium-ion batteries
- Wireless power transfer for electric vehicles

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	18	–	–
Sponsors	–	–	–

www.iea.org/tcp/end-use-transport/hev/

CLEAN COAL CENTRE (CCC TCP)

The potential impact of higher-efficiency coal-fired power plants on CO_2 emissions.

Power plant technology	Efficiency (%)	Relative CO_2 emissions (Mt)
Subcritical	35	100
Supercritical	40	87
Ultra-supercritical (USC)	43	81
Advanced USC	50	70

Source: Adapted from information provided by the CCC

Highlight

Reducing emissions from coal-fired power plants

The CCC TCP gathers, assesses and disseminates knowledge on the energy efficient and environmentally sustainable use of coal. High-efficiency low-emissions (HELE) coal-fired power generation plants offer significantly lower carbon intensity than conventional units and are a sound basis for the addition of carbon capture and storage.

Compared to other fuel sources, coal provides an abundant, relatively low-cost fuel for electricity generation. However, unless managed carefully, coal-fired power plants emit pollutants such as sulphur dioxide (SO_2), nitrous oxide (NO_X), particulates, and high levels of greenhouse gases.

Addressing the environmental issues of coal-fired power generation is therefore a priority, one which can be addressed through a highly efficient combustion process and by reducing the pollutants and emissions. A high-efficiency coal-fired power plant could emit 20% less CO_2, would be more reliable, and have a longer life expectancy than older plants. Several countries have established such technologies through the use of energy and environmental policies and regulations.

For these reasons, the CCC TCP examined the potential of high-efficiency, low-emissions (HELE) technologies for coal-fired power plants in the top ten coal-consuming countries: Australia, China, Germany, India, Japan, Poland, Russian Federation ("Russia"), South Africa, South Korea and the United States. The age and efficiency of the existing coal-fired power plants were analysed, together with the rate of economic growth, electricity demand, and the policy and regulatory framework.

A profile of each country to meet future electricity demand was modelled under three scenarios: (1) continuing with the existing fleet, (2) retiring and replacing older plants after 25 years, and (3) retiring and replacing older plants after 50 years. The potential impact of HELE improvements on emissions of CO_2 were quantified as well as the costs of implementation.

A number of trends emerged from the analysis. First, economic considerations will govern the decision to replace a plant unless policies and incentives prompt the earlier selection of HELE technologies. Thereafter, the greatest gains are achieved when the operating life is limited to 25 years (evolving practice in China) rather than 40 years or more (common in OECD countries), especially when HELE plants are combined with carbon capture and storage (CCS). This option could be particularly relevant for India to curb emissions from the rapidly increasing electricity demand.

These results were compiled in the CCC TCP report, *Upgrading the Efficiency of the World's Coal Fleet to Reduce CO_2 Emissions* (CCC TCP, 2014).

Activities

- CO_2 mitigation
- Coal markets
- Coal properties and analysis
- Combustion
- Conversion and industrial use of coal
- Country studies
- Emissions and control
- Environmental policy and legislation
- Gasification
- Mining, production and preparation
- Residues and management
- Pollution control technologies
- Power generation
- Social acceptance
- Technology implementation

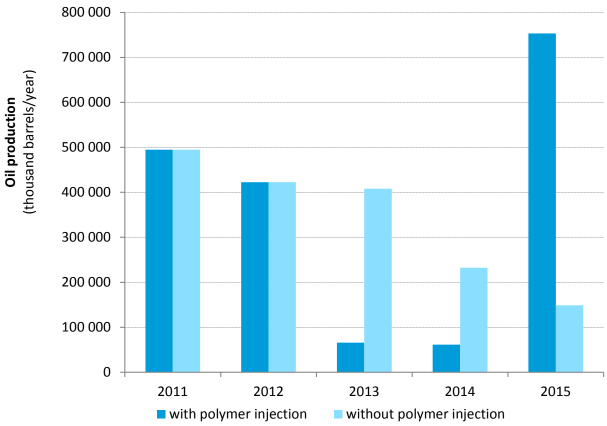
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	8	1	1
Sponsors	–	6	–

www.iea.org/tcp/fossilfuels/ccc/

ENHANCED OIL RECOVERY (EOR TCP)

Results of a field test of oil production before and after polymer injection (Matzen, Austria).



Source: Adapted from data provided by the EOR TCP.

Highlight

Increasing oil production from mature reservoirs

The EOR TCP supports national efforts to reduce costs of existing technologies and to research new technologies to enhance reservoir oil recovery. Between 30% to 70% more oil could be recovered from mature oil reservoirs through the use of enhanced oil recovery technologies such as polymer injection, or "flooding".

Crude oil is expected to supply 26% of the world's energy until 2040 (IEA, 2014b). Given that the average recovery factor per oil reservoir is only 20% to 40% and that the majority of oil reservoirs are mature, improving the amount of oil extracted in existing reservoirs is a priority. For these reasons the EOR organises symposia to assess state-of-the-art applications for oil exploitation: reservoir characterisation and injection of gases or liquids to increase the amount of oil recovered.

The challenge of oil production is to maintain sufficient pressure within the reservoir to push the oil upwards. This is facilitated by injecting a gas such as CO_2, steam or a liquid into the reservoir. Water may be effective for oils that are lighter in density, but it only results in a 10% extraction rate for reservoirs containing heavier oils.

The focus of one ongoing activity of the EOR TCP is to examine the addition of chemical compounds (surfactants and/or polymers) to the water to facilitate movement of the oil within the reservoir and resulting increase in oil extraction. Surfactants lower the surface tension between the water and the oil while polymers with a higher viscosity than water push the oil through the reservoir.

Injection of surfactants and/or polymers has been shown to increase oil recovery by a further 5% to 20%, a considerable benefit, particularly for fields with dense or heavy oils. Yet some challenges remain, particularly for polymers. Obtaining the appropriate viscosity based on the quality of the oil, adhesion to the reservoir rocks, and the plugging of injection wells are some of the key challenges.

For these reasons polymer flooding has been relatively limited to date except in China where a recent policy required that oil companies make all efforts to maximise recovery rates. Following an earlier symposium in China, and further benefiting from the experience exchanged with experts in China, four participants of the EOR TCP aimed to reduce the uncertainty and risk of polymer flooding through a pilot test of the technology.

In Austria, polymer flooding was tested in a mature oil reservoir (8th Reservoir, Matzen Field) where the share of oil produced was on the decline. After injecting the polymer, more oil was produced, demonstrating enhanced mobility of the oil. The additional oil recovered was found to be a result of acceleration (30%) and improved oil mobility (70%).

In addition, through the use of tracer tests and laboratory experiments, polymer adherence to the reservoir rock could be simulated. The simulations were consistent with the results obtained in the reservoir – incremental amounts of oil were recovered and the amount of polymer required could be quantified.

These and other findings are described in the report, *User Tracer Data to Determine Polymer Flooding Effects in a Heterogeneous Reservoir* (Laoroongroj et al., 2015).

Activities

- Development of gas flooding techniques
- Dynamic reservoir characterisation
- Fluids and interfaces in porous media
- Surfactants and polymers
- Thermal recovery

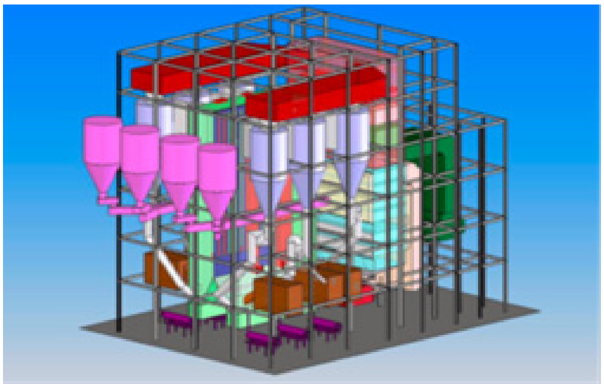
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	9	4	–
Sponsors	–	–	–

www.iea.org/tcp/fossilfuels/eor/

FLUIDIZED BED COMBUSTION (FBC TCP)

The world's first 600 MW circulating fluidized bed plant (Baima, China).



Highlight

Building larger fluidized bed boilers reduces emissions

The FBC TCP aims to support dissemination of research results on fluidized bed conversion technology, thereby advancing the knowledge of national experts and industry professionals. The increased size of recent fluidized bed coal power plants has resulted in improved efficiencies and lower GHG emissions.

Compared to traditional coal-fired power plants, fluidized bed boilers are designed to maintain the coal in a fluidized motion in order to burn the coal thoroughly and to achieve a constant temperature in the boiler. This results in efficient combustion and a higher, regular production of steam (and electricity) over time.

By adding absorbent materials such as limestone or dolomite into the combustion chamber, it is possible to reduce the SO_2 emissions by up to 90%. The NO_x emissions are inherently low but may be further reduced with additional processes. Furthermore, coal can be burned together with biomass and waste fuels (e.g. coal discard, rubber) at a high efficiency of combustion.

To accelerate further development of this technology, the experts participating in the FBC TCP activity share recent progress with their respective fluidized bed pilot plants (designed according to the local fuel supplies) through regular symposia. These information-sharing opportunities have contributed to larger and more efficient boilers, from the original pilot plants in the early 1980s to the larger, commercial-scale boilers capable of providing electricity to the grid. While design and construction of large-scale boilers benefits from the experience of building smaller boilers, there is currently less experience with operations and detailed behaviour of the large-scale boilers.

The 69th symposium of the FBC TCP (Beijing, China) focused on recent developments concerning new large-scale boilers. Large-scale application has been of particular interest as several of the participants (e.g. Tsinghua University of China, the Korean Electric Power Corporation, and Czestochowa University of Technology) are directly engaged in the design and evaluation of large-scale fluidized bed boilers.

Tsinghua University has substantially contributed to the design of the world's largest fluidized bed boiler (600 megawatts electrical [MWe]) in Baima, China. After construction the first testing was carried out in October 2013. Operational data observed during a 168-hour test period were consistent with design values. The SO_2 and NO_x emissions were lower than the national requirements. However it was noted that by reducing and harmonising the size of the coal fed into the boiler, the combustion process could be improved. Some ash leakage was also noted.

In Yeosu, Korea, the performance of a 340 MW fluidized bed boiler, which had been in operation since 2011, was evaluated by using the model originally created by the FBC TCP. The calculated results were comparable to the measured values from the plant. It was found that by changing the ratio of pressure to air intake that the boiler performance (temperature, pressure, GHG emissions) could be improved. Presentations from the symposium may be viewed on the website of the FBC TCP.

Activities

- Co-firing and ash problems
- Energy crops and fluidized bed conversion
- Fluidized bed design aspects
- Mathematical, three-dimensional modelling
- Recent trends in participating countries
- Sewage sludge conversion

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	15	2	–
Sponsors	1	–	–

www.iea.org/tcp/fossilfuels/fbc/

GAS AND OIL TECHNOLOGIES (GOTCP)

The Atlantis oil and gas facility moored at greatest depth worldwide – 2.1 km below sea level – and 305 km from shore.

Highlight

Collaboration for safe, sustainable oil and gas production

Created in 2013, the GOTCP aims to catalyse innovation across oil and gas technologies and to provide collaborative opportunities for enhancing national capabilities within both onshore and offshore activities. Co-operation between policy makers, research centres and companies to examines safety and environmental aspects of gas and oil technologies would reduce risks and increase economic and environmental benefits.

As many existing oil and gas (O&G) reservoirs have been in operation for some time, with their best producing years behind them, new deposits must be found to satisfy demand. However, with O&G from the more accessible resources in decline, exploration is focusing increasingly on "frontier" areas such as deep ocean waters, which present higher risks (safety, environment) as well as additional costs. In addition, exploration of unconventional O&G is raising new environmental concerns. Developing and deploying advanced technologies are crucial if these fossil fuels are to be produced in a safe, affordable and environmentally sustainable manner.

Since its creation in 2013, the GOTCP has promoted dialogue among high-level government officials, senior executives from multinational O&G companies and the research community to share solutions to their respective challenges and outline areas for further co-operation.

Participants recommend that governments maintain a consistent, balanced regulatory environment that ensures the safety of employees and protects the environment while at the same time providing financial incentives to O&G companies to invest in further R&D.

National public-private initiatives are already addressing some elements of safety and environmental issues, with noteworthy examples being Norway, with its DEMO 2000 Programme, and the United States, with the Research Partnership to Secure Energy for America. Connecting these efforts via an international forum, where stakeholders are able to carry out joint activities, was a means to facilitate safer and more sustainable global fossil energy development worldwide. A best practice that provides for 1% of income from production to be invested in R&D was initially adopted by Norway and is now implemented by O&G producers in Brazil, Canada and Kazakhstan.

Technology plays an important role in ensuring safe operation and reducing environmental risk. Yet once a technology has been developed, having it adopted by O&G producers faces challenges. Establishing funding for pilot programmes was identified as one solution. Even then, however, further challenges exist. For example, the technology designed to improve safety must be developed based on the needs of O&G operators (easily implemented) and, without regulation, a technology to reduce environmental risk may not be purchased or adopted at all. Connecting development of a technology, regulation and deployment of that technology in the field is seen as an important value added for the GOTCP.

Given the risks associated with offshore production, co-operation between O&G companies with complementary strengths makes economic sense. Sharing data, computational modelling techniques and R&D of new materials were identified as possible areas for co-operation. Yet technology manufacturers may be reluctant to co-operate as their respective technologies were designed to maintain a competitive advantage. In October 2014 a workshop held by GOTCP in Washington, D.C. highlighted best practices for innovation in other sectors applicable to O&G production. The high-level dialogue, facilitated by the GOTCP, achieved the desired outcome: conference participants expressed keen interest in working together to address common issues relating to deep-water offshore O&G production.

Activities

- Conventional hydrocarbon technologies
- Innovation challenges and responses
- Licence to operate innovation
- Unconventional hydrocarbon technologies

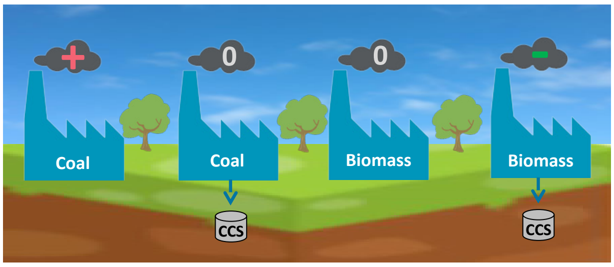
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	5	–	–
Sponsors	–	–	–

www.iea.org/tcp/fossilfuels/got/

GREENHOUSE GAS R&D (GHG TCP)

CO_2 emissions from power plants burning coal or biomass, with and without carbon capture and storage (CCS).



Source: Adapted from information provided by the GHG TCP.

Highlight

Zero-emission technology for coal and biomass

The GHG TCP examines technologies that can reduce GHG emissions derived from fossil-fuel use, with a focus on CCS. Equipping a biomass power plant with CCS technology may result in negative emissions, yet trading schemes do not currently enable reporting of negative emissions.

Combining CCS with combustion of fuels with high carbon content (e.g. coal-fired power plants, use of diesel in heavy industry) may significantly reduce or even neutralise CO_2 emissions. Combining CCS with combustion of a low-carbon fuel such as biomass from agricultural crops can actually result in “negative” CO_2 emissions and, as a result, offset CO_2 emissions from fossil fuel use.

Despite this considerable advantage, there remain a number of barriers to widespread development of biomass combined with CCS (bio-CCS). The most important barrier is the fact that few emissions accounting methodologies acknowledge negative emissions from bio-CCS and, without the means to recognise, attribute, or allocate them, it would not be possible to benefit from the concept within an emissions trading scheme. Additional barriers include carbon leakage into the ground, and land use. For example, crops used for energy purposes may compete for land used for food crops.

Recognising bio-CCS remains a task for policy-makers. While incentives and rewards have been used with some success, policy makers and regulators are discussing how to address – and overcome – these barriers.

For these reasons, experts in the GHG TCP are actively engaged in providing input to meetings of the European regulatory bodies and to the joint task force on bio-CCS led by the European Commission. These contributions are built on three recent studies of the topic carried out by the GHG TCP. Six possible options for large-scale electricity generation from biomass and for production of biofuels were evaluated.

Among the technology options identified to achieve negative CO_2 emissions, only around one-third appeared to be economically attractive. A further report reviewed the methodologies for monitoring, reporting and verification of emissions. The report found that emissions trading schemes do not recognise or attribute negative emissions, resulting in few incentives to deploy bio-CCS.

The potential of two additional technology options for producing natural gas from crops (biomethane) in combination with CCS were assessed. Again, the technical options were promising in terms of CO_2 reductions, yet the economic benefits were smaller, with niche applications in anaerobic digestion seeming favourable (Koornneef et al., 2013). The study found that the barriers to large-scale commercialisation of biomethane production with CCS include the price of CO_2 in emissions trading markets, the lack of necessary infrastructure, and the price and availability of crops.

These and other findings are comprised in the reports Biomass and CCS – *Guidance for Accounting for Negative Emissions* (GHG, 2014) and *Global Potential for Biomethane Production with CCS* up to 2050 (GHG, 2013).

Activities

- Conferences
- Expert networks
- Information papers
- Modelling and databases
- Summer school and student mentoring
- Technical evaluations and reports
- Technical workshops

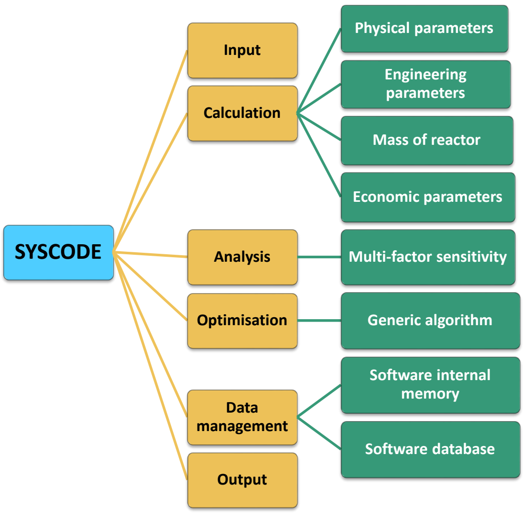
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	13	4	2
Sponsors	15	3	–

www.iea.org/tcp/fossilfuels/ghg/

ENVIRONMENTAL, SAFETY AND ECONOMIC ASPECTS OF FUSION POWER (ESEFP TCP)

Systems analysis modelling provides important information for socio-economic analysis of fusion power.



Source: Adapted from information provided by the ESEFP TCP.

Highlight

Calculating the safety and economics of fusion power

The ESEFP TCP conducts research, tests materials and develops analytical tools to advance the safety and cost-effectiveness of fusion. A revised socio-economic model for fusion power enables a valuable range of analyses such as comparing electricity extracted from fusion to wind, coal, natural gas, and nuclear fission.

Fusion energy has the potential to be a safe, environmentally attractive and inexhaustible source of power. Fusion could play a key role in meeting the growing global electricity demand in the future as well as reducing greenhouse gas emissions. Yet a significant amount of research must still be performed to demonstrate the safety and economic viability of fusion power.

For these reasons, an important activity of the ESEFP TCP is to develop reliable research methodologies that characterise the safety and viability of fusion reactors. Recently, this activity has focused on analytical tools to gain understanding of the expected costs and social acceptance of generating electricity from fusion power. In 2013, the seven countries participating in this activity sought to modernise the System Analysis Programme for Parameter Optimisation and Economic Assessment of Fusion Reactors (SYSCODE). The main functions of SYSCODE consist of systems design and design optimisation, cost assessments and engineering analysis.

To date, SYSCODE has been applied to a wide range of fusion power plant systems. For the FDS-I device (a fusion-drive subcritical system), SYSCODE enabled cost analysis of the electricity extracted showed that while fusion would be more expensive than wind energy the costs would be lower than costs of producing electricity from other sources (coal, natural gas, and nuclear fission).

For FDS-MFX (Multi-Functional eXperimental Reactor), SYSCODE was used to detail the costs depending on the phase of operations. Lastly, SYSCODE was applied to the China Fusion Engineering Test Reactor (CFETR) which resulted in two economic options for capital construction cost and electricity consumption costs.

Participants in the study validated SYSCODE parameters by comparing them with the international system codes benchmark for demonstration power plant design (DEMO)[8] reported in the 2nd International Atomic Energy Agency (IAEA) DEMO workshop.

The next phase of activity will focus on the comparison of cost assessment between SYSCODE and PROCESS, which assesses the engineering and economic viability of future fusion power plant by using simple models of all components of a reactor system.

To further understand safety issues and public attitudes towards fusion energy, participants in the ESEFP TCP are also examining stakeholder engagement, public opinion, and media framing of dedicated fusion devices, hybrid devices, and specific aspects of the fusion process such as tritiated water (including tritium),[9] a fusion by-product.

Activities

- Activation product source terms
- Failure rate database
- Fusion power plant studies
- In-vessel tritium source terms
- Magnet safety
- Radioactive waste study
- Socio-economic aspects of fusion power
- Transient thermo-fluid modelling and validation tests

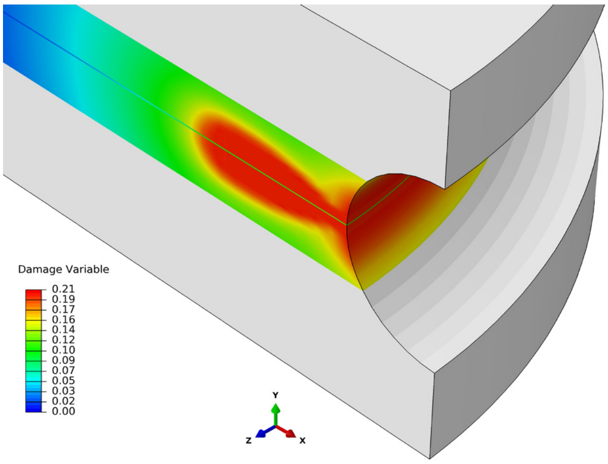
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	4	2	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/esefp/

FUSION MATERIALS (FM TCP)

The predicted state of damage and cracking in a silicon carbide joint. Research on materials is crucial for advancements in fusion power.



Highlight

Testing ceramic materials under extreme conditions

Materials able to withstand extreme temperatures and neutron bombardment in the fusion chamber are a priority for fusion. The FM TCP develops materials for the first wall and blanket of the fusion chamber capable of operating under extreme temperatures and with a high flux of neutrons. Silicon carbide and silicon carbide composites are the focus of recent testing as they are among the few than can withstand extreme temperatures for long periods of time.

A significant challenge for fusion power science is to identify materials able to withstand extreme heat radiating from plasma as well as the effects of the neutron bombardment. Other important challenges include identifying materials that are able to provide safe, reliable and predictable performance as well as a long service life at elevated temperatures with minimum latent radioactivity to enable simplified, environmentally safe recycling.

