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REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
6 & 7 - Batteries and Hydrogen Electrolysers

{COM(2021) 950 final} - {COM(2021) 952 final}

BATTERIES

INTRODUCTION

Batteries are a key enabling technology to reap the benefits of electrification, in a cost effective manner. At utilisation stage, batteries are the most energy efficient storage technology: most advanced batteries have a round trip efficiency of just around 95%[1,2]. This contributes to the overall high energy efficiency of battery electric transport modes of 77%[3] or higher: EVs convert over 77% of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 12%–30% of the energy stored in gasoline to power at the wheels[4].

Because the transport sector is the primary market for batteries, this report generally puts focus on lithium-ion batteries for electric vehicles (EV). However, other end uses, such as stationary energy storage are of increasing importance and have potential to develop beyond lithium based technologies, with the possibility of increasing sustainability and value chain security. Therefore, where possible, indicators in this report will also assess other battery technologies and storage end uses.

19. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK (EU-27)

19.1. Technology maturity status

Even in 2020, most batteries brought on the market (in terms of electricity storage capacity) were still lead-acid batteries[5] and their production continues to benefit from moderate growth of around 4% per year[6]. These are mainly used in conventional cars or to provide a backup for uninterrupted electricity supply in case of unforeseen outages. The EU has a strong position in this market, with a turnover of over EUR 7 billion[7], and a net-export[8]. Europe accounts for ~20% of world-wide supply (around 75 GWh in Europe).

EU production of lithium-ion batteries is still far from the level of the lead-acid battery market. Still, it is a dynamic sector and the e-mobility boom is now leading to significant growth of lithium-ion production thanks to their superior energy density.

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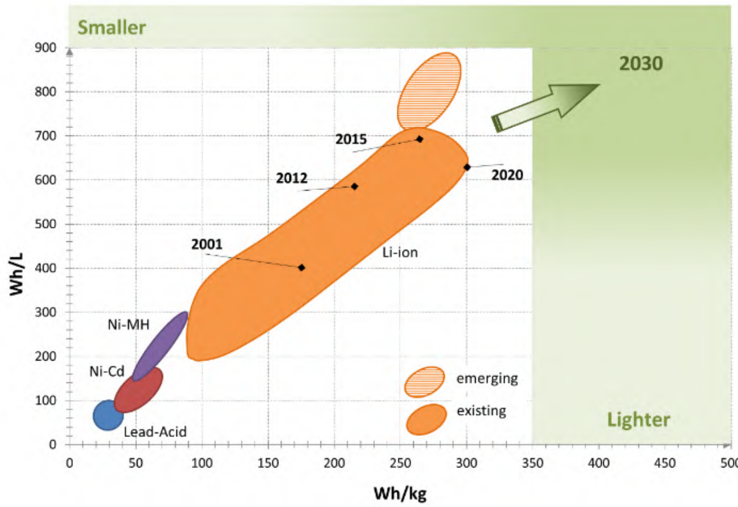
1 US National Renewable Energy Laboratory, Energy Storage, Days of Service Sensitivity Analysis, 2019.
2 Lithium ion battery test centre, 2021. https://batterytestcentre.com.au/project/lithium-ion/
3 Transport & Environment, How to decarbonise European transport by 2050, 2018.
4 US DoE: All-Electric Vehicles (fueleconomy.gov)
5 EUROBAT, Lead based battery technologies, 2021.
6 Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021.
7 Ibid.
8 SWD(2019) 1300 final.

Figure 1 Energy density of lithium-ion batteries at cell level over recent years



Source: JRC, 2020[9]

Various battery chemistries exist today and are being further developed. These battery chemistries may differ depending on whether the application focus is mobility or stationary usage. In 2020, Batteries Europe technology platform[10] published a strategic research agenda for the entire batteries value chain. In 2021 it provided detailed technology road-maps for all segments of the value chain as well as guidance on cross-cutting issues such as safety, sustainability, digitalisation, and skills.

19.1.1. Battery technology and e-mobility

In e-mobility space, technology development mostly focusses on lithium-ion chemistries. Today, lithium-ion batteries with lower energy density such as lithium iron-phosphate batteries are typically used e.g. in city busses while "generation 3a" lithium-ion[11] batteries are used in the most performant electric vehicles. Iron-phosphate batteries are increasingly used in entry-level and cheaper passenger cars, including by leading producers such as Tesla and BYD, and soon also Volkswagen[12]. Such batteries are not dependent on scarce and price-volatile raw materials like cobalt and nickel. They also have some other advantages in their intrinsic characteristics, like, e.g. higher safety or cycle-life durability.

At the same time long-haul truck sector and even more so - the aviation sector (air taxis, commuter planes, hybrid planes) require batteries with much higher energy density than today's state of the art. In this respect, lithium-ion technology still offers considerable untapped potential: energy density can roughly be doubled and exceed 450 Wh/kg when Generation 4 batteries get commercialized[13].

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9 Updated from Strategic Energy Technology (SET) Plan: At the heart of Energy Research and Innovation in Europe. SET PLAN 10th anniversary 2007-2017; doi:10.2777/476339 (2017)

10 https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe_en

11 E.g. batteries with cathode ranging from NMC622 to NMC 811 and carbon graphite anode + silicon content (5-10%).

12 Techcrunch (Aria Alamalhodaei), What *Tesla's bet on iron*-based batteries means for manufacturers, July 28, 2021

13 European Technology and Innovation Platform, Batteries Europe, Strategic Research Agenda for batteries 2020.

According to the BNEF 2021 EV outlook[14], average battery energy density of EVs is currently rising at 7% per year.

Lithium-ion cells can usually be quite small cells (e.g. diameter 21 mm x length 70 mm) and are packed in thousands in an EV. Mass-produced prismatic and pouch cells for EVs are generally bigger (e.g. 168 mm x 255 mm x 42 mm). Such batteries are packed in hundreds in an EV. A trend towards larger and prismatic cells could be identified[15] for example, Tesla/Panasonic has introduced the next generation of cylindrical cells that measures 46MM x 80mm.

Ongoing innovation focusses on advanced materials for lithium-ion technology. Innovation areas include use of graphene, silicon anodes, solid state electrolytes, room-temperature polymer electrolytes, and big-data-driven component recycling/repurposing techniques. In solid-state batteries (Generation 4), both the electrodes and the electrolytes are solid state. They can potentially be made thinner, more flexible, contain more energy per unit weight than conventional lithium-ion batteries while being safer at the same time. Their commercialisation would represent the next major mile-stone in development of EV batteries. The currently open Horizon Europe call[16] targets TRL6 for solid-state lithium batteries. In parallel, development of the current lithium-ion technology and post- li-ion technologies take place. Another technology that should be observed is lithium-sulfur, however recently the companies focusing on this technology has dropped it (Sion) or entered bankruptcy (OXIS Energy).

19.1.2. Battery technology and stationary storage

Given the economies of scale related to the rise of e-mobility, lithium-ion batteries are also increasingly used for stationary electricity storage and have reached a market share of around 90% (if UPS batteries are not counted)[17]. There are projects focused on tailoring lithium-ion batteries to the needs of stationary storage sector in terms of cost, number of cycles, etc. In stationary storage sector the trend towards increasing use of iron phosphate type of lithium-ion batteries (i.e. cobalt and nickel- free batteries) is even more pronounced as energy density has less importance and price sensitivity is higher[18].

Lithium-ion batteries are viable in short-duration applications where services can be stacked and adapted to market pricing (e.g. hourly balancing, peak shaving and ancillary services), but are less cost effective for longer duration storage (above 4-6 hours). There are cases of 2nd life EV batteries being used for stationary storage. Most of these installations relate to research and innovation projects.

There are a variety of other technologies on the market, including well-established lead-acid[19] and nickel metal hybrid technologies[20].

Redox flow batteries are one of the main lithium-ion battery competitors currently approaching the market[21]. Flow batteries offer a unique advantage compared to traditional batteries, because the power

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14 BloombergNEF, Electrical Vehicle Outlook 2021, 2021.
15 World Electricle Vehicle Journal, 10 December, 2020.
16 HORIZON-CL5-2021-D2-01-03
17 Energy Storage News (Andy Colthorpe), China's energy storage deployments for first nine months of 2020 up 157% year-on-year, 2020.
18 Greentechmedia (Mitalee Gupta), A New Battery Chemistry Will Lead the Stationary Energy Storage Market by 2030, August 20, 2020
19 Research and Markets, Global Lead Acid Battery Markets, 2016-2020 & 2021-2026 - Growing Digitalization has Created an Enormous Demand for UPS in the Workforce, 2021.
20 See e.g. https://www.nilar.com/
21 Daniele Gati, IDTechEx Overview of the Redox Flow Battery Market, 2021.

(kW) rating of the system is based on the power stack size selected, and the energy (kWh) capacity is independently selected based on the storage tank size and volume of electrolytes in the tanks. In principle, this means that any combination of energy and power can be configured.

The gradually maturing sodium-ion battery technology is gradually entering the market[22], yet has a good chance to become the next generation of small-scale storage technology. Unlike lithium batteries, they don't require increasingly scarce cobalt[23] nickel nor lithium, and copper might be replaced with less costly aluminum. They are safer and easier in transportation. Sodium-ion batteries could ultimately compete with lithium-ion batteries also in the grid scale applications, home energy storage or backup power for data centres, where cost is more important than size and energy density. Energy density improvements would increase these batteries' relevance for the transport sector[24]. In mid-2021 one of the leading Chinese producers of lithium-ion batteries, CATL, unveiled its intention to set up by 2023 a supply chain for newly-developed sodium-ion battery, together with its battery pack solution. The latter enables the integration of sodium-ion cells and lithium-ion cells into one pack targeting the segment of low cost electric vehicles market[25]. A trend to be monitored.

Such alternative technologies to lithium-ion can offer cost-efficient and sustainable solutions not depending on critical raw materials. The extraction of lithium is largely limited to a few places in the world and linked to geopolitical risks, while sodium is an abundant resource.

19.2. Capacity installed

Over 90% of clean energy transition-related additions to battery capacity in EU were related to e-mobility in 2020[26]. At the same time, stationary batteries are normally used much more intensively, for many more cycles, thus providing much higher energy throughput per installed capacity. The extreme case is batteries used in frequency regulation which can be in continuous charge/discharge cycles. Stationary batteries will play an important role in supporting fast-charging of EVs.

19.2.1. Capacity installed: batteries for clean energy transition in transport

19.2.1.1. Car sales

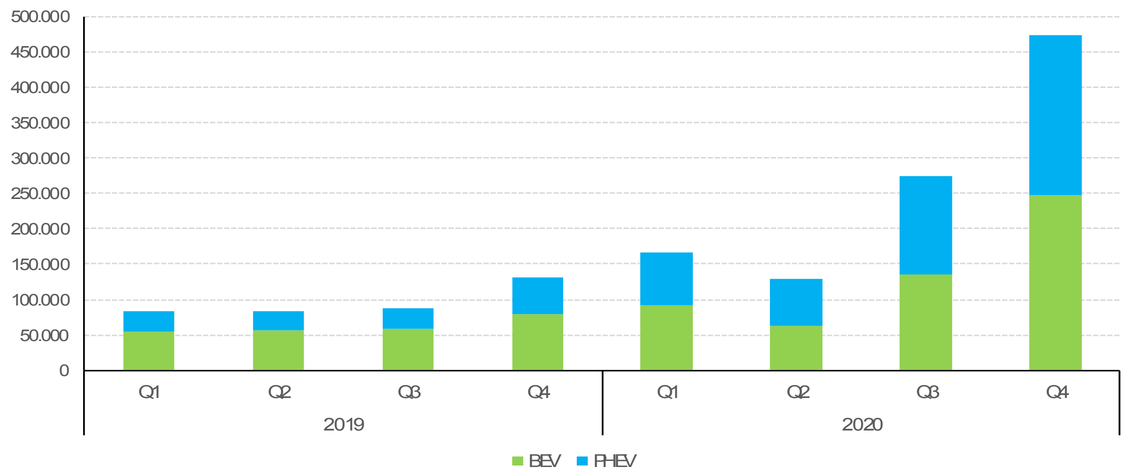
Only about 17 thousands electric cars were on the world's roads in 2010[27] and just few of them in the EU. Just 10 years later, EVs hit historic highs with 1 045 000 cars sold in the EU in 2020 representing 10.5% of the market share (an increase from 3% market share in 2019)[28]. This was driven in part by enhanced support to acquisition of EVs. Public opinion and consumer choice are also driven by some Member States announcing bans on conventional car sales as early as 2030[29]. The European Commission, in turn, proposed that only zero-emission cars could be sold in the EU as of 2035. The number of EVs on the road doubled to more than two million in the EU from end-2019 to end-2020, an equivalent of more than 60

22 Brand Essence Research, Sodium Ion Battery Market by Product Type, By End Use, Forecast to 2027 and Analysis 2019-2025, 2021.
23 Paul Hockenos, In Germany consumers embrace a shift to home batteries, Yale Environment 360, 18 March 2019.
24 Bridie Schmidt, Researchers say the salty sodium battery as good as lithium-ion, The Driven, 3 June 2020.
25 Reuters, China's CATL unveils sodium-ion battery - a first for a major car battery maker, 29 July 2021
26 Derived from ACEA data on EV sales and EMMES data on stationary storage deployments (excluding pumped hydro)
27 IEA, Global EV outlook 2020, 2020.
28 Transport and Environment, CO2 targets propel Europe to 1st place in e-mobility race, 2021.
29 DK, IRL, NL, SE, SI and a number of non-EU countries: see page 47 of IEA Global EV outlook 2021.

GWh storage capacity given an average battery capacity of 55 kilowatt-hours (kWh) for BEVs and 14 kWh for PHEVs[30].

While somewhat fewer EVs were sold in the EU than in China (1.2 million EVs[31]), the share of EV sales in the EU was significantly larger (twice higher EV share in the last two quarters of 2020)[32].

Figure 2 Quarterly EV sales in EU



Source: ACEA, 2020

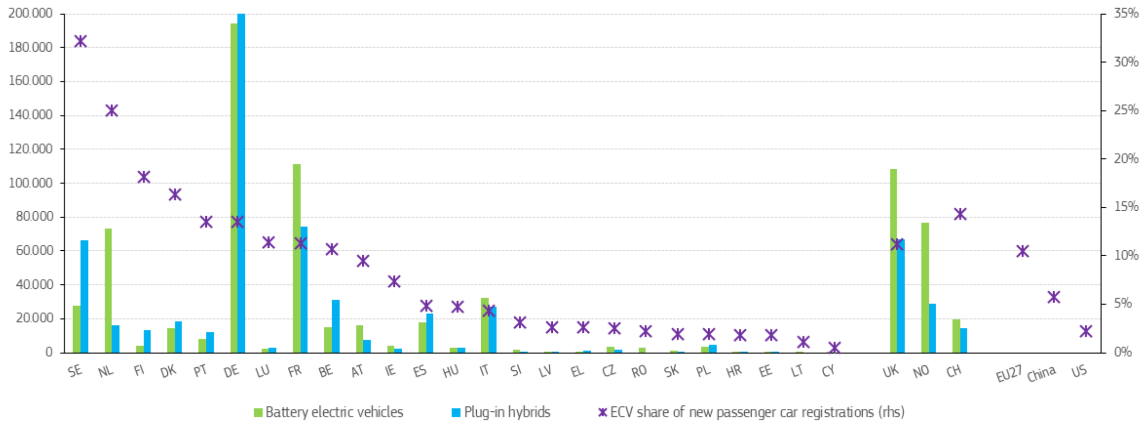
Policy support was strong as 2020 was an important target year in the EU for emissions standards: 95 g CO_2/km for cars and 147 g CO_2/km for vans[33]. Purchase incentives increased, notably in Germany[34]. Germany had higher EV sales (395 000) than the entire US (295 000), where only about 2% of sold vehicles were electric. This will likely change with a new US administration and its different stance on decarbonisation and e-mobility[35].

The plug-in shares in the largest markets were 13.5% in Germany and 11.3% in France in 2020[36]. Both included electric vehicle subsidies in their economic recovery packages.

In relative terms, Sweden (32%), and the Netherlands (25%) ranked highest in plug-in market shares in 2020, having announced bans on combustion engine car sales as of 2030 along with a number of other countries[37]. In this respect, Norway, which will be the first country to ban the sales of conventional cars (2025), had 74% share of EVs in car sales in 2020.

30 IEA Global EV outlook 2021, 2021.
31 EIT InnoEnergy, The European Battery Alliance A European Success Story, 2021.
32 European Commission, 2021 (https://ec.europa.eu/energy/data-analysis/market-analysis_en)
33 Regulations (EC) No 443/2009 and (EU) No 510/2011
34 IEA, How global electric car sales defied Covid-19 in 2020, 2021.
35 Time (Joey Lautrup), The Biden administration is trying to kickstart the great American electric vehicle race, 19 April 2021.
36 Transport&Environment, CO2 targets propel Europe to 1st place in e-mobility race, February 2021.
37 ICCT (Sandra Wappelhorst and Hongyang Cui), Growing momentum: global overview of government targets for phasing out sales of new internal combustion engine vehicles 2020

Figure 3 Number and share of new electric vehicles in 2020



Source: European Commission Electricity market reports, based on data of ACEA CPCA, BNEF, 2021

The data for the first months of 2021 indicate a new record in number of EVs sold and EV share in car sales will be reached in 2021. E.g. Sweden saw the plugin electric vehicle market share reach new record 39.1% in May 2021, likely as a result of a generous bonus-malus scheme[38].

