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EU support for energy storage

Briefing Paper

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Contents

Executive summary

I This briefing paper, which is not an audit report, highlights specific challenges that the EU faces in seeking to ensure that its support for energy storage contributes effectively to the EU's energy and climate goals.

II To mitigate climate change, the EU has set itself targets and objectives to reduce its emissions of greenhouse gases. Energy and climate change are closely linked: energy production and use account for 79 % of EU greenhouse gas emissions, with the heaviest share of emissions coming from energy supply and transport. Tackling this climate change threat requires a fundamental shift from the current, fossil fuels-based energy system to a low-carbon, mainly renewables-based energy system: the 'energy transition'.

III Energy storage technologies provide a flexible response to the imbalances caused by an increased share of variable renewable energy sources, such as solar and wind, in the power grid. Fuels produced from renewable sources, such as renewable electricity or hydrogen, can help to reduce transport emissions; improved energy storage technology can support the expansion of the fleet of vehicles using such fuels.

IV Numerous energy storage technologies are available or under development, such as pumped-hydro storage, different types of batteries, hydrogen storage, compressed air storage, thermal storage systems and different types of gas storage.The EU policy framework for energy storage is based on strategic initiatives such as the European Battery Alliance, support for research and innovation in energy storage technologies, and legislation covering the electricity markets and low-carbon transport. In view of the fundamental role of energy storage in achieving a low-carbon, mainly renewables-based energy system, this briefing paper outlines the main challenges to the development and deployment of energy storage in the EU.

Designing a strategy for energy storage

V The EU has taken steps to develop a strategic framework for energy storage, in view of accelerating the transformation of the EU's energy system and bringing promising new low-carbon technologies to the market. However, there is a risk that the measures taken so far will not be sufficient to achieve the EU's strategic objectives for clean energy.

VI The SET Plan for research into the development of innovative battery technologies seeks to build consensus on the actions needed. The European Battery Alliance is largely focused on existing rather than breakthrough technologies and risks not achieving its ambitious objectives.The EU is behind its competitors in terms of battery cell manufacturing capacity. There is a risk that the current EU strategic framework will not meet the challenges of the energy transition.

Using research and innovation effectively

VII The Commission recognises the importance of effective research and innovation in accelerating the transformation of the EU's energy system and bringing promising new low-carbon technologies to the market. Between 2014 and October 2018, Horizon 2020, the principal research programme of the Commission, had granted €1.34 billion to projects for grid energy storage or for low carbon mobility. The Commission has taken steps to simplify Horizon 2020, but there remains scope to reduce further the complexity of EU research funding and increase participation by innovative companies. There is also a risk that the EU has not sufficiently supported the market deployment of innovative energy storage solutions.

Establishing a supportive legislative framework

VIII Until 2019, investors in energy storage solutions on the power grid faced obstacles. The recent EU legislation should help to overcome these obstacles. The Commission addressed most issues in the Common Rules for the Internal Market in Electricity Directive and the Regulation on the Internal Market for Electricity, due to be adopted at the beginning of 2019. For electric mobility, late and inconsistent deployment of charging infrastructure could delay the widespread take-up of electric vehicles.

IX In this Briefing Paper, we identified seven main challenges to the EU support to the development and deployment of energy storage technologies:

(1) Ensure a coherent EU strategy;

(2) Increase stakeholder support ;

(3) Reduce the complexity of EU research funding;

(4) Support research and innovation in energy storage technologies;

(5) Deploy energy storage technologies;

(6) Remove obstacles encountered by investors; and

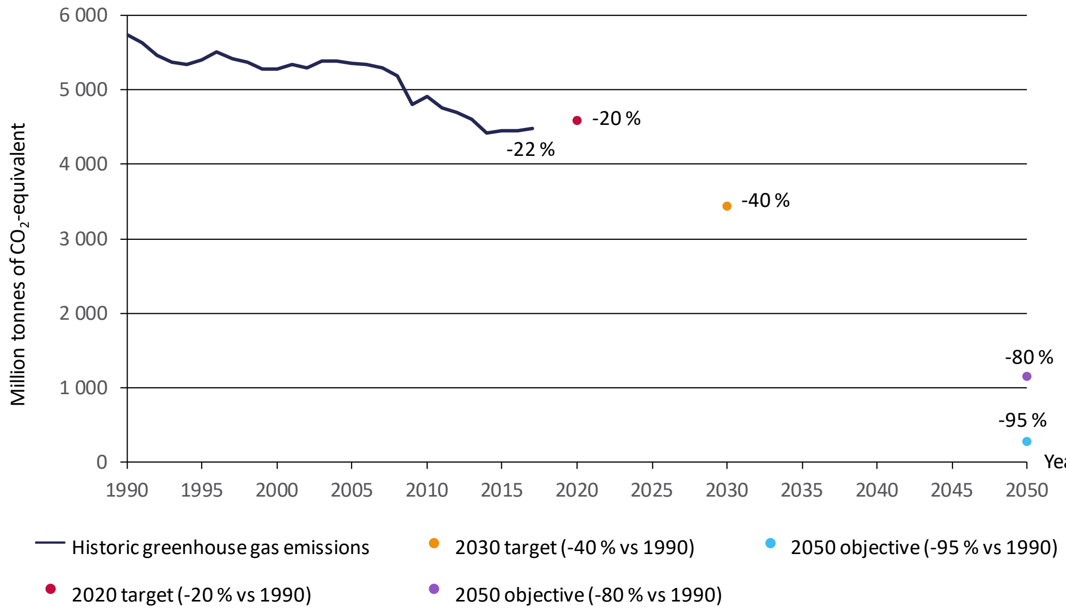
(7) Develop alternative fuels infrastructures.

Introduction

Why energy storage matters

01 In 2015, 195 states responsible for 99.75 % of global greenhouse gas emissions signed the Paris Agreement. They committed to keeping the rise in global average temperature this century to "well below" 2°C above pre-industrial levels, aiming to limit it to 1.5°C[1]. The EU has set itself targets and objectives to reduce its greenhouse gas emissions (see ***Figure 1***).

Figure 1 – EU greenhouse gas emissions trends and targets



Source: Trends and projections in Europe 2018, EEA, 2018.

02 Energy and climate change are closely linked: tackling the climate change threat requires a fundamental shift away from the current fossil fuels-dependent energy system. Energy production and use account for 79 % of EU greenhouse gas emissions, with the heaviest sectoral emissions coming from energy supply and transport. These sectors must increasingly use renewable energies and new technologies to achieve the greenhouse gas emissions targets and objectives.

03 For at least two decades, the EU has used a range of instruments to develop low-carbon energy. For example, since 2005, with the EU Emissions Trading System (EU ETS), the EU has set a limit on overall emissions from some sectors of energy supply,

[1] Paris Agreement, UNFCCC, 2015 (Articles 2 and 4).

energy-intensive industries and, since 2012, intra-EEA flights[2], and created a marketplace for emissions quotas. It aimed, amongst other things, at encouraging the power sector to use more low-carbon energy.

04 In sectors not covered by the EU ETS, such as the transport sector, since 2009, under “effort-sharing”, the European Parliament and Council have set binding national targets for reductions in greenhouse gas emissions.

05 To support the transition to a low-carbon energy-supply sector, the EU has also set targets for the proportion of renewable energy in final energy consumption: **20 % by 2020**[3] **and 32 % by 2030**[4]. This includes renewable energy used to produce electricity, for heating and cooling, and for transport. The 2009 EU Directive on renewable energy also requires Member States to develop storage facilities to stabilise the electricity system as it accommodates more renewable energy.

06 Between 2004 and 2017, the share of EU gross final electricity consumption coming from renewable sources grew from 14 % to 31 %[5]. This share was as high as 72 % in Austria but below 15 % in seven Member States[6]. More than two thirds of the EU’s renewable electricity comes from hydropower (35 %) and wind (34 %)[7].

07 Given that the additional renewable electricity generation is likely to come from the variable sun and wind energy sources, this target should trigger additional demand for energy storage.

08 The EU set specific targets for the share of renewable energy used in **transport: 10 % by 2020**[3] **and 14 % by 2030**[4]. For transport, new renewable energy sources will

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[2] The EEA includes all EU Member States and Iceland, Liechtenstein and Norway.

[3] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (OJ L 140, 05.06.2009, p. 16).

[4] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (OJ L 328/82, 21.12.2018).

[5] Share of electricity from renewable sources in gross electricity consumption 2004-2017, SHARES, Eurostat, February 2019.

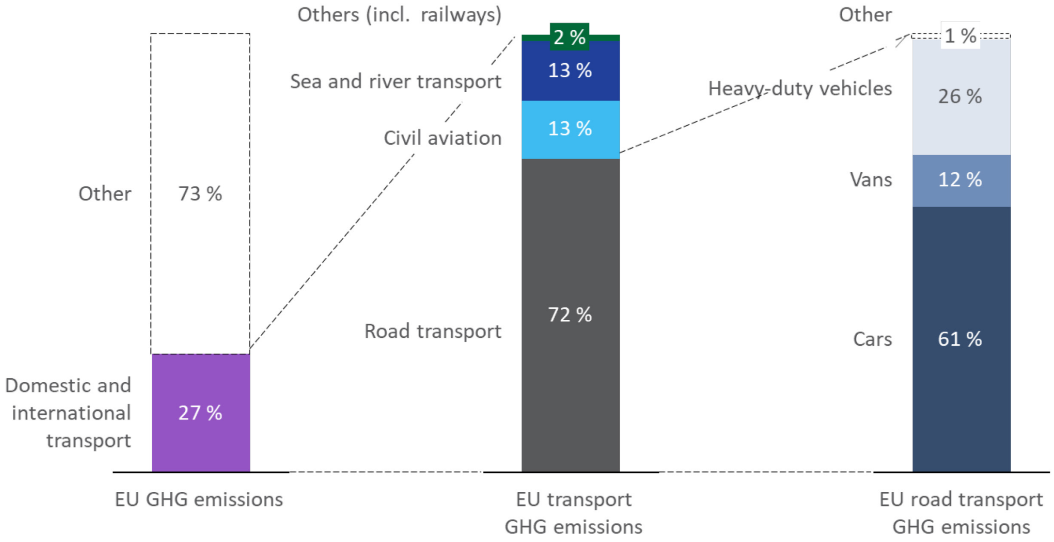
[6] Czechia, Cyprus, Hungary, Luxembourg, Netherlands, Malta, and Poland (Source: Eurostat).

