
# Report
## for the Feasibility Study

**Innovation Region Fessenheim**
**Barbara Koch (Ed.)**

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Baden-Württemberg

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**Preamble**

The project on the future of the Fessenheim region, adopted in 2019, pursues the "common goal of becoming a European region for low-carbon economy based on excellence and innovation, these creating jobs and adding value, and in which citizens, companies and stakeholders from research and institutions participate".

Against this backdrop, the French State, the Grand Est Region, the German Federal Republic and the Federal State Baden-Württemberg supported the "Innovation Region Fessenheim" feasibility study.

The study was carried out by the European Groupings of Territorial Cooperation (EGTCs) Eucor - The European Campus and in coordination with the Upper Rhine Cluster for Sustainability Research.

The French State, the Grand Est Region, the German Federal Republic and the Federal State Baden-Württemberg would like to thank all the scientific teams for carrying out this far-reaching project as well as the economic actors for their contributions. They recognise the great value of the multidisciplinary work done within the last 18 months.

The study, recommendations and pilot projects described are the result of expert cooperation. These will be presented to the decision makers, funding partners of the study, yet are not binding in nature for the French State, the Grand Est Region, the German Federal Republic or the Federal State Baden-Württemberg. They form the basis for further potential future discussions between the institutions and partners of the Upper Rhine region. In accordance with the political guidelines of the respective funding partners, the conclusions of the study can, in conjunction with the business world, contribute to the transformation of the Fessenheim region.

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# List of Abbreviations

| | |
|---|---|
| AEY | Annual Energy Yield |
| ADEME | Agence de l'Environnement et de la Maîtrise de l'Énergie |
| AGRO-PV/APV | Agricultural Photovoltaics |
| ANR | French National Research Agency |
| BauGB | Baugesetzbuch |
| BEV | Battery Electric Vehicle |
| BImSchG | Bundes-Immissionsschutzgesetz |
| BImSchV | Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes |
| BMF | Battery Materials Factory |
| BPI | Banque Publique d'Investissement |
| BW | Baden-Württemberg |
| CAM | Cathode-Active Materials |
| CeA | Collectivité européenne d'Alsace |
| $CGH_2$ | Compressed Gaseous Hydrogen |
| CHP | Combined Heat and Power |
| CLC | CORINE Land Cover |
| $CO_2$ | Carbon Dioxide |
| CRE | Commission de Régulation de l'Énergie |
| DF | Dark Fermentation |
| EDF | Électricité de France (EDF) |
| EEA | European Environment Agency |
| EES | Electrical Energy-Storage |
| EnBW | Energie Baden-Württemberg |
| EnWG | Energiewirtschaftsgesetz |
| EoL | End of Life |
| EPP | Early Pilot Plant |
| EU | European Union |
| EV | Electric Vehicle |
| FeLis | Chair of Remote Sensing and Landscape Information Systems |
| FhG | Fraunhofer Gesellschaft |
| GDP | Gross Domestic Product |
| GDPR | General Data Protection Regulation |
| GHG | Greenhouse Gases |
| GIS | Geographical Information System |
| GM-PV | Ground-Mounted Photovoltaics |
| GSHP | Ground Source Heat Pump |
| $H_2$ | Hydrogen |
| HFS | Hydrogen Fuel Station |
| HT | High Temperature |
| HT Electrolysis | High Temperature Solid State Electrolysers |
| ICE | Internal Combustion Engines |
| ICPE | Classified Installation for Environmental Protection |
| ICPR | International Commission for the Protection of the Rhine |
| IFES | Integrated Food-Energy System |
| ISO | International Organisation for Standardisation |
| KIT | Karlsruhe Institute of Technology |
| LCA | Life Cycle Assessment |

| | |
|---|---|
| LCIA | Life Cycle Impact Assessment |
| $LH_2$ | Liquid Hydrogen |
| LHV | Lower Heating Value |
| LIB | Lithium-Ion Battery |
| LIVE | Laboratoire Image, Ville, Environnement |
| LNG | Liquid Natural Gas |
| LOI | Letter of Intent |
| LPP | Late Pilot Plant |
| MEC | Microbial Electrolysis Cells |
| MP | Meteorological potential |
| NAS battery | Sodium-Sulfur battery |
| NDA | Non-Disclosure Agreement |
| NGO | Non-Governmental Organization |
| NMP | N-Methyl-2-pyrrolidone |
| NIMBY | Not In My Back Yard |
| OEM | Original Equipment Manufacturer |
| OSM | Open Street Maps |
| P2H/PtH | Power to Hydrogen |
| PBRM | Perception-Based Regional Mapping |
| PEM | Polymer Electrolyte Membrane / Proton exchange membrane |
| PIA | Programme d'Investissements d'Avenir |
| PV | Photovoltaics |
| PVDF | Polyvinylidene Fluoride |
| R&D | Research and Development |
| RE | Renewable Energy |
| REP | Registre des Émissions Pollutante |
| RES | Renewable Energy Systems |
| $RH_2INE$ | Rhine Hydrogen Integration Network of Excellence |
| SMES | Superconducting Magnetic Energy Storage |
| SMR | Steam Methane Reforming |
| SWOT | Strengths, Weaknesses, Opportunities and Threats |
| TCO | Total Cost of Ownership |
| TMO | Trinationale Metropolregion Oberrhein |
| TRL | Technological Readiness Level |
| URCforSR | Upper Rhine Cluster for Sustainability Research |
| URG | Upper Rhine Graben |
| URR | Upper Rhine Region |
| UVPG | Gesetz über die Umweltverträglichkeitsprüfung |
| WPD | Wind Power Density |
| WP2 | Working Package 2 |
| WSWS | Wind Speed Wind Shear Model |
| ZAC | Concerted Development Zone |

# Executive Summary

The feasibility study Innovation Region Fessenheim presents ideas for innovation pilots in the wider Fessenheim-Colmar-Freiburg region. The focus of the study is on developing a pilot innovation region that aims to attain emission neutrality and sustainability in the energy system based on innovative new technologies and promote local value addition and job creation. Based on a bilateral understanding, the feasibility study will develop a role model for cross-border European regional development. The study proposes ideas for demonstration projects particularly in the fields of “Green Batteries”, “Green Hydrogen” and “Smart Grids” and sheds light on the interlinkages and co-benefits of their potential implementation.

The main idea of the feasibility study is to identify viable transformation fields for the innovation region by factoring in the total regional primary energy consumption in order to induce a transformation towards a future-oriented industry and energy market. After analyzing the regional assets of the Upper Rhine and the Fessenheim innovation region and linking them to the postulated goals of the Projet de Territoire, ideas for pilot development that fulfill the requirements of the political requests, highlighted in the Projet de Territoire, were identified. The ideas for the development of pilots as best practice examples for the region are based on four competence groups in the aforementioned technology fields of “Green Batteries”, “Green Hydrogen” and “Smart Grids”. The fourth competence group links the pilot ideas from the three technology innovation groups by framing them in a territorial context.

For the acceleration of the regional transformation, the technical innovation pilots, as carriers for this transformation, are described comprehensively in the report along with information on the interlinkages between them, their technical readiness and possible timelines. Moreover, the territorial framework competence group elaborates on the constraints and opportunities in respect to economic rationality, environmental impact, legal aspects, and societal acceptability of the technical innovation ideas. For all technical innovation pilots, a detailed description in the form of pilot sheets is provided in the attachment.

Finally, in the conclusion, a list of next steps for possible activities on political, societal and industrial level is provided.

# 1. Background and Aim of the Study

The initial impetus of the study originates from the closing down of the nuclear power plant of Fessenheim. The deactivation of the nuclear plant was accompanied by a political commitment from the French and German governments as well as various regional authorities (Projet de Territoire, 2019). The idea was to develop a pilot innovation region towards aiming at emission neutrality and sustainability,  based on innovative new technologies for a clean energy system, and while at the same time promoting local value addition and job creation. Based on a bilateral understanding, the feasibility study develops a role model for cross-border European regional development. It aims to advance de-fossilisation by posing key questions of transformation:

- To what extent can we create a regional cross-border energy transformation?
- What are the suitable innovation pilots for the region?
- What are the costs and benefits?
- On which governance and industrial levels do we have to act?

The study proposes ideas for demonstration projects in the fields of "Green Batteries", "Green Hydrogen" and "Smart Grids" and shows interlinkages and co-benefits of their implementation. Findings build on extensive research on renewable energy system-based, resource-efficient, region-specific energy concepts in the Upper Rhine region (Hamman (Ed.), 2021).

A study by Weichenhein et al. at Roland Berger GmbH (2020), which focuses on Green Hydrogen, highlights the main criteria points (Fig. 1.1) for making the transformation into innovative and climate neutral technology successful.

The conclusions of Roland Berger study  (2020) support the idea of the feasibility study: the development of a roadmap, the improvement of competitiveness and the development of pilot projects as best practice examples. Within the overall vision,  the report concludes that pushing this transformation forward is of utmost importance. to push the transformation forward.

Pilot projects are interfaces between academia and industry, where scientific knowledge meets practical expertise. Furthermore, when tested in a real-world environment, these pilot project developments offer testbeds for innovations to adapt large scale applications on one side and to trigger further research. This idea of coupling science and industry is fully in compliance with the intentions of the feasibility study.

The feasibility study takes an interdisciplinary and praxis-oriented approach. It aims to work with partners and stakeholders from science, business, politics, administration and civil sectors, to advance the de-fossilisation of the energy system and consequently the economy in the region. The project employs competences within the tri-national platform for sustainability research in the Upper Rhine (URCforSR), individual research institutes (e.g., FhG) and the European Campus (Eucor), which is an overarching coalition of universities. Combining them with the applied expertise of TriRhenaTech, brings together the scientific knowledge  and expertise in the Upper Rhine valley from in the fields of technical, economic, legal and socio-cultural sustainability research and innovation. The concepts for sustainability transformation are then further developed with stakeholders from industry and society.


Fig. 1.1: Successful transformation criteria for green Hydrogen as a climate neutral innovation technology (Source: Roland Berger GmbH, 2020:131)

The feasibility study builds upon the priorities expressed in the Projet de Territoire (2019) and the Treaty of Aachen (2019) to enhance cross-border innovation for and de-fossilisation of industrial systems (Fig. 1.2). These goals are embedded in the ambitions expressed by European Green Deal and to provide regions with support for reaching their respective National Determined Contributions (NDCs) as guided by the climate policies.

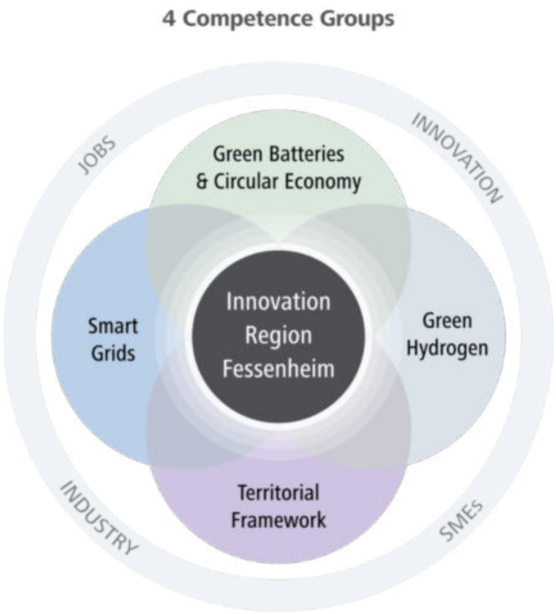


Fig. 1.2: Fields identified for the feasibility study based on the challenges defined in the Projet de Territoire (2019) by communal and regional politicians.

The study works with key stakeholders in four thematic working groups, to provide ideas for pilot/demonstration projects that will aid in the development of key technologies related to which are part of energy transformation pathways. The goal is also to analyze the environmental, economic and regulatory frameworks for the implementation of the pilot projects and derive actions at different governance levels.

As presented in figure 1.2 three technical innovation fields have been established. These innovation fields meet the challenges formulated by the Projet de Territoire for achieving value addition through innovative industries well as to create new jobs through innovation. The three technical innovation fields are complemented by a competence field of analyzing the territorial frame conditions. Based on the identified fields, the following competence groups were established (Fig. 1.3):

I. Green Battery and Battery Recycling (lead: University of Freiburg and FhG ISE)
II. Green Hydrogen (lead: KIT)
III. Smart Grids (lead: University of Haute-Alsace)
IV. Territorial Framework (lead: University of Strasbourg)

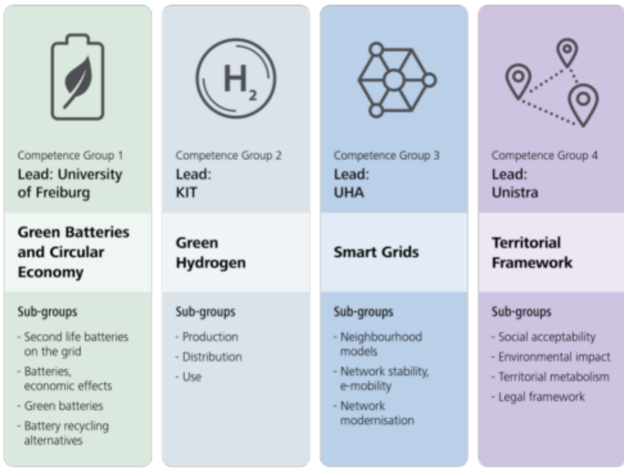


Fig. 1.3: Competence groups for the feasibility study "Innovation Region Fessenheim".

The study was conducted in steady exchange with funding agencies and political members represented in the Strategic Steering Committee. The overall strategic planning was done by a coordination group which monitored the process and was the main link between the experts and the funding organizations (Fig. 1.4).


Fig. 1.4: Governance structure of the feasibility study

The above mentioned fields of innovation are interrelated to each other and the study highlights the idea that transformation towards sustainability needs interlinked thinking. Figure 1.5 illustrates this idea further. The link between batteries and green hydrogen is of great importance for the overall regional transformation, as they are complementary in terms of implementing a storage system for volatile renewable energy, stabilizing the grid, and contributing to climate neutral transport, and industry processes and applications. Different temporalities of hydrogen and battery storage systems and their different transport applications provide complementary security and flexibility in the energy system. For example, in terms of industrial applications, batteries are agile in their energy supply, but are not adapted to the energy intensive processes, while green hydrogen is efficient and energy saving, especially in energy intensive industrial processes. In terms of transport, batteries could not be completely relied on for passenger traffic, while green hydrogen might outperform batteries in heavy duty transport of ships and trains. In addition, the adaptation of the grid to renewables is necessary for increasing the energy supplied by renewable energy sources and can be supported by the innovative applications described in the battery and green hydrogen innovation hubs, as they can both contribute to a sufficient and timely electricity supply.

The interdependence of the different fields of innovation focused on in this study is visualised in figure 1.5.

By and large, the idea to focus on the above-mentioned fields of innovation has developed out of the need for a holistic approach to transform a region towards sustainability and the analyses of the regional strength in the Upper Rhine. This strength will be described in the following chapter on geographical and regional assets.

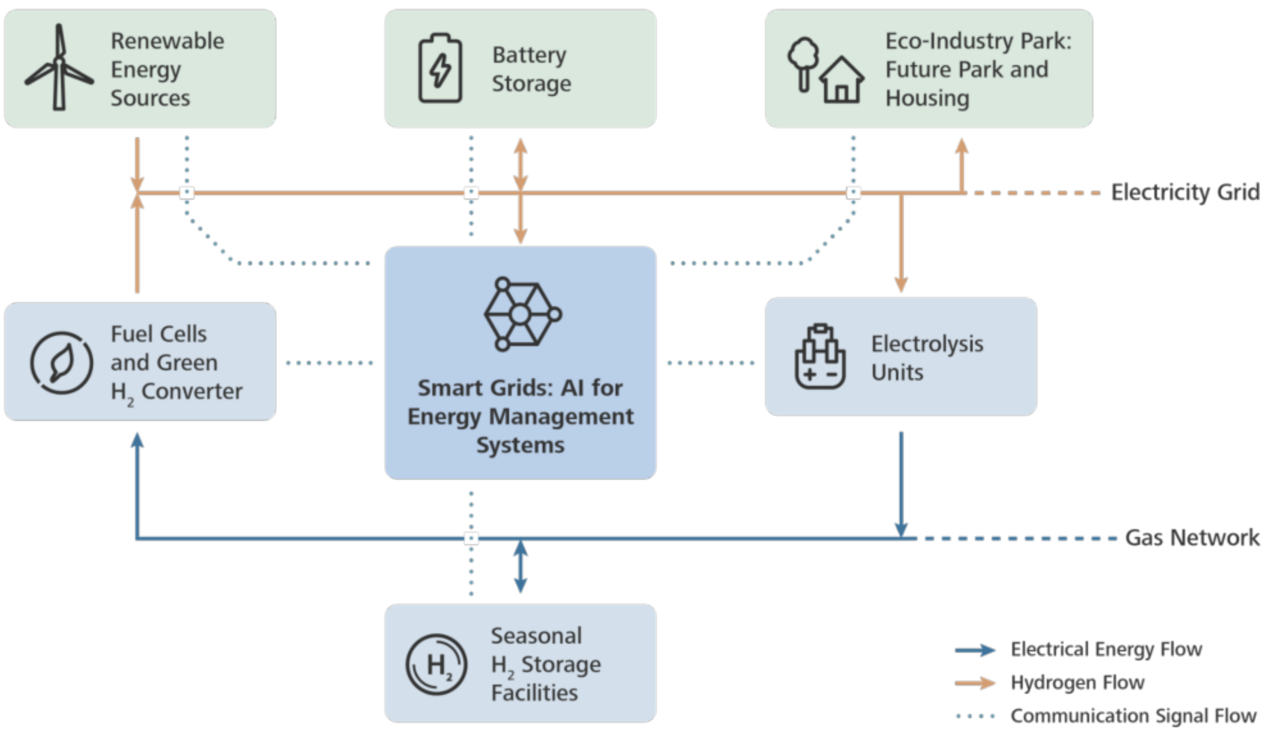


Figure 1.5: Complementarity of energy systems and storage linked by artificicial intelligence (AI) Smart Grid management systems

# 2. Geography and Regional Assets

## 2.1 Geographical definition of the region

The current geographical framework of the Projet de Territoire is defined at three scales. The first perimeter of priority impact addresses the challenges of economic reconversion and includes the commune of Fessenheim and the neighboring communes in the Communauté de Communes Pays Rhin-Brisach.