More than 50 million EVs are expected on EU roads by 2030[39] and the European Commission has proposed that only zero-emission cars could be sold in EU as of 2035[40].

19.2.1.2. Capacity installed: e-busses and heavy-duty vehicles

In Europe, electric bus sales grew 170% in 2019 and a further 7% in 2020, however totaling only 1714 busses and accounting for only 6.1% of new bus registrations in Europe[41]. Nearly twice as many new busses run on natural gas. Also striking is that the share of privately purchased electric vehicles in EU is higher than public purchases of busses.

In 2020, the Netherlands was the leading market for electric busses with 446 electric buses sold last year, followed by Germany (388 units) and Poland (200 units)[42]. Performance in terms of electric busses acquisition varies strongly across the EU: from a negligible share in some eastern and southern Member States to over three quarters of new vehicles in Denmark, where all the six largest municipalities buy only zero emission buses from 2021. EIB ELENA facility played an important role in facilitating procurement of electric vehicles in a number of Member States[43].

The US lags even more in electric bus sales[44], while China leads with more than 61 000 annual electric bus sales[45] and 60%[46] of its bus fleet already electrified.

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38 CleanTechnica (Maximilian Holland), Sweden Continues Electric Vehicle Progress In May With 39.1% Plugin Vehicle Share, 2021.
39 central MIX scenario of the Fit for 55 proposals (COM(2021) 550 final)
40 COM(2021) 556 final.
41 ACEA, Medium and heavy busses (over 3.5t) new registrations by fuel type in the EU, 2020.
42 Ibid.
43 e.g. TEBB and HELLO projects.
44 CALSTART, Zeroing in on ZEBS: 2020 Edition, 2020.
45 Sustainable-bus.com "Over 61,000 e-buses sold by Chinese bus makers in 2020", 15 January 2020.

The situation is similar for electric heavy duty trucks. Global electric heavy duty vehicle registrations were 7 400 in 2020, up 10% since 2019, while global stock reached 31 000 vehicles. China continues to lead, with 6 700 new registrations in 2020, up 10% after a fourfold increase in 2019. Electric heavy duty vehicle registrations in Europe rose 23% to about 450 vehicles and in the United States increased to 240 vehicles, while electric trucks are still below 1% of sales in both[47].

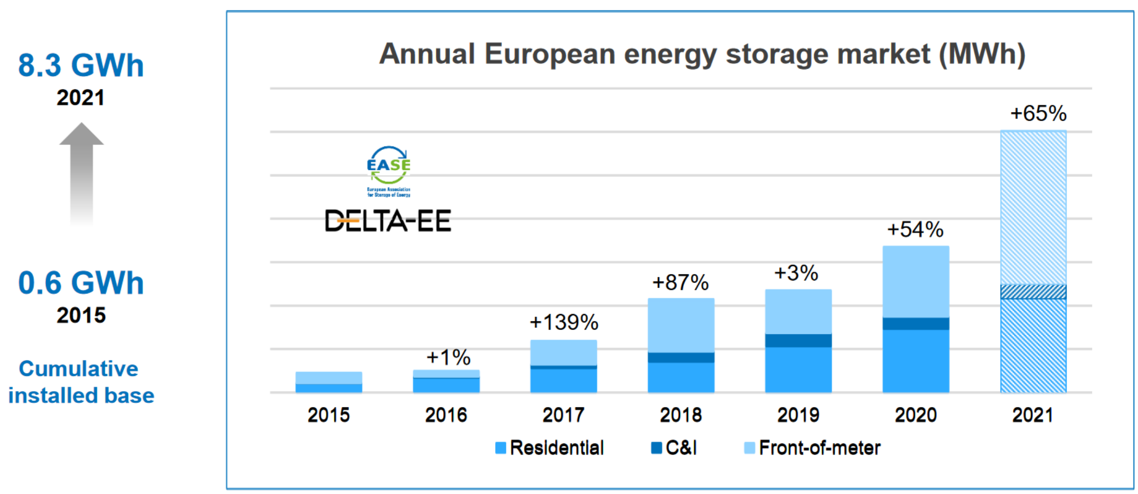
The EU's leading truck manufacturers and climate researchers agreed in December 2020 that by 2040 all new trucks sold must be fossil free[48].

19.2.2. Capacity installed: stationary batteries for clean energy transition

As recently as in 2015 the worldwide capacity of battery stationary storage was just 1.5 GW[49]. In EU installed capacity in 2015 was 0.6 GWh[50] (which should be less than 0.6 GW).

According to EASE[51], the European annual energy storage market (other than pumped hydro, i.e. mostly batteries) grew to 1.7 GWh in 2020, with a cumulative installed base of 5.4 GWh across all segments. The EU roughly accounts for 4/5th of the installed capacity (4.3GWh). Despite the quick growth, this may not be enough even to store the volume of electricity generated during one hour by the new wind generation capacity installed in the EU in 2020[52].

Figure 4 Annual European energy storage market (MWh)



Source: EASE, EMMES 5.0 market data and forecasts - electrical energy storage, 2021. Vertical gradient/horizontal division of the graph on the right is of 0.5 GWh of annual storage deployment

46 News of China, 60% of China's buses go electric amid clean energy push, 26 October, 2020.
47 IEA Global EV Outlook 2021, 2021.
48 ACEA, All new trucks sold must be fossil free by 2040, 15 December 2020.
49 Global Data, Grid connected battery storage system- market size, competitive landscape, key country analysis and forecasts to 2020, 2016.
50 Ecofys, commissioned by DG ENER- Support to R&D strategy for battery based energy storage costs and benefits for deployment scenarios of battery systems (D7) (Final 2017).
51 EASE, EMMES 5.0 market data and forecasts electrical energy storage, 2021.
52 10.5 GW of wind power installations (WindPower, 2021).

The total annual energy storage market in Europe is expected to reach 3 000 MWh in 2021 (4/5th in the EU). Global storage market is expected to reach 10 GW/28 GWh[53] at the same time.

World-wide battery energy storage systems (BESS) market is anticipated to grow at least at 33% a year (compound annual growth rate) from 2019 to 2030[54].

While Europe outpaces both China and the US for renewable energy capacity growth, it is not (yet) the case for stationary battery deployments[55]. On the one hand, the EU has much more robust and dense electricity grid, limiting current dependence on storage. However, a patchwork of legislation within the EU often reflects the past flexibility offered by conventional power plants[56]. With fundamental common enabling provisions on energy storage brought about by the Clean Energy Package[57] the situation is swiftly changing.

Looking at the largest stationary battery projects recently started in the EU, new capacities were entering into operation or planned in the context of renewable energy auctions (co-location of renewable electricity generation and storage)[58] or frequency response[59] or balancing services[60] for transmission systems operators (TSOs).

In addition, TSOs started to prepare for congestion management with 98 MWh storage capacities deployed in 2021 in France[61] and 450 MWh grid booster capacity planned in Germany for 2022[62].

While the largest grid-scale battery installations occur in the US and Australia (e.g. US biggest battery system at 300 MW/1 200 MWh[63] and 1.2 GW mega battery system in the pipeline in Australia[64]), Germany stands out with the largest number of home battery systems installed every year[65], with cumulative capacity reaching about 2.3 GWh across more than 300 000 households by the end of 2020[66]. In Germany, battery attachment rates in today's residential solar market are over 90%. Most German federal states support storage through direct upfront subsidies, typically with energy content-based incentives ranging between EUR 200–300 per kWh. More importantly, and as opposed to other Member States, Germany does not employ full net metering support schemes for residential PV installations[67]

53 PV Magazine (Michael Longson), Strong growth ahead for battery storage, 2021.
54 Markets and Markets, Battery energy storage system market, 2020.
55 Energy Storage News (Andy Colthorpe), Europe predicted to deploy nearly twice as much electrical storage in 2021 than last year, 2021.
56 Ecofys, commissioned by DG ENER- Support to R&D strategy for battery based energy storage, Battery Promoting Strategies in Selected Member States (Final 2018).
57 Communication from the European Commission "Clean Energy For All Europeans" COM(2016) 860 final.
58 E.g. in Germany see: Energy Storage News (Andy Colthorpe), Solar-plus-storage projects win 258 MW of capacity in Germany's latest renewable energy auction, 5 May 2021.
59 E.g. in Italy, see: Energy Storage News (Andy Colthorpe), Italy's battery storage market, 2021.
60 E.g. in Ireland, see: Energy Storage News (Molley Lempriere and Alice Grundy), UK listed fund Gore Street issues new shares, completes 100MW of Northern Ireland battery projects, 2021.
61 Energy Storage News (Andy Colthorpe), France's grid battery 'experiments' take aim at creating market fit for carbon neutrality, 2020.
62 TenneT, Der Netzbooster, die wichtigste Fragen und Antworten, 2019.
63 Energy Storage News (Andy Colthorpe), At 300MW / 1,200MWh, the world's largest battery storage system so far is up and running, 2021.
64 EBA250, World's biggest battery project to date to be implemented in Australia, 2021
65 Solar Power Europe, European market outlook for residential battery storage 2020-2024, 2020.
66 Energy Storage News (Andy Colthorpe), Europe predicted to deploy nearly twice as much electrical storage in 2021 than last year, 2021.
67 With the retail electricity rate for households being about 0.30 EUR/kWh for many years now, and the feed-in tariff offered by the EEG continuing to go down steadily on a monthly basis, the value for increasing self-consumption is high.

which dis-incentivise self-consumption and the installation of battery energy storage systems. Promoting self-consumption has gained Germany two-thirds of the EU residential battery storage market[68].

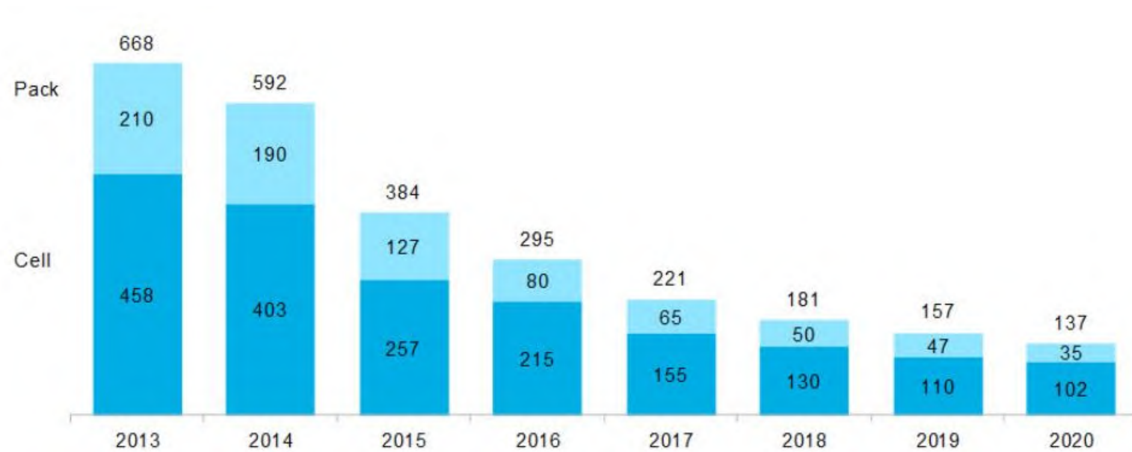
By 2030 grid scale applications of batteries will be approaching the importance of pumped hydropower (PHS) in EU stationary storage in terms of energy throughput. By 2050 batteries will cover close to half of the total need for storage within the EU energy system (more than 100 TWh annually[69]), bypassing the currently dominant pumped hydro storage technology. Stationary batteries will likely reach an installed capacity of close to 40 GW in 2030[70] and over 100 GW in 2050[71] (for comparison: PHS is expected to reach 64 GW in 2030, with limited further increase up to 2050) .

19.3. Cost

19.3.1. Cost of EV battery cells and cell packs and approach of cost parity for ICE vehicles and EVs

Electric vehicle (EV) demand is the main driver of cost reduction in Lithium-ion batteries. According to BNEF, Lithium-ion battery prices, which were above USD 1 100/kWh in 2010, have fallen 89% in real terms to USD 137/kWh in 2020. BloombergNEF's annual battery price survey finds prices fell 13% from 2019.

Figure 5 Volume weighted average pack and cell price split



Source: Bloomberg BNEF, 2021

By 2023, average prices will be close to USD 100 per kWh, according to the latest forecast from research company BloombergNEF. This is an important precondition for addressing bigger up-front costs that electric cars and buses incur compared to fossil combustion vehicles.

Furthermore, PV systems may export only up to 60% of their electricity production on the EEG feed-in tariff, incentivising homeowners willing to install higher capacity PV systems to invest in a coupled BESS.

68 Solar Power Europe, European market outlook for residential battery storage 2020-2024, 2020.

69 COM (2018) 773 final, page 79.

70 SWD(2020) 176 final PART 2/2, page 60, see central MIX scenario of the Fit for 55 proposals.

71 Ibid.

For the first time, battery pack prices of less than USD 100 per kWh have been reported in 2020. These were for batteries in e-buses in China[72]. BNEF expects EV battery pack prices to fall to USD 58 per kWh by 2030.

Indeed, already today the overall cost for owning an electric car is comparable to conventional cars. Therefore the share of government incentives in the total world-wide spending on electric cars has drastically decreased over the last five years, down to 10%[73]. While the purchase price of electric cars can be relatively high, they are cheaper to run, as electricity costs less and is taxed less than petrol. Electric vehicles are also cheaper to maintain[74]. The difference in the purchase price of a new electric car and a new conventional car is expected to disappear well within the current decade[75, 76].

19.3.2. Cost of stationary lithium-ion systems

Worldwide lithium-ion batteries make up about 90% of stationary battery storage capacity[77]. The prices for stationary lithium-ion systems are also dropping. However, the cost reduction, like in waterborne transport, has been slower than in road transport sector. There are a number of additional cost components (e.g. inverters, balance of system hardware, soft costs such as engineering, procurement and construction) that come into play, and there are many use cases with different requirements. In addition, early stage of the market development also plays a role, notably in terms of lack of competition compared to automotive market. Thus today, the whole system costs between EUR 300 and 400 per kWh (for grid-scale applications), depending on configuration of the storage system[78].

Reducing battery energy system cost to half current prices is key for mass deployment throughout Europe[79], which may take an entire decade. There are economic driving forces to substitute large conventional thermal power plants by combination of renewables electricity generation and batteries. As the total cost of solar and wind electricity continually declines, the capacity to pay for supplementary batteries will increase, helping batteries (in combination with renewable energy generation) to out-compete thermal power plants[80]. In the near future until 2025 the expected reduction in lithium-ion cell costs will be the main driver for stationary energy storage system cost reduction. In the medium to long-term the cost share of the electronic and hardware components will become more significant and further cost reduction strategies need to be identified[81].

As batteries are expected to represent shrinking portion of all-in system costs, there will be heightened focus on balance of system cost reductions moving forward.

Home batteries of +/- 10 kWh are at least twice as expensive per kWh. Nevertheless, they often already pay off, especially in the southern EU regions. With sufficiently high irradiation factors and difference in electricity price and feed-in tariff of +/- EUR 0.15 per kWh, it usually makes economic sense to buy a home battery.

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72 BloombergNEF, Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh, 2020.

73 IEA 2021 Global EV Outlook, 2021

74 Benjamin Preston, Pay Less for Vehicle Maintenance With an EVCR research shows that EVs cost less to maintain than gasoline-powered vehicles, Consumer Reports, 2020.

75 Jasper Jolly, Electric cars 'as cheap to manufacture' as regular models by 2024, The Guardian, 21 October 2020.

76 Transport &Environment (Eoin Bannon), EVs will be cheaper than petrol cars in all segments by 2027, May 10, 2021.

77 Energy Storage News (Anthony Colthorpe), China’s energy storage deployments for first nine months of 2020 up 157% year-on-year, 2 December 2020.

78 Batteries Europe, WG on stationary integration, 2021

79 Ibid.

80 EBA250, Fast-growing grid scale stationary battery storage, 2021.

81 BloombergNEF (James Frith), Lithium-Ion Batteries: The Incumbent Technology, 2019.

Even higher difference between electricity and feed-in prices in Germany, coupled with public support for deployment of storage, make Germany the largest European market for home batteries.

19.4. Public R&I funding and Private R&I funding

Public R&I funding is rising considerably. At the EU level, EUR 925 million have been earmarked for collaborative research on batteries under Horizon Europe programme covering the period 2021-2027 (to be implemented through the Batteries Partnership[82]). The continuation of Battery 2030+ initiative (focused on ICT based research) will also be funded under the Batteries Partnership within Horizon Europe.

This is almost twice the funding under the previous Horizon 2020 programme. In addition, the battery integration is funded under the 2 Zero partnership - a partnership to achieve carbon-neutrality in road transport, European Partnership for Zero Emission Waterborne Transport, Clean Sky partnership and other headings of Climate, energy and mobility work programme of Horizon Europe. For example, many calls related to renewable energy and smart energy systems will support innovative deployments of stationary batteries and EV integration aspects not covered by specific partnerships. Horizon Europe funding will also allow greater support to Batteries Europe to foster a common R&I agenda throughout EU and facilitate its implementation in a coordinated way.

At national level, a number of Member States are strengthening their R&I capacity. One prominent example includes the Fraunhofer Gesellschaft (Germany) with its own "battery alliance", consisting of a number of institutes and the biggest research production facility[83]. Other important R&I players include CEA (France), ENEA (Italy), CIC energiGUNE (Spain) and many others as can be seen in Batteries Europe publications[84].

