Decarbonizing the European energy system: the SET-Plan actions in the industry and transport sectors*

Abstract: All European citizens should have access to secure, sustainable and affordable energy. This is the primary objective of the Energy Union, one of the key priorities of the current Commission. This objective can only be achieved through a fundamental transformation of our energy system. In such a system, energy would be used efficiently in all economic sectors, low-carbon conversion technologies would generate electricity along with heating and cooling for homes and industries, and renewable fuels would be used for transport as an alternative to liquid hydrocarbons. This transformation of the energy system will bring additional benefits: the fight against climate change will become more effective and new business opportunities will be created, driven by the need for new services and technologies. The success of this transformation depends largely on the effective development and commercialization of low-carbon, low-cost and high-performance energy technologies and their integration into all facets of the energy system. To meet this challenge, research and innovation (R&I) has become one of the five priorities, or dimensions, of the Energy Union strategy. Placed at the core of the EU’s overall energy and climate policy since its launch, the SET-Plan this year reaches a milestone – its 10th anniversary. During this period, it has contributed to boosting low-carbon energy innovation by triggering an increased alignment between public and private, European and national research agendas. Technological roadmaps and strategic targets helped maintain a focus on

* The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the European Commission.

priorities, while new structures and processes stimulated cooperation and the pooling of resources. During these ten years, the SET-Plan has been a reference point for Europe’s R&I policies at the national and EU levels. The SET-Plan will also play a key role in the completion of the Energy Union, by supporting efforts to develop national energy and climate plans for the implementation of the Energy Union’s 5th dimension. The SET-Plan will continue to function as a cornerstone of Europe’s energy system transformation to a low-carbon and sustainable, smarter energy system for the benefit of European society.

The ongoing transformation of the energy system and the role of the SET-Plan

All European citizens should have access to secure, sustainable and affordable energy. This is the primary objective of the Energy Union, one of the key priorities of the current Commission. This objective can only be achieved through a fundamental transformation of our energy system. In such a system, energy would be used efficiently in all economic sectors, low-carbon conversion technologies would generate electricity along with heating and cooling for homes and industries, and renewable fuels would be used for transport as an alternative to liquid hydrocarbons. This transformation of the energy system will bring additional benefits: the fight against climate change will become more effective and new business opportunities will be created, driven by the need for new services and technologies. The success of this transformation depends largely on the effective development and commercialization of low-carbon, low-cost and high-performance energy technologies and their integration into all facets of the energy system. To meet this challenge, research and innovation (R&I) has become one of the five priorities, or dimensions, of the Energy Union strategy.1

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Since 2007, the European Strategic Energy Technology Plan (SET-Plan)\(^2\) has supported the transformation of the European energy system through the accelerated development of low-carbon technologies and their integration into the energy system. This is achieved by setting collective targets and aligning national and European instruments and funds to meet them, attracting private investments and stimulating joint activities between member states, the industry and the European Union. The important contribution of the SET-Plan in energy policy was confirmed in 2015, when it was identified as the key implementing instrument of the research, innovation and competitiveness dimension of the Energy Union. That year, the European Commission presented a new strategy for an integrated SET-Plan\(^3\) with ten actions structured around the Energy Union R&I priorities, to respond to new challenges in terms of what is needed to accelerate the European energy system transformation towards a competitive low carbon economy with consumers at the center. Currently, the SET-Plan is designing the implementation of these ten R&I actions through a wide participatory process\(^4\) involving national governments, industry and research actors. The output of the process includes ambitious targets for the further development of low-carbon technologies and the acceleration of the European energy system transformation as well as robust implementation plans. Examples of such targets include cost reductions for offshore wind energy and Li-ion batteries for electro-mobility and stationary storage in homes and in utilities, more flexible energy systems, the deployment of smart cities and communities solutions, better management of electricity consumption in homes, and the development of holistic refurbishment packages for buildings. The implementation plans identify a limited number of concrete R&I activities considered essential to reach the agreed targets. The effort to define the implementation plans is led by member states and co-led by industry, with the European Commission acting as facilitator of the process. This work


\(^4\) Coordinated by DG JRC together with DG ENER and DG RTD.
is based on platforms of discussion between countries and industries that share similar strategic interests in specific energy sectors, and is expected to lead to more coordinated activities between countries as well as more coordination between public and private investments, and possibly to new public-private partnerships.