[7] SHARES 2017 Summary Results, Eurostat, February 2019. The Court plans to publish a Special Report on electricity production from wind and solar later this year.

also bring new energy storage challenges. So there will be a need for more energy storage, both in the grid and for transport[8].

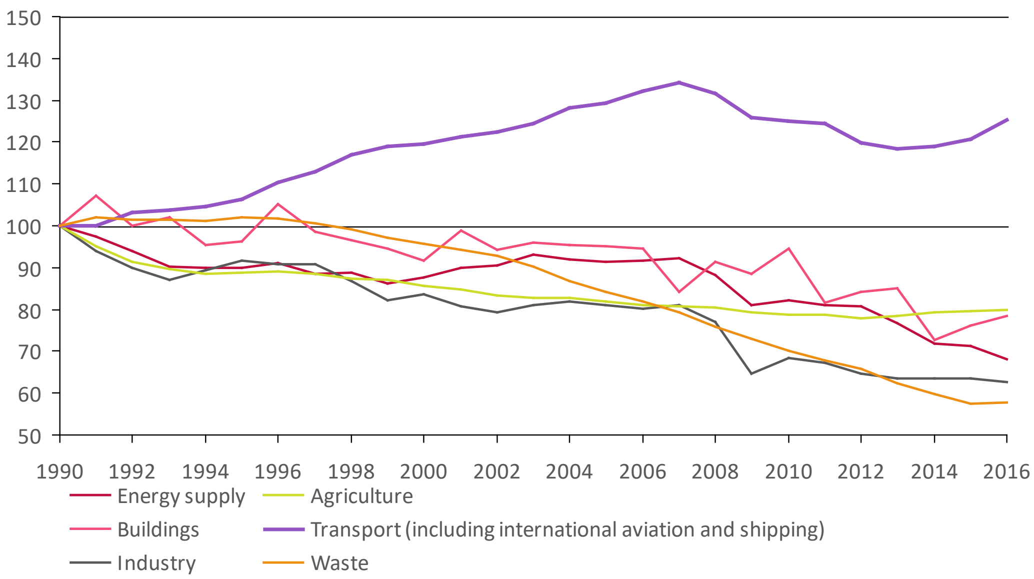
09 Around three-quarters of EU transport greenhouse gas emissions come from road transport, mostly cars (see ***Figure 2***). Following a decrease between 2007 and 2013, transport emissions rose between 2014 and 2016 (see ***Figure 3***).

Figure 2 – EU greenhouse gas emissions in the transport sector in 2016



Note: Includes international aviation and shipping.
Source: European Environment Agency, *EEA greenhouse gas – data viewer*, 2018; ECA analysis.

Figure 3 – Trend in EU greenhouse gas emissions, by sector, 1990-2016



Source: European Environment Agency, *EEA greenhouse gas – data viewer*, 2018; ECA analysis.

[8] Landscape Review on EU action on energy and climate change, ECA 2017, paragraph 214.

Energy storage technologies

10 An overview of the main energy storage technologies for grid and transport applications is presented in ***Figure 4***.

Figure 4 – Overview of main energy storage technologies and their uses[9]

Storage technology needed...		Batteries								
	Pumped-hydro	Lithium-ion	Lead-acid	Redox flow	Sodium sulphur	Super-capacitor	Hydrogen Fuel cell	Flywheel	Compressed or liquid air	Thermal storage
... in the grid for...										
Seasonal storage Need: Large storage capacity, slow discharge	✓						✓			
Daily storage (peak demand shifting) Need: Hours of supply	✓	✓	✓	✓	✓		✓		✓	✓
Grid support services (e.g. frequency response) Need: Fast response, seconds to hours of supply	✓	✓	✓	✓	✓	✓	✓	✓		✓
Households Need: Small scale, long lifetime		✓	✓	✓			✓			
... for transport for...										
Road Need: High power, low weight, small size		✓				✓	✓			
Aviation/shipping Need: High power, high energy per volume						✓	✓			

Source: ECA, informed by Electrical energy storage for mitigating climate change, Imperial College London.

On the grid

11 Transforming the energy system presents significant challenges for integrating variable renewable energy sources into the electricity system, and balancing supply and demand. Three main methods would need to be deployed:

- First, **grid interconnections** make it more likely that supply across the grid will meet demand. However, we have found in our 2015 audit that EU energy infrastructure, within and between Member States, is generally not yet designed for fully integrated markets[10].

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[9] See Annex II for a description of these technologies.

[10] Special Report 16/2015 Improving the security of energy supply by developing the internal energy market: more efforts needed, European Court of Auditors, 2015. This was also confirmed in the Commission's Second Report on the State of the Energy Union, COM(2017) 53 final, 2017.

- Second, **demand can be managed**: factories can adjust their production, and thus their energy use, to times when electricity is more abundant and cheaper. Similarly, in some households, hot water tanks can be remotely switched on and off by the electricity provider to manage the timing of demand. However, consumption can usually be postponed only for a few hours, not for days. Demand management in the residential and service sectors also faces regulatory and market design barriers[11].

- Third, **electricity can be stored** so that it can be used later. Storage solutions can also provide additional grid support services[12]. To meet its 2050 climate goals, the Commission has estimated that the EU may need to increase energy storage up to six-fold[13].

12 In the EU, for the power grid, **pumped-hydro storage** is the most common electricity-storage technology, representing 88 % of installed storage capacity[14]. It is used both for daily storage and seasonal storage. Geological restrictions, environmental sustainability and public acceptance present challenges to the construction of new large-scale pumped-hydro storage facilities[15].

13 **Batteries** store electrical energy in chemical form and convert that energy into electricity. A battery typically has three parts: two electrodes and an electrolyte between them. When a loaded battery is connected to a circuit, charged ions flow between the electrodes through the electrolyte. This transfer of charges generates electricity in the circuit. Batteries can be used for short-term energy storage, over the course of hours and days, for example for shifting daily peak demand. However, when loaded, they cannot maintain their charge for weeks or months without serious losses.

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[11] The potential of electricity demand response, European Parliament, 2017.

[12] For example, mismatch between electricity generation and demand can cause variations in frequency; some storage technologies can bring the frequency back to its proper value. This is called “frequency response”.

[13] A Clean Planet for all, European Commission, COM(2018) 773 final of 28.11.2018, p. 7. The Commission developed pathways for the transition to a net-zero greenhouse gas emissions economy. The Commission’s estimation for storage needs is based on pathways that focus on intense electrification in end-use sectors.

[14] Source: Pumped Hydro Storage, European Association for Storage of Energy; Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?, Policy Department A: Economic and Scientific Policy. European Parliament, 2015.

[15] Assessment of the European potential for pumped hydropower energy storage, Joint Research Centre, 2013.

Many types of battery, such as lead-acid and lithium-ion, are in commercial use. New versions of these technologies are being developed. Researchers are working on alternatives, such as solid-state lithium batteries.

In transport

14 In addition to biofuels, renewable fuels such as **renewable electricity, renewable hydrogen and synthetic natural gas** can reduce greenhouse gas emissions in the transport sector. The expansion of the fleet of vehicles using such fuels is currently constrained by, for example, their range, cost, and the lack of refuelling infrastructure.

15 Electric and hybrid road vehicles usually store energy in lithium-ion batteries. They represented 0.4 % of all EU road vehicles at the end of 2018[16]. Electric vehicles currently make up roughly 1 % of all vehicles globally; according to private companies' projections, this figure could reach 20 % by 2030[17].

16 Hydrogen produced from renewable sources can also power fuel cells in cars and other vehicles. These vehicles can be refuelled in a few minutes. Hydrogen can be converted into synthetic natural gas, which could also power planes and ships. However, hydrogen production currently has cost challenges to overcome.

Objective and approach of this Briefing Paper

17 In September 2017, we published our landscape review on EU action on energy and climate change, which identified seven major challenges in the field of energy and climate change. These included the energy transition and using research and innovation effectively.

18 In the light of these challenges and the fundamental role of energy storage in achieving a low-carbon, mainly renewables-based energy system, this Briefing Paper describes the EU support for energy storage since 2014, focusing on:

- the **strategic framework** for the development of energy storage technologies, since the revision of the SET Plan in 2015;

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[16] ECA estimation based on data from the European Alternative Fuels Observatory, the European Automobile Manufacturers Association and Eurostat.

[17] See for example How battery storage can help charge the electric-vehicle market, McKinsey&Company, 2018.

- the **EU research and innovation** funding instruments for energy storage technologies in the current programming period (2014-2020)[18];
- the **EU legislative framework** supporting the deployment of energy storage technologies from 2014 onwards.

19 This paper, which is not an audit report, highlights specific challenges that the EU faces in seeking to ensure that its support for energy storage contributes effectively to the EU's energy and climate goals.

