IRENA
International Renewable Energy Agency

INNOVATION PRIORITIES TO TRANSFORM THE ENERGY SYSTEM

AN OVERVIEW FOR POLICY MAKERS

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

Contributors: Paul Durrant, Francisco Boshell, Arina Anisie, Roland Roesch, Nicholas Wagner and Dolf Gielen (IRENA)

Key Findings

- The transformation of the **global energy system** is under way, driven by the needs to address climate change and broaden access to affordable and secure energy, and enabled by cost-competitive renewable power and emerging innovative technical, policy and market solutions.
- Technology innovation has been and will continue to be a critical enabler of progress, but **innovation priorities** need to be refreshed to address the new challenges of integrating high shares of renewable power and electrifying the end-use sectors of transport, industry and buildings.
- Innovation must be **broader than just technological** research, development and demonstration (RD&D). Improved technology must be accompanied by and integrated with innovations in business models, policies, processes and market design.
- Government support for innovation has a **crucial enabling role** at all stages of the innovation journey, and national support programmes need to be carefully prioritised.
- The most critical global innovation needs can be placed in three groups – **"push"**, **"nurture"** and **"facilitate"** – each requiring different approaches for governmental support.
- Pledges to boost **public sector spending** on clean energy innovation need to be delivered and then investment sustained or increased. Boosting private sector investment will require fresh thinking and co-ordinated action.
- Increased support and stronger international collaboration is needed to accelerate:
  - » **innovation in the integration and operation of the energy system (systemic innovation),** which is key to integrating more variable renewable energy and electrifying end-use sectors.
  - » **innovation in industrial processes –** particularly cement, iron and steel, and chemicals, which together account for 17% of current carbon dioxide (CO_2) emissions.
  - » **innovation in transport –** particularly in freight and aviation, which together account for 11% of current CO_2 emissions.

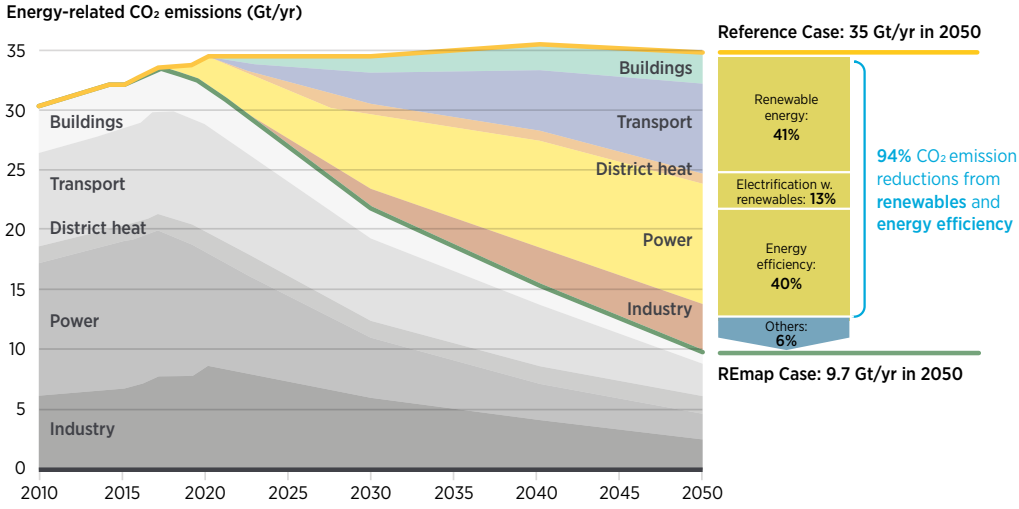
Aims and scope of this brief

- This brief draws on analytical studies and reports by the International Renewable Energy Agency (IRENA). It aims to provide policy makers with a **high-level overview** of priorities for increased government action, specifically to accelerate technological and systemic innovation in support of the global shift to an energy system based on renewables.
- The brief describes the status of the **ongoing transformation** of the global energy system, discusses the role of innovation and government support, and highlights priorities for increased government action and international co-operation. Pointers to IRENA's more detailed analysis of these issues are provided throughout.
- The insights in this brief will be most relevant to countries that are making the transition from an **established national energy system** so as to fully utilise renewable energy. Some of the insights also may be relevant to countries that are constructing wholly new energy systems, although the innovation priorities for such systems may go beyond those highlighted in this brief.
- This brief focuses on both **technological innovations** and associated **systemic innovations** that enable the uptake and use of technological innovations. It highlights the need for an integrated, system-wide view of innovation that combines technological innovation with innovation in business models, in processes, and in market design and regulation to transform the energy system.
- Innovation in other aspects of the energy transition, such as in policy frameworks or in financing, are also critical but are not addressed in this brief.

The energy system needs to be transformed

- Energy systems around the world are already undergoing **radical changes,** driven by a combination of technological innovations, the need to expand affordable energy access and the urgent need to tackle climate change. This global energy transformation can pave the way for a more inclusive, secure, cost-effective and sustainable future, with the current energy mix, dominated by fossil fuels, making way for clean, abundant renewable energy.
- In recent years, the **cost of key renewable energy technologies** has fallen dramatically, to the extent that many currently commercially available renewable power generation technologies are expected to be **cost-competitive with fossil fuels** by 2020.
- In parallel, **dramatic shifts** have begun in the way that **energy systems operate**, driven by trends such as increased digitalisation, the decentralisation and democratisation of power generation, and the growing electrification of end-use sectors.
- The **pace of the transformation**, however, still **falls far short** of what is needed to meet energy, climate and development policy goals, particularly to deliver on the Paris Agreement's aim to slash CO_2 emissions and keep the rise in average global temperatures to, at minimum, well below 2 degrees Celsius.