In addition, a number of major research and innovation needs are addressed by two multi-billion euro Important Projects of Common European Interest (IPCEIs), the first coordinated by France[85] and the second by Germany[86]. 2020 was the first year of implementation of the first IPCEI and 2021 is the first year of implementation of the 2nd IPCEI. They involve 12 EU countries and tens of companies and research organisations across the EU, along the whole value chain. This involves both public and private funding: EUR 6.1 billion of public funding by participating member states, which is expected to unlock an additional EUR 14 billion funding in private investments.

Mostly funded by industry, innovation also continues on established battery technologies, such as lead-acid nickel-cadmium and nickel-metal hydride[87].

Beyond R&I funding, the EU industry has invested significantly in batteries and end use integration. In total, the European Battery Alliance has generated investments of EUR 100 billion[88]. The EU is closing the investment gap with its competitors, with investment to produce electric vehicles and batteries reaching EUR 60 billion in 2019 compared to EUR 17 billion in China the same year[89]. In a survey conducted on the

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82 BATT4EU (bepassociation.eu).
83 Fraunhofer Institute 2021: https://www.fraunhofer.de/en/research/key-strategic-initiatives/battery-cell-production.html.
84 https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en
85 IP/19/6705.
86 IP/21/226.
87 EUROBAT, Battery Innovation Roadmap 2030, 2020.
88 https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en.
89 Transport & Environment, Can electric cars beat the COVID crunch? The EU electric car market and the impact of the COVID-19 crisis, 2020.

industrial manufacturing projects disclosing financial details, Western Europe figured a 43.5% share of the total global investment into battery manufacturing projects in 2020, followed closely by Asia with 37%[90].

19.5. Patents

Historically, most patent applications have been filed outside the EU[91].

According to a 2020 EPO-IEA study[92], firms from Asia have a clear lead as of 2018, in the global race for battery technology, with Japanese and South Korean companies at the forefront. Asian companies account for nine of the top ten global applicants for patents related to batteries, and for two-thirds of the top 25, which also includes six firms/organisations from Europe (mostly Germany)[93] and two from the US.

At the same time it is recognised that Europe and the US can count on a rich innovation ecosystem, including a large number of SMEs and research institutions, to help them stay in the race for the next generation of batteries. Recent investments in production facilities and R&I in the EU should soon have a positive impact also on patent indicators.

19.6. Level of scientific publications

According to Batteries Europe, EU publications stagnated in 2020, most probably because researchers are needed by the booming battery industry in EU. Recent publications of Batteries Europe members in the Journal of Power sources are summarised on Batteries Europe web-site[94].

19.7. Final Considerations

In the past few years batteries have led in the sales of zero emission vehicles and stationary storage deployment in the EU. This is the start of a boom since only recently did development in battery technology enable a major break-through in EV driving range and EV price.

A number of tipping points reached in 2020 fuelled EU demand for EVs, notably in terms of total cost of ownership, charging speed, availability of models. Further decrease in price of lithium-ion battery packs is necessary to ensure purchase price parity with conventional cars. The latter is expected to gradually happen in the coming years, starting with 2023. Sunset policies for conventional vehicles in some EU and third party countries, as well as [95] the Commission proposal envisaging that only zero-emission cars could be sold in the EU as of 2035, accelerate the development and deployment of EVs.

When it comes to lithium-ion battery stationary storage, the cost reduction has been slower due to the contribution of non-battery-related major cost components (e.g. inverters, balance of system hardware, soft costs such as engineering, procurement and construction). Still, in some markets battery storage is competitive and much depends on national conditions or level of feed in tariffs for residential PV installations.

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[90] "Batteries Investment Round Up: Diversification Trend Sees Europe Claim Biggest Share" Fitch Solutions / Autos / Global / 13 April, 2021

[91] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study, 2020.

[92] EPO & IEA, Innovation in batteries and electricity storage- a global analysis based on patent data, 2020.

[93] Bosch, Daimler, CEA, Johnson Control, BASF, Volkswagen.

[94] https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en

[95] DK, IRL, NL, SE, SI and a number of non-EU countries: see page 47 of IEA Global EV outlook 2021.

In 2020 and 2021, there were promising developments also in alternative chemistries for stationary storage, especially flow batteries sodium-ion batteries which may reduce demand for critical raw materials.

Plenty of R&I is still needed to improve performance of EV and stationary batteries. In addition, research should help to improve sustainability and decrease dependence on critical raw materials. “Batteries Europe” technology platform is the leading European forum for identifying what would be the most meaningful R&I spending in each segment of the value chain, in view of already ongoing research activities, the issues identified and the needs of the economy of a specific Member State.

20. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

20.1. Introduction/Summary

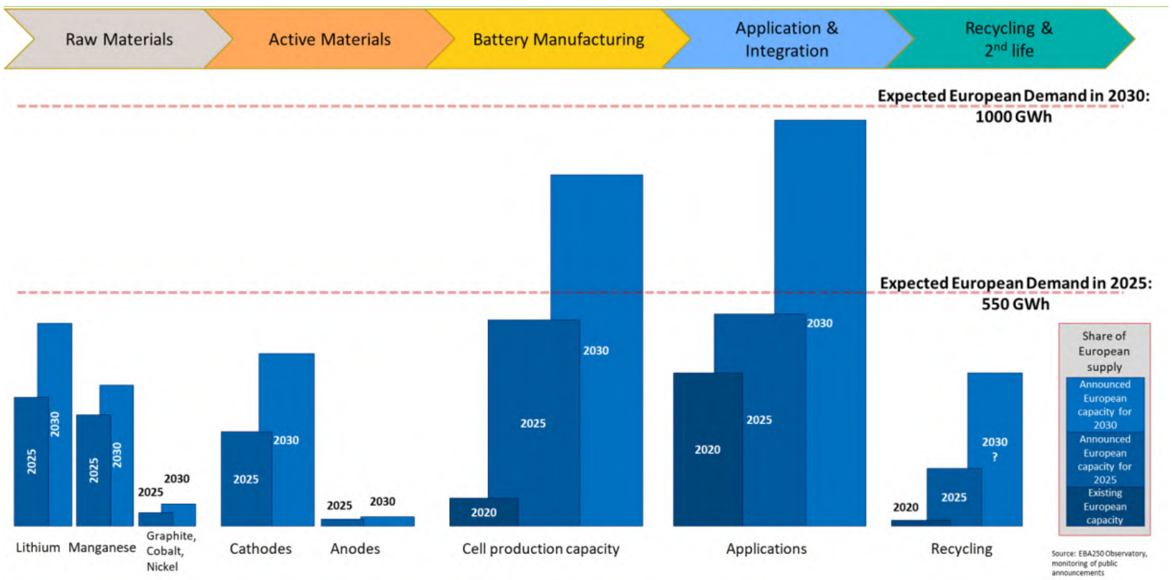
As recently as 2016[96], the EU was severely lagging in key segments of the lithium-ion battery value chain. It was largely absent in key raw materials markets (e.g. lithium, cobalt, graphite) and lithium-ion cells market. Particularly in processed materials, the EU activity in cathode and electrolyte markets was limited, and the EU was absent from anode market.

2017 marked the start of EU’s industrial policy on batteries when the Commission launched the European Battery Alliance with EU countries and industrial actors. A strategic action plan for batteries, covering the whole process from producer to end-user, was adopted in May 2018[97]. Since autumn 2019, the Business Investment Platform of the European Battery Alliance also gathers stakeholders along the entire battery value chain to accelerate transactions between investee and investor[98].

The European Battery Alliance has proved to be a catalyst into turning the EU into a region with well-developed battery eco-system across the entire value chain. Major EU initiatives are being implemented by the EU based on the Action Plan on Batteries. They are complemented by a buoyant industry network facilitated by EIT InnoEnergy – EBA250[99].

[96] JRC Lithium ion battery value chain and related opportunities for Europe, 2016.
[97] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[98] https://eit.europa.eu/news-events/news/european-battery-alliance-eit-innoenergy-launch-business-investment-platform
[99] https://www.eba250.com/

Figure 6: Expected supply and demand balance in Europe from present day to 2030 for the batteries value chain



Source: EBA250, 2021.

Currently, the weakest point in the value chain for the EU are critical raw materials, in particular graphite, cobalt and lithium. Anode production is also a weak point, but recently there have been some positive developments, mostly in Finland and Sweden[100].

20.2. Turnover – Batteries

Currently separate statistics on lithium-ion battery turnover have only been collected for 2019 and these are incomplete, not even covering Member States of main producers, as reporting is voluntary.

To give at least a general idea, according to Avicenne, the overall demand for Lithium-ion batteries in 2020 was estimated at roughly EUR 9 billion in Europe[101] and local production satisfied much less than half of this demand. For comparison turnover from lead acid-battery production is still higher in Europe (with over EUR 7 billion)[102].

20.3. Gross value added growth

Due to incompleteness of turnover data, statistical data for gross value added is also not available.

20.4. Number of EU companies

At least 10 EU headquartered companies or company groups will start battery cell production in the coming years:

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100 https://www.eba250.com/supply-of-graphite-from-europe/

101 Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021: https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf

102 EUROBAT, 2021

- ACC (France and Germany – JV of TOTAL/Stellantis[103]), building on technological strength of SAFT
- CELLFORCE (Germany – JV of Porsche/Fraunhofer)
- Eneris/Leclanché (tbc)
- FAAM/LITHOPS (Italy)
- INOBAT (Slovakia)
- MES (Czechia)
- NORTHVOLT (Sweden and beyond)
- VARTA (Germany)
- VERKOR (France)
- VOLKSWAGEN (Germany and beyond)

Northvolt Ett in Sweden and MES HE3DA factory in Czechia are at advanced stage of the construction.

In 2021, 16 European flow battery stakeholders came together to confirm the formation of Flow Batteries Europe (FBE): 5 industrial companies, including the EU's largest producer of flow batteries CellCube[104], 5 start-ups, 5 research centres and a global vanadium organisation[105]. While flow batteries are usually associated with large-scale storage, German company Voltstorage, claims to be the only developer and maker of home solar energy storage systems using vanadium flow batteries.

Major EU companies in battery integration in vehicles include:[106]

- Volkswagen, targeting 1 million electric vehicle sales in 2021; by 2030 70% of its vehicles sold in Europe will be fully electric which represents 5 million cars. It has also announced plans to build 240 GWh of lithium-ion manufacturing capacity in Europe by 2030;
- Daimler - electrifying entire fleet by 2025;
- BMW – aiming to build "a quarter of a million more electric cars than originally planned between 2021 and 2023 and double the share of electrified vehicles from 8% in 2021 to 20 % by 2023;
- Stellantis group - aiming for 70% electric cars sales in Europe by 2030 (Peugeot will electrify its entire line-up by 2023);
- Renault -increasing EV sales to 65% by 2025. By 2030, the goal is a share of at least 90 per cent[107].
- Volvo will only sell full electric cars by 2030.

There are numerous European players entering the electric bus market: Solaris (PL), Volvo, Daimler, VDL (NL), Ebusco (NL), Bluebus - Bolloré (FR), Alstom (FR), Iveco Heulliez (FR), Irizar (ES) Linkker (DE), Sileo (DE), Caetano (PT), etc.

At the end of 2020 leading EU truck producers Daimler, Scania, Man, Volvo, Daf, Iveco, and Ford – have signed a pledge to phase out traditional combustion engines by 2040[108].

Siemens[109] and Alstom[110] hold the first contracts in the EU in the field of battery driven trains.

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[103] Formed after merger of PSA and Fiat Chrysler
[104] DMG MORI AG (Gildemeister)
[105] https://www.flowbatterieseurope.eu/
[106] EBA2050, New EV targets for the European car industry fuel the battery industry, 15 March 2021.
[107] Electrive.com (Chris Randall), Renault plans to gear up EV sales to 65% by 2025, 26 April 2021.
[108] ACEA, All new trucks sold must be fossil free by 2040.

Leading companies in the region for equipping ships with battery storage and electric propulsion include: Siemens in Germany and beyond, Echandia Marine AB and ABB in Sweden, Wärtsilä in Finland and Danfoss in Denmark.

Many electric ships are integrated at Damen shipyards[111], also Holland shipyards, even if storage solutions are provided by other companies, like Echandia or ABB. Other EU shipyards are also involved as there seem to be no shipyards specifically specialised in electric ships.

Major EU actors in stationary storage sector include Fluence, co-owned by Siemens and American AES (grid storage) and Sonnen (now owned by SHELL for home storage). Among others, TOTAL/SAFT, Engie, ENEL X, ABB also play an important role.

20.5. Employment in the selected value chain segment(s) and skills

If Europe becomes the second largest lithium-ion battery cell manufacturer in the world[112], this will alone require reskilling and upskilling 800 000 people by 2025, as a direct effect. Each Member State will need professionals being able to maintain EVs and install stationary batteries as well as to take proper care of batteries when they reach their end of life[113]. In total 3 to 4 million jobs could be created by 2025[114].

EIT InnoEnergy facilitates the 'EBA250 Academy' helping to bridge the emerging battery value chain skills gap by upskilling and reskilling citizens. In addition, under the EU's Erasmus + programme, the Alliance for Batteries Technology, Training and Skills (ALBATTS) has been established to design a blueprint for competences and training schemes of the future, in the battery and electromobility sector. It is due to report by the end of 2023[115].

The current situation and educational offer as well as gaps and projects under way are e.g. described in Batteries Europe position paper on skills[116].

The European Commission encouraged Member States to use funding available in the Recovery and Resilience Facility and the Just Transition Fund to bridge the skills gap.

While it is up to each Member State and company to actively enter production of raw materials, or advanced batteries, production of battery cells and systems and their repurposing or recycling, the trend is clear: battery-based technologies are taking over transportation market and energy storage market. This means that each and every Member State will need plenty of qualified staff and innovators capable of installing, maintaining and optimising batteries.

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109 Green Car Reports (Bengt Halvorson), Battery-powered electric trains will soon bring cleaner air- especially in Europe, 29 March 2020.

110 EBA250, Bombardier (now Alstom) to replace diesel engines by Li-ion batteries on AGC trains, 4 February, 2021.

111 https://www.damen.com/en/innovation/electrification

112 Fraunhofer ISI, Li-ion Battery cell production capacity to be built up, April 2021; Benchmark Minerals, Li-ion battery cell capacity by region, 2021.

113 https://www.eba250.com/eba250-academy/about-eba250-academy/

114 SPEECH/21/1142

115 Project ALBATTS (project-albatts.eu)

116 https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications/education-skills-position-paper_en

20.6. Energy intensity considerations, and labour productivity considerations

All factories in the pipe-line should be new, energy efficient and highly automated. Labour costs account for a relatively small share of the overall battery production cost.

A trend towards ever bigger EVs (the sports utility vehicle (SUV) market is quickest growing EV market[117]) implies high energy consumption at production and utilisation stages and risks increasing dependence on critical raw materials. According to IEA, currently SUV models account for half of the available electric car models in all markets around the world. In Europe, the share of electric SUVs is even higher than for the overall market. This may be a temporary trend related to the wealthier part of population opting quicker for e-mobility, leading to most polluting cars being replaced first.

In this respect, China, unlike EU, has an official policy of reducing average power consumption of new pure electric passenger cars to 12.0 kWh/100 km by 2025[118]. SUVs consume up to twice this amount. Today, the bestselling model on the Chinese market, a small EV, consumes 8.1 kWh per 100 km.

20.7. Community Production (Annual production values)

Subsidiaries of mostly Korean companies make up the community production of lithium-ion battery cells for e-mobility and storage in the EU which has reached 44 GWh as of the end-2020. Annual production volumes are increasing. This constitutes roughly 6% of the of global EV lithium-ion cell manufacturing capacity in 2020 (747 GWh)[119] and this represents already a large increase since the start of the European Battery Alliance (3% in 2018).

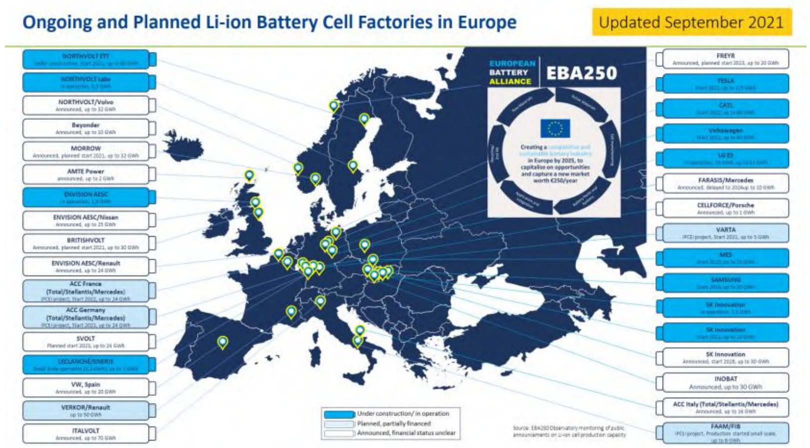
The meta-study "Batteries for electric cars: Fact check and need for action," commissioned by VDMA and carried out by the Fraunhofer Institute for Systems and Innovation Research ISI suggests that production capacities of up to 400 GWh could be achieved by 2025. This is consistent with the EBA250 forecast.

EU head-quartered companies (such as Saft and Varta), currently occupying high-end lithium-ion niche applications, are preparing for mass production for e-mobility and energy storage.

