CHAPTER 3

INNOVATION DRIVING THE ENERGY TRANSITION

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The world is moving towards a more inclusive, secure, cost-effective, and sustainable future based on renewable energy. Energy transition is not a new phenomenon: humanity first relied on wood for energy, followed by peat and then coal, which began to be used around 1750. Oil came later, around 1875, and natural gas around 1950.[1] These past experiences indicate that energy transitions—enabled by technology development—occur regularly and are chiefly caused by economic and geopolitical considerations rather than primary resource scarcity.[2]

The current energy transition

The ongoing energy transition is evolving in the same vein, with innovation as a major driver. But this time it is fostered by unprecedented public pressure and policy action, triggered by rising climate change concerns across the world. The present energy transition may be the swiftest yet, bolstered by rapid renewable power deployment and innovations and technology developments that have enabled the implementation of more ambitious policies. This has created a virtuous circle. In 2017 the world's total renewable power capacity reached 2,179 gigawatts (GW),[3] surpassing the close to 2,000 GW of total global coal power capacity. In the last decade, global installed solar photovoltaic (PV) capacity grew from 6.1 GW to 390 GW by the end of 2017.[4] Cumulative installed wind capacity reached nearly 514 GW the same year.[5] At present, around a quarter of the world's electricity is produced from renewable energy sources.

Decarbonization of the energy sector is the backbone of the current transition. At the Paris climate conference (COP21) in December 2015, countries agreed to set out an action plan to decarbonize the global economy and limit global warming to well below 2°C compared to pre-industrial levels. Around two-thirds of global greenhouse gas emissions can be attributed to fossil fuel energy supply and use.[6] To achieve our climate goals, energy-related CO_2 emissions must decline by 2.6% per year, or 0.6 metric gigatons per year on average, all while ensuring that sufficient energy is available for economic growth.[7]

Innovation in the driver's seat

Innovation has historically been—and will continue to be—a key driver of energy transitions. At its core, innovation is simply the application of new technologies and practices with enhanced and desirable features. At present, technological development is accelerating and renewable energy costs have decreased at a remarkable pace. In the case of wind, onshore projects commissioned in 2017 largely fell within the range of fossil fuel–fired electricity generation costs, with recent auctions indicating a levelized cost of electricity (LCOE) as low as US$0.03 per kilowatt-hour (kWh).[8] The development of larger wind turbines, installed in new locations (including offshore), along with stable incentives, policies, and regulatory frameworks have resulted in an accelerated learning curve for wind power technologies over the last two decades.

PV technologies have made even more remarkable advances. The global weighted average LCOE of utility-scale solar PV fell by 73% between 2010 and 2017, to US$0.10/kWh, due to the 81% decrease in solar PV module prices and increased module efficiencies, along with reductions in the balance of system costs. Increasingly this technology is competing head-to-head with conventional power sources without financial support.[9]

Moving the energy transition forward

Energy efficiency and renewable energy form the core of the energy transition, since they can achieve 90% of the required CO_2 emission reductions by 2050 compared to the Reference Case (the most likely case based on current and planned policies and expected market developments for each country's energy sector).[10] The remaining 10% would be achieved through other options, including fossil fuel switching, continued use of nuclear energy, and carbon capture and storage (CCS).

Energy efficiency and renewable energy must grow in tandem. Decarbonization will require accelerated improvements in energy efficiency across all sectors to keep total primary energy supply at the same level between 2015 and 2050, all while the world economy grows threefold. By 2050, two-thirds of total primary energy supply must come from renewables. This requires the share of renewables to increase at a rate of about 1.4% per year, a sevenfold acceleration compared to recent years.[11] To achieve this, innovation must support both faster deployment of available technologies and the development of new renewable energy technologies.[12]

The role of other energy technology options remains uncertain. CCS and nuclear deployment have lagged behind expectations as a result of related risks, added cost, and limited acceptance. Moreover, efforts to develop nuclear and CCS options have been geographically unevenly distributed.

Economic benefits of a transition beyond climate change

The global energy transition could create around 6 million additional jobs by 2050 compared to the Reference Case.[13] Job losses in fossil fuels would be completely offset by new jobs in renewables alone, with millions of additional jobs created in related sectors as well. Global gross domestic product (GDP) could also be boosted around 0.8% in 2050 compared to the Reference Case. The cumulative gain through increased GDP from 2015 to 2050 would amount to some US$19 trillion.[14] Greater economic growth is driven by the increasingly strong business case of renewable energy and the stimulus of higher investment in renewables and energy efficiency, and is enhanced by pro-growth policies, particularly carbon pricing. Policy makers need to consider strategies to adapt and benefit national economies from this transition.