**Ongoing efforts to make EU industry less energy intensive and more competitive**

The transformation of the energy system has had a substantial impact on all economic activity, including European industry. The future of European industry will depend on its ability to compete in a global environment, by continuously adapting and innovating through investments in new technologies and embracing changes brought on by increased digitization and the transition to a low-carbon and circular economy. In this context, the renewed EU industrial policy strategy brings together all existing and new horizontal and sector-specific initiatives into a comprehensive industrial strategy while ensuring leadership in the strategic technologies for the industry of the future. A high-level group will review key enabling technologies and the best possible ways to maximize their industrial deployment. Finally, the EU clean energy competitiveness forum will showcase these industry-led initiatives in key strategic sectors for the clean energy transition and attract international investors around EU innovation pipelines and projects and thus build bridges between private sector financiers and the innovation ecosystem.

Europe’s industry is strong and has retained a leading position in many sectors in global markets. Industry accounts for two thirds of the EU’s exports and provides jobs to 32 million people, with 1.5 million of these jobs created since 2013. But to maintain and reinforce its competitive advantage, an important modernization effort is required. This is why industry is at the heart of the current Commission’s political priorities. As stated during President Juncker’s State of the Union address this year, the new EU industrial policy aims at assisting EU industries to remain or to become world leaders in innovation, digitization and decarbonization.

The issues of energy consumption and cost, and their impact on industrial competitiveness, have become central to EU policy making in the context of the EU’s ambitious energy and climate objectives, and against the challenge of growing competitive pressures from emerging economies. At the EU level,
the energy efficiency of industrial companies is mainly driven by four pieces of EU legislation:

1. the Energy Efficiency Directive (EED),\(^5\) which requires energy distributors or retail energy sales companies to achieve 1.5 per cent energy savings per year through the implementation of energy efficiency measures, and which require large companies to make energy audits and also member states to support and foster voluntary energy audits in SMEs;

2. the EU Emission Trading System (ETS) Directive\(^6\);

3. the Industrial Emissions Directive (IED)\(^7\), which stipulates that Best Available Techniques (BAT) shall be the reference for setting the permit conditions for installations covered by the IED; and

4. the Eco-Design\(^8\) Directive and the recent Regulation 2017/1369/EU that sets up a framework for energy labelling.

These policies are geared to empower industry to create jobs and boost Europe’s competitiveness, foster investment and innovation in clean and digital technologies, and defend Europe’s regions and workers most affected by industrial change. R&I in energy and resources efficiency in industry, as well as in CO\(_2\) emissions reduction, is needed to ensure that industry contributes to climate change targets and to further increase European competitiveness in international markets – in an environment where manufacturing companies from across the globe have increasing access to the same energy saving


technologies, materials resources and markets. R&I investments are therefore necessary to further improve EU technological leadership and innovation know-how. This should help European industrial companies tap into their existing technical energy-saving potential and support the development and commercialization of future disruptive technologies. This strategy is in line with the Council’s conclusions on competitiveness\(^9\) that called on the European Commission to provide a holistic EU industry policy strategy and action plan. In this regard, the EU has launched a number of initiatives which aim to increase the efficiency of energy use, reduce energy demand and attempt to decouple it from economic growth. Several instruments and implementing measures are available in this field, including the promotion of co-generation, the energy performance of buildings (whether private or public buildings), and energy labelling for domestic appliances.

