T20 Policy Brief

Task Force 4
Refuelling Growth: Clean Energy and Green Transitions

COLLABORATIVE INDUSTRIAL TECHNOLOGY INNOVATION FOR CLEAN ENERGY TRANSITION: BRIDGING THE 'VALLEY OF DEATH'

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Abstract

Technology innovation is essential for clean energy transition globally, including in the G20 economies. The challenge is accelerating multi-stakeholder collaborative Research, Development and Demonstration (RD&D) to advance lab-scale prototypes to commercially demonstrated technologies. This Policy Brief recommends three enablers for large collaborative industrial technology innovation initiatives, which could prove critical to bridging the valley between clean energy research on one side, and ambitious clean energy deployment targets on the other. First, such innovation initiatives must become prominent components in national and international clean energy missions and should include transnational collaboration among G20 regions. Second, there is a need for national guidelines that will outline shared principles for collaborative RD&D. Lastly, investments should be made in pilot-scale manufacturing infrastructures.

The Challenge

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Global clean energy transition is predicated on accelerated innovation in clean energy technologies. Global 'Net Zero by 2050' scenarios require up to 50 percent of reductions in greenhouse gas (GHG) emissions by 2050 to come from large-scale deployment of technologies that are still under research or not ready yet for commercialisation.[1,2] New energy technologies take many decades to move from lab-prototype stage to large-scale deployment. Therefore, achieving net-zero emissions in the next few decades will require shrinking the lab-to-market timelines of technologies that are at the lab-prototype stage or yet to be invented.[3] A key question is how to shrink these timelines.

New inventions in clean energy technologies typically arise in the form of new materials, components or new processes to manufacture or operate them. Advancing these technologies to market solutions involves manufacturing them at scale, establishing supply chains and integrating them with other components, into end-use systems and manufacturing processes, while optimising the system-level performance under real-world conditions. The process of translating lab prototypes to pilot manufacturing and commercial demonstrations involves research, development[4] and demonstration[5] (RD&D). R&D to develop lab-scale prototypes of new inventions are generally funded by the government and performed by academic research groups in universities or R&D institutions (or sometimes by industrial research groups); once manufacturability of new technologies is proven, along with their performance in commercial-scale demonstrations, investments in further scaling up are sufficiently de-risked for investments by industry alone. RD&D efforts between these two stages are often deemed beyond the scope of publicly funded academic research and too risky for industrial investments and efforts. These translational RD&D activities therefore become the 'valley of death', where even inventions with large market potential struggle to find investments from the public sector or the private sector, and experience lack of interest (and capabilities) from academic or industrial R&D groups to pursue RD&D on their own.

To accelerate clean energy transition and achieve the climate action targets, it is imperative to foster translational

RD&D towards innovative clean energy technologies. This requires the public and private sectors to share funding and risks and universities, R&D institutions and industry to collaborate. We call such RD&D initiatives as "collaborative industrial technology innovation" initiatives.

Universities, R&D institutions and industry stakeholders have unique and complementary strengths that are essential in technology innovation, although they typically work with disparate priorities. For universities, often a research paper or a patent is the final output; national labs are supposed to engage in RD&D to increase technology readiness; and industrial enterprises need to prioritise RD&D to increase manufacturing readiness and develop commercially viable products. These stakeholders often deem collaborative innovation either too risky or non-essential for their respective priorities. Therefore, a key issue is how to foster collaboration among these stakeholders to enhance readiness of new clean energy technologies for industrial manufacturing and commercial deployment. It is the challenge of designing and implementing appropriate, organisational and operational structures.

Energy RD&D investments and inventions (patent filings) are growing rapidly around the world and shifting towards clean energy technologies.[6] However, emerging clean energy technologies are becoming increasingly complex, with supply chains for their materials and components spanning multiple countries or sometimes highly concentrated in a few countries, thus increasing risks of supply chain disruptions, as experienced during the COVID-19 pandemic.[7,8] For clean energy technologies, such as electrolysers, heat pumps, and bioenergy with carbon capture, manufacturing capacity in 2030 is expected to be 40-85 percent lower than the demand, with more than two years of lead times.[9] For other technologies such as batteries, solar cells and wafers, although the manufacturing capacity would be sufficient to meet the demand, it would be concentrated in few geographies, raising supply chain risks.

Even with growing research on clean energy technologies, it is becoming increasingly challenging to make new clean energy technologies ready for large-scale manufacturing and deployment, at the pace that is necessary for global clean transition and net-zero targets.