To date, materials R&D has focused on three candidate systems: steels, vanadium alloys, and silicon carbon composites. Steels containing alloys such as chromium, and tungsten have been the focus of much research and as such have the highest probability of being used in components for the demonstration phase of fusion (DEMO). Advanced steel alloys under development (oxide dispersion strengthened alloys) offer promise to withstand higher temperatures and improved resistance to radiation damage. Vanadium alloys (vanadium, chromium and titanium) also have attractive properties, especially for use with liquid lithium-cooled fusion chamber wall (blanket) designs.

Compared to metals, silicon carbide (SiC) and SiC composites show promise due to their ability to withstand the highest temperatures. Further research is needed, particularly with regard to the effects of irradiation on the material and joints between SiC device components. The use of SiC for fusion will require development of advanced ceramic joining technologies for assembling components able to tolerate the extreme environment. Improved understanding of the effectiveness of joining the two fusion device components is crucial.

For these reasons, the FM TCP participants carried out irradiation experiments on SiC joints by inserting small test specimens into the fusion device High Flux Isotope Reactor (HFIR). The specimens were twisted (torsion) to test the strength and durability of various joining methods before and after irradiation. A computer-based model was developed to analyse the model results, which showed that high-strength joints were not likely to fail in a manner that enabled exact measurement of the true strength of the joint. Yet changes in joint strength associated with radiation damage could be revealed during tests after irradiation. The damage model provides a valuable tool for interpreting the experimental data by revealing the effects of various parameters on SiC joint strength and integrity.

Results from the experimental campaign showed that strength measurements combined with information on the location of the failure could be used to assess and improve joining methods for SiC components (Henager et al., 2014).

Activities

- Diagnostics and control insulating ceramics
- Fundamental studies of irradiation effects
- Irradiation facilities and post-irradiation tests
- Modelling, computer simulation and validation
- Reduced activation ferritic steels and advanced ferritic alloys
- Silicon carbide composites
- Tungsten and tungsten-based alloys
- Vanadium base alloys

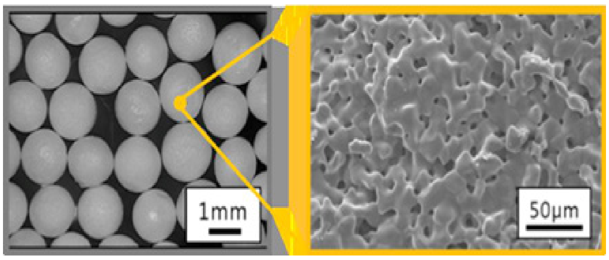
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	5	3	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/fm/

NUCLEAR TECHNOLOGY OF FUSION REACTORS (NTFR TCP)

Lithium pebbles used to extract tritium from the fusion process, one of the promising materials for the future DEMO reactors (left: pebbles, right: pebble surface).



Highlight

Improving fusion sustainability with lithium pebbles

The NTFR TCP conducts research experiments on key components of fusion power plants, in particular those close to the fusion plasma. As tritium is a rare element, it will need to be recycled from the plasma for fusion to be economically viable. Activities under this TCP found that lithium pebbles offer an innovative, low-cost approach to recycling tritium.

Developing materials that can resist extreme heat radiating from the plasma is a challenging task from a scientific and engineering viewpoint. For fusion to be achieved, we need to understand how to contain – and maintain – hot plasma. The next step will be to learn how to extract ("breed") fuel ("tritium") from the hot plasma in order to regenerate the fusion ignition.[10] Technology plays a critical role in accomplishing this task through components lining the wall called "blanket modules". Several materials for blanket modules have been examined to date, both solid and liquid, and a variety of blanket module concepts have been considered ranging from more conservative concepts to higher-risk higher-payoff concepts for future reactors. The major candidate breeding materials consist of liquid breeders, mainly liquid metals, although more recently some attention has been given to multi-materials such as steel/lithium/beryllium and lithium ceramic breeders.

A recent advance for breeding tritium is through ceramic pebbles containing lithium. Lithium meta-titanate (Li2TiO3) pebbles are being considered as one of the most promising tritium breeding materials for future DEMO reactors because of its reasonable lithium atom density, prominent tritium release rate at low temperatures, its low activation characteristics, low thermal expansion coefficient and high thermal conductivity.

For these reasons, the participants in the NTFR TCP working group "Characterization of newly developed ceramic breeder pebbles" launched round-robin tests of pebble samples in facilities of each of the participants (China, Europe, India, Japan, and Korea). They set out to characterise the optimal chemical composition, fabrication method, and thermal and mechanical properties of tritium breeder pebbles under fusion conditions in order to establish benchmarks.

In China, experiments focused on optimising the present fabrication process, researching the fundamental character of ceramic pebbles, and enhancing the tritium release properties of ceramic pebbles to supplement the tritium breeder database. In India, the test facility is based on the principal of steady state and axial heat flow methods, aiming to develop tritium breeder material by solid state reaction and solution combustion method. In the European Union (Karlsruhe Institute of Technology, Germany), the EU test facility is based on the hot wire method (Knitter et al., 2014). In Japan, experiments aimed to define accurate understandings of the vaporisation properties from the breeder materials, the measurements in proper temperature ranges are required. Korea focused research on the fabrication methods. A slurry droplet wetting method was effective based on the cross-linking reaction between PVA and boric acid.

These results have greatly improved the thermo-mechanical design of the ITER Test Blanket Modules, which are the key technology of the fusion DEMO reactors to extract high performance, safe and clean energy from the fusion reaction.

Activities

- Liquid breeding blankets
- Neutronics
- Plasma-facing components
- Plasma surface interactions
- Solid breeding blankets
- Tritium processing

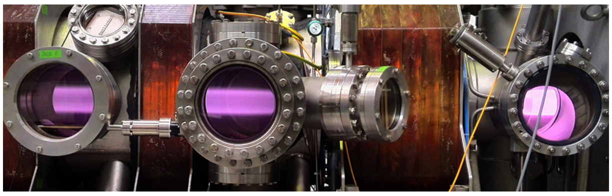
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	4	3	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/ntfr/

PLASMA WALL INTERACTION (PWI TCP)

Results of tests in the linear plasma device PSI-2 may inform materials choices for ITER.



Highlight

Testing materials with linear plasma devices

The PWI TCP conducts research to understand the phenomena of interaction between the plasma and the chamber walls and to develop relevant wall materials for applications in fusion power. To reproduce the radiation levels expected with ITER, materials for plasma wall-facing components are being tested in linear plasma devices.

Materials that line the fusion chamber walls must withstand extreme temperatures of 100 million°C and be robust enough to maintain structural homogeneity when coming into contact or interaction with the plasma. The effect of the plasma on the wall components and the influence of eroded material on the plasma is an important focus of fusion research.

In ITER and DEMO the amount of heat and particles from the plasma is expected to be much larger than in any existing device. Fast neutrons released by the deuterium-tritium reaction risk damaging chamber wall materials and degrading the plasma-facing components. The combined effects of heat, particles and neutrons will affect the lifetime of the wall components in a fusion reactor – and the cost-efficiency of the facility.

For these reasons the PWI has been focusing research on chamber wall materials in dedicated facilities such as linear plasma devices.[11] These facilities enable experiments in the field of plasma wall interactions similar to conditions expected with ITER and DEMO. The new devices are also capable of handling neutron irradiated materials that allow for a combination of different scenarios.

The PWI TCP experimental programme is closely linked with the development of novel, advanced materials capable of withstanding extreme conditions. Tungsten-based materials are the most promising for fusion reactors because of their high melting point (3 422°C) and efficient thermal conductivity.

Nevertheless the bombardment of tungsten surfaces with a high amount of particles erodes the surface, leading to microstructural changes in the material. Tungsten can also absorb hydrogen during plasma exposure, which increases the risk of the release of a significant amount of radioactive fusion fuel in the event of an accident.

The PWI TCP compared the impact of plasma exposure on surfaces and hydrogen retention in tungsten in steady-state and short-lived modes of plasma operation. Findings from recent experiments show that the absorption of hydrogen and the formation of defects in the tungsten components are strongly dependent on the magnetic force passing through the plasma and the surface temperature during exposure.

Further research is required to select and develop suitable first wall materials for future fusion reactors. Results of these experiments are detailed in the report, *Influence of Particle Flux Density and Temperature on Surface Modifications of Tungsten and Deuterium Retention* (Buzi et al., 2014).

Activities

- Characterisation of plasma edge properties
- Development and qualification of first wall materials
- Development of diagnostics for edge plasma and material surface characterisation
- Modelling of plasma wall interaction studies
- Surface characteristics under intense particle and heat loads

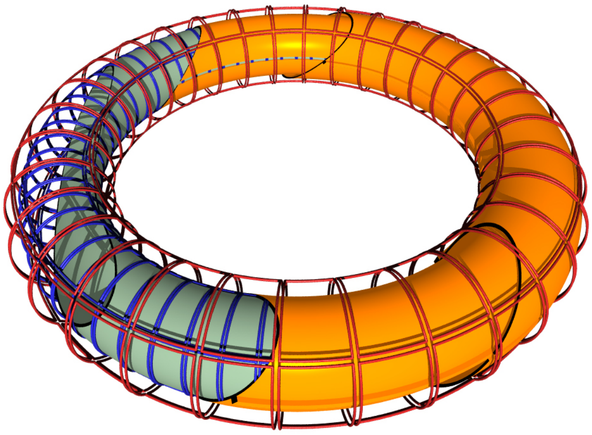
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	2	–	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/pwi/

REVERSED FIELD PINCHES (RFP TCP)

Studying the reversed-field pinch through 3D imaging provides insights for the design of fusion technologies (shown here on the EXTRAP T2-R, Sweden).



Highlight

Identifying common research challenges

The RFP TCP shares instrumentation and carries out joint experiments to develop theories and models of the physics phenomenon of reversed-field pinches (RFP) and related technologies. Collaborative activities and a joint workshop with scientists researching the stellarator-heliotron concept of fusion reactors identified common research grounds such as three-dimensional (3D) computational tools.

The most highly developed approach to fusion power, the tokamak, confines hot plasmas through the use of large, superconducting magnets that create a powerful magnetic field. However, the magnetic coils are located outside of the chamber, creating physics and engineering challenges that must be overcome. In the RFP approach, the current in the plasma generates almost all of the magnetic field, heating the plasma and reducing the magnetic field that must be applied from the outside. This increases efficiency, yielding a larger fraction of kinetic energy in the plasma relative to the magnetic energy in the magnets.

As a close relative to the tokamak and stellarator configurations, RFP research advances fusion science and engineering while resolving key challenges specific to fusion reactors based on this concept. Knowledge gained from physics research of the RFP phenomena bridges the gap between tokamaks and stellarators by developing predictive models for achieving and maintaining fusion plasma.

There are four RFP devices worldwide. Therefore close collaboration enables these fusion research laboratories to leverage scarce resources by sharing experimental results during periodic workshops. In September 2013, a first joint workshop was organised between the RFP TCP and the stellarator-heliotron (SH) research communities. This was an important first step towards aligning research goals and mutually benefitting from experimental results in both types of fusion reactors. The workshop underlined that despite differences in the configurations among the devices, the magnetic confinement community shares several 3D are important issues.

Both SH and RFP research communities gain knowledge from sharing three-dimensional (3D) computational tools. Therefore (3D) geometry was a recurring theme of the workshop. One of the most critical common issues is the role of fast ions and their confinement with many fusion-generated alpha particles (high-speed helium atoms). Another important issue highlighted was the need to remove the helium "ash" from the plasma in order to maintain the fusion reaction.

Other common issues discussed include power exhaust, stability control, plasma confinement, closer integration of the optimisation of physics performance and engineering design issues, and critical evaluation and testing of models of particle, momentum and energy transport, and development of diagnostics.

These are some of the topics discussed at the workshop that provided a valuable opportunity to understand more clearly commonalities and differences between the SH and RFP theoretical approaches to technology for nuclear fusion, and demonstrated the value of exploring common research grounds. Presentations and the workshop summary are available upon request.

Activities

- Co-ordinated experiments on RFP fusion devices:
  - EXTRAP T2-R (Sweden)
  - Madison Symmetric Torus (MST) (United States)
  - Reversed Field Experiment (RFX) (Italy)
  - Reversed Field Pinch of Low Aspect Ratio (Japan)

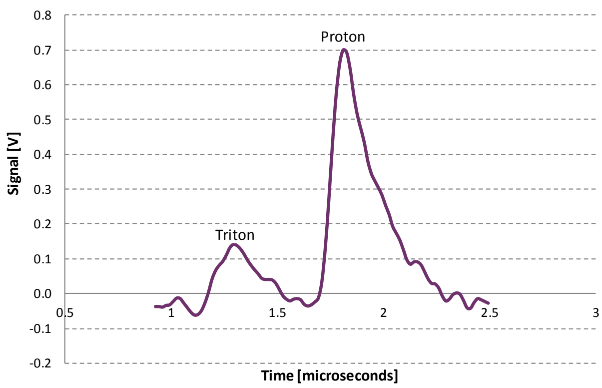
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	2	–	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/rfp

SPHERICAL TORI (ST TCP)

Proton and triton data gathered from experiments on the new charged fusion production detector.



Source: Adapted from data provided by the ST TCP.

Highlight

Enabling benchmarks of fusion physics

The ST TCP supports co-operation among spherical torus research programmes and facilities worldwide in order to advance the scientific and technology knowledge of plasma confinement. A new, small, inexpensive device measures turbulence and the energy contained in the plasma across several devices in order to establish benchmarks and enable comparative analysis.

While much research in fusion science has focused on tokamak devices, the ball-shaped spherical tori (ST) have recently emerged as an innovative approach to fusion confinement. As the STs are smaller than tokamaks they offer particular advantages including lower construction and operating costs and facilitating control of the physics parameters of the plasma.

In addition, due to the improved stability of an ST device, the plasma has a higher plasma pressure relative to the magnetic field pressure, an important element in fusion science. Higher plasma pressure combined with a significantly smaller magnetic field result in greater power output as less electricity is required to create the magnetic field.

Further research is required to understand how modifications in the magnetic field impact the stability and confinement of the plasma in ST fusion reactors. Additional research is also needed to assess the effectiveness of STs in using external sources of heat to maintain the plasma.

The plasma in STs is heated by injecting fuel using neutral beam injection (NBI). As the neutral particles are injected they collide and transfer energy to the plasma particles. NBI also helps sustain the plasma by pushing the flow (current) and spinning the plasma which suppresses turbulence and increases the plasma temperature. Therefore, measuring and understanding how NBI particles are deposited, transported or lost from the plasma is critical.

For these reasons the ST TCP set out to increase the knowledge and understanding of ST physics through improved measurements of the turbulent fluctuations and the energy contained in the plasma.

A new "charged fusion product detector" developed by participants from Florida International University (FIU) in collaboration with the Princeton Plasma Physics Laboratory (United States) measures the production of protons and tritons from NBI-induced fusion reactions. The particles are measured as they pass through the detector. The new detector was successfully installed and tested on the Mega Ampere Spherical Tokamak (MAST) device (United Kingdom) for the first time during its final experimental campaign in 2013.

The resulting data were found to be consistent with results of other devices installed in fusion devices, thereby validating the new detector's capabilities. In addition, as the new detector is more compact, less expensive and easier to implement, it may be easily installed for use on other devices, providing further data sets which may be compared to those obtained on MAST. These and other results are available in the ST TCP *Annual Report 2014* (ST TCP, 2014).

Activities

- Physics and technologies
- Science and R&D
- Steady-state operation

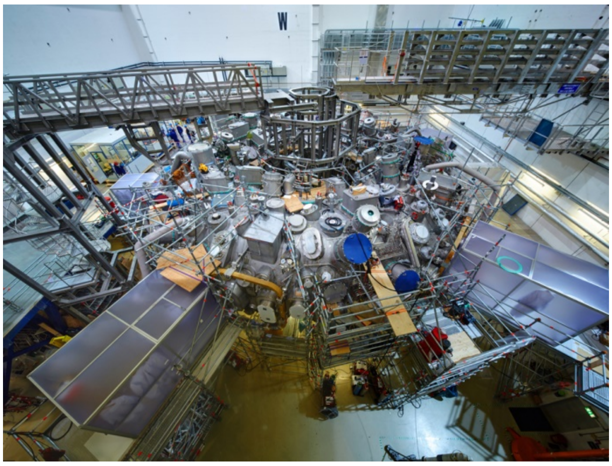
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	2	–	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/st/

STELLARATOR-HELIOTRON CONCEPT (SH TCP)

The commissioning and in-vessel assembly of the Wendelstein 7-X device (Greifswald, Germany).



Highlight

Achieving milestones in magnetic fusion

The SH TCP aims to advance applications of physics for fusion power, in particular magnetic fusion devices by developing the stellarator-heliotron concept of fusion reactors. A new world record of stable plasma for 48 minutes was attained in the Large Helical Device (Japan). Construction of the world's largest stellarator device, Wendelstein 7-X (Germany), reached completion in 2014.

Stellarators and heliotrons[12] are fusion devices with external magnetic field coils that confine the plasma. Unlike tokamaks, stellarators and heliotrons do not run electric current through the plasma, thereby reducing instability and avoiding disruptions in the plasma and enabling steady-state operations, an element required to extract power from the fusion process.

For this reason the SH TCP has engaged in the joint planning and co-ordination of experimental programmes and personnel exchanges between the participating countries to accelerate plasma performance and develop a comprehensive understanding of the physics of toroidal-shaped plasmas. Developments of three of the SH participants are outlined below.

The Large Helical Device (LHD) (Japan) is the largest experimental platform for exploring the heliotron concept. The LHD has provided many opportunities for international collaborations which have in turn led to steady progress in knowledge of fusion science. In 2013, experiments resulted in high-density plasmas at high temperatures (exceeding 90 million°C in the central ions). The steady-state operation of the plasma was sustained for nearly 48 minutes at a temperature of 2 000 electron volts (eV)[13] with a heating power of 1.2 MW, resulting in a total energy input of 3.36 gigajoules (GJ) – more than twice the world record of 1.6 GJ previously attained by LHD.

Progress has also been made on construction of the Wendelstein 7-X (W7-X) (Germany), the world's largest stellarator device with modular superconducting coils. The main assembly of W7-X was concluded in 2014. All technical systems were verified, and the first plasma took place on schedule in 2015.

With the implementation of the EUROfusion Consortium for the Development of Fusion Energy in 2014,[14] W7-X has become an integral part of the European Fusion Development Agreement (EFDA) *Roadmap to the Realisation of Fusion Energy*, which aims at integrating fusion electricity into the energy supply network by 2050.

Experiments carried out on the medium-sized heliac device, TJ-II (Spain) have focused largely on fulfilling the scientific and research objectives of the work packages defined in the EUROfusion roadmap as well as development of diagnostics, in particular the understanding of the TJ-II confinement configurations, including isotope and fast particle physics, plasma stability and the effects of impurities.

Other devices that contribute to the work programme of the SH TCP include the Heliotron J (Japan), HSX (United States), H-1NF (Australia) and Uragan 2M and 3M (the Ukraine) and L2-M (Russia). Activities of all the SH TCP participants were compiled in the *Executive Committee Annual Report 2014* (SH TCP, 2015).

Activities

- Confinement and profile database
- Co-ordinated working group meetings
- DEMO assessment based on SH concepts
- High-performance and steady-state plasma confinement
- International workshops
- Joint experiments, model validations
- Numerical code verifications

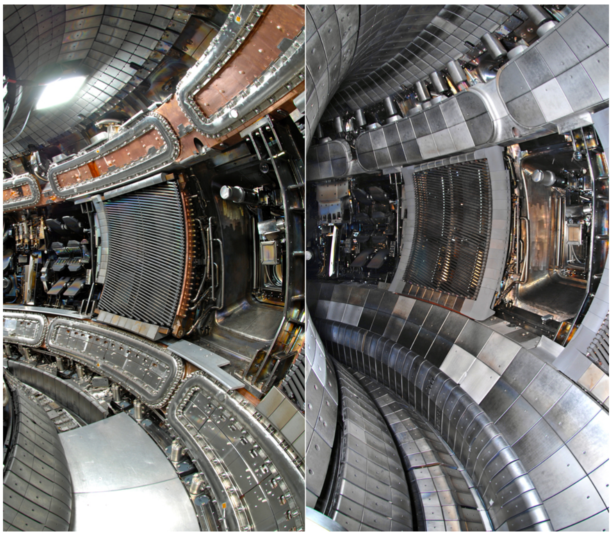
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	3	2	1
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/sh/

TOKAMAK PROGRAMMES (CTP TCP)

In-vessel coil devices designed to mitigate transient thermal energy losses in the ASDEX-Upgrade tokamak (Garching, Germany).



Highlight

Reducing, avoiding and mitigating plasma instabilities

The CTP TCP carries out collaborative research activities on tokamak[15] fusion reactors and joint experiments to enhance scientific and technological understanding of these doughnut-shaped devices for fusion power. Given the volatility of fusion plasma, identifying and testing systems to remedy plasma disruptions is crucial to advancing fusion power technology.

Fusion energy could play a primary role in reducing GHG emissions while enhancing energy security, diversifying fuel sources, and providing large-scale electricity at stable production costs. Much fusion research focuses on maintaining the plasma in equilibrium and finding suitable materials to withstand the extreme temperatures. Co-ordinated experiments are needed to understand and master this complex science.

To date, tokamak fusion reactors are the most promising fusion confinement devices. The International Thermonuclear Experimental Reactor (ITER),[16] the world's largest tokamak pilot reactor, is an international collaboration between seven parties. ITER is expected to produce approximately 500 MW of electricity from an input of 50 MW. Despite this potential, further research is needed to demonstrate the safety of this experimental reactor. The successful exploitation of ITER depends on developing reliable and effective strategies to predict, and work to avoid, ejections and disruptions in the plasma. When small amounts of the plasma are regularly ejected, or when the plasma loses density and it is disrupted, energy is deposited on the inner walls of the reactor. These deposits interact with further operations and damage the metallic surfaces.

For these reasons, the CTP TCP worked to characterise these ejections (edge localised modes) and disruptions and to explore solutions and to develop systems and methodologies to reduce them. Most participants have now equipped their respective devices with in-vessel coils designed to minimise the ejections. In addition, many devices are now equipped with dedicated exhaust valves designed to dissipate excess energy bursts before they can affect the chamber walls.

If these plasma control systems fail to stabilise the plasma, a disruption system must be activated. Two possible avenues for disruption systems were considered. The first was massive injection of gases such as neon or argon into the plasma. A second solution was to inject cork-sized pellets of frozen gas (mostly neon and deuterium) into the plasma. Both methods must be deployed very quickly to mitigate the disruption.

