Karelia University of Applied Sciences

Stakeholder Project

German solutions for energy storage

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1 Introduction

The following report was written in the context of the 3 ECTS course "Stakeholder Project" at the Karelia University of Applied Sciences in Joensuu, Finland.

The purpose of this report is to give the project manager of the project "UusiuWat", Kim Blomqvist, a general overview of the energy storage market in Germany. In UusiuWat project, the research is concentrated on the possibilities to store renewable energy to compensate variations in the production of green energy caused by wind or sun intensities. The author's task is to give an inside into the situation at the German market.

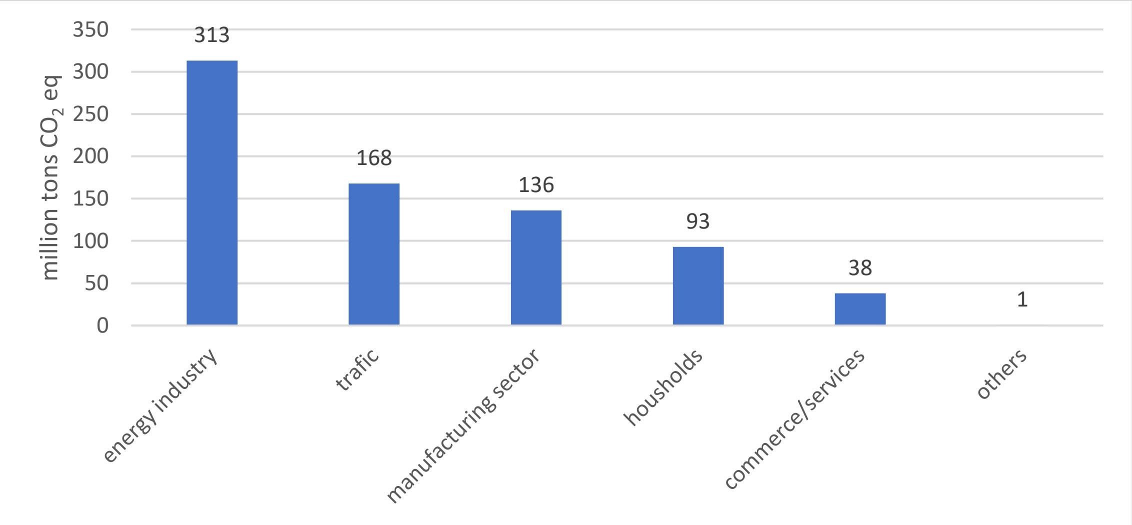
To create this report mostly German sources have been used to give the Finnish research team access to German literature on the matter.

The report starts to give a description of the current situation of the German energy market (Chapter 2), followed by the role of energy storage in the German energy sector (Chapter 3). Chapter 4 and Chapter 5 are dealing with the current solutions and technologies, as well as the latest inventions and pilots.

2 Current situation of the German energy market

Nowadays, the availability of electrical energy is taken for granted by most people in the world. The energy network as we see it today grew over decades and it is a complex system of power plants, transformers, storages, and the supply grid. The backbone of the German energy infrastructure is the energy transport grid, maintained by the grid operators. The high voltage energy grid has a total length of more than 35,000 km, supplies energy for more than 82,000,000 people and is essential for the German economy. [1]

