Clean energy transitions: Accelerating innovation beyond 2020

Focus on India

International Energy Agency

IEA Discussion Paper

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Executive summary

In recent years, governments have increasingly focused on innovation as a means to accelerate clean energy transitions and meet climate targets under the Paris Agreement. Since 2015, for instance, Mission Innovation (MI) countries have been implementing their pledge to double public research and development (R&D) spending in clean energy over a five-year period. That period comes to an end around 2020.

Despite these efforts, much remains to be done. In many sectors, critical innovation gaps need to be overcome to improve performance and reduce costs of emerging low-carbon technologies. Robust innovation policies and strategic energy technology roadmaps can ensure that increased research, development and demonstration (RD&D) budgets bring about the desired outcomes while contributing to national priorities.

India is making commendable efforts to deliver on its MI doubling goal, and notable success stories have emerged from the national innovation landscape. India's engagement and active participation under MI have been impressive, demonstrating leadership and motivation across more work strands than nearly any other MI country. There is also room for further improvement: technology-specific policy support, further public-private collaboration, and enhanced inter-agency co-ordination remain key to achieve the desired level of ambition.

To complement national efforts, a range of international partnerships can work together with MI. As part of MI discussions around the "Beyond 2020" phase, policy and decision makers should consider focusing on (1) identifying common innovation priorities based on pressing gaps, (2) tracking RD&D indicators including public funding for innovation activities, and sustaining spending levels, (3) sharing successful innovation policy practices, including to leverage corporate capabilities, (4) strengthening collaboration with and across emerging market countries, and (5) enhancing co-ordination with other existing multilateral initiatives such as the Technology Collaboration Programmes (TCPs) by the International Energy Agency (IEA) and the Clean Energy Ministerial (CEM).

Building on a 45-year history of promoting energy technology innovation globally, the IEA seeks to support such stakeholders' efforts. This Discussion Paper draws on recent analysis of the clean energy innovation landscape in India, which is becoming a key actor in the world's energy innovation landscape, as a source of insights about how to successfully engage with emerging market countries. It provides an overview of IEA work on innovation as part of clean energy transitions, tapping into India's experiences and success stories. It also considers aspects relevant to multilateral innovation partnerships and suggests ways forward for policy and decision makers beyond 2020.

Main discussion points

As IEA analysis of energy innovation makes clear, multilateral efforts have a crucial role to play to foster R&D and deployment of clean energy technologies. This paper sets out a number of key issues for consideration to maximise impacts, benefits and effectiveness of international collaboration to accelerate energy innovation. In particular, the paper seeks to inform discussions co-led by India and Canada under MI's Analysis and Joint Research (AJR) group in support of efforts to mobilise the collective knowledge, capabilities and resources across eight technology areas, known as Innovation Challenges, which MI members have identified as critical to clean energy transitions.

The main discussion points of the paper are summarised below.

- **Despite significant efforts since the launch of Mission Innovation, more energy innovation is needed.** The IEA Innovation Gap analysis has mapped around 100 gaps across the energy technology landscape. Which energy technology innovation gaps should MI stakeholders most focus on beyond 2020? Which ideas and cross-cutting technologies hold the highest potential for disruptive innovation in the next decade to 2030? What do we need most from governments, companies and other key stakeholders in order to best take advantage of the innovation opportunities?

- **Tracking energy innovation efforts to inform policy making.** What should be the balance for tracking inputs versus outputs and outcomes in MI? Are there creative ways to better track outputs and outcomes? How can international organisations and others best help governments and companies to provide actionable metrics?

- **A more comprehensive approach to energy innovation policy.** How can MI countries best learn from each other's successes and new ideas for innovation policies and practices? Looking beyond 2020, what can MI stakeholders collectively do to improve the "ease of doing energy innovation"?

- **Learning from the Indian case.** The IEA is carrying out an in-depth review (IDR) of energy policies of India, which incorporates an analysis of the energy R&D landscape and policies. As part of this analysis, many success stories relating to India's energy innovation system have been identified. What lessons can be learned from these experiences?

- **Priorities for energy technology innovation partnerships.** Beyond 2020, what can MI stakeholders do to strengthen multilateral innovation initiatives and to broaden activities to other strategic emerging market players? What can MI stakeholders do to pursue synergies between bilateral and multilateral work, and to identify strategic opportunities for collaboration across existing initiatives?

1. More energy innovation is needed

Discussion questions

- When examining all 45 sectors and technologies in the IEA Tracking Clean Energy Progress site (TCEP), as well as the IEA Innovation Gaps framework, which of the identified technology innovation gaps should Mission Innovation stakeholders most focus on beyond 2020?
- Which ideas and cross-cutting technologies hold the highest potential for disruptive innovation in the next decade to 2030?
- What do we need most from governments, companies and other key stakeholders to best take advantage of the innovation opportunities?

Tracking clean energy progress

To achieve clean energy transitions while simultaneously fulfilling other national policy goals, countries need to develop and deploy a broad range of existing and emerging technologies. Yet, based on implemented and announced policies, globally the energy sector is not on track to meet the climate targets set out in the Paris Agreement, the Sustainable Development Goals, and other international and domestic goals. The IEA Tracking Clean Energy Progress (TCEP) analysis shows that only seven technologies (e.g. solar photovoltaics [PV], bioenergy and electric vehicles) are on track to achieve their contribution to sustainable development (IEA, 2019a). Out of the 45 technologies under study, 19 require more efforts and 13 are not on track.

In most technology areas, including many that are presently on track under TCEP, further RD&D is needed to bridge innovation gaps and to reach energy and climate goals. While policy making often focuses on market uptake, specific attention should be given to innovation, which can enable deployment by improving performance as well as reducing costs.

Identifying pressing technology innovation gaps

The IEA Innovation Gaps framework identifies key long-term technology challenges for RD&D that need to be filled in order to meet long-term clean energy transition goals (IEA, 2019b). The framework highlights around 100 innovation gaps across 45 key technologies and sectors including power, industry, buildings, transport and energy integration, and it lays out the necessary actions to advance innovation in these areas. For instance, transport biofuels require more innovation to scale up production of advanced biofuel such as cellulosic ethanol and biomass-to-liquid (BtL) synthetic fuels. Potential technology solutions are examined, such as gasification or pyrolysis production processes for BtL technologies. In buildings, cooling may be improved by ongoing RD&D activities to develop fully integrated solar PV, solar thermal or liquid desiccant cooling solutions. In the power sector, carbon capture, utilisation and storage (CCUS) technologies may also benefit from the attention of innovation stakeholders. Table 1 aims to provide an overview of pressing RD&D gaps across the energy sector.

In the last decades, significant progress has been made in clean energy innovation. International collaborative partnerships such as Mission Innovation (MI) illustrate these efforts, with countries pledging to double public spending in clean energy RD&D over five years to 2020. The Technology Collaboration Programmes (TCPs) by the IEA have also made significant contributions to global energy innovation, including in low-carbon technologies, by pooling together resources and experts from over 50 countries for the past four decades.

In India, building on the National Action Plan on Climate Change (2008), the government has initiated technology-specific "national missions" to accelerate the development and deployment of clean energy solutions, such as the National Solar Mission (2010), the National Electric Mobility Mission (2012) and the National Smart Grid Mission (2015). More recently, and consistent with its participation in the corresponding MI innovation challenges, India put in place the National Policy on Biofuels (2018) and the Cooling Action Plan (2019), which address RD&D alongside deployment targets.

While important milestones have been set, notably by MI stakeholders, much remains to be done. Many innovation gaps need to be tackled to ensure successful clean energy transitions.

Table 1. Further RD&D efforts are needed to tackle critical innovation gaps globally

Sector	Selected innovation gaps by technology area
Transport	• **Biofuels:** Commercialisation of cellulosic ethanol; development of biomass-to-liquids fuel production from thermochemical processes • **Trucks and buses:** Deploying electric road system (ERS) corridors; improving the cost and performance of lithium-ion batteries; cost-competitive hydrogen fuel cell systems for fuel cell electric vehicles (FCEVs); deploying hydrogen supply infrastructure and fuel cell electric heavy-duty vehicles • **Rail:** Digitalisation of rail: automation, management and control systems; establishing and expanding urban rail networks in existing and future large cities • **Fuel economy of cars and vans:** Lightweighting of light-duty vehicles (LDVs); advanced internal combustion engine technologies • **Aviation:** Shortening flight distances through better routing • **Electric vehicles (EVs):** Allowing EVs to become a flexibility resource for the grid; advancing technologies and reducing battery costs • **Shipping:** Transitioning to low-carbon ammonia or hydrogen fuel
Buildings	• **Building envelope:** Advanced windows; advanced air flow, air sealing and ventilation controls; integrated storage and renewable energy technologies for buildings • **Heat pumps:** Raise heat pump attractiveness; enhance heat pump flexibility; reduce costs of geothermal heat pump technologies • **Cooling:** Research needs into potential for liquid desiccant cooling; reducing the costs of solar thermal cooling; fully integrated solar PV cooling solutions • **Lighting:** Defining and enhancing the quality of light for high-efficacy LED products; ensuring policy makers have the best metrics for regulation; ensuring energy savings through smart lamps and luminaires • **Appliances and equipment:** Development of vacuum-insulated panels and insulating materials for refrigeration; high cost of heat pumps in tumble dryers • **Data centres and networks:** Accelerating energy efficiency of mobile networks; applying artificial intelligence in data centres