The second perimeter involves the Colmar-Freiburg-Mulhouse triangle (Fig. 2.1), whose operational geographical framework has been defined according to the relations between the neighboring territories on both sides of the Rhine.

Due to the globality of the economic, social and environmental impacts the third scale goes beyond this initial framework and includes the Upper Rhine (Fig. 2.2) alongwith and the interconnections between the Upper Rhine and the outside world, especially the bordering states and Europe as a whole.

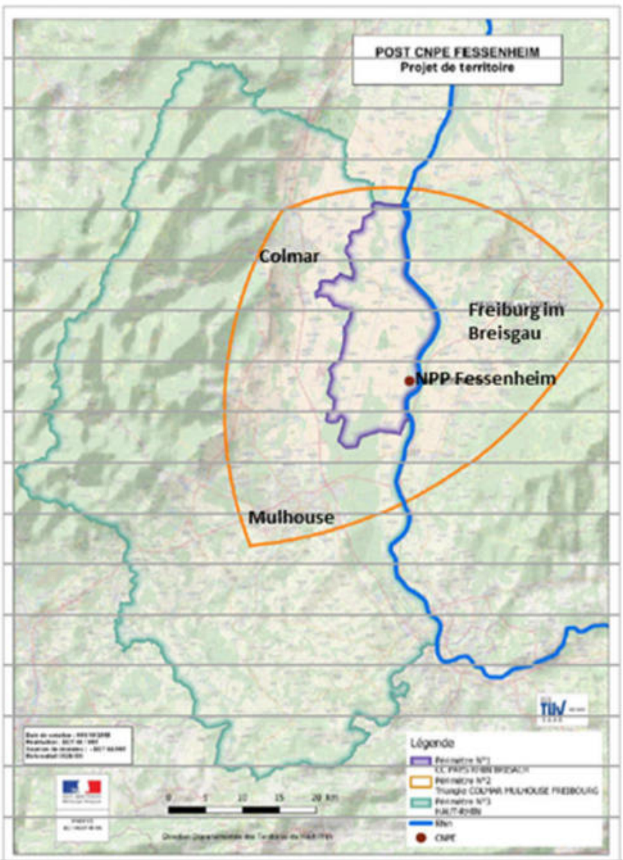


Fig. 2.1: Location of the Innovation Region Fessenheim (Projet de Territoire, 2019)


Fig. 2.2: Upper Rhine region (Upper Rhine Conference 2008)

The Innovation Region Fessenheim is located in the Upper Rhine Region at the border triangle of Germany, France and Switzerland (Fig. 2.3). The Upper Rhine Region is dominated by diverse geographies and the Rhine River as the main transport route and natural border. It is characterized by the Rhine valley, enclosed by the mountainous regions of the Vosges in the west and the Black Forest in the east. On the southern edge are the foothills of the Jura in Switzerland. The tri-national metropolitan region has six million inhabitants, strong economic performance and good infrastructure.

The specific geographical and regional characteristics of the Fessenheim region are major assets that enhance its eligibility for above mentioned innovation fields. Further in this chapter, the main considerations for the development of pilots under the aforementioned technological innovation fields are elucidated

## 2.2. Regional Assets of the Upper Rhine

In the subsequent sections, the significance of Upper Rhine valley is highlighted as its regional assets offer the best conditions for promoting cross-border transformation towards sustainability.

### Transport Infrastructure

The natural geographical and political conditions have led to a concentration of energy-intensive industries along the Rhine. They have favored a strong north-south split of transport and supply lines, while east-west connections are concentrated on a few bridges across the Rhine. The Upper Rhine valley is one of the most important European transport corridors connecting the leading European sea harbors Rotterdam – Genoa – Marseille (Fig. 2.3). There exists a network of major train railways from north to south, the highway infrastructure that runs along the Upper Rhine through the alpine areas and there are shipping routes of the Rhine and the Rhone. Therefore, the Upper Rhine allows for multimodal and efficient transport of goods, given the importance of the transport of heavy goods through vessels. Also, the numerous harbors along the Upper Rhine provide excellent conditions for port loading and unloading (Deutsch-französisch-schweizerische Oberrheinkonferenz, 2014).

Fig. 2.3: The Upper Rhine region within European transport corridors (edited from European Commission 2020: TEN-T Core Network Corridors).

Besides the European transport corridors in the Upper Rhine valley, important European gas pipelines and power lines are also located within the area. These are facilities which can be used to transport green electricity or green hydrogen in the future (Fig. 2.4). Pipelines for transporting natural gas and green hydrogen can be adapted to allow for different usage of existing infrastructure.

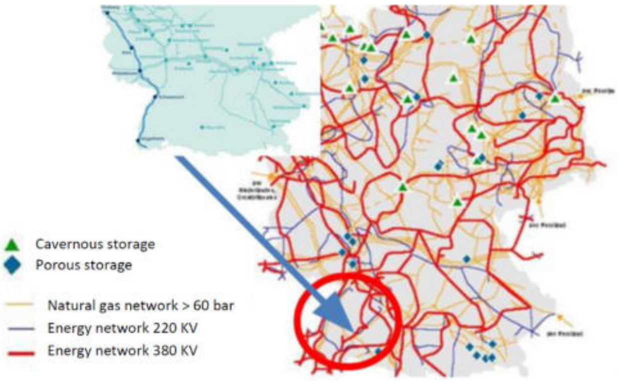


Fig. 2.4: European electricity power lines (red) and gas pipelines (yellow) (BHKW jetzt, n.d.).

### Legal frame

The Innovation Region Fessenheim is one of the priority projects defined by the Treaty of Aachen (2019). In Chapter 4, Article 13 - 17 and in Chapter 5 Article 18 – 22, the commitment to regional transnational cooperation and to sustainable development is clearly expressed. Activities of France and Germany are bound to "constitutional rules of the two states and within the framework of European Union law" (Ibid. 2019). The Aachen Treaty further states to "provide local authorities of border regions as well as cross-border entities such as Euro districts with adequate competences, dedicated resources and accelerated procedures". This is to make sure that obstacles involved with the implementation of cross-border projects are overcome, particularly in the economic, social, environmental, health, energy and transport fields. If no other instrument enables them to overcome such obstacles, adapted laws, regulations and administrative provisions, including derogations, may also be provided for. In this case, it is for both States to introduce relevant legislation" (Ibid. Article 13, §2).

The legal frame of the Aachen Treaty and the derived priority projects identified under the treaty, provide the best conditions for the development of innovative ideas and projects designed in this feasibility study. The objectives defined in the Treaty of Aachen and the highlighted priority projects are fully compliant with the goals and innovation pilots of the feasibility study.

### Economy

The Upper Rhine is an area with high economic potential. It has a GDP of €272 billion/year, which is more than that of Finland and Ireland combined (Regierungspräsidium Freiburg 2020, n.d.). In addition to the relatively high number of big industries that push for development, there are several small and medium enterprises that may contribute effectively (Interreg Upper Rhine, 2019). Chemical and pharmaceutical industries, some of which are significant global players, play a key role in employment and value creation (Fig. 2.5). Vehicle manufacturing and other production industries are equivalently important and have a strong impact on production chains (e.g., metal construction and engineering).

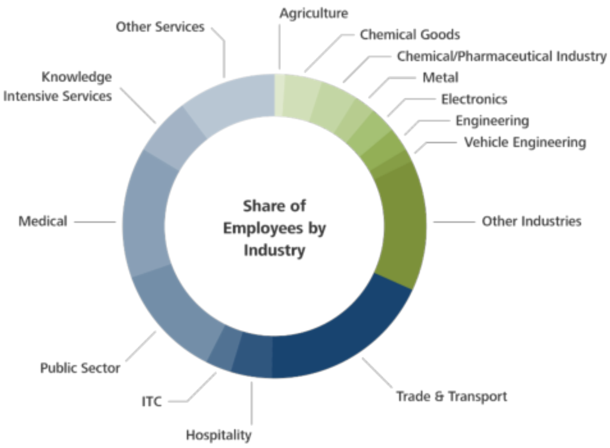


Fig. 2.5: Employee shares according to economic branches in the Upper Rhine Valley (Regio Basiliensis, 2021)

Annual growth rates (2010-2018) in the Upper Rhine region correspond to the German and Swiss national average. They are significantly lower in Alsace compared to the rest of France and lag behind other border regions (e.g., South Palatinate) (Fig. 2.6). Innovative potential from a growing science sector (Regio Basiliensis, 2020) has not yet paid out. To keep and accelerate the green economic growth in the Upper Rhine region, technology transfer towards enterprises must be increased. The EU study on "Quantification of the Effects of Legal and Administrative Border Obstacles in Land Border Regions" (EC, 2017) shows that better economic, administrative and legal interconnections in the EU member states could boost growth by €485 billion and create 8 million new jobs in border regions.

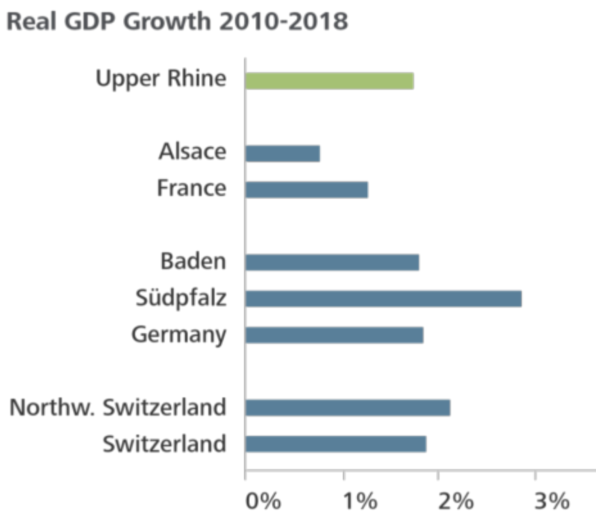


Fig. 2.6: The economic growth of the Upper Rhine region during the years 2010 to 2018 (Regio Basiliensis, 2021).

The global competitiveness of the energy intensive, high wage industries in the region will depend on their innovative capability and more efficient resource use (Zuoza and Pilinkiene, 2021). The Upper Rhine must not lose out in the energy and circular economy sector. The connection to the European value chains as described in the European Commission communication "New Industrial Strategy of Europe" (COM, 2020 102 final) is of great importance for the region and for the strategic autonomy of Europe as a whole. With the importance of traffic and trade in the Upper Rhine, climate neutrality heavily relies on reductions in the transport sector. The active involvement of automotive companies like Stellantis and Daimler is deemed inevitable for the feasibility of a green transition. Pilots in this study are chosen to enable economic co-benefits between sectors. For instance, green transformation is thought to make tourism more attractive.

### Science Capacity and Education

The Upper Rhine is home to a high density of research and education organizations (Fig. 2.7). Internationally renowned companies and organizations in the fields of energy, technology and sustainability, along-with in addition to universities and private enterprises, create a vast network for innovation. Additionally, there is vast experience in tri-national cooperation and cross-border competence, shared among the various regional players in subregional networks such as Eucor - The European Campus and TriRhenaTech and the Upper Rhine Cluster for Sustainability Research (URCforSR). Projects on regional transformation in competence fields such as “Green Hydrogen”, “Green Batteries” and “Smart Grids” benefit from the strong coalition of basic and applied science.


Fig. 2.7: Overview of the science research competences in the Upper Rhine (Trifob n.d.)

**Human resources**

There is a high concentration of human resources, especially among young students and workers in the Upper Rhine. This is amongst others, due to an exceptional education infrastructure and attractive job opportunities. Mobility and interdisciplinary exchange also play a significant role. The Eucor Universities with 117.000 students in total (Eucor, 2022) already provide 15 cross border programs. TriRehnaTech offers a number of tri-national studies, especially in engineering sciences. Applied projects support local competences, influence the design of new courses and create valuable knowledge on the Upper Rhine sustainability transformation. With a yearly release of approximately more the 2000 graduates from the EUCOR universities only, there is a considerable potential for human resources.

**Transnationality**

The Upper Rhine valley is located in the triangle of Switzerland, France and Germany. Along the common borders of the three nations there exists intensive exchange between administrative, scientific and economic organizations. Overcoming administrative and legal barriers, providing regional expertise that transcend national borders, and accelerating knowledge transfer between companies, societies and science organizations is an asset which privileges border regions in general. This has been confirmed by the report from the European Commission study on the quantification of cross border effects (EC, 2017), and the Upper Rhine Valley specifically, due to the long common past of cross-border activities. Cross-border hubs increase cross-border flexibility for employees and multiply the resources for joint investments. Likewise, cross-border hubs advance intercultural understanding, joint political visions, and strengthen Europe’s position in the world.

## 2.3. Local assets of the communities within the innovation region Fessenheim

In this section, the more specific assets of the innovation region Fessenheim are described, which are embedded in the Upper Rhine overall significance benefits.

### 2.3.1. Fessenheim

Fessenheim (Alsatian: Fàssene) is a French community in the Haut-Rhin Department within the Grand Est region with a population of approximately 2300. It is located about 25 km northeast of Mulhouse on the Rhine canal and thus is close to the German border. Southeast of the village center is France's oldest nuclear power plant, the Centrale Nucléaire de Fessenheim operated by Électricité de France (EDF). From 1978 to 2020, two pressurized water reactors were in service, each with a net electricity output of 880 MW. With 2000 people working at this station, it was a major employer in the region (EDF, 2019).

Fessenheim connects to the neighboring areas through the D52 motorway on the French side and the Alain-Foechterle-Erich-Dilger Bridge to the German side. The single-lane bridge, opened in 2006, links to Junction 64b of the Federal German Motorway 5. From here, the twin municipalities of Hartheim and the towns of Grißheim and Heitersheim are within reach. The international EuroAirport Basel-Mulhouse-Freiburg and other small airports are located nearby.

### 2.3.2 Nambsheim / EcoRhena

New industries are expected to settle in the vicinity of Nambsheim as part of the EcoRhena Project (Projet de Territoire, 2019). Located close to the Fessenheim area, the project EcoRhena aims to attract new companies by offering them a large and flexible area; furthermore, it intends to develop a business park on the banks of the Grand Canal d'Alsace. With Hartheim on the opposite side of the Rhine, Nambsheim faces a strong industrial counter-area. The surface area for the business park was estimated at 220 hectares but reduced to 82 hectares for environmental constraints (Conseil Départemental du Haut-Rhin and Conseil Départemental du Bas-Rhin, 2019). The development project of this park and the creation of the concerted development zone (ZAC), initiated by the officials of the Communauté de Communes Pays Rhin Brisach and the municipalities of Balgau, Nambsheim, Heiteren and Geiswasser, are among the "Plans d'Avenir" alternative measures to address and overcome the closure of the Fessenheim power plant (Préfecture du Haut-Rhin, 2021). This area offers several advantages, such as privileged geographic border location, river transport infrastructures, tax reductions, job creation subsidies, environmental richness of the territory. However, despite the dedicated commitment to sustainable development through encouragement for setting up international and local companies, considering EcoRhena as a zone for hosting the intended pilot projects seems challenging. Today the schedule for its commercialization does not correspond very well with the feasibility study specification. This is due to the complicated nature protection concerns, which must be duly considered. A faster implementation might be possible with a test innovation park, for convincing local citizens and investors, if the process for the innovation park Fessenheim yankees time to speed up.