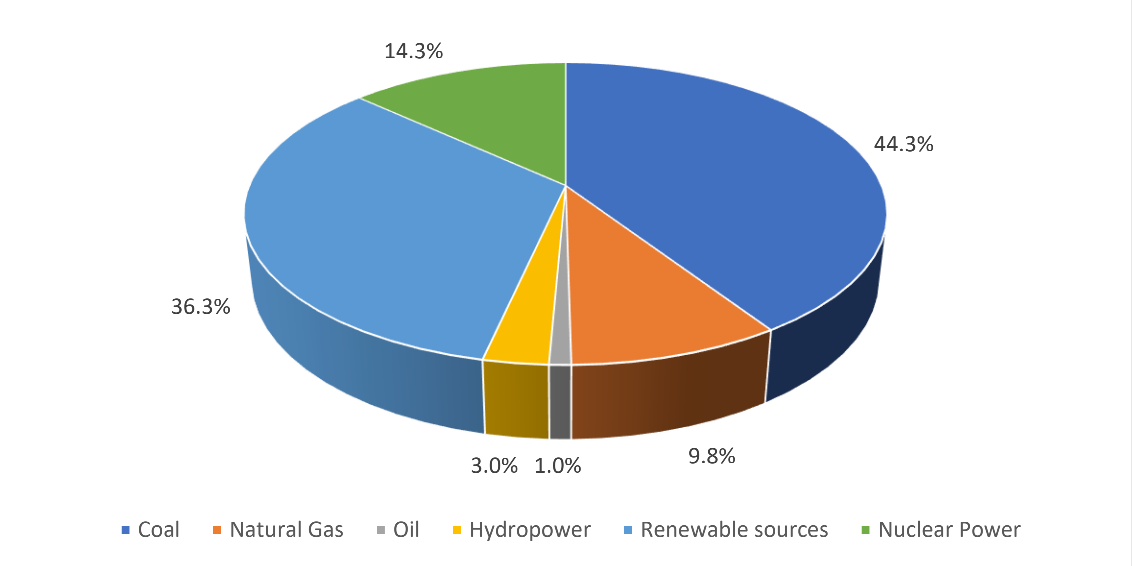
Figure 1: Greenhouse gas emissions in Germany by sector in 2017 (in million tons CO_2 eq)



In order to save the earth's climate, the German government set a goal to reduce the CO_2 eq emissions and achieve the 1.5°C goal from Paris 2015. To do so, a drastic change in power production is necessary. Until 2030 a reduction of CO_2 emissions by at least 55% and until 2050 of 100% compared to the level of 1990 is targeted.[2] The energy sector is by far the biggest emitter of greenhouse gases in Germany, as Figure 1 shows.[3] To reach the climate goals the energy sector has to be redesigned from the ground up. As Figure 2 shows, a big part (44.3%) of the produced energy comes from coal.[4] A piece of import information while looking at Figure 2 is that Germany decided to quit using nuclear energy after 2022 as a result of the reactor disaster in Fukushima.

[1] netzentwicklungsplan.de.
[2] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit.
[3] Statista, 2019a.
[4] The World Bank.

Figure 2: Electricity production and sources in Germany in 2015



To ensure energy security in Germany and the whole European continent, while at the same time conventional power plants (e.g. coal plant or nuclear energy plants) are shut down, a lot of work has to be done. Just on German soil, more than 7,500 km of the power grid must be optimized, reinforced or newly built.[5]

Most wind parks (onshore or offshore) in Germany are located in the coastal area of the country, so in the north. Most photovoltaic systems (PV) are located in the north-east. At the same time, the biggest energy-consuming factories are mainly located in the south-west region. To connect the biggest "green" energy plants with the biggest energy consumers big high-voltage transmission lines have to be built. The problem with the grid expansion is, that many people filing suits against these transmissions lines in their neighborhood. These longterm lawsuits are delaying big projects by years.[6]

Even though the German power grid is one of the best in the world[7], next to the improvements mentioned above, further steps are necessary to prepare Europe's biggest economy for the future. There is the linkage between other European countries[8], or the general decentralization including power storages at various places around the countries, just to name a few.

[5] Bundesministerium für Wirtschaft und Energie.
[6] Heiko Weckbrodt, 2014.
[7] Bundesministerium für Wirtschaft und Energie, 2017: 4.
[8] Bundesministerium für Wirtschaft und Energie.

3 Role of energy storage in the German the energy sector - political factors and strategies

According to the *DOE Global Energy Storage Database* by the Office of Energy, a U.S. Governmental institution, Germany has operating energy facilities with a total capacity of about 6.69 GW, another 251,2 MW are Offline/Under Repair, Under Construction or Contracted and 32 MW are already announced.[9] Not part of this statistic are small storages operated by individuals or companies for their internal use.

As already mentioned above, a lot of conventional power plants are being shut down, all the German nuclear power plants by 2022 or earlier. This development brings the need for a smarter power grid along. In the future the energy has to flow not just from "top to bottom" but also from "bottom to top", the grid has to become smarter.[10]

Energy storages have a big influence on the way energy is being produced, transported and used. They are not just supporting the energy grid in case of a blackout caused by storms, hardware failure or accidents. Their most important function is to compensate for fluctuations in the grid in milliseconds. In this way, the whole grid gets more resistant.