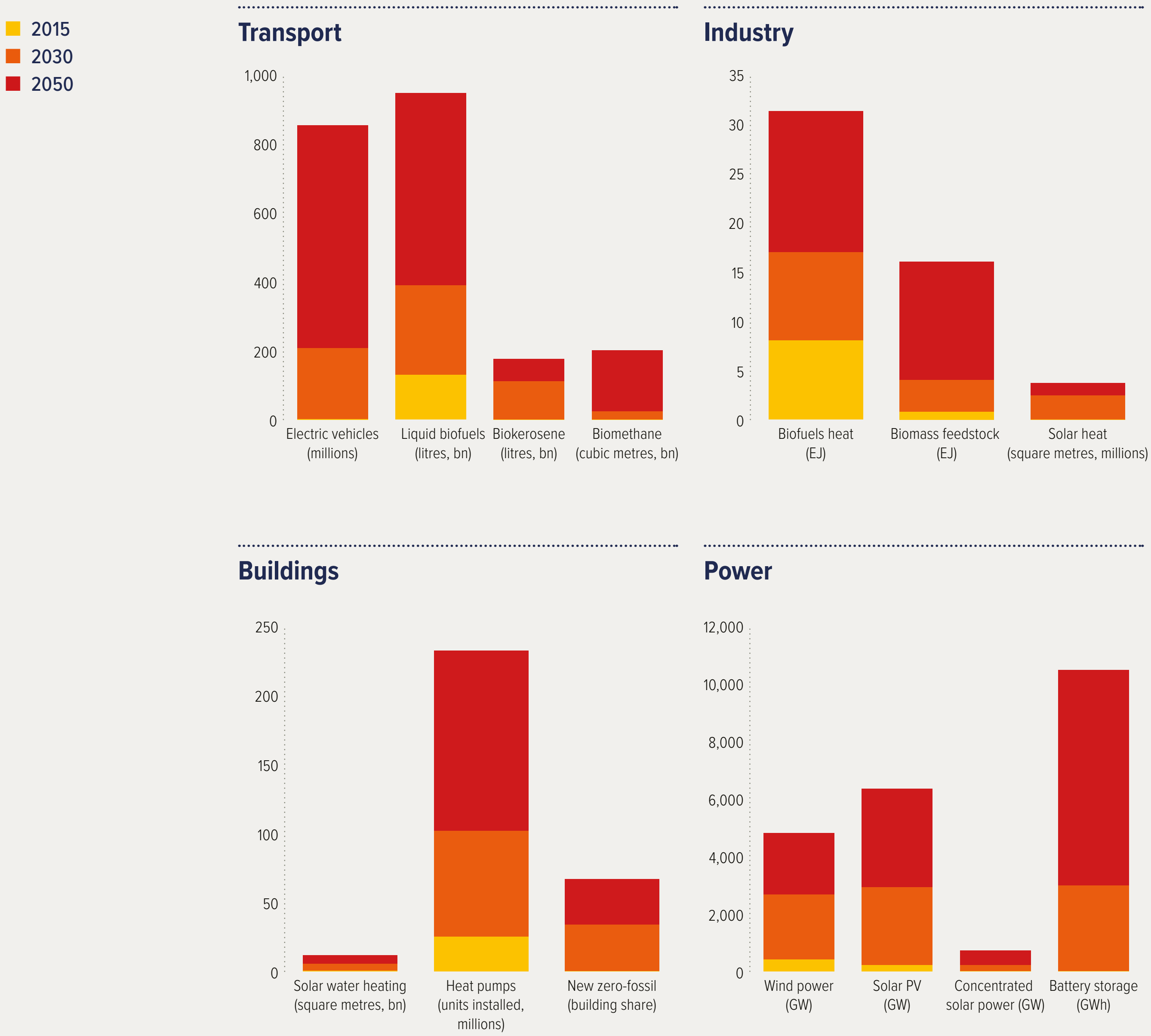
Challenges ahead

Recent analysis from IRENA indicates that technologies are available today that can significantly advance the low-carbon energy transition through 2030.[15] However, major technology challenges remain to complete the transition to a renewables-based energy supply by the middle of the century. To reach our climate goals within the needed timeframe, competitive low-carbon technologies must rapidly reach commercialization to supply all energy needs. The good news is that technology solutions exist for two-thirds of the global primary energy supply, and deployment rates for solar PV, wind power, heat pumps, and electric vehicles are on track. For bio-jet fuels (biokerosene), biofuels for road transport, solar heat for industrial processes, and battery storage,[16] deployment growth rates need to increase by several orders of magnitude (Figure 1). The important next step is to create enabling frameworks to scale up their deployment.