Sector	Selected innovation gaps by technology area
Industry	• **Chemicals:** Ammonia production using electrolytic hydrogen; methanol production using electrolytic hydrogen and CO2; producing aromatic compounds from methanol; CCUS applied to the chemical sector • **Iron and steel:** Need for lower carbon steel production processes based on fossil fuels; direct reduction based on hydrogen; CCS applied to commercial iron and steel technologies; using steel works arising gases for chemical and fuel production (CCU) • **Cement:** CCS applied to cement manufacturing; alternative cement constituents; using BCSA clinker as an alternative binding material • **Pulp and paper:** Black liquor gasification; using deep eutectic solvents as low-carbon alternatives to traditional pulping • **Aluminium:** Inert anodes for primary aluminium production; multipolar cells; novel physical designs for anodes • **CCUS in industry and transformation:** CCUS applied to the chemical sector; CCS applied to cement manufacturing
Power and fuel supply	• **Nuclear:** Small modular reactors and advanced reactor demonstration; innovative fuels for nuclear power; coupling reactors with non-electric applications • **Natural gas-fired power:** Flexible operation of gas-fired power plants • **Coal power:** Need for higher combustion temperatures and efficiencies for pulverised coal-fired power plants • **CCUS in power:** Reduce the energy penalty and cost of CCUS capture; demonstrating supercritical CO2 power cycles at scale; CCUS applied to gas-fired power generation at scale • **Other fuel supply:** Mobile gas utilisation technologies for small-scale operations; leak detection and repair (LDAR); monitoring and measuring methane emissions
Renewables	• **Ocean:** Scaling up low cost mechanical concepts and manufacturing for wave energy; exploiting ocean energy through advanced design concepts • **Geothermal:** Development of advanced drilling technologies; expanding geothermal energy use; improving understanding of geothermal resources • **Hydropower:** Innovative hydropower designs; reducing the cost and impact of civil works; modernising hydro plants for the energy transition • **Offshore wind:** Innovation in installation processes for offshore wind plant; tapping deeper offshore wind resources through floating wind turbines; reducing cost and risk of transmission and distribution of electricity from offshore wind • **Onshore wind:** Next generation turbine, power-train and system management technology; advanced contribution of wind power to grid integration; improve resource assessment and spatial planning • **Solar PV:** Maintaining the cost reduction trajectory for solar PV; smarter inverter systems and BOS cost reductions; increased integration of off-grid electrification systems
Integration	• **Storage:** Advanced technologies to reach below the floor costs of current generation Lithium-ion batteries; battery recycling and re-use; low active metal use in batteries • **Hydrogen:** Advanced electrolysis; cost-competitive fuel cell system for FCEVs; novel hydrogen production methods; hydrogen from fossil fuels with CCS • **Demand response:** Smarter monitoring and control mechanisms, including artifical intelligence; regulatory innovation to enable aggregation and nodal control; distributed trading platforms • **Smart grids:** Distributed energy resource control platforms; more flexible high-voltage transmission; cost-effective deployment of Internet of Things devices

Source: IEA (2019b), *Innovation Gaps*, www.iea.org/topics/innovation/innovationgaps/.

2. Tracking energy innovation efforts to inform policy making

Discussion questions

- What should be the balance for tracking inputs (e.g. funding for clean energy RD&D) versus outputs and outcomes in Mission Innovation?
- Are there creative ways to better track outputs and outcomes? How can international organisations best help governments and companies to provide actionable metrics?
- Is there a correlation between the increasing "maturity" of certain climate change mitigation technologies (e.g. solar and wind) and lower propensity to patent?

Public spending in energy RD&D activities

As governments increasingly focus on innovation as part of clean energy transitions, tracking and monitoring key RD&D indicators can inform policy making and help decision makers identify challenges and priorities. Reliable data collection is therefore critical.

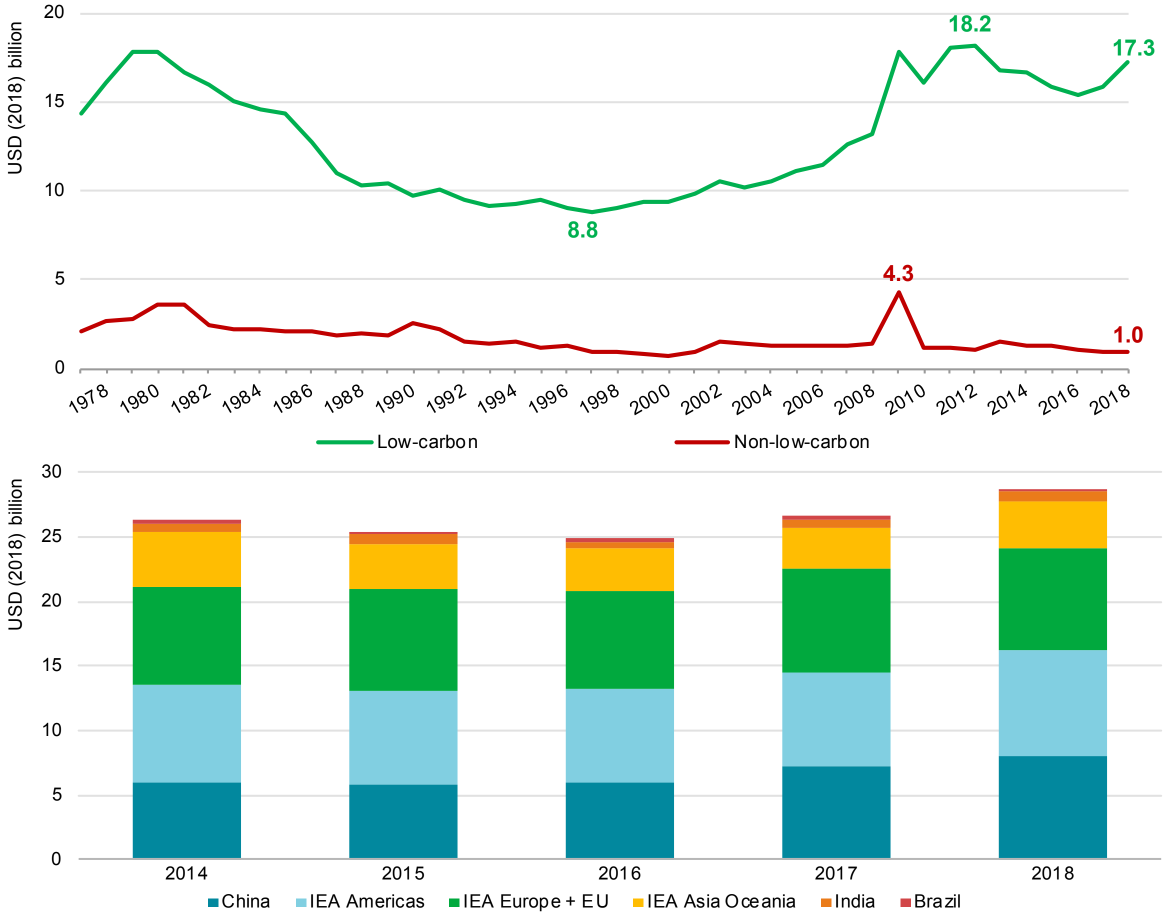
In 2018, IEA member countries spent USD 17.3 billion[1] on low-carbon[2] energy RD&D, consolidating the 2017 increase after years of decline. This effort was led by countries including the United States, Canada, Japan, France and Germany (IEA, 2018a; IEA, 2019c). Simultaneously, other energy technology spending remained flat in 2018 after the 2017 decrease, at about USD 1 billion (see Figure 1). Globally, the IEA estimates that public spending in energy RD&D reached about USD 28.7 billion in 2018, of which USD 23.2 billion was spent on low-carbon technologies.

Collecting reliable data on energy RD&D spending can be challenging in many countries. Ongoing IEA co-operation with India includes a focus on enhancing RD&D data collection and classification. As reported under MI, it is estimated that India's total central government funding for clean energy RD&D in 2017-18 was USD 110.6 million. Available data suggest a growth trajectory consistent with the five-year doubling target set in 2015. In 2018, the IEA estimated India's total government spending for energy RD&D at USD 652.8 million across nearly a dozen ministries (see Annex 1).

[1] Throughout the paper, spending levels are in USD (2018), market exchange rate basis.

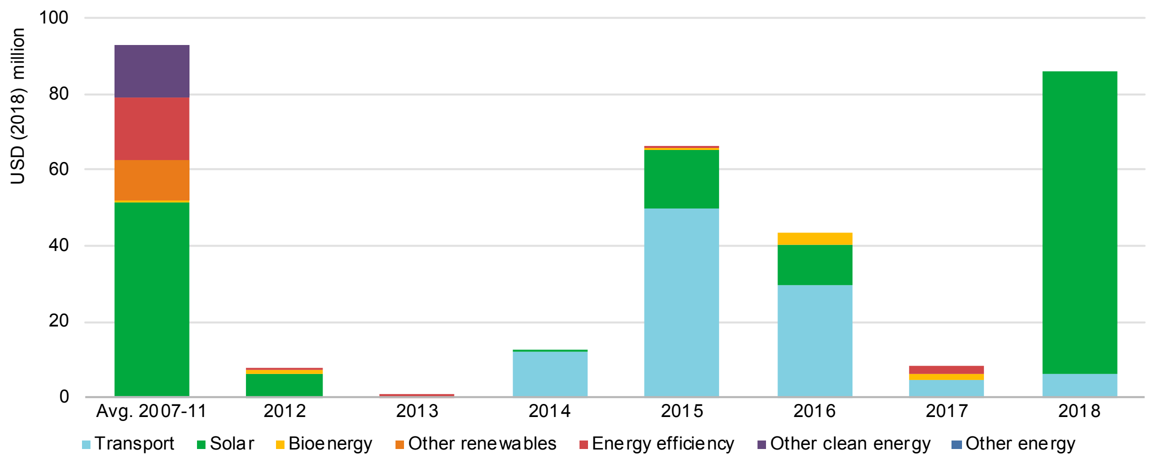
[2] In the IEA RD&D categorisation (IEA, 2018; IEA, 2019c), low-carbon energy technologies are defined as: energy efficiency; carbon capture and storage; renewable energy sources; nuclear; hydrogen and fuel cells; other power and storage; and other cross-cutting technologies and research. Non-low-carbon energy technologies represent coal, gas, oil and other fossil fuels.

Figure 1. Evolution of energy RD&D public spending in IEA member countries (above) and globally, by region or country (below)



Note: China = People's Republic of China.
Source: IEA (2019b), *Innovation Gaps*, www.iea.org/topics/innovation/innovationgaps/.