Carbon dioxide (CO_2) emission reductions needed by 2050, compared to 2017



Gt = gigatonne; yr = year.

Figures derived by IRENA REMap modelling.

Source: IRENA (2018), Global Energy Transformation: A roadmap to 2050, International Renewable Energy Agency, Abu Dhabi.

IRENA's 2018 report, *Global energy transformation: A roadmap to 2050*, concludes that:

- Renewable energy and energy efficiency provide the optimal pathway to deliver the bulk of the emission cuts needed at the necessary speed. Together they can provide over 90% of the energy-related CO_2 emission reductions needed to keep the global **average temperature increase** below 2 degrees Celsius (with a 66% probability).
- Under current and planned policies, however, **emission trends** are not on track to meet that goal – the world would exhaust its energy-related "carbon budget" in under 20 years.
- The **power sector** has made considerable progress in recent years, but the speed of progress must be accelerated. Renewable energy needs to be scaled up at least six times faster across the entire energy system.
- The total share of renewable energy must rise from around **15% of the total primary energy supply** (in 2015) to around **65% by 2050**. The share of renewable power must rise to 85% by 2050.
- The **energy intensity** of the global economy will need to fall by about two-thirds by 2050. This can be achieved, despite significant population and economic growth, by substantially improving energy efficiency. The energy intensity improvement rate must increase from an estimated 1.8% per year to 2.8% per year to achieve this.
- **Energy efficiency improvements** are not being adopted fast enough. For example, the renovation rate of existing building stock is just 1% per year. A three-fold increase is needed.
- In industry, the high energy demand of certain industries and the high carbon intensity of certain processes require **full life-cycle analysis**, novel solutions and co-ordinated international action.

The challenge for governments around the world is how to build on the potential of low-cost renewable power and to accelerate the pace of the transformation.

To learn more, see: ***Global energy transformation: A roadmap to 2050*** (IRENA, 2018); ***REthinking energy 2017: Accelerating the global energy transformation*** (IRENA, 2017)

Innovation can accelerate progress

- Technological innovation has played an important enabling role in the early phases of the world's energy transition.
- We now have many of the **tools we need** to transform the energy system, and the immediate policy priority must be to accelerate the deployment of renewable energy technologies. However, **more – and faster – innovation** is still needed in many aspects of the energy system to address gaps in capability and to support accelerated progress.
- Both **technological and systemic innovation** will be important to the next phase. Continued RD&D can further reduce costs, improve performance and adapt solutions to local conditions, as well as develop and prove new approaches.
- Innovation priorities, however, need to be **refreshed** to reflect both progress to date and the new challenges emerging.
- Innovation must be **broader** than just technological RD&D. Improved technology must be accompanied by **innovations** in business models, policies, processes and market design.
- While innovation in renewable power generation technologies could help further reduce costs and accelerate uptake, the most pressing innovation needs are now in the **end-use sectors** of transport, industry and buildings, as well as in overall **system design and operation**.
- Innovation is needed to support the increased **electrification** of end-use sectors, accompanied by ways to integrate high shares of variable renewable power. Emerging technologies such as the **digitalisation** of grid services, local and grid-scale e**nergy storage**, smart charging for electric vehicles, wider utilisation of **mini-grids**, and many others will be crucial.
- Beyond electrification, additional innovation is needed to affordably decarbonise industrial activities, such as **iron and steel** making, **cement** production, and **chemical** and petrochemical production, along with **freight** and maritime transport and **aviation**.
- Addressing those substantial innovation needs will require concerted action by multiple parties on multiple fronts.

To learn more, see: ***Accelerating the energy transition through innovation*** (IRENA, 2017)

Government support is essential

- To a large extent, the global energy transformation is being driven by a **policy imperative** – to reduce carbon emissions while providing modern, affordable and reliable energy to all.
- The **private sector**, in most cases, is critical to the successful commercialisation and scale-up of innovations. However, given the **policy-driven** nature of the transformation, governments have a crucial enabling role throughout the innovation journey.
- Both **public and private investment** in innovation **must grow** significantly, and innovation support must be **co-ordinated** across national governments and international initiatives, and with the private sector.
- The private sector typically will not invest in early-stage innovations, mainly because their market potential is too uncertain. Governments' first role, therefore, is to **fund research** that will **create a pipeline** of innovations, the best of which the private sector can subsequently refine and ultimately bring to market.
- Governments also must play a role in the **later stages** of the innovation chain. Because of policy and market uncertainties, the private sector historically has **under-invested** in key renewable energy technologies. A combination of government and private sector investment in innovation puts technologies such as solar photovoltaics (PV) and wind on a path to today's cost-competitiveness.
- Governments may need to invest where others cannot or will not. Yet government actions also can help to unlock private sector investment in several important ways:
  - » through **clear signalling** of innovation priorities
  - » by addressing **policy or regulatory** barriers to innovation
  - » by providing enabling **infrastructure**
  - » by **convening** different actors to move projects forward, and
  - » where needed, by **co-investing** to reduce financial risks.