The giga-factory projects announced by EU and foreign companies should largely satisfy the expected EU demand in 2025 (400 GWh)[120]. In the most optimistic estimations, Europe could supply almost 90% of its batteries from production facilities within Europe. Even with more conservative estimates, about 80% of supply from European facilities[121].

Figure 7 Ongoing and Planned Li-ion Battery Cell Factories in Europe

[117] IEA, Global EV outlook 2021, 2021.
[118] State Council Information Office of the People’s Republic of China, New energy vehicle industrial development plan (2021-2035), 2020.
[119] US Department of Energy, National blueprint for lithium batteries 2021-2030, 2021.
[120] SPEECH/21/1142
[121] EBA250, Internal document “A Battery Market Outlook for 2025 and 2030”, 2021



Source: EBA 250, 2021

The world's biggest automotive manufacturer VW will go for a new business model for the production of batteries for electric vehicles based on a single, massive-scale "unified cell" platform. The unified cell is expected to enter production in 2023 in cooperation with Northvolt. In total, VW plans to bring 240 GWh of battery production capacity to Europe by 2030 (and a third of it by 2025). This would be enough battery-making capability to supply 4 to 4.5 million EVs per year[122].

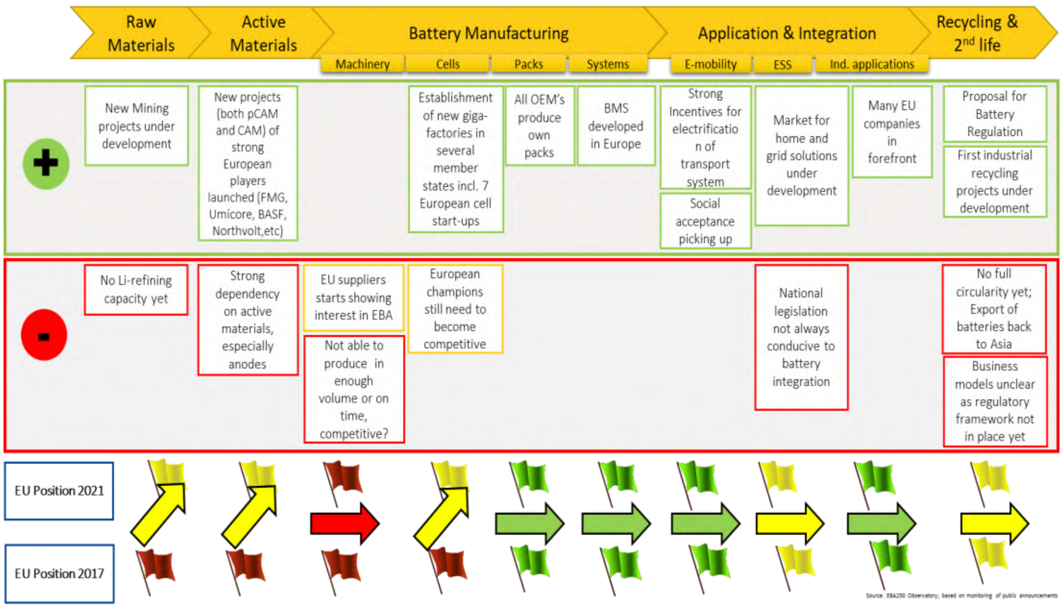
20.8. Final Considerations

Progress along value chain of batteries within the EU between 2017 and 2021 can be summarised in the following figure compiled by EBA 250[123].

[122] Volkswagen, Power Day: roadmap for batteries and charging up to 2030, 15 March 2021

[123] N.B. legislative obstacles for grid-scale applications should come to an end with transposition of the Clean energy package.

Figure 8 Progress along the batteries value chain in the EU



Source: EBA 250, 2021

21. GLOBAL MARKET ANALYSIS

21.1. Introduction/summary

According to EBA250, in 2020 the EU reached a tipping point when the parity of the total cost of ownership (TCO) with combustion fuelled vehicles was achieved. This is important since about 60 % of the automotive market consists of leasing cars, where monthly costs are the most important purchasing consideration, not on the cost for purchasing the vehicle. Here a tipping point was reached in 2020 when EV became cost competitive in more than 50 % of the total European automotive market[124]. Falling battery costs are of course adding to this picture, also reducing the cost of EV's. In addition, with maximum charging speed exceeding 10 km driving range per charging minute for most models, and average range above 350 km, major obstacles for uptake of e-mobility were addressed[125].

According to Avicenne[126], in 2020, global market of Lithium-ion batteries exceeded that for lead-acid batteries in value USD 47 billion vs USD 37.5 billion with e-mobility booming. In terms of storage capacity, lead-acid batteries were still ahead with 410 GWh vs 230 GWh for Lithium-ion.

Other consultancies also estimate Lithium-ion battery market over USD 40 billion in 2020:

- Statista Research department - USD 40.5 billion in 2020[127].
- Markets and markets USD 44.2 billion in 2020[128]

Consultancies forecast market to grow at CAGR of up to 17.1% and will reach up to USD 100.43 billion by 2025[129]. This figure is likely to be revised upwards given the unprecedented boom in the EV market.

As regards lithium-ion stationary battery energy storage systems' market size, according to ReportLinker, it is expected to grow at a CAGR of 32.8% from 2020 to 2025, reaching USD 12.1 billion by 2025, up from USD 2.9 billion in 2020[130].

21.2. Trade (imports, exports)

EU imports nearly all raw materials needed for battery production. It imports most of advanced materials. It also imports most of cell manufacturing equipment.

When it comes to battery cells, trade deficit continued to increase in 2019: it widened from EUR 3.6 billion to EUR 4.2 billion[131]. While 2020 data are not yet available, it is clear that most of battery cells used for clean energy transition were still imported, given limited local production capacity and booming EV industry. Normally this trend should significantly reduce given the increasing production volumes in the EU. Similarly as in automotive industry, the recent trend is towards local production, as demonstrated by numerous third country battery cell producers setting up/planning production capacities in EU.

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124 Leasplan, Annual Car Cost Index, 30 September 2020.
125 EBA250, internal document "A Battery Market Outlook for 2025 and 2030".
126 Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021: https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf
127 Statista, Lithium-ion batteries: statistcs and facts, 15 July 2021.
128 Markets and Markets, Battery energy storage system market, 2020.
129 GlobalNewsWire (Allied Market Research), Global Li-ion battery market, 19 February 2020.
130 GlobalNewsWire (Reportlinker) The global battery energy storage system market, 13 October 2020.
131 Eurostat, COMEXT, 2020.

According to Trade data monitor, in the first 10 months of 2020, China exported USD 12.5 billion of lithium-ion batteries, followed by South Korea (USD 4 billion), Poland (USD 3.2 billion), and Germany (USD 2.7 billion), according to Trade Data Monitor[132]. Even if Germany was also exporting lithium-ion batteries (normally, battery modules and system), globally it is still a net importer, unlike other listed countries.

During the month of December 2020, Poland recorded a record value of the lithium-ion battery export, amounting to EUR 609 million. In relative terms, Poland is the fastest-growing exporter of lithium-ion batteries since 2015[133]. More generally, Central Europe is gradually becoming an important EU EV battery supplier[134].

While being net exporter of cars, the EU is importing slightly more electric cars than exporting as at end 2020[135]. This is explained by the fact that the EU automotive industry took some time to embrace e-mobility. All major announcements by the EU automotive industry regarding electrification date mostly from 2020 or 2021. The positive fact is that exports of EVs are growing faster than imports. The automotive sector as such is a net exporter[136] and it is expected that, in 2021 or 2022, the EU will become net exporter also of EVs. As regards cars, it has to be noted that they are mostly produced in the region of consumers. For example, EU automotive companies are scaling up their subsidiaries in China, rather than exporting cars. US car manufacturers do the same. EU companies have subsidiaries also in other regions, notably the US. The EU itself also hosts a number of subsidiaries of foreign automotive companies.

21.3. Global market leaders vs. EU market leaders (market share)

In cathode materials field, the EU has two strong players Umicore and BASF, while the EU is still a net importer from Asia[137]. Asian players include Fujitsu Limited, Hitachi Chemical Co., Ltd., LG Chem Ltd., Mitsubishi Chemical Holdings Corp, NICHIA Corporation, Sumitomo Chemicals[138]. Chinese GEM is an important player in lithium-ion cathode precursors[139] and collaborates with Korean EcoPro.

In other advanced materials for batteries, except polymers for lithium-ion batteries (cf Solvay), EU is weak. According to BNEF, overall, China holds 60% of battery component manufacturing capacity[140].

In battery cells sector, all leading manufacturers are Asian manufacturers: BYD, CATL, LG Chem, Samsung, SK Innovation, etc. According to BNEF, 77% of cell production capacity is controlled by China. This should change with a number of EU head-quartered companies setting up lithium-ion battery cell production facilities. For example, Northvolt is expanding rapidly and aims to produce 25% of Europe's batteries by 2030. With the EU's Green Deal agenda, demand and production capacities for lithium-ion batteries are growing faster in Europe than in any other region of the world. According to

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[132] Trade data monitoring, 2021: https://www.tradedatamonitor.com/index.php/data-news-articles/120-china-leads-global-trade-in-lithium-ion-batteries

[133] Daniel Workman, Lithium-ion batteries exports by country, World's top exports, 2021: https://www.worldstopexports.com/lithium-ion-batteries-exports-by-country/

[134] Politico (Wojciech Kosc), Central Europe becomes the EU's e-car battery supplier, 10 February 2021.

[135] Eurostat, 2021. Data retrieved: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210524-1

[136] Eurostat, 2021. Data retrieved: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=International_trade_in_cars

[137] Green Car Congress, 2021: https://www.greencarcongress.com/2021/01/20210108-roskill.html

[138] Polaris Market Research, Lithium-ion battery cathode market size global industry report, 2020.

[139] Roskill (Ying Liu), Nickel sulphate: GEM and ECOPRO to build high-nickel Li-ion precursor capacity in Fujian, 17 April 2020.

[140] PV Magazine (Marian Willuhn), National lithium-ion battery supply chains ranked, 16 September 2020.

Fraunhofer, Europe's share in this global battery manufacturing business will increase from around 6 % today up to 24% in 2025 and 29% in 2030 (most optimistic of currently available estimates).

However, it is important to note that the global battery production capacity is continuously being upgraded in volume. For example, Benchmark Minerals predicted a global production volume of about 3 000 GWh by 2030 two years ago and today this volume is expected already to be achieved by 2025.

Notwithstanding the general dominance of Asian manufacturers, the European SAFT and VARTA companies play an important role in high-end niche applications for lithium-ion cells. Leclanché seems to be the main European lithium-ion cell producer for waterborne applications.

Although Asia is currently the global hub of EV battery making, in principle, European manufacturers should be able with a bit of effort to compete on price, because the biggest costs in battery making are (raw) materials, the capital-intensive manufacturing process and the cost of energy. In these three areas, there is hardly any competitive disadvantage compared to Asian manufacturers. The share of labour in the overall cost of a battery is limited, and the difference between the labour cost in Europe and Asia is offset by the cost of shipping batteries to Europe[141].

In manufacturing of lithium-ion cell production equipment, Asian companies are leading and most of equipment is being imported from Asia. Manz is the only EU company playing an important role in this segment[142, 143].

As regards other promising battery technologies, over the last 10 years, only 7% of the world's flow battery projects were installed in Europe, with much more R&D and commercial support taking place in North America and Asia[144]. At the same time, Austrian CellCube[145], belongs to top-three flow battery producers in the world, together with Sumitomo Electric Industries Ltd. (Japan) and UniEnergy Technologies (US)[146]. Recent establishment of Flow batteries Europe association can help to improve the EU's competitiveness in this segment.

As regards nascent market of sodium-ion batteries, "Sodium Ion Battery Market - Growth, Trends, and Forecasts (2020 - 2025)" shows that Europe/EU have good potential in this market, with French start-up Tiamat and Swedish start-up Altris being most active[147] and important long-standing EU battery producer SAFT also involved in development of this technology. At the same time, Chinese CATL is the first of the world major EV battery producers to go to large-scale commercialisation of sodium-ion technology[148]. CATL plans to include sodium-ion batteries into the EVs in combination with lithium-ion batteries. While lithium-ion batteries have advantage of higher energy density, sodium-ion batteries have superior low-temperature power and cycle performances. Several other countries (e.g. UK, India, US) follow China establishing production facilities for sodium-ion cells. This trend is to be observed, and eventually followed in the EU.

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141 SAFT, ACC's European EV battery venture on track for production, 2020:

142 Decisive Market Insights, Lithium battery manufacturing equipment market report, 2021.

143 Manz AG: Https://www.manz.com/en/industries/battery-production/

144 Robin Whitlock, Flow Batteries Europe (FBE) established to represent flow battery stakeholders, Renewable Energy Magazine 03 May 2021.

145 DMG MORI AG (Gildemeister)

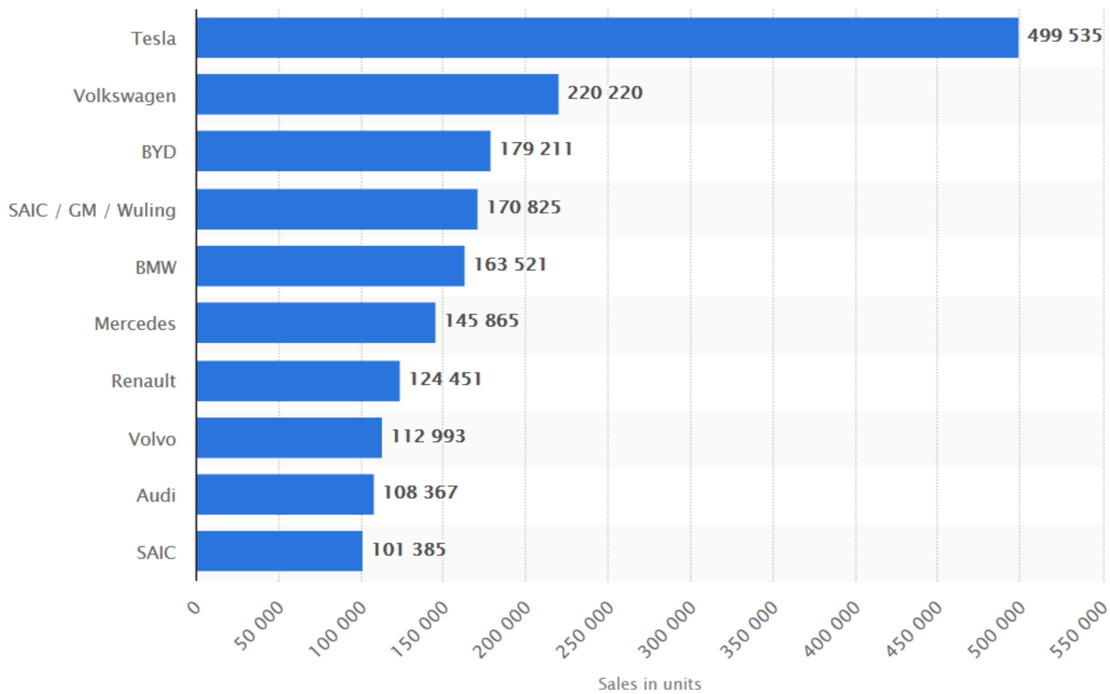
146 JRC Batteries - Technology Development Report 2020

147 Mordor Intelligence LLP, Sodium Ion Battery Market - Growth, Trends, and Forecasts (2020 - 2025), 2020. Verified Market research, Top 7 Sodium-Ion Battery Manufacturers, , August 2021.

148 PV magazine (Marian Willuhn), CATL claims to have made sodium-ion batteries a commercial reality, 29 July 2021

The EU plays very strong role when it comes to battery systems and final products: electric vehicles and stationary storage systems. It has a potential to become a net exporter, even if the general tendency is that final products are manufactured in the end-use jurisdictions – China, EU, US (i.e. not much inter-continental trade is expected). Main EU manufacturers have production facilities in major global markets, China and US, as do key US producers. Chinese automotive companies are just entering the EU market for electric cars[149] and stationary storage. US based Tesla remains leading EV manufacturer[150], while total sales of EVs under EU brands (including cars produced in consumer countries) were higher.

Figure 9 Estimated plug-in electric vehicle sales worldwide in 2020, by automaker



Source: Statista, 2021 (Data retrieved: [Worldwide PEV sales - by brand 2020 | Statista](#))

All EU car manufacturers embraced electrification race and compete with American Tesla and Chinese BYD, SAIC, NIO, Xpeng and others. VW aims to sell 1 million electric cars in 2021 and become the global EV market leader by 2025 at the latest[151].

In an optimistic scenario, the EU may achieve an annual production of 6 million electric cars by 2025[152]. The global data firm, LMC Automotive, estimates China will produce over 8 million electric cars a year

149 See e.g. https://www.autoexpress.co.uk/nio/354921/chinese-ev-brand-nio-enters-european-market
150 Statista, 2021. Data retrieved: https://www.statista.com/statistics/977407/global-sales-of-plugin-electric-vehicles-by-brand/
151 Automotive News Europe, VW targets electric-car lead by 2025 in platform push, 16 March 2021.
152 https://ec.europa.eu/commission/presscorner/detail/en/speech_20_2378

by 2028, compared with 1 million in 2020[153]. The US also set a clear course towards electrification under the new administration [154].