The energy storage market in a growing business. Experts see big potentials in the market of compensation of wind power plants and PVs as well as battery storage and Power-to-X technologies, for example, Power-to-Heat, Power-to-Gas, Power-to-Chemicals, and Power-to-Liquids. Even though the big potential and importance is recognized by policymakers, there are still barriers that complicate the construction of storages. Legally, energy storages are treated as end-users, which means taxes and dues are being paid while charging a storage. After discharging the storage, the actual consumer pays the same taxes and dues on the same energy a second time. This highly questionable practice increases the price in an unfair manner. The "Bundesverband Energiespeicher" (German Energy Storage Association) demands an independent role in the energy system[11] and appropriate laws for energy storage to reach climate goals.[12]

[9] Office of Electricity, 2019.
[10] Bundesministerium für Wirtschaft und Energie.
[11] Bundesministerium für Wirtschaft und Energie.
[12] Bundesverband Energiespeicher.

3.1 Strategically important funding areas

The Federal Government issued a list of strategically important funding areas. These are:

- electrical storage (batteries, pressurized air storage, virtual storage, condensers, flywheel, and pumped storage),
- material storage (conversion of flexible quantities of electricity into hydrogen and methane, geological storage, efficient reconversion of electricity stored in materials),
- thermal storage (materials and design principles, concepts for solar thermal power stations, for supplying buildings, integration in heating networks),
- overarching issues (management of distributed storage facilities, manufacturing processes, systems analysis and public acceptance of storage facilities).

In addition to these areas, the Federal Ministry for Economic Affairs and Energy’s actions are concentrated on the following areas:

- electrical storage with a focus on the further development of the lithium technology,
- material storage, particularly for the use of hydrogen,
- thermal storage with a view to efficiency, availability and costs of application in power stations, industrial processes and buildings.[13]

3.2 Funding by the Federal Government of Germany

The following subsections show the ways the German Federal Government funds research and innovation projects. Different approaches and techniques are described.

3.2.1 Federal Funding Advisory Service on Research and Innovation

The German Government provides an Advisory Service on Research and Innovation in English and German: This service is supported by seven different ministries, e.g. the Federal Ministry of Education and Research (BMBF), the Federal Ministry for Economic Affairs and Energy (BMWi) or the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU). The offered services are: identifying suitable

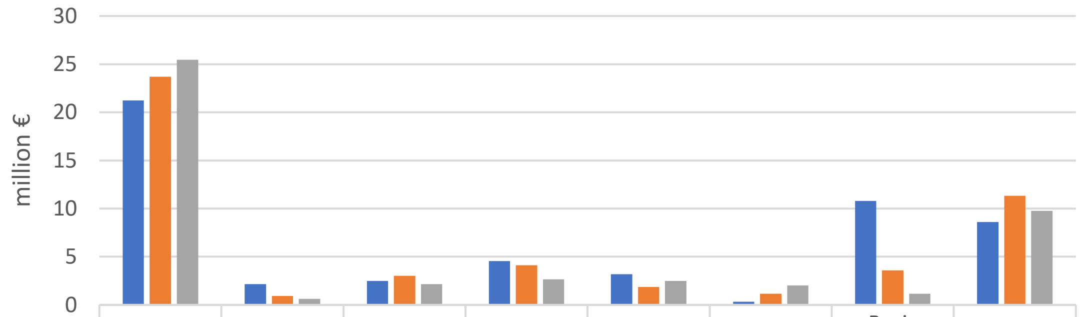
[13] Bundesministerium für Wirtschaft und Energie.

funding programs, advising on the Federal, Länder and EU research and funding landscape, assisting the classification of project ideas, and others.[14]

3.2.2 2019 federal Government Report on Energy Research

The federal Government Report on Energy Research gives a detailed overview of the Federal Government's energy research funding policy and estimates funds by the federal states, as well as EU-research policy. In 2018 the federal government spent around 1.06 billion euro for research, development and demonstration of modern energy- and efficiency technologies.

Figure 3: Development funds of the federal government by sector 2016-2018 (in million €)



	Elctrochemical storage	High temperature storage	Mechanical storage	Electrical storage	Low temperature storage	Material storage	Basic research (incl. other programmes)	other
2016	21.24	2.16	2.48	4.54	3.19	0.34	10.79	8.61
2017	23.71	0.92	3.01	4.11	1.86	1.15	3.6	11.34
2018	25.45	0.62	2.16	2.67	2.49	2.02	1.17	9.77

Figure 3 shows the development funds by the federal government in the years 2016 to 2018. Some obvious tendencies are visible, for example, the governmental spendings on electrochemical storages are not only by far the highest amount of all sectors (more than 25 million € in 2018), but the public funds are also rising by 7.3% in 2018 compared to the previous year.[15]

[14] Bundesregierung.
[15] Bundesministerium für Wirtschaft und Energie.