To learn more, see: ***Renewable energy technology innovation policy: A process development guide*** (IRENA, 2015)

Governments need clear innovation strategies

The transparency and consistency of government support is critical to enable both innovators and investors to engage. To create the right conditions for innovation to thrive, a national energy innovation support strategy should:

Action	Reason
Define clear, ambitious (but deliverable) objectives...	...because doing so inspires action, focuses efforts and drives synergies.
Communicate objectives widely and clearly...	...because many actors have a role to play and a shared understanding and buy-in is critical to collaborative working.
Take a portfolio approach that supports potentially competing approaches (and expect failures)...	...because innovation is often unpredictable.
Be focused on the medium term but retain flexibility to adapt along the way...	...because innovation and energy transitions can take a long time and take unpredictable paths.
Encourage a multidisciplinary approach...	...because the most attractive new solutions are often found at the interface of different areas, such as between the energy sector and ICT.
Balance support for both iterative and potentially game-change innovation...	...because most progress comes from a long hard slog of iterative improvements with only rare dramatic breakthroughs.
Foster collaboration between the public and private sector...	...because it is the private sector that ultimately must bring innovations to market.
Promote harmonized technical standards and quality infrastructure...	...because novel technologies can better compete in globalized markets if requirements are harmonised and safety and performance is quality assured.
Seek out cross-border collaborations to burden share and allow for mutual learning...	...because many challenges are shared and are too large for one government alone, and the best ideas are not usually all in one place

To learn more, see: ***Renewable energy technology innovation policy: A process development guide*** (IRENA, 2015)

Government investment in RD&D must grow

- The world looks to be **under-investing in RD&D** if it is to achieve the cost reductions and performance improvements that are needed to deliver on climate change targets. In comparison to the scale of the challenge and to investment in deployment, current levels of public sector investment (and likely private sector investment) in RD&D look low.
- In 2015 global new investment (public and private) in the deployment of renewables (excluding large hydropower) was about **USD 312 billion**[1]. In the same year, the member countries of the International Energy Agency (IEA) – which account for an estimated 80% of total public sector spending on energy RD&D – invested some USD 14 billion in clean energy RD&D, of which about **USD 3 billion** was invested in RD&D for renewable sources[2]. Reliable data on equivalent private sector investment in energy RD&D are not currently available.
- Despite the recognised global importance of the energy transition, **public sector investment** in clean energy RD&D stagnated during the period 2012-2016.
- The pledges made by the 22 Mission Innovation countries and the European Commission to **"seek to double" investment** in clean energy RD&D (from a combined self-declared baseline of some USD 15 billion annually in 2015) were a welcome recognition of the importance of RD&D and innovation and of the need for increased funding.
- Those **pledges need to be honoured**, and the levels and impacts of that investment boost need to be tracked.
- Private sector investment also needs to grow, but the current **lack of precise data** makes the needed amounts hard to accurately gauge. Better insights into the level of private sector investment and (likely) strategies to increase this investment are urgently needed.
- The "right amount to invest" is highly uncertain – and further analysis is needed – but it seems unlikely that current commitments by Mission Innovation members and others will be sufficient. The scale of the energy transformation challenge means that **investment in clean energy RD&D** must be sustained and **further increased into the 2020s**.

1 **Source:** Frankfurt School-UNEP Centre/BNEF (2017), Global trends in renewable energy investment 2017, http://www.fs-unep-centre.org.

2 **Source:** IEA (2017), Energy technology RD&D budgets: Overview, International Energy Agency, Paris.

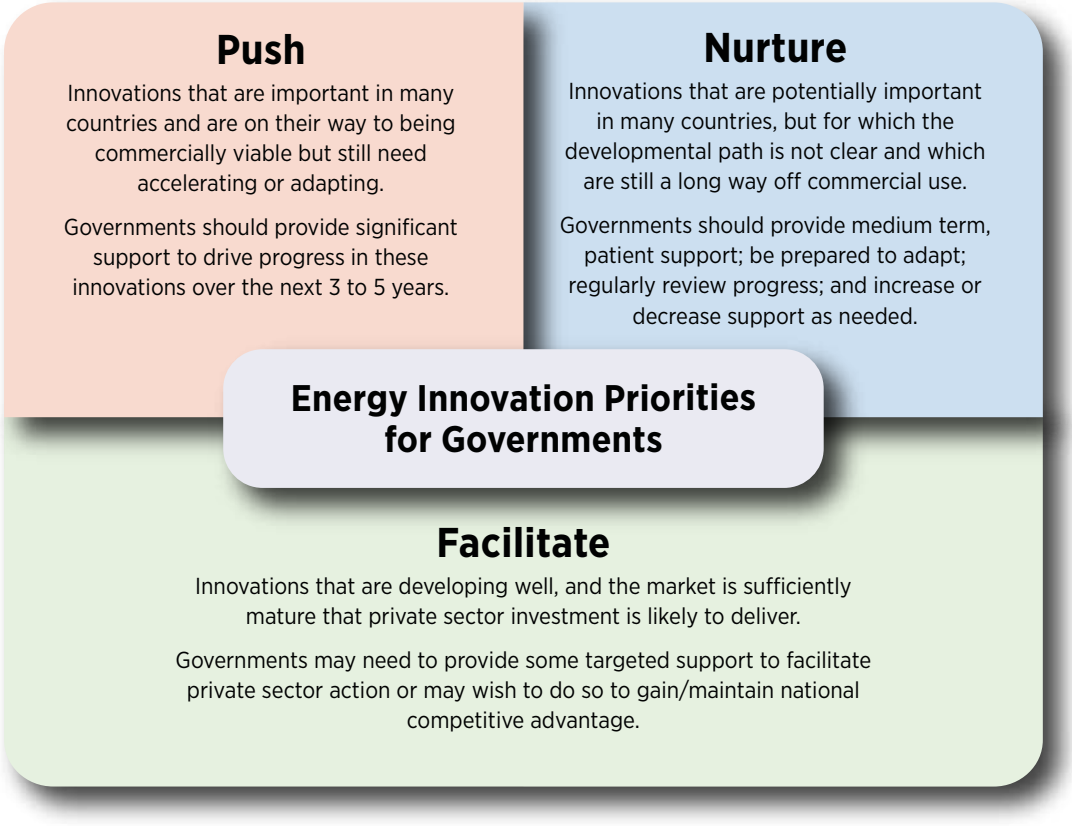
International partnerships can assist

Alongside private sector investment, the investments of governments to address national needs will have the biggest impact on innovation. International partnerships and collaborations, however, can assist and amplify those efforts in some key areas.