In this context, SET-Plan priority action No. 6 has set highly ambitious R&I targets to improve European industry’s energy efficiency and competitiveness in key sectors which have the highest potential for energy savings and enhanced competitiveness: iron and steel, chemicals and pharmaceuticals, and petroleum refineries. Following consultation with the relevant stakeholders, it became evident that the petroleum refineries sector would benefit most from the cross-cutting technologies. Therefore the SET-Plan now focuses on two sectors: iron and steel, and chemicals and pharmaceuticals. Following the endorsement of the targets set\(^10\) by the SET-Plan steering group on April 20, 2016, where public and private stakeholders agreed to collaborate in a coordinated way to jointly address all relevant issues in order to achieve the agreed R&I targets, a temporary working group for SET-Plan action 6 (TWG6) was setup. Twenty countries joined TWG6 (Austria, Belgium, Switzerland, Cyprus, Czech Republic, Germany, Spain, Finland, France, Ireland, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Sweden, Slovakia, Turkey and United Kingdom). Finland took up the chairmanship and the A.SPIRE association was the co-chair. Stakeholders who joined TWG6 were represented by European associations of the relevant industry sectors, research associations, and education. Their goal was to identify optimal cooperation methods for reaching specific targets:


By 2025, develop and demonstrate:

- cost effective excess heat/cold recovery solutions (to TRL 8), e.g. heat exchangers, higher temperature upgrades, storage, distribution, heat-to-power, heat-to-cold, power-to-heat;
- solutions enabling small and large industries to reduce their energy consumption by 20 per cent while striving to reduce GHG emissions proportionally.

By 2030, for iron and steel and chemical and pharmaceutical sectors:

- make economically viable at least 1/3 of the technical potential of the energy savings related to sector-specific technologies;
- successfully demonstrate at large scale (TRL>=8) 1/3 of the currently promising emerging technologies.

Subsequently, the working group agreed on an implementation plan that contains a short list of essential R&I activities considered as priority for achieving these targets. As an example, one of the concrete activities included in the implementation plan for the Iron and Steel industry is related to a successful scale-up of the HiSarna technology. Up till now, four successful campaigns (during 2011–2014) in the pilot-plant (65 kt/a of hot metal capacity) at Tata Steel (NL) have brought the technology to TRL 6. In 2017, a fifth campaign (supported by the SILC-2 sub-program of Horizon 2020, see below) is analyzing long-term operating stability as well as several aspects of energy savings. HiSarna could reduce specific CO₂ emissions by 20 per cent (without CCS), corresponding to a maximum energy savings of 3.75 GJ/t of steel. The 20 per cent reduction in CO₂ emissions is equivalent to a savings of around 360 ktCO₂eq per million metric tons of hot metal produced, as compared to blast furnace practice.

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11 Payback <= 3 years.
12 “SET-Plan action 6 implementation plan,” op. cit.
13 HiSarna is an oxygen-based process and the top-gas is very rich in CO₂. Up to now, concentrations of ~ 75 per cent CO₂ have been achieved on a pilot-plant scale – the remaining gas being N2 from raw material injection (coal is injected with N2). Having such a concentration of CO₂ opens up possibilities for more energy efficient capture technologies as compared to standard amine technology, for example cryogenic separation.
14 An H2020 project where the JRC is a partner with the consortium that targets a 35 per cent reduction in CO₂ emission intensity vs. BAT by utilizing scrap and biomass and involves tests of limited duration with these materials.
In parallel, the industry-driven European initiative ULCOS (ultra-low carbon dioxide steelmaking) is investigating and demonstrating alternative steelmaking options with the goal to significantly decarbonize the steelmaking process. ULCOS is partially financed through the 6th framework program for research, and the RFCS (research fund for coal and steel).

Other SET-Plan action 6 activities include:

- **steel sector**: Iron ore reduction using hydrogen, and top gas recycling – blast furnace (TGR-BF) using plasma torch;
- **chemical/pharmaceutical sectors**: Chemical reactor, process and plant re-design and optimization – process intensification, separation technologies, power-to-X and the use of unconventional energy sources;
- **crosscutting activities** that other industry sectors can benefit from include:
  - **Heat/cold related activities**: New technologies for utilization of high temperature waste heat in industrial systems, from heat production to delivery and end use; heat or cool upgrade from low to high grade (via heat pump or refrigeration); heat-to-power (electrical) recovery (low and high temperature); and polygeneration (heat, cold, electrical power) and hybrid plants;
  - **System integration activities**: Industrial symbiosis between energy intensive industries to valorize energy loss streams and better manage energy globally; non-conventional energy sources in process industry; digitization; further integration in process and plant management, including plant/process design phase and processing plant retrofit; and improving the exchange of technological, economic, behavioral and social knowledge, training, capacity building and dissemination.