20 The facts presented in this briefing paper derive from:

- documentary reviews and interviews with eight Commission Directorates-General[19] and five other EU bodies[20];
- review of 452 relevant Horizon 2020 research projects, including in-depth analysis of a sample of 57 projects;
- visits to 17 energy storage research projects: 13 co-financed by Horizon 2020 grants, two supported by EIB loans and two projects financed by national and/or private funds;
- interviews with 40 active stakeholders, including research institutions, international organisations, energy associations, energy regulators and companies from the energy, automotive and battery sectors[21]. Twenty-eight of the stakeholders also replied to a questionnaire[22]. Fourteen of the stakeholders had participated in EU-funded research projects for energy storage;
- our previous audits and reviews; and

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[18] Some of the research projects we looked at had been initiated under the previous programming period (2007-2013).

[19] Directorates-General for Research and Innovation; Climate Action; Environment; Energy; Mobility and Transport; Communications Networks, Content and Technology; Internal Market, Industry, Entrepreneurship and SMEs; and the Joint Research Centre (JRC).

[20] The Innovation and Networks Executive Agency (INEA); the Fuel Cells and Hydrogen JU; the European Green Vehicles Initiative; the EIT InnoEnergy KIC; the EIT RawMaterials.

[21] Battery cell production; battery pack assembly; and applications for the grid and electric mobility.

[22] The stakeholders answered the parts of the questionnaire relevant to their organisation. For instance, energy regulators replied to the sections on EU strategy and legislation, but not to questions on research and innovation.

- a literature review and consultation with an expert in energy storage technologies and markets.

21 This Briefing Paper covers the EU support for storage of electricity, either for the grid or for vehicles, and for synthetic gas production. We excluded storage of fossil fuels from the scope of this paper.

22 It takes into account developments in the EU energy storage sector until the end of January 2019.

Review of EU support to energy storage

Strategic framework for energy storage

23 The main milestones in EU support, since 2007, for stationary storage, mobile storage, and research and innovation in energy storage are summarised in ***Annex I***.

The Strategic Energy Technology plan

24 The Commission presented the Integrated Strategic Energy Technology Plan (SET-Plan) in 2007 and revised it in 2015[23]. This plan underpinned an EU approach to energy research and innovation, designed to accelerate the transformation of the EU's energy system and bring promising new low-carbon technologies to the market. It seeks to coordinate research and innovation activities in the Member States and other associated countries (Iceland, Norway, Switzerland and Turkey). It stated that a breakthrough in the cost-efficiency of energy storage technologies was needed to complete decarbonisation by 2050[24].

25 The SET plan contains ten key actions, four of which are relevant to energy storage:

- Action 4: development and operation of resilient, reliable, and efficient energy systems, able to integrate variable renewable sources;
- Action 6: continue efforts to make EU industry less energy intensive and more competitive, e.g. by developing thermal energy storage technologies;
- Action 7: batteries for electric mobility and stationary energy storage;
- Action 8: bioenergy and renewable fuels for sustainable transport[25].

26 Under action 7, the Commission, several Member States and research and industry stakeholders agreed in 2016 on battery performance, cost and manufacturing

[23] Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation, European Commission C(2015) 6317 final, 2015.

[24] A European Strategic Energy Technology Plan (SET Plan). European Commission COM(2007) 723 final, 2007.

[25] Under Action 8, hydrogen was not considered in the context of energy storage until 2014, when demonstrating the feasibility of hydrogen energy storage became an explicit objective of the Fuel Cells and Hydrogen 2 Joint Undertaking.

targets to be achieved by 2020 and 2030[26]. In November 2017, they put forward an implementation plan for the period from 2018 to 2030, which indicates technology readiness levels[27] to be reached, expected timelines and required budgets.

The European Battery Alliance

27 Batteries are a crucial component of electric vehicles: they represent around 50 % of the vehicle's cost[28]. According to a leading international consulting company, the closer battery suppliers are located to car manufacturers, the shorter, cheaper, safer[29] and more flexible the supply chain is, and the easier it is to innovate by testing battery components. To strengthen the developing EU electric car industry, the Commission considers it important for the EU to have its own battery manufacturing capacity[30].

28 The growth of electric vehicle production increases the demand for lithium and cobalt, core raw materials needed for lithium-ion battery production. According to the KIC InnoEnergy, China owns around 50 % of lithium and cobalt mining operations. The Commission considers it important to secure access to raw materials from resource-rich countries outside the EU, facilitate access to European sources of raw materials, as well as accessing secondary raw materials through recycling in a circular economy of batteries[31].

29 By 2018, the EU accounted for around 3 % of global battery cell manufacturing capacity. This compares to 84 % of the capacity in the Asia-Pacific region[32] and 12 % in

[26] Become competitive in the global battery sector to drive e-mobility forward, 2016.

[27] A measurement scale developed to assess the maturity of a particular technology. On a scale from 1 to 9, TRL 1 corresponds roughly to basic research, TRLs 2-4 to applied research, TRLs 5-6 to applied research/development, TRLs 7-8 to demonstration and TRL 9 to full-scale deployment.

[28] Bloomberg New Energy Finance, April 2017, p. 6.

[29] As hazardous goods, batteries are subject to special handling regimes when being transported. The raw materials needed to manufacture battery cells, however, are not.

[30] Speech on the EU Battery Alliance by Vice-President Maroš Šefčovič, Industry Days Forum, Brussels, 23 February 2018.

[31] Strategic Action Plan on Batteries COM(2018) 293 final.

[32] In China, South Korea and Japan.

North America[33]. China, in particular, has taken several actions to promote the development of hybrid or electric vehicles (see ***Box 1***).

Box 1 - China's initiatives to promote hybrid and electric vehicles

China has introduced a credit system for new, low-carbon, passenger cars. Each hybrid, fuel cell or fully electric vehicle is awarded two to six credits. In 2019, automobile companies with annual production or import volumes of at least 30,000 cars must earn a number of credits equivalent to 10 % of their total car sales. This will rise to 20 % in 2025[34].China also gives incentives for the production of electric buses, subsidies to consumers who purchase electric vehicles and priority issuance of vehicle licenses to electric vehicle owners in major cities.

30 In light of the EU's low battery cell manufacturing capacity, in October 2017 the Commission announced the European Battery Alliance. The Alliance aims to create a competitive, sustainable battery-manufacturing value chain in Europe. It encapsulates the Commission's efforts to bring together EU industry partners, research and innovation partners and Member States to make "*Europe a global leader in sustainable battery production and use*".

31 The associated 2018 Strategic Action Plan on Batteries describes measures to facilitate access to raw materials for batteries, support large-scale battery cell manufacturing, accelerate research and innovation in the field, develop a highly skilled workforce, and ensure consistency with the EU regulatory framework. The Action Plan consists of 37 key actions, mainly focused on the increased and more integrated use of existing regulatory and funding instruments.

32 The Commission considers that meeting EU battery demand alone, which it estimates could reach a value of €250 billion a year by 2025, would require at least 10 to 20 large-scale battery cell production facilities, or "gigafactories", producing around 200 GWh of lithium-ion batteries per year[35]. The Commission estimates the total required investment to be around €20 billion.

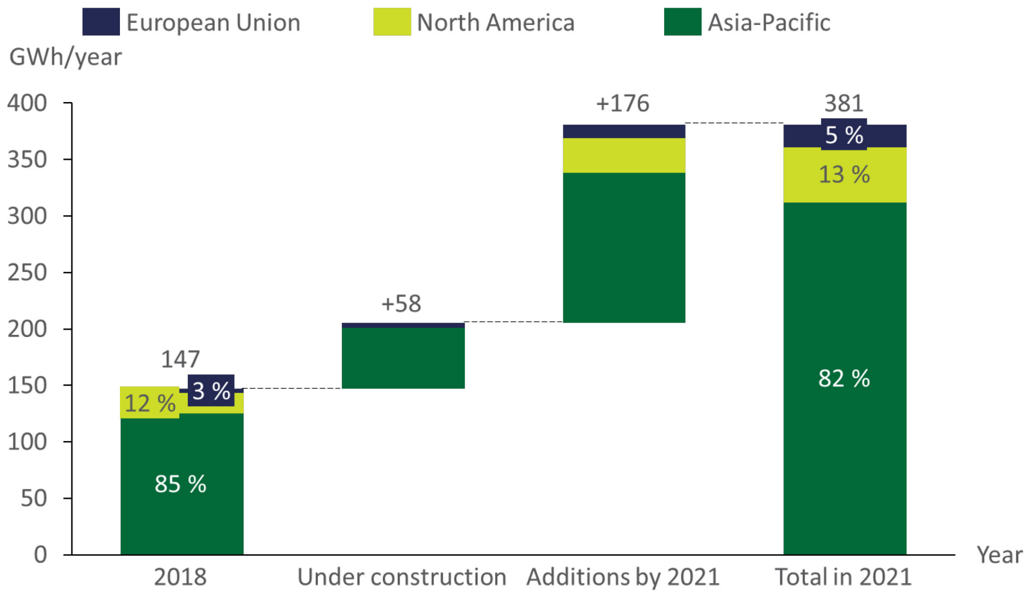
33 Between 2018 and 2021, the EU will develop its battery-manufacturing capacity later than other leading global regions (see ***Figure 5***).

[33] Li-ion batteries for mobility and stationary storage applications, JRC, November 2018, p. 24.

[34] China's new energy vehicle mandate policy, ICCT, January 2018.

[35] European Battery Alliance website, Speech on the EU Battery Alliance by Vice-President Maroš Šefčovič, Industry Days Forum, Brussels, 23 February 2018.