While experiments have demonstrated reliable mitigation of electromagnetic loads using gas injection, uncertainties remain. Consequently, the CTP TCP recommends developing a flexible disruption system that includes both massive gas injection and shattered pellets to ensure successful and safe operations. ITER will be equipped with ELM and disruption mitigation systems similar to those being developed and tested on current tokamaks. These and other findings are consolidated in the report, *Disruptions in ITER and Strategies for their Control and Mitigation* (Lehnen et al., 2014).

Activities

- Confinement and transport
- Disruption and ELM mitigation
- Edge and pedestal physics
- Energetic particles
- Plasma control and scenario development
- Plasma diagnostics
- Plasma-wall interaction
- SOL and divertor physics

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	3	2	2
Sponsors	–	–	–

www.iea.org/tcp/fusionpower/ctp/

BIOENERGY TCP

Bus fuelled by biomethane (Malmö, Sweden).

Highlight

Moving ahead with biogas

The Bioenergy TCP aims to accelerate the production and use of sustainable and cost-competitive biomass for energy. Activities under this TCP assist policy makers to gain perspective on progress in bioenergy and working with industry to develop standards. Recent analysis shed light on the significant potential of biomethane in transport applications, enabling an 80% reduction in GHG emissions compared with fossil fuel alternatives.

Oil accounts for 76% of CO_2 emissions in the transport sector worldwide (IEA, 2014a). Replacing oil with fuels from renewable sources could offer a sustainable alternative particularly when produced locally.

Renewable fuels may be obtained from biomass feedstocks derived from animals or plants, such as wood and agricultural crops, municipal and industrial organic waste. Biogas, a mixture of methane and carbon dioxide used as fuel and produced by bacterial degradation of organic matter or through gasification of biomass, can be converted in electricity, heat, or upgraded to biomethane for use in motor vehicles. Alternatively it may be injected into the natural gas supply network making it readily available to consumers, particularly in Europe.

The Bioenergy TCP carried out two studies of biogas fuels. The first study aimed to identify and understand the economic and environmental sustainability aspects of successful development and implementation of modern biogas projects.

Participants in the study carried out a wide-ranging inventory and case studies of the full value chain of the production process of biogas in IEA member countries. The findings of the study were collected into a number of focused publications, including the Biogas Handbook (designed for governmental bodies and industry), as well as technical brochures (e.g. exploring the role of biogas in smart energy grids) and country reports (Bioenergy TCP, 2013).

The aim of the second study was to provide researchers, policy makers and industry leaders with an up-to-date overview of the status of biomethane production from biomass in IEA countries, the elaboration of supply strategies, challenges facing expansion of trade, and expected future perspectives for development of the biomethane sector. The findings show that replacing fossil fuels such as natural gas with biomethane may result in a significant reduction in GHG emissions from the transport sector. Depending on the plant design/operation, the specific fossil fuel displaced, and GHG calculation methodology, findings from the study suggest that it is possible to achieve up to 80% reductions in GHG emissions with biomethane compare to fossil fuel.

Yet biomethane production is currently more costly than natural gas. Adopting international standards for biomethane composition and quality is necessary to ensure sustainable biomass production, as well as sound and transparent methodology to determine adequate requirements for biomethane to be transported and traded through the natural gas supply network. These and other results of this study have been synthesised into the *Bioenergy TCP final report, Biomethane – Status and Factors Affecting Market Development and Trade* (Bioenergy TCP, 2014).

Activities

- Biomass combustion and co-firing
- Biomass feedstocks for energy markets
- Bio-refining
- Climate change from biomass and bioenergy systems
- Commercialising biofuels from biomass
- Energy from biogas
- Energy recovery from solid waste management
- Pyrolysis of biomass
- Sustainable international bioenergy trade
- Thermal gasification of biomass

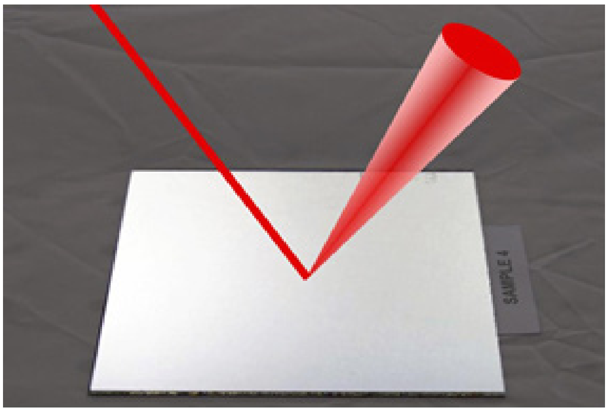
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	19	3	1
Sponsors	–	–	–

www.iea.org/tcp/renewables/bioenergy/

CONCENTRATED SOLAR POWER (SOLARPACES TCP)

Illustration of sunlight reflection and scattering on a sun-tracking mirror (Almeria, Spain).



Highlight

Standardising solar mirror tests reduces costs

The SolarPACES TCP aims to facilitate technology development, market deployment and collaborations for concentrating solar technologies. Identifying less expensive, lighter and more robust alternatives to glass mirrors will enable widespread development of solar concentrating technology.

Concentrated solar power (CSP) technologies use sun-tracking mirrors to collect and concentrate the sunlight and use it as a form of high-temperature heat for electricity generation and industrial processes. Despite the higher investment cost, operating costs for CSP plants are lower than fossil fuel alternatives, and there are no costs for the "fuel". Identifying economical reflecting materials could further reduce investment costs.

Yet currently there is a lack of standard measurement procedures for these materials as well as a lack of commercially available instruments capable of measuring the reflectance (the ratio between the amount of energy of the reflected and naturally occurring sunlight) that is a fundamental measure of the performance of a reflector material.

Currently glass mirrors lined with silver are the most efficient material for CSP (95%), yet due to their high cost, weight, fragility and risk of corrosion from dust storms, CSP developers and operators are seeking alternatives.

For these reasons the SolarPACES TCP set out to establish guidelines for measuring and testing reflective materials for CSP collectors in collaboration with ISO and IEC. The project consisted of two elements: setting a standard procedure for materials measurements and testing the procedures under laboratory conditions.

Two parameters were defined to assess the quality of all types of solar reflector materials: reflectance and specularity (capacity to reflect all light into the direction of the solar receiver). Four commercially available materials (floating glass mirrors, metalised polymer films, polished aluminium and anodised aluminium) were tested. The best optical performance was achieved by glass mirrors lined with silver as they presented the highest solar reflectance and optimum specular behaviour.

Three recommendations emerged from the study. First, commercial products should specify the wavelength and angle of the measured reflectance in order to be comparable. Second, with highly specular materials (e.g. silvered-glass mirrors) the recommended procedure is to measure two types of reflectance (hemispheric and monochromatic) within acceptable ranges. Finally, innovative reflector materials (e.g. multi-layer silvered polymer films or aluminium mirrors) require a deeper investigation of the specular properties (at several acceptance angles),[17] due to scattering of light rays. Further research is being conducted to update the guidelines for these new types of materials.

These and further findings are available in the report, *Parameters and Method to Evaluate the Solar Reflectance Properties of Reflector Materials of Concentrating Solar Power Technology* (SolarPACES TCP, 2013).

Activities

- Solar chemistry research
- Solar energy and water processes and applications
- Solar heat integration in industrial processes
- Solar resource assessment and forecasting
- Solar technologies and advanced applications
- Solar thermal electric systems

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	10	10	1
Sponsors	–	–	–

www.iea.org/tcp/renewables/solarpaces/

GEOTHERMAL ENERGY (GEOTHERMAL TCP)

Direct use of low-temperature geothermal heat (hot springs at Whangaroa, Atiamuri, New Zealand).

Highlight

Reducing costs by combining geothermal sources

The Geothermal TCP provides a flexible and effective framework for international collaboration on R&D concerning the sustainable use of geothermal energy. Recent studies found that combining high-temperature geothermal for electricity generation with direct use of low-temperature geothermal heat (space and water applications) can greatly improve the overall economics of the system and reduce payback time.

Geothermal resources (water or steam) may be used directly for applications such as space heating or swimming pools. Higher temperature resources enable heat as well as electricity generation. Because geothermal energy has definite base-load characteristics and relatively high annual full-load hours, the return on investment for geothermal installations can be attractive. In 2014, some 80 countries used geothermal energy for heat generation and 25 for electricity production (Geothermal TCP, 2015).

In order to maximise the benefits from geothermal it is beneficial to take full advantage of the "cascading" uses of hot water or steam from geothermal sources such as wastewater from a geothermal electricity plant. These multiple uses offer several advantages, including better resource efficiency and higher rate of return on the initial investment when waste heat or wastewater can be used in an industrial process or agriculture application located at relevant distance.

To date geothermal cascading has been successfully implemented throughout the world. Applications include greenhouses that are heated with wastewater from an electricity plant; reusing wastewater from a pavement snow melting system to heat water in spas; and cascading uses of geothermal steam and hot water for residential space heating and swimming pools. The Geothermal TCP identified over 50 known applications of geothermal heat. As such there is considerable further potential for expansion of geothermal projects, particularly in those countries where there is an abundance of high-temperature ground water close to the surface.

The Geothermal TCP set out to assess the current status of technologies for direct use of geothermal heat, to establish guidelines for project development and design, to identify barriers to commercial development and possible responses, and to examine further potentials. A recent report focused on Canada, a country with more than 150 hot springs though with a relatively limited number of geothermal installations. Low-temperature geothermal resources are currently used directly for heating buildings, swimming pools or therapeutic spas (a capacity of 8.8 MWth). Yet there remains considerable further geothermal resources estimated at 12 000 MWth. Through cascading, these resources could be used for greenhouses, agricultural processes or industrial applications.

Despite high potential, a number of barriers hamper further development of geothermal sources in Canada. First, there is no complete or current survey of geothermal resources (the 1986 Geological Survey of Canada shows only 40% of land mass as surveyed). Second, the economics of the geothermal systems are affected by the high initial investment cost of the technology and the relatively low market price of energy due to Canada's abundant natural gas reserves. These and other findings are the focus of the publication *Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada* (Cangea, 2014).

Activities

- Advanced drilling and logging technologies
- Data collection and information
- Deep roots of volcanic geothermal systems
- Direct use of geothermal energy
- Enhanced geothermal systems
- Environmental impacts
- Induced seismicity

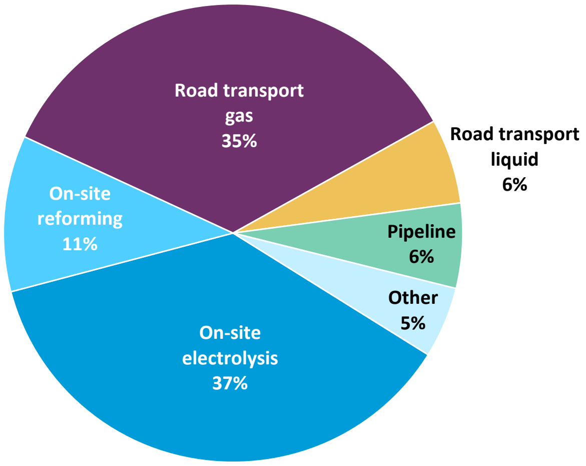
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	12	2	1
Sponsors	3	–	–

www.iea.org/tcp/renewables/geothermal/

HYDROGEN TCP

Hydrogen refuelling stations worldwide.



Source: Adapted from data provided by the Hydrogen TCP.

Highlight

Exploring pathways for fuel cell vehicles with hydrogen

The Hydrogen TCP aims to accelerate deployment and use of hydrogen technologies by carrying out and co-ordinating collaborative activities of analysis, applied research and communication. Recent work indicates that the availability of widespread hydrogen delivery infrastructure is of crucial importance and it should be based on national, regional and local conditions.

Fuel cell electric vehicles (FCEV) powered by hydrogen are approaching commercialisation. Yet further development of large-scale hydrogen delivery infrastructure is needed. While hydrogen refuelling stations have grown eightfold since 2004, better understanding of the technical and economic viability of such refuelling points aid to further commercialise FCEVs.

For these reasons the Hydrogen TCP set out to develop a common knowledge base on concepts and components for the large-scale delivery of hydrogen; evaluate delivery infrastructure pathways and scenarios; identify knowledge gaps with regards to hydrogen deployment strategies; and explore potential synergies with storage applications for variable renewable energy sources.

Activities of this important four-year study completed in 2014 comprise data collection, comprehensive overviews of the eight countries participating in the project, analysis and scenarios. An important element of the study involved an inventory (mapping) of existing hydrogen refuelling stations worldwide, including an evaluation of the technical feasibility, capacity and functional requirements of each. While some 250 hydrogen refuelling stations exist worldwide, the majority of these are found in Europe (40%) and are located on industrial sites and at university pilot projects; therefore, they are not accessible to the general public.

Significant differences were noted in the delivery options available in each country. On-site reforming (converting natural gas to hydrogen) is virtually absent in Europe but prevalent in Asia. While compressed hydrogen-dispensing techniques are used in Europe, Asia and North America, on-site reforming is more common in North America.

Understanding the costs associated with integrating the hydrogen refuelling stations will enable further technology deployment. The study set guidelines and definitions of the costs of equipment and of integrating the equipment into the service station. Further analysis of the cost of distribution networks and cash flows is needed. Finally, the study explored options for combining widespread hydrogen refuelling stations with renewable sources.

Designed for industries and policy makers, the preliminary findings highlight that all hydrogen delivery options are feasible, yet the most practical and economic options will depend on national, regional and local circumstances. In addition, the standardisation of regulations, codes and standards is the key to driving down hydrogen refuelling system integration and component costs. The insights and experiences gained are being compiled into the report, *Large-Scale Hydrogen Delivery Infrastructure: Final Report* (Hydrogen TCP, 2015).

Activities

- Bio-hydrogen
- Distributed and community hydrogen
- Fundamental and applied hydrogen storage materials deployment
- Global hydrogen systems analysis
- Hydrogen-based energy storage
- Hydrogen safety
- Local hydrogen supply for energy applications
- Near-term market routes to hydrogen
- Production of hydrogen from renewables
- Water photolysis

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	18	2	1
Sponsors	3	–	–

www.iea.org/tcp/renewables/hydrogen/

HYDROPOWER TCP

Fish ladders facilitate the upstream migration of fish past a hydropower plant (Trondheim, Norway).

Highlight

Easing fish migration past hydropower plants

The objectives of the Hydropower TCP are to raise awareness, knowledge and support for the sustainable use of water resources for the development and management of hydropower. Recent activities included promoting best practices that enable hydropower plant operators to manage wildlife migration while ensuring protection of species and habitats.

Hydropower is a mature technology and the largest current source of renewable power in the world (IEA, 2015a). Hydropower plants provide reliable, baseload power and each installation may have a lifetime of 50 years or more. Hydropower plants are designed for the specific topography of the operation site and thus exist in many different configurations.

Despite the significant potential for hydropower technology to provide clean supply of baseload electricity, concerns over the environmental impacts of large hydropower plants may delay some future developments and result in increased costs.

This interrelationship between hydropower and fish is an important aspect that is increasingly addressed by environmental impact studies associated with hydropower projects. There is considerable interest in research to formulate best practices for fish management in rivers with dams and other aspects directly or indirectly affecting the passage of migratory fish, altering the water temperature, flow rate and other factors.

For these reasons the Hydropower TCP initiated a study that aimed to collect complete information and advice on fish management, fish migration and river sustainability issues, which decision makers could take into consideration when overseeing the development and operation of hydropower projects.

Participants in the Hydropower TCP work stream, "Hydropower and Fish", conducted fact-finding workshops focusing on two-way fish migration past hydropower structures in rivers in Finland, Italy, Lao People's Democratic Republic (Lao PDR), and Norway. Australia, France, and the United States also contributed information to the study.

Workshop discussions focused on principles for sustainable fish management, effective measures for ecological continuity (fish passage), and effective measures for fish protection for migrating and non-migratory species. In addition regulatory regimes for fish management and effective management models were reviewed.

These events resulted in the collection of case histories and studies, surveys and research reports on fish management topics, including specific species such as salmon, trout and eels.

Best practices highlighted from the workshops include fish-friendly turbines in the Lower Mekong river basin (Lao PDR), protection of eels in the Weser river basin (Germany), and dam removal and habitat restoration for Atlantic salmon (Norway).

These findings, together with a comparative analysis of fish management approaches, best practices, and a gap analysis of the needs for future research are currently being compiled into the final compendium, *Fish Management in a Hydropower Context* (Hydropower TCP, forthcoming).

Activities

- Hydropower and fish
- Hydropower services
- Managing GHG emissions from freshwater reservoirs
- Renewal and upgrading of hydropower plants
- Small-scale hydropower

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	6	2	–
Sponsors	–	–	–

www.iea.org/tcp/renewables/hydropower/

Ocean Energy Systems (OES TCP)

More research and monitoring are needed on the interaction between marine mammals and ocean energy technologies.

Highlight

Monitoring effects of ocean technologies on marine life

The OES TCP carries out a range of activities relating to the viability, uptake, sustainability and acceptance of ocean energy technologies. Findings from recent work point to the need to monitor regularly interactions between marine mammals and ocean technologies in order to identify the most severe risks and implement mitigation actions.

The OES TCP estimates that if deployed worldwide, ocean technologies could meet the world's current electricity demand of close to 20 000 TWh. While a range of technologies and devices have been demonstrated through pilot projects, widespread commercialisation is slow due to relatively high costs and concerns over environmental issues in coastal waters such as the risks to marine mammals and habitats.

For these reasons the OES TCP set out to assess the environmental effects of ocean wave, current and tidal energy systems. An earlier first phase of the study aimed to collect data on research and monitoring projects around wave and tidal devices.

Activities of the second phase of the project included targeted workshops to develop recommendations for the research community, regulators and marine energy developers for designing monitoring programmes and instrumentation to investigate the highest risks associated with wave and tidal technologies.

Workshop participants defined specific interactions between marine animals and ocean energy devices (collision, attraction, avoidance and entrapment), and proposed optimal approaches to measure interactions, and assesses monitoring costs. Of these, collision/evasion was identified as the highest risk. Examples cited include harbour porpoises interacting with tidal devices, large whales and harbour seals changing movement patterns around wave arrays, and monitoring interactions of large fish around tidal turbines, including evasion and passage through the turbine. For these issues, monitoring and observation is most appropriate via boats or airplanes.

While there appeared to be consensus among participants representing the research community that the risk of collision between marine animals and tidal blades is very low, the interaction remains of concern to regulators and stakeholders. Therefore, further monitoring and research are needed. Key methods to improve monitoring of collision/evasion include tagging mammals to track movements; acoustic monitoring to detect, localise and characterise species attracted to sounds emitted by wave and tidal devices; and assessing fish populations so as to track developments over time.

These best practices provide insight into the interactions between marine wildlife and wave and tidal devices that enable policy makers and regulators to make informed decisions on deployment projects. These findings, together with best practices for monitoring the environmental effects of marine energy devices, have been collected into a final report, *Best Practices for Monitoring Environmental Effects of Marine Energy Devices* (OES TCP, 2014).

Activities

- Assessment of environmental effects and monitoring
- Assessment of project information and experience
- Consenting processes for ocean energy
- Cost of energy assessments
- Detailed global information related to ocean energy
- Worldwide Web Global Information Service database

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	17	6	–
Sponsors	–	–	–

www.iea.org/tcp/renewables/oes/

PHOTOVOLTAIC POWER SYSTEMS (PVPS TCP)

Very large-scale (500 MW) photovoltaic installation (Germud, Qinghai, China).

Highlight

Producing energy in the desert with photovoltaics

The PVPS TCP aims to promote the role of energy from solar photovoltaic (PV) technologies as a cornerstone in the transition to sustainable energy systems. It conducts a variety of collaborative projects relevant to solar PV technologies and systems, including cost reduction, analysis of barriers and raising awareness of the potential of PV electricity. Recent work has cast light on solar PV installations in deserts, including consideration of scale and the specific operating conditions that enable an attractive return on investments.

Solar PV modules are commercially available, reliable technologies that may be installed on buildings for individual consumption or in large arrays to provide power for regional or national electricity networks. Given this flexibility, there is significant potential for growth of PV in nearly all world regions, and particularly in those regions where there is unobstructed sunlight (irradiation) year-round.

Because deserts are vast areas of land with high levels of irradiation year-round, they provide good siting conditions for the deployment of solar PV technologies. Large-scale solar PV installations (from 10 to 550 MW) are possible, and landowners are able to derive economic benefits from land that is not suitable for agriculture or other industrial activities. Yet, electricity networks are typically limited in desert regions. This may raise costs for project developers to upgrade the electricity transmission and/or distribution networks to operate the system, which is often far from urban and/or industrial centres of consumption. Transmission and distribution losses may pose additional challenges.

For these reasons, the PVPS TCP set out to assess the potential and feasibility of such systems; to develop practical concepts towards implementing very large-scale PV installations in deserts; to actively engage in dissemination and communication with relevant stakeholders; and to develop recommendations on how to overcome barriers to deployment. Technical and economic feasibility, socio-economic benefits, and lessons learned from very large-scale PV installations around the world were also considered.

Since desert temperature, humidity, aerosol clouds and soiling differ considerably from the standard industry conditions used to characterise performance of PV. More accurate data on these conditions improves the performance of PV installations in deserts and the cost-efficiency of the technology, and reduces uncertainty in potential PV production.

Given that much of China's western provinces are comprised of arid land (Gobi, Ordos and Takla Makan deserts and the Tibetan plateau), this country was chosen as a case study. In developing and operating very large-scale PV installations it was found that policy incentives, such as the adoption of feed-in tariff schemes and the development of subsidy standards and project application and management rules, facilitated expansion of PV technologies in China. Innovation in design and configuration was also found to reduce the costs and increase capacity of PV power plants. In addition, by increasing the PV installations beyond what would normally be considered standard performance, very large-scale PV operators were able to generate 25% more output with only half of the investment. These and other findings have been collected in the summary report, *Energy from the Desert: Very Large Scale Photovoltaic Power – State of the Art* (PVPS TCP, 2015).

Activities

- High penetration of PV systems in electricity grids
- Performance and reliability of PV systems
- PV environmental, health and safety
- PV services for developing countries
- Strategic analysis and outreach
- Very large-scale PV power generation systems

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	21	5	1
Sponsors	3	–	1

www.iea.org/tcp/renewables/pvps/

RENEWABLE ENERGY TECHNOLOGY DEPLOYMENT (RETD TCP)

A home equipped with photovoltaic panels may sell electricity to others (Utrecht, the Netherlands).