# 3. Renewable Energy Potentials in the Upper Rhine Region

The transformation towards sustainability is connected with the transformation to clean green energy. In fact, the European Parliament defines renewable sources of energy as: wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass and biofuels. Latest discussions in the European Commission also propose nuclear energy under certain conditions and within a limited time frame as green energy. However, this view is not shared by all member states, and especially not by Germany. In this report we define the term green energy using the stricter definition that was used before 2022 and described in the Renewable Energy Directive. Green energy sources reduce GHG emissions and are better alternatives for energy production than fossil fuels. In July 2021, the European Commission proposed increasing the proportion of renewable energy in the EU energy mix as part of its binding targets in the Renewable Energy Directive and the promotion of renewable fuels such as hydrogen (European Parliament, n.d.). In a study carried out within the Interreg Upper Rhine project, named Regionale Konzepte für eine integrierte, effiziente und nachhaltige Energieversorgung und Speicherung in der Trinationalen Metropolregion Oberrhein (RES-TMO), the technical potentials for renewable energy generation in the Upper Rhine Region were investigated. The results are briefly presented in this chapter. For a better understanding of the results, it is important to define the different types of potentials for renewable energy generation and to explain the methodology, i.e., how the results have been reached.

The following chapter is based on the outcome of the RES-TMO project and taken from the report titled "Representation of RES Potentials in the Upper Rhine Region" by Najjar et. al. (2022). The methodology is only briefly presented in this section as further explanations can be found in the original report.

## 3.1 Methodology and results of the potential studies on renewable energy production

It is possible to study different categories of potentials; therefore, it is important to clearly define the different levels before analyzing the renewable energy potential. As presented in the table below, the different potential levels are: theoretical, geographical, technical, economic and feasible. The complexity of the potential output increases incrementally with each potential level as more and more criteria are included. Mc. Kenna et al. (2021) presented the different potential analysis levels for wind energy. The different categories are also valid for other renewable energy studies. In the table below, the potential levels for renewable energy studies are defined and are additionally classified according to their political relevance (Tab. 3.1).

| Potential term | Definition | Policy relevance |
|---|---|---|
| **Theoretical or physical potential** | Total energy content of wind, e.g., globally | Generally irrelevant |
| **Geographical potential** | The geographical area available for wind turbines, e.g., globally | Generally irrelevant |
| **Technical potential** | Electricity that can be generated from wind turbines within the geographical potential, over a given period of time (e.g. a long-term average on an hourly time series over a specific year), and with a given turbine technology (e.g., current, future) | Wind industry R&D, innovation and market dynamics |
| **Economic potential** | Subset of the technical potential that can be realized economically | Energy-political frameworks |
| **Feasible potential** | Subset of the economic potential after accounting for non-technical and non-economic constraints | Public acceptance, market barriers, inertia / resistance |

Tab. 3.1: The different potential study categories (McKenna et. al, 2021)

The results presented in RES-TMO are based on the study of the theoretical, geographical and technical potential, and the final results depict the technical potential which according to McKenna et al. (2021) is of high political relevance for starting innovations and understanding this report's innovation programs and pilots. The economic potential and the feasible potential were not taken into consideration, because they are strongly influenced by concrete market measures and pilot implementation in defined locations. For the Upper Rhine Region, the potentials have been studied on the technical potential level so far.

Based on the definition by Jäger et al. (2016), the technical potential takes into account technical constraints limiting the theoretical energy yield like conversion efficiencies of PV modules and wind turbines. Numerous parameters shape the technical potential. Consequently, the complexity of the applied model to estimate the technical potential heavily determines the accuracy of the resulting potential. The conversion efficiency of PV modules or wind turbines is determined by wind turbine-specific or PV module specific power curves (Huld, 2017 & Jung & Schindler, 2018). For wind energy, the air density is an additional parameter shaping the energy yield (Jung & Schindler, 2019). Moreover, wake effects (turbulence and reduced wind speed) determine the technical wind energy potential. The technical PV energy output is-among others- influenced by the reflectivity of the PV module itself, which is related to the solar angle of incidence, the PV module temperature that is depending on the surrounding temperature and the prevalent surface wind speed (Huld, 2017).

The study conducted for RES-TMO started with an expert opinion investigation by interviewing experts in France, Switzerland and Germany to better understand the major regulatory and process barriers for the RES production infrastructure implementation and to take them into consideration as much as possible in the frame of accessible data. Unlike the theoretical and technical potentials, which transcend international boundaries, the tri-nationality of the study area translates into a tri-national regulatory environment, which affects by definition the geographical potential. The geographical potential by definition should take into consideration the areas that are by regulation classified as inadequate for the dissemination of renewable energy projects. Because the study area comprises three different countries with their own regulatory environment and structure, there is a large disparity in the quality and quantity of publicly available information.

The geographical potential entails the calculation of the usable area, which is source-dependent and calculated separately for the different sources of renewable energy: wind, rooftop PV, and free-range PV. In the case of wind energy and free-range PV potential, the usable area is the area that remains after subtracting the restricted areas for each source such as residential or protected areas and their distance buffers from the total area of the URR. The distance buffer simply takes into consideration the distance that must be respected between the possible renewable energy project sites and the different restricted areas such as cities and roads. In the case of rooftop PV, the usable area is the area of the rooftops in the URR. Moreover, because the geographical potential is closely related to competing land uses, taking it a step further, free-land PV can also be divided into two types of potential that require different land-use area types: conventional GM-PV and AGRO-PV. The potential of GM-PV and AGRO-PV is calculated by dividing the remaining usable area for free-range PV further and accounting for the type of land-use pattern.

In Switzerland, there are stringent regulations and no clear guidelines when it comes to wind energy and GM-PV projects and in France, the evaluation of renewable energy projects happens on a case-to-case basis. On the other hand, the criteria published by the state of Baden-Württemberg establishes clear and concrete guidelines that can be used to determine the areas where wind or solar dissemination would not be favorable. Therefore, for solar PV and wind energy, the BW criteria catalogues were used in the mapping of the restricted areas and consequently the available usable area. In this way, the methodological framework is more homogeneous and comparable between the three countries. However, an adaptation is needed for distinct pilot projects.

The report also includes an analysis of the land use, topography and meteorological conditions for each investigated RES in order to help estimate the technical potential in a credible way. In the following paragraphs, a short description of the methodology divided by RES and developed by WP2 of the RES-TMO project is presented.

### 3.1.1 Wind

The mountainous terrain and orographic complexity of the study area requires a high-resolution grid and a high temporal resolution in order to capture the small-scale features of the wind distribution, a process that needs enormous computational resources. Therefore, the wind energy potential is based on data from the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017) with an 250m x 250m. Using this information, conclusions about the geographical variations of the wind energy potential in the Upper Rhine Region was possible. The model provides reasonable results for long-term annual and monthly averages of wind speed.

In the calculations of wind potential, Grau et al. (2017) aptly and descriptively name the broadest potential category (the theoretical potential), the meteorological potential (MP), because it depicts the "available kinetic energy contained in the atmosphere over an area" which can be assessed by the wind power density (WPD in W/m²). Therefore, the first step of calculating the MP requires the calculation of the WPD which is mathematically related to the wind speed.  The yearly and monthly median wind speeds were extrapolated to three chosen hub heights at 120m, 140m and 160m by using the Hellmann power law. The WPD at the level of the three chosen turbines was calculated by using the wind speed values. Based on Manwell et al. (2009), potential wind turbine sites can then be classified according to the available wind power density into three categories:

- WPD < 100 W/m² is considered inappropriate
- WPD ≈ 400 W/m² is considered as appropriate
- WPD > 700W/m² defines regions of great wind power resources

By classifying the study area according to the three WPD categories described above, the meteorologically suitable areas are found.

The meteorological potential is limited by the geographic potential which takes into consideration the restrictions related to orography and competing land use specified by legislation. The geographic potential was estimated by defining the restricted areas in the total study area. After that, the restricted areas were subtracted from the total study area and the usable area for wind dissemination was left. The Baden-Württemberg criteria catalogue was used as a reference for the calculations of the restricted area.

Finally, the technical potential is calculated. The technical potential minimizes the geographic potential by factoring in turbine efficiency in the conversion of the kinetic energy found in the usable area into electrical energy (kWh/year) (Grau et al., 2017). In the literature, Jung (2016) describes in detail the steps to calculate the Annual Energy Yield (AEY) estimation by using power curves.

The GIS raster files used for the calculations are taken from the raster files developed for the Master's thesis, Wind Energy Assessment in the Upper Rhine Region submitted in 2020 by Michael Chimeremeze Ezem. The author used the measurements of 64 weather stations, divided over the three countries, for surface wind speed to calculate the meteorological potential in the study area based on the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017).

The results of the method described above are presented below Fig. 3.1 and 3.2.

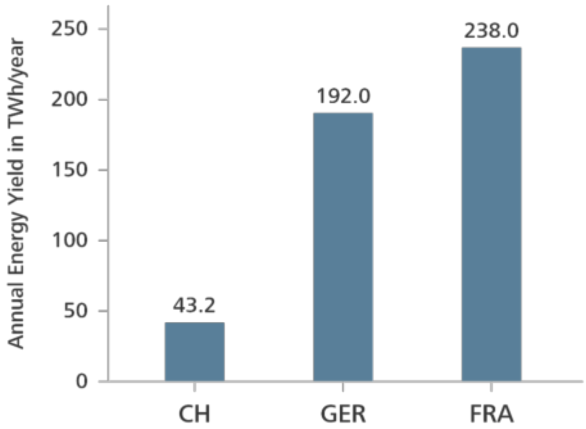


Fig. 3.1: Preliminary wind technical energy potential in TWh per year by country in the Upper Rhine

| | | |
|---|---|---|
| **Previous Wind Energy Potential** | 473 | 473 |
| **Wind Potential Reduction Factor** | 27 | % |
| **New Wind Energy Potential** | 128 | TWh |

Tab. 3.2 Wind Energy Potential after corrections and refinement by Najjar et al. (2022)

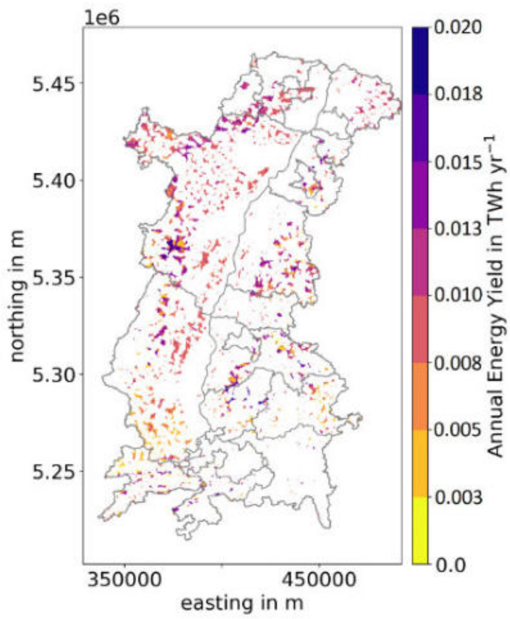


Fig. 3.2: Distribution of technical potential for wind energy on the usable area in the Upper Rhine in TWh per year (Najjar et al., 2022, 21)

The results show that the technical potential for wind energy production in the Upper Rhine Region is relatively high in France and Germany. Taking into consideration that for the whole Upper Rhine Region according to statistical assessment as calculated from the energy use per capita in 2016 for Grand Est, Basel department and City as well as Baden-Württemberg (Tri-National Climate and Energy Report, TRION-climate 2019/27) the total energy demand per year in the Upper Rhine Area is approximately 212,41 TWh per year as per the calculations in the table 3.3 below.

| URR | Population in 2019 | Final Energy demand in 2016 in MWh /capita | Energy demand in URR in MWh/yr | Energy demand in URR in TWh/yr |
|---|---|---|---|---|
| **CH** | 1.507.718 | 49 | 73.878.182 | 73,88 |
| **GER** | 2.858.606 | 26 | 74.323.756 | 74,32 |
| **FR** | 1.888.480 | 34 | 64.208.320 | 64,21 |
| **Total** | 6.254.804 | | 212.410.258 | 212,41 |

Tab.3.3: Energy demand in the URR in TWh/yr (Sources: *Eurostat (n.d.) ** Tri-National Climate and Energy Report, TRION-climate 2019/27 *** calculated)

If all the technical potential had been used, more than 50% of the final energy demand in 2016 could have been covered by wind energy. However, it is clear that only a smaller percentage of the technical potential can be implemented because it depends on the economic and regulative conditions as well as societal acceptance. The economic and feasible potential take the aforementioned elements into account but as stated earlier will require a case-to-case analysis.

### 3.1.2 Solar PV

The investigation of the solar energy potential in the Upper Rhine was divided into two categories: roof-top PV and free-range PV installations that was also divided into two sub-categories ground-mounted GM-PV and AGRO-PV as described in the sections below.

a) Rooftop Potential

The possibility of placing PV panels on building roofs (PV rooftop potential) offers a large potential for electricity production. Compared to the free-land PV energy potential, the rooftop potential does not evoke land use conflicts and only to a small degree conflicts with monument protection issues, resulting in a higher public acceptance (Mainzer et al., 2017).

For the theoretical energy potential, the software package PVMAPS was used to calculate the solar irradiation. PVMAPS takes into consideration factors that affect the power generation of solar modules such as: air temperature, wind speed data, and the content of water vapour and aerosol in the atmosphere. Moreover, the software also takes into account terrain elevation, a factor which is important in the determination of clear-sky radiation and the more accurate calculation of the air temperature. (Huld, 2017) The generated rasters depict average yearly global irradiation in Wh/m² received by the URR and can be calculated based on the inclination angle of the solar panels and their orientation. The choice of orientation and inclination angles was determined by assumptions related to the geographical potential and are discussed below.

The geographical potential consists of roof areas, so buildings in the URR were extracted from Open Street Maps (OSM), clustered, and mapped; consequently, an estimation of the ground area of buildings and number of buildings per municipality was obtained. It was important for buildings to be clustered together because taking individual buildings into account results in large files that often lead to problems and computational errors. It was assumed that the ground area of the buildings is equal to the roof area. Mainzer et al. (2014) developed a method for solar PV rooftop potential calculation and used it to perform a high-resolution estimation of the residential rooftop PV potential in Germany. The method used here to calculate the geographical and technical potential is based on the one used by Mainzer et al. (2014).

All possible combinations of orientation and inclination are considered together and are generated by using the PVMAPS package resulting in different maps depicting solar irradiation. Applying the generated solar irradiation maps to the available roof area (usable area in this case) results in the geographical potential of rooftop PV in the URR. The last step of the geographical potential is factoring in the roof utilisation factor, which accounts for the "share of the roof area that may be used for PV installations, due to constructional constraints like chimneys, ventilation systems, antennas etc." (Mainzer et al, 2014, p. 719). The roof utilisation factor has been estimated by many previous studies. Mainzer et al. (2014) propose that this factor be considered 58 % for slanted roofs. In comparison to those from previously conducted studies, it is a larger than average number because no orientation direction is excluded.

The final step is the calculation of the technical potential which can be achieved by factoring in the technical parameters of the polycrystalline silicon solar cell installations, the most used type so far, such as average module efficiency (14.5%) and the performance ratio (85%). The output of this stage is the energy produced (in Wh/year) by the rooftop PV panels (Mainzer et al., 2014).

The results are presented in the figures below. It has to be highlighted that the rooftop calculations do not factor in any monument restrictions due to the clustering method used for buildings.

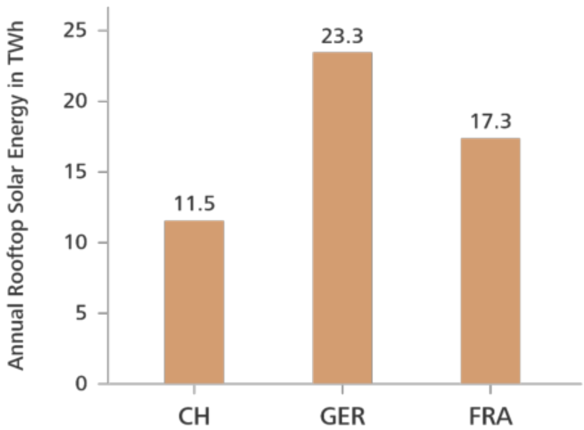


Fig. 3.3: Rooftop Solar PV potential in the Upper Rhine Region in TWh/y (Najjar et al., 2022, 22).

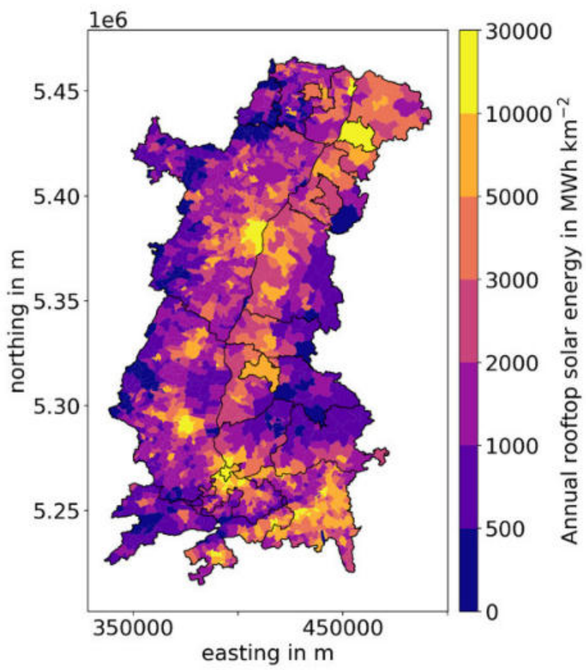


Fig. 3.4: Distribution of the rooftop PV potential per municipality in the Upper Rhine Region (Najjar et al., 2022, 23).