Additional examples of activities highlighted in the implementation plan of action 6, endorsed by SET-Plan steering group members last September, include the organization of workshops on cooperation, at which country representatives meet to share information on their program portfolios and project examples, and discuss existing forms of cooperation and opportunities for future cooperation (bilateral or multi-lateral, e.g. following the Berlin model: ex-post cooperation of running projects, new projects with European added-value). The workshop sessions will be open to countries and stakeholders and will focus on further developing such activities as:
detailing projects, identifying specific actors, and identifying potential funding/financing sources.

Another complementary instrument available for the development of innovative technologies in energy-intensive industry is the Sustainable Industry Low Carbon initiative (SILC), which is implemented via two funding programs: SILC-I and SILC-II. SILC financially supports energy-intensive industries in developing, demonstrating and disseminating low-carbon solutions, and promoting their adoption within and across sectors. The SILC-I program (2011–2019) finances technological and non-technical innovation measures to reduce greenhouse gas emissions that can be implemented in the short term. Eight projects have been funded, covering the following sectors: iron and steel, ferroalloys, cement, glass, ceramics, and pulp and paper. The solutions developed – which include process optimization, implementation of new systems, development of new products, development of best practice guidelines and knowledge hubs, and formulation of new financing models – are not plant-specific, and thus have the potential to be replicated in these sectors and beyond, in already existing production lines.

The SILC-II program (2014–2020) finances the technical and economic demonstration of breakthrough, low-carbon solutions which can bring significant greenhouse gas emissions reduction (more than 30 per cent as compared to the current best technology) and have a high potential for technology transfer within and across sectors. Two large-scale projects – covering the iron and steel and aluminum sectors – have been funded to test proposed solutions in industrial plants under real conditions while developing exploitation and business plans. The first SILC-II project will further optimize and demonstrate the Hlsarna technology which, as previously mentioned, is one of the activities included in action 6 of the implementation plan for the iron and steel industry. The second SILC-II project aims to develop inert anode technology which would enable the decreasing of direct CO2 emissions during the electrolysis process in the manufacturing of aluminum.

R&I investment in energy efficiency in industry has been steadily increasing; nonetheless public investment in this area accounts for only five per cent of R&I investments in all SET-Plan actions. Private investments in R&I have increased by 23 per cent during the period 2007–2013 and account for 17 per cent of private investment in all SET-Plan actions. At the same time, patenting output has more than doubled. China is the world leader in patents, which are predominantly aimed at their internal market, while the EU and Japan are global leaders in terms of international patents. Leading member
states in innovation for energy efficiency in industry are Germany, France, the Netherlands, and the UK.

Energy efficiency, low GHG emissions and competitiveness go hand-in-hand with resource efficiency, industrial symbiosis and a circular economy. Additionally, energy efficiency is a key element for the EU’s energy intensive industries, as they are subject to the emissions trading system.\textsuperscript{15} Hence, a systematic approach is necessary in order to maintain and underpin EU industrial competitiveness in the long run and on a global scale, given the lower energy prices in other parts of the world.

**Ongoing efforts to promote sustainable mobility: clean, competitive and connected**

Mobility and transport directly affect all European citizens. The success of the current Commission’s Energy Union priorities, the digital single market, and the jobs, growth and investment agenda, all relate to transport and mobility. The aim of the European Commission is to promote mobility that is efficient, safe, secure and environmentally friendly, and to create the conditions for a competitive industry generating growth and jobs, boosting the European economy and competitiveness. The role of transport is catalytic: about one fourth of the total EU business R&D expenditure\textsuperscript{16} is transport related. In 2016, European transport companies invested more than 50 billion Euro in industrial R&D, equal to 47 per cent of the world share\textsuperscript{16} well ahead of Japanese and American companies. The impact of this sector in Europe’s energy transition to a low-carbon era is reflected in the wide range of other EU policy frameworks having a decisive influence on the sector: As result of these European policy efforts, European GHG emissions related to transport in 2015 were 10 per cent lower than in 2007.\textsuperscript{17} Road transport has the highest share of GHG emissions among all modes, almost 73 per cent. The Energy Union strategy\textsuperscript{18} identified the transition to an energy efficient,