Many strong examples exist of collaboration across borders, and several international bodies and initiatives are facilitating such cross-border work on clean energy innovation. However, given the scale of the global energy transformation challenge and the urgent need to accelerate progress, there is substantial scope for increased action. Governments could make fuller use of such programmes and initiatives to complement and increase the impacts of their national programmes.

Identifying global innovation priorities

With finite resources, governments need to target their support carefully. To aid discussion of the priorities for government-backed innovation support programmes, globally relevant innovation needs can be broadly placed into three groups depending on their stage of development and on the urgency of the need. Each group will require different approaches to governmental support.



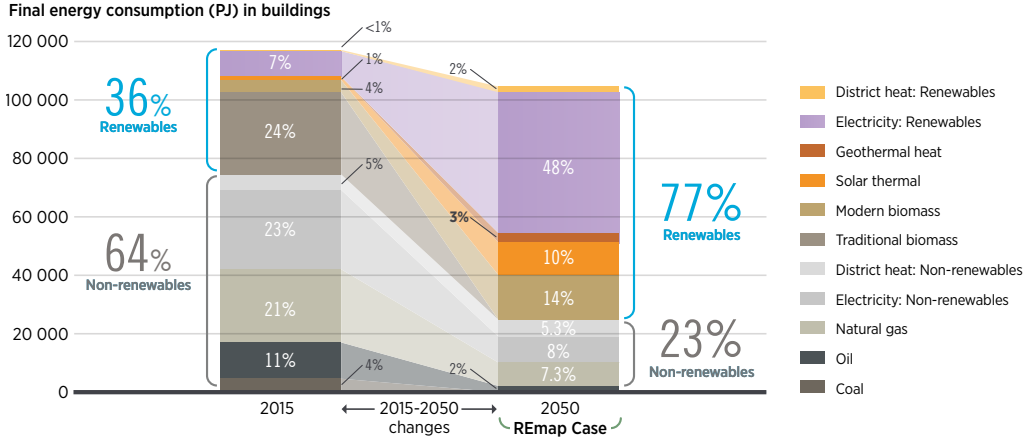
Not every innovation will be relevant to every country. The innovations highlighted in the following pages, however, are all relevant to a range of countries and will require the collective efforts of multiple countries to be successfully developed, demonstrated and brought to market at the pace needed.

International initiatives can assist with that by facilitating cross-border collaboration and highlighting where efforts may be falling short.

Priority innovation needs in buildings

Modern renewable energy in the buildings sector needs to increase significantly. Up to three-quarters of total energy consumption in buildings could be supplied by renewables. Electricity should supply almost 60% of the sector's energy demand.

Buildings accounted for 12% of global CO_2 emissions in 2015.
Emissions need to fall by over 80% by 2050 compared to current and planned policies.



Breakdown of final energy consumption in the buildings sector, by source (PJ/yr), taken from IRENA (2018), ***Global energy transformation: A roadmap to 2050****, International Renewable Energy Agency, Abu Dhabi.*

Implications for energy innovation support:

- Building stocks and living environments vary widely around the world. The optimum mix of solutions to address local needs will be diverse.
- As an example, reductions in existing emissions from heating and cooling homes and offices in developed and emerging economies will likely best come from a combination of heat pumps, modern bioenergy, district heating and cooling, and solar thermal heating.
- These technologies exist and are in use in many countries, but innovation is needed to further improve performance, adapt to local conditions and simplify installation to facilitate more widespread deployment.
- Progress in low-carbon heating and cooling systems must be underpinned by significant improvements in energy efficiency in both new and existing buildings. Solutions for this exist, but innovation is needed to broaden their application and to make installation more affordable and practical.

Strategy	Innovation	Scale-up*	Priorities for support
Push	Retrofit/renovate existing buildings	3x	Regulate for and enforce progressively higher standards Support RD&D into innovative solutions, including installation techniques, for 'hard-to-treat' properties
	District Heating and Cooling from renewable energy	5x	Support demonstration projects that use renewable energy and share learning
Nurture	Hydrogen as a heating fuel	–	Establish multiple demonstration projects and share learning
	Seasonal heat storage	–	Increase support for R&D Support demonstration projects and share learning
Facilitate	Heat Pumps	13x	Alongside support for up-take support RD&D to address deployment challenges, improve efficiency and integrate flexibly with the wider system
	Solar assisted water/space heating	10x	Alongside support for up-take encourage RD&D to address deployment challenges
	Zero energy new builds	>100x	Regulate for, verify and enforce stringent standards
	New super-efficient appliances	–	Alongside support for up-take encourage RD&D for cost reduction
	Clean cooking from renewable energy	18x	Alongside support for up-take encourage RD&D to improve suitability Develop enabling policy frameworks and business models

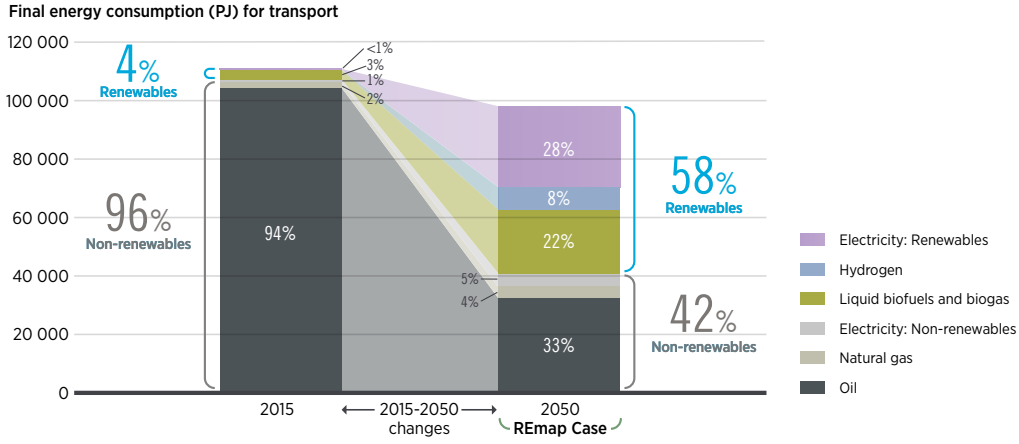
*An indication of the growth in capacity or activity needed between 2015 and 2050. Based on IRENA's REMap analysis.