Figure 2. Early-stage VC in energy technology reaches new high in India



Note: Growth equity and late-stage deals are not included.
Source: IEA (forthcoming), *Energy Policies Beyond IEA Countries: India 2020*. Analysis based on Cleantech Group i3 database (2018).

Corporate spending in energy RD&D activities

Government institutions are not the sole actors in energy technology innovation. The private sector plays an important role in ensuring that key technologies reach markets. Tracking corporate activities and investments can help policy makers understand the broader innovation ecosystem, engage with industry, and strategically allocate public investments in technology areas that remain underfunded due to high risks and costs. While corporate R&D spending tends to be allocated to incremental technology improvements and is often oriented towards product development as much as to technological advances, in total it amounts to more capital for energy R&D than that received from the public sector.

Global reported corporate R&D spending on low-carbon energy technology is estimated to have grown by 5% to about USD 65 billion in 2018. A major factor in recent years has been increasing R&D spending in transport and renewables, as well as greater focus on electricity storage, smart electricity systems and energy efficiency (IEA, 2018b; IEA, 2019d).

The IEA has identified USD 418 million of R&D spending reported publicly by Indian companies active in energy technologies in 2018. Further, Indian automakers spent around USD 900 million on R&D, a significant share of which was directed to more efficient and alternative fuel vehicle technologies.

Venture capital deals in energy technologies

Early-stage (i.e. seed, series A and B) venture capital (VC) investments indicate the technology areas in which the private sector invests most when it comes to new start-up companies. In India, VC activity remains limited, with only a handful of highly relevant clean energy deals each year, mostly in the range of USD 1 to 2 million. However, the number and volumes of deals are rising. More early-stage VC activity was seen for India-based start-ups in 2018 than since the 2012 "clean technology bust" (see Figure 2).

Most early-stage VC investments in India in 2018 were in solar technologies, and some were in alternative fuels in transports such as for electric vehicles, providing evidence that investors are bullish about the policy and market environment for these technologies in the medium term. Conversely, the start-up community is not as active in bioenergy technologies, an area in which policy efforts to stimulate the industry have been increasing but have not yet delivered successful new companies with VC funding.

Relevant VC deals in 2018-19 include: Ecozen Solutions (solar irrigation); Cygni Energy (solar systems); ZunRoof (solar services); Fourth Partner Energy (solar products); Tork Motorcycles (EV bike); ION Energy (storage); Swadha Energies (efficient HVAC); and ProKlean technologies (bioenergy, 2017). Growth equity and late-stage deals include: Punjab Renewables (bioenergy); CleanMax solar (solar products and services); and Husk Power Systems (rural utility).

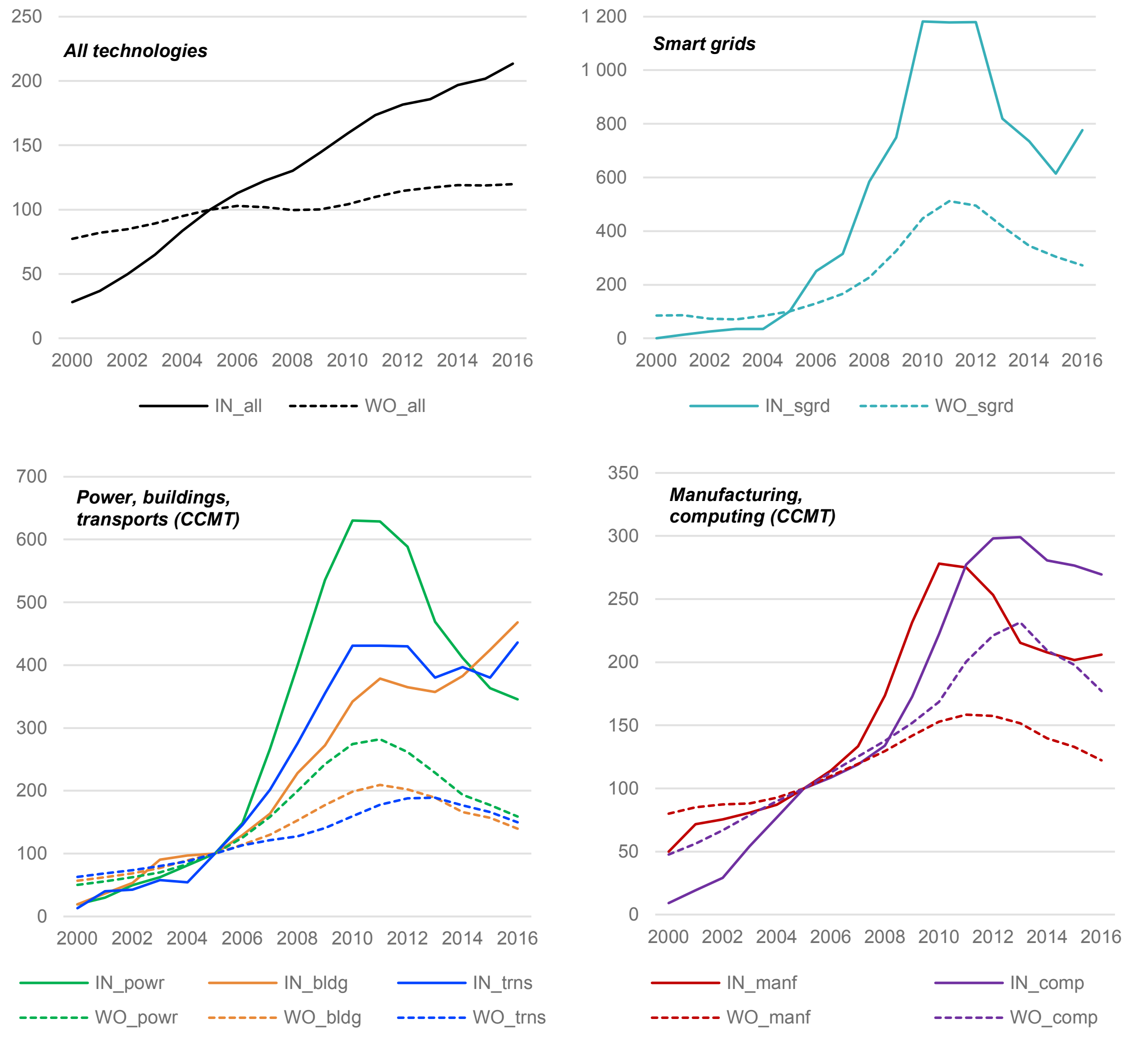
Patents in climate change mitigation technologies

Patent documents can be a useful indicator of different countries' capacity to generate knowledge and useful inventions in different fields. Countries with successful innovation systems tend to feature dynamic patenting activity. While there can be considerable variation in the value of different patented inventions, the figures presented below relate to inventions that have been protected at a minimum of two offices, a threshold that only higher-value patents usually exceed.

Trends in patenting can be useful information for policy makers, providing leading indicators of market developments in the different energy technology areas that they aim to support.

According to recent IEA analysis, global high-value patenting in climate change mitigation technologies (CCMTs) has decreased in recent years (IEA, 2019e). No similar drop-off was observed in patenting in general, nor in other fields such as health, engineering, and information and communication technologies. Although inventors residing in India are only responsible for approximately one percent of global CCMT inventions, Indian patenting in CCMTs has significantly increased in the last decade and at a much faster pace than in other technology fields in India or than global trends in CCMTs (see Figure 3).

Figure 3. Indian patenting in CCMTs increases at a much faster pace than in other technology fields in the country and than global trends in CCMTs (2000-16)



Notes: Index (2005 = 100 for all curves) of three-year moving average of high-value patents (claimed priorities) in India and the world.

Abbreviations: CCMT = climate change mitigation technology, IN = India, WO = world, all = all technologies, comp = CCMT computing, sgrd = smart grids, manf = CCMT manufacturing, powr = CCMT power, bldg = CCMT buildings, trns = CCMT transports.

Sources: Patent extractions from EPO World Patent Statistical Database (PATSTAT) by OECD/ENV and IEA/EDC (2019).

Between 2005 and 2016, Indian patenting across all technology fields (i.e. technologies not limited to CCMTs) grew steadily and, by 2016, had doubled. Over the same period, Indian patenting in CCMTs related to smart grids, power, transport and buildings more than tripled, while CCMTs in manufacturing and computing doubled.

Between 2005 and 2016, Indian patenting in smart grids increased by eight times, with very high growth rates between 2005 and 2010, while global patenting in smart grids did not achieve a tripling. Indian patenting more than tripled in the CCMTs in the power sector and roughly quadrupled in CCMTs related to transport and buildings despite a slowdown between 2010 and 2012, while global patenting in these three sectors did not double over the same period. In CCMTs related to manufacturing, Indian patenting doubled between 2005 and 2016, and nearly tripled for computing.

These findings warrant further analysis to better understand global trends as well as the specific drivers of Indian patenting growth, including the possible interplay with recent developments in information and computer technologies associated with the digitalisation of the energy sector.

3. A more comprehensive approach to energy technology innovation policy

Discussion questions

- How can MI countries best learn from each other's successes and new ideas for innovation policies and practices? Looking beyond 2020, what can MI stakeholders collectively do to improve the "ease of doing energy innovation"?
- In recent years, many success stories have emerged relating to India's energy technology research and innovation system. Solutions often termed as "frugal innovation" have also been developed, which were not sustained by massive investments but rather propelled by ingenuous applications at scale of simple and inexpensive energy and information and communications technologies. What lessons can be learned from these experiences?

What are energy innovation systems?

Technology innovation processes are complex, and it can be challenging for decision makers to take a holistic approach to energy innovation. As energy technologies iteratively move through the successive stages of innovation, their development may be accelerated or hindered by various feedback loops and external factors, such as policy action, changes in macro-economic or market fundamentals, regional specificities, and breakthroughs that "spill over" from other engineering fields.