If the technical potential of rooftops is fully usable then approximately 24% of the total energy use from 2016 will be covered. However, as shown previously, the total technical potential is not usable due to restrictions like load capacity of roofs, shadowed roofs and monumental restrictions as well as the preparedness of citizens to invest in the installations. If 40% to 50% of roofs covered by solar panels can be reached in the long run this would be a strong success and is only achievable under best frame conditions. The societal acceptance for this renewable energy source is relatively high (Cousse, 2021).

b) Ground-/ AGRO-PV Installations

Ground-PV installations are considered one of the most competitive sources for energy production worldwide and the demand for it is continuously increasing regardless of the decreasing availability of land, especially in Europe, or its lower acceptability compared to rooftop-PV (Cousse, 2021). In order to avoid future economic, social, ecological and political conflicts, one of the proposed solutions for the land-use conflict and competition evoked by ground-PV is to resort it to the Integrated Food-Energy System (IFES) which allows for a simultaneous production of energy and food through agro-photovoltaic systems (APV). France has already implemented APV dissemination policies and these policies are in discussion in Germany. Since 2015 in Germany, crop-land used for GM-PV is no longer considered eligible for the subsidies awarded by the common agricultural policy of the European Union because it is considered as an expansion of built-up area. Schindele et al. (2020) proposes that in the general discussion of land-management, the land used for GM-PV dissemination should be considered as expansion of built-up area and therefore should not include arable land with certain agricultural practises, which in turn should be explicitly related to APV as it may even improve the agricultural yield according to some studies and observations.

For the assessment of the potential free-range PV installations, the land use data sets offered by Copernicus land monitoring services, specifically the CORINE land cover (CLC) data from 2018 was used. The land cover dataset was taken from the Copernicus website[1]. This land-cover dataset includes around 44 layers representing different land-cover and land-use classes. A published guide, Updated CLC Illustrated Nomenclature Guidelines, also thoroughly describes the components of the different layers. In the calculations for free range-PV potential, at the geographical potential level, after the exclusion of the restricted areas, the usable land was further divided into two categories:

a) Arable land which includes non-irrigated arable land, vineyards, fruit tree and berry plantations. For further details we refer to EEA et al. 2019. This category depicts arable land where agricultural activities take place and by definition was assumed to be the usable land for AGRO-PV installations.

b) Arable land which includes the following class pastures respectively permanent grassland. For further details please refer to EEA et al. 2019. This category depicts the arable land - pastures - used for animal husbandry activities and which by definition was assumed to be the usable land for GM-PV installations.

CLC maps were also used to determine the restricted areas, in addition to the restricted area guidelines taken from the criteria catalogue of Baden Württemberg. Some layers were evaluated as inappropriate for PV dissemination by studying their description.

For calculating the theoretical potential of APV & GM-PV as defined above, PVMAPS package was again used; however, in this case, the orientation and inclination angle could be optimised because they are not constrained by the architecture of already existing structures like the solar rooftop PV potential is. The geographical potential was then calculated in two steps: the first step was to include the restrictions found in the criteria catalogue from Baden Württemberg and the CLC land cover areas that are unsuitable. The second step was to separate the usable area depending on the type of land: agricultural activity area or pastures so that the potential could be divided at this stage between GM-PV and AGRO-PV. Finally, the technical potential factors in the conversion efficiency and the performance ratio of the PV panels. These two parameters were considered to be the same as rooftop PV for homogeneity.

The figures below depict the results (3.5 and 3.6) for GM-PV (free-range PV on pastures) and AGRO-PV (free-range PV on land where agricultural activities take place). In addition, in Fig. 3.7 and 3.8 the spatial distribution of the technical potential of free-range PV (as divided between GM-PV and AGRO-PV) is presented. Considered to be beyond the scope of the study is the technical potential of floating PV.

[1] https://land.copernicus.eu/pan-european/corine-land-cover

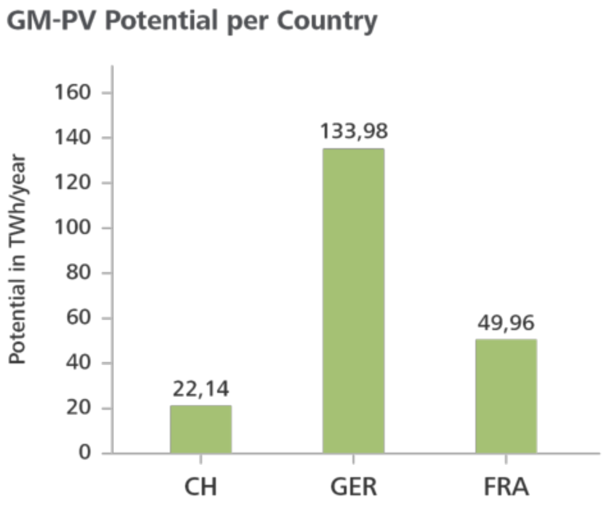


Fig. 3.5: Preliminary technical potential of GM-PV in the Upper Rhine Region (Najjar et al., 2022, 24).

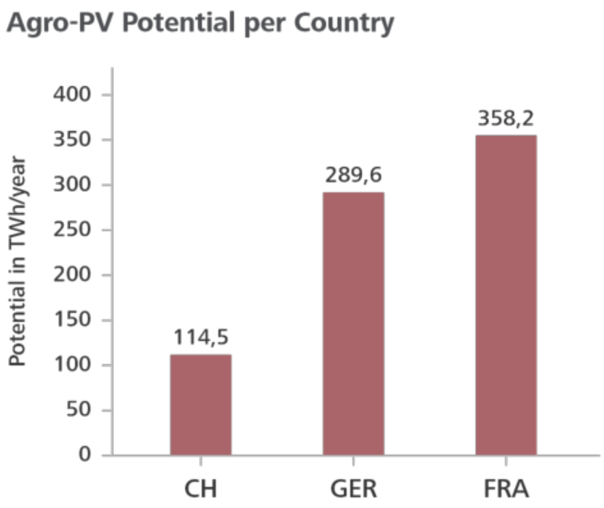


Fig. 3.6: Preliminary technical potential of AGRO-PV in the Upper Rhine Region (Najjar et al., 2022, 25).

| RES | Potential (in Twh) |
|---|---|
| **AGRO-PV** | 91,5 |
| **GM-PV** | 68,0 |
| **Rooftop PV** | 52,2 |

Tab. 3.4: The technical potential after the spacing reduction factor for AGRO-PV and GM-PV was included in Najjar et al. (2022)

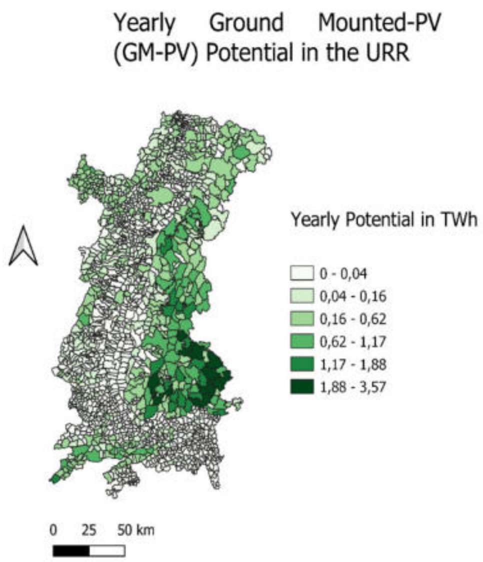


Fig. 3.7: The technical potential of GM-PV per municipality of the Upper Rhine Region (Najjar et al., 2022, 24).

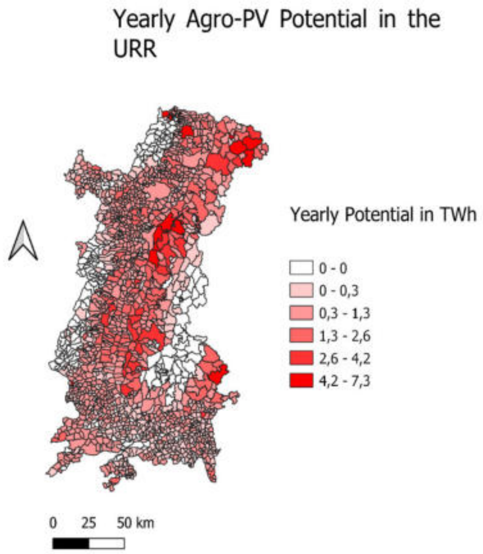


Fig. 3.8: The technical potential of Agro-PV per municipality of the Upper Rhine Region (Najjar et al., 2022, 24).

The estimated technical potential is large (159,5 TWh/yr), but only a small percentage of agricultural fields and grassland might be covered with PV installations, due to other constraints that can be factored in when calculating the economic and feasible potential as mentioned earlier. Reasons for reduced potential could be the impact on landscape, biodiversity and food production. (Vrînceanu et al., 2019). However, if only 20 % of the technical potential can be utilised, a significant energy contribution to the total energy demand of nearly 42 TWh per year is possible.

### 3.1.3 Hydropower

The Rhine is considered one of the most important rivers in Europe. It connects the Swiss Alps, where it originates from, with the North Sea and its catchment area spreads over nine states. In addition to hydropower, its major functional uses include navigation, agriculture, and water supply among many others. Because of navigation, hydropower, and flood protection surfaces, there are numerous hydraulic structures on the Rhine that have been built to regulate the water level of the mainstream water body. These structures can be in the form of locks, impoundments, and dikes. The phenomenon called "hydropeaking", which happens during consumption peaks, when hydropower plants adjust the water supply to accommodate the power supply, directly impacts the flora and fauna. (ICPR, 2015).

The negative effects on the Rhine River system due to the aforementioned structures have been investigated widely in the ICPR report 2015, but are beyond the scope of this report on the existing infrastructures. If new or enhanced infrastructures are planned then the environmental aspects will have to be taken into consideration.

Trion-Climate conducted a study in the Upper Rhine area along the Rhine about the built-up potential of renewable energy related installations and established a best practice map. When it comes to hydropower, there are numerous installations of hydropower plants along the German-French and the German-Swiss border. The German-French hydropower plants are: Kembs, Ottmarsheim, Fessenheim, Vogelgrün, Marckolsheim, Rhinau, Gerstheim, Strasbourg, Gambsheim, and Iffezheim. The last two power plants mentioned are operated by both Germany and France. They have an overall installed capacity of 1450 MW. The Swiss-German hydropower plants are: Birsfelden, Reckingen, Albbruck-Dogern, Laufenburg, Säckingen, Ryburg-Schwörstadt, Rheinfelden, and Augst-Wyhlen. Two of the 8 hydro-power plants (Ryburg-Schwörstadt and Augst-Wyhlen) are operated by a German-Swiss energy company. They have a joint capacity of approximately 635 MW. (TRION-Climate e.V., 2019).

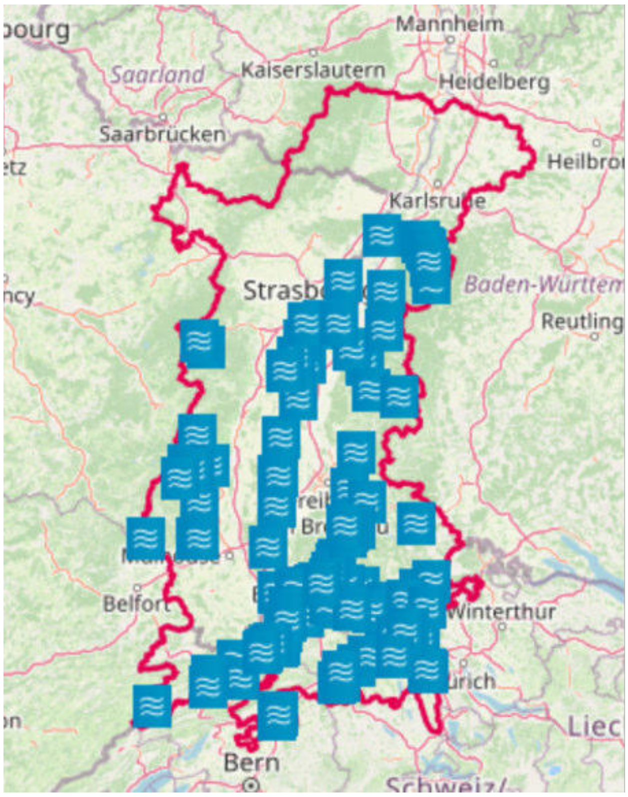


Fig. 3.9: Hydropower stations' map along the Rhine in the Upper Rhine region (TRION-climate, GeoRhena 2020).

Fig. 3.9 presents the density of the hydropower infrastructure along the Rhine (TRION-climate, GeoRhena 2020).

In the Alsace region, hydropower is already extensively used with a lot of energy produced by installations on the Rhine. The Directorate of Agriculture, Tourism and the Environment of the Regional Council of Alsace (Dafte) stated that extra kWh shouldn't be built at the expense of biodiversity or stream life. Therefore, the Regional Council of Alsace along with the Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME) has been financing studies to evaluate the repowering of old turbines even if their production capacity is not optimal. The published article also states that micro-hydropower installations could also contribute to the future energy system of the region if engineering costs could be adjusted by EDF in favour of micro-scale projects (Banque des Territoires, 2010).

On the German side of the Rhine, EnBW is an electric utility company in Baden-Württemberg. According to its website, in Germany, the potential of hydropower is nearly exhausted as there are no possible new locations for large hydropower plants. In order to achieve an increase in production, the focus is on replacing, expanding, and modernising the already existing power plants (EnBW, n.d.).

Axpo is the largest energy company in Switzerland and according to its website, it is also the largest Swiss producer of renewable energy - a large portion of which is hydropower. According to an article published on their website, on the Rhine stretch between Schaffhausen and Basel, where the Rhine flows on the border between Germany and Switzerland, there are already 11 power plants (8 of which are located in the URR). Also, according to Axpo, there is no more space on this route for additional power plants and the only possible solution would be to increase the efficiency of the already existing plants (Axpo, 2018).

In conclusion, the same observation can be found in the statements of experts and energy producers in the three countries; the hydropower potential is nearly exhausted in the study region specifically on the Rhine and the way forward is through improving the efficiency of the already existing power plants.

As for the hydropower potential on the French side, according to EDF (n.d.), the 10 French-German turbines produce on average 10 TWh per year. On the German-Swiss side, according to Axpo (2018), there are 11 turbines delivering almost 5 TWh of electricity per year. Assuming that the energy produced can be equally divided over the 11 turbines, 8 turbines would have a combined output of 3.6 TWh per year (Fig. 3.10).

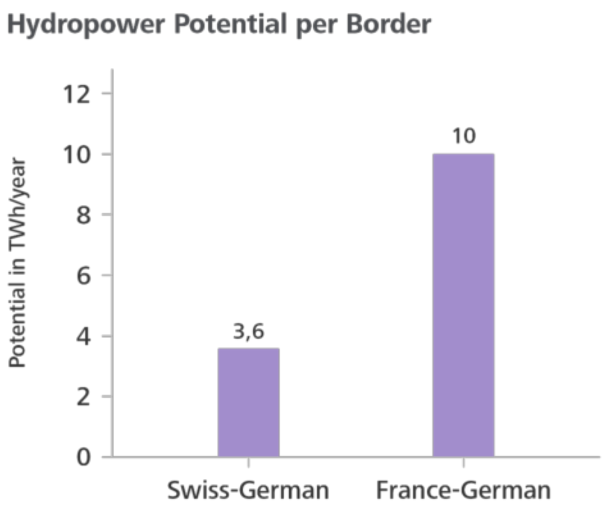


Fig. 3.10: The current potential of hydropower in the Upper Rhine Region (Najjar et al., 2022, 26)

The result of the investigation shows that the contribution of hydropower to the energy transmission will be quite limited, because the produced electricity is already used for power supply today.

### 3.1.4 Bioenergy & Biomass

Biomass is used increasingly nowadays to substitute fossil fuels in the transport and the energy sectors. It has the advantage of regional availability in Europe in comparison to fossil fuels and its ability to be stored in comparison to the intermittent renewable energy sources like wind and solar. Its future demand is expected to rise because of the depleting fossil fuel reserves and their decreasing availability, political incentives, and changing consumption patterns. On the other hand, increasing biomass usage is accompanied by numerous social challenges like public acceptance and sustainability challenges such as land use competition, resource overexploitation and mono-cropping, biodiversity losses, soil degradation, and air and water pollution. However, because the national goals of the three countries align in the need to increase the production of renewable energy, biomass will have to contribute as well (Schumacher et al. (Eds.), 2017).