To learn more, see: ***Accelerating the energy transition through innovation*** (IRENA, 2017) ***Biogas for domestic cooking: Technology brief*** (IRENA, 2017); ***Renewable energy in district heating and cooling: A sector roadmap for REmap*** (IRENA, 2017); ***Renewable energy in cities*** (IRENA, 2016)

Priority innovation needs in transport

The transport sector is dominated by fossil fuels and needs to undergo a profound transformation. Electrification will play a major role, but sustainable liquid biofuels and hydrogen generated from renewable electricity also could play a significant part.

Transport accounted for 23% of global CO_2 emissions in 2015. That needs to fall by around 60% by 2050.



Breakdown of final energy consumption in the buildings sector, by source (PJ/yr), taken from IRENA (2018), ***Global energy transformation: A roadmap to 2050****, International Renewable Energy Agency, Abu Dhabi.*

Implications for energy innovation support:

- Innovation in electric vehicles will be driven mainly by the industry but can be enabled by clear government policy signals and targets such as bans on sales of conventional vehicles from a future date.
- Government investment is needed in enhancing battery / energy storage technologies and in the standardisation and uptake of smart charging infrastructure that could assist in the integration of high shares of renewable energy.
- The role of hydrogen remains uncertain, but RD&D for the renewables- based production, distribution and use of hydrogen is needed to make that option viable.
- Liquid biofuels will play an important role in sectors such as aviation and freight. The main innovation challenges for biofuels relate to ensuring sufficient sustainable bio-feedstocks and reducing the cost of conversion processes.

Strategy	Innovation	Scale-up*	Priorities for support
Push	Electric vehicles and charging infrastructure	811x	Establish multiple demonstration projects for EV smart charging and vehicle-to-grid as a grid-flexibility option to integrate more renewables Supporting standardisation of charging infrastructure Research the energy implications of changes in transport use e.g. autonomous driving
	Advanced biofuels as diesel and jet-fuel substitutes	600x	Support research and development (R&D) for cost reduction Develop sustainable, reliable, affordable supply chains for biomass feedstock Establish multiple demonstration projects and share learning
Nurture	Electricity powered shipping and aircraft	–	Support a range of RD&D projects, share learning and monitor progress
Facilitate	Hydrogen vehicles	–	Support R&D for lower-cost hydrogen vehicles. Establish trial deployment of hydrogen infrastructure Facilitate low-cost hydrogen production from renewable energy Research links to and implications to wider hydrogen use
	Conventional biofuels	4x	Agree international technical and sustainability requirements
	Energy efficiency	2x	Support RD&D into powertrains and lightweight materials

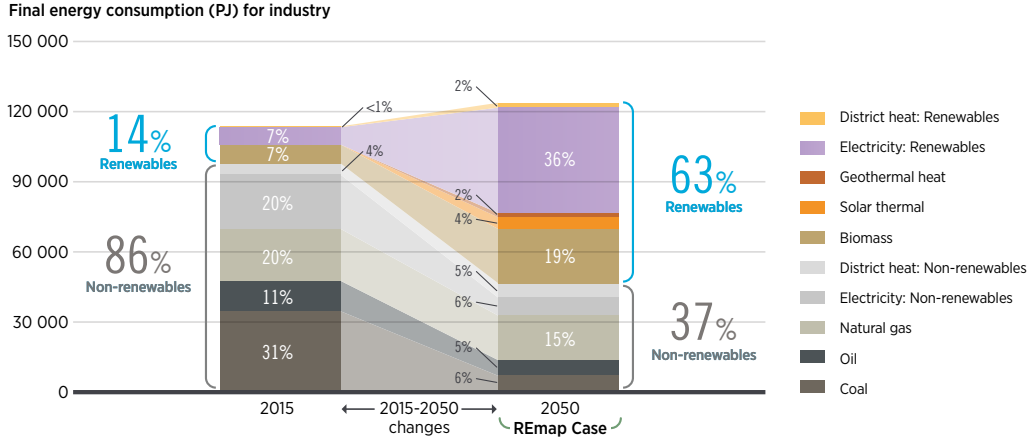
*An indication of the growth in capacity or activity needed between 2015 and 2050. Based on IRENA's REMap analysis.

To learn more, see: ***Accelerating the energy transition through innovation*** (IRENA, 2017); ***Innovation outlook: Advanced liquid biofuels*** (IRENA, 2016); ***Electric vehicles: Technology brief*** (IRENA, 2017); ***The renewable route to sustainable transport: A working paper based on REmap*** (IRENA, 2016); ***Biofuels for aviation: Technology brief*** (IRENA, 2017); ***Renewable energy options for shipping*** (IRENA, 2015); ***Biogas for road vehicles: Technology brief*** (IRENA, 2017)

Priority innovation needs in industry

By 2050, renewable energy use in industry needs to grow to more than four times present levels. Biomass and renewable electrification are expected to play a prominent role.

Industry accounted for 28% of global CO_2 emissions in 2015. That needs to fall by around 50% by 2050.