Highlight

Supporting electricity consumers as PV producers

As a cross-cutting and policy-focused platform, the RETD TCP accelerates the deployment of renewables; enhances international co-operation on policies, best practices and market instruments; and supports deployment of renewable energy technologies. The improving cost trends of some technologies (e.g. solar PV modules) have resulted in sustained growth in key markets worldwide. However, policies remain critical as recent RETD TCP analysis has shown.

In recent years, the cost of variable renewable technologies such as onshore wind and solar PV has declined, while key markets have expanded, resulting in new technology and business models that affect how renewable energy can be produced, distributed and consumed. A growing number of policy makers have begun to explore the potential of so-called "prosumers" – grid-connected consumers that also produce energy, partially for self-consumption, thus contributing to the wider objectives of decarbonisation and economic development.

For many, solar PV has emerged as the technology of choice due to its scalability, relatively low cost, versatility and increased availability. An increase in PV prosumers could help electricity networks become more decentralised and interactive, reducing strain on the ageing infrastructure.

The RETD TCP looked at whether significant growth of prosumers is achievable and, if so, to identify socio-economic drivers, policy options and stakeholder considerations that could affect such growth. The study identified four broad scenarios that affect development of prosumers: "no prosumers", "constraining prosumers", "enabling prosumers", and a "prosumer transition". In a "no prosumer" scenario, there is a lack of incentives (e.g. low electricity prices) as well as a lack of policies or regulations permitting interconnection or feeding into the grid. This reflects the current situation in some countries in the Middle East and North Africa.

Countries with a "constraining prosumers" scenario take measures to prevent PV prosumer development in order to maintain a low level of competition and to protect the grid reliability. This is the case in countries where there has historically been a state-owned monopoly and an electricity network in poor condition despite good market conditions for prosumers (e.g. high electricity prices and low installation costs). According to the study of RETD TCP, this is the case for Spain and some Central and Latin American countries.

Under an "enabling" scenario, national conditions are in place to create a competitive environment for prosumers, and enabling policies allow prosumers to rapidly emerge without incentives. The drawback is the lack of planning, which results in unfair competition. In Europe, the recent boom in residential PV installations has raised concerns because prosumers do not pay the fixed costs or system taxes that grid operators may pay.

With a "prosumer transition" scenario, all the conditions are in place to facilitate growth in prosumers while protecting utilities, including suitable national conditions and enabling policies. Most importantly, policy makers have identified clear objectives for supporting prosumers, including upgrading the electricity infrastructure and encouraging development of alternative utility business models (e.g. Hawaii). Details of each scenario, together with relevant case studies and other findings are included in the report, *Residential Prosumers: Drivers and Policy Options* (RETD TCP, 2014).

Activities

- Commercial prosumers: developments and policy options
- Integrating renewable energy: conditions, market design and renewable energy deployment
- Next-generation policy instruments for renewable transport

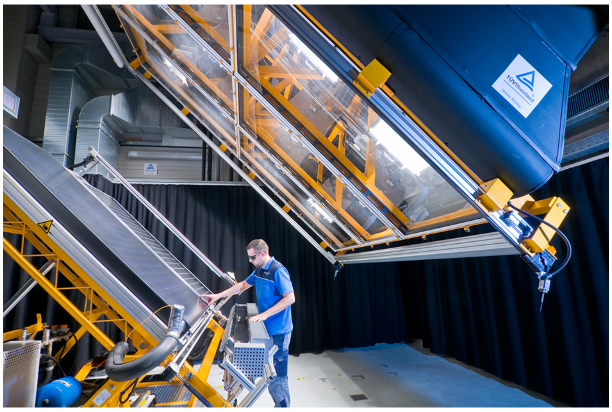
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	9	–	–
Sponsors	–	–	–

www.iea.org/tcp/renewables/retd/

SOLAR HEATING AND COOLING (SHC TCP)

Testing a solar thermal collector (Cologne, Germany).



Highlight

Promoting standards for market uptake

The SHC TCP aims to promote the use of all aspects of solar thermal energy and increase the global market share of related technologies by engaging in research and development of components, materials and design as well as raising political and public awareness. In light of the fast pace with technology developments, recent activities include a focus on how industry standards can instil consumer confidence in products from all world regions.

Rigorous testing, certification schemes and international standards improve the quality, reliability and durability of technologies – and instil consumer confidence. While the first international standard for solar heating and cooling collectors was approved in 1994 (ISO 9086), the technology has improved since then. At that time it did not include durability and reliability tests now required by many national standards. As a result national certification bodies and laboratories did not adopt a uniform approach.

For these reasons, the SHC TCP set out to update and harmonise the 1994 test procedures and certification schemes. In 2013, the revised protocols led to approval of a new standard (EN ISO 9806:2013) that specifies test methods to assess the durability, reliability and safety of solar heating collectors, including procedures to characterise performance. The 2013 standard has been adopted by several certification schemes and standards bodies, such as the European Committee for Standardization (CEN), and used in test labs.

To promote adoption of the 2013 standard, the SHC TCP created the Global Solar Certification Network (GSCN), a framework for co-operation among representatives from industry, certification bodies and test labs in Africa, Asia, Europe, North America and Oceania. The GCSN promotes adoption of the global solar collector certification scheme (GSC). The GSC reduces the need for new testing, inspection and certification in each country where the products are commercialised.

To assess the likelihood that the 2013 standard was in use, the SHC TCP conducted a survey of 30 countries. Respondents were asked how likely they were to adopt the standard and what, if any changes could be made to improve it.

The survey results revealed that further improvements to the 2013 standard would be needed to increase the likelihood of its adoption in major international markets, in particular the call for additional testing requirements and further clarification of the test methodology in order to avoid misinterpretation by test laboratories and certification bodies. The ISO TC180 team is revising the 2013 standard to incorporate the findings of the SHC TCP survey with a view of adopting a uniform, harmonised international standard for solar thermal collectors through the GSC.

A description of the modifications to the standards and survey results are compiled in the final report, *Utilisation of ISO9806:2013 in Global Solar Certification* (SHC TCP, 2014).

Activities

- Advanced lighting solutions for retrofitting buildings
- Compact thermal energy storage
- Large-scale solar heating and cooling systems
- New-generation solar cooling and heating systems
- Polymeric materials for solar thermal applications
- Quality assurance and support measures for solar cooling systems
- Solar energy and urban planning
- Solar heat integration in industry processes
- Solar rating and certification procedures
- Solar renovation of non-residential buildings
- Solar resource assessment and forecasting
- Solar thermal and energy economics

Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	16	4	1
Sponsors	–	1	3

www.iea.org/tcp/renewables/shc/

WIND ENERGY SYSTEMS (WIND TCP)

Wind turbine and an electricity network substation (Prince Edward Island, Canada).

Highlight

Integrating wind energy through recommended practices

The Wind TCP undertakes co-operative R&D and provides authoritative information to participating governments and industry leaders to support the uptake of wind power. Drawing on previous work, the Wind TCP identified recommended practices for project developers and policy makers for large-scale integration of wind power.

Electricity from land-based wind energy can be fully cost-competitive, particularly when emissions are factored into conventional fuel prices. Offshore wind power projects have the potential to significantly increase the contribution of wind energy if the costs can be lowered. To capture the potential of wind energy on land and offshore, electricity networks will need to be upgraded and power systems operation enhanced to accommodate the additional capacity and to balance the variability of wind energy.

There is a great need of reliable, comparable studies on the effects of large-scale integration of wind power into existing electricity networks. Findings from the existing wind energy integration studies are not easily comparable. As a result, it may be difficult to derive prescriptive standards or best practices.

For these reasons, in 2013 the Wind TCP developed a set of recommended practices for wind integration studies. This study is the last in a series covering a wide range of issues, based on a common approach and rigorously reviewed by experts in the field before providing input to international standards bodies.

Based on more than eight years of real experiences in integrating wind energy technology, the recommended practices published by the Wind TCP focus on wind integration into power systems. The study provides system operators, research institutes and consultants with the best available information on how to perform a wind integration feasibility study in order to ensure power system reliability, efficiency and the ability to balance energy supply and demand.

Key elements of the recommended practices include data (e.g. wind power plant size, location and output); developing scenarios for wind energy generation; power supply and demand; estimating the capacity value of the wind power; simulating power system operation; assessing flexibility needs of generation; adequacy of electricity networks and analysing and interpreting the results. The recommended practices stress that studies of wind integration should be an iterative process, especially when studying larger shares of wind power in future energy systems. For example, if wind power has unexpectedly high technical and economic impacts on the power system, it could be cost-effective to consider options such as changing operational practices or revising scenarios for generation or transmission.

During 2014, the Wind TCP recommended practices were used to create a roadmap on renewable electricity network integration in Mexico and to identify needed data to undertake wind integration studies in Japan. The final results have been published in the *Recommended Practice 16 – Wind Integration Studies* (Wind TCP, 2013).

Activities

- Benchmarking wind farm flow models
- Comparing codes for offshore wind foundations
- Cost of electricity from wind
- Environmental monitoring and assessment
- Ground testing of turbines and their components
- Improving aerodynamic models
- Integrating wind into power systems
- Small turbine quality labelling
- Social acceptance of wind energy projects
- Standardising turbine reliability data
- Remote sensing technologies
- Wind energy in cold climates

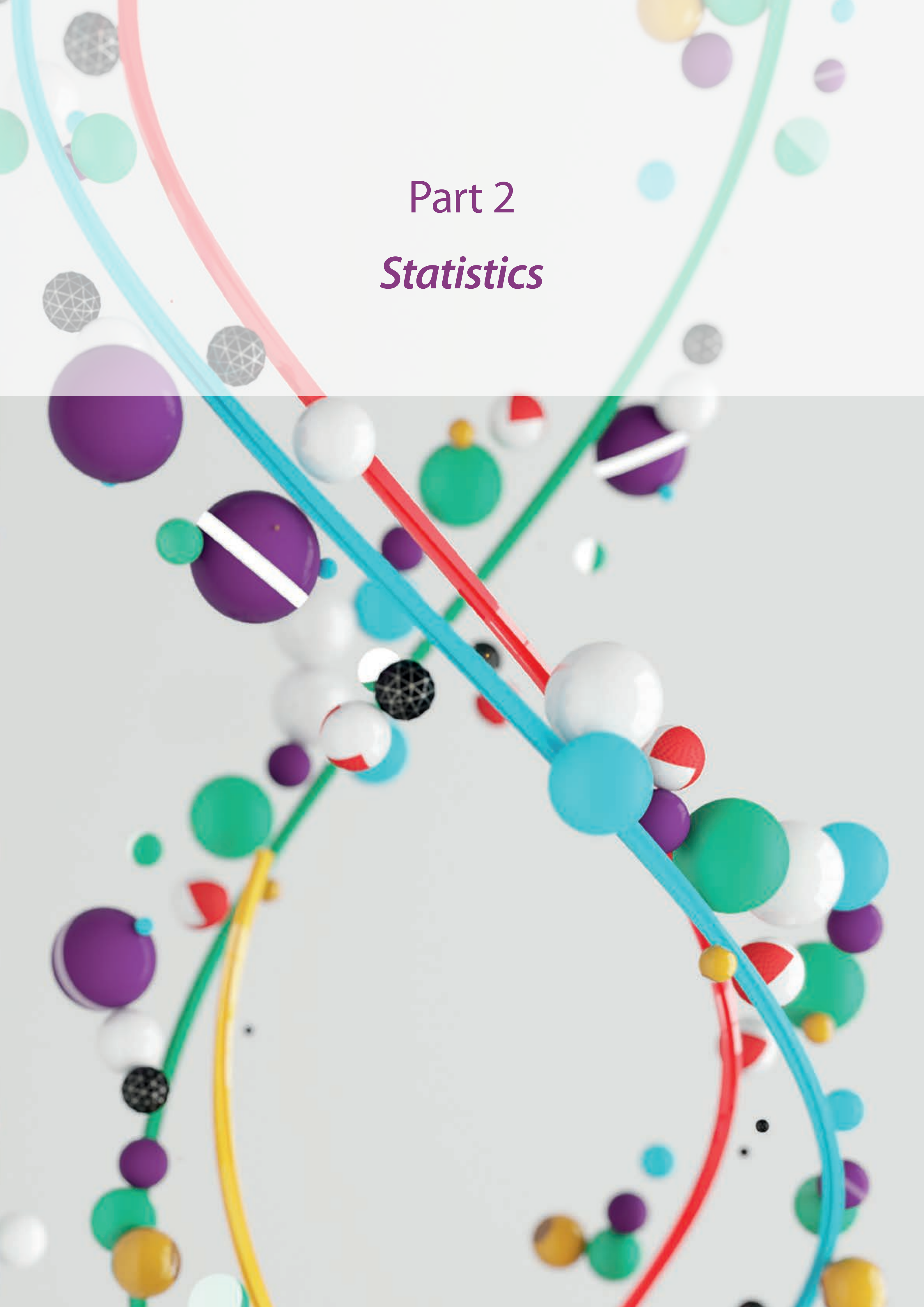
Participants

	IEA member countries	Partner countries	RO/IO
Contracting Parties	21	1	1
Sponsors	–	1	1

www.iea.org/tcp/renewables/wind/

Part 2

Statistics



Scope and portfolios

Technology Collaboration Programme (TCP)		Basic Science[1]	Applied Science[2]	Demonstration and Deployment[3]	Socio-economic Issues[4]
Cross-cutting	Climate Technology Initiative (CTI TCP)				✓
	Energy Technology Systems Analysis (ETSAP TCP)			✓	✓
End use: Buildings	Buildings and Communities (EBC TCP)		✓	✓	✓
	District Heating and Cooling (DHC TCP)		✓	✓	✓
	Energy Storage (ECES TCP)		✓	✓	✓
	Energy Efficient End-Use Equipment (4E TCP)		✓	✓	✓
	Heat Pumping Technologies (HPT TCP)		✓	✓	✓
End use: Electricity	Demand-Side Management (DSM TCP)		✓	✓	✓
	High-Temperature Superconductivity (HTS TCP)		✓	✓	✓
	Smart Grids (ISGAN TCP)		✓	✓	✓
End use: Industry	Industrial Technologies and Systems (IETS TCP)		✓	✓	✓
End use: Transport	Advanced Fuel Cells (AFC TCP)	✓	✓	✓	✓
	Advanced Materials For Transportation (AMT TCP)	✓	✓	✓	✓
	Advanced Motor Fuels (AMF TCP)	✓	✓	✓	✓
	Emissions Reduction In Combustion (Combustion TCP)	✓	✓	✓	✓
	Hybrid and Electric Vehicles (HEV TCP)	✓	✓	✓	✓
Fossil fuels	Clean Coal Centre (CCC TCP)	✓	✓	✓	✓
	Enhanced Oil Recovery (EOR TCP)	✓	✓	✓	✓
	Fluidized Bed Conversion (FBC TCP)	✓	✓	✓	✓
	Gas and Oil Technologies (GOTCP)	✓	✓	✓	✓
	Greenhouse Gas R&D (GHG TCP)	✓	✓	✓	✓
Fusion power	Environmental, Safety and Economy of Fusion Power (ESEFP TCP)	✓		✓	✓
	Fusion Materials (FM TCP)	✓	✓	✓	✓
	Nuclear Technology of Fusion Reactors (NTFR TCP)	✓	✓	✓	✓
	Plasma Wall Interaction (PWI TCP)	✓	✓	✓	✓
	Reversed Field Pinches (RFP TCP)	✓	✓	✓	✓
	Spherical Tori (ST TCP)	✓	✓	✓	✓
	Stellarator-Heliotron Concept (SH TCP)	✓	✓	✓	✓
	Tokamak Programmes (CTP TCP)	✓	✓	✓	✓
Renewable energy and hydrogen	Bioenergy TCP	✓	✓	✓	✓
	Concentrated Solar Power (SolarPACES TCP)	✓	✓	✓	✓
	Geothermal Energy (Geothermal TCP)	✓	✓	✓	✓
	Hydrogen TCP	✓	✓	✓	✓
	Hydropower TCP	✓	✓	✓	✓
	Ocean Energy Systems (OES TCP)	✓	✓	✓	✓
	Photovoltaic Power Systems (PVPS TCP)	✓	✓	✓	✓
	Renewable Energy Technology Deployment (RETD TCP)	✓	✓	✓	✓
	Solar Heating and Cooling (SHC TCP)	✓	✓	✓	✓
	Wind Energy (Wind TCP)	✓	✓	✓	✓

1. Physics, chemistry, conversion processes mechanisms, commercial technologies and materials.
2. Characterisation, *in-situ* testing, and literature reviews of existing technologies or energy sources.
3. Market introduction, sectoral analysis, or technology transfer.
4. Includes employment, social acceptance, trade and other socio-economic or policy issues related to use of the technology or energy source.

Energy sectors

Technology Collaboration Programme (TCP)		Supply	Transformation [1]	Demand
Cross-cutting	Climate Technology Initiative (CTI TCP)			✓
	Energy Technology Systems Analysis (ETSAP TCP)	✓	✓	✓
End use: Buildings	Buildings and Communities (EBC TCP)		✓	✓
	District Heating and Cooling (DHC TCP)	✓	✓	✓
	Energy Storage (ECES TCP)	✓	✓	✓
	Energy Efficient End-Use Equipment (4E TCP)		✓	✓
	Heat Pumping Technologies (HPT TCP)	✓	✓	✓
End use: Electricity	Demand-Side Management (DSM TCP)		✓	✓
	High-Temperature Superconductivity (HTS TCP)		✓	✓
	Smart Grids (ISGAN TCP)		✓	✓
End use: Industry	Industrial Technologies and Systems (IETS TCP)		✓	✓
End use: Transport	Advanced Fuel Cells (AFC TCP)		✓	✓
	Advanced Materials For Transportation (AMT TCP)		✓	✓
	Advanced Motor Fuels (AMF TCP)	✓	✓	✓
	Emissions Reduction In Combustion (Combustion TCP)		✓	✓
	Hybrid and Electric Vehicles (HEV TCP)	✓	✓	✓
Fossil fuels	Clean Coal Centre (CCC TCP)	✓	✓	✓
	Enhanced Oil Recovery (EOR TCP)	✓	✓	
	Fluidized Bed Conversion (FBC TCP)	✓	✓	
	Gas and Oil Technologies (GOTCP)	✓	✓	
	Greenhouse Gas R&D (GHG TCP)	✓	✓	
Fusion power	Environmental, Safety and Economy of Fusion Power (ESEFP TCP)	✓	✓	
	Fusion Materials (FM TCP)	✓	✓	
	Nuclear Technology of Fusion Reactors (NTFR TCP)	✓	✓	
	Plasma Wall Interaction (PWI TCP)	✓	✓	
	Reversed Field Pinches (RFP TCP)	✓	✓	
	Spherical Tori (ST TCP)	✓	✓	
	Stellarator-Heliotron Concept (SH TCP)	✓	✓	
	Tokamak Programmes (CTP TCP)	✓	✓	✓
Renewable energy and hydrogen	Bioenergy TCP	✓	✓	✓
	Concentrated Solar Power (SolarPACES TCP)	✓	✓	✓
	Geothermal Energy (Geothermal TCP)	✓	✓	✓
	Hydrogen TCP	✓	✓	✓
	Hydropower TCP	✓	✓	✓
	Ocean Energy Systems (OES TCP)	✓	✓	✓
	Photovoltaic Power Systems (PVPS TCP)	✓	✓	✓
	Renewable Energy Technology Deployment (RETD TCP)	✓	✓	✓
	Solar Heating and Cooling (SHC TCP)	✓	✓	✓
	Wind Energy (Wind TCP)	✓	✓	✓

1. Electricity or heat generation and distribution, transformation from one state to another and combustion processes.

TCP activities

CROSS-CUTTING

Climate Technology Initiative (CTI TCP)

- Application of clean energy technologies
- Capacity building market mechanisms for climate action at the urban level
- Clean technology business network
- Collaboration with climate-related international efforts and fora
- Exchange of experts
- Facilitation of private financing for technology transfer
- Financing adaptation-related projects
- Private financing advisory network (PFAN)
- Regional clean energy financing forums
- Support assessment of developing country technology needs
- Technology needs assessments

Energy Technology Systems Analysis (ETSAP TCP)

- Advances in modelling, tools and training modules
- Building and improving a global multi-regional model
- Contributing to the World Bank Climate Smart Planning Platform
- Energy technology briefs
- Linking energy systems models and macroeconomic models
- Modelling behaviour in energy systems models

END USE: BUILDINGS

Buildings and Communities (EBC TCP)

- Air infiltration and ventilation centre
- Cooling with ventilation
- Deep energy retrofits of public buildings
- Embodied energy and emissions with construction
- Energy efficient retrofitting
- Energy flexible buildings
- Energy strategies in communities
- High-temperature cooling, low-temperature heating
- Integrating micro-generation and other technologies
- Long-term performance of super-insulating materials
- New generation computational tools
- Occupant behaviour
- Optimised performance of energy supply systems
- Reducing energy and emissions through renovations
- Reliable energy performance characterisation

District Heating and Cooling (DHC TCP)

- Governance models and strategic decision-making processes
- Reducing consumption and greenhouse gas emissions
- Strategic decision-making processes for DH systems
- Transformation roadmap: high- to low- temperature district heating systems
- User-centred approaches to operations and management

Energy Storage (ECES TCP)

- Distributed energy storage for renewable energy
- Future electric energy storage demand
- Materials R&D for improved systems (activity with SHC TCP)
- Optimisation and automation for net zero energy buildings

Energy Efficient End-Use Equipment (4E TCP)

- Electronic devices and networks
- Engagement with international standardisation organisations
- G20 energy efficiency action plan: networked devices
- International mapping and benchmarking
- Monitoring verification and enforcement
- Motor systems
- Policy-driven innovation
- Smart metering infrastructure
- Solid-state lighting
- Technology forcing standards for energy efficiency

Heat Pumping Technologies (HPT TCP)

- Cold climate heat pumps
- Energy efficient supermarket buildings pumps
- Field measurements of building heat pump systems
- Fuel-driven sorption heat pumps
- Industrial heat pumps
- Near zero-energy buildings heat pump concepts
- Quality installation and maintenance
- Smart grids and heat pumps
- Solar thermal energy systems and heat pumps
- Testing and rating residential heat pumps

END USE: ELECTRICITY

Demand-Side Management (DSM TCP)

- Behaviour change: theory, policies, practice
- Branding energy efficiency
- Business models for energy services
- Competitive energy services (phase 3)
- DSM, energy efficiency, distributed generation and renewables (phase 3)
- Effective smart grids

High-Temperature Superconductivity (HTS TCP)