4 Solutions and Technologies at the moment

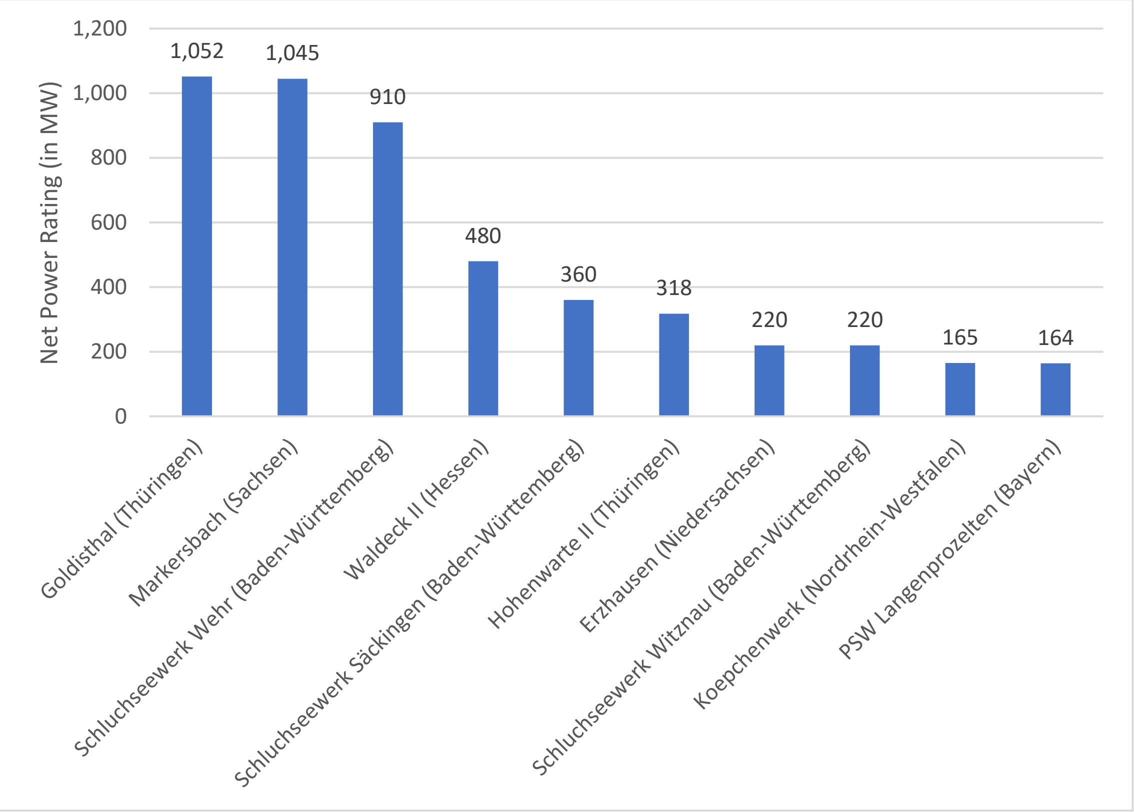
On the following pages, different technologies are described in more detail. Mechanical, electrochemical and cross-sectoral storages are mentioned.

4.1 Mechanical Storages

4.1.1 Pumped Hydro Electric Storage (PHES)

Pumped Hydro Electric Storages are regarded to be the most reliable technologies to store big amounts of energy.[16] PHESes have usually an efficiency factor of 0.7 to 0.8 and are the most used energy storeges at the moment. They have a relatively high capacity and are flexible and fast to release energy. Concerns about this technology are rising, because PHESes have a big, irreversible impact on nature and there are not many places left that fit the special, especially topological, requirements.[17] Figure 4 shows the biggest pumped storage power plants in 2019 in Germany by installed net power ratings in MW.[18]

Figure 4: Biggest Pumped Hydro Electric Storages in Germany (in MW)



[16] Heiko Weckbrodt, 2014.
[17] Energie Experten.
[18] Statista, 2019b.