The G20's Role

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Addressing this challenge is of paramount importance for the G20 members, as they are the largest energy producers and consumers, GHG emitters, and investors in clean energy transition, including in energy RD&D. G20 countries account for about 80 percent of global primary energy demand (see Table 1). This demand is no longer dominated only by developed countries. China and five other emerging economies (Brazil, India, Indonesia, Mexico, South Africa) of the G20 contribute more than one-third of the global energy demand.[10] G20 countries produce more than 90 percent of global renewable electricity, with China and the emerging economies producing about 43 percent.[11]

Table 1. Share of G20 and of China + 5 Emerging Economies of G20 in Key Indicators of Energy and Industrial R&D

Indicator description	G20's Value (Share in the world (%) if applicable)	Value (Share in the world (%)) for six G20 countries that are future growth centres: Brazil, China, India, Indonesia, Mexico, S. Africa	Data source
Energy demand per year in 2021	135,615 TWh (82%)	62,700 TWh (38%)	BP Statistical Review of World Energy 2022
Renewable energy capacity in 2021	3395 TWh (93%)	1556 TWh (43%)	BP Statistical Review of World Energy 2022
Gross R&D expenditure as % of GDP in 2020 *	1.70% of GDP on average	0.90% of GDP on average	UN Institute of Statistics
Energy RD&D expenditure in 2019**	US $17 billion	US $7.5 billion***	IEA Energy RD&D Expenditure Database, Meckling et.al. 2022[12]
R&D expenditure by top 2500 R&D investing companies in the world in 2021	US $1094 billion (94%)	US $202 billion (19%)	EU Industrial R&D Scoreboard 2022
Number of companies among top 2500 R&D investing companies in the world in 2021	2315 (93%)	708 (28%)	EU Industrial R&D Scoreboard 2022
Global rankings in University-Industry R&D Collaboration Score in Global Innovation Index 2022	Range of ranks 1-91	Range of ranks 5-84	Global Innovation Index 2022

** Simple averages of national ratios of R&D expenditures and GDP are used. The EU is not included in calculations, as it is a group of nations. Due to unavailability of 2020 data, the latest available data is used for the UK (2019), Australia (2019), India (2018), South Africa (2019). ** Data for Argentina, Indonesia, Russia, Saudi Arabia, South Africa was not available. *** Sum of energy RD&D in Brazil, China, India, Mexico.*

In the coming decades, the success of global clean energy transition would be predicated on clean energy transition not only in advanced economies but also in emerging economies. The advanced economies of the G20 have been the technological leaders in the past, while the emerging economies have had limited success in innovating at the technological frontier. (The exception is China in the past two decades.) India has a large clean energy research ecosystem but has yet to commercialise research outputs on a large scale and is dependent mainly on imports of clean energy technologies. Therefore, while important for G20 broadly, it is perhaps more critical and challenging to accelerate collaborative industrial technology innovation in emerging economies of the G20.

The G20 needs to address the following questions: What are the essential building blocks of collaborative industrial technology innovation initiatives on clean energy technologies,

- to motivate both the public sector and the private sector to share investments in such initiatives;
- to bring together diverse stakeholders like universities, R&D institutions and industry to collaborate on translational RD&D; and
- to build capacity to accelerate translational RD&D especially in emerging economies?

Recommendations to the G20

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The following points outline the three critical building blocks of such collaborative industrial technology innovation initiatives.

Collaborative industrial technology innovation as a component of clean energy missions

Recognising the importance of university-R&D institutions-industry collaboration, countries around the world support collaborative R&D with public and private funding. Table 2 shows different models of innovation-focused public-private partnership initiatives in various countries.

Such short-term initiatives typically support projects by two or three collaborating organisations. Support for ensuring follow-up funding to enhance manufacturability of the R&D outputs is not part of these initiatives. Long-term

Table 2. Models of Public-Private Partnerships (PPP) on Technology Innovation

Category of PPP models	PPP models	Examples
Short- and Medium-Term (1-5 years)	R&D projects	Industrial Collective Research Scheme (Germany), IMPRINT (India), DST-EU Joint Research Program (EU+India), ARPA-E (USA)
	Training and Mobility Programs	Industrial PhD/Postdoc Schemes (Sweden, India)
Long-term (5-10 years)	Large-scale collaborative R&D projects	Industry-Research Strategic Alliances (China) Grand Solutions (Denmark), NMITLI (India)
	Centres of Excellence	Networks of Centres of Excellence (Canada, India, USA)
	Collaborative Research Centres	Centre of Innovation (Japan), Fraunhofer Institutes (Germany)
Thematic Industry Cluster	R&D Consortia	Factories of the Future (EU), United States Advanced Battery Consortium (USABC), Fraunhofer Battery Alliance (Germany)
	Technology/Competence Centres	Catapult Centres (UK)
	Technology Commercialization	A-Step (Japan), Hydrogen Valleys (EU)
	Collaborative R&D Institutes	National Additive Manufacturing Innovation Institute (USA), New Sunshine Program (Japan)
Thematic Mission-oriented	Mission-oriented Research Centres	Societal Innovation Partnerships (Denmark),