- Efficient and resilient power networks

Fault current limiters, cables, machines for large wind turbines
Low-cost, high-current, superconductors
Roadmap
Smart Grids (ISGAN TCP)
Advanced metering infrastructure and demand side management
Consumer engagement and empowerment
Policy briefs
Simulation and testing of grid-to-PV
Smart grids drivers and technologies
Standardised methods for cost-benefit analysis
Transmission and distribution briefs and case studies
END USE: INDUSTRY
Industrial Technologies and Systems (IETS TCP)
Energy efficiency in small and medium enterprises
Energy-efficient separation systems
Industrial excess heat recovery
Industrial heat pumps
Industry-based bio-refineries
Membrane technologies
Process integration in the iron and steel industry
END USE: TRANSPORT
Advanced Fuel Cells (AFC TCP)
Electrolysis
Modelling
Molten carbonate fuel cells
Polymer electrolyte fuel cells
Portable applications
Solid oxide fuel cells
Stationary applications
System analysis
Transportation
Advanced Materials for Transportation (AMT TCP)
Integrated surface technology for engine friction reduction
International standards and testing for low-cost carbon fibres
Model-based design of coating systems
Multiple-material joining for lightweight vehicles
Technology assessment and policy implications
Thermoelectric materials for waste heat recovery
Advanced Motor Fuels (AMF TCP)
Alcohol: application in compression-ignition engines
Alcohol fuels: unregulated pollutants
Commercial vehicles: fuel and technology alternatives

Dimethyl ether specifications
Ethanol and butanol: direct-injection, spark ignition engines
Hydro treated oils and fats for engines
Internal combustion engines: exhaust gas and particles
Methane emissions control
On-road vehicles: natural gas pathways
Off-road engines: fuel and technology alternatives
Passenger cars: fuel performance evaluation
Emissions Reduction in Combustion (Combustion TCP)
Alternative fuels
Chemistry
Gas engines
Hydrogen for extremely low-emissions gas turbines
Low-temperatures
Nanoparticle diagnostics
Single contributor tasks
Sprays
Hybrid and Electric Vehicles (HEV TCP)
Economic impact assessment of E-mobility
Electric vehicle business models
Electrification of transport logistic vehicles
Electrochemical systems
Home grids and V2X technologies
Life-cycle assessment of electric vehicles
Light electric vehicle parking and charging infrastructure
Plug-in electric vehicles
Quick charging technology
System optimisation and vehicle integration
Testing the lifetime of lithium-ion batteries
Wireless power transfer for electric vehicles
FOSSIL FUELS
Clean Coal Centre (CCC TCP) – 37 reports focusing on:
CO_2 mitigation
Coal markets
Coal properties and analysis
Combustion
Conversion and industrial use of coal
Country studies
Emissions and control
Environmental policy and legislation
Gasification
Mining, production and preparation
Pollution control technologies
Power generation

Residues and management
Social acceptance
Technology implementation
Enhanced Oil Recovery (EOR TCP)
Development of gas flooding techniques
Dynamic reservoir characterisation
Fluids and interfaces in porous media
Surfactants and polymers
Thermal recovery
Fluidized Bed Conversion (FBC TCP)
Co-firing and ash problems
Energy crops and fluidized bed conversion
Fluidized bed design aspects
Mathematical, three-dimensional modelling
Recent trends in participating countries
Sewage sludge conversion
Gas and Oil Technologies (GOTCP)
Conventional hydrocarbon technologies
Innovation challenges and responses
Licence to operate innovation
Unconventional hydrocarbon technologies
Greenhouse Gas R&D (GHG TCP)
36 information papers, technical evaluations and reports, proceedings, and facts sheets
Conferences
Experts' networks
Modelling and databases
Summer school and student mentoring
Technical workshops
FUSION POWER
Environmental, Safety, Economic Aspects of Fusion Power (ESEFP TCP)
Activation product source terms
Failure rate data base
Fusion power plant studies
In-vessel tritium source terms
Magnet safety
Radioactive waste study
Socio-economic aspects of fusion power
Transient thermo-fluid modelling and validation tests
Fusion Materials (FM TCP)
Diagnostics and control insulating ceramics
Fundamental studies of irradiation effects
Irradiation facilities and post-irradiation tests
Modelling, computer simulation and validation

Reduced activation and advanced ferritic steels
Silicon carbide composite materials
Tungsten and tungsten alloys
Vanadium base alloys
Nuclear Technology of Fusion Reactors (NTFR TCP)
Liquid breeding blankets
Neutronics
Plasma surface interactions
Plasma-facing components
Solid breeding blankets
Tritium processing
Plasma Wall Interaction (PWI TCP)
Confinement and transport
Disruption and ELM mitigation
Edge and pedestal physics
Energetic particles
Plasma control and scenario development
Plasma diagnostics
SOL and divertor physics, plasma-wall interaction
Reversed Field Pinches (RFP TCP)
Co-ordinated experiments on the following devices:
EXTRAP T2-R (Sweden)
Madison symmetric torus (United States)
Reversed field experiment (Italy)
TPE-RX (Japan)
Spherical Tori (ST TCP)
Physics and technology
Science and R&D
Steady state operation
Stellerator-Heliotron Concept (SH TCP)
Confinement and profile database
Co-ordinated Working Group Meetings
DEMO assessment based on SH concepts
High-performance and steady-state plasma confinement
International Stellarator and Heliotron Concept Workshops
Joint experiments, model validations
Numerical code verifications
Tokamak Programmes (CTP TCP)
Confinement database and modelling
Edge and pedestal physics
Magneto-hydrodynamics, disruptions and control
Sol and divertor physics
Steady states operation
Transport and internal transport barrier physics
Tritium and remote-handling technologies

RENEWABLE ENERGY AND HYDROGEN
Bioenergy TCP
Biomass combustion and co-firing
Biomass feedstocks for energy markets
Biorefining
Commercialising biofuels from biomass
Climate change effects from biomass and bioenergy systems
Energy from biogas
Energy recovery from solid waste management
Pyrolysis of biomass
Sustainable international bioenergy trade
Thermal gasification of biomass
Concentrated Solar Power (SolarPACES TCP)
Solar chemistry research
Solar energy and water processes and applications
Solar heat integration in industrial processes
Solar resource assessment and forecasting
Solar technologies and advanced applications
Solar thermal electric systems
Geothermal Energy (Geothermal TCP)
Advanced drilling and logging technologies
Data collection and information
Deep roots of volcanic geothermal systems
Direct use of geothermal energy
Enhanced geothermal systems
Environmental impacts
Induced seismicity
Hydrogen TCP
Bio-hydrogen
Distributed and community hydrogen
Fundamental and applied hydrogen storage materials deployment
Global hydrogen systems analysis
Hydrogen-based energy storage
Hydrogen safety
Local hydrogen supply for energy applications
Near-term market routes to hydrogen
Water photolysis
Hydropower TCP
Hydropower and fish
Hydropower services
Managing GHG emissions from freshwater reservoirs
Renewal and upgrading of hydropower plants
Small-scale hydropower
Ocean Energy Systems (OES TCP)
Assessing project information and experience
Assessment of environmental effects and monitoring
Consenting processes for ocean energies
Cost of international energy assessments
Detailed global information related to ocean energy
Photovoltaic Power Systems (PVPS TCP)
High penetration of PV systems in electricity grids
Performance and reliability of PV systems
PV environmental, health and safety activities
PV services for developing countries
Strategic analysis and outreach
Very large-scale PV power generation systems
Renewable Energy Technology Deployment (RETD TCP)
Commercial prosumers – developments and policy options
Integrating renewable energy – conditions, market design and renewable energy deployment
Next-generation policy instruments for renewable transport
Solar Heating and Cooling (SHC TCP)
Advanced lighting solutions for retrofitting buildings
Compact thermal energy storage
Large-scale solar heating and cooling systems
New-generation solar cooling and heating systems
Polymeric materials for solar thermal applications
Quality assurance and support measures for solar cooling systems
Solar energy and urban planning
Solar heat integration in industry processes
Solar rating and certification procedures
Solar renovation of non-residential buildings
Solar resource assessment and forecasting
Solar thermal and energy economics
Wind Energy (Wind TCP)
Benchmarking wind farm flow models
Comparing codes for offshore wind foundations
Cost of wind energy
Environmental monitoring and assessment
Full-size, ground testing of wind turbines and their components
Improving aerodynamic models
Integrating wind into power systems
Small wind turbine quality labelling
Social acceptance of wind energy projects
Standardising wind turbine reliability data
Remote sensing technology for wind energy deployment
Wind energy in cold climates

Overview of participation in TCPs

(as of 31 December 2015)

Entities from:	TCPs in which the country or entity participates	Distinct Entities	Participation in TCPs[1]																Total participation in TCPs
			Cross-cutting		End-use, efficiency								Fossil fuels		Fusion		Renewables and hydrogen		
					Buildings		Electricity		Industry		Transport								
			CP	SP	CP	SP	CP	SP	CP	SP	CP	SP	CP	SP	CP	SP	CP	SP	
United States	36	12	2		5		3	2	1		5		3	4	8		8	4	45
Japan	31	16	2		5		2				4		4	1	8		8		34
Korea	29	11	2		5		3		1		5		2		4		7		29
Germany	25	16	2		4		3		1		5		1	3			9	2	30
Canada	24	8	1		5		2				3		3		3		6	1	24
Sweden	22	3	2		6		3		1		4		1				6		23
Norway	22	6	2		4		2		1		1		3	1			10		24
United Kingdom	22	15	1		6		2				3		4	3			7		26
France	22	12	3		4		1				4		3	2			9		26
Italy	21	11		1	3		3	1			4		2				10		24
Switzerland	21	6	1		3		3				4		2	1	1		7		22
Denmark	20	7	1		5		1		1		3		2				7		20
Netherlands	19	6	1		4		3		1		1		1	1			7	1	20
Austria	18	9	1		3		2				3		4				5		18
Australia	18	14			2		1				2		4		1		8		18
Finland	17	3	1		3		3				4		1				6		18
Spain	18	10	1		1	1	2				3		3				7	1	19
Belgium	13	9	3		3		2		1		2						5		16
Ireland	8	3	1		1		1				1						4		8
New Zealand	7	7			1		1						1				4		7
Portugal	8	4			1				1		1		1				4		8
Greece	5	5	1										1				3		5
Turkey	4	4			1						1						2		4
Poland	3	3				1							2						3
Czech Republic	2	2			1								1						2
Hungary	1	1											1						1
Estonia																			
Luxembourg																			
Slovak Republic																			
IEA COUNTRIES	**n.a.**	**203**	**28**	**1**	**76**	**2**	**43**	**3**	**9**		**63**		**50**	**16**	**25**		**149**	**9**	**474**
China	18	18			2		1				3		2	2	4		5	1	20
Mexico	10	3					1				1		1	1			6		10
Russia	9	6	1				1						2	1	4				9
Israel	8	4			1		1				3						3		8
India	7	7					2						3	1	3				9
South Africa	7	4					1						2	1			4		8
Brazil	4	3												1			3		4
Singapore	3	3					1										2		3
Thailand	3	3									1			1			1		3
U.A.E.	2	2												1			1		2
Algeria	1	1															1		1
Chile	1	1									1								1
Croatia	1	1															1		1
Egypt	1	1															1		1
Iceland	1	1															1		1
Kazakhstan	1	1	1																1
Lithuania	1	1															1		1
Malaysia	1	1															1		1
Monaco	1	1															1		1
Morocco	1	2															2		2
Nigeria	1	1															1		1
Qatar	1	1																1	1
Slovenia	1	1			1														1
Ukraine	1	1													1				1
Venezuela	1	1											1						1
PARTNER COUNTRIES	**n.a.**	**69**	**2**		**4**		**8**				**9**		**11**	**9**	**12**		**35**	**2**	**92**
EC	20	1	1		1		1						2		8		7		20
ECI	2	1						1										1	2
ECOWAS	1	1																1	1
ITER	1	1													1				1
OPEC	1	1											1						1
RCREEE	1	1																1	1
SolarPower Europe	1	1																1	1
Wind Europe	1	1																1	1
INTL/REG. ORGS	**n.a.**	**8**	**1**		**1**		**1**	**1**					**3**		**9**		**7**	**5**	**28**
TOTAL	**n.a.**	**280**	**31**	**1**	**81**	**2**	**52**	**4**	**9**		**72**		**64**	**25**	**46**		**191**	**16**	**594**

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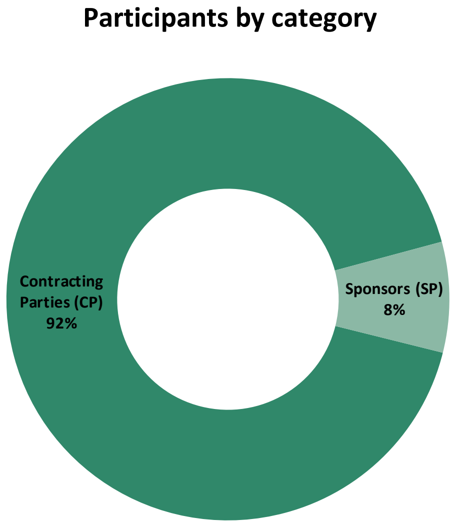

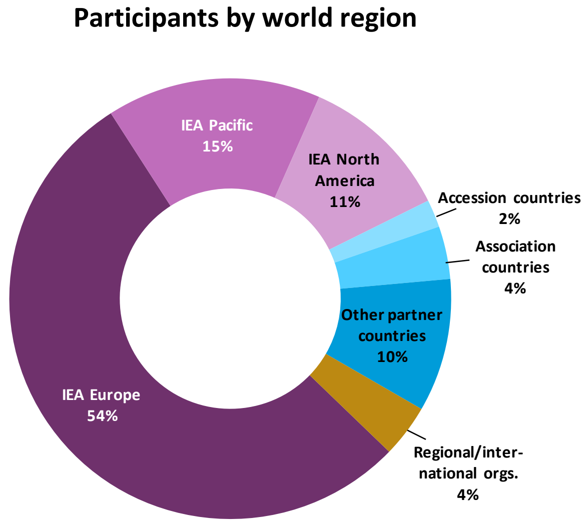

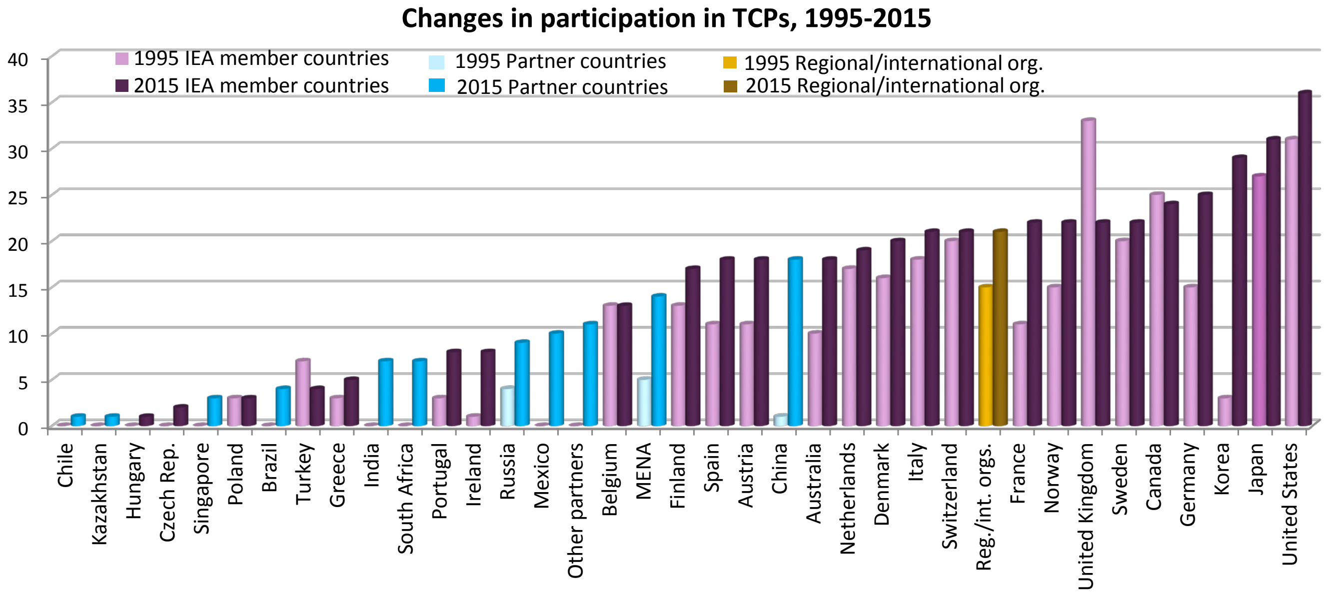

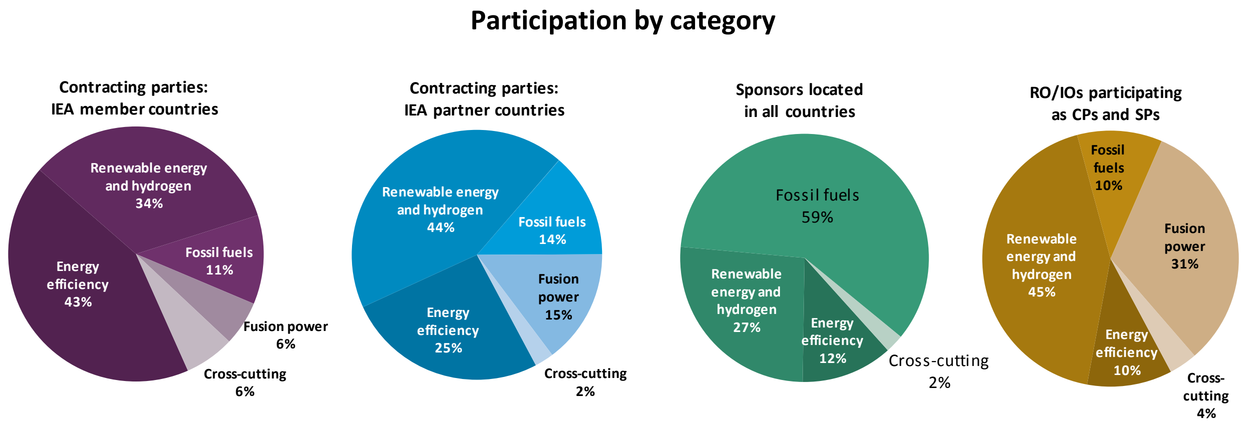

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TCPs in which IEA member countries participate

Technology Collaboration Programmes (TCPs)	Australia	Austria	Belgium	Canada	Czech Rep.	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Japan
Climate Technology Initiative (CTI TCP)		●		●						●					●
Energy Tech. Systems Analysis (ETSAP TCP)			●			●		●	●	●	●		●	●	●
CROSS-CUTTING		1	1	1		1		1	1	2	1		1	1	2
Buildings and Communities (EBC TCP)	●	●	●	●	●	●			●	●			●	●	●
District Heating and Cooling (DHC TCP)				●		●		●		●					
Energy Storage (ECES TCP)			●	●		●		●	●	●				●	●
Energy Efficient End-use Equipment (4E TCP)	●	●		●		●			●						●
Heat Pumping Technologies (HPT TCP)		●		●		●		●	●	●				●	●
End-use: Buildings	2	3	2	5	1	5		3	4	4			1	3	4
Demand-Side Management (DSM TCP)		●	●					●						●	
High-Temperature Superconductivity (HTS TCP)				●				●		●				●	●
Smart Grids (ISGAN TCP)	●	●	●	●		●		●	●	●			●	●	●
End use: Electricity	1	2	2	2		1		3	1	2			1	3	2
Industrial Techologies and Systems (IETS TCP)			●			●				●					
End use: Industry			1			1				1					
Advanced Fuel Cells (AFC TCP)	●	●				●			●	●				●	●
Advanced Materials for Transportation (AMT TCP)	●			●				●		●					
Advanced Motor Fuels (AMF TCP)		●		●		●		●	●	●				●	●
Emissions Reduction in Combustion (Combustion TCP)			●					●	●	●				●	●
Hybrid and Electric Vehicles (HEV TCP)		●	●	●		●		●	●	●			●	●	
End use: Transport	2	3	2	3		3		4	4	5			1	4	3
END USE	5	8	7	10	1	10		10	9	12			3	10	9
Clean Coal Centre (CCC TCP)	●	●								●				●	●
Enhanced Oil Recovery (EOR TCP)	●	●		●		●			●						●
Fluidized Bed Conversion (FBC TCP)		●		●	●			●	●		●	●		●	●
Gas and Oil (GO TCP)	●														
Greenhouse Gas R&D (GHG TCP)	●	●		●		●			●	●					●
FOSSIL FUELS	4	4		3	1	2		1	3	2	1	1		2	4
Environmental, Safety, Economic Aspects (ESEFP TCP)				●											●
Fusion Materials (FM TCP)				●											●
Nuclear Tech. Fusion Reactors (NTFR TCP)				●											●
Plasma-Wall Interaction (PWI TCP)															●
Reverse-Field Pinches (RFP TCP)															●
Spherical Tori (ST TCP)															●
Stellerator-Heliotron (SH TCP)	●														●
Tokamak Programmes (CTP TCP)															●
FUSION POWER	1			3											8
Bioenergy TCP	●	●	●	●		●		●	●	●			●	●	●
Concentrated Solar Power (SolarPACES TCP)	●	●							●	●	●			●	
Geothermal Energy (Geothermal TCP)	●			●					●	●				●	●
Hydrogen TCP	●		●			●		●	●	●	●			●	●
Hydropower TCP	●							●	●						●
Ocean Energy Systems (OES TCP)	●		●	●		●				●			●	●	●
Photovoltaic Power Systems (PVPS TCP)	●	●	●	●		●		●	●	●				●	●
Renewable Energy Technology Deployment (RETD TCP)				●		●			●	●			●		●
Solar Heating and Cooling (SHC TCP)	●	●	●	●		●			●	●				●	
Wind Energy (Wind TCP)		●		●		●		●	●	●	●		●	●	●
RENEWABLE ENERGY AND HYDROGEN	8	5	5	7		7		5	9	9	3		4	8	8
TOTAL ALL CATEGORIES	18	18	13	24	2	20		17	22	25	5	1	8	21	31