4.1.2 Flywheel Energy Storage System

Flywheel Energy Storage Systems store electrical energy in terms of kinetic energy. The storage capacity depends on the moment of inertia of the Flywheel, this means, its diameter and its mass. The rotational speed of the wheel can be between a few thousand and a few hundred thousand cycles per minute. Flywheel energy storages are able to store big amounts of energy, but they are basically exceptions on the market.[19]

Figure 5: Flywheel Energy Storage System next to train tracks in Zwickau

In the Eastern German Bundesland Sachsen (Engl. Saxony) the city of Zwickau installed Flywheel Energy Storage Systems to recover braking energy from the local trains. In this system, the braking energy is transported via the current collector to the storage facilities next to the tracks and there it moves a 165 kg carbon-fiber-ring to store the energy.

The advantages of these technologies are the nearly endless durability and the recyclability of almost 100% of the used materials.[20]

4.2 Electrochemical Storage

4.2.1 Decentralized battery storages

At the moment electrochemical energy storages are mainly used on a small scale, widely used in single-or-double-family houses. These small-scale systems are quite

[19] Adolf J. Schwab, 2017: 277.
[20] Thomas Wolf, 2018.

expansive, the capacity relatively small and the ongoing charging-discharging processes are decreasing the overall capacity of these batteries.[21]

4.2.2 Centralized battery storages

Figure 6: Energy storage made out of different battery systems

More and more often, batteries are also used in bigger scales. In these cases, many batteries are interconnected and then connected with the low voltage grid. These systems are acting like local buffers to compensate ups and downs in the local power grid. In Figure 6 an energy storage, which is used in the project "SmartRegion Pellworm", is shown. This device helps to use the triple amount of renewable energy in this area per year.[22]

4.3 Cross-sectoral energy storage concepts: Power-to-X technologies

"Cross-sectoral" describes the connection between different energy sectors, like the power- with the gas- or heat-sector. This kind of energy storage can be used in connection with or without a reconversion into electricity. The Power-to-X technologies allow the relief of the electricity grid by using, for example, the system of gas pipelines as an energy distributor.[23]

4.3.1 Power-to-Gas

This "energy storage" transforms water with the use of electricity into hydrogen (process: electrolysis) or in a second step into methane. Both gases can be injected into

[21] Energie Experten.
[22] Ibid.
[23] Ibid.

the existing pipelines. Another upside to this method is the fact, that this “renewable” gas the same properties as fossil natural gas.

To actually store the gas, gas tanks are just the supply grid are used. After the storing process, the gas can be retransformed into electricity, if needed.[24]

4.3.2 Power-to-Heat

Figure 7: High-temperature storage by Siemens Gamesa in Hamburg

Power-to-heat plants transform, as the name suggests, electricity into heat. The heat can be stored in different ways and be retransformed into electricity, or the heat can be used in teleheating systems to heat buildings.

In Figure 7 a high-temperature storage facility, operated by Siemens Gamesa is shown. The plant is located in the Hamburg Harbor area and uses volcanic rocks as the main heat-storage.

4.3.3 Power-to-Liquid

Hydrogen (see Chapter 4.3.1 Power-to-Gas) can be used to produce liquid fuels. Using the P2L technology fuels are produced, that can be stored or distributed in the existing fuel infrastructure.

Figure 8 on the right shows a Power-to-Liquid plant operated by the Dresdner company *Sunfire*.[25]

Figure 8: Power-to-Liquid plant by Sunfire in Dresden

[24] Ibid.
[25] Ibid.