The project "Biomass OUI" studied the biomass potentials of the Upper Rhine Region, ran over the course of three years, and was completed in July 2015. The project was composed of six individual research areas systematically looped together - each of which relied on the expert contributions of a large number of scientists from different disciplines and backgrounds. The contributors included economists, engineers, forestry scientists, physicists, biologists, chemists, geographers, and sociologists from prime research institutions across the trinational region. Moreover, as part of the project, this network of scientists interacted with a large number of stakeholders in the industry and in politics in addition to NGOs and civilian groups of the region through various stakeholder workshops throughout the project in order to make the study more comprehensive, relevant, and realistic. The main themes of the six research areas included studying the biomass resources and land use change, biomass value change and logistics, biomass conversion pathways, biomass scenario development and analysis, and biomass sustainability impact analysis. All these themes converge in order to establish a roadmap for sustainable biomass utilisation in the URR. The output of the project was the publishing of a report called: "Innovations for Sustainable Biomass Utilisation in the Upper Rhine Region" which described the methodology used and the outputs of the different research area groups (Schumacher et al. (Eds.), 2017).

According to Rudi et al. (2017, Abstract), "Valorisation of biomass as a source of energy is challenging due to the large variety of biomass feedstocks and conversion technologies." In other words, the calculation of the biomass potential is not as straightforward a task from a methodological perspective as calculating the potential of wind energy or solar PV because bioenergy can be attributed to different sources (woody biomass, manure, energy crops…) that can also be imported into the region and exported out of it. Moreover, these sources can be matched with a range of different technologies and conversion pathways (anaerobic digestion, combustion…) that produce different outputs (heat, biogas, bioethanol, biodiesel…). Also, the location of biomass plants does not necessarily have to be in the vicinity of the biomass sources. Therefore, because the "Biomass OUI" project is a heavily researched and comprehensive project with concrete outputs, it was used as a basis for the RES-TMO's mapping of the biomass potential of the URR.

In fact, the first research group (RA1) had the task of identifying local biomass resources and land use conflicts in the Upper Rhine Region. The researchers in this group completed their task by relying on "statistical data, maps, remote sensing, and Geographical Information System (GIS) modelling". The main aim of this group was to establish "an inventory of the currently available biomass resources and land use in the URR" by determining for each of the three sub-regions, "the total agricultural land area and the proportions of the different cultivated crop plants and their respective yields". Additionally, the forest areas were geographically mapped and their wood yields were statistically determined. The amounts of secondary biomass such as "organic household waste, bulk waste, green waste, and vineyard residues" which make up a portion of organic waste were also calculated. The outputs determined by this group were an estimated technical biomass potential and these outputs were consequently later used as an input for some of the other research areas (Schumacher et al. (Eds.), 2017). RA1 also published a report, "Synthesis Report on Current Resources of Land and Biomass to Produce Bioenergy in the Upper Rhine Region (URR)" which explained the methodology and defined the terms used by the scientists to collect and map the information.

The bioenergy potential that can be produced by the different biomass sources is presented by source for the Upper Rhine Region in table 3.5. The unit for the potentials is kWh per capita which is different from what has been calculated for the other RES as these values are based on the Biomass Oui Project.

| Biomass Potential Category | Yearly Value (in kWh/capita) | Country/Region |
|---|---|---|
| **Energy Wood** | 520 | Germany |
| **Energy Wood** | 400 | France |
| **Energy Wood** | 570 | Switzerland |
| **Agricultural Residues** | 170 | The URR |
| **Manure** | 30 | The URR |
| **Organic household waste** | 36 | The URR |
| **Green waste** | 50 | The URR |
| **Sewage sludge** | 50 | The URR |

Tab. 3.5: The bioenergy potential per biomass source in the Upper Rhine Region (Schumacher et al. (Eds.), 2017) (Najjar et al., 2022).

The unit of the calculated potentials is given per capita; therefore, the calculated potential and its geographical distribution does not depict the physical location of the biomass but rather its potential per URR citizen. In the case of agricultural residues, the report confirms that the number is 170 kWh/ca. represents the energetic content of 50% of the agricultural residues in the URR and in fact at the moment, agricultural residues are not used for bioenergy production. In addition, the value of 30 kWh/ca. attributed to manure is the potential that arises from processing 50% of the manure generated in the URR in biogas plants. When it comes to generated household and bulk waste, it is mainly incinerated and is considered to be only 50% renewable. It has to be mentioned that the study also highlighted that the energy resources for wood residues is already exhausted (Najjar et al., 2022).

Najjar et al. (2022) converted the results mentioned in the table above to TWh per year to make the energy potential results comparable to the other investigated RES. In Fig 3.11 the technical biomass potential in the Upper Rhine, as described in the Oui Biomass report (Schumacher et al. (Eds.), 2017), is converted into TWh per year and the distribution of the technical potential is presented per French department, German Stadt/Landkreis, and Swiss Canton.

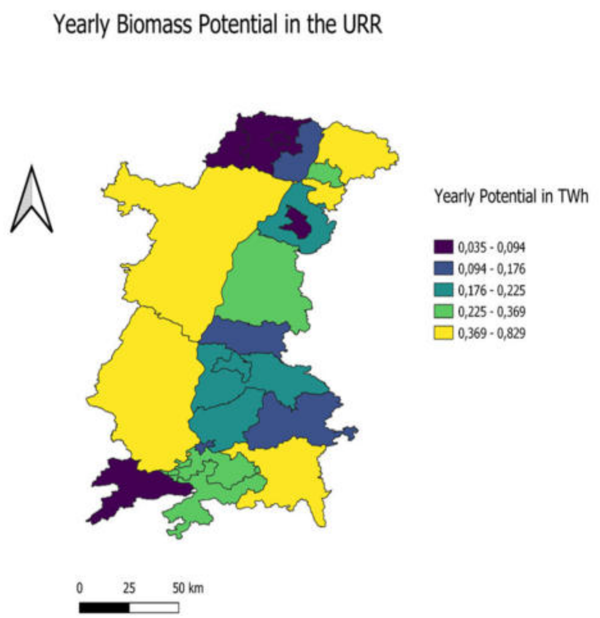


Fig. 3.11: Technical biomass potential in the Upper Rhine Region as derived from the project Biomass Oui in TWh/y (Najjar et al., 2022, 27).

### 3.1.5 Geothermal

"Geothermal energy sources can be differentiated into technologies utilising the shallow subsurface (10s to 100m depth) and methods exploiting the deep subsurface (1000s of metres depth) for energy extraction. Shallow geothermal energy is commonly used to supply heating or cooling energy, while deep geothermal energy can be employed for both electricity generation and space heating" (Miocic., 2021). In the following section, the potential for both types of geothermal energy in the TMO region is briefly explained.

"Shallow geothermal energy systems generally take advantage of the constant temperature of the shallow subsurface (~10°C) and, coupled with heat pumps, are predominantly used for heating and cooling family homes (Sarbu, Sebarchievici, 2014). Climate, with cold winters and hot summers being advantageous, and electricity prices and sources determine whether ground source heat pump (GSHP) systems are more cost-effective than conventional heating systems. The combination of GSHPs with electricity from other types of renewable energy (solar, wind) allows for a significant reduction of the carbon footprint of heating and cooling residential buildings. The Vosges Mountains and the Black Forest experience cold winter months with the average temperature dropping below 0°C from December to February, making borehole heat exchangers more efficient than air-water heat pumps. Contrarily, the lowlands of the Upper Rhine area have warm summers (around 20°C) and in recent years have commonly experienced heatwaves with tropical nights, highlighting the potential of shallow geothermal energy for cooling. There are already several 10.000s of GSHPs installed in the TMO region, predominantly in the German and Swiss sections. However, there are several 100.000s of single-family homes in the region which could be heated and cooled with GSHPs, in particular when combined with a future-proof low-energy renovation. Thus, increasing the share of GSHPs used in the TMO will enable a drastic reduction in carbon emissions related to space heating and cooling" (Miocic., 2021).

Deep geothermal technologies produce waters with temperatures in the range of 100 to 250°C for district heating and electricity generation (Barbier, 2002). The efficiency of deep geothermal wells is dependent on how deep hot fluids are encountered as well as the properties of the rocks the fluids are sourced from. Geologically, the TMO region is dominated by the major rift of the Upper Rhine Graben (URG) with the Vosges and Black Forest mountains forming the Graben shoulders to the West and the East of the North-South oriented Graben structure (Dèzes et al., 2004). As a result of the rifting and the associated crustal thinning, the URG has a high heat flow density which leads to high temperatures in the relatively shallow subsurface, and thus represents an ideal region for deep geothermal exploitation (Harlé et al., 2019). The first scientific geothermal wells in the URG were drilled in the late 1980s in Riehen (Switzerland) and the early 1990s at Soultz-sous-Forêts (France). At the latter location a pilot geothermal power plant was installed subsequently and started producing electricity in 2010 (Sanjuan et al., 2006). Currently, there are nine geothermal energy plants operating or in construction in the TMO region, producing 22 MWel and 101 MWth (TRION-Climate e.V., 2019). The theoretically recoverable heat in the rocks that lie at a depth shallower than 7000 m depth in the URG is in the order of $7.4*10^{12}$ GJ (GeORG-project team, 2013), which is equivalent to $2*10^{12}$ MWh. While only a fraction of this energy is technically recoverable, there is an enormous potential for both heating and electricity generation from deep geothermal power plants in the TMO region. One of the main issues related to exploration and production of deep geothermal energy in the URG is the complex geological situation and the need for reservoir stimulation in the tectonically strongly affected region, which has more or less stopped the construction of deep geothermal infrastructures. According to the study carried out within the GeORG project, 25% of the heat request in the URG could be covered by shallow geothermal infrastructures Fig 3.12 (Miocic, 2021).

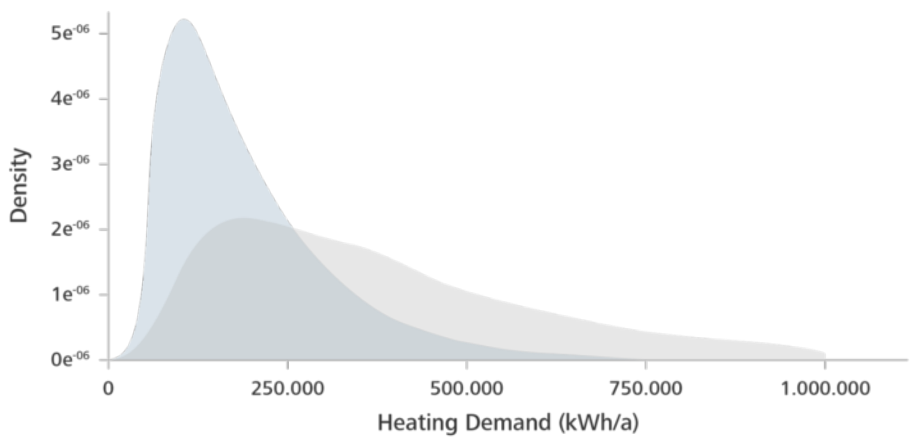


Fig. 3.12: Geothermal potentials in comparison to heating demands for shallow geothermal (Miocic, 2021).

## 3.2 Overall technical potentials in the Upper Rhine without geothermal

The sum of the technical potentials calculated above (including the refinements for wind and solar) amounts to 358,5 TWh. (Tab. 3.6) The wind and solar PV potentials were also validated by comparing them to other results obtained in the RES-TMO project. (Najjar, 2022) The calculated potential could cover 100% of the total energy demand of the Upper Rhine (212 TWh/year) without even considering the geothermal potential. In general, it can be observed that the largest potential is for solar PV (211,7 TWh). The second largest potential in the region is wind (128 TWh). For wind, the total usable area is about 15.5% of the total URR area. According to Fraunhofer ISE (Ed.) (2020), PV and wind power are considered pillars of the future energy supply. They constitute the bulk of the region's potential.

| RE Source | Annual Potential (in TWh) |
|---|---|
| Wind | 128 |
| Solar PV Rooftops | 52,2 |
| Solar PV AGRO | 91,5 |
| Solar PV GM | 68 |
| Biomass | 5,2 |
| Hydropower | 13,6 |

Tab. 3.6: Yearly Technical URR Renewable Energy Potential by Source (Najjar et al., 2022)

However, it is clear that only a small percentage of the technical potential is usable due to legal, social and economic reasons. In addition, there are some methodological limitations for the estimations such as:

**Wind:** When it comes to wind energy, limitations in the methodology include the focus on yearly timescales that don't take into consideration the monthly variations in wind energy potential that could vary significantly between the different months of the year. However, for the purpose of this task, yearly averages help in the estimation of the average yearly potential.

**Solar:** The initially calculated potential for free-range PV was overestimated as it took into consideration the whole area that is available without accounting for the installations and the significant spacing requirements needed for equipment, activities related to agriculture or even maintenance purposes. However, the spacing factor was considered at a later stage of the RES-TMO project and is included in the modified potentials found in Tab. 3.6. Moreover, the different needs and preferences of crop types and the effects that free-range PV could have on them have not been considered. Floating PV was not looked into and solar panels along transport lines were not considered separately (Najjar et al., 2022). Historical buildings were not factored out in the rooftop potential. As discussed in the methodology section, the rooftop potential usable area consists of clusters of buildings for technical purposes, so it was not possible to subtract historical buildings and structures. However, this is not a critical criterion as for example in Switzerland, it is possible to install but better not to significantly interfere with historical buildings as per the website, Sonnendach[2]. The roof load bearing capacities were also not considered because the calculations should be performed on a case-to-case basis for each roof and are part of the feasible potential (Tab. 2).

**Biomass:** When it comes to biomass, the limitations are defined by the limitations of the data acquisition part of the Biomass Oui project and are mainly related to the heterogeneity of the available information from the three different countries due to different factors including confidentiality. Moreover, the smallest level of detail could not be achieved in France for example, which meant that the results could not be portrayed at the lowest level of the arrondissement, Kantone, Landkreise (Weber et al., 2014).

**Legal:** The main limitations, when it comes to calculating the solar and wind potential, stem from the tri-national nature of the region and specifically the difference in regulatory structure. For example, in the German state of Baden-Württemberg, a clear definition of the areas that are restricted for PV and wind dissemination are found in the form of a document with the title, "Kriterien Katalog" (a criteria catalogue), on the website Energy Atlas Baden Württemberg[3] which lists the hard restriction areas that are considered a forbidden zone for the propagation of wind and solar farms and a conditionally or partially restricted zone which can be utilised in theory. In France, as it was determined by our expert opinion, when it comes to renewable energy projects, the decision and study is made on a case-to-case basis and an extensive environmental impact assessment study should be completed. In Switzerland, GM-PV projects are in general not recommended and the focus of PV propagation is on rooftop installations (EEA et al., 2019).

As mentioned above the technical potential does not depict the potential which can be realised in reality because it is limited to a large extent by factors such as land-use competition due to food production, environmental impacts, landscape aspects, societal acceptance, economic framework conditions, regulations and others. Nevertheless, the technical potential supports the development of better frame conditions and free spaces to better exploit the potentials in an integrative process with strong participation of citizens

[2] https://www.sonnendach.ch
[3] https://www.energieatlas-bw.de

and enterprises. If 20% to 30% of the overall technical potential could be activated in the long term, this would be a strong contribution to total energy needs in the URR, including not only electricity but also the heating and cooling demand. Citizens' resistance to the implementation of RE technologies is different in the three countries (Wüstenhagen et al., 2007). Therefore, it is important to include them in the decision-making process so that the transition into the future energy system will be smoother.

# 4. Green Batteries with Circular Economy

Lithium-ion batteries (LIBs) are a key technology for a sustainable energy sector without $CO_2$ emissions. The competence group Green Batteries describes possible projects connected to a circular use and recycling of batteries that could be realised in the region of Fessenheim.

The synergies of the competence group "Green Batteries with Circular Economy" and the competence groups "Green Hydrogen" and "Smart Electricity Grids" will also be addressed in this chapter.

## 4.1 Background

A circular economy for battery materials, as promoted for example by the EU Circular Economy Action Plan (EC, 2020), is important for several reasons:

- The availability of LIBs is limited because they contain critical raw materials (e.g. cobalt, nickel and natural graphite); therefore, reusing materials from batteries at their end of life (EoL-batteries) is crucial to becoming independent from countries that mine these materials and in helping to secure a safe supply chain.
- Most raw materials are not mined in Europe, so transporting them is an energy intensive process; however, the materials from EoL-batteries are already available in Europe, so transport distances are much shorter and less energy consuming.
- By implementing a circular economy, all concerned industries will be located in one place (e.g. the Fessenheim region) which leads to the reduction of transportation distances for all relevant battery components and the decrease in the carbon footprint of batteries.
- Providing electricity exclusively by renewable energy-sources (RES) urgently requires more electrical energy-storage (EES). Batteries, e.g., old batteries from electric vehicles (EV), are one of the most promising technologies that are suited to this purpose (2$^{nd}$-life application).

At the moment, recycling of battery materials focuses on regaining the original raw materials that are used for the synthesis of new active battery material. This is done using high energy-consuming processes and therefore, recycling has a negative impact on the carbon footprint of the battery.