While public spending on RD&D is an important indicator of a country's innovation capacity, many other components underpin successful innovation systems. Policy makers may benefit from taking a more comprehensive approach to energy innovation, for instance, based on four core functions: (1) resource push, (2) knowledge management, (3) market pull, and (4) socio-political support (see Table 2).

Successful energy innovation ecosystems cover all four bases, whether internationally for a given technology (e.g. the development of solar PV technologies across different countries and over time), or nationally for a range of technologies.

Table 2. A more comprehensive approach to energy technology innovation, based on four core functions

Core function	Description (e.g. key considerations, indicators, possible policy instruments)
Resource Push	• Technology innovation requires a **sustained flow of RD&D funding**. Given the high risks of early-stage technology development, governments play an important role in strategically investing these resources, based on national priorities and financing gaps. Tracking public and corporate funding for RD&D activities can help identify funding priorities. • Successful RD&D projects are driven by a **skilled workforce** (e.g. researchers, engineers). A variety of indicators may inform policy making, such as the number and quality of research and academic institutions, of graduates, of R&D support staff; number of highly sighted researchers. • To guide the search, decision makers need to **identify gaps and priorities**, and may lay out a national energy RD&D strategy or roadmaps for individual technology areas.
Knowledge Management	• New products and processes usually combine novel and existing ideas that have been **generated** by researchers and **codified** by knowledge management institutions to make them accessible and attributable. This process may be tracked thanks to publication and patenting statistics. • The effectiveness of innovation relies on **strong networks** for knowledge exchange between research teams, academia, industry, policy makers, and international partners. Promoting co-ordination and collaboration between these actors can maximise knowledge spillovers from a range of other relevant fields to the energy sector.
Market Pull	• To enable the entry of new products into markets, policy makers need to **align incentives** through the innovation value chain and provide market signals that the new technology can be profitable if successful, thereby fostering the overall "ease of doing innovation" environment. Policy instruments may include tax incentives, public procurement, or financial incentives that complement capital grants (*resource push*) to enable demonstration projects. • Among the most powerful tools for stimulating innovation that are available to policy makers are **performance-based market instruments** that value the attributes of the new technology, such as carbon pricing, public procurement rules or standards. Often, these have clearly scheduled timetables for introduction or strengthening, to provide a lead time to innovators.
Socio-political Support	• In many cases, successful innovation requires **domestic support from citizens** or, at a minimum, no effective opposition. The enthusiasm or approval of consumers will determine the uptake of end-use technologies. Likewise, the actions of vocal groups of opponents can derail a new technology at the final stage of market introduction. Inclusive processes (e.g. by seeking feedback from citizens and advocacy groups) that ensure robust governance and promote transparency can help identify concerns at an early stage and smooth the innovation phases. • Policy makers need to be aware of the perspectives of **industry stakeholders** (e.g. by consulting industry associations) to help ensure that private-sector efforts can be aligned with national policy goals. Technologies with strong political advocates will stand a better chance in the later stages of the innovation process, all other things being equal. • **Multilateral co-operation in international fora** is an increasingly important part of strategies to accelerate energy innovation, such as high-level international political commitments providing legitimacy to national efforts, as illustrated by Mission Innovation.

Learning from the Indian case

In India, the Cooling Action Plan (2019), which aims to achieve "sustainable cooling and thermal comfort for all while securing environmental and socio-economic benefits" (Ministry of Environment, Forest and Climate Change, 2019a), illustrates how decision makers aspire to put some of these core functions of energy innovation systems in operation.

Firstly, the plan identifies key technology innovation gaps, while also taking into account "Make in India" considerations to align the plan with broader national priorities. For instance, acknowledging that many refrigerants with low global warming potential (GWP) are "heavily patented by multinational companies", the plan seeks to develop domestically cost effective low-GWP alternative technologies to hydrofluorocarbons (Ministry of Environment, Forest and Climate Change, 2019b). The plan determines that further innovation related to natural refrigerants (e.g. hydrocarbons, carbon dixiode, ammonia) is needed, notably to ensure safety standards are met for emerging technologies. Other innovation priorities mentioned in the plan include: manufacturing and design of refrigeration and air conditioning equipment to improve component efficiency (e.g. compressors, fans, heat exchangers, expansion valves); advanced building design and materials; district cooling using low-grade energy from thermal power plants and waste heat; basic molecule research for novel refrigerants; etc. For each identified priority, the plan proposes a plan of R&D activities in the short, medium, and long term.

Secondly, designing the plan required inputs from multiple stakeholders, including several public bodies, industry, think tanks, academia and R&D institutions, which foster socio-political support and strengthen innovation networks. The plan acknowledges that diverse expertise is readily available in various Indian R&D institutions and that these capabilities need to be linked to maximise knowledge exchange. To pursue these synergies and co-ordinate national innovation efforts, the plan recommends instituting a "steering committee" with broad representation from public and private players. This committee would first develop a detailed "cooling R&D roadmap" building on the plan's preliminary recommendations and, thereafter, lead its implementation under a public-private R&D consortium model. The plan also considers setting up a public R&D centre open to all stakeholders to foster collaboration among stakeholders, including private companies, and recommends consolidating innovation activities in the long term under a dedicated "Centre of Excellence for Cooling technologies".

Thirdly, the plan provides funding opportunities at different stages of technology development. In 2018, India launched the Mission Innovation-backed Global Cooling Prize, an impact-oriented innovation programme offering USD 3 million for technology solutions that have at least five times less climate impact than current room air conditioners. About 140 teams from 31 countries submitted ideas for the prize; ten finalists will develop prototypes with financing of USD 200 000 in 2020; and the winning cooling technology will be awarded USD 1 million by the end of 2020. In addition, the plan aims to provide access to testing and application centres, possibly in collaboration with industry when physical infrastructure is lacking, where R&D teams can conduct demonstration projects of emerging refrigerant technologies.

Overall, the Cooling Action Plan combines a resource and policy push including RD&D funding; impact-oriented market levers for entrepreneurs such as prototyping and demonstration budgets; and an inclusive process to foster socio-political support. As a result, the plan aspires to provide incentives for a wider range of technology developers to innovate than budget-constrained RD&D funding alone.

Two additional examples drawn from the Indian case are provided below. Box 1 gives an example that indicates that clearly identified technology gaps, targeted public RD&D funding, and support for product deployment at scale can stimulate innovation and contribute to achieving policy goals such as clean energy access in rural areas. Box 2 describes successful innovation from a state-owned enterprise to develop advanced biofuels, in which a government programme leverages corporate RD&D capabilities to increase resource push, accelerate market pull, promote public-private networks and ensure industry buy-in.

Box 1. Public RD&D funding supports "Mission Innovation Champions" and fosters clean energy access in rural India

Despite substantial improvements in electrification, many Indians rely on kerosene lamps or diesel generators, facing indoors pollution and fuel expenses. Innovation helps finding local solutions and shifting to cleaner energy sources, thereby contributing to national policy goals.

The Micro Solar Dome (MSD) is a low-cost, hybrid solar lighting device developed in 2016 by a Kolkata-based team from the NB Institute of Rural Technology (NBIRT). It concentrates daylight collected from a rooftop dome to an indoors ceiling dome. In addition to light, it provides heat in cold regions. Four versions have been developed, including a device paired with two solar panels, a battery and LEDs for night lighting, and USB charging. Production costs below INR 1 800 (USD 25) allow a payback in less than three months. The MSD innovation team was recognised as International Mission Innovation Champion in 2019.

Starting in 2015, the Department of Science and Technology (DST), among India's largest public sector clean energy funding bodies, supported the development of the MSD via long-term core support grants to the NBIRT. Under its Core Support Programmes, the Science for Equity, Empowerment, and Development (SEED) Division funds scientific initiatives to develop technology solutions for rural areas. "Energy, lighting, and fuel" is one of SEED's eight technology focus areas. Over 30 innovations have been developed, including devices for more energy efficient agriculture, clean cooking, and biomass use.

Approximately 4 000 MSDs have been installed experimentally, with promising results. Individuals report better quality of life, wealth-creation opportunities and easier education. In 2016, DST had set ambition to deploy 10 million MSDs and as of 2019, it considers the technology ready for commercialisation. NBIRT is training locals to manufacture and install the devices. An inter-ministerial deployment plan is being crafted, building on past successes such as the UJALA programme, which distributed nearly 350 million LEDs across India in the last decade.

Source: IEA (forthcoming), *Energy Policies Beyond IEA Countries: India 2020*.

Box 2. Energy innovation in Indian state-owned enterprises: advanced biofuels

Among emerging economies, India is a leader in seeking to use international collaboration to accelerate bioenergy innovation. India is a co-leader of Mission Innovation's Innovation Challenge #4 on Sustainable Biofuels, it is part of the Biofuture Platform's strategic leadership, and it is a member of the IEA Bioenergy TCP.

Developing sustainable biofuels is aligned with India's broader national policy goals. In 2018, the government updated its National Policy on Biofuels to reduce oil imports, foster rural development, and bring environmental benefits. It reaffirmed the need for bioenergy research such as the development of advanced biofuels from non-food crop feedstock. The Department of Biotechnology (DBT) and the Ministry of Petroleum and Natural Gas (MoPNG) co-ordinate RD&D initiatives such as the DBT-Indian Oil Corporation (IOC) Advanced Bioenergy Research Centre near New Delhi.

IOC is a vertically-integrated petroleum public sector undertaking (PSU) under MoPNG, among the country's largest and most profitable corporations. Since 2012, the DBT-IOC Centre conducts research on lignocellulosic ethanol (a biofuel produced from non-food crop biomass, such as residues from cotton, wheat, rice or sugarcane), on issues related to pre-treatment, integration and scale-up. In 2013, a 250-kg/day cellulosic ethanol pilot plant was built with support from the U.S. National Renewable Energy Laboratory. The DBT-IOC Centre designed new enzyme production processes for biofuels development, achieving cost savings up to 50%. The Centre also discovered the so-called Simultaneous Saccharification and Co-Fermentation (SSCF) technique, which reduces process time.