Figure 5 – Projected development of lithium-ion battery cell manufacturing capacity, 2018-2021



"Rest of the World" not shown (approximately 0.7% in 2018 and an additional 0.8% in 2021).
Source: ECA, adapted from Li-ion batteries for mobility and stationary storage applications, JRC, 2018.

34 Beyond 2021, the EU Commission's Joint Research Centre (JRC) expects four other plants to add further manufacturing capacity in the EU[36]. According to the KIC InnoEnergy, it takes four years to build cell-manufacturing infrastructure[37]. In total, the EU's manufacturing capacity may reach 70 GWh in 2023[38], well below the EU target of 200 GWh set by the Alliance for 2025. By then, the EU battery market may already be largely supplied by plants not located in the EU, or car manufacturers might have relocated part of their production outside of the EU closer to battery manufacturers.

35 In 2014, the Commission issued guidelines[39] on the compatibility of the public financing of important projects of common European interest (IPCEIs), such as energy

[36] Source: Li-ion batteries for mobility and stationary storage applications, JRC, 2018.

[37] Bridging the gap between Financial Institutions and Industry, Event organised by InnoEnergy, Brussels, January 2019.

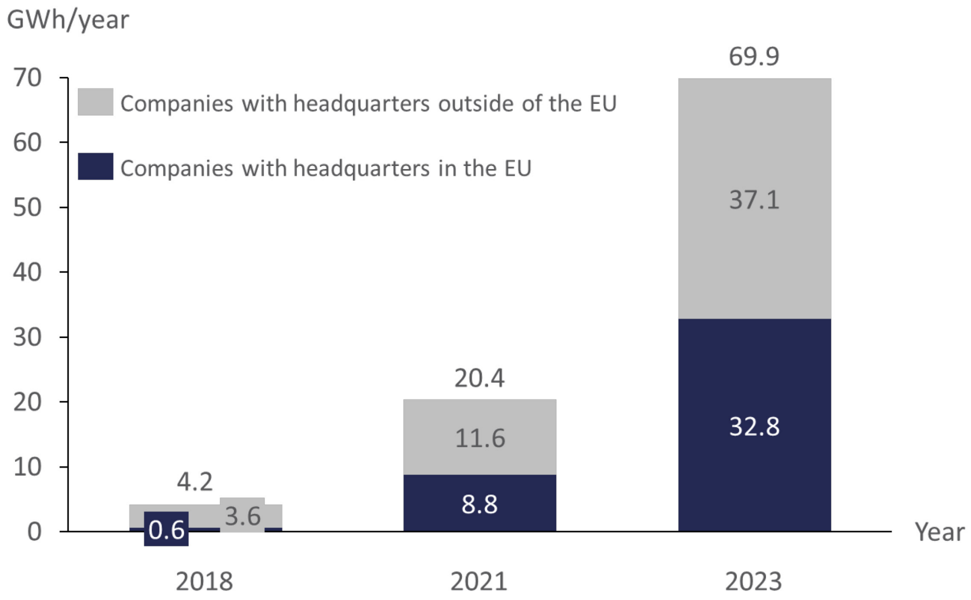
[38] ECA calculation based on Li-ion batteries for mobility and stationary storage applications, JRC, 2018.

[39] Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest (2014/C 188/02), European Commission, 2014.

storage projects, with state-aid rules[40]. In December 2018, France and Germany launched a process to identify credible consortia, including car manufacturers, which could participate in such a scheme. Their aim is to develop investment plans and get them approved by the Commission in 2019.

36 Non-EU companies will fund some plants in the EU. JRC projected that non-EU companies may capture 53 % of the manufacturing capacity in the EU by 2023 (see ***Figure 6***)[41].

Figure 6 – Producers of lithium-ion battery cell manufacturing capacity for large applications, such as grid and transport, in the EU



Source: ECA, adapted from Li-ion batteries for mobility and stationary storage applications, JRC, 2018.

37 In 2017, existing lithium-ion electric vehicle battery factories worldwide operated at around 40 to 50 % capacity[42]. According to a leading international consulting company, in the short term, it will therefore be difficult for new entrants to penetrate cost-effectively the current generation lithium-ion battery market: incumbents can use their surplus production capacity to make, or threaten to make and sell, more batteries at a marginal cost. As the EU will enter the battery-production market as a

[40] Investing in a smart, innovative and sustainable Industry: A renewed EU Industrial Policy Strategy COM(2017) 479 final, European Commission, 2017.

[41] Assuming that the manufacturing capacity of LG Chem Sp. z o.o will increase to 12 GWh/year by 2023.

[42] Lithium-ion battery costs and market: Squeezed margins seek technology improvements & new business models, Bloomberg New Energy Finance, 2017, pp. 3-4.

"second mover", it may have difficulties to generate a competitive advantage unless it exploits technological advantages.

Stakeholder support

38 We received survey responses from 28 stakeholders[43] about the Commission's strategy – both the SET-Plan and the European Battery Alliance:

- All were aware of the Commission's strategic framework for energy;
- Around half considered that the Commission's framework for energy storage was appropriate and helpful for their organisation;
- But two-thirds also said it could be improved:
  - ten replied that the strategy was too focused on lithium-ion batteries for vehicles;
  - five drew attention to shortcomings in legislation, market design and standard-setting;
  - two referred to a lack of long-term vision, raising the prospect that the EU car industry could disappear altogether.

39 Eighty participants joined the European Battery Alliance when it was launched in October 2017. According to the Commission[44], one year later, this number had increased to around 260.

40 Some important stakeholders, other than those surveyed, decided not to join the Alliance. For example, one major EU-based electronics company considered it too risky to invest in large-scale lithium-ion battery-cell manufacturing in the context of a market already dominated by Asian manufacturers (see ***Box 2***).

[43] From public research and innovation, energy industry, transport industry, battery industry, energy associations, international organisations.

[44] European Battery Alliance website.

Box 2 - A European company opts for outsourcing for battery cells instead of in-house manufacture

A major EU engineering and electronics company decided not to join the European Battery Alliance. It said it would outsource rather than manufacture lithium-ion battery cells in-house. The company considered it would be difficult to exploit a competitive advantage, given that three quarters of manufacturing cost is for raw materials, in a market dominated by low-cost Asian competitors.

It decided to disband its research into current and future cell technologies and to dissolve its joint venture for lithium-ion technology. Instead, the company decided to focus on battery systems.

41 Similarly, a French consortium decided to seek to develop next-generation lithium-ion battery cells in the short-term, and then focus on solid-state batteries, for which it expects a technological breakthrough in around 2023[45].

Energy storage research and innovation

42 The 2014-2020 Framework Programme for Research and Innovation, Horizon 2020, is the EU's main research and innovation funding instrument. By October 2018, Horizon 2020 had granted €1.34 billion to projects for grid energy storage or for low carbon mobility. This represents 3.9 % of the total EU contribution (€34 billion) awarded to Horizon 2020 projects by that date.

43 The breakdown of EU grants to energy storage projects by October 2018, under these various instruments, is shown in ***Figure 7***. In 2019, Horizon 2020 included a call for battery projects worth €114 million[46], with more funding to come in 2020.

44 The Commission manages most **Horizon 2020** programmes directly. It mainly funds grants to researchers and specific instruments supporting research and innovation in small and medium-sized enterprises. Horizon 2020 also co-finances public-private partnerships, such as the Fuel Cells and Hydrogen Joint Undertaking. Horizon 2020 further supports research and innovation networks, such as the European Institute of Technology Knowledge and Innovation Communities InnoEnergy (EIT InnoEnergy KIC) and RawMaterials (EIT RawMaterials KIC).

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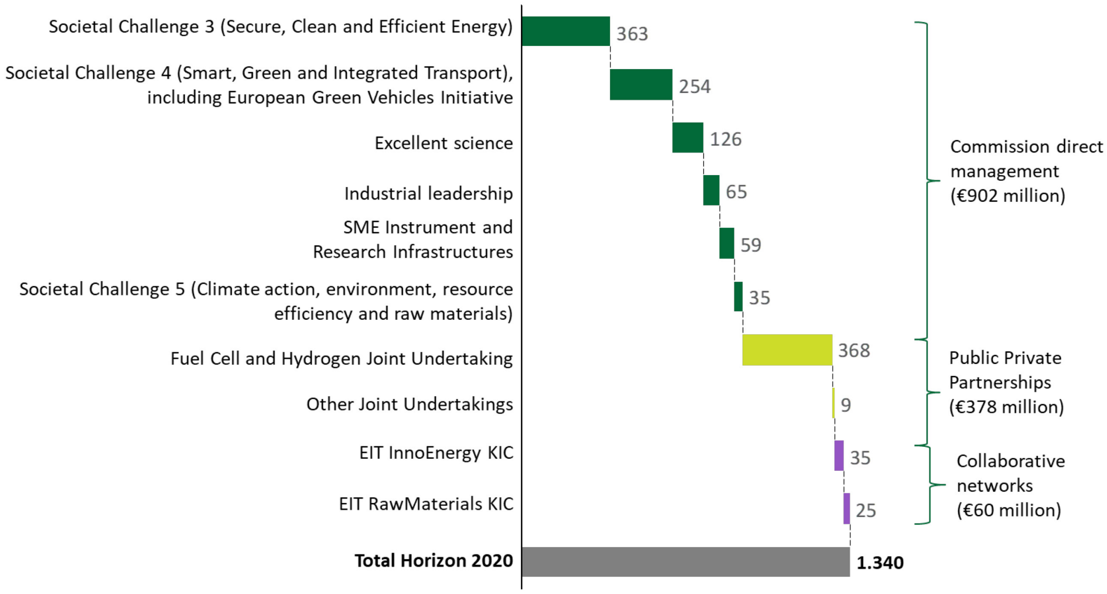
[45] Réunion du comité exécutif, Conseil national de l'industrie, 28 May 2018, p. 23.