For the remaining one-third of global primary energy supply, the currently foreseeable solutions are either not yet available at scale or their costs remain too high. The next step is to foster technology innovation, along with enabling policy, social, and financial measures, to rapidly bring emerging clean technologies to the marketplace. Major challenges remain in end-use sectors, namely industry (iron and steel, cement, and chemical/petrochemical), aviation, and freight transport, as shown in Figure 2.

Figure 1.

Technology deployment needs by sector and application in REmap, 2015–50

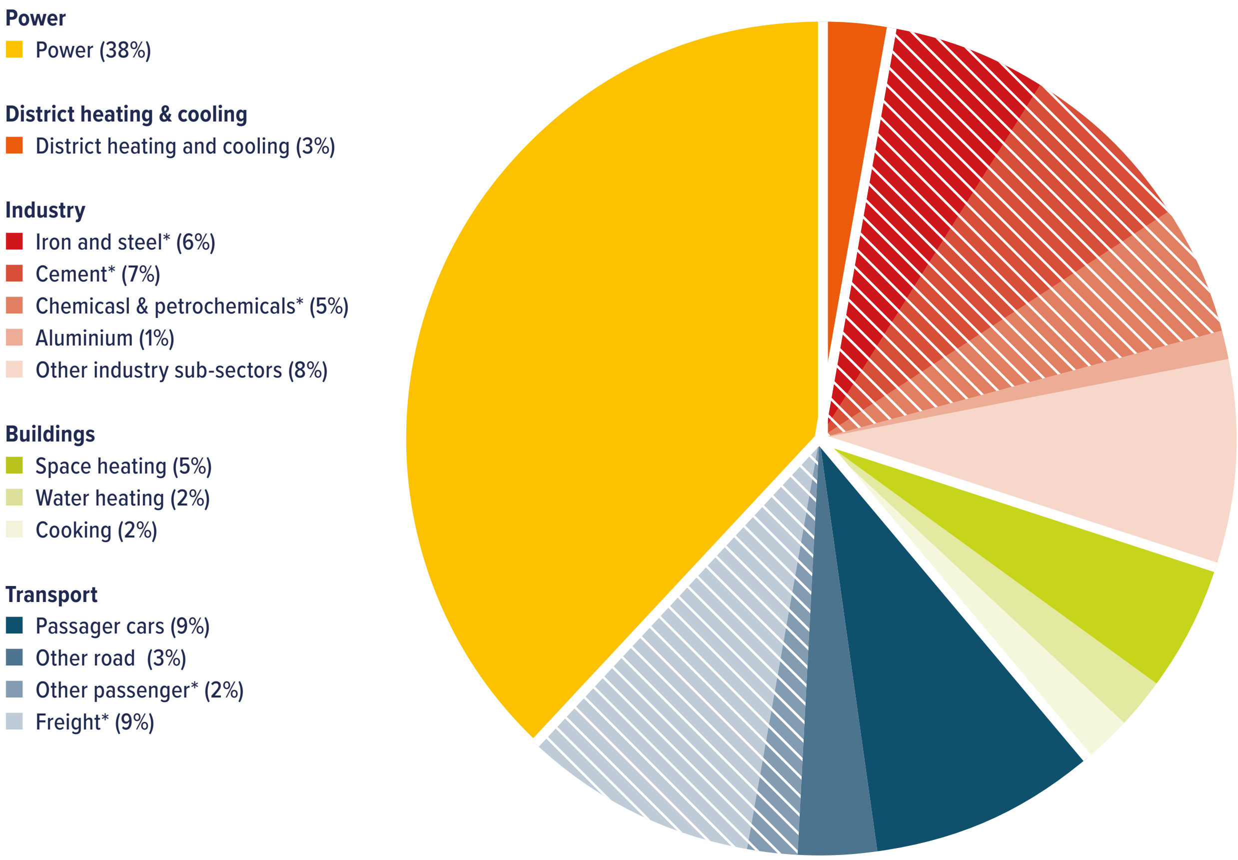


Source: IRENA, 2017a.