The recycling of battery materials is still in its infancy, since EoL-batteries from EVs, that are needed for the recycling processes, are still scarce. With more and more EVs entering the market this field is becoming extremely important for the future and holds a lot of potential for the industry.

As described in the following text and according to the local and regional assets described above, conditions are suitable for setting up the battery industry in Fessenheim.

Facilities that recycle or produce battery materials need a lot of electricity. As described in Chapter 3, the Upper Rhine valley has a vast potential for generating electricity from wind and PV. These RES will help provide cheap and $CO_2$-neutral electricity for the corresponding facilities. This is a crucial requirement for setting up an industry with a low environmental footprint.

Furthermore, the already existing grid-infrastructure of the old nuclear power plant can be useful for suggested pilot projects like the "Utility-Scale Hybrid Electrical-Energy Storage, complemented with 2ndlife EV Batteries" (see below), which is important for the extended use of RES. Setting up the envisioned facility on the site of the old nuclear power plant would therefore be reasonable, but it is not a prerequisite for the establishment of a second life battery-storage utility.

Another important advantage of the Fessenheim region is the already existing infrastructure for the transportation of goods. This is especially important for suggested pilot projects that deal with battery recycling and battery material production. The different facilities depend on such an infrastructure, e.g., the transportation of EoL-batteries to an envisioned recycling plant. As mentioned in the introduction, the ports nearby provide connections with many relevant companies along the Rhine. An example of this is the BASF in Ludwigshafen, which has been involved in the production of battery materials for LIBs for a long time. In addition, the previously mentioned European transport corridors Rotterdam-Genoa and Marseille-Basel-Rotterdam provide a unique European transport infrastructure which also connects to global markets. This infrastructure is a very important factor in today's globalised economy.

From a social, but also economical perspective the installations envisioned within the pilot projects of the green battery group will provide many jobs in the Fessenheim region. Because the transformation of the energy sector towards $CO_2$-neutrality is politically supported, jobs connected with this will be safe for a very long time since they are linked with the European lead in innovation technologies to achieve $CO_2$ neutrality, and can therefore be denoted as future-proof jobs.

## 4.2 Scope of the Competence Group Green Batteries

The competence group Green Batteries evaluates the potential of the Fessenheim region to turn into an innovation region covering all aspects of the circular economy for batteries. This includes the production of battery materials, the 2$^{nd}$-life utilisation of batteries from electric vehicles (EVs) as well as the recycling of these batteries after their 2$^{nd}$-life utilisation (Fig. 4.1). Additionally, a utilisation-scale battery for electrical energy storage (EES) is included in the evaluation.

Facilities that represent a part of a circular economy usually have several interfaces that exchange know-how and materials, which are discussed in detail later in this chapter. In fact, transportation can be reduced drastically, if these facilities are located close to each other. This is not only financially attractive, but it also saves $CO_2$-emissions.

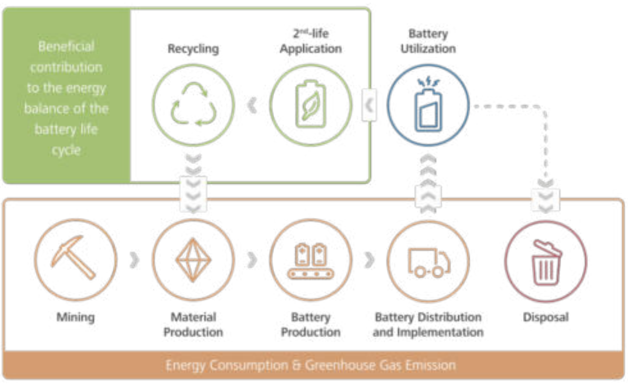


Fig. 4.1: Lifecycle of a battery (Dühnen et al., 2020: 3).

The subgroups (see chapter 4.3) identify potential interfaces which are important for the industry among their activities.

## 4.3 Subgroups of the Competence Group Green Batteries

The competence group "Green Batteries" is divided into four subgroups:

I. Battery Materials
II. Batteries for 2$^{nd}$-life energy storage
III. Battery Recycling
IV. Economic Impact of Batteries

The subgroups work on specific pilot projects that could be realised in the region of Fessenheim and could result in possible pilot projects. The subgroup "Economic Impact of Batteries" does not suggest pilot projects itself, but supports the other subgroups. Fig. 4.2 gives a brief overview of the possible installations (pilot projects) envisioned by each subgroup and shows the connection between them.

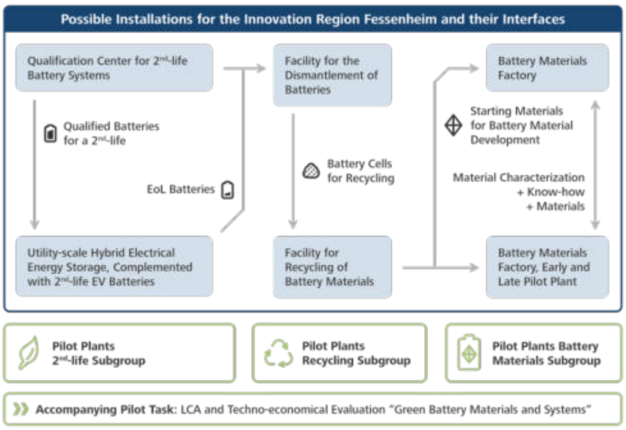


Fig. 4.2: Pilot projects developed by the Green Batteries group and their interlinkages

### 4.3.1 Focus of the "Battery Material" Subgroup

Research on new and refined battery materials is an ongoing task which has been driven by improving the performance of the batteries in the last decades (higher energy density, higher power output, longer cycle life and so forth). Although these parameters are still important and need to be further improved, the focus is shifting towards "green" battery materials that are sustainable. Sustainability can be achieved by finding/refining materials based on amply available elements as well as developing processes for their preparation with a low $CO_2$ and environmental footprint. Developing more sustainable battery materials will remain important in the future and includes almost every battery component; for example, cathode and anode active materials as well as all the inactive supporting materials. The composition of the required materials will also be influenced by the recycling aspect, the new recycled material flow and vice versa. Potential pilot projects and projects that offer room for innovation in the required materials are developed by this subgroup. For a sustainable energy sector, which is a part of the "European Green Deal" (EC, 2019), such pilot projects strongly promote the long term vision of a sustainable innovation region.

### 4.3.2 Focus of the "Batteries for 2nd-Life Energy Storage" Subgroup

The widespread use of electric vehicles (EVs) towards a mass market is essential to reduce emissions of pollutants and greenhouse gases in the transport sector. However, the production of vehicle batteries is still very energy intensive. So, the advantages of electromobility in terms of $CO_2$ emissions will only become evident after a long service life of the batteries and correspondingly more kilometres being travelled with these vehicles. Due to the ageing (capacity fade and increase of inner resistance) of the lithium-ion batteries used in an EV, the range and performance of the latter decrease over their service life. However, a necessary replacement of the battery in the vehicle does not necessarily mean the end of battery operation. It can be further used in a 2nd-life application and still provide sufficient capacity, e. g. at lower power rates. The $CO_2$ balance is thus improved, considering the longer service life of the battery.

As 2nd-life applications, various different concepts can be considered and are currently investigated within demonstration projects. In so-called behind-the-metre applications (residential, commercial & industrial) stationary buffer storage combined with PV systems can, for example, increase the self-sufficiency rate (IRENA, 2019). The buffer storage can also  be used to reduce peak loads, support load shifting and provide grid services. Such revenue stacking strategies improve the economics of stationary storage investments. Furthermore, large-scale buffer storage can be coupled with PV or wind power plants and can be installed at old sites, where conventional power plants have been recently shut down (e.g., in Fessenheim) and where the electrical installations and grid connections can be ideally used for such centralised storage plants. For such large-scale storage installations, hybridisation of different technologies can be an interesting concept as site-specific requirements and the corresponding operating control strategies can vary depending on the business models and regulatory framework in place. Exemplarily, (2nd-life) batteries can be coupled with grid-scale / large-scale storage units such as redox-flow batteries, high-temperature batteries and even Carnot batteries. Besides this huge variety of stationary applications, used EV-batteries are meanwhile also of interest for floor-borne vehicles (e. g., forklifts), on grounds of economic considerations. Although opportunities for 2nd-life storage are impressive, challenges have to be tackled in terms of qualification for re-utilisation, prediction of the remaining useful lifetime and development of efficient dismantlement strategies. Within the Innovation Region Fessenheim a pilot for 2nd-life battery qualification can be established and later transferred as a model for decentralised 2nd-life qualification stations.

### 4.3.3 Focus of the "Battery Recycling" Subgroup

After a period of first and second life, each battery reaches its end of life (EoL) state. To achieve a circular economy, these batteries must be regarded as a source of (critical) raw materials. The individual process steps, starting from the evaluation of a 2nd-life potential for battery systems, modules, and cells to the disassembly steps to separating the material fractions and processing the active material, are separated into pilot projects. Several recycling approaches are already implemented on an industrial scale. However, there is still a lot of potential for optimising the disassembly process in terms of safety and efficiency; in addition to the comminution, sorting technologies, recovery rate, and recyclate quality.

Currently, the disassembly is a manual process in all known recycling plants. Several public- funded projects deal with robot-automated disassembly for the purpose of separating all parts in a non-destructive (smart) way. In this case, robots need to be inputed with data specific to each battery type. The present approaches are categorised by dismantling type, as smart or robust. The robust approach considers destructive separation in favour of lower sensitivity and higher efficiency.

The challenge of the following steps in the recycling process is the generation of pure fractions, especially in the case of active materials. The performance of lithium-ion batteries is highly dependent on high quality anode and cathode materials. Small amounts of impurities, defects and structural failure lead to a functional decrease and lower the performance of a battery. Therefore, each step of the recycling process is crucial to the quality of the output fraction, the type of mechanical shredding, intelligent sorting with mechanical and sensor-based technologies, and tailored chemical and thermal treatment of the black mass. In-process analysis and recyclate analysis need to be linked with feedback from the cell manufacturer/developer implementing these recyclates. Intelligent recycling infrastructure will be needed at several places within Europe, in order to return valuable materials back into the production process. These places need to be strategically selected according to the best frame conditions provided by the Upper Rhine.

In the strategical context of the Innovation Region Fessenheim, battery recycling is one of the building blocks that can be used for establishing battery plants and facilities where research can be linked to the actual application of renewable energy, energy storage and green-hydrogen production and usage.

## 4.4 Interfaces with the other Competence Groups

Interfaces with the other competence groups – Hydrogen and Smart Grids – are evaluated. Fig. 4.3. shows the major interfaces of the installations (pilot projects) envisioned by the Green Batteries group with the other competence groups.

## 4.5 The Future of Green Batteries in the Fessenheim Region

As already mentioned, there is a lot of potential available for a successful implementation of green-battery facilities in the Fessenheim region. However, some demands, and challenges remain. The following paragraphs will show what is already available and what is still needed.

### 4.5.1 Status

A lot of expertise as well as R&D support regarding technologies for a circular economy of batteries is already available in the Fessenheim region to assist companies that are willing to invest in such facilities. However, companies, especially large ones,that produce and further develop such technologies, are not yet linked together.

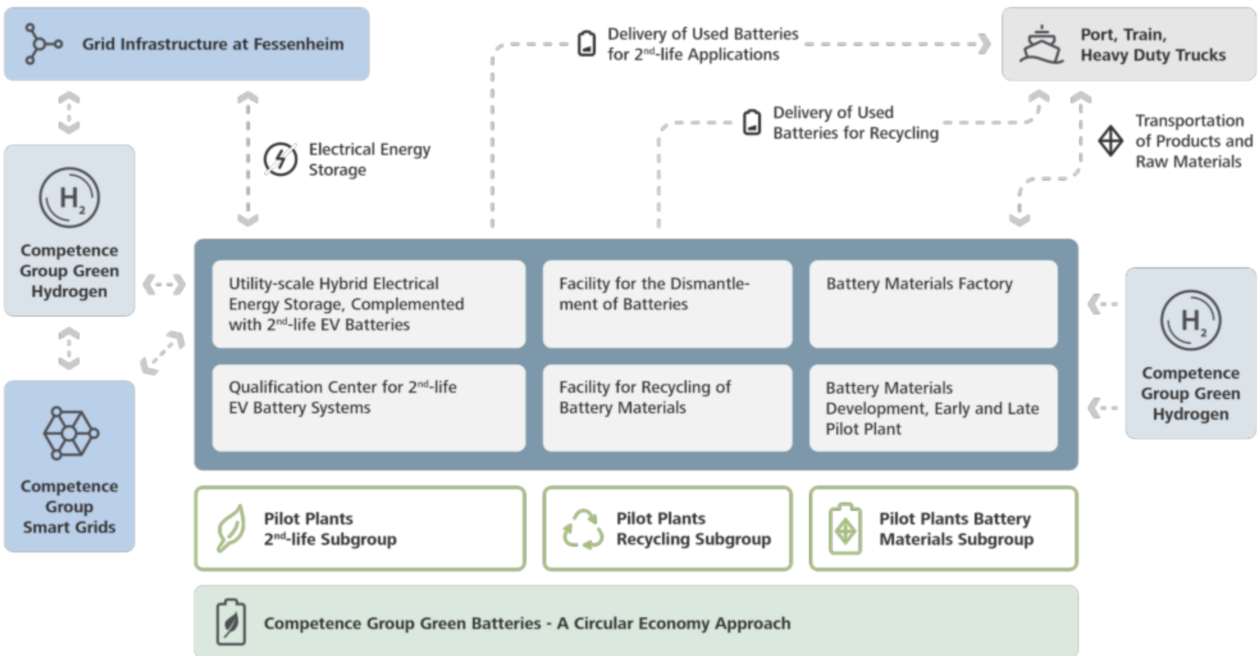


Fig 4.3: Interfaces between the Green Batteries Group's envisioned installations (pilot projects) and the other competence groups as well as the importance of the harbour at Fessenheim

The installation of electrical-energy storage, as envisioned by the 2nd-life subgroup, is directly related to the establishment of a smart grid.

Additionally, all installations dealing with the energy-intensive development and production of battery materials can profit from the electrolysers envisioned by the Hydrogen Group. Electrolysis produces oxygen, which is required for the synthesis of cathode-active materials (CAM), as a by-product.

Replacing a base load deliverer like the old nuclear power plant by implementation of fluctuating RES requires advances in EES-capacities both on the German and French side. Investments in the proposed pilots would thus be viable.

## 4.5.2 Potentials

### Transport Infrastructure and Location

Every production facility requires a well-developed infrastructure and access to logistically important trading hubs. The study revealed the outstanding importance of the Rhine and the existing ports in the Fessenheim region for the shipping of batteries and refined materials from all other areas in Europe.

A holistic approach including battery and hydrogen technology combined with a smart grid is a huge advantage because of the many interfaces that connect the different areas.

### Jobs

The installations, envisioned by the Green Batteries Group, have the potential to generate future-proofed jobs in the Fessenheim region. These jobs need multifarious areas of expertise in the field of batteries such as battery-material production and characterisation as well as knowledge about recycling and characterisation of batteries. Due to the universities and research institutes located in Switzerland, France and Germany that teach all the relevant competencies, people with the required expertise are already in place in the Fessenheim region. Their presence also helps to develop and offer training courses to advance the knowledge of employees that were employed at the nuclear power plant and previously held technician and service level jobs. In that way, these employees can be easily integrated in future working fields.

### Available Competences and Expertise

The Fessenheim region conveniently encompasses available expertise concerning battery materials, represented by universities, research institutes and companies located in Switzerland, France and Germany each with special competencies (Fig. 4.4). Advantageously, this supports the intended pilot projects that will need R&D-support from these institutions for successful work.

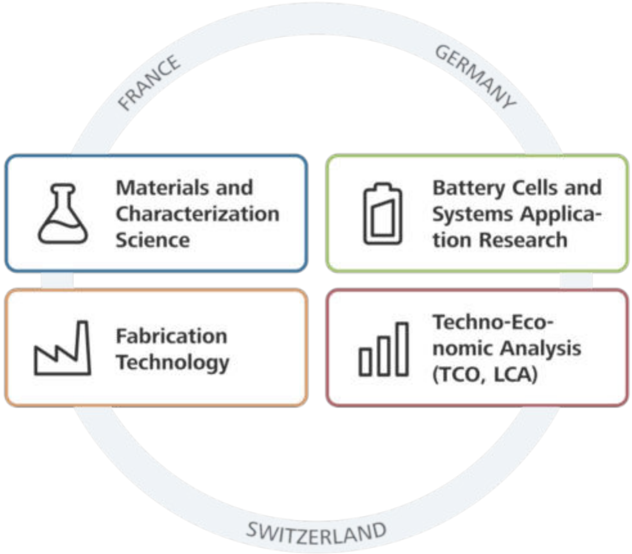


Fig. 4.4: Complementary Competences of the Competence Group Members that are available in the Fessenheim Region

The Innovation Region Fessenheim will focus on aspects of battery innovations that are not yet represented within the scientific landscape of Germany by utilising the available expertise found abundantly in the region. Additionally, links may be formed with the already existing competence centres in Ulm (HIU), Münster (FFB) and the institut Carnot Mica in Mulhouse – a future network between these competence centres will be envisaged.