The DBT-IOC Centre recently began the construction of a 10-ton/day biofuel production facility, co-located with IOC's Mathura Refinery. The INR 1.10 billion (USD 16 million) project is expected to start operations by the end of 2019, a final demonstration step before commercial scale production. IOC and other petroleum state-owned enterprises are also building twelve biorefineries using agricultural residue and municipal solid waste, for INR 100 billion (USD 1.5 billion). In 2018, Bharat Petroleum launched the construction of a rice straw feedstock-based biorefinery in Odisha, with operations to start by December 2020.

The DBT-IOC Centre is one of five DBT joint Centres of Excellence specialising in biorefinery. The five centres mobilise a significant portion of the overall public investments in biofuels research. While the other centres are managed for DBT by an academic or non-profit organisation, the DBT-IOC Centre is co-funded equally by both entities. In addition, researchers have access to IOC's engineering facilities and broader RD&D capabilities.

Source: IEA (forthcoming), *Energy Policies Beyond IEA Countries: India 2020*.

4. Priorities for energy innovation partnerships beyond 2020

Discussion questions

- What can Mission Innovation stakeholders do to consolidate existing innovation multilateral initiatives, and broaden activities to other strategic emerging market players?
- What are the main opportunities and barriers relating to further interaction across multilateral initiatives? What can Mission Innovation stakeholders do to strengthen linkages and identify strategic opportunities for collaboration across existing multilateral initiatives?
- How can various organisations and stakeholders best help countries to collaborate more efficiently and effectively?

Enhanced engagement with emerging markets

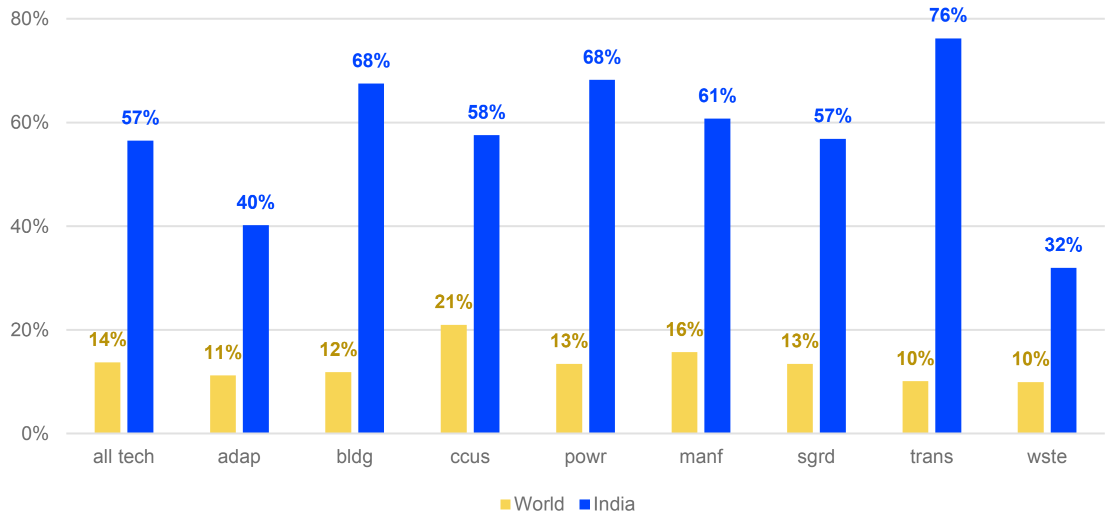
India is an example of a country that is actively seeking to use international co-operation to complement and enhance its national energy innovation system.

In addition to its leadership role under Mission Innovation, India participates in 11 TCPs (see Annex 2) covering a broad range of technology areas including renewables, transport and hydrogen. India is also a member of the Biofuture Platform, and hosts the International Solar Alliance until 2021. Strong bilateral relations have been developed, such as with the United States (e.g. Indo-U.S. Joint Clean Energy Research and Development Centre in smart grids and energy storage), the United Kingdom (e.g. Joint UK-India Clean Energy Centre), the European Union and a number of its member countries. Box 3 illustrates Indian efforts to attract international entrepreneurs under Mission Innovation.

The impacts of such international co-operation show up clearly in data, such as patenting trends. Co-patenting data reveal that, even though inventors residing in India are only responsible for approximately one percent of global CCMT inventions, they are significantly more likely to co-operate with foreign inventors, relative to those from other countries, according to IEA analysis (see Figure 4). Tracking these types of quantitative indicators can help to inform policy and decision making.

In CCMTs related to transport, for instance, 76% of Indian patent applications are done jointly with an inventor residing in another country, while this holds true for only 10% of global applications in the sector. Overall, the sectoral rates of co-invention in India rank among the highest globally, such as in CCMTs in the power sector and buildings (68% in India, relative to 13% and 12% for global applications in these sectors, respectively), in manufacturing (61% relative to 16%), CCUS (58% relative to 21%) and smart grids (57% relative to 13%). These high co-invention rates in CCMTs follow broader co-invention trends in India: among all Indian technology patent applications, 57% are filed with a third country inventor – only 14% for global inventors. Research co-operation in CCMTs with inventors based in the United States appears to be particularly common (see Table 3), having risen markedly in recent years (IEA, 2019e).

Figure 4. Inventors of CCMTs residing in India tend to co-invent with a foreign partner more often than the average inventor



Note: Percentage of joint applications by country of residence of inventors relative to total domestic applications, applying fractional counts. Disclaimer: intra-firm co-invention is not controlled for.

Abbreviations: tech = technologies; adap = adaptation; bldg = buildings; ccus = carbon capture, utilisation and storage; powr = power; manf = manufacturing; sgrd = smart grids; trans = transports; wste = waste.

Source: Patent extractions from EPO World Patent Statistical Database (PATSTAT) by OECD/ENV and IEA/EDC (2019).

Table 3. Co-invention of CCMTs involving India and the United States is particularly common across several energy sectors

Buildings	CCUS	Computing	Power	Manufacturing	Smart Grids	Transport	Waste
CHN-USA	FRA-USA	**IND-USA**	CHN-USA	DEU-USA	CAN-USA	DEU-USA	CHN-USA
CHN-TWN	GBR-USA	CHN-USA	DEU-USA	CHN-USA	**IND-USA**	**IND-USA**	CAN-USA
CAN-USA	**IND-USA**	CAN-USA	**IND-USA**	**IND-USA**	FRA-USA	AUT-DEU	KOR-USA
IND-USA	DEU-USA	ISR-USA	KOR-USA	CAN-USA	DEU-USA	DEU-NLD	**IND-USA**
TWN-USA	JPN-USA	GBR-USA	CAN-USA	GBR-USA	CHN-USA	CHN-USA	JPN-KOR
DEU-USA	DEU-FRA	KOR-USA	GBR-USA	KOR-USA	KOR-USA	DEU-FRA	AUT-DEU
GBR-USA	FRA-GBR	DEU-USA	CHE-DEU	FRA-USA	CHE-USA	CHE-DEU	ITA-USA
AUT-DEU	**IND-KOR**	FRA-USA	DEU-FRA	CHN-TWN	DEU-FRA	BEL-DEU	CHN-KOR
KOR-USA	CHN-FRA	CHN-TWN	FRA-USA	DEU-FRA	JPN-USA	DEU-GBR	FRA-GBR
CHN-KOR	CHN-DEU	CHN-KOR	CHN-TWN	CHE-DEU	CHE-DEU	ITA-USA	DEU-USA

Notes: Rank of top ten country-pairs in terms of counts of joint applications by country of residence of inventors, applying fractional counts. Abbreviations: section at the end of the report. Disclaimer: intra-firm co-invention is not controlled for.
Source: Patent extractions from EPO World Patent Statistical Database (PATSTAT) by OECD/ENV and IEA/EDC (2019).

Rapid and sustainable transformation in the energy sector is particularly important in developing countries, as projections suggest that these will significantly shape the future of the global energy landscape. In recent years, the IEA has been strengthening its focus on key emerging market countries including India as part of the Clean Energy Transitions Programme (CETP).

Under the CETP, the IEA seeks to foster international engagement with emerging economies on energy innovation, such as through TCPs or co-operation with Mission Innovation. Partnering with other countries bilaterally or through multilateral initiatives facilitates technology transfer, the adoption and adaptation of existing foreign technologies, the development of broad scientific networks and dissemination of domestic RD&D output, and may attract foreign direct investments in RD&D activities.

There are many opportunities for more collaboration between all countries, and with and between emerging economies in particular. Existing collaborative partnerships tend to seek further engagement with developing economies, including with India. According to a recent survey under the IEA TCP mechanism (see Annex 2), India is regarded by TCP leaders a top priority country for further engagement in addition to the 11 collaborations currently active (see Figure 5). If prospective participation in 14 additional TCPs materialised, India would join a group of "top-collaborator" countries that each participate in over 20 TCPs, MI and the CEM.

Box 3. India opens public-private Clean Energy International Incubation Centre to all Mission Innovation stakeholders near New Delhi

In 2018, the Department of Biotechnology (DBT) and its state-owned Biotechnology Industry Research Assistance Council partnered with Tata Trusts to establish a Clean Energy International Incubation Centre (CEIIC) near New Delhi. It offers lab-to-market incubation support for clean energy entrepreneurs from all MI countries.

With a total initial investment of about USD 5 million, the incubator promotes innovation in clean energy by providing facilities and infrastructure, training and mentorship, shared consultancy services, intellectual property-related services, live test beds, seed support, exchange programmes and collaborations, and market linkages to innovators across the MI countries to test their technologies in local markets. The centre may also support end-use deployment of successful innovations.

To date, selected start-ups have been working on "EV charging equipment and charging station, solar powered efficient machine for agriculture, biomass conversion equipment, innovative battery technologies, smart meters and data analytics platform, zero-emissions turbine-based energy storage and power generation engine" (Tata Trusts, 2019).

Source: Department of Biotechnology, India; Tata Trusts (2019).