Note: 'Biomass feedstock' is biological material that can be used directly as a fuel or converted to another form of fuel or energy product; 'new zero-fossil' refers to new buildings with enhanced insulation resulting in zero or almost zero energy demand for space heating; 'REmap' is a low-carbon technology pathway assessed by IRENA that goes beyond the Reference Case for an energy transition in line with the goal of the Paris Agreement to limit an increase in global average temperature below 2°C in comparison to pre-industrialization levels, with a 66% probability of meeting that target (IRENA, 2017b). EJ = exajoules; GW = gigawatts; GWh = gigawatt-hours; PV = photovoltaic.

Figure 2.

Breakdown of global CO_2 emissions by sector and sub-sector, 2015



Source: IRENA, 2017a.

Notes: 'District heating & cooling' is defined as the centralized heating or cooling of water, which is then distributed to multiple buildings through a pipe network (IRENA, 2017d); 'Other passenger' is passenger transport by air or sea; 'Other road' includes all on-the-ground transport for passengers that is not cars; sectors with no current economically viable option for deep decarbonization are shaded.

* Sectors with no current economically viable option for deep carbonization. These sectors are shaded in the figure above.

Early action is essential, as a full-scale energy transition takes decades because of the different technology development steps needed and the long lifespans of existing infrastructure.

Innovation needs

This section considers the different innovation needs in the power sector and the end-user sectors.

Innovation needs in the power sector

Many renewable generation technologies in the power sector are already economically viable, and innovation, together with economies of scale, will continue to reduce their costs. The next step, therefore, is to focus innovation efforts on integrating high shares of variable renewable energy (VRE) in power systems.[17] This requires options that create flexibility, such as grid strengthening, demand-side management, energy storage, sector coupling (which links the electricity sector with heating, cooling, and transport), and flexible conventional power generation.

The benefits of increased innovation in renewable energy systems integration are clear. Innovation reduces costs of enabling technologies, such as energy storage and grid infrastructure, and unlocks new approaches for operating power systems, designing markets, and creating business models and thus enabling reliable, affordable, and renewable power systems.

Countries such as Denmark, Germany, Portugal, Spain, and Uruguay have proven that power systems with annual VRE shares in excess of 25% are manageable, and have even handled short periods of time with VRE shares close to 100%.[18] Best practices—such as the electricity system operated by 50Hertz in eastern Germany that managed a sustained share of VRE of 50% in 2017—are possible.[19] However, the optimal strategy for integrating shares of VRE in excess of 50% on an annual basis is not yet fully known, and innovation will continue to be crucial for grid integration.

Innovation needed in the end-use sectors

Decarbonizing end-use sectors will require a combination of electrification, technology breakthroughs, and sector-specific global agreements. The electrification of end-use sectors is a win-win, since it reduces emissions while also supporting the integration of higher shares of VRE in power systems. Beyond electrification, no economically viable emission reduction solutions are currently available for carbon-intensive activities such as iron and steel making, cement production, chemical and petrochemical production, maritime transport, aviation, freight transport, or the replacement of non-sustainable traditional biomass. Industry—particularly steel and iron, cement, and chemicals—followed by certain transport modes are the most challenging in this regard and require new technology solutions to be developed and commercialized quickly. Table 1 includes a list of technology options for the energy transition for each sector and their current deployment status. A detailed description of these technology options is available in IRENA's 2017 report *Accelerating the Energy Transition through Innovation.*

New policies are also needed. Energy-intensive industries, such as cement or steel and iron production, have been largely exempt from ambitious climate policies because of international competitiveness issues and potential carbon leakage.[20] Buildings and city designs should facilitate renewable energy integration. Regulations are needed to ensure that new buildings are of the highest efficiency, and the retrofitting and refurbishment of existing buildings needs to be accelerated. In transport, cross-border regulations of jet fuels in aviation and bunker fuels in maritime transport have yet to be addressed.[21]

Some emerging innovation trends for the energy transition

The low-carbon energy transition has begun with renewables deployment at its core. Distributed generation, combined with information and communication technology (ICT) developments, has the capability of transforming the way power systems are operated and regulated, leading to more informed, empowered—and flexible—consumers.