\textsuperscript{16} EU industrial R&D scoreboard, 2016 – calculated on the top 2500 world corporations, of which 165 are transport-related (automobile and parts, industrial transportation), and 43 in the EU.
\textsuperscript{17} European Environment Agency (EEA), June 2017 – * including international maritime bunkers.
\textsuperscript{18} “Energy Union Package ...,” op. cit.
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The decarbonized transport sector as one of its key areas of policy action. The measures that were already outlined in the European strategy for low-emission mobility, adopted in July 2016, will gradually be implemented. Investment in infrastructure under the investment plan for Europe provides a powerful stimulus for putting in place Europe’s clean, competitive and connected mobility of the future. In June 2017, the European Commission proposed investing €2.7 billion in 152 key transport projects that support competitive, clean and connected mobility in Europe. In so doing, the Commission is firmly delivering on its investment plan for Europe and on Europe’s connectivity including the “Europe on the Move” agenda.

In its May 31, 2017 Communication “Europe on the Move,” the European Commission re-affirmed its support for wide-ranging industry-led initiatives that will make traffic safer, encourage fairer road charging, reduce CO2 emissions, air pollution and congestion, cut red-tape for businesses, fight illicit employment, and ensure proper conditions and rest times for workers. The long-term benefits of these measures will extend far beyond the transport sector by their promoting jobs, growth and investment, strengthening social fairness, widening consumer choices, and putting Europe firmly on the path towards low emissions.

The European Commission has recently launched an online tool to help analyze the role of transport innovation in delivering the EU’s energy and transport strategy. The transport research and innovation monitoring and information system, or TRIMIS, maps and analyses research trends and

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innovation capacities across Europe’s transport sector. TRIMIS supports transport policy makers and researchers by helping to identify innovations with the greatest promise for the future, and helping aid policy makers to focus on areas where public intervention can create the highest added value.

Transport research projects are arranged within the seven Strategic Transport Research and Innovation Agenda (STRIA) roadmaps that were adopted in the “Europe on the Move” package in May 2017. These cover a number of areas, namely: cooperative, connected and automated transport; transport electrification; vehicle design and manufacturing; low-emission alternative energy for transport; network and traffic management systems; smart mobility; and services infrastructure. TRIMIS will monitor the effectiveness of research funded at the EU or member state level by assessing how research projects contribute to a clean, connected and competitive European transport system.

Sustainable transport, which also encompasses batteries and biofuels, received nearly a third of all private R&I funding in Energy Union RIC priorities in 2013. It is an area in which the EU has a specialization advantage, measured in terms of patenting output [the share of sustainable transport in EU energy patents, divided by the equivalent global share], surpassed only by Japan. Leading member states in sustainable transport innovation include Germany, France, Sweden, the UK, and Italy.

**Becoming competitive in the global battery sector in order to drive e-mobility and stationary storage forward**

Electricity, as an energy vector for vehicle propulsion, offers the possibility to substitute for oil a wide range of primary energy sources. This could ensure security of energy supply and the broad use of renewable and carbon-free energy sources in the transport sector, which will help achieve European Union targets on CO₂ emissions reduction.

Policies related to batteries for e-mobility and stationary storage applications are mainly focused on technological optimization and market development. Lithium-ion and post lithium-ion chemistries are considered the most promising and relevant chemistries for electrochemical energy storage within the time frame up to 2030. Future technical challenges include the reliability and durability of batteries and super-capacitors, the reduction of
battery weight and volume, safety, cost reduction, improved hybrid electric power-trains, charging infrastructure, and plug-in solutions.