Strengthening synergies between existing partnerships

International collaboration is one of the key channels countries use to complement national energy technology innovation efforts. Global partnerships such as the TCP by IEA, MI, the CEM or initiatives under the United Nations illustrate efforts to find solutions to pressing common challenges. There are also numerous regional partnerships bringing valuable contributions to energy technology innovation in Africa, the Arab region, Asia-Pacific, Europe and Latin America. Partnerships such as the Biofuture Platform also promote energy innovation collaboration in specific technology areas. In the case of India, there is considerable evidence of research collaboration between domestic inventors and inventors residing in other countries, and particularly countries at the technology frontier (see Figure 4).

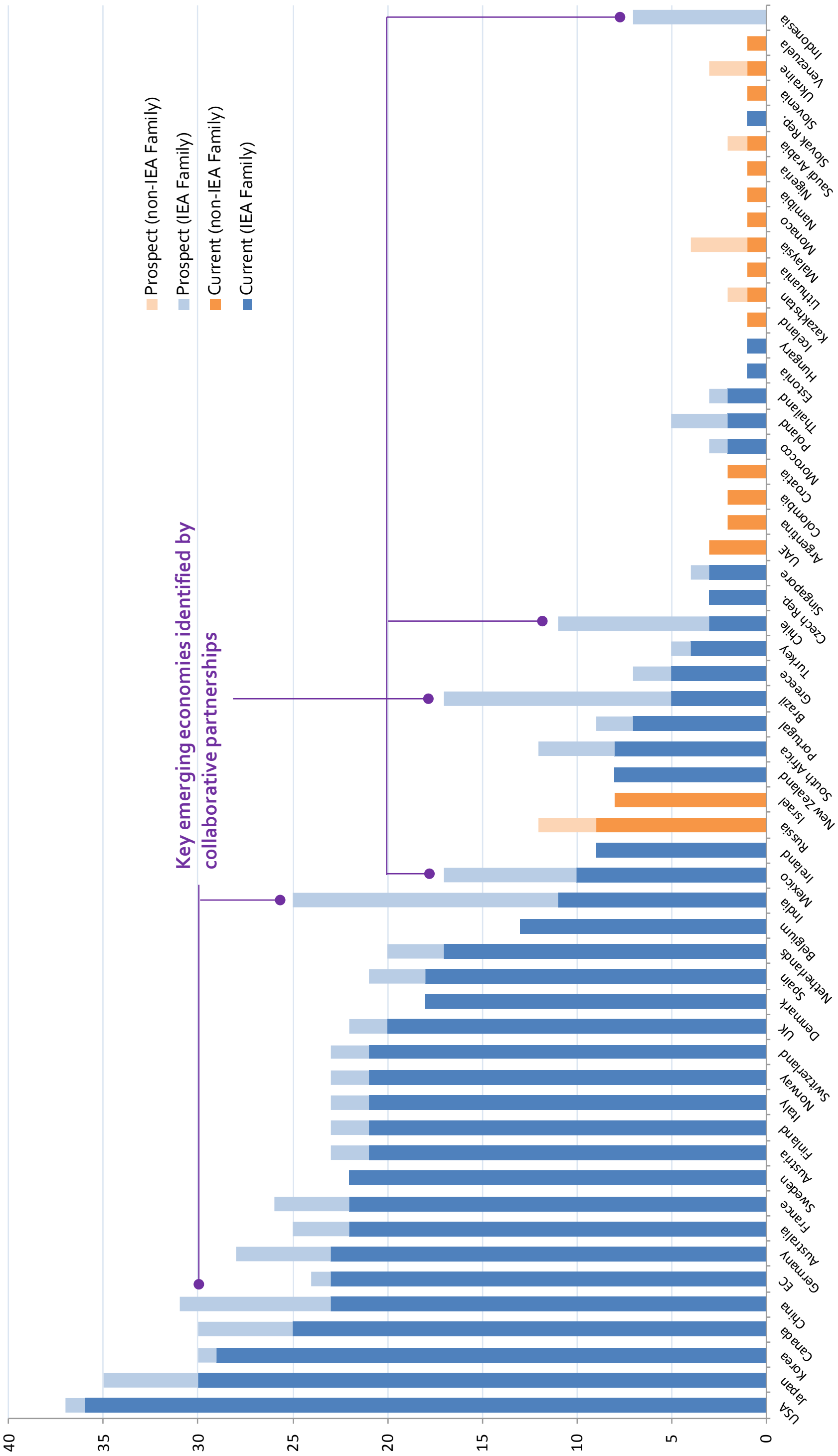
Given the growing number of collaborations, the landscape of multilateral initiatives relevant to energy technology innovation has become more and more complex in recent years. In some cases, notably in emerging economies, it can be challenging for decision and policy makers to identify and prioritise engagement opportunities.

Recent IEA analysis shows that there is at least some degree of overlap in membership, technology focus and activities across different collaborative partnerships (IEA, 2019f). Regarding membership, for instance, all MI countries participate in the TCP mechanism, which calls for greater interaction between MI Innovation Challenges and the relevant TCPs. Examining the TCPs, MI Innovation Challenges, CEM initiatives and the European Technology and Innovation Platforms reveals substantial overlap between technology focus areas. In eight instances, three or four of these mechanisms conduct work on the same technologies: CCUS, smart grids, solar, heating and cooling, nuclear, bioenergy, wind, and hydrogen. The overlap increases when including other collaborative partnerships that are technology specific such as the Biofuture Platform or the International Partnership for Hydrogen and Fuel Cells in the Economy. Furthermore, activities in different partnerships appear to be of similar types, such as stakeholder dialogue, analyses and reports, and capacity building – with fewer activities involving the direct execution of energy technology RD&D.

While there is a growing number of working-level interactions between multilateral initiatives, there is no streamlined co-ordination of innovation activities. As a result, overlaps may induce risks of duplication, the dilution of policy makers' attention, and fundraising and political support challenges. The IEA analysis brings forward the view that strong synergies can be pursued across initiatives that share similar goals (IEA, 2019g). Existing partnerships would benefit from more in-depth and regular mapping of ongoing initiatives in order to identify areas for potential cross-mechanism collaboration. As a starting point, they may explore co-location opportunities for conferences and meetings, as well as co-branding for relevant innovation activities.

Enhancing co-ordination between existing partnerships can increase the synergies and the impact of individual innovation efforts, and encourage entities to focus carefully on their own value added. In addition to developing synergies and seeking efficiencies, in the near term a focus on consolidation of and support for existing entities ought to be considered ahead of proposing the creation of new initiatives.

Figure 5. Current and prospective engagement of the IEA family under the IEA Technology Collaboration Programme



Note: "IEA family" comprises member, association, and accession countries. China = People's Republic of China; EC = European Commission; UAE = United Arab Emirates; UK = United Kingdom; USA = United States of America; Russia = Russian Federation. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: IEA (2019g), Commentary: Three priorities for energy technology innovation partnerships, www.iea.org/newsroom/news/2019/august/three-priorities-for-energy-technology-innovation-partnerships.html

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Annexes

Annex 1. India's public sector institutional landscape for energy RD&D

Institution	Description of key activities relevant to energy RD&D
Ministry of Science and Technology (MST)	MST is the umbrella government body for public sector science and technology rules, regulations, policy, and research support in India.
Department of Science and Technology (DST)	• DST is the country's nodal department for organising, co-ordinating and promoting innovation activities. Research proposals are solicited under annual calls. • DST's Technology Missions Division (TMD) runs a Clean Energy Research Initiative (CERI) since 2009, funding research initiatives in solar energy, energy storage, coal, CCUS, building energy efficiency, smart grids and energy systems, hydrogen and fuel cells, among others.
Department of Biotechnology (DBT)	• DBT supports RD&D in bioenergy and advanced biofuels. In accordance with the National Biofuel Policy, DBT oversees five Centres of Excellence providing long-term support to scientists, academia, research institutes and PSUs. • DBT also issues competitive calls for extramural RD&D (over 150 projects presently supported), awards prizes (e.g. "National Champions" innovation grants), sponsors capacity building, fellowships and international exchange programmes for Indian researchers. It has established the Biotechnology Industry Research Assistance Council (BIRAC), a PSU promoting innovation for start-ups and SMEs, notably through the new Clean Energy International Incubation Centre (CEIIC). • DBT also oversees an "MI Unit" to co-ordinate national efforts in clean energy for Mission Innovation. The MI Unit also co-funds research activities linked to the three MI Innovation Challenges for which India is a co-lead.
Department of Scientific and Industrial Research (DSIR)	• DSIR promotes industrial RD&D in India and hosts the Council of Scientific and Industrial Research (CSIR), a network of nearly 40 government laboratories. • Two CSIR labs, the Central Institute of Mining and Fuel Research, and the Indian Institute of Petroleum, specifically focus on energy. Over 15 others pursue some energy RD&D, mostly in fossil fuels use efficiency and renewable energy sources.
Department of Atomic Energy (DAE)	• DAE funds nuclear power RD&D, supported by the advisory Board of Research in Nuclear Sciences. DAE oversees two research centres, the Bhabha Atomic Research Centre and the Indira Gandhi Centre for Atomic Research, with RD&D topics including advanced reactors, waste management, fuels and materials. • DAE also grants financial support to extramural RD&D including basic and applied physics; materials, engineering and metallurgical sciences; systems design; reactor and repository design; chemical and process engineering; etc.