China is the world's largest producing region of electric busses (61 000 in 2020)[155]. This has been initially facilitated by considerable support to acquisition of electric busses, while recently strict public procurement rules play an important role[156]. Largest producers include: Yutong, BYD, CRRC, Zhongtong and Suzhou King Long. In comparison, the EU market for electric busses accounted for less than two thousand units in 2020. Yutong and BYD played an important role also in the EU market, while majority of the market was held by EU companies, primarily Solaris, Volvo, and VDL among others[157].

The heavy duty vehicles market is nascent, with China by far leading the sales[158]. All EU truck manufacturers are finally on board. There will be some catching up to be done as new players like American Tesla and Nikola entered the market since a while and Chinese BYD and Japanese Toyota have been making gains so far[159].

According to the International Transport Forum (ITF), Nordic EU countries as well as Norway are world leaders in electrification of short sea shipping and provision of onshore power supply and related R&I For example, Siemens in collaboration with Echandia won the contract to equip the largest electric-ferry fleet in India (78 ferries)[160]. Danfoss Editron is part of the team delivering Thailand's first fleet of fully-electric passenger ferries[161]. In 2021 ABB won a major deal for equipping 10 all-electric ferries in Lisbon[162]. Echandia, ABB, Siemens, Wärtsilä, Danfoss and many more are among leading EU companies equipping electric/hybrid ships.

When it comes to the nascent market of battery electric locomotives, Alstom[163] and Siemens are key players in Europe, while facing certain competition from the largest railway rolling stock manufacturer - Chinese CRRC[164].

In the nascent market of urban air taxi's there are plenty of opportunities for EU companies including CityAirbus and many other EU start-ups[165]. At the same time there is already considerable competition. E.g. American Airlines, Virgin Atlantic and aircraft leasing group Avolon have made preliminary commitments to buy up to 1 000 electric air taxis from a British start-up "Vertical Aerospace", a big sign of a radical shift to urban air mobility[166]

While an EU stationary storage market is only gradually developing, the EU is not lacking strong players as regards stationary battery storage systems and hybrid storage systems. Fluence (co-owned by German

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153 New York Times (Keith Bradsher), As cars go electric, China builds a big lead in factories, 6 May 2021.
154 Time (Joey Lautrup), The Biden administration is trying to kickstart the great American electric vehicle race, 19 April 2021.
155 Inside EVs (Mark Kane), There is one company that sells more EV buses than BYD: Yutong, 27 January 2021.
156 from 2021 "new energy vehicles" (plug-ins or FCEVs) should account for not less than 80% of the vehicles newly added and replaced to public transport areas of key regions for prevention of atmospheric pollution
157 Sustainable Bus, The pandemic doesn't stop the European e-bus market: +22% in 2020, 19 February 2021.
158 IEA Global EV outlook 2021, 2021, pp. 28-29
159 Electrive.com (Nora Manthey), Major truck makers pledge to go zero-emission by 2040, 15 December 2020.
160 Echandia, 2020: https://echandia.se/echandia-marine-division-wins-battery-contract-for-the-worlds-largest-fleet-of-electric-passenger-ferries/
161 Danfoss, Thailand's first fleet of fully-electric passenger ferries to hit the water in 2020, 01 October 2020.
162 ShipInsight, ABB wins major deal for 10 all-electric ferries in Lisbon, 13 April 2021.
163 Rail division of Canadian Bombardier is part of Alstom, following merger clearance in July 2020.
164 Rail Journal, CRRC rolls out first battery-equipped locomotive for Rail Cargo Hungary, 12 September 2020
165 Silicon Canals, The future of urban mobility in Europe, 8 July 2020
166 Financial Times (Sylvia Pfifer), UK air taxi start-up finds early buyers for 1,000 vehicles, 11 June 11, 2021.

Siemens and American AEG) remains the top utility-scale energy storage system integrator in the world.[167]

Sonnen/SHELL is the leading EU company in home storage, with main competitors being US Tesla and Korean LG Chem[168,169]. Sonnen (now owned by SHELL) has put Germany's and the EU's largest virtual battery into operation.

21.4. Resource efficiency and dependence

Most raw and refined materials are imported. China holds 80% of the world's battery raw material refining capacity.

The 2020 critical raw materials assessment indicated a high economic importance and a high supply risk for lithium. This resulted in including lithium on the Critical Raw Materials list for the EU[170]. It is clear that the EU needs to diversify its raw materials supply chains to achieve open strategic autonomy. A secure and sustainable supply of raw materials for battery applications is one of the key challenges. Therefore, the EU and its Member States should ensure a proper framework for a sustainable, environmentally neutral and responsible sourcing.

According to EBA250, Europe should be able to cover more than a half of the battery ecosystem's needs for lithium by 2025 thanks to projects under way. An encouraging development is the trend to investigate also larger occurrences of geothermal brines as possible lithium resources, such as the Rheingraben on both sides of the German-French border where Vulcan Energy Resources just has completed a pre-feasibility study. Other areas of great geological potential for extraction of lithium from brines are found in the Pannonian Basin, Hungary. A lithium refining project is under way in Finland.

The Democratic Republic of Congo alone produces 64 per cent of the world's cobalt supply[171]. This being said, Europe, is a relatively important producer of refined cobalt with Finland (12%) having the largest share of the world's production after China[172]. The cobalt refinery in Kokkola, Finland, (now owned by Umicore) is the largest cobalt refinery outside of China. Terrafame is further developing the mining and refining capacity of cobalt in Finland.

Although the supply of nickel is more diversified, the EU relies on imports of the high-purity material necessary for battery production with a share of around 56%[173].

EU subsidiaries of Asian companies might face fewer raw materials bottlenecks as many raw materials are mined in Asia and most are processed in Asia. At the same time EU headquartered battery companies should unlock the potential of local raw material deposits and local recycling facilities.

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167 Energy Storage News (Andy Colthorpe), Guidehouse: Fluence ahead of Tesla in global utility-scale energy storage leaderboard, 29 January 2021.

168 Reuters (Vera Eckert), Christoph Steitz, Shell-owned German solar battery firm sonnen sets sights on growth, 15 January 2021.

169 YSG Solar, Top 50 Energy Storage Companies in 2021, 12 January 2021: https://www.ysgsolar.com/blog/top-50-energy-storage-companies-2021-ysg-solar

170 COM(2020) 474 final.

171 European Commission, Report on Raw Materials for Battery Applications, 22 November 2018, SWD(2018) 245/2 final.

172 European Commission, Study on the EU's list of Critical Raw Materials (2020), Factsheets on Critical Raw Materials.

173 European Commission, DG ENER "Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis", 8 October 2021.

As regards secondary raw materials, currently most of the batteries at the end of life are sent to Asia. The recycling industry is concentrated in China and South Korea, where the vast majority of the batteries are also made, but there are several dozen recycling start-ups in North America and Europe. Chinese GEM and Brunp (CATL subsidiary) and a number of other Chinese and Korean companies account for up to 88% of the market[174]. Competition is so intense in China that recyclers are willing to pay to for used batteries, which is not yet the case in EU. For the time being, Umicore, with its world-wide capacities, is the only company headquartered outside Asia belonging to leading global recyclers[175].

Overall, recycling capacities in the EU are still low. Together with significant export to Asia of end-of-life li-ion batteries this means lost opportunity for EU to retain raw materials, including critical lithium and cobalt. Umicore's existing facility in Belgium has an installed capacity of 7 000 tons per year and Northvolt's recycling plant will have the capability to recycle approximately 25 000 tons of battery cells per year from 2022. Limited recycling capacity will be added in 2021 through VW pilot recycling plant in Salziger (1 200 t/year) andFortum's plant in Ikaalinen (3 000 t/year). There are also other companies active on local markets, e.g. Nickelhütte Aue (DE) or Elemental Holding (PL).

Other projects have been announced and are under development which will enable Europe to recover important raw materials, such as lithium, cobalt and nickel. In addition, Akkuser OY, Duesenfeld, Recupyl, SNAM and a number of other EU companies have technological expertise relevant to recycling of lithium-ion batteries. Yet, capacities will need to ramp up much more quickly to meet the increasing amount of batteries that reach their end-of-life in some years from now.

EBA250 is planning to launch a Sustainable Battery Material Fund in 2021 to accelerate scoping pre-feasibility studies and definite feasibility studies. Private capital will be involved in this fund. In addition, the batteries value chain will benefit from the European Raw Materials Alliance (ERMA)[176] launched in September 2020, as part of an Action Plan on Critical Raw Materials[177].

21.5. Final Considerations

The EU is strong in the segment of integration/final products (EVs and stationary storage).

It is rather weak when it comes to raw materials, advanced materials (except cathodes) and equipment for manufacturing of lithium-ion cells. Recycling capacities are also insufficient, even if there is considerable know-how. This leads to imports from third countries and in case of recycling – export to third countries.

In the central part of the value chain – lithium-ion cell manufacturing, EU is gradually increasing its weight. It will still take a number of years before EU is largely self-sufficient in lithium-ion cell production for EVs and stationary storage.

22. SWOT AND CONCLUSIONS

STRENGTHS	WEAKNESS
• Large ecosystem around batteries in a growing economic sector. EBA250	• Battery industry is highly dependent on third countries for sourcing of raw

[174] Greentechmedia, (Jason Deign), How China Is Cornering the Lithium-Ion Cell Recycling Market, 11 September 2019.
[175] In4Research, Lithium ion Battery Recycling Market - Strategic recommendations, Trends, Segmentation, Use case Analysis, Competitive Intelligence, Global and Regional Forecast (to 2026), 2020.
[176] https://erma.eu/
[177] Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability, COM(2020) 474 final.

Business investment platform facilitating match making between investees and investors • All key world producers of batteries are establishing their subsidiaries in the EU or have plans to do so. Annual total production capacities of batteries in the EU are steadily growing. Dependence on imported battery cells is set to decrease. • EU has decades long expertise in high-end lithium-ion battery cells (Saft, Varta, Leclanché) • A number of EU headquartered companies are advancing with giga-factory plans for lithium-ion cells. • Very strong companies in end-products sector (EVs and storage systems); their active involvement in lithium-ion battery cells giga-factory projects • The EU finally has strategic research agenda for the entire batteries value chain (Batteries Europe, 2020). • Europe is increasing R&I spending, notably through multi-billion Member States-led IPCEIs and increased EU funding (Horizon 2020 and Horizon Europe). • EU CO_2 norms for cars and renewable energy targets push local demand. Some Member States have offered a number of incentives to encourage the move to electric vehicles and have envisaged sun-set clauses for sale of conventional cars. Some cities (e.g. in Denmark) stopped buying conventional busses as of 2021.	materials. • The EU has no lithium refining capacity. • Battery cell production equipment is largely imported from Asia. • EU head-quartered companies don't yet have experience in mass production of lithium-ion batteries. For the time being, EU mass production for e-mobility and storage needs is entirely dependent on subsidiaries of South Korean companies in Poland and Hungary. • Batteries are largely exported to Asia for recycling at the end of life. Even EU headquartered Umicore has most of recycling capabilities in Asia. • Trade deficit in lithium-ion batteries kept growing (at least as at end 2019), due to higher imports than exports. This trend is likely to change soon. • Firms from Asia have a clear lead as at end 2018 in the global race for battery technology, with Japanese and South Korean companies at the forefront. It is to be seen how the situation changes with recent initiatives to support R&I and giga-factory projects. • In some MS support to residential PV (notably, feed-in conditions) is organised in a way that there are no incentives for self-consumption and storage. • Lack of skills across most of the value chain, albeit a series of facilitating measures in the pipe-line. • Relatively low activity of the EU in sodium-ion battery race may mean lost opportunity to reduce dependence on critical lithium and cobalt. • Relatively low activity of EU countries on stationary BESS markets cause the price of the solutions is disproportionally high, comparing with automotive batteries, hindering wide entry on the markets.

OPPORTUNITIES	THREATS
• Coordination of different battery R&I activities can be strengthened using Batteries Europe technology platform. • Increased attention to the issue of raw materials through creation of the European Raw Materials Alliance. Possibility to attract investments in mining in the EU; possibility to facilitate social acceptance by sharing benefits from mining; If EBA250 sustainable battery material fund, to be established in 2021, manages to attract enough resources from private investors, it can play an important role. • Expand EU industry for lithium-ion cell production machinery based on strength of EU players such as Manz. • Expand EU competence in active materials beyond cathode materials. • Build strong lithium-ion battery recycling industry based on strength of companies such as Umicore. • Build on the strength of Nordic countries in electrification of short-sea shipping and provision of shore side electricity. • MS using possibilities under regional aid, environmental and R&I aid rules to intervene in cases of market failure. More active use of national allocations of EU funds for the benefit of weaker segments of the value chain. • Future EU Regulation on Batteries and Waste batteries can help Europe becoming a world leader in clean batteries and limit market access of batteries with high CO_2 footprint. • EBA250 Academy established in 2021 provides good opportunities to close skills gap, but support from each MS is needed to deploy the new training platform across the EU. • Through the ALBATTS project, the EU is	• Europe is increasingly dependent for both raw materials and also some active materials on third countries. EU headquartered battery cell producers may even be more concerned than EU subsidiaries of Asian companies. • Current trend towards ever bigger EVs may compromise energy efficiency and exacerbate the issue of raw materials, unless it is a temporary trend and contributes to most polluting cars being replaced first. Consumer awareness is necessary. • EU head-quartered companies face a big challenge of being able to mass-produce battery cells at competitive prices. • Ability of EU cell manufacturers to embrace cell standardization challenge launched by VW (currently, EV battery cells are produced in different shapes and sizes). • Charging infrastructure deployment may not be advancing at a needed pace (albeit a number of measures to address the issue are in the pipeline).

establishing a long-term strategy to identify and meet skills needs in the EU battery sector. • Demand strengthening measures: strengthened EU CO_2 norms for transport for 2030 at EU level; more countries setting/advancing sun-set clauses for sale of conventional vehicles; more cities moving towards zero emission zones; countries/cities being more ambitious in their public procurement of busses/bus services than required by the Clean Vehicle Directive. • Strengthened renewable energy targets for 2030 at EU level should further boost demand for stationary storage. • With the end of transposition deadlines for the Clean energy package norms, there should soon be no major legal barriers for deployment of stationary batteries It should also help deployment of batteries if MS were more ambitious with rolling out smart meters, than legally required.	

HYDROGEN ELECTROLYSERS

INTRODUCTION

With the policy impetus initiated by the European Commission's Green Deal to cut greenhouse gas (GHG) emissions by 55% by 2030 and restrict global warming to 1.5 degrees Celsius for the Long Term Scenario in 2050, there has been renewed policy and industrial interest to support renewable and low carbon hydrogen production and use, as a key contributor to European decarbonisation.

The Hydrogen Strategy for a Climate Neutral Europe Communication[178] - thereafter referred to as the Hydrogen Strategy – has outlined the policy context and necessary actions for the development and deployment of Renewable and Low Carbon Hydrogen[179].

The current EU's demand for hydrogen of about 7.7 million tonnes per year[180] is still largely met by fossil fuels. In this context, renewable hydrogen obtained through water electrolysis[181] (today's estimates for water electrolysis-produced hydrogen is less than 1% of the overall production[182]) has the potential to decarbonize hard-to-electrify and hard-to-abate sectors such as industry and heavy-duty transport, and contribute to energy services such as the grid balancing and seasonal storage.

This analysis will focus on the four main technologies used to produce renewable hydrogen through the use of water electrolysis by using (renewable) electricity, in order to contribute to the EU objectives of decarbonisation. Therefore the scope of this section will focus on Alkaline electrolysis, Polymer Electrolyte Membrane (PEM) electrolysis, Solid Oxide (SOE) electrolysis and Anion Exchange Membrane (AEM) electrolysis.

The Hydrogen Strategy aims at kick-starting and enabling the penetration of hydrogen technologies inside Europe, thus making it possible to achieve the sustainable scenarios as outlined in the LTS.

The 2030 goals of the Hydrogen Strategy are supplemented by an array of policies and funding measures, including.

1. Launching of the Clean Hydrogen Joint Undertaking - as a Public Private Partnership EU body continuing the mandate from the Fuel Cells and Hydrogen Joint Undertaking (FCHJU) during the period of the Horizon Europe Programme - to manage the R&I funding (EC proposal of EUR 1 billion) for renewable / low carbon hydrogen production, applications and storage.
2. Setting up a dedicated call for proposals from the Green Deal call in Horizon 2020 (launched in 2020) to support projects with 100 MW electrolyser capacity in real life operations, which

[178] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[179] Renewable hydrogen, as defined in the Hydrogen Strategy, is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources.

[180] Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand data for EU MS that exclude UK, Norway, Switzerland and Iceland.

[181] For the purpose of the analysis, Renewable Hydrogen refers only to hydrogen produced through water electrolysis powered by renewable electricity.

[182] To note that in addition to Water Electrolysis, about 2%-4% are estimated to come from Chlor-Alkali Electrolysis.

resulted in selection of 3 projects and ought to lead to an increased production capacity in the EU[183].