Decentralization and distributed generation

With the rise of distributed generation, individuals and communities have greater control over generation and energy consumption.[22] Incentive programmes to encourage distributed generation, particularly distributed solar PV, have been extremely effective in many countries. Deployment of solar PV has increased dramatically in recent years.[23] In 2016, more than 30% of Germany's installed renewable energy systems were owned by citizens.[24]

Distributed storage has also gained momentum recently with a behind-the-metre business model that allows customers to store electricity generated by their rooftop solar panels and use it when needed—for example, after the sun sets.[25]

Decentralization of the energy sector also brings new innovative business models around peer-to-peer power trading, demand-side responses, and power to buildings. All of this enables consumers to move out of the monopolistic markets driven by utilities and participate in a more transparent and independent manner, leading to a 'democratization of electricity'. Pay-as-you-go (PAYG) business models, which allow customers

Table 1.

Innovation progress of technology options in the energy transition, by sector

Pace of innovation progress	Sector: Power generation	Industry	Transport	Buildings
On track	• Hydropower • Solar PV • Onshore wind • Offshore wind • Smart grids • Battery storage • Energy efficiency in end uses	—	• EVs	—
Lagging but viable	• Biopower • Geothermal • Interconnector capacity • Ultra-high-voltage DC • Demand-side response • Solar CSP	• DRI iron-making gas + CCS • Clinker substitutes • Clinker kilns + CCS • Clinker kilns biomass • Gas ammonia production + CCS • Biomass supply at scale	• Conventional biofuels • Energy efficiency • Biomass supply at scale	• Zero-energy buildings • Energy renovation and existing stock • Clean cooking using renewables • Solar-assisted water/ space heating systems • Heat pumps
Not viable at current pace	• CCS for natural gas and biomass (BECCS)	• DRI iron-making hydrogen • Blast furnace iron-making + CCS • Blast furnace iron-making biomass • Biomass for chemicals + recycling • Hydrogen ammonia production • Material efficiency • CO_2 transportation and storage infrastructure	• Hydrogen vehicles • Advanced biofuels • Railway infrastructure for modal shift	• District heating & cooling with renewables
Not currently available	• Various negative emission technologies • New materials for advanced battery storage	• Solar thermal aluminium smelting • Direct conversion of CO_2 to fuels and materials	• Solar passenger cars • Electric aircraft	• Advanced lightweight materials for construction • New appliance technologies such as magnetic refrigerators; breakthrough materials for insulation; and advanced smart heating, cooling, and appliance use and control systems

Source: Based on IRENA, 2017a.

Notes: 'Clinker' is the residue from burnt coal or from a furnace; 'district heating & cooling' is the centralized heating or cooling of water, which is then distributed to multiple buildings through a pipe network (IRENA, 2017d). BECCS = bioenergy with carbon capture and storage; CCS = carbon capture and storage; CSP = concentrated solar power; DC = direct current; DRI = direct-reduced iron; EV = electric vehicle; — = not known or not applicable.

to pay directly for the electricity they require at a rate they are willing to pay, are beneficial for developing regions where customers' access to financing is limited. PAYG has been implemented in regions in Africa (e.g., M-Kopa) and India (e.g., Simpa Networks).

Digitalization

Interesting opportunities exist at the crossroads of ICT and energy technology. The application of digital monitoring and control technologies in the generation and transmission domain of the electricity system has penetrated deeper into the local grids. Wider use of smart metres and sensors, along with the application of Internet of Things, has created opportunities to provide new services to consumers. Enhanced communication and control enables aggregators to bundle demand response and create 'virtual power plants'.

Smart technologies are providing data and insights on consumer behaviour that enable better planning by grid operators. With improved communications, system operators gain valuable information about distributed energy sources in real time, thus enabling better production and consumption forecast models. These developments result in greater flexibility to accommodate new and variable energy sources.

Sector coupling

The coupling of diverse energy applications also creates opportunities for the integration of clean technologies. Electric vehicles (EVs), for example, will be a game changer not only for transport, but also for renewable power. Increasing numbers of EVs present both a challenge and an opportunity for further renewable energy integration and sector decarbonization. Over 2 million EVs have now been sold globally, with China, Japan, and the United States of America (notably the state of California) accounting for around two-thirds of the total global EV stock.[26] New EV registrations hit a world record in 2016 with nearly 800,000 units, around 1% of all car sales. Countries such as China, France, Germany, India, Norway, and the United Kingdom are now committing to electric mobility by establishing targets for the coming decades.