Institution	Description of key activities relevant to energy RD&D
Ministry of Coal (MoC)	• MoC's PSU Coal India Limited (CIL) co-ordinates coal-related RD&D through its Central Mine Planning and Design Institute (CMPDI). RD&D focuses on exploration, production, safety, and environmental impacts. Other ministries, such as MST and MoP, focus on mitigating the impacts of coal use (e.g. efficiency, carbon capture). • Recent RD&D performers include the CMPDI itself, CIL coal producing subsidiaries, Indian academic institutions, but also a number of Australian government and academic institutions, and in a small number of cases, Indian private sector industrial partners.
Ministry of Earth Sciences (MoES)	• MoES leads science and technology for ocean resources. It engages with industry, academia and other research organisations to perform RD&D via its laboratory, the National Institute for Ocean Technology (NIOT). • The Ocean Energy and Fresh Water programme funds RD&D in desalination (including a large-scale floating demonstrator in the Lakhshadweep Islands), thermal energy conversion, wave energy, and hybrid wind/solar/wave systems. • MoES also sponsors gas hydrate resource assessment activities in the Indian Exclusive Economic Zone (EEZ) in collaboration with several national laboratories. Exploration and production technology development are carried out by NIOT.
Ministry of Heavy Industries (MoHI)	• MoHI supports RD&D in the automotive sector through the Automotive Research Association of India (ARAI). ARAI carries out research in fuel economy, emissions reductions, light weighting, biomass engine, and EVs, with public-private funding. • MoHI also conducts RD&D through its PSU Bharat Heavy Electricals Limited (BHEL), among the world's largest power plant equipment manufacturers. BHEL oversees 12 specialised research institutes and Centres of Excellence, collaborates with academia and other research institutes in India and abroad, and each BHEL unit includes an RD&D group. Research areas include: advanced ultra-supercritical technology, advanced boilers and turbines, transmission, solar thermal, materials and robotics. Overall, BHEL spends over 2.5% of turnover on RD&D: in 2016-17, innovation expenditures reached INR 793.62 crores.
Ministry of New and Renewable Energy (MNRE)	• MNRE's RD&D Coordination Division promotes innovation for new and renewable energy. It oversees RD&D programmes, three research centres and two PSUs. • MNRE's Technology Development in New and Renewable Energy Programme supports extramural RD&D in solar (majority of RD&D), wind, bio- and small hydro energy, supercritical CO2 technologies, power electronics, hydrogen and fuel cells. MNRE also supports the National Institutes of Solar Energy (NISE), Wind Energy (NIWE), and Bio-energy (NIBE). • MNRE leads two PSUs, the Solar Energy Corporation of India and the Indian Renewable Energy Deployment Agency, which conduct some degree of energy RD&D but remain mostly focused on deployment.

Institution	Description of key activities relevant to energy RD&D
Ministry of Petroleum and Natural Gas (MoPNG)	• MoPNG conducts RD&D related to the exploration, production, refining, distribution and conservation of petroleum and natural gas products. • On behalf of MoPNG, the Oil Industry Development Board (OIDB) provides grants for oil and gas RD&D to the Directorate General of Hydrocarbons, Centre for High Technology, and Petroleum Conservation Research Association, as well as to academia, national laboratories and research institutes. OIDB reported INR 356.9 crores in RD&D grants in 2016-17. • PSUs under MoPNG engage in many RD&D projects. The Oil and Natural Gas Corporation's (ONGC) Energy Centre conducts research in hydrogen, bioenergy, nuclear, geothermal, hydropower, fossil, and solar technologies. ONGC also supports other institutes such as the Gas Hydrate Research and Technology Centre or the Institute of Drilling Technology. ONGC reported spending INR 586 crores on RD&D in 2017-18. • Other PSUs conducting RD&D include Indian Oil (e.g. lubricants, concentrating solar for refineries, synthetic fuels), GAIL (e.g. deep sea, gas transportation, coal-to-gas, gas-to-liquids), Hindustan Petroleum (e.g. catalysts and lubricants, membranes, bio-hydrogen), Oil India Limited (e.g. geochemistry, enhanced oil recovery, petroleum biotechnology), Bharat Petroleum (e.g. fuel additives, development of new grades and alternate formulations of lube oil), and Balmer Lawrie (e.g. high-performance, bio-degradable grease and lubricant).
Ministry of Power (MoP)	• MoP conducts power sector-related RD&D under the supervision of the Central Electricity Authority, which reviews and approves projects. RD&D is guided by the National Perspective Plan on R&D in the Power Sector (2002), a 15-year plan which identified research needs in eight key areas: thermal, hydro, nuclear, and new and renewable energy sources, transmission, distribution, environment, and conservation and energy efficiency. • The Central Power Research Institute (CPRI), a national laboratory for applied research in electric power engineering, conducts RD&D either in-house or with industry, utilities, PSUs, academia and research institutions. The Bureau of Energy Efficiency (BEE) is a statutory body which promotes RD&D in energy efficiency. • The National Thermal Power Corporation (NTPC), India's largest utility, is a PSU under MoP. NTPC's Energy Technology Research Alliance (NETRA), the company's RD&D unit, focuses on four main technology areas: climate change and environment (e.g. CCUS), waste management (e.g. waste-to-energy), new and renewable energy (e.g. solar, batteries, micro-grids, biodiesel), and efficiency improvement and cost reduction (e.g. fusion, grid power electronics, and power plant efficiency technologies). • The National Hydroelectric Power Corporation (NHPC), another PSU, solicits RD&D proposals directly from power plants (e.g. silt reduction, turbine components, station design). Other PSUs indicate some degree of RD&D, including the Damodar Valley Corporation (hydro) and Satluj Jal Vidyut Nigam Ltd (hydro and wind).

Source: IEA (forthcoming), *Energy Policies Beyond IEA Countries: India 2020*.

Annex 2. Accelerating innovation under the IEA Technology Collaboration Programme: opportunities for India

The IEA was established in 1974 in response to disruptions to global oil supply, specifically the crisis of 1973-74. While this remains a key aspect of its work, the mandate of the IEA has evolved to include the full spectrum of energy issues and energy technology innovation.

The Technology Collaboration Programme (TCP), known as Implementing Agreements prior to 2016, was established as a mechanism for international collaboration the same year of the establishment of the IEA. Many of the original TCPs still exist today, having altered their programme of work to address emerging technologies specific to their energy topic or sector.

Some 80 TCPs have been created in the past four decades, with 38 currently operating. Today around 6 000 experts from nearly 300 public and private sector organisations from 55 countries (IEA member and non-member countries) participate in TCPs across five broad technology areas: energy efficiency end-use technologies (buildings, transport, industry and electricity), renewable energy and hydrogen, fossil fuels, fusion power, and cross-cutting issues.

What is a Technology Collaboration Programme?

A TCP is a co-operative project established by at least two IEA member countries to carry out a wide range of activities such as energy technology RD&D and analysis, capacity building, dissemination and scientific exchanges.[3] The majority of TCPs carry out energy technology analysis and dissemination activities. Many TCPs undertake applied research and innovation activities, and some carry out fundamental research.

While they are part of the IEA global innovation network, TCPs are functionally and legally autonomous from the organisational structure of the IEA. 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) comprising representatives designated by each participant. The ExCo makes 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.

There are two membership categories within TCPs, Contracting Party and Sponsor. A Contracting Party is either a national government, the European Commission or an international organisation or an entity designated by a national government which may include a national agency, public organisation or a private company.

[3] A TCP is established as a "special activity" under Article 65 of the IEA's constitutional document, the International Energy Programme Agreement (IEP, 1974). Further information on TCPs is available at www.iea.org/tcp.

Role of the IEA

The IEA does not provide direct financial support to TCPs through funding, either as a signatory or as a programme manager (e.g. 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.

India's participation in TCPs

India formally joined the IEA energy network in 2004 when it became a member of the TCP on Greenhouse Gas R&D. Since then, both public and private entities from India have steadily continued to join the network. Today, India participates in 11 TCPs covering a broad range of energy technologies covering renewables, transport, hydrogen and fusion power.

India currently participates in the following TCPs.

Technology Collaboration Programme on…	Participant from India
Advanced Motor Fuels (AMF TCP)	MoPNG
Bioenergy (Bioenergy TCP)	MoPNG
Clean Coal Centre (CCC TCP)	Bharat Heavy Electricals Ltd. (BHEL)
Tokamak Programmes (CTP TCP)	Institute for Plasma Research (IPR)
Demand-side Management (DSM TCP)	MoP, Bureau of Energy Efficiency (BEE)
Fusion Materials (FM TCP)	Institute for Plasma Research (IPR)
Greenhouse Gas R&D	The Energy and Resources Institute (TERI)
Hydrogen (Hydrogen TCP)	Reliance Industries Limited (RIL)
Smart Grids (ISGAN TCP)	MoP
Nuclear Technology Fusion Reactors (NTFR TCP)	Institute for Plasma Research (IPR)
Ocean Energy Systems (OES TCP)	National Institute of Ocean Technology (NIOT)

Engagement opportunities within the global innovation network (2019 TCP survey)

In April 2019, the IEA Secretariat conducted a TCP wide survey to collect views, inputs and comments on ways to strengthen TCPs further and to identify growth and engagement opportunities within the IEA's global innovation network. The survey addressed several topics including preparations for the 3rd TCP Universal Meeting, TCP collaboration and operations, legal modernisation and engagement with emerging economies.

TCPs were asked to identify which national governments where their highest priority to explore further engagement and membership. Fourteen TCPs identified India as the country of highest priority for future membership and collaboration. India received the most mentions amongst the thirty countries listed in the survey responses.

Figure 6. Discussions at the 3rd TCP Universal Meeting (Paris, June 2019)

(Photograph: IEA)

On 18-19 June 2019 at the 3rd TCP Universal Meeting, innovators and strategic thinkers from around the world discuss key trends in energy technology and research with representatives of IEA family countries.

Opportunities for India's further engagement under the TCP

Based on the 2019 TCP survey responses, below is a summary of TCPs interested in further engagement with India.

Advanced Fuel Cell TCP

The AFC TCP seeks to make a significant contribution to address the opportunities and barriers to fuel cell commercialisation by fostering the development of fuel cell technologies and their application on an international basis, and conveying key messages to policy makers and the wider community as appropriate.

Main areas of work include: Modelling: Validated open-source fuel cell models and degradation models; Technology-based projects: Electrolysis, SOFC and PEFC; Stationary applications: Analysis of real conditions and future possibilities; Renewable fuels; Fuel cell electric vehicles; light- and heavy-duty vehicles; Systems analysis.