Breakdown of final energy consumption in the buildings sector, by source (PJ/yr), taken from IRENA (2018), ***Global energy transformation: A roadmap to 2050****, International Renewable Energy Agency, Abu Dhabi.*

Implications for energy innovation support:

- Significant innovation is needed in the most energy- or carbon-intensive industries in order to decrease costs, increase industry acceptance and inform policy. Co-ordinated international policy and regulatory action will be essential to overcome competitiveness concerns.
- In the iron and steel sector – focus on both enhancing the efficiency of existing processes and demonstrating new technologies and fuels such as renewable hydrogen and carbon capture and storage (CCS).
- In the cement sector [3] focus on demonstration projects to explore the blending or replacement of clinker with lower-carbon substitutes; demonstrate the use of biomass and alternative fuels; and utilise CCS.
- In the chemical and petrochemical sector – focus on increasing recycling of chemicals and utilising biomass as both a feedstock and a fuel for plastics production.

3 Clinker is an intermediate product of cement manufacture made by heating ground limestone and clay. Its production is particularly carbon-intensive because it releases CO_2 directly (from the limestone) and from the fossil fuel energy used in heating.

Strategy	Innovation	Scale-up*	Priorities for support
Push	Lower carbon processes for cement making e.g. alternatives to clinker, use of biomass or CCS	>100x	Establish multiple demonstration projects and share learning internationally Support R&D, international sectoral agreements and business models to secure affordable, sustainable biomass supply at scale.
	Direct use of renewable energy in industrial heat	4x	Support RD&D for cost reduction Support sustainable biomass supply (see above)
	Hydrogen use in direct reduced Iron making	10x	Establish multiple demonstration projects and share learning.
	Hydrogen used in ammonium production	11x	Establish multiple demonstration projects and share learning.
Nurture	Biomass used in blast furnaces	10x	Extend application from small- to large-capacity blast furnaces Support sustainable bio-mass supply (see above)
	Chemicals from recycling and biomass feedstock	13x	Support sustainable biomass supply (see above)
	CCS applied to iron-making	12x	Establish multiple demonstration projects and share learning.
Facilitate	Material efficiency	2x	Enforce regulation to promote circular economy in industries
	Energy management systems	3x	Broaden ISO50001 adoption and ensure that it is enforced

*An indication of the growth in capacity or activity needed between 2015 and 2050.

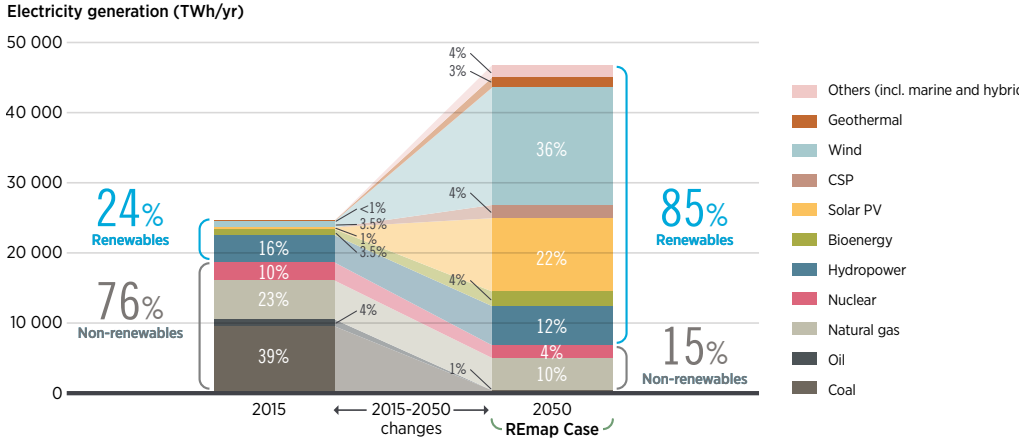
Source: IRENA (2018), ***Global energy transformation: A roadmap to 2050,*** International Renewable Energy Agency, Abu Dhabi.

To learn more, see: ***Global energy transformation: A roadmap to 2050*** (IRENA, 2018); ***Accelerating the energy transition through innovation*** (IRENA, 2017); ***Solar heat for industrial processes*** (IRENA, 2015); ***Renewable energy in manufacturing*** (IRENA, 2014)

Priority innovation needs in power generation

By 2050 the global power sector will need to have transitioned from fossil fuels to renewables. Gross power generation should almost double, with renewable energy providing 85% of electricity.

Power accounted for 37% of CO_2 emissions in 2015. That needs to fall by around 90% by 2050.



Breakdown of electricity generation, by source (TWh/yr), taken from IRENA (2018), ***Global energy transformation: A roadmap to 2050****, International Renewable Energy Agency, Abu Dhabi.*

Implications for energy innovation support:

- The focus of innovation support must shift towards enabling the integration of higher shares of variable renewables such as solar and wind electricity. This will require supporting wider systemic innovations that can increase flexibility, as well as innovation that helps electrify end-use sectors.
- Further innovation in technologies that are becoming established, such as solar and wind power, may still be beneficial – particularly innovations in the ways that these technologies are manufactured, deployed and used. Such innovations can be driven mainly by competition in the private sector, but governments could highlight specific innovation needs and new applications and, where needed, facilitate collaborations to address gaps in capability.
- Broad government support should focus on accelerating progress in under-deployed solutions such as concentrated solar power (CSP) and geothermal energy, which could play valuable roles in some locations as part of the future global energy mix