In industry sectors such as chemical and steel production, some applications have started using converted forms of power such as hydrogen, ammonia, and others, thus allowing intermittent renewable energy generation to be absorbed during off-peak time. However, further innovation in the industry sector is needed: the share of renewables has remained unchanged for the past few decades at around 10%.[27]

Nurturing innovation at all stages

Innovation efforts should encompass the complete technology life cycle and all aspects of renewable energy integration in all sectors. Governments can play a key role in setting the right framework to foster innovation.

R&D investment

For those end-use sectors with no clear technology solutions commercially available, basic research and engineering efforts are needed. Innovation requires funding. Over the past seven years, government and corporate investment in clean energy technology research and development (R&D) has been stagnant. Although investments in renewable energy have risen to around US$300 billion per year, R&D expenditures for clean energy amount to US$10 billion per year.[28] This 3% R&D investment share is well below that of other innovative sectors, such as ICT and vehicle manufacturing. Additional R&D efforts would result in additional—and cheaper—low-carbon technology solutions, thereby decreasing the overall costs of the energy transition. Today most R&D investment flows into the power sector, such as solar and wind, rather than into end-use technologies, such as bioenergy and solar thermal, where the urgency is greater.

Innovation beyond R&D

The innovation challenge for energy goes beyond traditional R&D efforts. The end-use sectors that have made the least progress in innovation for decarbonization—such as heavy industry, freight transport, and aviation—are those where proper policy incentives and long-term perspectives are lacking. Although costly low-carbon technologies have a role to play here, a uniform global carbon price is needed to create a level playing field. Politically viable, economically viable, and efficient policy frameworks are needed.

This challenge cannot be met by increased R&D investment alone. It requires global sectoral approaches that help to overcome a lack of cost-competitiveness while addressing carbon leakage concerns. Innovation also includes a fundamental rethinking of production processes and energy technologies required for the energy transition. A sustainable solution is one that increases productivity and enhances performance while eliminating emissions.

Efforts to increase innovation must cover the complete technology life cycle, including the demonstration, deployment (technology learning), and commercialization stages. Furthermore, the innovation ecosystem should extend across a range of activities to include creating new market designs, building innovative enabling infrastructure, forming new ways to operate energy systems, establishing standards and quality control systems, and implementing new regulatory measures. It is too early to say what the new sector structure will be, but it is clear that the traditional centralized utility model is being challenged.

Overcoming the valley of death

A sound commercialization strategy is essential to translate ground-breaking concepts in clean energy into marketable outputs—that is, to take ideas from demonstration to commercial diffusion, a phase also known as the 'valley of death'. Commercialization thrives not only in a healthy investment climate but also in an environment supported by strong institutional arrangements and other governmental mechanisms.

Some tools allow both policy makers and entrepreneurs to develop market diffusion mechanisms for innovative technologies. These tools aim to enable matching innovation initiators (e.g., national institutes, private companies, and technology transfer offices) with the neediest innovation recipients (e.g., new customer groups and market niches). Examples include crowdfunding, joint ventures, patents and licenses, spin-offs, and technology incubators.

Increased public investment in R&D will continue to be crucial. Mission Innovation is a recent international initiative announced at COP21 that sets the target of doubling government R&D investment in clean energy technologies. Through Mission Innovation, 22 countries and the European Union have pledged to double their public clean energy R&D investment over five years.[29] Initiatives that increase R&D funding are very encouraging. However, more attention could be paid to monitoring and verifying that those investments have the desired impact.[30]

Private funding is also essential. To take one example, the Breakthrough Energy Coalition is a global group of wealthy investors committed to funding clean energy companies. The coalition is designed to help mobilize 'patient capital', which can wait longer for early-stage technologies to mature from lab to market.

Policy messages

Renewable energy and energy efficiency will be at the core of the energy transition, representing 90% of emission reductions and necessitating a significant transformation of how the world produces and consumes energy.[31] The share of renewables in the energy mix needs to increase to two-thirds of the world's total primary energy supply by 2050, up from 15% today. It is also crucial that current international climate change debates lead to appropriate market signals—for example, carbon pricing or the ban of CO_2-emitting technologies—to accelerate decarbonization.