EU industry has a production base in all segments of the lithium-ion battery value chain, but it is far from being self-sufficient. Raw materials, cell component manufacturing, and cell manufacturing segments are historically dominated by Asian industry, with a steadily growing role being played by China. There is a concern that Europe’s lack of a domestic cell manufacturing capacity will render European industry (in the growing battery-dependent automotive, stationary, and portable electronic markets) increasingly dependent on Asian lithium-ion battery cell suppliers. Nevertheless, EU industry has a strong and dominant position in other segments of the lithium-ion battery value chain, including the recycling segment. The reported recycling capacity of European lithium-ion battery recycling services is estimated to be around 40,000 tons of batteries per year. EU pioneering legislation (e.g. Batteries and Accumulators Directive)24 in this area has made it possible to develop a well-structured industry. Recycling also helps alleviate concerns about the security of supply of critical raw materials used in batteries. However, the battery recycling sector is currently struggling to prepare for the expected large volumes of battery waste from the automotive traction sector. In China, there is currently a shortage of appropriate policies and collection systems for batteries, despite a growing concern in society about the impact of lithium-ion battery waste on the environment and the public.

The annual investment in battery technology R&I coming from the EU’s private sector nearly tripled during the period 2007–2013, accounting for 22 per cent of private R&I investment in all SET-Plan actions. Patenting output increased by a factor of six during the same period. The EU was in third place globally in terms of patenting activity, behind the world leaders Japan and Korea. The EU specialization index revealed that its competitive advantage in this area (the share of battery technologies in EU energy patents, divided by the equivalent global share) has also been increasing, edging out the world average. Specialization in battery manufacturing and recycling was advancing at a slower rate. Importantly, half of EU-based patent applicants have also sought international patent protection, predominantly targeting the US and

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Chinese markets. The leading member states in battery technology R&I are Germany, France, Belgium, and the UK.

In order to become globally competitive in the global battery sector in the near future, consolidated R&I action at the European level is needed, including:

- R&I investment in improved contemporary lithium-ion chemistries, from materials up to large scale cell manufacturing capabilities, to achieve the incremental performance improvements currently demanded.
- R&I investment in post-lithium-ion chemistries, to allow sufficient time for their development and subsequent translation into a manufacturing process so as to realize significant improvements in performance.
- R&I support for developing new mining/extraction techniques, in order to alleviate potential supply concerns for materials whose reserves are located outside EU territory and hence their supply involves a possible risk.
- R&I on alternative Li-ion chemistries made of more accessible raw materials to alleviate the need for the critical materials, cobalt and natural graphite. This could include development of alternative chemistries.
- R&I for improving the cost effectiveness of recycling processes and developing more efficient processes, and for pre-normative research to develop standards and guidelines for the collection and transportation of used batteries, as well as standards and guidelines for battery second-use.

Electrification of transport (electromobility) is a priority in the European Community research program. It also figures prominently in the European Economic Recovery Plan presented in November 2008, and within the

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framework of the European Green Vehicles Initiative.\textsuperscript{27} As stated recently by the Vice President for Energy Union Maroš Šefčovic,\textsuperscript{28} following a high-level meeting on battery development and production in Europe:

Batteries are at the heart of the ongoing industrial revolution. They represent a key enabling technology\textsuperscript{29} in the context of the Energy Union. Their development and production play a strategic role in the ongoing transition to clean mobility and clean energy systems. Batteries embody our ambition, as set out in President Juncker’s State of the Union,\textsuperscript{30} to help our industries remain or become world leaders in innovation, digitization and decarbonization.

Against this backdrop the Vice President announced the creation of a European battery alliance tasked with drafting a roadmap on the future of batteries in Europe.

In the context of the integrated SET-Plan, the aim of action 7 is to become competitive in the global battery sector in order to drive e-mobility and stationary storage forward. Facilitated by the Commission, member states and interested industries – together with representatives from stakeholder associations and clusters – created a SET-Plan temporary working group (TWG7). The TWG7 are drafting a blueprint (implementation plan)\textsuperscript{12} for future European battery R&I (activities, actors and financing) to reach the ambitious targets agreed in July 2016 by member states, industry and the Commission to position Europe competitively in the global battery market. More than 40 actors, led by France and including representatives from member states (France, Germany, Italy, Austria, Norway, Turkey, Belgium, Spain, Estonia, Sweden, United Kingdom), industry, and research stakeholders – representing the full value chain of batteries and battery production systems – have shared their vision and proposals for bringing about a competitive European battery

\textsuperscript{27} “European Green Vehicles Initiative.” Available online: http://www.egvi.eu/ [accessed on October 9, 2017].