5 Latest inventions and pilots

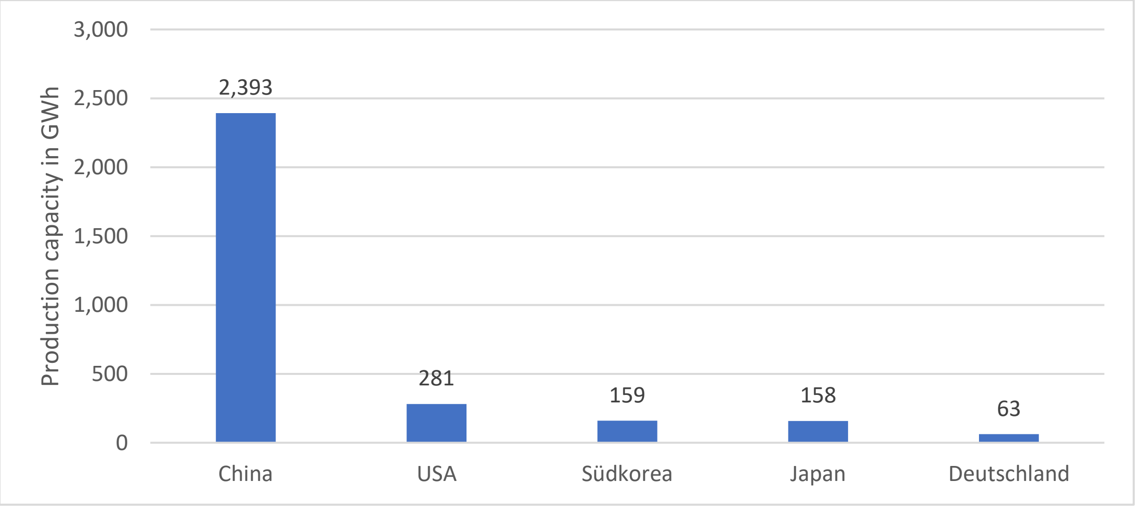
5.1 A general overview of innovations and pilots

Germany as one of the leading technology locations in Europe and in the world is putting a lot of effort into the development and research of new, future technologies. The energy turnaround is not something, that is deeply founded in German mentality and politics, but the awareness grew in recent years. There was a lack of innovation in the last decades, so today Germany is not top of the class, but it wants to get there.

Direct consequences of the lack of innovation are:

- Today Germany does not have enough long-term energy storages, so electricity from German Off-Shore power plants is transported to pumped hydro electrical storages and stored there,[26]
- A dependency on other (mostly) Asian countries in battery cell production for electrical vehicles, as Figure 8 shows.[27]

Figure 9: Forecast of battery cell production for electrical vehicles from 2017 until 2022



As already mentioned above, Germany, as the world-leading car producer, does not yet has the technologies to produce enough batteries for electric cars or the energy transition. In the last years, this grievance has been acknowledged by politicians and the industry and today a lot of money is spent on research and development projects (see Figure 3: Development funds of the federal government by sector 2016-2018 (in million €)" on page 6).

[26] Volker Kühn, 2015.
[27] Roland Berger, 2019.

5.2 Innovative area "Dresden"

One major focus area for energy storage research and development projects is the city of Dresden in the eastern part of Germany.

5.2.1 DRESDEN-concept

DRESDEN-concept is a research alliance, mainly initialized by the Technische Universität Dresden (TU Dresden; Engl.: Technical University Dresden). DRESDEN-concept is a vivid network of different regional research institutions and it stands for "Dresden Research and Education Synergies for the Development of Excellence and Novelty".[28]

Figure 10 shows the main actors of DRESDEN-concept, who are involved in energy storage research.[29]

Figure 10: DRESDEN-concept Structure/Function

5.2.1.1 Technische Universität Dresden

The Technische Universität Dresden operates a research cluster, named "Combined Storage System Integration" (CSSI), dedicated to the research on different energy storage possibilities. "The goal of the CSSI is to serve as a partner for public institutions, government, and industry regarding research and development in the field of energy storage."[30]

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[28] DRESDEN-concept.
[29] Kathleen Mehnert.
[30] TU Dresden.

5.2.1.2 Fraunhofer IWS and Fraunhofer IKTS

A second big actor in Dresden is the Fraunhofer Gesellschaft (Engl.: Fraunhofer Society). The society operates various research institutes in Dresden, of which two dedicated their work mainly to the research on energy storage.

Fraunhofer IWS worked on the development of electrode materials and manufacturing processes to produce high-density battery cells based on *lithium-sulfur technology* in a cost-effective manner. In 2015, a battery cell with an energy density of more than 300 Wh/kg was presented, which was a 25 percent increase over classic lithium-ion batteries.[31]

Fraunhofer IKTS has been working on *electricity from ceramics*. In their research, Fraunhofer IKTS has been focused on batteries based on sodium-nickel-chloride to develop a cost-effective, long-lasting and reliable solution for stationary energy supply.[32]