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Technology Collaboration Programmes (TCPs)	Korea	Luxembourg	Netherlands	N. Zealand	Norway	Poland	Portugal	Slovak Rep.	Spain	Sweden	Switzerland	Turkey	U. Kingdom	U. States
Climate Technology Initiative (CTI TCP)	●				●					●				●
Energy Tech. Systems Analysis (ETSAP TCP)	●		●		●				●	●	●		●	●
CROSS-CUTTING	**2**		**1**		**2**				**1**	**2**	**1**		**1**	**2**
Buildings and Communities (EBC TCP)	●		●	●	●		●		●	●	●		●	●
District Heating and Cooling (DHC TCP)	●				●					●			●	●
Energy Storage (ECES TCP)	●		●		●	●			●	●		●	●	●
Energy Efficient End-use Equipment (4E TCP)	●		●							●	●		●	●
Heat Pumping Technologies (HPT TCP)	●		●		●					●	●		●	●
End use: Buildings	**5**		**4**	**1**	**4**	**1**	**1**		**2**	**5**	**3**	**1**	**5**	**5**
Demand-Side Management (DSM TCP)	●		●	●	●				●	●	●		●	●
High-Temperature Superconductivity (HTS TCP)	●		●							●	●		●	●
Smart Grids (ISGAN TCP)	●		●		●				●	●	●			●
End use: Electricity	**3**		**3**	**1**	**2**				**2**	**3**	**3**		**2**	**3**
Industrial Techologies and Systems (IETS TCP)	●		●		●		●			●				●
End use: Industry	**1**		**1**		**1**		**1**			**1**				**1**
Advanced Fuel Cells (AFC TCP)	●									●	●			●
Advanced Materials for Transportation (AMT TCP)	●												●	●
Advanced Motor Fuels (AMF TCP)	●								●	●	●			●
Emissions Reduction in Combustion (Combustion TCP)	●				●				●	●	●		●	●
Hybrid and Electric Vehicles (HEV TCP)	●		●				●		●	●	●	●	●	●
End use: Transport	**5**		**1**		**1**		**1**		**3**	**4**	**4**	**1**	**3**	**5**
END USE	**14**		**9**	**2**	**8**	**1**	**3**		**7**	**13**	**10**	**2**	**10**	**14**
Clean Coal Centre (CCC TCP)						●							●	●
Enhanced Oil Recovery (EOR TCP)					●								●	●
Fluidized Bed Conversion (FBC TCP)	●					●	●		●	●			●	●
Gas and Oil (GO TCP)			●		●				●		●			
Greenhouse Gas R&D (GHG TCP)	●		●	●	●				●		●		●	●
FOSSIL FUELS	**2**		**2**	**1**	**3**	**2**	**1**		**3**	**1**	**2**		**4**	**4**
Environmental, Safety, Economic Aspects (ESEFP TCP)	●													●
Fusion Materials (FM TCP)	●										●			●
Nuclear Tech. Fusion Reactors (NTFR TCP)	●													●
Plasma-Wall Interaction (PWI TCP)														●
Reverse-Field Pinches (RFP TCP)														●
Spherical Tori (ST TCP)														●
Stellerator-Heliotron (SH TCP)														●
Tokamak Programmes (CTP TCP)	●													●
FUSION POWER	**4**										**1**			**8**
Bioenergy TCP	●		●	●	●					●	●		●	●
Concentrated Solar Power (SolarPACES TCP)	●								●		●			●
Geothermal Energy (Geothermal TCP)	●			●	●				●		●		●	●
Hydrogen TCP	●		●	●	●				●	●	●		●	●
Hydropower TCP					●									●
Ocean Energy Systems (OES TCP)	●		●	●	●		●		●	●			●	●
Photovoltaic Power Systems (PVPS TCP)	●		●		●		●		●	●	●	●		●
Renewable Energy Technology Deployment (RETD TCP)			●		●								●	
Solar Heating and Cooling (SHC TCP)			●		●		●		●	●	●	●	●	
Wind Energy (Wind TCP)	●		●		●		●		●	●	●		●	●
RENEWABLE ENERGY AND HYDROGEN	**7**		**7**	**4**	**9**		**4**		**7**	**6**	**7**	**2**	**7**	**8**
TOTAL ALL CATEGORIES	**29**		**19**	**7**	**22**	**3**	**8**		**18**	**22**	**21**	**4**	**22**	**36**

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TCPs in which partner countries participate

Technology Collaboration Programmes (TCPs)	Algeria	Brazil	Chile	China	Croatia	Egypt	Iceland	India	Israel	Kazakhstan	Lithuania	Malaysia	Mexico
Climate Technology Initiative (CTI TCP)													
Energy Tech. Systems Analysis (ETSAP TCP)										●			
CROSS-CUTTING										1			
Buildings and Communities (EBC TCP)				●					●				
District Heating and Cooling (DHC TCP)													
Energy Storage (ECES TCP)				●									
Energy Efficient End-use Equipment (4E TCP)													
Heat Pumping Technologies (HPT TCP)													
End use: Buildings				2					1				
Demand-Side Management (DSM TCP)								●					
High-Temperature Superconductivity (HTS TCP)									●				
Smart Grids (ISGAN TCP)				●				●					●
End use: Electricity				1				2	1				1
Industrial Techologies and Systems (IETS TCP)													
End use: Industry													
Advanced Fuel Cells (AFC TCP)									●				●
Advanced Materials for Transportation (AMT TCP)				●					●				
Advanced Motor Fuels (AMF TCP)			●	●					●				
Emissions Reduction in Combustion (Combustion TCP)													
Hybrid and Electric Vehicles (HEV TCP)													
End use: Transport			1	2					3				1
END USE			1	5				2	5				2
Clean Coal Centre (CCC TCP)				●				●					
Enhanced Oil Recovery (EOR TCP)				●									●
Fluidized Bed Conversion (FBC TCP)				●									
Gas and Oil (GO TCP)													
Greenhouse Gas R&D (GHG TCP)		●						●					●
FOSSIL FUELS		1		3				2					2
Environmental, Safety, Economic Aspects (ESEFP TCP)				●									
Fusion Materials (FM TCP)				●				●					
Nuclear Tech. Fusion Reactors (NTFR TCP)				●				●					
Plasma-Wall Interaction (PWI TCP)													
Reverse-Field Pinches (RFP TCP)													
Spherical Tori (ST TCP)													
Stellerator-Heliotron (SH TCP)													
Tokamak Programmes (CTP TCP)				●				●					
FUSION POWER				4				3					
Bioenergy TCP		●			●								
Concentrated Solar Power (SolarPACES TCP)	●	●		●		●			●				●
Geothermal Energy (Geothermal TCP)							●						●
Hydrogen TCP									●		●		
Hydropower TCP		●		●									
Ocean Energy Systems (OES TCP)				●									●
Photovoltaic Power Systems (PVPS TCP)				●					●			●	●
Renewable Energy Technology Deployment (RETD TCP)													
Solar Heating and Cooling (SHC TCP)				●									●
Wind Energy (Wind TCP)				●									●
RENEWABLE ENERGY AND HYDROGEN	1	3		6	1	1	1		3		1	1	6
TOTAL ALL CATEGORIES	1	4	1	18	1	1	1	7	8	1	1	1	10

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Technology Collaboration Programmes (TCPs)	Monaco	Morocco	Nigeria	Qatar	Russia	Singapore	Slovenia	South Africa	Thailand	Ukraine	U.A.E.	Venezuela
Climate Technology Initiative (CTI TCP)												
Energy Tech. Systems Analysis (ETSAP TCP)					●							
CROSS-CUTTING					1							
Buildings and Communities (EBC TCP)												
District Heating and Cooling (DHC TCP)												
Energy Storage (ECES TCP)							●					
Energy Efficient End-use Equipment (4E TCP)												
Heat Pumping Technologies (HPT TCP)												
End use: Buildings							1					
Demand-Side Management (DSM TCP)												
High-Temperature Superconductivity (HTS TCP)												
Smart Grids (ISGAN TCP)					●	●		●				
End use: Electricity					1	1		1				
Industrial Techologies and Systems (IETS TCP)												
End use: Industry												
Advanced Fuel Cells (AFC TCP)												
Advanced Materials for Transportation (AMT TCP)												
Advanced Motor Fuels (AMF TCP)									●			
Emissions Reduction in Combustion (Combustion TCP)												
Hybrid and Electric Vehicles (HEV TCP)												
End use: Transport									1			
END USE					1	1	1	1	1			
Clean Coal Centre (CCC TCP)					●			●	●			
Enhanced Oil Recovery (EOR TCP)					●							●
Fluidized Bed Conversion (FBC TCP)					●							
Gas and Oil (GO TCP)												
Greenhouse Gas R&D (GHG TCP)								●			●	
FOSSIL FUELS					3			2	1		1	1
Environmental, Safety, Economic Aspects (ESEFP TCP)					●							
Fusion Materials (FM TCP)					●							
Nuclear Tech. Fusion Reactors (NTFR TCP)					●							
Plasma-Wall Interaction (PWI TCP)												
Reverse-Field Pinches (RFP TCP)												
Spherical Tori (ST TCP)												
Stellerator-Heliotron (SH TCP)					●					●		
Tokamak Programmes (CTP TCP)												
FUSION POWER					4					1		
Bioenergy TCP								●				
Concentrated Solar Power (SolarPACES TCP)		●						●			●	
Geothermal Energy (Geothermal TCP)												
Hydrogen TCP												
Hydropower TCP												
Ocean Energy Systems (OES TCP)	●		●			●		●				
Photovoltaic Power Systems (PVPS TCP)									●			
Renewable Energy Technology Deployment (RETD TCP)												
Solar Heating and Cooling (SHC TCP)				●		●		●				
Wind Energy (Wind TCP)												
RENEWABLE ENERGY AND HYDROGEN	1	1	1	1		2		4	1		1	
TOTAL ALL CATEGORIES	1	1	1	1	9	3	1	7	3	1	2	1

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TCPs in which regional and international organisations participate

Technology Collaboration Programmes (TCPs)	EC	ECI	ECOWAS	ITER	OPEC	RCREEE	SolarPower Europe	Wind Europe
Climate Technology Initiative (CTI TCP)								
Energy Tech. Systems Analysis (ETSAP TCP)	●							
CROSS-CUTTING	1							
Buildings and Communities (EBC TCP)								
District Heating and Cooling (DHC TCP)								
Energy Storage (ECES TCP)	●							
Energy Efficient End-use Equipment (4E TCP)								
Heat Pumping Technologies (HPT TCP)								
End use: Buildings	1							
Demand-Side Management (DSM TCP)		●						
High-Temperature Superconductivity (HTS TCP)								
Smart Grids (ISGAN TCP)	●							
End use: Electricity	1	1						
Industrial Techologies and Systems (IETS TCP)								
End-use: Industry								
Advanced Fuel Cells (AFC TCP)								
Advanced Materials for Transportation (AMT TCP)								
Advanced Motor Fuels (AMF TCP)								
Emissions Reduction in Combustion (Combustion TCP)								
Hybrid and Electric Vehicles (HEV TCP)								
End use: Transport								
END USE	2	1						
Clean Coal Centre (CCC TCP)	●							
Enhanced Oil Recovery (EOR TCP)								
Fluidized Bed Conversion (FBC TCP)								
Gas and Oil (GO TCP)								
Greenhouse Gas R&D (GHG TCP)	●				●			
FOSSIL FUELS	2				1			
Environmental, Safety, Economic Aspects (ESEFP TCP)	●							
Fusion Materials (FM TCP)	●							
Nuclear Tech. Fusion Reactors (NTFR TCP)	●							
Plasma-Wall Interaction (PWI TCP)	●							
Reverse-Field Pinches (RFP TCP)	●							
Spherical Tori (ST TCP)	●							
Stellerator-Heliotron (SH TCP)	●							
Tokamak Programmes (CTP TCP)	●			●				
FUSION POWER	8			1				
Bioenergy TCP	●							
Concentrated Solar Power (SolarPACES TCP)	●							
Geothermal Energy (Geothermal TCP)	●							
Hydrogen TCP	●							
Hydropower TCP								
Ocean Energy Systems (OES TCP)								
Photovoltaic Power Systems (PVPS TCP)	●							
Renewable Energy Technology Deployment (RETD TCP)								
Solar Heating and Cooling (SHC TCP)	●	●	●			●	●	
Wind Energy (Wind TCP)	●							●
RENEWABLE ENERGY AND HYDROGEN	7	1	1			1	1	1
TOTAL ALL CATEGORIES	20	2	1	1	1	1	1	1

An entity may participate in more than one TCP. There are two possible categories of participation in a TCP, as a Contracting Party, or CP (an entity designated by the government of an OECD member or non-member country or intergovernmental organisations) or as a Sponsor, or SP (an entity of an OECD member or non-member country or a non-intergovernmental organisation that is not designated by the government of their respective country). EC refers to the European Commission and the European Atomic Energy Community; ECI (European Copper Institute); ECOWAS (Economic Community of West African States); ITER (International Thermonuclear Experimental Reactor); OPEC (Organisation for Petroleum Exporting Countries); RCREEE (Regional Centre for Renewable Energy and Energy Efficiency); SolarPower Europe; and Wind Europe.

Sponsors participating in TCPs

		Cross-cutting	End-use			Fossil fuels			Renewable Energy and Hydrogen					
Entities from IEA member countries	*Entity location*	Energy Tech. Systems Analysis (ETSAP TCP)	Energy Storage (ECES TCP)	Demand-Side Management (DSM TCP)	High-Temperature Superconductivity (HTS TCP)	Clean Coal Centre (CCC TCP)	Fluidized Bed Conversion (FBC TCP)	Greenhouse Gas R&D (GHG TCP)	Geothermal Energy (Geothermal TCP)	Hydrogen TCP	Photovoltaic Power Systems (PVPS TCP)	Solar Heating and Cooling (SHC TCP)	Wind Energy (Wind TCP)	TOTAL
GE Power	*USA*							❹						
BG-Group	*GBR*							❹						
BP Global	*GBR*							❹						
Bruker Corporation	*DEU*				❹									
Canadian Geothermal Energy Association	*CAN*								❹					
Chevron Corporation	*USA*							❹						
Coal Industry Advisory Board	*FRA*							❹						
Columbus Superconductors	*ITA*				❹									
Doosan Power Systems	*GBR*							❹						
Electric Power Research Institute	*USA*							❹						
EnBW Energie Baden-Württemberg AG	*DEU*							❹						
Enel Foundation	*ITA*	❹												
ExxonMobil Corporation	*USA*							❹						
Forschungszentrum Jülich	*DEU*							❹						
International Association for Hydrogen Safety	*BEL*									❹				
International Copper Assoc. - Copper Alliance	*USA*										❹			
JGC Corporation	*JPN*							❹						
Nat. Org. Hydrogen and Fuel Cell Technology	*DEU*									❹				
ORMAT Technologies, Inc	*USA*								❹					
Regulatory Assistance Project	*USA*			❹										
RWE AG	*DEU*							❹						
Shaw Consultants International	*USA*						❹							
Shell Global Solutions	*NLD*									❹				
Shell International B.V.	*NLD*							❹						
Smart Electric Power Alliance	*USA*										❹			
Solar Energy Industries Association	*ESP*										❹			
Spanish Renewable Energy Association	*ESP*								❹					
Statoil	*NOR*							❹						
Total	*FRA*							❹						
University of Lleida	*ESP*		❹											
Warsaw University of Technology	*POL*		❹											
	Total	1	2	1	2		1	15	3	3	3			31
Entities from Partner Countries														
Anglo American South Africa	*ZAF*					❹								
Banpu Public Company Limited	*THA*					❹								
Beijing Research Institute for Coal Chemistry, China Coal Research Institute	*CHN*					❹								
Bharat Heavy Electricals Limited	*IND*					❹								
Chinese Wind Energy Assocation	*CHN*													
Electric Power Planning and Engineering Institute	*CHN*					❹							❹	
Gulf Organisation for Research & Development	*QAT*											❹		
Instituto de Investigaciones Eléctricas	*MEX*							❹						
Masdar Institute	*UAE*							❹						
Petrobras	*BRA*							❹						
SUEK AG	*RUS*					❹								
	Total					6		3				1	1	11
Regional or international organisations														
Economic Community of West African States (ECOWAS)	*TGO*											❹		
European Copper Institute - Copper Alliance	*BEL*			❹								❹		
Regional Centre for Renewable Energy and Energy Efficiency (RCREEE)	*EGY*											❹		
SolarPower Europe	*BEL*										❹			
Wind Europe	*BEL*												❹	
	Total			1							1	3	1	6
Total		**1**	**2**	**2**	**2**	**6**	**1**	**18**	**3**	**3**	**4**	**4**	**2**	**48**

Sponsors (SPs) refer to entities of OECD member or non-member countries or non-intergovernmental organisations that are not designated by the government of their respective country).

Part 3

IEA Energy Technology Activities and Engagement Worldwide

Technology analysis, forecasting and strategies

This section provides a short overview of IEA energy technology activities and highlights how the TCPs fit within this wider programme.

Energy Technology Perspectives

The *Energy Technology Perspectives (ETP)* series is the IEA's flagship publication regarding the potential for energy technologies to contribute to a secure energy system that enables stable economic growth while minimising environmental impacts. The *ETP* analysis focuses on the status and outlook for current and future energy technologies and on identifying what actions can accelerate progress, while considering regulatory and macroeconomic drivers that influence technology pathways. The *ETP* series demonstrates how technologies can make a decisive difference in achieving the objective of limiting the long-term global temperature rise to 2°C (2DS) while at the same time improving energy security and enhancing economic development, supporting prioritisation of research, demonstration, development and deployment (RDD&D) actions. Since 2006, the *ETP* series has aimed to:

- Guide short-term action based on long-term analysis.
- Outline the technological options for achieving deep cuts in carbon emissions over the next 40 years – and beyond.
- Assess the state of progress in clean energy deployment consistent with the 2DS.
- Outline possible pathways to a more sustainable energy system.
- Identify potential stumbling blocks and how to avoid them.
- Provide guidance on which policies are best suited to bring about necessary changes at least cost and most effectively.
- Assess benefits and costs associated with different scenarios.

The *ETP* is the IEA's most long-term outlook, with results presented up to 2050. Importantly for the purposes of this publication, *ETP* regularly draws on work carried out in relevant TCPs, particularly on data and through expert reviews.

Technology Roadmaps

At the request of ministers from the (then) G8, China, India and South Korea, the IEA has led an international initiative since 2008 to develop roadmaps for the most promising low-carbon energy technologies. To date, 21 technology-specific roadmaps have been published, covering energy supply (e.g. wind power), energy demand (e.g. transport fuel efficiency), integration (e.g. smart grids), sectors (e.g. cement production) and mitigation (e.g. CCS). All roadmaps are prepared in close consultation with governments, industry, research institutions and the relevant TCPs.

Each roadmap sets out milestones for technology development, legal and regulatory needs, investment requirements, public engagement, and international collaboration in order for each technology or sector to fulfil its contribution to realise the 2DS by 2050. Importantly, several TCPs have been instrumental in providing expertise to the technology roadmaps. Roadmaps published to date include:

- *Bioenergy for Heat and Power*
- *Biofuels for Transport*
- *Carbon Capture and Storage*
- *Carbon Capture and Storage in Industrial Applications*
- *Cement*
- *Chemical Industry via Catalytic Processes*
- *Electric and Plug-in Hybrid Vehicles*
- *Energy Efficient Buildings: Heating and Cooling Equipment*
- *Energy-efficient Building Envelopes*
- *Energy Storage*
- *Fuel Economy of Road Vehicles*
- *Geothermal Heat and Power*
- *High-Efficiency, Low-Emissions Coal-Fired Power Generation*
- *Hydrogen*
- *Hydropower*
- *Nuclear Energy*
- *Solar Photovoltaic Energy*
- *Solar Thermal Electricity*
- *Smart Grids*
- *Solar Heating and Cooling*
- *Wind Energy*

The Roadmaps have acted as a key dissemination tool for the *Energy Technology Perspectives* modelling and analysis. Each roadmap is underpinned by *ETP* scenarios of energy system decarbonisation. The roadmaps have in turn generated other prominent IEA Roadmaps have in turn generated other prominent IEA contributions to advancing low-carbon technologies. These include two national roadmaps for partner countries (*Low-Carbon Technologies for the India Cement Industry*, and *China Wind Energy Development Roadmap 2050*) as well as *How2Guides* that have been spearheaded by the International Low Carbon Energy Technology Platform (Technology Platform). The *How2Guides* draw on the IEA methodology for global roadmaps to provide technology specific policy and methodology guidance for roadmap development at the national or regional level. Several of the roadmaps have been translated into languages other than English, including Arabic, Mandarin and Russian. The annual IEA *Tracking Clean Energy Progress* report also arose from the Roadmaps programme.

IEA analysis

TCPs also contribute to a range of IEA Secretariat analysis focusing on the current status of technologies, applications to particular sectors, and further potentials. Such analytical works to which TCPs contributed include:

- *More Data, Less Energy: Making Network Standby More Efficient in Billions of Connected Devices*
- *Transition to Sustainable Buildings*
- *Linking Heat and Electricity Systems: Co-generation and District Heating and Cooling, Solutions for a Clean Energy Future*
- *Heating Without Global Warming: Market Developments and Policy Considerations for Renewable Heat*
- *Global Electric Vehicle Outlook*
- *Medium-Term Renewable Energy Market Report*

Energy Technology Network

Under the oversight of the IEA Governing Board, the Committee on Energy Research and Technology (CERT) is responsible for implementing IEA priorities with regard to research, development, demonstration and deployment (RDD&D). It is supported in these efforts by four working parties and two informal experts' groups. Together with the TCPs, these entities comprise what is known as the IEA energy technology network.

Committee on Energy Research and Technology

Comprised of senior experts from IEA member governments, the CERT considers effective energy technology and policies to improve energy security, encourage environmental protection and maintain economic growth. Under the guidance of the IEA Governing Board, the CERT oversees the technology forecasting, analyses and RDD&D strategies of the IEA Secretariat, notably through the flagship publication, *Energy Technology Perspectives*, and the series of energy technology roadmaps mentioned above.

The CERT also provides guidance to its working parties and experts' groups to examine topics that address current energy technology, or technology policy, issues. Through briefing papers and on the basis of presentations of selected external experts, including from TCPs, CERT dedicated discussions have focused, for example, on the following topics:

- gaps, strategic opportunities and international collaboration on low-carbon energy technologies
- integrated energy systems.

Working parties

There are four CERT Working Parties (WPs), each considering national policy developments and technology trends relating to their area of specialisation. They support and facilitate RDD&D co-operation among member countries, and, as appropriate, seek opportunities to collaborate with partner countries. They also regularly review the accomplishments of each TCP in their relevant area of expertise and make a recommendation to the CERT for the continuation of each such TCP. Working parties are comprised of programme managers and technology experts representing governmental agencies.

Working Party on End-Use Technologies (EUWP)

The main objectives of the EUWP are to guide the work of the end-use technology TCPs and to identify gaps in technologies and energy end-use systems. The EUWP builds relationships and engages with industry and partner countries through the work of the end-use TCPs.