3. Establishing the European Clean Hydrogen Alliance, which puts together industry, investors, civil society and public authorities to facilitate the large-scale deployment of clean hydrogen in Europe. The European Clean Hydrogen Alliance aims to promote projects that deliver a robust foundation for the hydrogen value chain, starting from investments in clean hydrogen production and hydrogen infrastructure and covering several hydrogen use sectors (i.e. industrial use, buildings, mobility and energy). The Alliance is also assessing bottlenecks and framework conditions that would contribute to a favourable investment climate that supports EU policies. Alliance members submitted about 1050 projects for the preparation of a pipeline of investment projects for the large-scale deployment of clean hydrogen, some of which were presented during the first Hydrogen Forum in June 2021. To date[184], the European Clean Hydrogen Alliance collected projects amounting to 60 GW electrolyser capacity by 2030, out of which, the large majority may be powered by renewable electricity.
4. Member States have notified to the EC of first hydrogen Important Projects of Common European Interest (IPCEIs), which will allow them to offer state aid to such projects under the relevant EU rules. Member States may award state aid to hydrogen also under other State aid rules, notably the Environmental protection and Energy Aid Guidelines, which are currently being reviewed. Other activities in the international arena such as, for example, Mission Innovation (cooperation launched in the context of the Conference of the Parties of the United Nations COP) and the Clean Hydrogen Mission with the European Commission co-leading, the group of the Clean Energy Ministerial on Hydrogen and the Global Ports Coalition, all supplement EU and national efforts.
5. The Commission presented an interactive online hydrogen public funding compass allowing stakeholders to navigate EU and Member States public funding opportunities for their clean hydrogen projects[185].

The Resilience and Recovery plans will include policy support mechanisms, including new schemes such as pilots for Contracts for Difference auctions for RES based hydrogen for difficult to decarbonize sectors, or it is linked with other measures in RES production such as offshore installations, or onshore wind, PV installations.

Some of the commercial and trade data for Water Electrolysis are not available mostly due to the fact that many of the reports provide only global overviews and do not cover specifically hydrogen produced through Water Electrolysis technology.

23. Technology Analysis – Current situation and Outlook

23.1. Introduction

Hydrogen offers the opportunity to be used as both an energy vector and a feedstock molecule, therefore having several potential uses across sectors (industry, transport, power and buildings sectors). Hydrogen does not emit CO_2 when consumed, and offers the option to decarbonise several hydrogen-based

[183] European Commission Green Deal Call, 2020: https://ec.europa.eu/info/sites/default/files/research_and_innovation/green_deal/200506_gdc_brief_slides_2-2_electrolyser.pdf

[184] The assessment is based on the preliminary findings of the EC at the time of the publication of this report, and contain data on the projects submitted through the European Clean Hydrogen Alliance.

[185] Hydrogen Public Funding Compass | Internal Market, Industry, Entrepreneurship and SMEs (europa.eu).

applications, provided its production is sustainable and hydrogen does not carry a considerable carbon footprint.

Currently, the most mature and promising hydrogen production technology, which can be coupled with renewable electricity, is water electrolysis.

In short, water electrolysis, involves the dissociation of water molecules into hydrogen and oxygen and requires large amounts of electrical energy: for low temperature electrolysis, around 55 kWh[186] (about 200 MJ) of electricity are needed to produce 1 kg of hydrogen from a stoichiometric minimum of 9 kg of water. The thermodynamic limit for dissociating water at room temperature through electrolysis is around 40 kWh/kgH_2.

Solid Oxide Electrolysis (SOE) exploits the more favourable thermodynamics of water splitting at higher temperatures (usually above 800ºC) and can have efficiencies around 41 kWh/kgH_2, provided a suitable heat source is available; otherwise the heat requirements for maintaining the high temperature should also be factored in the efficiency[187].

The main electrolysis technologies[188], as well as their added values and drawbacks, are summarised below, and will be further analysed in the next sections:

Alkaline electrolysis is a well-established low temperature water electrolysis technology for hydrogen production, with relatively cost-effective stacks already available in the megawatt range. Alkaline electrolysers do not use noble metal catalysts and are stable, with a very long lifetime. Their main drawbacks are that alkaline electrolysers can only operate at relatively low current densities and their lack of flexibility. Historically, alkaline electrolysers systems have shown poor dynamic behaviour, with limited load flexibility as low loads may present a safety issue. However, progress is being made on adapting this technology for flexible operation.

Polymer Exchange Membrane (PEM) electrolysers can reach high current and power density and can operate well under dynamic operations and partial load. Therefore, they are highly responsive, which makes coupling with RES easier. Their main drawbacks are associated with durability, related to catalyst loss and membrane lifetime, and cost, partly due to their catalysts consisting of expensive and rare platinum group metals.

Solid Oxide electrolysers (SOE) must use materials capable of withstanding the higher temperatures involved with the use of this technology. They have slow ramp rates from cold-start due to the necessity to reach high temperatures and the necessity to avoid thermal shocks for the ceramic materials constituting the electrochemical cell. Therefore, they also have limited flexibility. They also contain critical raw materials such as rare-earth metals. Despite having reached a technological level able to support large demos, R&I actions are still necessary and materials related challenges have to be tackled in order to guarantee the possibility of deploying the technology at large scale.

In addition to the two main low temperature electrolyser technologies (alkaline and PEM electrolysis), recent years have also seen the development of Anion Exchange Membrane electrolysers (AEM). This

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[186] The system efficiency value of 55kWh.kgH2 is an overall estimate. MAWP (Multi Annual Work Plan) targets of the Fuel Cell Hydrogen Joint Undertaking for 2020 are 55kwh/kgH2 for PEM and 50kWh/kgH2 for Alkaline.

[187] It is estimated that, in practice around 12- 13 kg kg of water are used for the production of 1 kg of H2. The reason for this assessment is linked to losses in purifying/deionising water down to 1-10 µS before feeding it to the electrolyser.

[188] Historical Analysis of FCH 2 JU Electrolyser Projects, JRC (European Commission) Technical Report, 2021.

technology operates in alkaline media but using a solid electrolyte. In principle, this means they can combine the use of non-platinum group metal catalysts with the production of high-purity hydrogen due to the presence of the solid electrolyte. This technology is currently at a relatively low Technology Readiness Level (TRL 3-5) and cannot presently achieve the performance and durability of other water electrolysis technologies.

Electrolysers Capacity installed, generation/production

Whilst renewable hydrogen production is still at a very low capacity, a large number of demonstration projects have been announced and production is expected to grow significantly in the coming decade.

The Hydrogen Strategy envisioned a step by step path towards a European hydrogen ecosystem:

- in a first phase, from 2020 to 2024, the strategic objective is to install at least 6 GW of electrolysers in the EU, and the production of up to 1 Mt of renewable hydrogen per year;
- in a second phase, from 2025 to 2030, the strategic objective is to install 40 GW of electrolysers and the production of up to 10 Mt of renewable hydrogen per year[189].

The European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy Communication[190] - thereafter referred to as the Long Term Strategy (LTS) - foresees that the share of hydrogen in Europe's energy mix will grow from the current level of less than 2% to 13-14% by 2050, thus amounting from 60 up to 80 million tonnes of oil equivalent (Mtoe) in 2050. This forecast increases to 16-19% if hydrogen is used for the production of synthetic fuels (i.e. fuels synthetized using hydrogen produced from electrolysis)[191].

In terms of installed electrolyser capacity, the LTS foresees up to 511 GW (scenario referring to containment of global warming at 1.5 Degrees Celsius TECH scenario[192]), whilst other studies suggest a 1 000 GW European market by 2050[193].

In 2019, the EU had around 80 MW of dedicated water electrolysis capacity installed (all technologies), of which around 30 MW were located in Germany in 2018[194].An analysis performed by a private organisation[195] in May 2021, collecting information on planned and installed capacity in the EU, and taking into account the announcements of governments in their National Strategies on Hydrogen, concluded that electrolysers pledges would sum up to 34 GW by 2030[196], making it close to the EC target of 40 GW by 2030. The estimate includes 7 EU MSs (DE, FR, NL, PT, ES, IT) and the UK.

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189 A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

190 A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.

191 European Commission, Hydrogen use in EU decarbonisation scenarios, JRC EU Science Hub.

192 A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.

193 Kanellopoulos, K., Blanco Reano, H., The potential role of H2 production in a sustainable future power system - An analysis with METIS of a decarbonised system powered by renewables in 2050, EUR 29695 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00820-0, doi:10.2760/540707, JRC115958.

194 DVGW, Wasserstoff Schlüssel für das Gelingen der Energiewende in allen Sektoren, 2019.
Fuel Cells and Hydrogen Observatory, Hydrogen Supply Capacity, 2021.

195 Aurora Energy Research, Hydrogen Market Attractiveness Report, 11 May 2021.

196 The estimate includes about 4-5 GW in UK in that presentation and include low carbon hydrogen.

Members of the European Clean Hydrogen Alliance are working on projects aiming at installing electrolysers with the capacity to produce over 6m tons of hydrogen by 2030[197.]

Calculations published by the Fuel Cell and Hydrogen Joint Undertaking (FCHJU) in their assessment of the National Energy and Climate Plans (NECPs) estimate a potential installed electrolyser capacity between 13 (less favourable scenario) and 56 GW (more favourable scenario) in EU and UK by 2030[198].

<u>Additional information on the main production pathways</u>

Today, the EU demand for hydrogen is about 7.7 million tonnes per year[199], out of about a global demand of 70 Mt/y of hydrogen in pure form, producing around 830 Mt of CO_2 globally[200]. Nowadays, the hydrogen production is almost completely based on the use of fossil fuels and associated with large industrial processes.

The dedicated worldwide production of hydrogen (hydrogen as primary product) can be classified according to the following feedstocks[201]:

- ca. 71% from natural gas (steam methane reforming), accounting for 6% of global natural gas use, and emitting around 10 tonnes of carbon dioxide per tonne of hydrogen (tCO2/tH2);
- ca. 27% from coal (coal gasification), accounting for 2% of global coal use, emitting around 19 tCO2/tH2;
- about 0.7% from Oil (reforming and partial oxidation),emitting around 6.12 tCO2/tH2);
- less than 0.7% potentially from renewable sources (water electrolysis).

<u>Additional information on the end use of hydrogen:</u>

The total worldwide hydrogen use is mainly[202]:

- ca. 33% as chemical feedstock in oil refining;
- ca. 27% is ammonia production;
- ca. 10% in methanol synthesis[203].

The remaining fractions are linked with other forms of pure hydrogen demand (e.g. chemicals, metals, electronics and glass-making industries) and use of mixtures of hydrogen with other gases (e.g. carbon monoxide) such as for heat or combined heat-and-power generation.

The current use of hydrogen as feedstock in the chemical and petrochemical industry has to be added to the future uses as i) use as feedstock in new industrial processes (e.g.: steelmaking, or carbon capture and use applications) ii) fuel for the transport sector (various modes), iii) cogeneration of electricity and heat, or electricity alone, iv) a storage option for electricity, v) for heat generation in industrial environments.

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[197] European Clean Hydrogen Hydrogen Alliance – Overview of projects collected, Hydrogen Forum, 17-18 June 2021.

[198] Fuel Cell Joint Undertaking, Opportunities for Hydrogen Energy Technologies Report, August 2020

[199] Fuel Cell Observatory website. 8.3 MtH2/y including EU, UK, Norway, Switzerland and Iceland.

[200] As a reference total European industrial emissions were estimated at 877 $MtCO_2$/y (around 10% of these can be associated with hydrogen production) in 2017, European Environment Agency.

[201] IEA, The Future of Hydrogen- Seizing today's opportunities, p.32 – 2018 estimates, June 2019

[202] IEA, The Future of Hydrogen- Seizing today's opportunities, 2019.

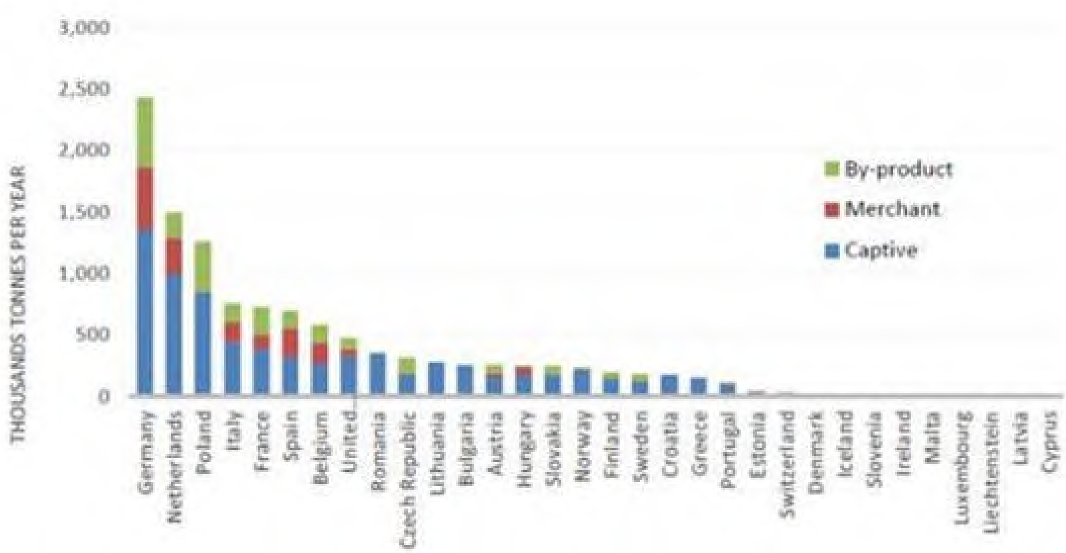
[203] In this case hydrogen is present as a component of syngas.

Transport of hydrogen, its storage and its conversion in end-use applications (e.g. industry, mobility, or buildings) are not part of the focus of the analysis performed in this report.

Figure 10 and

Figure 11 below show the production and consumption capacity per Member State (and UK), where largely the production matches the domestic demand.

Figure 10 Hydrogen production capacity (expressed in thousands of tonnes per annum)



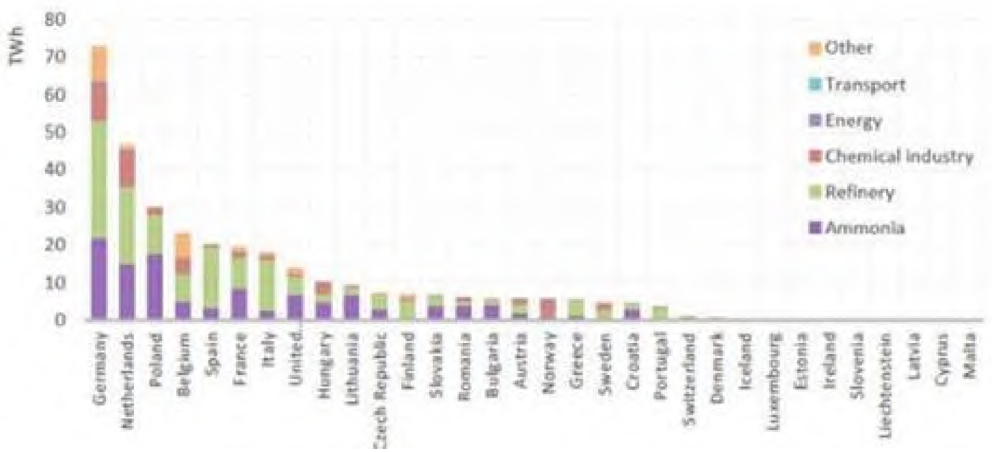
Source: Fuel Cell Hydrogen Joint Undertaking,2019 data

European hydrogen use in its pure form (both merchant and captive)[204]:

- ca. 47% used in oil refining;
- ca. 40% in ammonia production;
- ca.8% in methanol production and the remaining used mainly in other chemical productions and industrial processes.

Figure 11 Hydrogen Consumption (expressed in TWh)

[204] Fuel Cells and Hydrogen Joint Undertaking, Hydrogen Roadmap Europe, 2019.



Source: Fuel Cell Hydrogen Joint Undertaking (2019 data)

23.2. Cost of production of renewable and low carbon hydrogen; cost of electrolysers (CAPEX costs) and / other Operational (OPEX) costs including Cost of Electricity (CoE)

The cost of producing renewable and low carbon hydrogen through electrolysis depends on several factors.

1. Capital investment for electrolysers depends on the technology.
2. Operating costs, linked with the costs of electricity input (which can be a significant part of overall costs for both renewable and low-carbon hydrogen, and increasing as CAPEX costs are coming down).
3. Other electricity-related, or grid-related taxes and tariffs.
4. Load factor[205].

Other factors depends on the regulatory environment such as the price of carbon emission (e.g. in the Emission Trading System), as it impacts the competitiveness of hydrolysis (i.e. renewable hydrogen produced through water electrolysis using renewable electricity), versus other production pathways which emit CO2.

Other infrastructure or transportation cost elements such as availability and cost of storage should also be considered.

These factors may have a considerable impact on the final price of hydrogen, however the analysis of these factors is out of scope in this assessment.

Cost of Electrolysers:

Table 1 summarizes the main Key Performance Indicators for 4 main categories of Electrolysers i) Alkaline; ii) PEM Polymer Electrolyte Membrane; iii) AEM and iv) Solid Oxide Electrolysers (SOE).

[205] Amount of hours a production facility is able to run per year.

Alkaline and Polymer Electrolyte Membrane are technologies that have achieved commercial maturity and have been, or will be, deployed in demonstrations reaching a power of tens of MW[206].

Solid Oxide Electrolysers have been already tested in real life environment and planned demonstrations should deploy several hundreds of kW up to MW scale soon[207].

Anion Exchange Membrane Electrolysers are at a much lower technical maturity level (TRL 3-5), with only one European supplier[208] and a product offer in the range of few kWs.