Source: OECD[13] and authors' knowledge of innovation-focused PPP initiatives in different countries.

initiatives are in the form of Centres of Excellence (COEs), funded by the public sector or shared public and private sector and having a mandate to collaborate with industry. However, unless the industry commits long-term investments in COEs and utilises the COEs as a platform to convene consortiums of industrial enterprises from across the value chain in their technology domain to work towards common technological goals, the COE model is not best suited for collaborative industrial technology innovation.

Advancing new components or processes to pilot-scale manufacturing and commercial system-integrated demonstrations requires multiple years and large investments by multiple co-innovating organisations. Industrial enterprises would not share investments with the government in such initiatives unless there are well-defined technology improvement and commercialisation goals. Furthermore, large industrial enterprises operating in multiple international markets invest in RD&D only if the technology innovation is relevant for global markets. Collaborative industrial technology innovation initiatives must, therefore, become integral, prominent components in national and international energy transition missions and should include trans-national collaboration among G20 countries.

Collaborative industrial technology innovation initiatives designed as a component of a mission would signal to the market and the industry that these initiatives are important for national and shared international priorities, while also providing a rationale to invest public-sector funding in these initiatives. The framework of a mission would, in turn, motivate industrial enterprises to invest and collaborate in industrial technology innovation. The Hydrogen Valley initiatives in the European Union, New Sunshine Program in Japan, and the United States Advanced Battery Consortium (USABC) are a few examples of such mission-driven initiatives in clean energy technologies that have motivated industrial enterprises to share investments and risks in translational RD&D with the public-sector. They have also built consortiums of universities, R&D institutions and industrial R&D divisions.

Specifically, in emerging economies like Brazil, India, and Indonesia, such mission-driven collaborative industrial technology innovation initiatives need to incorporate three key elements primarily.

Defining techno-economic goals

Technology innovation goals of such mission-driven initiatives should be based on deep understanding of the technology domain and of capabilities and culture of the innovation ecosystem. The goals should set technology performance metrics (e.g., energy or materials efficiencies, production process efficiency, capital/operating costs, emissions abatement) and timelines that are relevant to the needs of the domestic market and aim to advance the global technological frontier. They should build on existing research and industrial capabilities in the country that are transferable and adaptable to the new technology domain of innovation, while also building new capabilities in the areas of weakness.

Support for SMEs including start-ups

SMEs need to upgrade their capabilities to manufacture new technologies, for large-scale manufacturing and deployment of clean energy technologies. Start-ups are young SMEs with new technologies, who do not have the capacity to make large-scale investments on their own to prove manufacturability and performance of their technology in commercial pilots. Therefore, it is imperative that collaborative industrial technology innovation initiatives provide a platform for SMEs including start-ups to enhance their capabilities and the manufacturability of new technologies.

Leveraging international capabilities, including those of MNCs

It is crucial, especially for emerging economies, to get access to financial and technological resources in advanced economies to support clean energy transitions domestically. The collaborative industrial technology innovation initiatives in emerging economies need international collaboration with advanced economies of the G20. MNCs from advanced economies can play a key role as conduits to strengthen international collaborations. MNCs are significant contributors to global RD&D. The top 100 global MNCs, ranked by their R&D investments, account for more than onefourth of global R&D expenditure; most of them are headquartered in advanced G20 economies.[14] Furthermore, MNCs from advanced economies such as the US[15] have been shifting their R&D to emerging economies like China, India, and Mexico. Growing MNC R&D in emerging economies could be a key asset for clean energy technology innovation in these countries.

Policy framework guidelines for collaborative industrial technology innovation

Collaborative industrial technology innovation initiatives would involve consortiums of diverse organisations – universities, R&D institutions, and multiple industrial enterprises. Organising concerted RD&D efforts by such a multitude of organisations is difficult, and perhaps more challenging in emerging economies because of their lack of experience in designing and implementing large technology innovation initiatives. A common set of guidelines for collaborative RD&D could help address these challenges.