To avoid carbon lock-in and minimize future stranded assets,[32] investment needs to be significantly scaled up and redirected into renewable capacity, infrastructure, and energy efficiency solutions. The numerous economic, financial, social, and environmental benefits of the transition should be included in cost/benefit assessments while defining energy sector investment strategies.

Electrification will be a key enabler in decarbonizing many energy services in the end-use sectors such as transport, buildings, and industry. However, to reach an 85% share of renewable electricity supply by 2050, increased emphasis on innovation is needed to integrate VRE shares as high as 60%. Policy makers need to study various new technology trends to address this issue, including long-term grid expansion and planning; the interlinkage of demand and supply through smart-grids, and digitalization; and the role of energy storage.

For end-use sectors that cannot be electrified, such as freight transport, aviation, and heavy industries, innovation is needed to bring breakthrough technology solutions to market while also scaling up options lagging in deployment. These options include modern biofuels, solar thermal heat, district energy systems, and hydrogen.

Four elements need to be included in a policy framework for the energy transition:

1. **A systemic innovation approach beyond R&D:** Leveraging synergies between innovations across all sectors and components of the system, and involving all actors, is crucial. Innovations in technology should be pursued equally assiduously as they are in enabling infrastructure and sector coupling, business models, market design, finance instruments, and policy frameworks.

2. **Approaches to nurture innovation:** Innovation is crucial for the decarbonization of the energy sector. International cooperation on innovation for clean energy should be pursued and should take advantage of relevant existing platforms such as IRENA, Mission Innovation, and Clean Energy Ministerial.[33]

3. **Advances in power-system integration:** Renewable power already has a strong business case, but achieving its potential requires additional efforts in innovation for systems integration.

4. **Support for a portfolio of options for the end-use sectors:** Effective support requires a combination of electrification, technology breakthroughs, and sector-specific global agreements.

This chapter has considered a pathway, based on the deployment of renewable energy and energy efficiency, for the ongoing energy transition towards a more sustainable, low-carbon energy sector. It highlights the role of innovation as a key enabler for the energy transition and indicates the low-carbon technology options for each energy sub-sector. Priority innovation areas, where action is urgently required, are discussed; and the elements of a comprehensive policy framework, to foster innovation for the energy transition, are described. This chapter has argued that a policy framework that encompasses these elements is well positioned to succeed.

Notes

1 Gielen et al., 2016; Grübler, 2012; Smil 2016; van Vuuren, 2012.

2 Cherif et al., 2017.

3 IRENA, 2018a.

4 IRENA, 2018a.

5 IRENA, 2018a.

6 IPCC, 2014.

7 IRENA and IEA, 2017.

8 IRENA, 2018b.

9 IRENA, 2018b.

10 IRENA has collected data from the G20 countries about their national energy plans and goals for the period 2015 to 2050. See IRENA and IEA, 2017.

11 IRENA, 2017a.

12 IRENA and IEA, 2017.

13 IRENA and IEA, 2017.

14 IRENA and IEA, 2017.

15 IRENA, 2017a; IRENA, 2017e.

16 IRENA, 2017b.

17 'Variable renewable energy' refers to fluctuating generation such as the energy obtained from solar PV and wind energy sources.

18 IRENA, 2016b.

19 DNV GL, 2017.

20 'Carbon leakage' refers to the increase in CO_2 emissions outside the countries that are taking carbon-mitigation steps that results from the cost associated with their policies.

21 A 'bunker fuel' is any type of fuel used for the maritime and aviation sectors.

22 IRENA, 2016a; Koirala et al., 2016.

23 World Economic Forum, 2017.

24 CLEW, 2018.

25 World Economic Forum, 2017.

26 IRENA, 2017c.

27 IRENA, 2014.

28 Frankfurt School et al., 2017.

29 The countries participating in Mission Innovation, and more information about the initiative, can be found at http://mission-innovation.net/countries/.

30 Ang et al., 2017.

31 IRENA, 2018c.

32 'Carbon lock-in' refers to the inertia perpetuated by fossil fuel–based energy systems that is an obstacle to public and private efforts to introduce alternative energy supplies.

33 Further information about Clean Energy Ministerial is available at http://www.cleanenergyministerial.org/.

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