Table 1 Key Performance Indicators for the four main Water Electrolysis technologies in 2020 and projected in 2030

	2020				2030			
	Alkaline	PEM	AEM	SO	Alkaline	PEM	AEM	SO
Chracteristic Temperature [°C]	70-90*	50-80*	40-60*	700-850*	-	-	-	-
Cell Pressure [bar]	<30*	<70*	<35*	<10*	-	-	-	-
Efficiency (system) [kWh/kgH2]	50	55	57*	40	48	50	<50*	37
Degradation [%/1,000h]	0.12	0.19	-	1.9	0.1	0.12	-	0.5
Capital Cost Range [€/kW - based on 100 MW production]	600	900	-	2700	400	500	-	972

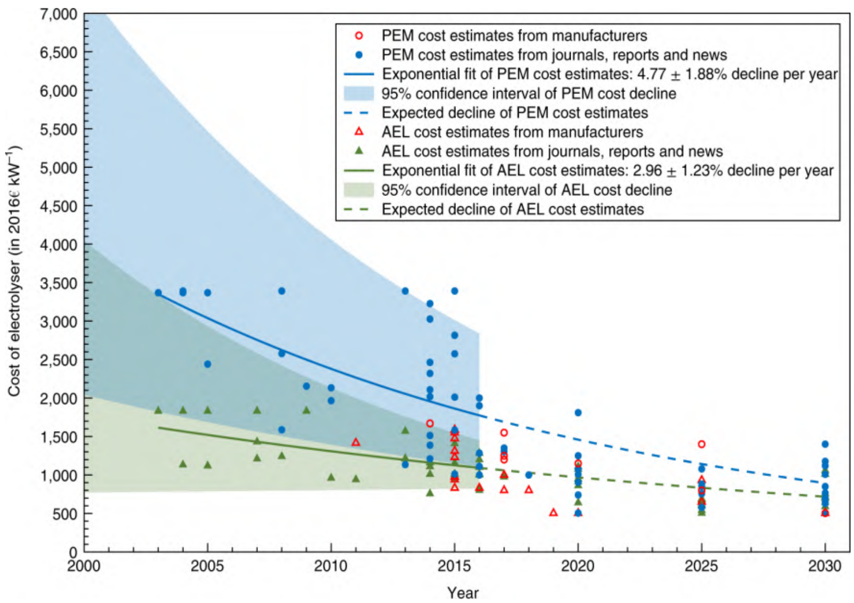
Source: Addendum to the Multi - Annual Work Plan 2014 – 2020, FCH JU, 2018 and for parameters labelled with '', DG ENERGY (European Commission) elaboration based on IRENA data from the "Green Hydrogen Cost Reduction" report", 2020[209].*

CAPEX (in particular for PEM) have already been significantly reduced in the last ten years, and are expected to roughly halve in 2030 compared to today thanks to economies of scale and acquired expertise.

Figure 12 gives an example of expected evolution of learning curves based on available historic data (until 2017).

[206] Examples of projects: DJEWELS (Akaline) and REFHYNE (PEM).
[207] MULTIPLHY project will demonstrate at MW scale (2.4 MW) https://www.green-industrial-hydrogen.com/
[208] Enapter.
[209] FCHJU Addendum to 2014-2020 Work Plan, and IRENA, Green hydrogen cost reduction, p12.

Figure 12 Cost trajectory for PEM and AEL electrolysers based on manufacturers estimates



Source: Economics of converting renewable power to hydrogen, G. Glenk, S. Reichselstein, [*https://www.nature.com/articles/s41560-019-0326-1*](https://www.nature.com/articles/s41560-019-0326-1)

Impact of the Cost of Electricity on the viability of Electrolyser investment

All analyses highlight that the price of hydrogen produced via electrolysis is reduced by increasing the number of operational hours and decreasing electricity prices; IRENA estimates that these factors have the capacity to decrease cost of hydrogen by 80% in the longer term[210]. These are the main factors that will influence the economic viability of the investment and are further strengthened by measures decreasing CAPEX impact on levelised cost of hydrogen, such as increasing system lifetime, or OPEX impact, such as increasing operational efficiency of the system. They will be key drivers for the progressive development of hydrogen across the EU economy.

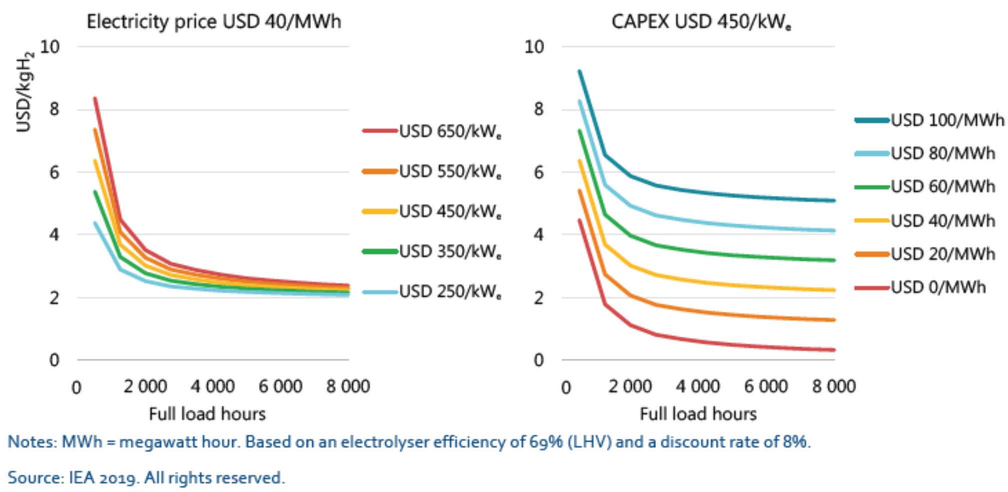
The European Clean Hydrogen Alliance is identifying the availability of required amounts of competitively priced renewable and low-carbon electricity as one of the main factors determining the actual deployment of large-scale electrolysers.

[210] IRENA, Green Hydrogen Cost Reduction, IRENA, 2020.

In regions with suitable costs of renewable electricity, electrolysers are expected to produce hydrogen that will compete with fossil-based hydrogen already in 2030[211].

Locating electrolysers in areas with high access to cheap renewable electricity is likely to decrease overall costs and contribute to viable investments.

Figure 13 Impact of electricity Costs (right) (USD/kg H2) and Electrolyser investment costs by operating hour (left)



Source: The Future of Hydrogen- Seizing today's opportunities, IEA, 2019

The Renewable Energy Directive (REDII) allows hydrogen produced from installations connected to the grid (even if the electricity mix has low shares of renewable electricity) to be statistically accounted for as 100% renewable, provided that certain conditions are met, including the additionality of the renewable electricity used.

With increasing full load hours, the impact of CAPEX on hydrogen production costs declines and the relative contribution of electricity costs to the levelised cost of hydrogen production via electrolysis becomes larger.

<u>Projected costs of renewable based hydrogen production:</u>

According to IRENA[212], '"in the best-case scenario," using low-cost renewable electricity at USD 20/MWh in "large, cost-competitive electrolyser facilities" could produce green hydrogen at a competitive cost with hydrogen already today'. However, this depends on the availability of required volumes of competitively priced renewable electricity.

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211 Assuming current electricity and gas prices, low-carbon fossil-based hydrogen is projected to cost in 2030 between 2-2.5 EUR/kg in the EU, and renewable hydrogen are projected to cost between 1.1-2.4 EUR/kg (IEA, IRENA, BNEF). Costs linked with transport over long distances should be added on top of production costs.

212 IRENA, Green Hydrogen Cost Reduction report, 2020.

Based on these assumptions for i.a. prices for electricity and carbon prices, the associated cost estimates for production range (based on IEA, IRENA, BNEF and the EC communication[213]) are:

- International prices of low-carbon fossil-based hydrogen: EUR 1.5-2.2/kg; renewable hydrogen: EUR 2.5-5.5/kg, depending on electricity price and load hours (see Figure 13).However, calculated costs depend on a number of assumptions used as input factors including electricity price and load hours. In countries relying on gas imports and characterised by good renewable resources, clean hydrogen production from renewable electricity can compete effectively with production that relies on natural gas[214].

Reducing the price of renewable hydrogen allows an increasing penetration of hydrogen into different sectors and applications. Usually, system boundaries for hydrogen production calculations are defined by the production side, but actual competitiveness for hydrogen uses comes from the opportunity offered by business cases outside the production boundaries, which likely include steps such as transport and storage. Industrial competitiveness could allow certain industrial processes to become affordable earlier than others which have to face more challenging economic competition against conventional fossil-based hydrogen (e.g. ammonia). As an additional advantage, renewable hydrogen may have a lower price volatility against hydrogen produced from fossil fuels, which follow natural gas prices. Its price will depend on the volatility of the (renewable) electricity used for electrolysis.

23.3. Public R&I funding

This section summarises the main sources of public funding at EU level.

- The Fuel Cell Joint Undertaking (established in 2008) as the Public Private Partnership (PPP);

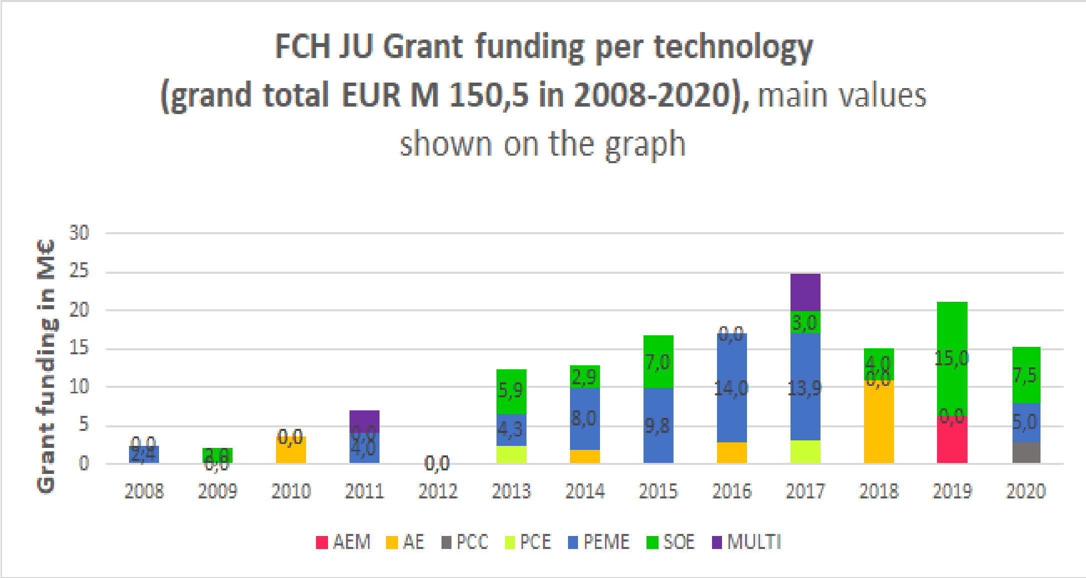
To date, the Fuel Cell Joint Undertaking established in 2008, as an EU body to manage funding in relation to Hydrogen and Fuel Cell technologies, has dedicated about EUR 150.5 million since 2008 to electrolyser technologies (EUR 74.7 million are for research actions and EUR 75.9 million for Innovation Actions (IA).

The main beneficiary countries are Germany, France and the UK with about EUR 31.4, 25.4 and 18.4 million respectively.

Figure 14 Fuel Cell and Hydrogen JU grant funding per technology in period 2008-2020

[213] Communication C(2020) 301 of 8 July 2020 Hydrogen Strategy.

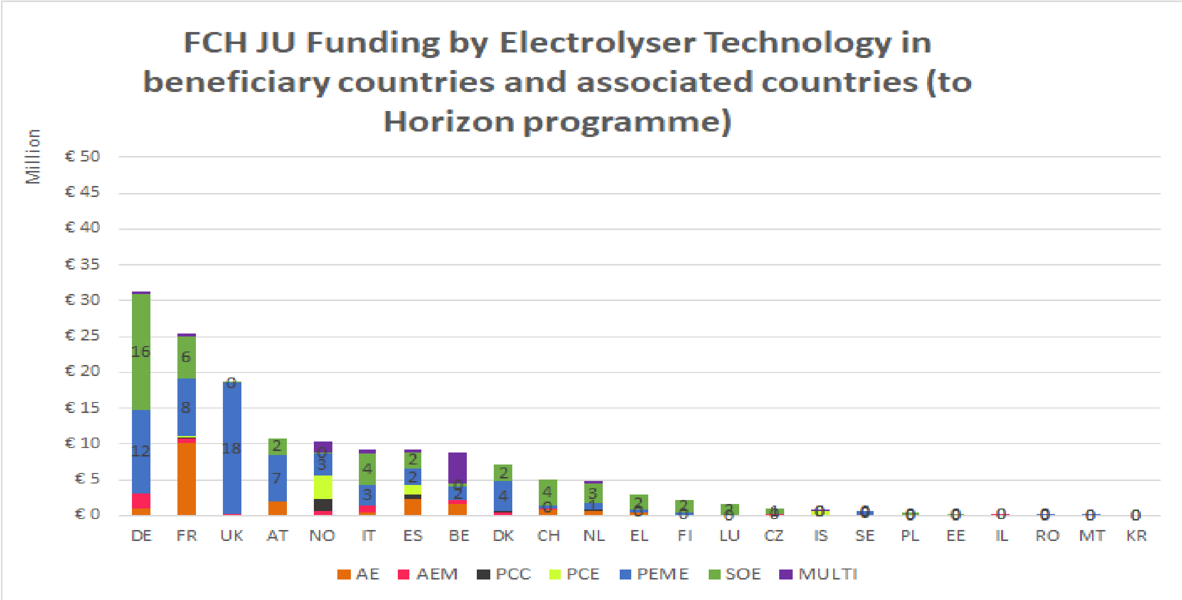
[214] IEA - The Future of Hydrogen, 2019, IRENA, Bloomberg BNEF, March 2020.



Source: Fuel Cell and Hydrogen JU, 2021

Notes:
PCE is proton conducting electrolyser (a low technology readiness level version of the Solid Oxide) which conducts protons through the solid oxide membrane
Multi- refers to multiple types of electrolyser technologies

Figure 15 Fuel Cell and Hydrogen JU funding by country and associated country, and per technology



Source: Fuel Cell Joint Undertaking, data 2021

Notes:
PCE is proton conducting electrolyser (a low technology readiness level version of the Solid Oxide) which conducts protons through the solid oxide membrane
Multi- refers to multiple types of electrolyser technologies

1) Dedicated call for proposals: 100 MW Electrolyser from the Green Deal Call (Horizon 2020 programme)

The European Commission has made circa EUR 90 million funding available in the Green Deal Call for proposals to install and operate electrolysers in real life environments.

After the competitive call for proposals and budget optimisation, 3 projects have been selected in 2021: one in the Netherlands to support electrolyser in the TSO and port environment, one in Germany in refining industry and one in Portugal combined with solar investments for multi end use applications.

Public national spending and European initiatives such as IPCEI and the ETS innovation Fund relevant for Renewable/ Low Carbon Hydrogen are today not easily measurable due to different reporting methodology and/or classifications and cannot be provided in an accurate and comprehensive way.

23.4. Private R&I funding

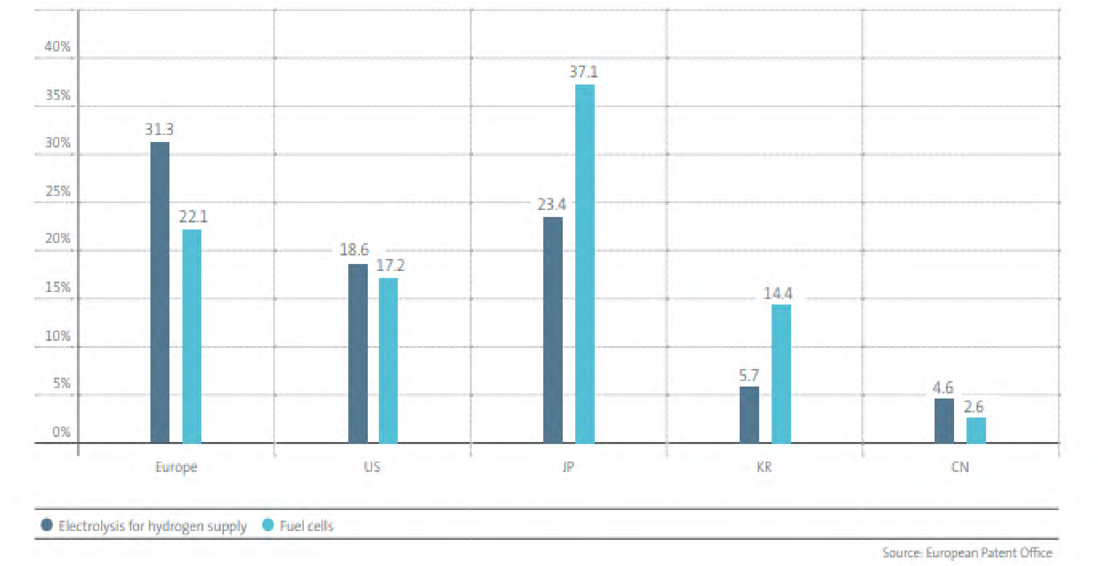
Due to the sensitivity of the information involved and the lack of fully developed electrolyser value chains outside of niche applications, it is very difficult to obtain accurate information on private R&I funding. It is expected that with the growth of electrolyser deployment this information will become more readily available in the following years. Venture capital has already announced dedicated interventions targeted at hydrogen technologies[215].