- The diverse stakeholders need to cooperate on RD&D by sharing risks, investments, knowledge and ownership of and rights to intellectual property, for which mutual trust among collaborators and co-innovators is crucial. A common set of guiding principles can facilitate trust building among diverse stakeholders.

- In mission-driven technology innovation, it is necessary but difficult to balance sustained long-term innovation efforts with agility to reorient innovation agenda with shifting global technological landscape and evolving domestic technological requirements. For example, although Lithium-ion batteries are the dominant technology choice for EV batteries today, if a new chemistry shows advantages in terms of costs and performance, then RD&D focusing on Lithium-ion battery technologies would need to consider redirecting their efforts to test viability of the new chemistry. Therefore, a guiding framework on how to balance sustained long-term efforts while avoiding a lock-in into a particular technology choice is important.

- It is also challenging to tailor organisational and operational models to the needs of the specific RD&D mission while ensuring common characteristics that are essential for any large mission-focused collaborative innovation initiative, including a culture of internal and external collaboration, appetite for high-risk RD&D, and autonomy over its budget and research agenda. A common set of guidelines is important to help design and operationalise such initiatives with a balance of common foundational elements while also catering to specific needs of the technology domain.

In short, the guidelines for collaborative industrial technology innovation initiatives need to specify:

- Multiple models to share intellectual property ownership and licensing rights;
- Organisational, operational, and funding models for such initiatives;
- Guidance on how to design the initiatives and define technological goals;
- Guidance to manage mobility of human resources—for example, even if research personnel change their employment and, thus, exit the consortium, it should not discontinue the part of the RD&D they were leading.

Pilot manufacturing and technology validation infrastructures

Proving manufacturability of hardware technologies, such as advanced chemistry cells (ACC), EV power electronics, or next-generation photo-voltaics, requires infrastructure to manufacture pilot batches that can be integrated into systems to be tested under real-world conditions. Often such innovative components technologies are developed by academic research institutions, start-ups, or other SMEs who do not have the financial capabilities for capital investments in pilot manufacturing facilities. Large industrial enterprises, meanwhile, generally consider investments in pilot manufacturing facilities for new-to-the-world technologies as too risky before their performance is proven in real-world conditions. Therefore, funding for pilot manufacturing infrastructure under a public-private partnership model should be an integral part of collaborative industrial technology innovation initiatives.

There are multiple examples of centralised pilot manufacturing and technology validation infrastructures made available to the industry and R&D institutions. The Materials Research Institute of the University of Michigan in the US has established a pilot ACC production line and offers it to industry and university users under a service agreement.[16] The University owns the manufacturing equipment and employs staff to operate the pilot line and also offer hands-on training programs. Many Fraunhofer Institutes in Germany have pilot-scale manufacturing facilities, which can be utilised by industry as a service.[17,18,19]

We have discussed above three building blocks of collaborative industrial technology innovation initiatives to bridge the 'valley of death' between clean energy research, on one hand, and on the other, realising ambitious clean energy and green transition targets:

- Driving such initiatives under an umbrella of national or international clean energy Missions that include specific techno-economic goals, support SMEs including start-ups and leveraging transnational capabilities, such as those of MNC R&D centres.
- Developing guidelines that lay out shared principles for consortium RD&D, including intellectual property ownership and licensing, and provide guidance to adapt based on deep understanding of the technology and the innovation system, and
- Establishing shared pilot manufacturing infrastructure that is accessible not only to large enterprises but also to SMEs including startups.

This is not a comprehensive blueprint of collaborative industrial technology innovation initiatives focusing on clean energy transition but a discussion of critical enablers for such initiatives. While relevant for all G20 countries, these are perhaps more important for emerging economies because they often launch a new-technology mission beginning with manufacturing or deployment subsidies, as the 'valley of death' is deeper in these countries. The collaborative initiatives discussed here can provide the foundation for the industry and market to build capabilities to sustain in the long-term even after discontinuation of the subsidies. Therefore, subsidy schemes in emerging economies should be accompanied by such initiatives, with fiscal outlay of at least 10-20 percent of the outlay for subsidies. The building blocks discussed here are risk-mitigation measures that can facilitate risk-sharing between public and private sectors and accelerate commercial deployment of new clean energy technologies. Collaborative industrial technology innovation initiatives should therefore be integral to clean energy transition in developed and developing G20 countries.

The opinions expressed in this Policy Brief are those of the authors and do not necessarily reflect those of the organisations with which they are affiliated.

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