[46] Including €25 million for solid-state batteries and €20 million for redox-flow batteries.

Figure 7 – Horizon 2020 contributions to projects related to energy storage on the grid or for low carbon mobility



Source: ECA analysis based on Commission's data.

45 In addition, to support first of a kind commercial-scale energy infrastructure demonstration projects which involve high levels of risk for private investors, the European Investment Bank (EIB) provides loans, guarantees and equity-type funding through the InnovFin Energy Demo Projects (EDP) facility. By October 2018, the facility had provided one loan of €52 million to a project in the field of energy storage.

46 In 2009, the Commission introduced the concept of Future and Emerging Technologies flagship initiatives[47]. The objective is to achieve an effect that is greater than the sum of individual efforts found in national initiatives. One of these initiatives, of relevance to energy storage, is the graphene flagship initiative. During 2018, the Commission consulted stakeholders, with a view to setting up a 10-year EU Flagship initiative supporting basic and applied research into future battery technologies. A group of research and industry stakeholders submitted a proposal for a battery flagship and published in December 2018 a "Battery 2030+ Manifesto"[48].

[47] Moving the ICT frontiers – a strategy for research on future and emerging technologies in Europe COM(2009) 184 final, European Commission, 2009; FET Flagships: A novel partnering approach to address grand scientific challenges and to boost innovation in Europe SWD(2014) 283 final, European Commission, 2014; FET Flagships Interim Evaluation, European Commission, 2017.

[48] See the Battery 2030+ website.

Administrative procedures

47 Horizon 2020 is a complex programme, although simpler than its predecessors[49]. In our audit on Horizon 2020[50], we noted that the administrative burden on beneficiaries had been reduced, but that the programme remained complex[51].

48 The more complex funding instruments are, the less attractive they are to potential participants. Complexity also disadvantages potential applicants who lack detailed knowledge of the instrument's funding rules, such as first-time participants and SMEs[52]. The interim evaluation of Horizon 2020 underlines that "*the funding architecture is too complex and may hinder organisations from identifying the calls and instruments that would best fit their needs and create risk of duplication*"[53].

Energy storage technologies supported

49 The Commission awarded grants totalling €1.34 billion from Horizon 2020 to 396 projects linked to energy storage on the grid and for low-carbon mobility: 25 % of money was for battery projects; and 37 % for hydrogen or fuel cell projects (see ***Figure 8***).

50 Out of the €315 million contracted to projects for research into batteries, more than half was for projects featuring lithium-ion batteries. The amounts spent on new, potentially next-generation types of batteries, were: 7 % for lithium-sulphur; 3 % for

[49] A contribution to simplification of EU research programme beyond Horizon 2020, Briefing Paper, ECA, March 2018.

[50] Special Report 28/2018 The majority of simplification measures brought to Horizon 2020 have made life easier for beneficiaries, but opportunities to improve still exist; European Court of Auditors, 2018.

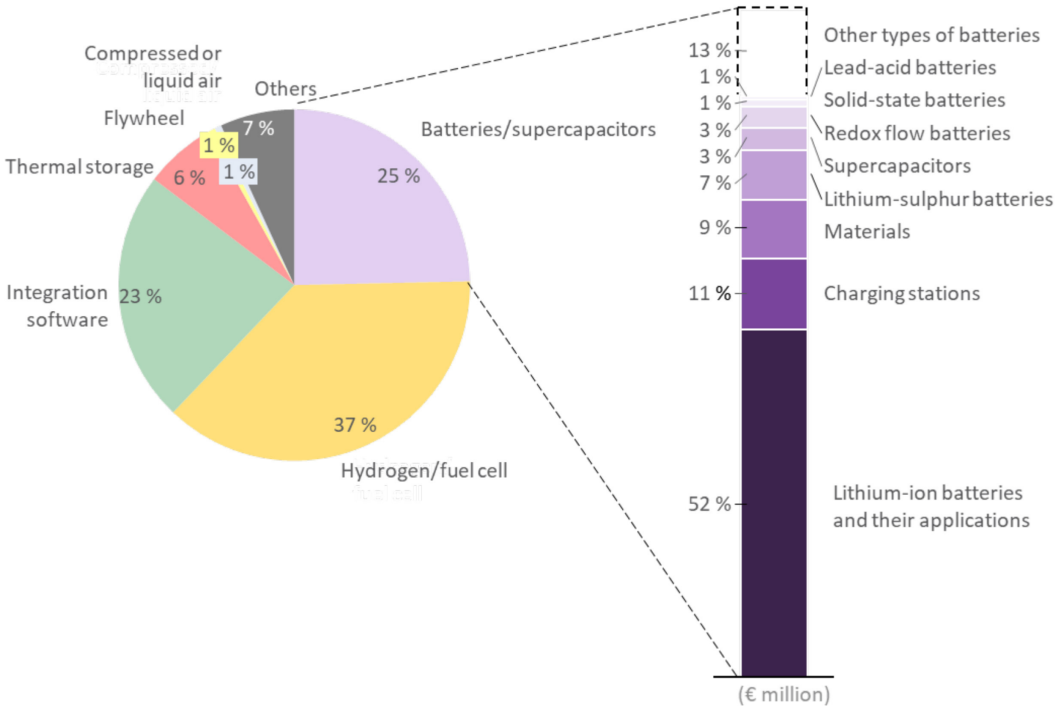
[51] In particular: the Commission's guidance is comprehensive but difficult to use; frequent modifications cause confusion and uncertainty; the Participant Portal was improved, but is still difficult to navigate; staff cost rules remain complex for participants; and SME participation has improved, but barriers remain.

[52] LAB – FAB – APP, Investing in the European future we want, European Commission, 2017, p. 16; Stakeholder's feedback obtained by the ECA.

[53] Horizon 2020 support to Smart, Green and Integrated transport: Interim evaluation report, European Commission, 2017, section 6.5.3. In-depth interim evaluation of Horizon 2020, European Commission, SWD(2017) 220 final, pp. 20, 79, 122, 150.

redox flow; 1 % for solid-state and less than 1 % for lead-acid. Another 13 % supported development of various other advanced battery technologies[54].

Figure 8 – Horizon 2020 energy storage projects



Source: ECA, based on Commission's data.

51 In 2017, the Commission assessed Horizon 2020 applied research or demonstration battery-related projects[55]. For the 28 projects completed by the time of the evaluation, the Commission's evaluators concluded that:

- 3 projects were successful, but did not produce any real breakthroughs;
- 8 projects were partially successful;
- 17 projects missed their objectives, achieved irrelevant results, or had limited impact.

Technology deployment

52 In several energy-related areas, Europe has a deployment deficit, struggling to bring promising innovations to market[56]. The Commission designed its main funding

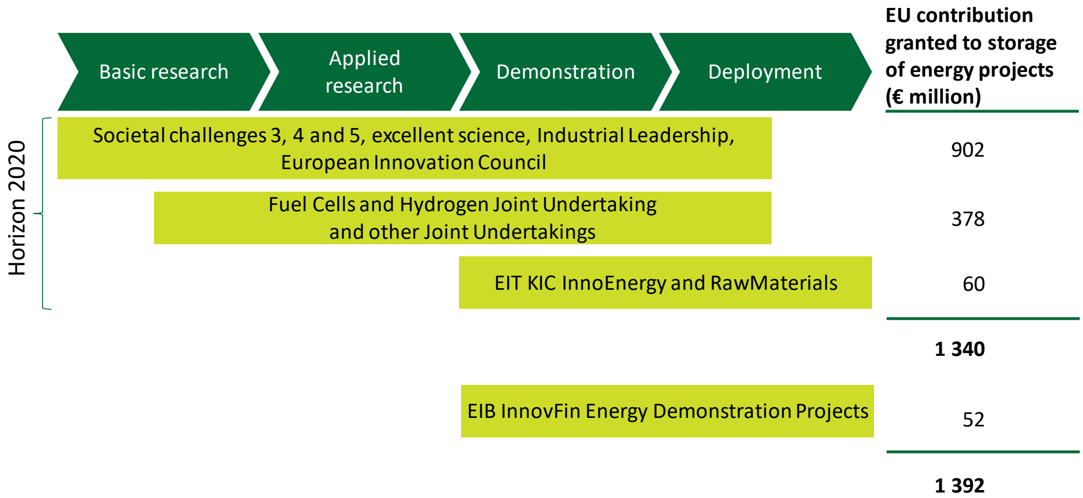
[54] Such as sodium-ion, sodium-sulphur, acid-base flow, zinc-air and calcium-ion.

[55] Batteries: A major opportunity for a sustainable society, European Commission, 2017.

[56] Scaling Up Innovation in the Energy Union, I24C and Cap Gemini, 2016; Communication on accelerating clean energy innovation, European Commission, COM(2016) 763 final of

instruments supporting research and innovation for energy storage technologies to address different stages of development (see ***Figure 9***).

Figure 9 – Overview of the main EU funding instruments supporting research and innovation for energy storage



Note: takes into account grants awarded before October 2018.
Source: ECA.

53 The Connecting Europe Facility (CEF), a €30 billion funding instrument for transport, energy and telecoms, funds alternative fuels infrastructure. Since 2014, it has contributed €270 million to fast-charging networks and hydrogen-refuelling stations. It also budgeted €113 million for energy-storage infrastructure. In 2016, it granted €98 million to fund the planning and construction of a compressed air energy storage plant. Therefore, these funds also support the deployment of energy storage technology.