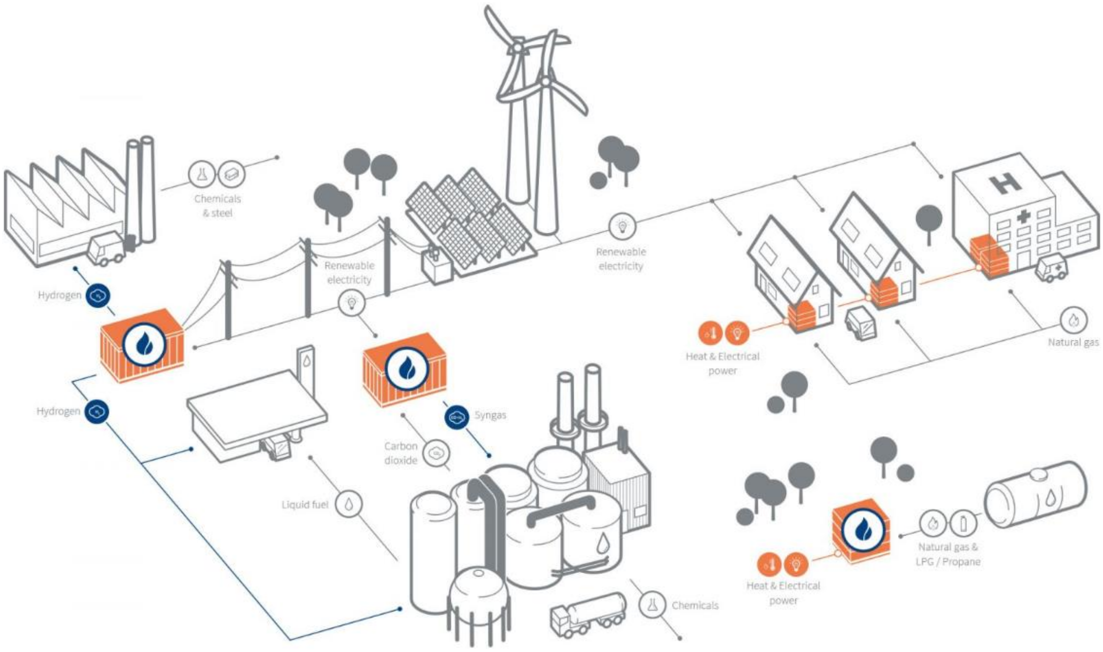
[31] Fraunhofer IWS.
[32] Fraunhofer IKTS.

5.2.2 Sunfire

Sunfire GmbH is a company, based in Dresden, whose goal is to help to achieve international energy and climate policy goals. Sunfire offers several products and services. Their main idea is to transform electrical energy into different energy carriers, such as e-Gas, e-Fuel or e-Chemicals. These sustainable and renewable products can work as substitutes to conventional, fossil gas or fuel.[33] One product of Sunfire has already been mentioned in Chapter 4.3.3 *Power-to-Liquid* on page 10.

Figure 11 shows all the application possibilities of the different products that *Sunfire* offers.[34]

Figure 11: Application possibilities of Sunfire products



[33] Sunfire, 2019a.
[34] Sunfire, 2019b.

6 Future demands and roles for energy storage in Germany

The presented information gives a brief insight into the German energy (storage) market. In the future, the storage will become a bigger factor in the energy grid, due to the energy transition and the growing share of renewable energy of the total energy production. The Federal Government and the EU pledged their selves to be Carbon neutral by the year 2050. This plan is quite ambitious and many different actions have to be taken.

One aspect of the energy transition is the ecological traffic turn. In the current public debate, the electrical car seems to be the savior, even though there are still many unanswered questions regarding the safety and battery disposal.

Most of the information given above is about Germany, but it is important to keep in mind, that no country can achieve climate goals by themselves. The European energy sector is growing closer together and as *Figure 9: Forecast of battery cell production for electrical vehicles from 2017 until 2022* showed, even a worldwide collaboration is necessary; knowledge and technologies have to be shared with one another.

7 References

Berger, Roland, 2019. *E-Mobility Index 2019*. https://www.fka.de/images/publikationen/2019/E-Mobility_Index_2019.pdf. Accessed 13 December 2019.

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit. *Der Klimaschutzplan 2050: Die deutsche Klimaschutzlangfriststrategie*. https://www.bmu.de/themen/klima-energie/klimaschutz/nationale-klimapolitik/klimaschutzplan-2050/#c8418. Accessed 8 December 2019.