Chair: Detlef Stolten, Germany (d.stolten@fz-juelich.de)

Primary contact: Michael Rex (secretariat@ieafuelcell.com)

For more information: www.ieafuelcell.com

Combustion TCP

The Combustion TCP provides a forum for international interdisciplinary exchange to advance the understanding of combustion processes and accelerate the development of combustion technologies that demonstrate reduced fuel consumption and have lower pollutant emissions in transportation, power generation, industry and buildings. The TCP seeks to generate, compile and disseminate independent information, expertise and knowledge related to combustion for the research community, industry, policy makers and society.

Main areas of work include: Low-temperature combustion engines; Gas engines; Solid fuels**;** Fundamental research on fuel sprays, soot formation and combustion chemistry**.**

Chair: Carina Alles, Switzerland (carina.alles@bfe.admin.ch)

Primary contact: Dennis Siebers (dlsiebers1@gmail.com)

For more information: https://iea-combustion.jimdo.com/home/iea-combustion/

Energy Storage TCP

The mission of the ES TCP is to facilitate research, development, implementation and integration of energy storage technologies to optimise the energy efficiency of all kinds of energy systems and enable the increasing use of renewable energy. Storage technologies are a central component in energy-efficient and sustainable energy systems. Energy storage is a cross-cutting issue that relies on expert knowledge of many disciplines. The ES TCP fosters widespread experience, synergies and cross-disciplinary co-ordination of working plans and research goals.

Main areas of work: Thermal storage (when the final energy to be stored is heat or cold); Electrical energy storage (such as pumped hydro, batteries, compressed air, etc.); Material storage systems (e.g. gas storage); Virtual storage (controllable loads which can be switched on or off depending on demand).

Chair: Teun Bokhoven, Netherlands (teunbokhoven@consolair.nl)

Primary contact: ESTCPSecretariat@zae-bayern.de

For more information: https://iea-eces.org/

Fluidised Bed Conversion TCP

The FBC TCP provides a framework for international collaboration on energy technology development and deployment of the fluidised bed conversion of solid fuels applied to clean energy. The main activity of the FBC TCP is technical exchange during meetings and workshops. Participants carry out research on operational issues in support of commercial fluidised bed conversion activities and share results. Fluidised bed conversion offers several advantages over pulverised fuel combustion, notably low emissions and the ability to burn a wide range of fuels including waste and biomass.

Main areas of work include: Co-firing and ash problems; Energy crops and fluidised bed conversion of biomass and waste; Fluidised bed design aspects and modelling.

Chair: Fabrizio Scala, Italy (scala@irc.cnr.it)

Primary contact: Franz Winter (franz.winter@tuwien.ac.at)

For more information: www.ieafbc.org/about-iea-fbc-tcp/

Greenhouse Gas R&D TCP

The remit of the GHG TCP is to evaluate options and assess the progress of carbon capture and storage, and other technologies that can reduce greenhouse gas emissions derived from the use of fossil fuels, biomass and waste. The GHG TCP aims to help accelerate energy technology innovation by ensuring that stakeholders from both the public and private sectors share knowledge, work collaboratively and, where appropriate, pool resources to deliver integrated and cost-effective solutions.

Main areas of work include: Evaluate technology options for greenhouse gas mitigation from fossil fuels; Facilitate implementation of potential mitigation options.

Chair: Kelly Thambimuthu, Australia (kelly.thambimuthu@bigpond.com)

Primary contact: Tim Dixon (Tim.Dixon@ieaghg.org)

For more information: https://ieaghg.org/

Gas and Oil TCP

The GOTCP brings together representatives from governments, industry and academia in a global dialogue to explore the role of oil and gas technology in the energy transition. 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.

Main areas of work include: Hydrocarbon renewable nexus; Energy choice assessment and dialogue programme; Gas to market; Brownfield, greenfield, and unconventional oil and gas.

Chair: vacant

Primary contact: Jostein Dahl Karlsen (jostein.dahl.karlsen@gotcp.net)

For more information: https://gotcp.net/

Heat Pumping Technologies TCP

The HPT TCP provides a forum for international co-operation and knowledge exchange in the field of heat pumping technologies used for heating, cooling, air-conditioning and refrigeration in buildings, industries, thermal grids and other applications. The HPT TCP's mission is to accelerate the transformation to an efficient, renewable, clean and secure energy sector in its member countries and beyond through collaboration research, demonstration and data collection and through enabling innovations and deployment in the area of heat pumping technologies.

Main areas of work include: Affordable and competitive heating and cooling technologies; Flexible, sustainable and clean system solutions for heat pump technologies; Heating and cooling developments in digitalisation and the Internet of Things; New or special market applications for heat pumps.

Chair: Stephan Renz, Switzerland (info@renzconsulting.ch)

Primary contact: Monica Axell (monica.axell@ri.se)

For more information: https://heatpumpingtechnologies.org/

Hybrid and Electric Vehicles TCP

The goal of the HEV TCP is to facilitate global co-operation on the development and deployment of electric vehicles. It supplies objective information to support decision making, functions as a facilitator for international collaboration in pre-competitive research and demonstration projects, fosters international exchange of information, and it can promote projects and programmes for research, development, demonstration and deployment.

Main areas of work include: Transport electrification for automotive and beyond (e.g. trucks, buses, ships, bicycles); Infrastructure issues (extreme fast charging, interoperability, wireless charging, vehicle/grid interactions); Connected and automated electric vehicles.

Chair: Carol Burelle, Canada (carol.burelle@canada.ca)

Primary contact: James Miller (james.miller@anl.gov)

For more information: www.ieahev.org/

Photovoltaic Power Systems TCP

The PVPS TCP supports international collaborative efforts to enhance the role of photovoltaic solar energy (PV) as a cornerstone in the transition to sustainable energy systems. The PVPS TCP seeks to serve as a global reference point for policy and industry decision makers; to act as an impartial and reliable source of information on trends, markets and costs; and to provide meaningful guidelines and recommended practices for state-of-the-art PV applications.

Main areas of work include: Strategic PV analysis and outreach; PV sustainability; Performance, operation and reliability of PV systems; Solar PV in a future 100% renewables-based power system; Enabling framework for the acceleration of building-integrated photovoltaics (BIPV); Solar resource for high penetration and large-scale applications; PV and transport; Off-grid and edge-of-grid photovoltaic systems.

Chair: Stephan Nowak, Switzerland (mary.brunisholz@netenergy.ch)

Primary contact: Mary Brunisholz (mary.brunisholz@netenergy.ch)

For more information: www.iea-pvps.org/

Solar Heating and Cooling TCP

Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the SHC TCP works to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers to increase deployment.

Main areas of work include: Building applications (solar water heating, solar combi systems, photovoltaic thermal systems and solar air conditioning; District scale systems for solar heating and cooling; Thermal storage (diurnal to seasonal); Solar process heating and cooling; Water treatment assisted by solar energy for agriculture and industry.

Chair: Daniel Mugnier, France (daniel.mugnier@tecsol.fr)

Primary contact: Pamela Murphy (secretariat@iea-shc.org)

For more information: www.iea-shc.org/

Concentrated Solar Power TCP

The SolarPACES TCP supports collaboration to advance development and deployment of concentrating solar thermal technologies. From a system perspective, concentrating solar power (CSP) offers significant advantages. With built-in thermal storage, CSP can improve the flexibility and stability of power systems, provide dispatchable electricity and help integrating more variable renewables.

Main areas of work include: Design, testing, demonstration, evaluation and application of concentrating solar power technologies; Platform for international co-operation to advance solar driven thermochemical processes for the production of fuels and materials; Development and promotion of solar process heat; Assessment of solar energy resource for concentrating solar technologies.

Chair: Robert Pitz-Paal, Germany (robert.pitz-paal@dlr.de)

Primary contact: Christoph Richter (christoph.richter@dlr.de)

For more information: www.solarpaces.org/

Wind Energy Systems TCP

The Wind TCP's mission is to stimulate international co-operation on wind energy research, development, and deployment (RD&D). The Wind TCP provides high quality information and analysis to member governments and commercial sector leaders by addressing technology development, deployment and its benefits, markets, and policy options.

Main areas of work include: Resource and site characterisation; Advanced technology for wind energy; Energy systems with high amounts of wind; Social, environmental and economic impacts.

Chair: John McCann, Ireland (john.mccann@seai.ie)

Primary contact: Ignacio Marti (secretariat@ieawind.org)

For more information: https://community.ieawind.org/home

How to join a TCP

Following is a brief overview of the steps required to become a participant in a TCP. For further information, visit www.iea.org/tcp/ or contact TCP@iea.org.

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!

Abbreviations and acronyms

AJR	analysis and joint research
BCSA	belite calcium sulphoaluminate
BIPV	building-integrated photovoltaics
BtL	biomass to liquid
CCMT	climate change mitigation technology
CCUS	carbon capture, utilisation and storage
CEM	Clean Energy Ministerial
ERS	electric road system
EV	electric vehicle
FCEVs	fuel cell electric vehicles
GWP	global warming potential
HVAC	heating, ventilation and air conditioning
IDR	in-depth review
IEA	International Energy Agency
LDV	light-duty vehicle
LED	light-emitting diode
MI	Mission Innovation
MSD	Mico Solar Dome
PSU	public sector undertaking
PV	photovoltaics
R&D	research and development
RD&D	research, development and demonstration
SME	small and medium-size enterprise
TCEP	Tracking Clean Energy Progress
TCP	Technology Collaboration Programme
VC	venture capital

Country acronyms (see Table 3)

AUT	Austria
BEL	Belgium
CAN	Canada

CHE	Switzerland
CHN	China (People's Republic of)
DEU	Germany
FRA	France
GBR	United Kingdom
IND	India
ISR	Israel
ITA	Italy
JPN	Japan
KOR	Korea
NLD	Netherlands
USA	United States
TWN	Chinese Taipei

List of figures, tables and boxes

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