\textsuperscript{29} “Key Enabling Technologies.” Available online: https://ec.europa.eu/growth/industry/policy/key-enabling-technologies_en [accessed on October 9, 2017].

manufacturing ecosystem. The implementation plan being prepared by the TWG7 addresses current technical and non-technical barriers and proposes R&I activities, including flagships, to be carried out by industry and member states, and supported by the Commission.

The TWG7 implementation plan takes into consideration existing R&I initiatives at the private, local, national and European levels, as well as the development of industrial infrastructures. The aspiration is to develop activities to complement existing ones, and through effective coordination to leverage the results and impact of European efforts. TWG7 members have identified challenges to competitiveness which can be met by exploiting synergies between European stakeholders across the full battery value chain. The establishment of synergies between R&I actors along the full battery value chain are encouraged, in order to establish a strong and sustainable European battery ecosystem covering battery development, battery production systems, second use, and battery recycling. The TWG members have flagged the need for a sustained R&I investment to make Europe competitive in this sector and to ensure a return on investments.

The implementation plan identifies and describes those R&I activities which will feasibly contribute to achieving the battery performance, cost, manufacturing, second use, and recycling targets identified in action 7. R&I activities are organized over 5 priority areas covering the whole battery value chain:

- materials, chemistry, design and recycling;
- manufacturing;
- application and integration;
- market / market access;
- education, and knowledge value chain.

Ultimately, the activities and flagship projects in the implementation plan comprise the strategic elements needed to establish a complete battery value circle in Europe, including a domestic large-scale battery cell manufacturing base that is compliant with the principles of a European circular economy.

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Strengthening the market take-up of renewable fuels needed for sustainable transport solutions

The renewable energy Directive\textsuperscript{32} established the goal of a 10 per cent share of renewable sources for transport in 2020. The debate on the sustainability of conventional biofuel production, however, has led to more stringent sustainability criteria for first generation biofuels, whilst second generation biofuels still face multiple technical and economic barriers. Significant improvements are still required to achieve the technical maturity and commercial availability of various conversion technologies for lignocellulosic biofuels production. In general, for advanced biofuel production, the necessary technical maturity and efficiency can only be achieved through experience with industrial scale-up and “first-of-a-kind” plants.

To address the sustainability of biofuels for transport, in 2015 the Council and Parliament\textsuperscript{33} set an upper limit of 7 per cent for the contribution of biofuels produced from food crops (e.g. cereal and other starch-rich crops, sugars and oil crops) and established an indicative target of 0.5 per cent for advanced renewable fuels in transport by 2020. Bioenergy production for heating and cooling, electricity and transport is expected to play a major role in decarbonization in all scenarios of the energy roadmap 2050.\textsuperscript{34}

The recently adopted European Strategy for Low-Emission Mobility accentuates the need to accelerate the European transition to low-emission alternative energy in transport. This offers Europe an opportunity to develop leadership in new products, such as advanced biofuels. The Commission already indicated that food-based biofuels have a limited role in decarbonizing the transport sector and should not receive public support after 2020. In the context of the ongoing analytical work to support the revision of the current


legislation on fuels and renewable energy, the Commission is focusing on their gradual phase-out and replacement by more advanced biofuels.\textsuperscript{35}

Facilitated by the Commission, member states and interested industries, together with representatives from stakeholder associations and clusters, kicked off a temporary working group (TWG8) on biofuels and bioenergy in the framework of the Integrated SET-Plan. So far, the following strategic targets regarding renewable fuels for sustainable transport have been agreed:

\textit{Renewable fuels for sustainable transport}

- Improve production performance for advanced biofuels and other renewable liquid and gaseous fuels
- Improve GHG savings
- Reduce costs for end biofuel products and for renewable liquid and gaseous fuels (excluding taxes and feedstock cost)

\textit{Bioenergy}

- Reduce conversion system costs for high efficiency large scale biomass cogeneration of heat and power
- Improve performance and reduce GHG emissions by increasing efficiency