Bundesministerium für Wirtschaft und Energie. Bundesbericht Energieforschung 2019.

Bundesministerium für Wirtschaft und Energie. *Ein Stromnetz für die Energiewende*. https://www.bmwi.de/Redaktion/DE/Dossier/netze-und-netzausbau.html. Accessed 8 December 2019.

Bundesministerium für Wirtschaft und Energie. *Energy storage*. https://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-priorities-energy-storage.html. Accessed 11 December 2019.

Bundesministerium für Wirtschaft und Energie, 2017. *Strom 2030: Langfristige Trends – Aufgaben für die kommenden Jahre*.

Bundesregierung. *Federal Funding Advisory Service on Research and Innovation*. https://www.bmbf.de/upload_filestore/pub/Federal_Funding_Advisory_Service.pdf. Accessed 11 December 2019.

Bundesverband Energiespeicher. *FAQ – BVES*. https://www.bves.de/faq/. Accessed 10 December 2019.

DRESDEN-concept. *Mission*. https://www.dresden-concept.de/en/alliance/mission.html. Accessed 13 December 2019.

Energie Experten. *Energiespeicher*. https://www.energie-experten.org/erneuerbare-energien/oekostrom/energiespeicher.html. Accessed 18 November 2019.

Fraunhofer IKTS. *Electricity from ceramics: environmentally friendly and cost-effective stationary energy storage systems*.

https://www.dresden.fraunhofer.de/en/institutes/fraunhofer_ikts/highlights.html#ikts1. Accessed 13 December 2019.

Fraunhofer IWS. *Milestone Battery Research*. https://www.dresden.fraunhofer.de/en/institutes/fraunhofer_iws/highlights.html#iws2. Accessed 13 December 2019.

Kühn, Volker, 2015. *Norwegens Stauseen speichern deutschen Ökostrom*. https://energiewinde.orsted.de/trends-technik/stauseen-norwegen-speicher-oekostrom-deutschland. Accessed 18 November 2019.

Mehnert, Kathleen. *Energy Storages*. https://tu-dresden.de/ing/forschung/forschungsschwerpunkte/energiespeicher. Accessed 13 December 2019.

netzentwicklungsplan.de. *Grundlage für Wachstum und Wohlstand*. https://www.netzentwicklungsplan.de/de/wissen/stromnetze.

Office of Electricity, 2019. *DOE Global Energy Storage Database*. https://energystorageexchange.org/. Accessed 10 December 2019.

Schwab, Adolf J., 2017. *Elektroenergiesysteme*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Statista, 2019a. *Treibhausgasemissionen nach Sektoren in Deutschland 2017*. https://de.statista.com/statistik/daten/studie/312450/umfrage/treibhausgasemissionen-in-deutschland-nach-quellgruppe/. Accessed 8 December 2019.

Statista, 2019b. *Wichtigste Pumpspeicherkraftwerke in Deutschland nach installierter Leistung 2019 | Statista*. https://de.statista.com/statistik/daten/studie/310041/umfrage/wichtigste-pumpspeicherkraftwerke-in-deutschland-nach-installierter-leistung/. Accessed 12 December 2019.

Sunfire, 2019a. *About Sunfire*. https://www.sunfire.de/en/company/about-sunfire. Accessed 13 December 2019.

Sunfire, 2019b. *Energy transition through Innovation and Technology*. https://www.sunfire.de/en/applications. Accessed 30 November 2019.

The World Bank. *World Development Indicators: Electricity production, sources, and access*. http://wdi.worldbank.org/table/3.7. Accessed 8 December 2019.

TU Dresden. *Energy Storages*. https://tu-dresden.de/ing/forschung/forschungsschwerpunkte/energiespeicher. Accessed 13 December 2019.

Weckbrodt, Heiko, 2014. *Schwefel-Akkus und Supercaps: Woran Dresdner Energiespeicher-Forscher arbeiten*. https://oiger.de/2014/02/04/schwefel-akkus-und-supercaps-woran-dresdner-energiespeicher-forscher-arbeiten/27100. Accessed 30 November 2019.

Wolf, Thomas, 2018. Schwungrad als Antriebsalternative in Sachsen. *DieSachsen.de,* 27 March 2018. https://www.diesachsen.de/future-mobility/schwungrad-als-antriebsalternative-in-sachsen-13666. Accessed 12 December 2019.