54 The Commission presents Horizon 2020 as a programme to "*take great ideas from the lab to the market*"[57]. Indeed, some Horizon 2020-financed projects contribute to market uptake. The InnoEnergy and RawMaterials KICs and the EIB's InnovFin EDP are funding instruments designed to support deployment and innovation (see ***Box 3***).

30.11.2016; Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation, European Commission, (C/2015/6317) of 15.09.2015.

[57] In particular, on the Horizon 2020 webpage.

Box 3 - Examples of companies receiving support to commercialise their energy storage solutions

- A company specialised in electric vehicle charging developed, with the support of Horizon 2020's SME instrument, a new smart charging point based on a previous product. The project included some technical development and preparation for market entry. The new smart charging point is now commercially available.
- A research centre in France participated in two projects managed by the Fuel Cells and Hydrogen Joint Undertaking, in 2009 and 2013. In 2015, it created a spin-off company to exploit the technology developed. It used venture capital from the InnoEnergy KIC to commercialise a market-ready solution that integrates energy production and storage for buildings and eco-districts wishing to secure energy supplies using local and renewable sources.
- An Italian/French SME has received funding from the Joint Undertaking since 2009 to develop energy storage for micro-grids. This solution changes variable renewable sources into stable sources for safe grid operation. In 2017, the company borrowed money from the European Fund for Strategic Investments facility, managed by the EIB, to further develop and market its product.

55 In its 2017 interim evaluation of Horizon 2020, the Commission noted signs of progress towards encouraging innovation – chiefly the increasing involvement of the private sector in Horizon 2020 projects – but acknowledged that an innovation gap remains. The evaluation recommended that support for breakthroughs and market-creating innovation be substantially improved[58]. The 2017 interim Commission Evaluation on the activities of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)[59] noted that FCH JU participants had made little use of the EIB's risk-sharing instruments in promoting the deployment of hydrogen-based solutions. It found limited coordination between FCH JU programmes and national and regional actions. In the next framework programme for 2021-2027, called Horizon Europe, the Commission proposed to "*strengthen the market deployment of innovative solutions*".

56 Almost three-quarters of stakeholders interviewed on research (14 out of 19 stakeholders) confirmed this lack of focus on deployment. They pointed out that mechanisms for improving the market uptake of the results of research projects were insufficient. They also said that there were no systems in place to follow up on projects once ended, nor to disseminate results of the research.

[58] Key findings from the Horizon 2020 interim evaluation, European Commission, 2017.

[59] Interim Evaluation of the Fuel Cells and Hydrogen 2 Joint Undertaking (2014-2016) operating under Horizon 2020, European Commission, 2017.

EU legislative framework for energy storage

Energy storage on the grid

57 A supportive legislative framework and more predictable market conditions, such as harmonised technical standards, can boost demand for energy storage, decrease the risk of investing, as a result triggering private investments in technological development[60].

The Clean Energy for all Europeans package

58 The Clean Energy for All Europeans Package proposed at the end of 2016, aimed to facilitate the clean energy transition. In particular, the proposals related to the electricity market aim to allow more flexibility to accommodate an increasing share of renewable energy. They include provisions designed to remove legislative barriers to storage. The Package consists of eight items of legislation. Four of them were adopted in 2018[61]:

- the Directive on the promotion of the use of energy from renewable sources;
- the Directive on the Energy Performance in Buildings;
- the Directive on Energy Efficiency; and
- the Regulation on the Governance of the Energy Union and Climate Action.

59 At the end of 2018, the European Council, the European Parliament and the European Commission reached an agreement on the remaining four pieces of legislation:

- the Regulation on Risk-Preparedness in the electricity sector;
- the Regulation establishing a European Union Agency for the Cooperation of Energy Regulators;
- the Common rules for the internal market in electricity Directive; and
- the Regulation on the internal market for electricity.

60 The two last pieces of legislation directly address energy storage. The Common rules for the internal market in electricity Directive establishes common rules for the generation, transmission, distribution, storage and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated competitive,

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[60] EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications –Opportunities and Actions., JRC Science for Policy Report, 2017; EASE-EERA Energy Storage Technology Development Roadmap, EASE-EERA, 2017; Roadmap Battery Production Equipment, VDMA, 2016.

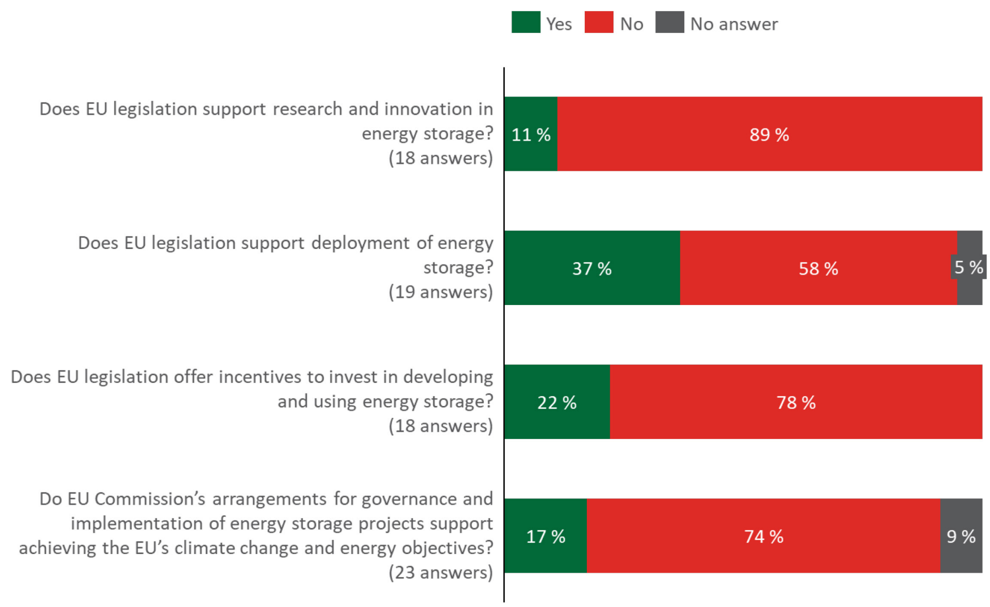
[61] See the Commission's webpage for the Clean Energy for All Europeans package.

consumer-centred, flexible, fair and transparent electricity markets in the Union. The Directive of 2018 also defines, for the first time, storage of electricity: "*deferring the final use of electricity to a later moment than when it was generated or the conversion of electrical energy into a form of energy which can be stored, the storing of that energy, and the subsequent reconversion of that energy back into electrical energy or use as another energy carrier*". An underlying principle is that the regulation of energy storage should be technologically neutral, to foster innovation and to allow a wide range of technologies to compete equally.

61 The Regulation on the internal market for electricity aims at setting principles for well-functioning, integrated electricity markets, which allow, in particular, non-discriminatory market access for providers of demand response and energy storage services. Disproportionate grid infrastructure should not be built where other options, including storage, provide a better economic option. Member States should also incentivise distribution system operators to procure flexibility services, including storage services.

62 Overall, stakeholders interviewed found current EU legislation unsupportive (see ***Figure 10***).

Figure 10 – Stakeholders' feedback on EU legislation (percentage)



Source: ECA survey, 2018.

Obstacles encountered by investors

63 The absence hitherto of a common regulatory approach has led to differences in how Member States treat storage in the energy system. This absence has also hindered the development of viable business cases for energy storage facilities. In particular, our interviewees made us aware of four key obstacles to greater private sector investments:

- grid fees;
- combining revenues from different services;
- ownership of energy storage facilities; and
- combining electricity with other forms of energy.

Grid fees

64 The current common rules for the internal market in electricity[62], adopted in 2009, require Member States to apply tariffs for accessing electricity networks in a transparent and non-discriminatory manner. However, they do not address the specific case of energy storage. In at least four Member States, owners of storage facilities have had to pay grid fees, i.e. network charges and/or taxes, twice, both as consumers and producers (see ***Box 4***). This has reduced the profitability of energy storage investments. Five stakeholders we surveyed said such double fees were a barrier to investing in energy storage.

65 The final draft version of December 2018 of the EU regulation on the internal market for electricity[63] states that network operators shall not apply charges to access their networks to "*discriminate either positively or negatively against energy storage*". This addresses the issue of double network charges applied to owners of storage facilities for using the grid both when they load and when they unload their storage facilities. This does not cover instances of double taxation, which remains in the remit of Member States. The Commission is currently carrying out an evaluation of the Energy Taxation Directive[64].

[62] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, article 25 (OJ L 211/55, 14.08.2009).

[63] The draft regulation is due to be adopted in the first half of 2019 and to apply from January 2020.

[64] Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity (OJ L 283/51, 31.10.2003).

Box 4 - Some energy storage facilities have to pay double grid fees

Grid charges are paid for the use of the electricity network to transport electricity. The final consumer pays them; in some Member States, electricity generators also pay fees for access to the grid. In addition, electricity consumers, and in some Member States also electricity producers, pay electricity taxes.

With storage, the electricity network is used twice: when the storage facility is charged, and again when it is discharged. However, the storage facility itself is neither a generator nor a final consumer. Storage facilities do not fall neatly into either category: some Member States require them to pay network charges and/or electricity taxes twice, both as a generator and again as a consumer.

Double fees have affected electricity storage facilities in several Member States, including Austria, Germany, Finland and the Netherlands. Finland and the Netherlands are revising their regulations to address this.