23.5. Patenting trends - including high value patents

Whilst Japan has been patenting consistently in this technical area for many years, in other regions (in particular China) a steady increase in the number of inventions related to electrolysers has occurred in recent years. For electrolysers, Europe (including UK) files proportionally higher numbers of International Patent Families (patent applications filed and published at several international patent offices) than other leading economies.

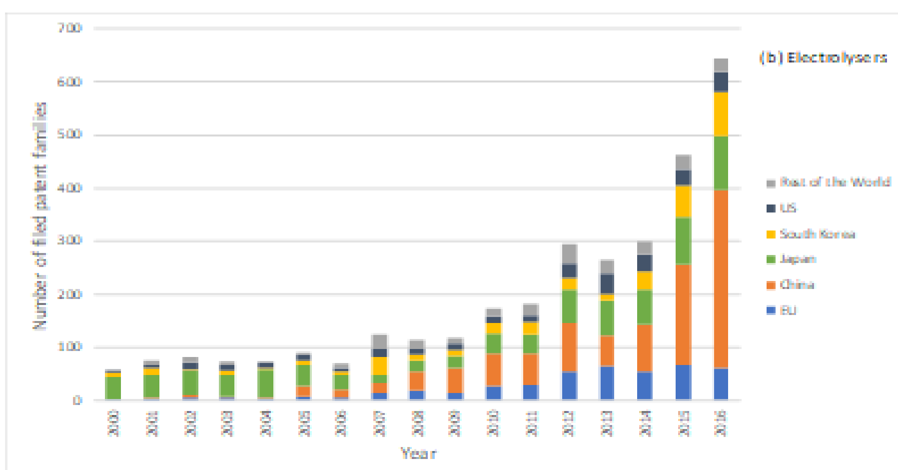
[215] E.g.: Breaktrhrough energy ventures / FiveT Hydrogen https://fivet.com/experience /AP Ventures https://apventures.com/hydrogen / Planet Power Finance AG/ White Summit Capital https://whitesummitcap.com/press/.

Figure 16 Share of International Patent Families (IPF) in major economies for hydrogen and fuel cell technologies (historic data 2010-2019). Each IPF covers a single invention and includes patent applications filed and published at several patent offices.



Source: European Patent Office/IEA[216]

Figure 17 Number of patent families for electrolysers and geographical area



Source: JRC based on EPO Patstat data, 2020.

[216] IEA, Patents and the energy transition, April 2021.

The majority of patent filings in Asia and in particular in China contain domestic patents.

23.6. Level of scientific publications

The Fuel Cell Observatory published some data[217] with regard to fuel cell and hydrogen production. The Fuel Cell Observatory lists the following countries ranking highest: Germany, France, Italy,

23.7. Final Considerations

To conclude on technology aspects for Water Electrolysis, four main technologies at different stages of maturity exist: Alkaline, Polymer Exchange Membrane, Solid Oxide and Anion Exchange Membrane electrolysis. Technology improvements are one of the factors that will contribute to lower the costs and availability of electrolysers on the market.

Most of the studies conclude that availability and cost of electricity will be the determining factor for the production of cost-competitive hydrogen.

As regards RI aspects[218], the technical report of the EC Joint Research Centre has provided recommendations based on the technology maturity and challenges to be addressed. These recommendations are summarised below.

For Alkaline electrolysers: The main challenge seems to be flexibility of use with renewable energy, however improvements are being made. Alkaline electrolysers seem to be more suited for the industrial use of hydrogen, rather than looking at flexibility for which PEM is more suited.

PEM electrolysers: future projects should consider the aspect of recyclability. This is of particular relevance because of the platinum group metals used. In particular, recycling of iridium is known to be challenging. An increase in operating hours (in order to reduce the share of CAPEX in the overall cost) will be important to the success of the technology.

AEM electrolysers are a promising technology, which could combine the positive aspects of AEL and PEMEL: the use of non-platinum group metal catalysts, with the production of high-purity hydrogen due to the presence of the solid electrolyte. They are however at a much earlier stage of technical development and there are still significant performance and durability challenges. AEM electrolysers have yet to be proven to be able to perform in real world conditions at the scale reached by PEM and alkaline electrolysers.

For SO Electrolyser longer term durability testing is required at system level and under real world operating conditions.

24. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

24.1. Introduction

There is a lack of fully developed electrolyser value chains outside of niche applications. The current market does not allow for a full value chain analysis. Ambitious future plans, such as those outlined in the

[217] FCHO, Publications: https://www.fchobservatory.eu/observatory/publications-eu28

[218] European Commission, Joint Research Center, 2021, Historical Analysis of FCH 2 JU Electrolyser Projects, Evaluation of contributions towards advancing the State of the Art. Davies, J. Dolci, F. Weidner, E.

Hydrogen Strategy point out to an exponential growth expected in future years. It is therefore not yet possible to provide relevant information on 'Turnover', 'Gross value added growth', 'Energy intensity and labour productivity' and 'Community Production'.

As of today Water Electrolysis for hydrogen production does not go beyond 1% of the overall hydrogen production.

Europe is highly competitive in clean hydrogen technologies manufacturing and is well positioned to benefit from a global development of clean hydrogen as an energy carrier.

As highlighted in the Hydrogen Strategy investments in electrolysers could range between EUR 24 and EUR 42 billion between 2020 and 2030. Over the same period, EUR 220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers and provide the necessary electricity. In addition, investments of EUR 65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refuelling stations[219, 220]. Finally, adapting end-use sectors to hydrogen consumption and hydrogen-based fuels will also require significant investments.

24.2. Number of EU companies

Main companies

The electrolysis market is very dynamic with several mergers and acquisitions registered in recent years. An overview of the manufacturers of medium to large scale electrolysis systems, considering only manufacturers of commercial systems and not manufacturers of laboratory-scale electrolysers[221], shows that:

Electrolysers based on alkaline electrolysis (AEL), are provided by:

- 9 EU producers (four in Germany, two in France, two in Italy and one in Denmark)
- 2 in Switzerland and 1 in Norway
- 2 in US
- 3 in China
- 3 in other countries (Canada, Russia and Japan).

Electrolysers based on proton exchange membrane (PEM) electrolysis, are provided by:

- 7 EU suppliers (four in Germany, one in France, one in Denmark and one in Spain)
- 1 supplier from UK and one from Norway
- 2 suppliers from US
- and 2 suppliers from other countries.

Electrolysers based on solid oxide electrolysis, are manufactured by 3 suppliers from EU (2 in Germany and 1France), 1 from the UK and 1 from the US.

219 FCH JU, Hydrogen Roadmap Europe, based on an ambitious scenario of electricity production of 665 TWh by 2030, 2019.

220 EC study Asset study (2020). Hydrogen generation in Europe: Overview of costs and key benefits. Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

221 A. Buttler, H. Spliethoff Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 updated with data from IRENA Green Hydrogen Reduction Costs 2020.

Table 2 Location of the manufacturers of large electrolysers, by technology

Electrolyser technology	EU	CH, NO, UK	US	China	Others
Alkaline AEL	**9**	**3**	**2**	**3**	**3**
Proton Exchange Membrane PEM	**7**	2	3		2
Solid Oxide Electrolysis SOEL	**3**	1	1		
Anion Exchange Membrane	**1**				

Source: A. Buttler, H. Spliethoff, Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 updated with IRENA Green Hydrogen Cost Reduction, 2020

24.3. Employment in the selected value chain segment(s)

As regards to employment in the value chain, various studies show different results, due to the different methodology and assumptions adopted (for example direct versus indirect jobs, sectors of employment including manufacturing of fuel cell vehicles).

A study commissioned by the EC DG Energy[222]does not single out clear figures for electrolysers, but evidences a significantly larger fraction of jobs located in sectors linked with the production of renewable electricity. The electricity sector is expected to be the largest sector of employment linked with large scale renewable hydrogen deployment in Europe (Electricity production would account for 5.9 million jobs created for each billion euros of investment and an estimated 7 million jobs in the electricity sector for each billion euros of investment).

According to a study published by the Fuel Cell Joint Undertaking[223], *"Hydrogen-related investments and operations are estimated to generate in 2020-2030 employment of 29 270 – 106 980 direct jobs (in production and operations & maintenance) and contribute to further 74 790 – 250 650 indirect jobs, depending on the scenario (these numbers are calculated as annual full time equivalent jobs). In summary, the hydrogen economy could by 2030 generate 104 060 – 357 630 jobs"*.

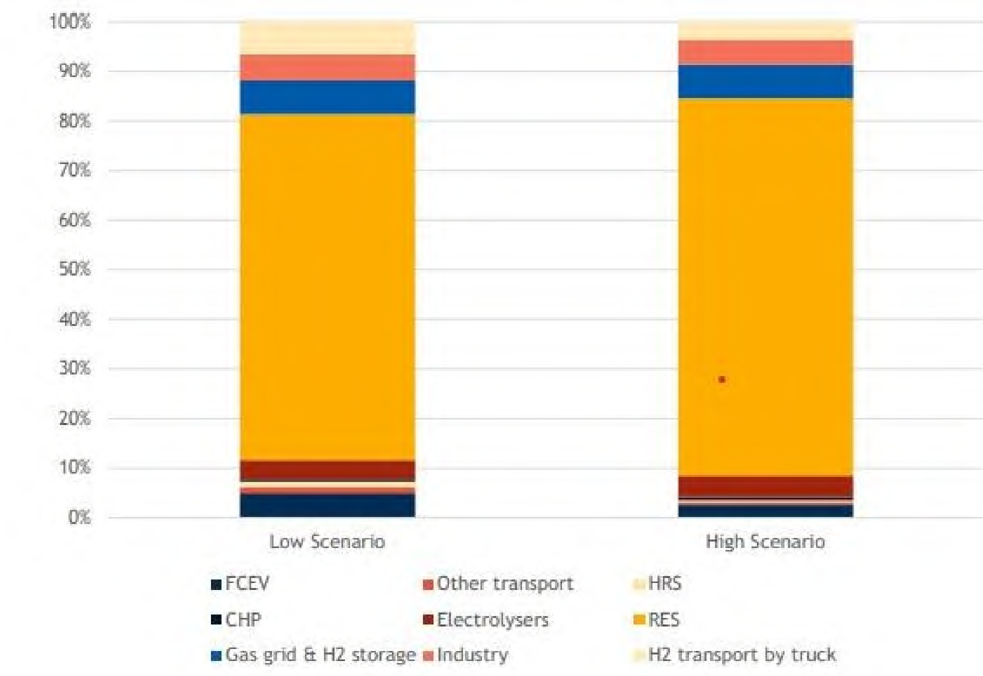
Their forecast for employment according to the sectors are highlighted in Figure 18 Value Added Share per Value Chain Segment – EU + UK

below.

[222] Hydrogen generation in Europe: Overview of costs and key benefits, ASSET study, 2020 Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

[223] FCH JU, Opportunities for Hydrogen Energy Technologies Considering the NECPs, August 2020.

Figure 18 Value Added Share per Value Chain Segment – EU + UK



Source: Fuel Cell Joint Undertaking, Opportunities for Hydrogen Energy Technologies and NECPs, 2020

Investments in electrolysers would represent a minor part of the overall value of the employment, with the main sector being the job creation in RES production.

24.4. Final Considerations

Despite the small size of the current value chains for electrolysers, the market for this applications is set to grow exponentially in the future, supported by the momentum of several announced hydrogen strategies. It is difficult to have accurate predictions, but overall it is expected that the magnitude of electrolyser value chains will be surpassed by that of renewable energy production value chains, which will be needed for achieving full electrolyser value chain maturity.

25. GLOBAL MARKET ANALYSIS

25.1. Introduction/summary

The Hydrogen Strategy[224] highlighted the potential of renewable and low carbon hydrogen to contribute to the EU goals of decarbonisation. From now until 2050, investments in production capacities would amount to EUR 180-470 billion in the EU[225].

[224] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[225] Asset study (2020). Hydrogen generation in Europe: Overview of costs and key benefits. Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

With regard to hydrogen production technologies, these announcements refer to low carbon hydrogen most likely using available technologies or technologies under development such as Carbon Capture and Storage (CCS).

While the global market capacity for hydrogen expands, competitiveness of the EU industries and producers needs to be contextualised taking into account the internal EU constraints such as the CO_2 pricing in the Emission Trading Scheme (ETS) prices.

As a general consideration, a level playing field between outside EU and internal EU companies producing hydrogen domestically, needs to be safeguarded.

25.2. Trade (imports, exports)

The current EU hydrogen demand matches its production with 7.7 million tonnes per year[226]. Imports to the EU may grow significantly for hydrogen imported as fuel. Data on the imports of electrolysers as a specific technology is unavailable.

25.3. Global market leaders vs. EU market leaders (market share)

Due to the lack of developed markets for electrolysis it is difficult to have a clear vision on global market leaders. As outlined in section 20.4 it seems that Europe has a higher concentration of producers for certain technologies with respects to other parts of the world (e.g. for Solid Oxide Electrolysis), it is however not possible to draw solid conclusions since the market is underdeveloped and is expected to significantly change in the coming years.

25.4. Resource efficiency and dependence

Around 30 raw materials are needed for producing fuel cells, electrolysers and hydrogen storage technologies. Of these materials, 13 materials are deemed critical for the EU economy according to the 2020 Critical Raw Materials (CRM) list[227]. The corrosive acidic regime employed by the PEM electrolyser, for instance, requires the use of noble metal catalysts like iridium for the anode and platinum for the cathode, both of which are mainly sourced from South Africa (84%), followed by Russia and Zimbabwe.

While the EU still has a relatively small production of fuel cells and electrolysers, risks related to the use of specific raw materials will become more apparent if large-scale manufacturing is to be developed in the EU.

For green hydrogen production, electrolysers will need to use electricity from renewable energy sources such as wind, solar power, hydropower and other renewable sources. This introduces additional pressure on the availability of materials required for these technologies, as well as other limitations, such as high land usage requirements. If 40 GW electrolysers are to be installed in the EU by 2030 and fed by renewable electricity, coming predominantly from wind and solar energy sources, the strong dependency on materials required for these two technologies should be carefully analysed. The critical materials for

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226 Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand data exclude UK, Norway, Switzerland and Iceland.

227 Joint Research Center report https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

wind turbines and solar panels, both crystalline and thin film panels, are supplied predominantly from China.

25.5. Final Considerations

Due to the lack of maturity of renewable and low-carbon hydrogen value chains it is impossible to have an accurate market overview since there is no remarkable global market dimension yet. It is likely that in the near future, international trading of large amounts of renewable or low-carbon hydrogen will become a viable option. Significant growth in electrolyser production and deployment on European territory will also bring to the forefront possible bottlenecks in the supply of electricity and critical raw materials, in particular for PEM and SO technology.

26. CONCLUSIONS

Even though renewable hydrogen is commercially available, its current high costs provide limits to its large-scale deployment. To ensure a full hydrogen supply chain to serve the EU economy, further research and innovation efforts are required[228]. It is also key to put into place a supportive regulatory and policy framework and to support the creation of a European hydrogen industry and market, including with public financial support during the ramp-up phase.

As outlined in the Hydrogen Strategy, upscaling the generation side will entail developing to larger size, more efficient and cost-effective electrolysers in the range of gigawatts that, together with mass manufacturing capabilities and new materials, will be able to supply hydrogen to large consumers. The Green Deal call (under Horizon 2020) for a 100 MW electrolyser has led to the selection of 3 projects that, when operational, will increase EU capacity by 300 MW. These projects will also offer the opportunity to test expansion options for electrolysers manufacturing capacity.

The availability and cost of electricity will be a main factor deciding upon the actual deployment of large-scale electrolysers. Research can also play a role in increasing electrolyser performance and reducing its costs for instance by increasing the durability of membranes, while reducing their critical raw materials dependence and recyclability.

Related to hydrogen production, subsequent new hydrogen technological chains should be developed. Infrastructure needs further development to distribute, store and dispense hydrogen in large volumes. Points of production of large quantities of hydrogen and points of use (especially of large quantities) are likely not to be close to each other. Hydrogen will have therefore to be transported over long distances and stored.

Large-scale end-use applications using renewable hydrogen need to be further developed, notably in industry (e.g. using hydrogen to replace coking coal in steel-making[229] or upscaling renewable hydrogen

[228] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[229] Already today, the H2FUTURE project in Austria operates a 6 MW electrolyser powered with renewable electricity that supplies hydrogen to a steel plant, while providing grid services at the same time. The HYBRIT project in Sweden is taking concrete action to become completely fossil-free steel plant by 2045, converting their production to use renewable hydrogen and electricity.

use in the chemical and petrochemical industries), and in transport (e.g. heavy duty[230], rail, waterborne transport and possibly aviation).

Finally, further research is also needed to enable improved and harmonised (safety) standards and monitoring, and assess social and labour market impacts. Reliable methodologies have to be developed for assessing the environmental impacts of hydrogen technologies and their associated value chains, including their full life-cycle greenhouse gas emissions and sustainability. Importantly, securing the supply of electricity and critical raw materials in parallel to their reduction, substitution, reuse, and recycling needs a thorough assessment in the light of the future expected increasing hydrogen technologies deployment, with due account being paid to ensure the security of supply and suitable levels of sustainability in Europe.

[230] European bus companies have also acquired expertise in production of fuel cell busses, due to several JIVE projects funded from the Fuel Cell Joint Undertaking and from the Connecting Europe Facility (transport).