The EUWP also follows closely the work of the Energy Efficiency Working Party (EEWP) and the International partnership for Energy Efficiency Co-operation (IPEEC). Recent workshops organised under the auspices of the EUWP, which generally involved experts from TCPs, included:

- waste heat and energy recovery: a key enhancer for energy efficiency in industry
- innovative technologies in heating distribution.

Working Party on Fossil Fuels (WPFF)

The objectives of the WPFF are to encourage energy security and environmental protection by monitoring fossil fuel technology-related policies and trends of IEA member and key partner countries. The WPFF has been instrumental in bringing CCS and clean coal technologies to the forefront of policy debates. It works closely with the IEA Coal Industry Advisory Board, the Global Carbon Capture and Storage Institute and the Carbon Sequestration Leadership Forum. The WPFF also oversees the activities of the TCPs operating in relevant technology fields. Recent topics examined under the auspices of the WPFF involving experts from TCPs included:

- advances in deployment of fossil fuel technologies.

Working Party on Renewable Energy Technologies (REWP)

The objectives of the REWP are to consider policies, market issues and technologies related to renewable energy sources and hydrogen. The REWP also co-ordinates the RD&D efforts of the renewable energy TCPs, in particular with regard to deployment. The REWP also ensures government-private sector dialogue by monitoring the role of finance and markets through the Renewable Industry Advisory Board (RIAB), an informal body created by the CERT in June 2011. Finally, the REWP maintains close ties with the International Renewable Energy Agency (IRENA). Recent topics examined under the auspices of the REWP, again involving experts from TCPs, have included:

- scaling up financing to expand the renewables portfolio
- the role of renewables in the energy transformation: the need for innovation in technology, business models and policy.

Fusion Power Co-ordinating Committee (FPCC)

The objectives of the FPCC are to provide a forum to co-ordinate international science and research with regard to fusion: device-specific research (tokamaks and alternate concepts) and cross-cutting research (materials, safety and technologies). As with the other working parties, the FPCC also oversees the eight TCPs operating in its area. Organisations and initiatives, such as the International Atomic Energy Agency and the ITER project, as well as key partner countries, regularly participate in FPCC meetings. Following the signing of the ITER treaty in 2007, discussions in the FPCC have focused on rationalising international scientific programmes concerning fusion, including among the fusion-related TCPs. One important recent action of the FPCC was the creation of a co-ordination group to examine "steady-state operations" in all fusion-related TCPs. Steady-state operation, or maintaining the plasma in equilibrium, is one of the key challenges to successfully creating power from fusion devices.

Experts' groups and advisory boards

From time to time, IEA member countries establish informal experts' groups to examine specific topics or to serve as advisory bodies. In the case of CERT, two such bodies currently exist to advise the CERT and working parties by examining cross-cutting issues relevant to energy technology research through expert workshops and discussions.

Experts' Group on R&D Priority-Setting and Evaluation (EGRD)

The EGRD examines analytical approaches to energy technologies, policies, and R&D. The results and recommendations support the CERT, feed into IEA analysis, and enable a broad perspective of energy technology issues. Recent topics examined under the auspices of the EGRD involving experts from TCPs included:

- the role of storage in energy system flexibility
- modelling and analyses in R&D priority-setting and innovation.

Renewable Industry Advisory Board (RIAB)

Created in 2011, the RIAB is composed of a selected group of executives representing leading industrial entities from the renewable energy sector. The RIAB provides a forum for strategic discussion among RIAB members, governments and the IEA on key issues which can aid the implementation of solutions for large-scale deployment of renewable energy technologies inside and outside OECD countries. RIAB members inform the REWP and the IEA Secretariat of up-to-date industry insights on significant industrial, market, regulatory, financial and innovation trends. RIAB workshops involving experts from TCPs include:

- the transformation of the power system: a consistent path for the integration of renewables and gas.

IEA engagement worldwide

The IEA typically agrees with its key partner countries on time-bound bilateral work programmes to outline concrete projects and co-operation areas of mutual interest to the IEA and its partners. This not only includes energy statistics and energy security, but also extends to projects that focus on energy technology. The development of country-focused technology roadmaps, such as Technology Roadmap: *China Wind Energy Development 2050*, and of the IEA *How2Guide* series for *Roadmap Development and Implementation* demonstrates this engagement. Increasingly, partner countries have sought greater participation in TCPs as they offer an excellent opportunity to connect with peers and energy technology research networks that are at the forefront of research in their respective areas.

International Low-Carbon Energy Technology Platform

Created in 2010 in response to a request from the (then) Group of Eight (G8) and IEA ministers, the International Low-Carbon Energy Technology Platform (Technology Platform) is a key IEA vehicle for engagement on fostering the deployment of renewable energy, energy efficiency and other low-carbon technologies. The Technology Platform is also a tool for energy technology and policy collaboration through joint projects among IEA member and partner countries, international organisations and the private sector. TCP experts regularly contributed to each of the three axes of Technology Platform:

Engagement worldwide: sharing best practice through workshops on low-carbon energy technologies, feeding into IEA analysis.

- bioenergy in South America, South Africa and Southeast Asia
- smart grids in South Africa
- wind energy in Asia and South Africa.

How2Guides: building on the IEA Technology Roadmaps series, the *How2Guides* are manuals that offer guidance to policy and decision makers for the development and implementation of technology specific roadmaps at the national/regional level.

- *How2Guide for Wind Energy*
- *How2Guide for Smart Grids*
- *How2Guide for Bioenergy* (forthcoming)

Cross-cutting analysis: on selected themes relevant to international collaboration on low-carbon technologies.

- Mapping multilateral collaboration on low-carbon energy technologies.
- In collaboration with the European Bank for Reconstruction and Development (EBRD), analysis of enabling frameworks for renewable energy and energy efficiency technologies in the Black Sea/Caspian and Middle East/North Africa regions as well as developing a methodology to assess market penetration of these technologies.
- Energy efficiency for energy security: activities in support of Ukraine's efforts to achieve energy savings in buildings, district heating and industry.

Training and Capacity-Building Programme

The IEA Training and Capacity Building Programme (TCB) aims to strengthen the capacity of energy agencies in partner countries to formulate and implement effective, comprehensive and transparent energy policies. The TCB regularly organises training modules and presentations relating to energy technologies: energy technology policy and collaboration, energy technology roadmaps, CCS, renewable energy sources and energy technology modelling. These sessions can be organised at any time of the year in agreement with a partner country/region and subject to available funding. In addition, energy technology modules feature prominently in the annual Energy Training Week held at the IEA, in Paris. As an example, participants in an energy technology roadmap course learned how to develop a national technology deployment roadmap, focusing on the country's energy technology strategies, priorities and targets and how to building consensus among stakeholders. A selection of recent events organised under the auspices of the TCB include:

- Annual Energy Training Week at the IEA (global participation)
- Annual Sustainable Energy Technology regional training courses (Central Asia, Latin America, southern and eastern Mediterranean region)
- Electricity systems and smart grids (Mexico, Southeast Asia)
- Energy efficiency policy and technology (Arab League countries, Latin America, Ukraine)
- Energy efficiency and renewable training (Mexico, Egypt)
- Energy statistics and energy efficiency indicators training (Caspian /Black Sea region, China, Egypt, Ethiopia, India, Indonesia, Mexico, South Africa, Ukraine, Viet Nam)
- Renewable energy technology, markets and roadmaps (Latin America, Morocco, South Africa, Ukraine).

Bilateral and multilateral symposia

The IEA actively co-operates on energy matters with partner countries and international energy organisations. The IEA hosts bilateral and multilateral events in partner countries to enable a broad range of experts from the IEA Secretariat to share experiences on topics of particular interest such as energy efficiency policy pathways, roadmaps, modelling, with contribution from the TCPs where relevant. The IEA also interacts with and contributes to the work of a wide array of international organisations, processes and fora. Bilateral and multilateral symposia to which TCPs contributed include:

- Kazakhstan (energy efficiency, renewables and sustainable development)
- Mexico (fossil fuel subsidy reform, energy efficiency, and training and capacity building)
- South Africa (energy efficiency, development of a national solar roadmap and statistics training)
- Ukraine (policy dialogue on energy efficiency)
- IEA/United Nations Economic and Social Commission for Western Asia/Masdar (Qatar) (carbon capture and storage)
- IEA/4E/Super-Efficient Equipment and Appliance Deployment (an initiative of the Clean Energy Ministerial) (network standby policy frameworks).

Partnering with the private sector

To develop and deploy more secure and sustainable energy systems, business and governments must work together to share the burden of reducing greenhouse gas emissions through use of low-carbon technologies. The IEA is uniquely placed to foster dialogue between policy makers and industry leaders and supports joint activities in diverse areas such as: transport and mobility modelling; long-range energy forecasting; CCS; emergency preparedness in the oil and gas sector; technology roadmaps; and policy recommendations. This market-relevant advice ensures that IEA publications encompass both regulatory and market considerations. Recent activities involving the private sector include:

Initiatives and bodies

- Energy Business Council
- Coal Industry Advisory Board (CIAB)
- Renewable Industry Advisory Board (RIAB)
- Chief Technology Officers roundtable
- Technology Platform
- Global Fuel Economy Initiative.

Recent activities

- Technology Roadmaps and How2Guides series
- Policy Pathways series (energy efficiency).

Part 4

Annexes

IEA "Shared Goals"*

The member countries of the IEA seek to create conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and to the well-being of their people and of the environment. In formulating energy policies, the establishment of free and open markets is a fundamental point of departure, though energy security and environmental protection need to be given particular emphasis by governments. IEA countries recognise the significance of increasing global interdependence in energy. They therefore seek to promote the effective operation of international energy markets and encourage dialogue with all participants.

In order to secure their objectives, member countries therefore aim to create a policy framework consistent with the following goals:

Diversity, efficiency and flexibility within the energy sector are basic conditions for longer-term energy security: the fuels used within and across sectors and the sources of those fuels should be as diverse as practicable. Non-fossil fuels, particularly nuclear and hydro power, make a substantial contribution to the energy supply diversity of IEA countries as a group.

Energy systems should have the ability to respond promptly and flexibly to energy emergencies. In some cases this requires collective mechanisms and action: IEA countries co-operate through the Agency in responding jointly to oil supply emergencies.

The environmentally sustainable provision and use of energy are central to the achievement of these shared goals. Decision makers should seek to minimise the adverse environmental impacts of energy activities, just as environmental decisions should take account of the energy consequences. Government interventions should respect the Polluter Pays Principle where practicable.

More environmentally acceptable energy sources need to be encouraged and developed. Clean and efficient use of fossil fuels is essential. The development of economic non-fossil sources is also a priority. A number of IEA member countries wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide. Renewable sources will also have an increasingly important contribution to make

Improved energy efficiency can promote both environmental protection and energy security in a cost-effective manner. There are significant opportunities for greater energy efficiency at all stages of the energy cycle from production to consumption. Strong efforts by governments and all energy users are needed to realise these opportunities.

Continued research, development and market deployment of new and improved energy technologies make a critical contribution to achieving the objectives outlined above. Energy technology policies should complement broader energy policies. International co-operation in the development and dissemination of energy technologies, including industry participation and co-operation with non-member countries, should be encouraged.

Undistorted energy prices enable markets to work efficiently. Energy prices should not be held artificially below the costs of supply to promote social or industrial goals. To the extent necessary and practicable, the environmental costs of energy production and use should be reflected in prices.

Free and open trade and a secure framework for investment contribute to efficient energy markets and energy security. Distortions to energy trade and investment should be avoided.

Co-operation among all energy market participants helps to improve information and understanding, and encourages the development of efficient, environmentally acceptable and flexible energy systems and markets worldwide. These are needed to help promote the investment, trade and confidence necessary to achieve global energy security and environmental objectives.

* The Shared Goals were adopted by IEA ministers at their 4 June 1993 meeting in Paris.

IEA Framework for International Energy Technology Co-operation (Framework)*

I. General Principles

Article 1. Mandate

1.1 In fulfilment of Chapter VII of the Agreement on an International Energy Program and in light of the Shared Goals of the IEA, the IEA operates Implementing Agreements to enable IEA member countries to carry out programmes and projects on energy technology research, development and deployment.

1.2 An Implementing Agreement is a contractual relationship established by at least two IEA member countries, and approved by the Governing Board, for the purpose set out in Article 1.1.

1.3 Participants in an Implementing Agreement shall contribute as fully as possible to the achievement of its objectives and shall endeavour to secure, through public and private support, the necessary scientific, technical and financial resources for the programmes and projects carried out under such an Implementing Agreement.

1.4 Each Implementing Agreement shall have an Executive Committee composed of representatives of all participants.

Article 2. Nature of Implementing Agreements

2.1 The activities of an Implementing Agreement may include, *inter alia*:

(a) co-ordination and planning of specific energy technology research, development and deployment studies, works or experiments carried out at a national or international level, with subsequent exchange, joint evaluation and pooling of the scientific and technical results acquired through such activities;

(b) participation in the operation of special research or pilot facilities and equipment provided by a participant, or the joint design, construction and operation of such facilities and equipment;

(c) exchange of information on (*i*) national programmes and policies, (*ii*) scientific and technological developments and (*iii*) energy legislation, regulations and practices;

(d) exchanges of scientists, technicians or other experts;

(e) joint development of energy related technologies; and

(f) any other energy technology related activity.

2.2 Participation in an Implementing Agreement shall be based on equitable sharing of obligations, contributions, rights and benefits. Participants in an Implementing Agreement shall undertake to make constructive contributions, whether technical, financial or otherwise, as may be agreed by the Executive Committee.

2.3 Some or all of the participants in an Implementing Agreement may choose to execute specific projects and/or programmes through Annexes to the Implementing Agreement.

II. Rules Applicable to IEA Implementing Agreements

Article 3. Participation, Admission and Withdrawal

3.1 An Implementing Agreement can be established by two or more IEA member countries subject to approval of the Committee on Energy Research and Technology (CERT) and of the Governing Board. There are two possible categories of participants in Implementing Agreements: Contracting Parties and sponsors.

3.2 Contracting Parties may be:

(a) the governments of both OECD member or OECD non-member countries;

(b) the European Communities;

(c) international organisations in which the governments of OECD member countries and/or OECD non-member countries participate; and

(d) any national agency, public organisation, private corporation or other entity designated by the government of an OECD member country or an OECD non-member country, or by the European Communities.

3.2.1 Participation in any Implementing Agreement for OECD non-member countries or for international organisations requires prior approval by the CERT. However, should the CERT consider a first time application by an OECD non-member country or an international organisation to be sensitive, it may refer the decision to the Governing Board as it deems appropriate.

3.2.2 Prior to CERT approval of participation of OECD non-member countries or international organisations in any Implementing Agreement, the Executive Committee shall:

* Each TCP is formally organised under the mechanism of an "Implementing Agreement", which is also commonly used to refer to the legal text of a TCP.

(a) have voted in favour of the applicant to join the Implementing Agreement and provide evidence of the same to the CERT;

(b) provide the CERT with a copy of the terms and conditions of the applicant's participation in the Implementing Agreement; and

(c) provide the CERT with a letter from the applicant expressing the applicant's desire to join the Implementing Agreement and specifying which Annexes it wishes to join; its acceptance of the terms and conditions of the Implementing Agreement; the name of its designated entity if it is not the applicant itself; and the name of the entity that will sign the Implementing Agreement.

3.2.3 The terms and conditions for the admission, participation and withdrawal of Contracting Parties (including their rights and obligations, in Implementing Agreements and their Annexes, if any, shall be established by the Executive Committee of each Implementing Agreement.

3.2.4 Notwithstanding Article 3.2.3, no Contracting Party from an OECD non-member country or international organisation shall have greater rights or benefits than Contracting Parties from OECD member countries.

3.3 Sponsors may be:

(a) entities of OECD member countries or OECD non-member countries which are not designated by the governments of their respective countries to participate in a particular Implementing Agreement; and

(b) non-intergovernmental international entities in which one or more entities of OECD member countries or OECD non-member countries participate.

3.3.1 Participation of sponsors in Implementing Agreements requires prior approval by the CERT.

3.3.2 Prior to CERT approval of Sponsor participation in any Implementing Agreement, the Executive Committee shall:

(a) have voted in favour of the applicant to join the Implementing Agreement and provide evidence of the same to the CERT;

(b) provide the CERT with a copy of the terms and conditions of the applicant's participation in the Implementing Agreement; and

(c) provide the CERT with a letter from the applicant expressing the applicant's desire to join the Implementing Agreement and specifying which Annexes it wishes to join; its acceptance of the terms and conditions of the Implementing Agreement; and the name of the entity that will sign the Implementing Agreement.

3.3.3 The terms and conditions for the admission, participation and withdrawal of sponsors, including rights and obligations, in Implementing Agreements and their Annexes, if any, shall be established by the Executive Committee of each Implementing Agreement.

3.3.4 Notwithstanding Article 3.3.3, no Sponsor shall have greater rights or benefits than Contracting Parties from OECD non-member countries and no Sponsor shall be designated Chair or Vice-chair of an Implementing Agreement.

3.3.5 The CERT shall have the right to not approve participation of a Sponsor if the terms and conditions of such participation do not comply with this Framework, any Decisions of the CERT or the Governing Board and the Shared Goals of the IEA.

Article 4. Specific Provisions

4.1 Unless the CERT otherwise agrees, based on exceptional circumstance and sufficient justification, Implementing Agreements shall be for an initial term of up to, but no more than, five years.

4.2 An Implementing Agreement may be extended for such additional periods as may be determined by its Executive Committee, subject to approval of the CERT. Any single extension period shall not be greater than five years unless the CERT otherwise decides, based on exceptional circumstances and sufficient justification.

4.3 Notwithstanding Paragraph 4.2, should the duration of the programme of work of an Annex exceed the term of the Implementing Agreement to which it relates, the CERT shall not unreasonably withhold approval to extend the Implementing Agreement for such additional period to permit the conclusion of the work then being conducted under the Annex.

4.4 Either the Contracting Parties or the Executive Committee of each Implementing Agreement shall:

4.4.1 approve the programme activities and the annual programme of work and budget for the relevant Implementing Agreement;

4.4.2 establish the terms of the contribution for scientific and technical information, know-how and studies, manpower, capital investment or other forms of financing to be provided by each participant in the Implementing Agreement;

4.4.3 establish the necessary provisions on information and intellectual property and ensure the protection of IEA copyrights, logos and other intellectual property rights as established by the IEA;

4.4.4 assign the responsibility for the operational management of the programme or project to an entity accountable to the Executive Committee of the relevant Implementing Agreement;

4.4.5 establish the initial term of the Implementing Agreement and its Annexes;

4.4.6 approve amendments to the text of the Implementing Agreement and Annexes; and

4.4.7 invite a representative of the IEA Secretariat to its Executive Committee meetings in an advisory capacity and, sufficiently in advance of the meeting, provide the Secretariat with all documentation made available to the Executive Committee members for purposes of the meeting.

Article 5. Copyright

5.1 Notwithstanding the use of the IEA name in the title of Implementing Agreements, the Implementing Agreements, the Executive Committee or the entity responsible for the operational management of the programme or project may use the name, acronym and emblem of the IEA as notified to the World Intellectual Property Organisation (WIPO) only upon prior written authorisation of the IEA and solely for the purposes of executing the Implementing Agreements.

5.2 The IEA shall retain the copyright to all IEA deliverables and published or unpublished IEA material. Implementing Agreements wishing to use, copy or print such IEA deliverables and/or material shall submit a prior written request of authorisation to the IEA.

Article 6. Reports to the IEA

6.1 Each Executive Committee shall submit to the IEA:

6.1.1 as soon as such events occur, notifications of any admissions and withdrawals of Contracting Parties and sponsors, any changes in the names or status of Contracting Parties or sponsors, any changes in the members of the Executive Committee or of the entity responsible for the operational management of the programme or project, or any amendments to an Implementing Agreement and Annex thereto;

6.1.2 annual reports on the progress of programmes and projects of the Implementing Agreement and any Annex;

6.1.3 notwithstanding Article 6.1.1, in addition to and with the Annual Report, annually provide the IEA with the following information:

(a) the names and contact details of all current Contracting Parties and sponsors;

(b) the names and contact details of all Contracting Parties and sponsors who may have withdrawn from the Implementing Agreement or any Annex in the year covered by the Annual Report;

(c) the names and contact details of all new Contracting Parties and sponsors who may have joined the Implementing Agreement or any Annex in the year covered by the Annual Report;

(d) any changes in the names or status of any Contracting Parties or sponsors;

(e) the names and contact details of the Executive Committee members and the entity responsible for the operational management of the programme or project; and

(f) any amendments to the text of an Implementing Agreement and any Annex thereto.

6.1.4 End of Term Reports, which shall include all the information and documentation required by Decisions of the CERT then in effect and relating thereto; and

6.1.5 at the request of the IEA, any other non-proprietary information as may be requested by the IEA in connection with the IEA's mandate.

Article 7. Effective Date

This Framework shall take effect and become binding on all participants in the Implementing Agreements and Annexes from the date of its approval as a decision by the Governing Board.

Frequently asked questions

What is the International Energy Agency (IEA)?

The IEA works to ensure reliable, affordable and clean energy for its 29 member countries and beyond. Founded in 1974, the IEA was initially designed to help countries co-ordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973/4. While this remains a key aspect of its work, the IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis.

The IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 member countries and beyond. The four main areas of focus are:

- energy security: promoting diversity, efficiency and flexibility within all energy sectors
- economic development: ensuring the stable supply of energy to IEA member countries and promoting free markets to foster economic growth and eliminate energy poverty
- environmental awareness: enhancing international knowledge of options for tackling climate change
- engagement worldwide: working closely with non-member countries, especially major producers and consumers, to find solutions to shared energy and environmental concerns.

For more information on the IEA, see the Frequently Asked Questions.

What is an IEA Technology Collaboration Programme?

Technology Collaboration Programmes (TCPs) are independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues. TCPs currently cover topics related to:

- efficient end use (buildings, electricity, industry, transport)
- cleaner fossil fuels (greenhouse-gas mitigation, extraction, supply, transformation)
- renewable energy and hydrogen (technologies and policies for deployment)
- cross-cutting issues (modelling, technology transfer, project financing)
- fusion power (safety, physics, materials, technologies).

The 6 000 experts in the TCPs work to advance the research, development and commercialisation of energy technologies. The scope and strategy of each TCP is in keeping with the IEA Shared Goals of energy security, environmental protection and economic growth, as well as engagement worldwide. Depending on the TCP, activities may include:

- basic and applied research, technology development and pilot plants
- technology assessment, feasibility studies, environmental impact studies, market analysis, policy implications
- information exchange of research results and programmes
- scientist exchanges
- databases, modelling and systems analysis
- experts' networks.