## 4.5.3 Challenges

### Companies

The motivation and conviction of companies to invest in installations in the Fessenheim region is the biggest challenge for a successful transformation of the region. In particular, a large sized company that is willing to participate in the building and operation of some of the envisioned installations would be very important. Smaller companies are more likely to follow suit and build supporting/complementary facilities in the Fessenheim region.

As a result of several meetings with interested industry partners, the following questions arose; they need to be addressed as comprehensively as possible as that might be crucial to the decision of a company considering an investment in a factory or installation in the Fessenheim region:

- Is it possible to get special frame conditions, like cheap loans or tax releases for the construction of a factory?

- Is it possible to get special conditions for the designated areas needed to install a factory?
- How many new industrial areas are available? When are they available and how big are they?
- What is the local infrastructure like at the designated areas?
- How expensive is local energy?
- Is there enough renewable energy in the area available, and if not what is the infrastructure available to transport green energy to the area? Are tax releases possible to have competitive energy costs, regarding the actual fluctuations?

### 4.5.4 Demands

**Funding**

Investments by private companies must be supported by suitable, holistic funding schemes. It is best, this be achieved through EU investments as part of the "Green Deal" (EC, 2019). Additionally, other funding schemes need to be identified or, best, be implemented through politics. All the described pilot projects have the potential for individual funding. Most of them fit well with current national and/or European tenders, but there is always a risk of competition from other project ideas.

Unlike most other public funded projects, the focus of all the present pilot projects is the implementation of demonstrators, pilot projects, labs etc. in one place. Therefore, the individual projects have above-average needs for investment. The budget estimation for the first setup of the pilot projects for a dismantlement plant, a recycling plant and a hybrid storage consisting of 2nd-life LIBs, a NAS battery, a vanadium redox-flow battery and a Carnot battery is estimated at €250 Mio. Additionally, for the planning phase of approximately five years €10 Mio. is needed for a professional project-coordination team.

**Embedding of the Pilots into the Regional Innovation Concept**

As discussed earlier, the installations suggested by the Green Batteries Group should be in close proximity to the port at Fessenheim or at least be well connected to it. Therefore, areas have to be identified, where the proposed installations can be realised.

### 4.5.5. SWOT Analysis of the Overall Concept

A SWOT analysis for each pilot project/plant can be found in the corresponding descriptions (see Pilot summery).

## 4.6 Pilot Projects

The pilot projects, envisioned from the different subgroups, will be presented in short with a rough timeline. Detailed descriptions of corresponding pilot projects can be found in the Pilot summary. In addition, a list of concerned companies is included at the end of this chapter.

### 4.6.1 Batteries for 2nd-life Energy Storage

The developed concept of 2nd-life storage is embedded in a holistic approach. Fig. 4.5 gives an overview on the logistics, qualification for re-utilisation, set-up of pilot projects for dismantlement and recycling as well as the design and installation of stationary battery-storage consisting of aged EV-LIBs. In total, the process is divided into seven sub-pilot projects (see Pilot summary).

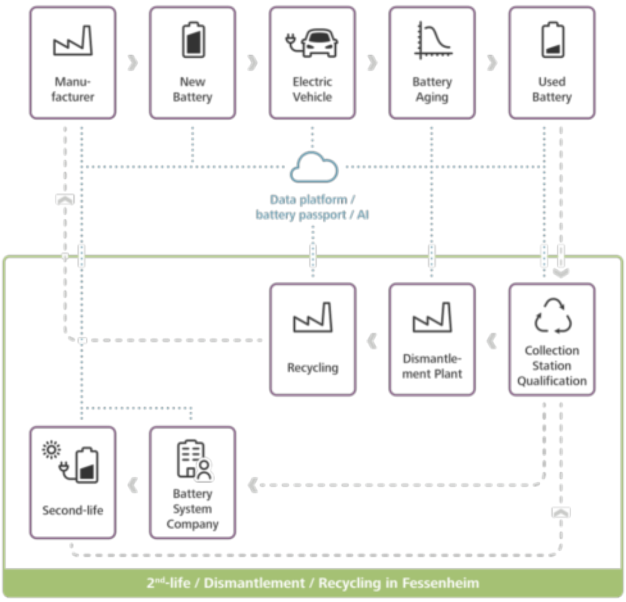


Fig. 4.5: Holistic approach of qualification, re-utilisation, dismantlement and recycling of aged electric vehicle batteries

For the realisation of the suggested 2nd-life battery pilot projects, the subgroup envisions the installation of two plants in the Fessenheim region:

**A. 2nd-life EV Battery System Manufacturing**

- This facility is closely linked to the dismantlement facility described later by the recycling subgroup.
- The qualification of batteries is done in this facility. Depending on the state of health (SoH), it will be determined whether a battery is suitable for a 2nd-life application or has to be recycled directly.

B. Utility-Scale 2nd-life Battery Storage

- This battery storage consists of old batteries from EVs.

C. Utility-Scale Battery Storage

- In this hybrid battery storage, different storage technologies like redox-flow batteries, NAS batteries and a carnot battery will be combined.

The "Utility-Scale 2nd-life Battery Storage" and the "Utility-Scale Battery Storage" combine various relevant stationary technologies for EES such as a vanadium redox-flow battery, a NAS battery, a Carnot battery (see Fig. 4.6) and shall be integrated into a grid-scale/large-scale hybrid electrical energy storage.

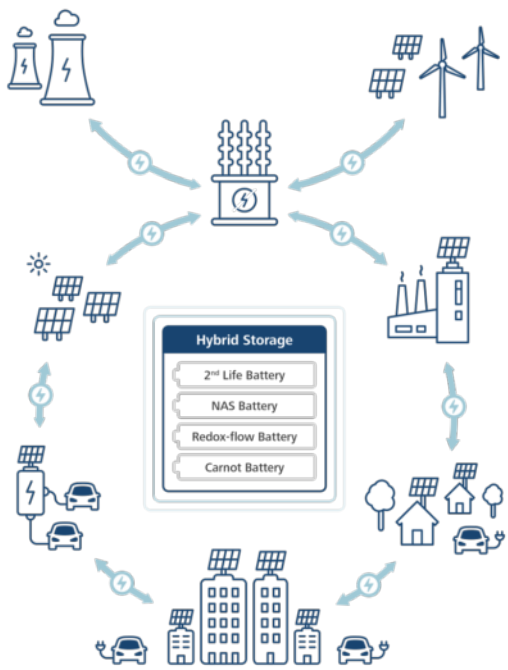


Fig. 4.6: Concept of grid-scale / large-scale hybrid EES consisting of second-life LIBs, a NAS battery, a vanadium redox-flow battery and a Carnot battery (edited from Gattiglio, 2017)

In Fig. 4.7 a timeline for the pilot projects suggested by the 2nd-life subgroup is presented.

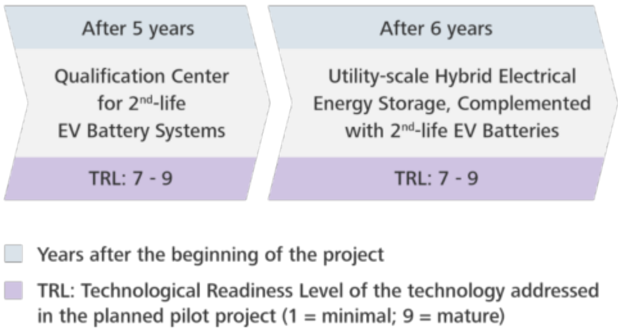


Fig. 4.7: Timeline and TRL for the installations envisioned by the 2nd-life subgroup

## 4.6.2 Battery Recycling

Battery recycling is the important link between 2nd-life utilisation of batteries and battery-materials production that enables a circular economy of the required materials. After a battery reaches its end of life (EoL), the valuable materials within the battery cells have to be recovered in a battery recycling plant. For this purpose, large amounts of old batteries are needed. Therefore, a close proximity to a facility that delivers batteries at their EoL would be a great advantage. The "Utility-Scale Hybrid Electrical-Energy Storage, Complemented with 2ndlife EV Batteries" - a pilot plant suggested by the 2nd-life subgroup - can provide batteries at their EoL, which would result in a great synergy between these two pilot projects. On the other hand, raw materials for battery-material production are produced at a recycling plant. Therefore, facilities that need these materials, along with all other pilot projects suggested by the Battery Materials subgroup, profit from having a nearby recycling plant.

The concept of the battery recycling subgroup includes dismantling (closely linked to 2nd-life) and recycling up to precursor materials for the production of new electrodes (Figure 4.8).

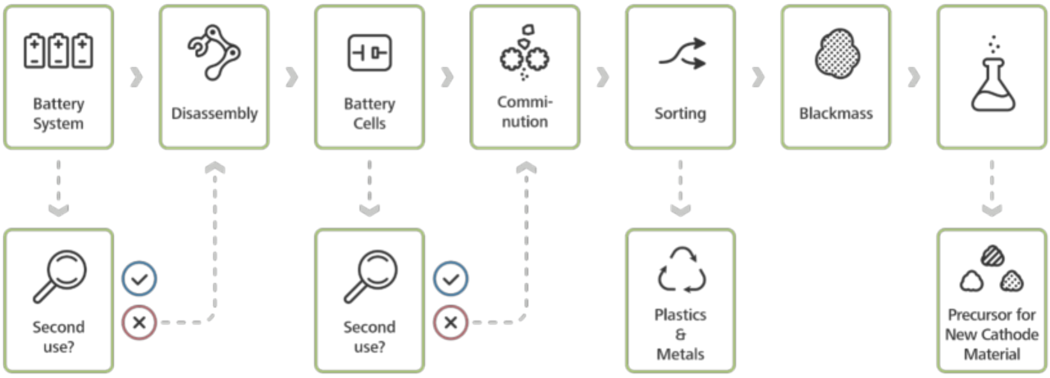


Figure 4.8: Approach of dismantlement and recycling of aged electric vehicle batteries including diagnostics

The purpose is the development of a full or semi-automated disassembly plant including diagnostics at the different stages of dismantling (system, module and cell level). Development is required for the automation to open battery systems and disassemble to at least module level without special knowledge of the battery systems.

For battery cell comminution and fraction sorting, innovative mechanical and hydro-mechanical processes will be developed. The development focus is on high material selectivity, i.e., a minimization of impurities in each fraction, in particular the black mass. Subsequently, the "pure" black mass needs to be treated by a hydrometallurgical process. This step concentrates on the development of solutions combining suitability for the production of electrode materials and protection of the environment. The steps in the process that need to be further developed are highlighted in figure 4.9.

The recycling subgroup suggests two pilot projects for the Fessenheim region where the suggested pilot projects (see Pilot summary) can be realised:

**A. Facility for the Dismantlement of Batteries**

- A dismantlement plant concept for used EV batteries (together with the 2nd-life subgroup)

**B. Pilot Plant for the Recycling of Battery Materials**

- Recyclate analytics and qualification concept
- Development of a mechanical process for highly material-selective comminution
- Methods for the hydrometallurgical recycling of the electrode materials

Fig. 4.10 shows a timeline for the suggested projects.

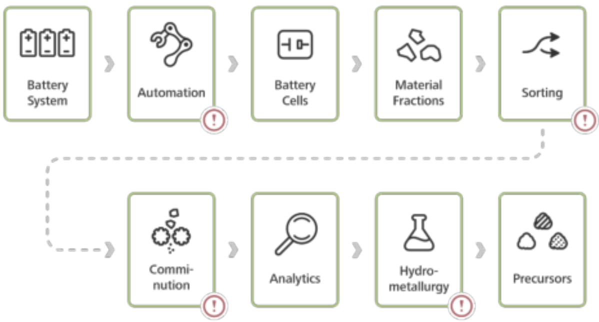


Fig. 4.9: Process steps in the disassembly and recycling process that will be further developed for the planned pilot projects

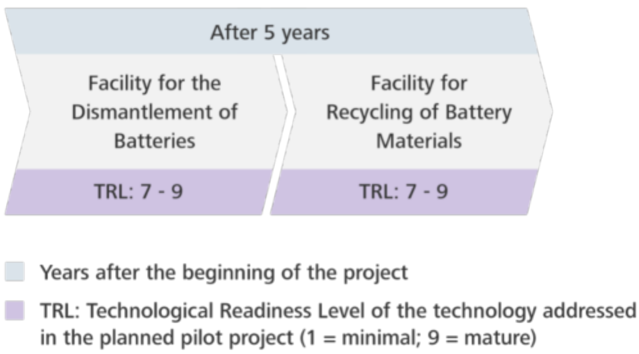


Fig. 4.10: Timeline and TRL for the installations envisioned by the recycling subgroup

### 4.6.3 Battery Materials

Nowadays, the major focus in the development of new battery materials and their production is on Lithium-ion batteries (LIBs). This is, due to their very good performance and the potential that still lies within this technology (e.g., utilisation of silicon or elemental lithium at the anode). Although a lot of research is done with respect to post-lithium chemistries, LIBs will dominate the battery market in the future, and it is not very likely that they will be completely replaced one day by another technology. However, the demand for electrical-energy storage (EES) will rise tremendously in the near future and LIBs will not be able to stem this on their own due to limited raw materials. It is therefore important to investigate new chemistries (e.g., organic materials, Al, Zn, Mg, and so forth) and further develop already existing alternatives like redox-flow batteries that can be used for special applications (e.g., large-scale EES). Therefore, the focus of the following pilot projects not only mainly represents the development and production of materials for LIBs, but it also presents the above-mentioned alternatives. Fig. 4.11 shows a timeline for the suggested pilot projects.

The battery materials subgroup suggests three pilot projects for the Fessenheim region:

**A. Early Pilot Plant for Battery Materials (EPP)**

- Deals with the development of battery materials with a low technological readiness level (TRL) of 1–6
- Will be closely linked with university laboratories in the Upper Rhine whose research outcomes can be interlinked to push the technological readiness level through joint projects

**B. Late Pilot Plant for Battery Materials (LPP)**

- Deals with the development of materials with a TRL of 7 - 9 and envisions a close cooperation with the EPP and the BMF
- Is strongly linked to the industry in order to implement field tests for production preparation and can be linked to innovation labs at the innovation park EcoRhena

**C. Battery Materials Factory (BMF)**

- Produces battery materials for sale and envisions a close cooperation with the late pilot plant for battery materials (LPP) to accelerate the production of novel materials

## 4.7 Summary and Recommendations

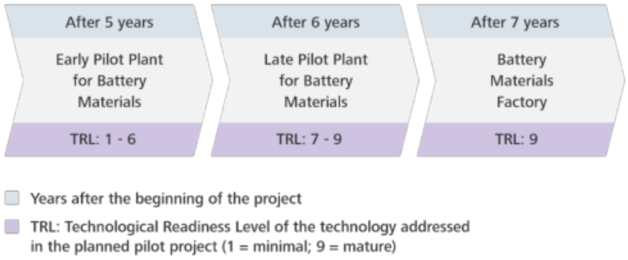


Fig. 4.11: Timeline and TRL for the installations envisioned by the battery materials subgroup

### 4.7.1 Summary

In this feasibility study, the Green-Batteries competence group suggests possible installations related to battery material production, 2nd-life applications, and battery recycling. As has been shown previously, these installations are capable of reducing greenhouse gas emissions related to battery production, are invaluable for gaining more independence from the material supply chain, and play a crucial role in implementing a circular economy of batteries.

It has been proven that the Fessenheim region is very well suited for the realisation of the proposed installations because of the available infrastructure as well as the battery-connected expertise that is already available through universities and research institutes.

Additionally, jobs that are connected with this industry will be future-proof, since there are not many alternatives to batteries when it comes to electromobility.

The biggest challenge for the implementation of pilot ideas is convincing companies to build their facilities in the region; therefore, easy access to start-up funding schemes, cheap energy from RES, and area provision for the proposed facilities are essential.

### 4.7.2 Recommendations

We recommend following the holistic approach described in this feasibility study by implementing as many of the suggested facilities from the different competence groups (batteries, hydrogen and smart grid) as possible. Regarding the circular economy approach for batteries described in this report, it is crucial to have a variety of installations that deal with battery materials, 2nd-life utilisation and battery recycling. These facilities can not only profit from each other, but also provide the advantage of reduced transportation distances.

We recommend an integrated concept "Circular Economy for Battery Electric Storage Systems and Electromobility" in the battery field. This concept can create huge economical opportunities for the region of the Upper Rhine valley in a booming battery market and includes a highly innovative dismantling and recycling plant and a utility-scale hybrid energy storage.

Implementation of a dismantling and recycling plant requires highly efficient infrastructure logistics for transportation and collection of used batteries, that are for example sourced from the exponentially growing electromobility market. Besides well-developed rail and road systems, the Rhine and its ports located in the Upper Rhine valley, particularly Fessenheim and Breisach, support an integrated cost-efficient approach. This concept is accompanied with a qualification station for used batteries and a second-life approach.