Combining revenues from different services

66 On top of storing electricity, storage technologies can provide other grid support services, such as frequency response (see ***paragraph 11***), voltage support[65], load following[66], or electricity trading. As a result, energy storage projects can be funded by several revenue streams[67], thus limiting investment risks.

67 The December 2018 version of the proposed Directive on common rules for the internal market in electricity[68] states that customers owning a storage facility "*are allowed to provide several services simultaneously, if technically feasible*". The draft directive applies to customers who store electricity generated within their premises, sell self-generated electricity or participate in flexibility schemes, provided that these activities do not constitute their primary commercial or professional activity. The draft directive does not address the case of companies who provide such services as their main activity.

65 Input or removal of power from the grid to maintain a constant voltage.

66 Mechanism to ensure that sufficient power is available to meet demand.

67 EASE-EERA Energy Storage Technology Development Roadmap, EASE-EERA, 2017; ECA audit feedback obtained from energy storage systems operators.

68 The draft directive is due to be adopted in the first half of 2019 and due to apply 20 days after its publication in the Official Journal of the European Union.

Ownership

68 Under the proposed Common rules for the internal market in electricity, Distribution System Operators (DSOs) would not be allowed to own, develop, manage or operate energy storage facilities, except in duly demonstrated cases[69], in order to maintain their neutrality in this regulated market. Similar provisions would apply to Transmission System Operators (TSOs), operating the transmission grid.

69 Until the new rules are adopted and ownership rights clarified, legal uncertainty is conducive for neither private companies nor regulated grid operators to invest in energy storage facilities.

Combining electricity with other forms of energy

70 Electricity can be stored in the form of heat, hydrogen or synthetic natural gas. Such cross-sector energy combinations can help provide competitive flexibility to the EU electricity system and transfer the share of renewables originally generated in the electricity sector to other sectors, helping to decarbonise them[70]. Cross-sector energy solutions were not regulated by EU legislation until December 2018.

71 This lack of regulation made it more difficult to define a positive business case for some such combinations in energy storage projects in support of the EU energy and climate goals.

72 Two surveyed stakeholders referred to the double grid fees discussed above as a barrier for storing electricity under a different energy form[71]. One stressed that there was no certification in place for green hydrogen, which further reduces the incentives to produce this gas. The EU addressed the certification of green hydrogen for the first time in the recast of the Renewable Energy Directive, adopted in December 2018. This Directive introduced guarantees of origin for green gas, which show final customers that a given share or quantity of energy was produced from renewable sources. Because guarantees of origin can be traded, this may increase the economic value of green gas.

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[69] For example, if there is no market offer for such services, or if the use of storage is limited to securing the efficient, reliable and secure operation of the distribution system.

[70] EASE-EERA Energy Storage Technology Development Roadmap, EASE-EERA, 2017; ECA audit feedback obtained from energy storage systems operators.

[71] This issue is also illustrated in Innovative large-scale energy storage technologies and Power-to-Gas concepts after optimisation, Store&Go, 2017.

73 The recast Renewable Energy Directive also obliges DSOs to assess, at least every four years, the potential for district heating or cooling systems to provide services such as demand response and storing of excess electricity from renewable sources. The proposed Common rules for the internal market in electricity Directive[72] would require Member States to facilitate the operation of secure, reliable and efficient non-discriminatory systems in relation to other energy networks: namely, gas and heat. These new provisions aim at reinforcing the links between the electricity, heat and gas sectors.

Energy storage for transport

National Policy Frameworks

74 The EU currently has around 160,000 public charging points for electric vehicles[73]. According to the Commission, two million public charging points could be needed by 2025[74]. The EU addressed the scarcity of charging points for electric vehicles in the 2014 Directive on alternative fuels infrastructure[75]. According to the Directive, Member States set their own targets in National Policy Frameworks for the development of charging infrastructure.

75 According to the Commission[76], the National Policy Frameworks are in some cases incomplete and incoherent between the Member States, and the national targets set by the Member States are much lower than what the Commission expects will be needed by 2020. The Commission considers that Member States may not reach

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[72] Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity (recast), Council of the European Union, 5076/19, 2019, Article 58 d).

[73] European Alternative Fuels Observatory, February 2019.

[74] Assuming 7 % of new vehicles are electric in 2025. Impact Assessment of the proposal for a Regulation of the European Parliament and of the Council setting emission performance standards for new passenger cars and for new light commercial vehicles SWD(2017) 650 final, European Commission, 2017 (source: Towards the broadest use of alternative fuels – An Action Plan on Alternative Fuels Infrastructure SWD(2017) 365 final, European Commission, 2017).

[75] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (OJ L 307, 28.10.2014, p. 1).

[76] Detailed Assessment of the National Policy Frameworks, European Commission, SWD(2017) 365 final Part 1.

even these national targets by 2020. This could result in insufficient coverage of charging infrastructure at EU level and within certain Member States, which could in turn deter people from buying electric vehicles.

76 The Directive requires the Commission to report, by 2020, on its implementation. In particular, the report should assess its economic and environmental impacts. If appropriate, the Commission may then submit a proposal to amend it.

Harmonisation of technical standards

77 Multiple types of connectors already co-exist in EU public charging points. In particular, three connector standards for fast-charging compete in the EU[77]:

- the CCS Type 2 (around 7,000 charging points), required by the Directive, and used by 18 car brands;
- the CHAdeMo (around 7,400 charging points), used by 13 brands; and
- the Tesla Supercharger (around 3,100 charging points), accessible only to Tesla cars. Tesla cars can access other charging points by means of an adaptor, but other cars cannot use Tesla charging points.

As a result, an electric car user might currently need to carry more than one cable, each costing hundreds of euros, to be able to access most, if not all, available charging infrastructure.

78 The Directive on alternative fuels infrastructure also provides technical specifications for the type of connectors to be used in charging. The aim is to make all charging points compatible with all electric vehicles. As of November 2017, all new or renewed charging points must have at least a connector meeting specific international standards: “Type 2” for slow-charging and “CCS Type 2” for fast-charging. The Directive does not set a specific timescale for the replacement of connectors in existing charging points if they are not refurbished.

Links between the grid and transport

79 If transport and electricity supply sectors were to be successfully made carbon-neutral, electric vehicles would need to be efficiently integrated into the grid[78]. Users

[77] JRC, February 2019.

[78] Vehicle-Grid Integration. A global overview of opportunities and issues, University of California Berkeley National Laboratory, June 2017; Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques, Kang Miao Tan

of electric vehicles demand rapid charging times, which can affect the stability of the grid. Connected electric vehicles' batteries could also take advantage of price fluctuations to decrease charging costs, and provide flexibility services[79] by providing electricity to the grid. On a large scale, this could make a significant contribution to grid flexibility.

80 The Common rules for the internal market in electricity Directive[80], to be adopted in 2019, require Member States to develop regulations to facilitate the connection of charging points to distribution networks. It mandates cooperation between electricity network operators and charging point operators, and requires Member States to remove administrative barriers to the rollout of electric vehicle charging infrastructure.

81 The 2006 Battery Directive[81] requires that battery producers finance the net costs of collecting and recycling waste batteries. In practice, this means that producers must pay a recycling fee to national collection schemes for the batteries that they put on the market. Used batteries from electric vehicles can be re-used by assembling them into larger battery units dedicated to grid-management operations. However, the Battery Directive classes used batteries as waste. Both initial battery producers and companies which re-assemble used batteries can have to pay recycling fees, independently of whether the batteries are re-used in another context. The Commission has already taken action to identify potential regulatory barriers to recycling of this kind, with a view to potentially amending the legislation. The Commission plans to publish an evaluation of the EU Batteries Directive in the first quarter of 2019.

Vigna, K. Ramachandaramurthy, Jia Ying Yong, Renewable and Sustainable Energy Reviews, Volume 53, January 2016.

[79] Such as putting electricity back in the grid at times of high demand and storing it at times of low demand.

[80] Common rules for the internal market in electricity (recast), European Commission, Council of the European Union, 5076/19, 2019.

[81] Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on waste batteries and accumulators and repealing Directive 91/157/EEC.

Concluding remarks

82 Energy storage is essential for the transition to a low-carbon, renewables-based energy system and the achievement of the EU's climate and energy goals. In this Briefing Paper, we have highlighted seven main challenges to the EU support to the development and deployment of energy storage technologies. The Commission has started to address some of these challenges, for example through the Clean Energy for All Europeans Package and the European Battery Alliance.

1. Ensure a coherent EU strategy

- EU lithium-ion battery-manufacturing capacity is being developed later than other leading, global regions, so gaining a competitive advantage may be difficult.

2. Increase stakeholder support

- Some stakeholders remain concerned about the EU strategic framework, in particular regarding technology choices.

3. Reduce the complexity of EU research funding

- Build on the simplification measures taken in Horizon 2020 in the next framework programme.

4. More effective support for research and innovation in energy storage technologies will require:

- Finding ways to increase the success rate of relevant research projects.

5. Deploy energy storage technologies

- Address the risk that mechanisms to support deployment and market uptake of innovative energy storage solutions remain insufficient in practice.

6. Remove obstacles encountered by investors

- Encouraging private sector investments in energy storage facilities will depend on the full and effective implementation of the relevant aspects of the new EU electricity legislation.

7. Develop alternative fuels infrastructures

- The National Policy Frameworks for the development of sufficient, accessible charging infrastructure will be vital to support the energy transition to a low-carbon energy system.