How are TCP activities financed?

Each TCP is self-financed by the participants, either through financial and/or in-kind contributions. The participants themselves decide whether cost-sharing, task-sharing or a combination of both is most appropriate. In TCPs funded through a cost-sharing approach, each participant contributes to a common fund which can then be used to finance activities under the TCP's programme of work. In TCPs funded through a task-sharing approach, each participant contributes resources in-kind (for example personnel or materials).

How are TCPs governed?

Each TCP is organised under the auspices of an Implementing Agreement which is most commonly used to describe the legal text of a TCP. The legal text includes key provisions regarding the purpose, management and implementation of the TCP. The activities of each TCP are overseen by an Executive Committee (ExCo) comprised of representatives designated by each participant. The ExCo takes decisions on the management, participation and implementation aspects of the TCP. Some TCPs entrust the management functions of the TCP, or of a particular activity, to an Operating Agent (OA).

What is the role of the IEA in the TCPs?

The IEA provides the framework for collaboration through TCPs, which is known as the *IEA Framework for International Technology Co-operation*.

This sets out the minimum requirements for TCPs and outlines the principal responsibilities of TCP participants and the various IEA bodies involved with TCPs. It is a legal structure that is designed to simplify international co-operation between national entities, business and industry. It also includes important information about participation and reporting requirements.

Furthermore, the Committee on Energy Research and Technology (CERT) and the four CERT Working Parties have regular dialogue with the TCPs and regularly consider the following aspects of a TCP:

- strategic direction
- scope
- contractual and management requirements
- contribution to technology evolution
- contribution to technology deployment and market facilitation
- policy relevance
- contribution to environmental protection
- information dissemination
- outreach to partner countries
- added value.

The IEA does not provide direct financial support to TCPs through funding, either as a signatory or as a programme manager (Operating Agent). However, the IEA Secretariat provides guidance, advice and support by acting as conduit between TCPs and policy makers, and by promoting TCP outcomes where possible. The IEA also provides legal advice in relation to processes, procedures and the legal structure of TCPs.

What are the benefits to participating in TCPs?

There are numerous advantages to participating in the ongoing activities of TCPs:

- voting on projects carried out
- reduced cost and duplication of work
- greater project scale
- information sharing and networking
- international collaboration with a wide range of stakeholders
- linking IEA member countries with partner countries
- linking research, industry and policy
- accelerated development and deployment
- harmonised technical standards
- strengthened research capabilities.

In addition, many activities carried out by the TCPs result in publications. A number of TCPs also carry out workshops and conferences which provide opportunities for experts worldwide to share their recent results.

More than 300 public and private entities worldwide participate in the TCPs. Governmental or non-governmental entities from OECD member countries or non-OECD countries, as well as intergovernmental and non-governmental organisations, are eligible to participate. Under the *IEA Framework for International Technology Co-operation*, it is possible for governments, international organisational and non-governmental entities such as the private sector, business and industry, academia and research entities to participate in TCPs.

How are new TCPs created?

A new TCP may be created at any time, provided that:

- It is established by at least two IEA member countries.
- The scope, strategic plan and work plan are consistent with the shared goals of the IEA.
- The IEA CERT recommends the establishment of the new TCP and the IEA Governing Board approves the creation of the new TCP.

Where can I find further information?

For further information regarding the TCPs, see the IEA website pages www.iea.org/tcp or send an email to tcp.forum[at]iea.org. For legal or procedural questions related to TCPs, please contact IMPAG.legal[at]iea.org.

How can my entity become a participant in a TCP?

Following is a brief overview of the steps required to become a participant in a TCP.

Steps required to become a TCP participant:

1. Contact the Chair of the TCP to explore benefits of working together and to discuss possible participation in the activities of the TCP.
2. Agree the terms and conditions of participation with the TCP.
3. Receive a formal letter of invitation from the Executive Committee (ExCo) of the TCP to become a participant as either a Contracting Party or a Sponsor.
4. Send the required letters of designation and/or acceptance to the IEA Executive Director, as set out in the letter of invitation from the TCP.
5. Sign the legal text (Implementing Agreement) of the TCP.
6. Participation begins!

Acronyms

ACRONYM	OFFICIAL TITLE
GB	IEA Governing Board
CERT	IEA Committee on Energy Research and Technology
EG	Experts' or ad hoc groups
EGRD	IEA Experts' Group on R&D Priority Setting and Evaluation
RIAB	Renewable Industry Advisory Board
WP	IEA Working Party
EUWP	IEA Working Party on Energy End-Use Technologies
FPCC	IEA Fusion Power Co-ordinating Committee
REWP	IEA Working Party on Renewable Energy Technologies
WPFF	IEA Working Party on Fossil Fuels
TCP	IEA Technology Collaboration Programme
4E TCP	Implementing Agreement for a Co-operative Programme on Energy Efficient End-Use Equipment
AFC TCP	Implementing Agreement for a Programme of Research, Development and Demonstration on Advanced Fuel Cells
AMF TCP	Implementing Agreement for Advanced Motor Fuels
AMT TCP	Implementing Agreement for a Co-operative Programme of Research and Development on Advanced Materials for Transportation Applications
Bioenergy TCP	Implementing Agreement for a Programme of Research, Development and Demonstration on Bioenergy
CCC TCP	Implementing Agreement for the IEA Clean Coal Centre
Combustion TCP	Implementing Agreement for a Programme of Energy Conservation and Emissions Reduction in Combustion
CTI TCP	Implementing Agreement for a Climate Technology Initiative
CTP TCP	Implementing Agreement for Co-operation on Tokamak Programmes
DHC TCP	Implementing Agreement on District Heating and Cooling including Combined Heat and Power
DSM TCP	Implementing Agreement for Co-operation on Technologies and Programmes for Demand side Management
EBC TCP	Implementing Agreement for a Programme of Research and Development on Energy in Buildings and Communities
ECES TCP	Implementing Agreement for a Programme of Research and Development on Energy Conservation in Energy Storage
EOR TCP	Implementing Agreement for a Programme of Research, Development and Demonstration on Enhanced Oil Recovery
ESEFP TCP	Implementing Agreement on a Co-operative Programme on Environmental, Safety, Economic Aspects of Fusion Power
ETSAP TCP	Implementing Agreement for a Programme of Energy Technology Systems Analysis
FBC TCP	Implementing Agreement for Co-operation in the Field of Fluidized Bed Conversion of Fuels Applied to Clean Energy Production
FM TCP	Implementing Agreement for a Programme of Research and Development on Radiation Damage in Fusion Materials
Geothermal TCP	Implementing Agreement for a Co-operative Programme on Geothermal Energy Research and Technology
GHG TCP	Greenhouse Gas R&D Implementing Agreement
GOTCP	Implementing Agreement for a Co-operative Programme on Gas and Oil Technologies
HEV TCP	Implementing Agreement for Co-operation on Hybrid and Electric Vehicles Technologies and Programmes

ACRONYM	OFFICIAL TITLE
HPT TCP	Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies
HTS TCP	Implementing Agreement for a Co-operative Programme for Assessing the Impacts of High Temperature Superconductivity on the Electric Power Sector
Hydrogen TCP	Implementing Agreement for a Programme of Research and Development on the Production and Utilisation of Hydrogen
Hydropower TCP	Implementing Agreement for a Co-operative Programme on Hydropower Technologies and Programmes
IETS TCP	Implementing Agreement on Industrial Energy Related Technologies and Systems
ISGAN TCP	Implementing Agreement for a Co-operative Programme on Smart Grids
NTFR TCP	Implementing Agreement on a Co-operative Programme on Nuclear Technology of Fusion Reactors
OES TCP	Implementing Agreement for a Co-operative Programme on Ocean Energy Systems
PVPS TCP	Implementing Agreement for a Co-operative Programme on Photovoltaic Power Systems
PWI TCP	Implementing Agreement for a Programme of Research and Development on Plasma Wall Interaction in Facilities for Fusion Reactors
RETD TCP	Implementing Agreement for Renewables Energy Technology Deployment
RFP TCP	Implementing Agreement for a Programme of Research and Development on Reversed Field Pinches
SH TCP	Implementing Agreement for Co-operation in Development of the Stellarator Heliotron Concept
SHC TCP	Implementing Agreement for a Programme to Develop and Test Solar Heating and Cooling Systems
SolarPACES TCP	Implementing Agreement for Solar Power and Chemical Energy Systems
ST TCP	Implementing Agreement for Co-operation on Spherical Tori
Wind TCP	Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Energy Systems

Glossary

TERM	DEFINITION
International Energy Agency (IEA)	An autonomous organisation which works to ensure reliable, affordable and clean energy for its member countries and beyond. The IEA's four main areas of focus are: energy security, economic development, environmental awareness, and engagement worldwide.
IEA member countries	There are 29 member countries of the IEA: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.
Accession countries	OECD member countries that have begun the formal process to become members of the IEA: Chile, Mexico.
Association countries	Partner countries with which the IEA has established joint activities: China, Indonesia and Thailand.
Partner countries	At the IEA Ministerial meeting in November 2015, the Join Ministerial Declaration Expressing the Activation of Association formally welcomed China, Indonesia and Thailand as Association countries of the IEA. The activation of Association marks an important milestone in IEA engagement worldwide, reflecting several years of concerted efforts on the part of IEA member countries, partner countries and the Secretariat, and opening doors to a new era of international energy co-operation.
IEA Committee on Energy Research and Technology (CERT)	Established in 1975, the CERT is the senior technology committee of the IEA and reports directly to the Governing Board. The CERT is responsible for identifying the IEA strategy for energy research and development (R&D) and for overseeing the implementation of this strategy. It also reviews national energy R&D programmes and those of the TCPs.
Working Parties (WPs)	CERT Working Parties (WPs) provide advice and support the CERT in carrying out its mandate, and to the IEA on issues relevant to each WP. The WPs support and facilitate co-operation among IEA member countries in research, development, demonstration and deployment of the respective technologies. WPs also seek to expand collaboration with partner countries. Each WP regularly reviews the accomplishments of the TCPs and makes a recommendation to the CERT concerning the request for extension of the TCP mandate.
Fusion Power Co-ordinating Committee (FPCC)	Established in 1975, the objective of the FPCC is to enhance fusion research and development activities worldwide, promoting, initiating and co-ordinating international co-operation on fusion activities. FPCC is one of the four CERT WPs.
Working Party on Energy End-Use Technologies (EUWP)	Established in 1981, the EUWP provides advice to the CERT and other IEA bodies on trends and policies relating to energy end-use technologies. EUWP is one of the four CERT WPs.
Working Party on Renewable Energy Technologies (REWP)	Established in 1981, the REWP provides advice to the CERT and other IEA bodies on trends and policies relating to renewable energy and hydrogen. REWP is one of the four CERT WPs.
Working Party on Fossil Fuels (WPFF)	Established in 1981, the WPFF provides advice to the CERT and the IEA on fossil fuel technology–related policies, trends, projects, programmes and strategies which address priority environmental protection and energy security interests, including adequate, flexible, and reliable supply of power and electrical service of member countries. WPFF is one of the four CERT WPs.
Experts' Group on R&D Priority Setting and Evaluation (EGRD)	The EGRD promotes development and refinement of analytical approaches to energy technology analysis; to R&D priority setting; and to assessment of benefits from R&D activities. The results and recommendations support the CERT and contribute to IEA analysis.
Renewable Industry Advisory Board (RIAB)	The RIAB is comprised of private-sector entities located within OECD member countries. The RIAB informs the Working Party on Renewable Energy Technologies and the IEA Secretariat of market-relevant information, industry advice and data.
IEA Energy Technology Network	Comprises the CERT, the four CERT Working Parties, advisory boards or experts' groups, and the TCPs.
IEA Framework	The IEA Framework for International Energy Technology Co-operation, adopted by the Governing Board in 2003, outlines who may participate in TCPs and the principal rights and responsibilities of the participants. The Framework also provides the minimum requirements of information and reports that each TCP is to transmit to the IEA Secretariat.
IEA Governing Board (GB)	The Governing Board is the main decision-making body of the IEA and is composed of energy ministers or their senior representatives from each IEA member country.

TERM	DEFINITION
IEA Technology Collaboration Programmes (TCPs)	The term indicates the collaborative programmes under the IEA Framework. Each TCP is formally organised under mechanism of an "Implementing Agreement", which is also commonly used to describe the legal text of a TCP.
Activity	A project or programme carried out under the auspices of a TCP. An activity may include: building or operating a pilot plant; engaging in a joint study (basic or applied research); collecting data and managing a database; managing a model to produce scenarios; maintaining experts' networks; facilitating technology or knowledge transfer through training, or workshops; project funding; scientist exchanges; or dedicated communication efforts.
Annex	IA project or study carried out under the auspices of a TCP. An Annex may comprise one or more sub-tasks. May also be referred to as a 'Task',
Executive Committee (ExCo)	The decision-making body of the TCP which supervises the programme activities. It is comprised of at least one representative from each of the TCP participants.
Operating Agent (OA)	The individual or entity that has been assigned with tasks related to all or some operational management of a TCP by the ExCo. Sometimes referred to as an ExCo Secretary.
Participants	Signatories to the TCP's legal text (Implementing Agreement). There are two categories of participants: Contracting Parties and Sponsors.
Contracting Party (CP)	TCP participants that represent governments of OECD member or non-member countries, the European Union, or intergovernmental organisations. CPs may be also any entity, including national agencies and private corporations, that has been designated by a government to participate in a TCP.
Sponsor	Participants that are not designated by a government to participate in the TCP. This may include public and private sector entities, as well as non-intergovernmental organisations. Sponsors are not eligible to serve as a TCP Chair and Vice-Chair.
Task	A project or study carried out under the auspices of a TCP. A task may comprise one or more sub-tasks. May also be referred to as an Annex.
Organisation for Economic Co-operation and Development (OECD)	The mission of the OECD is to promote policies that will improve the economic and social well-being of people around the world. The IEA is an autonomous agency of the OECD.

TCP websites[1]

ACTIVITY	TECHNOLOGY COLLABORATION PROGRAMME (TCP)	WEBSITE
Cross-cutting	Climate Technology Initiative (CTI TCP)	www.climatetech.net
	Energy Technology Systems Analysis (ETSAP TCP)	www.iea-etsap.org
End use: buildings	Buildings and Communities (EBC TCP)	www.iea-ebc.org/
	District Heating and Cooling (DHC TCP)	www.iea-dhc.org
	Energy Storage (ECES TCP)	www.iea-eces.org/
	Energy Efficient End-Use Equipment (4E TCP)	www.iea-4e.org
	Heat Pumping Technologies (HPT TCP)	www.heatpumpcentre.org
End use: electricity	Demand-Side Management (DSM TCP)	www.ieadsm.org
	High-Temperature Superconductivity (HTS TCP)	http://superconductivityiea.rse-web.it/
	Smart Grids (ISGAN TCP)	www.iea-isgan.org
End use: industry	Industrial Technologies and Systems (IETS TCP)	www.iea-industry.org
End use: transport	Advanced Fuel Cells (AFC TCP)	www.ieafuelcell.com
	Advanced Materials for Transportation (AMT TCP)	www.iea-ia-amt.org
	Advanced Motor Fuels (AMF TCP)	www.iea-amf.org
	Emissions Reduction in Combustion (Combustion TCP)	www.ieacombustion.com
	Hybrid and Electric Vehicles (HEV TCP)	www.ieahev.org
Fossil fuels	Clean Coal Centre (CCC TCP)	www.iea-coal.org.uk
	Enhanced Oil Recovery (EOR TCP)	http://iea-eor.ptrc.ca
	Fluidized Bed Conversion (FBC TCP)	www.iea-fbc.org
	Gas and Oil Technologies (GOTCP)	www.gotcp.org
	Greenhouse Gas R&D (GHG TCP)	www.ieaghg.org
Fusion Power	Environmental, Safety, Economic Aspects of Fusion Power (ESEFP TCP)	www.iea-esefp.net/portal.php
	Fusion Materials (FM TCP)	www.frascati.enea.it/ifmif/
	Nuclear Technology of Fusion Reactors (NTFR TCP)	www.iea-ntfr.net/portal.php
	Plasma Wall Interaction (PWI TCP)	www.pwi-ia.org/index.html[2]
	Reversed Field Pinches (RFP TCP)	under development
	Spherical Tori (ST TCP)	http://iea-st.pppl.gov/
	Stellarator-Heliotron Concept (SH TCP)	http://www.ipp.mpg.de/sh-tcp
	Tokamak Programmes (CTP TCP)	http://ctp.jet.efda.org/
Renewable energy and hydrogen	Bioenergy (Bioenergy TCP)	www.ieabioenergy.com
	Concentrated Solar Power (SolarPACES TCP)	www.solarpaces.org
	Hydrogen (Hydrogen TCP)	http://ieahia.org
	Hydropower (Hydropower TCP)	www.ieahydro.org
	Geothermal (Geothermal TCP)	www.iea-gia.org
	Ocean Energy Systems (OES TCP)	www.ocean-energy-systems.org
	Photovoltaic Power Systems (PVPS TCP)	www.iea-pvps.org
	Renewable Energy Technology Deployment (RETD TCP)	www.iea-retd.org
	Solar Heating and Cooling (SHC TCP)	www.iea-shc.org
	Wind Energy Systems (Wind TCP)	www.ieawind.org

1. The Technology Collaboration Programmes function within a framework created by the IEA in Paris. Views, findings, and publications of the TCPs do not necessarily represent the views or policies of the IEA or of its individual member countries.

2. The website is password protected. To request access, contact *fusion[at]fz-juelich.de.*

Notes

1. OPEC membership includes Algeria, Angola, Ecuador, Gabon, Indonesia, Kuwait, Libya, Nigeria, the Republic of Iran, Iraq, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

2. UNIDO comprises the 170 member states of the United Nations.

3. The International Thermonuclear Experimental Reactor (ITER) comprises China, European Commission, India, Japan, Korea, the Russian Federation and the United States. ITER participates in the TCP on Tokamak Programmes (CTP TCP).

4. Contracting Parties (CPs) are governments of OECD member or non-member countries, the European Union, intergovernmental organisations, or any entity designated by a government. Sponsors (SPs) are entities of OECD member or non-OECD countries or non-intergovernmental organisations that are not designated by the government to participate in TCPs. RO/IO refers to regional and/or international intergovernmental and nongovernmental organisations, which can participate in TCPs either as CPs or as SPs. Regional or international organisations participating in TCPs include the European Commission and the European Atomic Energy Community (EC); the European Copper Institute (ECI); the Economic Community of West African States (ECOWAS); the International Thermonuclear Experimental Reactor (ITER); the Organisation for Petroleum Exporting Countries (OPEC); the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE); SolarPower Europe; and Wind Europe.

5. ECOWAS comprises Benin, Burkina Faso, Cap Verde, Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

6. RCREEE comprises Algeria, Bahrain, Djibouti, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Palestine, Qatar, Syria, Tunisia, the United Arab Emirates, and Yemen.

7. ISGAN, an initiative of the Clean Energy Ministerial (CEM), is formally organised under the IEA's TCP mechanism as the Implementing Agreement for a Co-operative Programme on Smart Grids (ISGAN), also known as the TCP on Smart Grids.

8. The demonstration fusion reactor (DEMO) is the next experimental device to follow ITER, and predecessor to a commercial-sized fusion reactor. DEMO would generate electricity at the level of a few hundred MW and utilise all technologies required for commercial deployment.

9. Tritiated water, a radioactive form of water, contains the radioactive hydrogen isotope tritium. With a half-life of about 12 years it is not dangerous externally, but could be a hazard when inhaled, ingested via food or water, or absorbed through the skin.

10. As tritium is practically non-existent in a natural state, it is therefore very expensive. Fusion power plants must be able to recover and reuse all unused tritium.

11. Linear plasma devices include the PSI-2 (Jülich Forschungszentrum in Germany) which operates in a steady-state, and the Magnum PSI which operates in a temporary state with plasma density and temperatures close to those expected in the ITER divertor (Dutch FOM Institute for Plasma Physics Rijnhuizen).

12. The stellarator is a spherical fusion containment device invented by the astrophysicist Lyman Spitzer (United States). A heliotron is a stellarator device in which a helical coil is used to confine the plasma.

13. The electron volt (eV) is a unit of energy equal to the energy acquired by an electron in being accelerated through a potential difference of 1 volt.

14. The recently created EUROfusion Consortium for the Development of Fusion Energy manages European fusion research activities on behalf of Euratom (the European Atomic Energy Community).

15. The term *tokamak* is a transliteration of the Russian term for a toroidal chamber with magnetic coils (*toroidal'naya kamera v magnitnykh katushkakh*).

16. ITER is a large-scale scientific experiment that aims at demonstrating the technological and scientific feasibility of fusion energy by producing approximately 500 MW of fusion power from an input of 50 MW (Cadarache, France).

17. The acceptance angle is the maximum angle at which incoming sunlight can be captured by a solar collector.

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Further information

This publication was prepared by the IEA to raise awareness of the valuable work that is being carried out by the IEA Technology Collaboration Programmes (TCPs). A selected list of relevant IEA web pages is provided below for easy reference.

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For queries relating to TCPs or energy technology RD&D activities at the IEA please contact tcp.forum[at]iea.org.
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- Improve transparency of international markets through collection and analysis of energy data.
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International Energy Agency
9 rue de la Fédération
75739 Paris Cedex 15, France

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Technology Collaboration Programmes

Highlights and outcomes

Accelerating energy technology innovation is crucial to meet energy and climate goals, to support economic growth and to enhance energy security. Successful development and deployment of innovative energy technologies requires that stakeholders from both the public and private sector share knowledge, work collaboratively and, where appropriate, pool resources to deliver integrated, cost effective solutions to common challenges.

Four decades ago, the founders of the IEA had the foresight to create a multilateral technology collaboration mechanism – the IEA Implementing Agreements (IAs) – that has withstood the test of time and today is more relevant than ever to delivering solutions to global energy challenges. This network of experts produced a range of noteworthy results, including inventions, pilot plants, demonstration projects, databases and development of standards. The year 2015 marked the 40th anniversary of the mechanism as well as the rebranding of the IAs as Technology Collaboration Programmes (TCPs).

This publication provides an overview of the activities and recent accomplishments of TCPs. The 39 TCPs operating today involve about 6 000 experts from government, industry and research organisations in 51 countries around the world. Participants in TCPs have examined more than 1 900 energy-related topics in the areas of energy efficiency, renewable energy, fossil fuels, fusion power and cross-cutting issues.

The unrivalled breadth and coverage of analytical expertise seen in TCPs are unique assets that will underpin for the years to come IEA efforts to support innovation for energy security, economic growth and environmental protection.