Strategy	Innovation	Scale-up*	Priorities for support
Push	Battery storage	–	Support R&D for cost reduction and enhanced performance
	Smart grids	–	Support R&D and piloting for a wide range of smart technologies Standardise some components e.g. smart meters Alongside technology, support innovation in business models and market design
	Concentrated Solar Power (CSP)	130x	Support targeted RD&D for cost reduction including thermal storage solutions Establish multiple projects and share learning
	Geothermal	22x	Support innovations to reduce costs and risks for deep geothermal drilling
	Bio-power	3.2x	Develop sustainable, reliable, affordable supplies of biomass feedstock Support RD&D for more flexible operation.
Nurture	Novel energy storage solutions	–	Increase the scale and diversity of R&D including cross-border collaborations.
	Wave or tidal	–	Support R&D and share learning (wave). Establish demonstration projects and share learning (tidal flow).
Facilitate	Hydropower	1.5x	Enhance processes for modernising existing plant Establish trials for responsive uses of pumped hydro Improve river basin planning techniques Increase use of floating solar PV on reservoirs
	Solar PV	32x	Support RD&D for new PV materials, novel PV designs and techniques for deploying PV e.g. building integrated solutions.
	Onshore wind	12x	Encourage collaborative RD&D to enhance manufacturing and refine designs e.g. for hostile weather conditions.
	Offshore wind	43x	Encourage national (and international) collaborative RD&D that enables larger turbine use and makes installation and maintenance more efficient Fund RD&D for cost reduction of floating foundations, establish multiple commercial projects and share learning Support R&D into novel approaches, e.g., kites

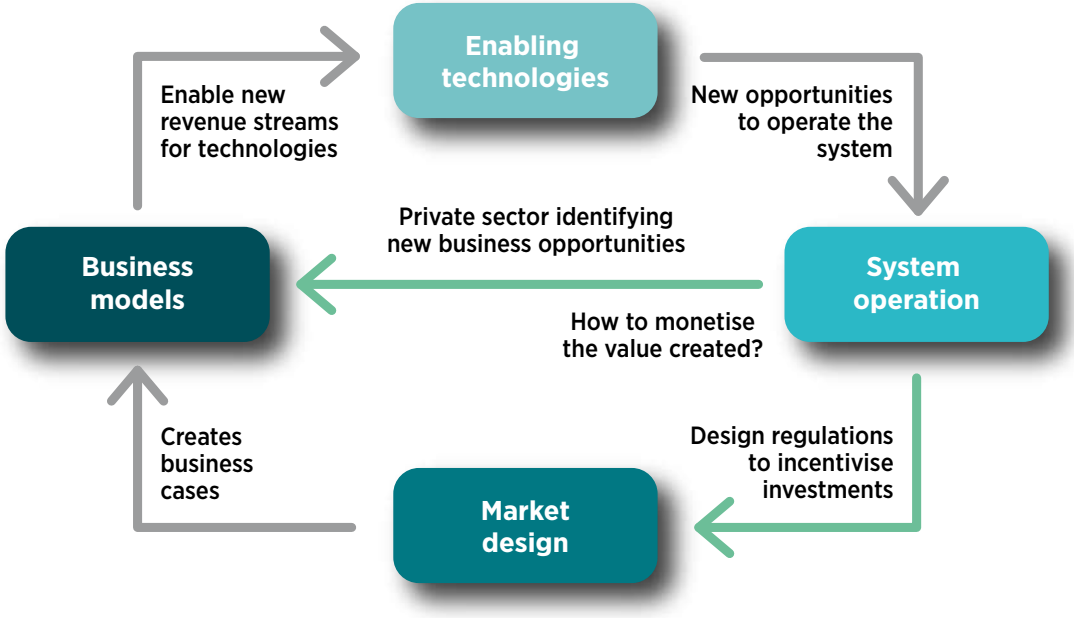
*An indication of the growth in capacity or activity needed between 2015 and 2050. Based on IRENA's REmap analysis.

To learn more, see: ***Accelerating the energy transition through innovation*** (IRENA, 2017); ***Innovation outlook: Offshore wind*** (IRENA, 2016); ***Innovation outlook: Renewable mini-grids*** (IRENA, 2016); ***Geothermal power: Technology brief*** (IRENA, 2017); ***Boosting global PV markets: The role of quality infrastructure*** (IRENA, 2017)