Annex I

Overview of main milestones in EU support for energy storage

Year	Stationary storage	Mobile storage	Research and innovation for storage of energy
2007			Strategic Energy Technology Plan Connecting Europe Facility Research programme FP7 Intelligent Energy Europe
2008			
2009		Promotion of Clean and Energy Efficient Road Transport Vehicles Directive	
2013	Renewable Energy Directive	Renewable Energy Directive	
2014		Regulations setting CO_2 emissions reduction targets for cars and vans Deployment of alternative fuels infrastructure Directive	Research programme Horizon 2020
2015			Towards an Integrated Strategic Energy Technology Plan: Accelerating the European Energy System Transformation
2016	Clean Energy for All Europeans Package	Strategy for Low-Emission Mobility	Accelerating Clean Energy Innovation
2017	Energy Storage- the role of electricity	Europe on the move (First mobility package) Clean mobility package (Second EU Mobility Package) European Battery Alliance	
2018	Promotion of the use of energy from renewable sources Directive (recast)	Promotion of the use of energy from renewable sources Directive (recast) Mobility of the future (Third EU Mobility Package)	

Source: ECA.

Annex II

Overview of main energy storage technologies

Applications – Legend

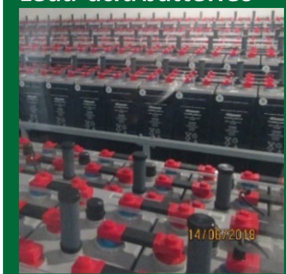
Grid support services	Daily storage	Road
Households	Seasonal storage	Aviation/shipping

Technology	Description	Applications

Pumped hydro

Each pumped hydro facility has two reservoirs at different altitudes. Water is transferred between them to store and release energy. In discharge mode, water from the upper reservoir is channelled through turbines, generating electricity. In charge mode, the same turbines pump water uphill. 85 % of global electricity storage capacity is pumped hydro. Europe still has sites with suitable geography available. Pumped hydro facilities are designed for large-scale grid storage, as their energy storage capacity may range from 100 MW (small scale facilities) to 3000 MW. In Europe, the average capacity of a plant is about 300 MW. Consequently, new facilities can cost around €1 billion.

Lead-acid batteries



Lead-acid batteries are the most common rechargeable battery design and have been widely used in conventional, combustion engine vehicles, though they are not widely used to power electric vehicles. They are cheaper than lithium-ion batteries. Their main drawbacks are their low efficiencies and shorter lifetimes compared to other batteries. Within the EU, 99 % of lead-acid automotive batteries are recycled. Advanced forms of lead-acid battery are under development.

Lithium-ion batteries

Lithium-ion batteries are the most common energy source for electric vehicles. They have increasingly high energy and power densities. There are many variants with different electrodes and electrolytes. Some electrode materials require the use of expensive or limited natural resources, such as cobalt. Lithium-ion batteries are currently more expensive than lead-acid batteries, but costs are falling rapidly.

Redox-flow batteries

Redox-flow batteries have two tanks of electrolyte, one positively charged and one negatively charged, separated by electrodes and a membrane. The difference of chemical oxidation levels between the tanks generates flows of ions and electricity across the membrane. This battery type is designed for large-scale grid storage. It can store large amounts of energy more effectively than many other technologies. To increase the battery capacity, facilities can add more of the cheap electrolyte. Flow batteries have longer lives than many other battery designs, but have lower energy density.

Sodium-sulphur batteries

Sodium-sulphur batteries have been deployed for grid services for 20 years. Most installations are between 1 and 10 MW in size. They operate at temperatures of 300 to 350°C, which makes them unsuitable for households' applications.

Supercapacitor

A supercapacitor is composed of two layers of a conducting material with an insulating layer sandwiched in between. Electricity is stored by building up electric charge between the conducting layers.
Supercapacitors are a form of short-term energy storage, absorbing and releasing large amounts of power very quickly. They need minimal maintenance. They are deployed to supply grid services, and as part of automotive braking and acceleration systems.

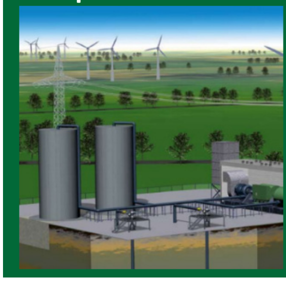
Flywheel

An electric motor spins a rotor at very high speed, up to around 100 000 rotations per minute. Energy is retrieved by slowing the rotor. Flywheels are best suited to short-term, high-power storage, and are ideal for grid services that need very rapid response times. They are also used in transport for providing short bursts of power.
They cannot be used for medium-or long-term storage as they lose c. 15 % of stored energy after an hour.

Fuel cell/electrolyser

Fuel cells convert hydrogen to electricity by making it react with oxygen from the air. They can also operate as electrolysers, using electricity to split water. They are the basic technology used in power-to-gas: Hydrogen can be stored for months, injected into the gas network or converted into natural gas.
They are an energy conversion technology, rather than energy storage, but they enable electricity to be stored as gas.

Compressed air



Compressed air energy storage makes use of underground caverns. In charge mode, air is compressed and can be stored underground at high pressure for months. The air is released and expanded in a turbine to regenerate electricity. Low-efficiency designs have been deployed since the 1970s. High-efficiency designs, which could also store the heat released during compression, are in development.

Liquid air

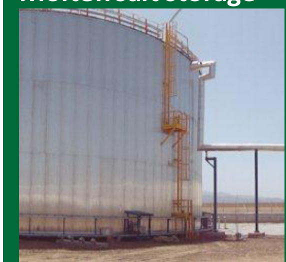
Liquid air energy storage (LAES) uses a cooling process to store electricity. Air is cooled until it liquefies, then the liquid air is stored in an insulated tank. To reverse the process and generate electricity, the air is expanded and drives a turbine.

Liquid air energy storage is a cheap form of storage because plants are constructed using standard industrial components. Only a few full-scale plants exist. The main disadvantage of liquid air storage is its low efficiency, under 50 %, compared to 75-90 % for batteries.

Thermal storage

Residential electric hot water heaters can be used as a form of storage device: heat can be stored in an insulated tank of water, giving households the option of storing energy for a few hours. Cold storage using chilled water or ice is also possible. Alternatively, for solid-state heat storage, radiators filled with bricks are heated using cheap electricity. The heat is discharged later as needed. Pit storage uses a heat pump attached to a borehole to store heat underground, seasonally, on a large scale.

Molten salt storage



In this form of thermal storage, electricity or solar energy is used to heat a container filled with molten salt. This storage medium becomes hot enough to create steam, so steam turbines can be used to generate electricity from the stored heat. In combination with concentrated solar power, this provides a method for daily storage of solar electricity.

Molten salt storage currently represents 75 % of global thermal storage capacity.

Source of pictures, in order: ENGIE/Electric Mountain; ECA; ECA, VoltStorage GmbH; NGK Insulators, LTD; Maxwell Technologies; ECA; Laurent Chamussy, 2010. European Union; RWE; Highview Power; Rotex Heating Systems GmBH; Marquesado Solar.

Glossary

Battery: A battery is a device that stores electrical energy in the form of chemical energy, and converts that energy into electricity. A battery typically has three parts: two electrodes and an electrolyte between them. When a loaded battery is connected to a circuit, charged ions flow between the electrodes through the electrolyte. This transfer of charges generates electricity in the circuit. Battery systems are made of battery packs. Battery packs are made of cells. The cells contain the electrolyte and the electrodes, which store the chemical energy.

Demonstration: Validation activity, through which a technology is shown to be technically and/or economically viable. Products can be demonstrated in laboratories or in real-world setting, at scale or near-scale.

Deployment: Action of making a new technology or service available in the market.

Distribution System Operator (DSO): Distribution System Operators are the operating managers (and sometimes the owners) of energy distribution networks. They work in a regulated market.

Energy storage: Deferring the use of an amount of energy from its moment of generation to a later time of consumption, either as final energy or converted into another energy carrier.

Fuel cell: Device that generates electricity through an electrochemical reaction of hydrogen with oxygen.

Greenhouse gases: Gases acting as a blanket in the Earth's atmosphere, trapping heat and warming the Earth's surface through what is known as the 'greenhouse effect'. The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (HFCs, PFCs, SF_6 and NF_3).

Horizon 2020: EU Framework Programme for Research and Innovation for 2014-2020.

Variable energy sources: Sources of energy, which do not continuously produce energy, and which cannot be directly controlled, are described as variable. For example, wind turbines do not produce energy when no wind is blowing. Solar panels do not produce energy at night.

Renewable energy: Energy collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, biomass and geothermal heat.

Transmission System Operators (TSOs): Transmission System Operators are entities responsible for the transmission of electric power on a national or regional level. They operate independently from the other electricity market players, such as energy producers.

Abbreviations

APAC: Asia Pacific. Includes 53 countries from East Asia, South Asia, Southeast Asia, North Asia and Oceania.

EIB: European Investment Bank.

EIT: European Institute of Innovation and Technology.

JRC: Joint Research Centre.

KIC: Knowledge and Innovation Community.

Li-ion battery: A lithium-ion battery.

SET-Plan: Strategic Energy Technology Plan.

SME: Small and Medium-Sized Enterprise.

ECA team

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To reduce its emissions of greenhouse gases, the EU needs to shift from the current, fossil fuels-based energy system to a low-carbon, mainly renewables-based energy system. To facilitate this energy transition, more energy storage is needed, both for the grid and for transport. This briefing paper outlines the main challenges to the development of energy storage in the EU.
We based our analysis on documentary reviews, visits to energy storage research projects, interviews with the Commission and stakeholders in the field of energy storage, our previous audits and briefing papers and consultation with an expert in energy storage technologies and markets.
The challenges we found are threefold: i) designing a strategy for energy storage; ii) using research and innovation effectively; and iii) establishing a supportive legislative framework.

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