\textit{Intermediate bioenergy carriers}

- Improve performance and reduce cost (excluding taxes and feedstock cost) for intermediate bioenergy carriers:
  - Liquid and gaseous intermediate bioenergy carriers by thermochemical or biochemical processing, and
  - Solid intermediate bioenergy carriers by thermochemical or biochemical processing

Given their positive contribution to both energy security and climate mitigation goals, advanced renewable fuels can justify the short-term high economic cost that their production implies, with a view to their proving to be viable and cost effective in the longer-term through technological

improvements. Many synergies exist between biofuels and other renewable fuels of non-biological origin, and there are many opportunities for process integration to optimize resource efficiency. The contribution of many different types of renewable fuels (e.g. a diverse range of alcohols, hydrocarbons, hydrogen, electricity, etc.) will be needed in order to achieve fossil fuel substitution across all transport modes (road, rail, waterways and aviation).

The alternative fuels infrastructure Directive\textsuperscript{36} establishes a common framework of measures for the deployment of an alternative fuels infrastructure in the Union. Member states have already submitted national policy frameworks for the implementation of this Directive. Among the 25 plans received by the Commission, 15 contain provisions for hydrogen along with other alternative fuels.

In parallel, the European Fuel Cells Hydrogen Joint Undertaking (FCH JU), a public-private partnership, is partially a project-financing consortium dealing with hydrogen technologies. Demonstration activities for fuel cell hydrogen vehicles (cars and buses) and hydrogen refueling stations have been consistently financed throughout the last decade. These activities have begun to take root in the mobility network, in particular at the regional and local levels, where hydrogen mobility programs have been taken up by public transport administrations.

Over the period 2007–2013, a fifth of the public and a tenth of the private R&I investment in all SET-Plan actions was directed to renewable fuel research, half of which was directed to biofuels. The EU is the world leader when it comes to international patents on renewable fuels, with a third of the globally patented innovations in this area in 2013 originating in the EU. The competitive advantage, or specialization, of the EU as measured against the rest of the world has also been increasing.

**The SET-Plan advancing the Energy Union**

Placed at the core of the EU’s overall energy and climate policy since its launch, the SET-Plan this year reaches a milestone – its 10th anniversary. During this period, it has contributed to boosting low-carbon energy innovation by

triggering an increased alignment between public and private, European and national research agendas. Technological roadmaps and strategic targets helped maintain a focus on priorities, while new structures and processes stimulated cooperation and the pooling of resources. During these ten years, the SET-Plan has been a reference point for Europe’s R&I policies at the national and EU levels. Moreover, the SET-Plan has served as a structural model for the Mission Innovation initiative.\textsuperscript{37}

The SET-Plan is now transitioning from its traditional planning phase into a real ‘implementation phase’. The focus is now on execution of the Implementation Plans for achieving the agreed SET-Plan targets, as well as on implementing those actions defined by the EC Communication “Accelerating clean energy innovation.”\textsuperscript{38} In order to ensure its ongoing success, and to build further on it, the SET-Plan aims at maintaining the active involvement of – and intensive cooperation between – member states, research organizations, and industrial groups. Translating these plans into real and effective projects will require a strong commitment from all stakeholders. Although public funding is certainly an important stimulus for R&I activities, the key player is and will continue to be the private sector. To take one example: the first three endorsed implementation plans\textsuperscript{39} – on concentrated solar power/solar thermal electricity (CSP/STE), carbon capture storage and use (CCUS), and energy efficiency in industry – were able to obtain commitments for as much as €7 billion in funding (up to 2030) from the public and private sectors combined.

The SET-Plan will also play a key role in the completion of the Energy Union, by supporting efforts to develop national energy and climate plans for the implementation of the Energy Union’s 5\textsuperscript{th} dimension. The SET-Plan will continue to function as a cornerstone of Europe’s energy system transformation to a low-carbon and sustainable, smarter energy system for the benefit of European society.

\textsuperscript{37} “Mission Innovation. Accelerating the Clean Energy Revolution.” Available online: http://mission-innovation.net/ [accessed on October 9, 2017].