Innovation priorities for an integrated energy system

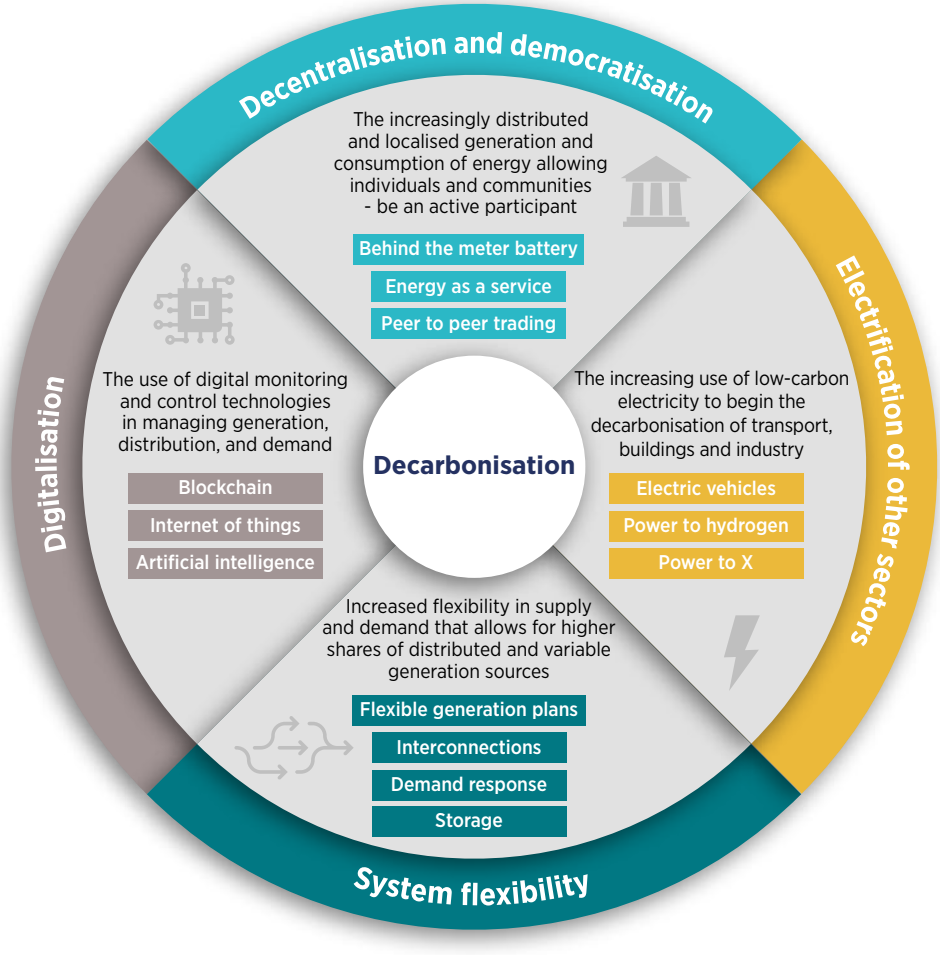
- The transformation of the power sector and the increased electrification of end-use sectors will require innovation beyond the technologies listed earlier. Low-cost renewable power will be key to a low-carbon energy system, but challenges will exist in integrating very large shares of variable renewable energy in power systems.
- Energy systems are evolving fast, but the increasing links and dependencies between the different parts of each system mean that an integrated, system-wide approach to innovation is needed.
- Alongside technological innovation, innovation is needed in enabling infrastructure, in business models, in systems operation and in market design, and those innovations need to be brought together to create integrated solutions that allow higher shares of variable renewable energy and assist in decarbonising end-use sectors.
- These "systemic" innovation needs should be "push" priorities for government support.

Systemic innovation is needed for an integrated renewable energy system



Innovation	'Push' Innovation
Enabling technologies Technologies that play a key role in facilitating the integration of renewable energy	• Storage technologies, able to back up the variability of renewables • Technologies that enable sector coupling, enabling new markets for renewable generation • Developments that introduce new applications in the power sector, changing the boundaries and dynamics of industry
System operation Innovative ways of operating the electricity system, allowing higher shares of variable renewable power generation to be integrated	• New services and tools that enhance electricity system flexibility, such as advanced renewable resource forecasting, facilitating demand-side response and providing flexibility through interconnections • For distributed generation deployment, possible innovations in current roles and interactions – for example, with distributed system operators taking on new roles as market facilitators and local-level system operators
Market design New market structures and changes in the regulatory framework to enable – and provide revenue streams to – new services in a renewable-based power system	• Implementing changes and new regulations in the wholesale markets that, for example, encourage flexibility from existing generators through properly remunerating their grid-support services • Design and regulatory changes in the retail market that stimulate flexibility, such as price-based demand-response programmes and allowing distributed energy resources to actively participate in electricity markets
Business models Innovative models that create the business case for new services, enhancing the system's flexibility and incentivising further integration of renewable energy technologies	• Business models that empower consumers, turning them into active participants – such as the aggregation of distributed energy resources (virtual power plants) or peer-to-peer trading platforms • Innovative schemes that enable renewable energy supply, such as co-operative community schemes or corporate power purchase agreements

These innovations are being driven by – and enabling – trends including increased digitalisation, the decentralisation and democratisation of power generation, and the growing electrification of end-use sectors.



To learn more, attend or read the proceedings of **IRENA Innovation Week 2018** (4 -7 September 2018) and look out for IRENA's upcoming report on the innovation landscape for power sector transformation

Recommendations

The previous pages highlight a range of innovation needs that will require increased national action. Of those, three innovation areas in particular are in need of substantially increased support at a national level and also would benefit from increased international co-operation.

Broaden support for systemic innovation

This refers to the innovative integration of technological innovation with innovation in business models, in processes and in market design – connecting different parts of the energy system to create integrated solutions that allow higher shares of variable renewable energy and assist in decarbonising end-use sectors.

This is a critical enabler of everything else. Many good examples exist of national programmes and international collaboration on aspects of systemic innovation – for example, on smart grids – but there is a need to broaden action beyond grid technologies and to accelerate the development and uptake of system-spanning integrated approaches.

Accelerate innovation to decarbonise industrial sectors

There is a particular need for action on cement, iron and steel, and chemicals. Together these sectors accounted for 17% of CO_2 emissions in 2015.

International trade in these commodities requires an international approach that addresses concerns about national competitiveness and the risk of ”offshoring” emissions. Cross-border collaboration on RD&D therefore must be accompanied by efforts to build international sector-specific agreements.

Develop innovative solutions for low-carbon freight and aviation

Freight and aviation together accounted for 11% of CO_2 emissions in 2015. Options to decarbonise these modes are currently limited and largely unproven.

Biofuels, "electric fuels" (such as hydrogen produced by electrolysis or synthetic fuels) and direct electrification are possibilities, but these options require substantial further development and testing before decisions can be made on the optimal routes. These modes may be decarbonised later in the transition, but given RD&D timescales, increased effort needs to begin now. As with industrial innovation, sector-specific international agreements also will be needed.

Foster deeper international co-operation

International co-operation can support and amplify national actions to accelerate progress – particularly in the above areas.

International organisations and initiatives should pursue this aim: by fostering a shared understanding of global priorities for innovation support; by assessing what investment is needed and who is best placed to take action; by communicating the gaps and opportunities clearly and widely; and by establishing new (or strengthening existing) cross-border collaborative programmes to address common challenges.

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