In this context, the EURO district Breisach/Biessheim seems to be able to provide space in its industrial zone because of its proximity to the local port on the Rhine and to the local train station and can contribute to creating a collection and qualification infrastructure and a test bed for dismantling and recycling pilot projects.

The electrical network of the old nuclear power plant could be ideally used for implementing a large-scale hybrid energy storage (several 100 MWh). Such storage systems are needed for the accelerated integration of fluctuating renewables (PV and Wind) to power grids. The suggested hybrid approach consists of a second-life battery block, a NAS battery, a redox-flow battery and a Carnot battery. With such storage systems, various solutions for stabilising the power grid can be addressed; from provision of short-term high power rates to buffering energy for a couple of days as a so-called long-duration energy storage[1].

**Cost estimations**

The integrated concept "Circular economy for Battery Electric Energy Storage Systems and Electromobility" has to be further developed. For the corresponding tasks an estimated budget of €10 Mio. for 10 people and 3 years is needed. This budget includes the coordination of three topics

- Second-life hybrid energy storage and application
- Dismantling plant
- Recycling plant

Thereby the coordination tasks include

- Engineering / technical development
- Economics / business plan development
- Regulatory framework / politics

In a first step, budget estimations have been conducted for the three topics of the integrated concept "Circular economy for Battery Electric Energy Storage Systems and Electromobility":

- €120 Mio.for 300 MWh second-life hybrid energy storage
- €130 Mio. for dismantling and recycling pilot projects

To convince companies to build their facilities in the region, easy access to funding schemes and the provision of areas for the planned facilities are essential. The conditions for the construction of factories have to be very clear. Important considerations to be addressed by industrial stakeholders were highlighted in section 4.5.3.

See Pilot Sheets.

## 4.8 Interested Industry Partners

- Tech3D France
- BASF
- Opta LP
- MobEnergy
- Veolia Euro Dieuze Industrie
- Daimler
- BMW
- Peugeot
- EDF
- DHL
- Knoll
- Storion
- Hydac International GmbH (Watercooling, process water filtration)
- Knoll Feinmechanik GmbH (Automation)
- KUKA AG (Robotics)
- LCOMS
- TDF Infrastructure SAS
- BENNING CMS Technology GmbH
- Stellantis (PSA)
- ASD Automatic Storage Device GmbH
- TRICERA energy GmbH

[1] Net-zero power - Long duration energy storage for a renewable grid, www.ldescouncil.com.

- Hitachi Energy Germany AG
- Enolcon
- MAN-ES
- Bouygues Construction (F) + Kraftanlagen München (D)

## 4.9 Contacts

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# 5. Multi-Modal Green Hydrogen Hub Fessenheim

As part of the feasibility study, a concept and different lines of action for Franco-German demonstration projects for the Fessenheim Innovative Region have been developed. The overall objective is to develop a sustainable and forward-looking $CO_2$-neutral economic region. The transformation of society and the economy towards a renewable energy supply and a sustainable use of resources, combined with the creation of future-oriented jobs, will be strongly promoted by implementing hydrogen as an energy carrier. Green Hydrogen allows seasonal storage of renewable electricity, allows to introduce green energy in industry processes that are not yet de-fossilised by green electricity, and to make the energy system more robust by coupling the different energy sectors in a flexible and efficient way.

## 5.1 Background

The current consumption and supply schemes in the region provide important insights with regard to potential consumers of green hydrogen and scope for using renewable sources for its production, respectively.

The most relevant information can be found in the Trinational Climate and Energy Report of TRION-climate e.V. (2019) and also in the framework of the Interreg Upper Rhine project RES-TMO. The total final energy consumption in the Upper Rhine Region amounted to 38.7 MWh per capita in 2016 on average (see Fig. 5.1), which is slightly above the averages of each studied sub- region alone. 52% of the secondary energy was consumed by industry and the energy sector, 27% by residential buildings and 19% by road transport.

The region provides quite a powerful spectrum of renewable energies. In 2016 the total renewable energy production in the Upper Rhine region was 28.5 TWh with the largest contribution by hydroelectricity (56%), followed by biomass and waste (30%) and then solar heat and photovoltaic (PV) (4%). There is a strong focus on PV and wind on the German side, whereas France and Switzerland have a stronger focus on hydroelectricity. Biomass use is equally intense on the French and German side (TRION-climate e.V., 2019). For further details see Chapter 3 of this report.

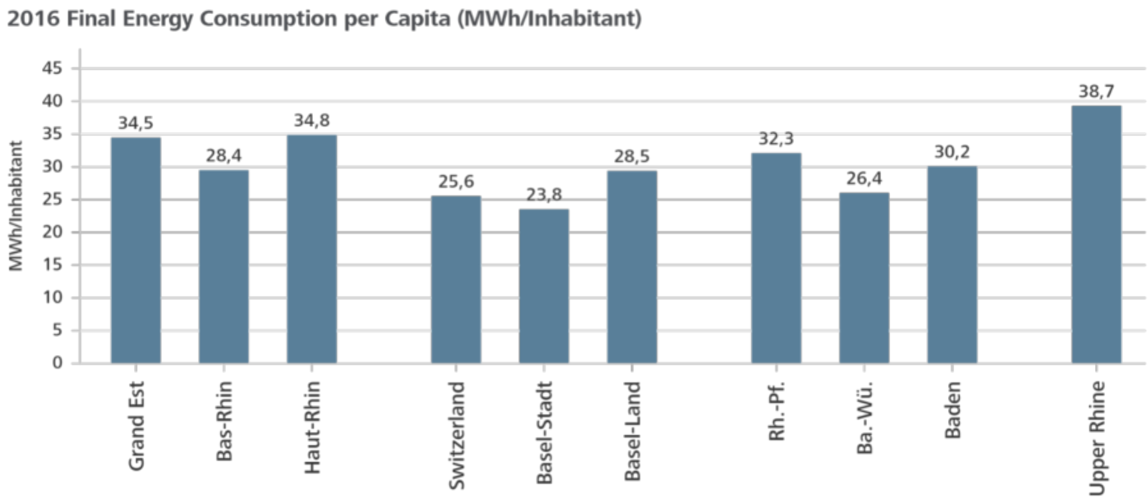


Fig. 5.1: Trinational Climate and Energy Report (TRION-climate, 2019)

## 5.2 Scope of the study within the competence group green hydrogen

The region is full of elements, projects and actors which may combine to form the Multi-Modal Hydrogen Hub covering the full value chain of production, distribution and usage of green hydrogen. This diversity and complementarity were revealed by the "South Rhine $H_2$ Summit", which was organised this November in Biesheim (Haut-Rhin) by the European Collectivity of Alsace.

Based on a set of key elements, the objective of the study was to compose the hydrogen hub in a long term vision as sketched in Fig. 5.2. The elements for production, storage and distribution as well as the usages are depicted with small buttons arranged close to the geographic implementation. The center is defined by the large scale infrastructures. This is surrounded by a more distributed scheme for production and use, mainly needed by refineries, chemical and pharmaceutical industries. The outer elements represent the wider distributed use cases, which are mainly used for heavy duty and public transport in the larger cities of the region: Freiburg, Colmar and Mulhouse. The outer block also includes the import/export interface, established mainly via transport on the river Rhine or on railways.


Fig. 5.2: The Multi-Modal Hydrogen Hub Fessenheim

Instead of the seemingly obvious sequence of the value chain of green hydrogen, i.e., "production - distribution - use", the following presentation of the key elements starts with the identification of potential consumers. From these most promising use cases, the actual need for green hydrogen production is derived. The corresponding scales and schemes for production then determine associated supply infrastructures. The latter includes solutions for importing and exporting green hydrogen beyond the regional scope.

## 5.3 Potential Applications of Green Hydrogen in the Region of Fessenheim

Hydrogen applications start with the large-scale use in industry and continue with the more distributed applications relying on the robust infrastructure and cost reductions realised with the initial industrial applications. This sequence was determined after several consultations with potential shareholders and was supported by a demand analysis "$H_2$-SO – Wasserstofftechnologien am Südlichen Oberrhein" of Fraunhofer-Institut für Solare Energiesysteme ISE, funded by the BW state department (Wasserstofftechnologien am Südlichen Oberrhein $H_2$-SO, n.d.) and in parallel with a study carried out by the researchers of the Felis department of the University of Freiburg (FeLis, 2021).

In the EU, EFTA & the UK the total demand for hydrogen is estimated to be 8.4 MT (million tonnes) of hydrogen or 327 TWh in the year 2019 (Hydrogen Europe, 2020).

The main consumers in the industry for the year 2019:

- Refineries, which accounted for 49% of the total hydrogen use. Refineries are the largest hydrogen consumers in the EU.
- The ammonia industry, which accounted for 31% of the total hydrogen use. The ammonia industry is second to refineries when it comes to hydrogen consumption.
- Other chemical industry consumed about 13%. In the chemical industry, hydrogen is used either as a feedstock or as an intermediate product used for the production of other chemical products (Hydrogen Europe, 2020).

The three industries mentioned above are responsible for a large percentage of the hydrogen demand in the EU (about 92% of the total demand). The rest of the demand can be attributed to the following industries or processes (Hydrogen Europe, 2020):

- Steel manufacturing & metal processing
- Glass manufacturing (as an inert or protective gas)
- Food processing (for margarine production)
- Energy production (for example in CHP plants)
- Fuel cells
- Generator cooling

The transportation sector and specifically clean applications for hydrogen made up a very small share of consumption (Hydrogen Europe, 2020).

The four EU countries with the highest production capacities also make up the largest portion of the EU consumption. These countries are Germany, the Netherlands, Poland and Spain. Out of the three countries of interest, Germany is the country with the largest hydrogen consumption comprising 20% of hydrogen consumption. France and Switzerland consume much less in comparison (see Fig. 5.3).

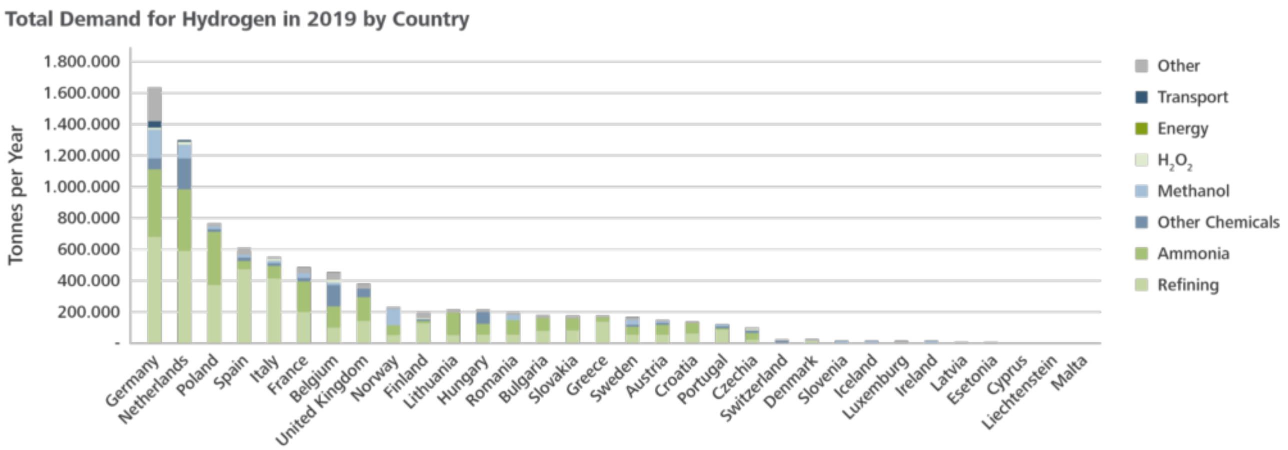


Fig. 5.3: Total demand for hydrogen in 2019 by country (Hydrogen Europe, 2020)

Based on a study by the Felis department of the University of Freiburg, two methods were used to estimate the hydrogen demand (FeLis, 2021). The first method included a questionnaire that was distributed to companies in the French and Swiss URR. The companies were chosen based on different criteria that included energy intensive manufacturing industries and industries that have a strong regional presence. Moreover, the industries included the manufacture of food and beverages, the manufacture of paper and paper products, the manufacture of basic metals, and the manufacture of non-metallic mineral products etc.

However, feedback from the companies was not sufficient to produce conclusive quantitative results despite the large number of companies contacted on both sides. Interesting information can be found in the report about the few companies that did reply.

The website *Géorisques*[1] which was used for compiling the list of companies publishes information about the different substances used by the different industrial establishments that are deemed risky. According to the website, any industrial or agricultural operation likely to create risks or cause pollution or nuisances, particularly for the safety and health of local residents, is a Classified Installation for Environmental Protection (ICPE). An ICPE is subject to numerous regulations for the prevention of environmental risks, particularly in terms of authorizations. Therefore, it was possible to filter the companies not only regionally (at the level of the department) and by industry, but also by risky substances used by the industry. The results for hydrogen and oxygen are included in the tables 5.1 and 5.2 below.

| **Company** | **Hydrogène (numéro CAS 133-74-0) (in tons)** |
|---|---|
| NLMK Strasbourg | 3.0 |
| Liebherr France SAS | 0.6 |
| TEREOS STARCH & SWEETENERS EUROPE | 3.0 |
| **Sum** | **6.6** |

Tab. 5.1: List of Companies using Hydrogen

| **Company** | **Oxygène (numéro CAS 7782-44-7) (in tons)** |
|---|---|
| CLEMESSY MOTORS | 1.0 |
| LIEBHERR FRANCE SAS | 22.7 |
| ESSITY (ex TISSUE FRANCE) | 2.8 |
| Hôpitaux civils de Colmar | 0.5 |
| JET AVIATION AG BASEL | 22.7 |
| SUPERBA SAS | 2.4 |
| NOVARTIS PHARMA SAS (biotechnologie) | 46.0 |
| SAREL | 9.2 |
| SENERVAL UIOM | 2.4 |
| RAVAGO Building Solutions France | 0.2 |
| GDE METALIFER Rohrschollen | 1.9 |
| CRISTAL UNION | 50.0 |
| MERCEDES-BENZ MOLSHEIM | 6.6 |
| LALIQUE | 3.4 |
| LES JUS DE FRUITS D'ALSACE | 4.7 |
| Hôpitaux Universitaires de Strasbourg | 51.3 |
| LEDVANCE SASU (ex-OSRAM) | 80.0 |
| **Sum** | **307.9** |

Tab. 5.2: List of Companies using Oxygen

The second method described in the report relied on statistics to estimate the use of hydrogen by assuming that the total current industrial consumption of natural gas in the Upper Rhine Region in France and Switzerland is substituted by hydrogen and therefore constitutes the future hydrogen demand theoretically. The table 5.3 depicts the total natural gas consumption of the industry in the French and Swiss URR.

[1] https://www.georisques.gouv.fr/

| Upper Rhine Region | Natural Gas consumed by the Manufacturing Industry (in GWh) |
|---|---|
| URR France | 4,791 |
| URR Switzerland | 2,550 |
| **Sum** | **7,341** |

Tab. 5.3: Natural gas consumption in the Upper Rhine on the French and Swiss side

The natural gas consumption of the French and Swiss Upper Rhine industry was then converted to future theoretical hydrogen demand by making the following assumptions were made:

- The natural gas consumed by the industry is replaced by hydrogen as a fuel
- Energy efficiency improvements in the industry are disregarded
- Other uses of hydrogen are disregarded and considered beyond the scope of the study

The method uses gravimetric energy density of hydrogen to calculate the needed amount (in tonnes) of hydrogen to produce the same amount of energy produced by the natural gas consumed by the industry. The detailed calculations and description of the methodology are included in the aforementioned report. The theoretical and future hydrogen demand in the URR was estimated to be 218,482 tonnes per year.

It is important to mention that the statistical method is limited by the availability of publicly accessible data that may differ from country to country. For example, for the French URR, natural gas consumption is found for the year 2019 whereas for Switzerland, it is from 2018. The natural gas consumed by the industry in both countries at the URR scale also had to be estimated from more general data.

Nevertheless, this approach is an important starting point for estimating the hydrogen demand and therefore the hydrogen potential for the Upper Rhine Region.

Despite the setbacks of the questionnaire method and the low response rate from the regional industry, our observation is that a survey of the most important natural gas consuming companies of the region is important to complete the picture of the URR hydrogen demand. Strong networking with the industry and access to relevant contact information is crucial. Among the interesting observations included in the report is that in general hydrogen is a relevant topic to the industry but their knowledge about it is limited.

When it comes to the large-scale production of hydrogen, it is also important to mention that the method used for production plays a big role in how green it is. Hydrogen produced via water electrolysis (Power to Hydrogen or PtH) is promising and can be generated with little to no carbon emissions, but the feasibility of its production will depend on lowering the costs of its production through renewable energy in order to ensure that hydrogen contributes to the EU decarbonization effort in general (Hydrogen Europe, 2020).

In 2020, France alone produced about 880,000 tons of hydrogen per year, which was mainly used for desulfurization of petroleum fuels (60%), ammonia synthesis (25%) and chemistry (10%). It is not only expected that the production rate will increase to 1,345,000 tons of hydrogen until 2030, but also that the decarbonized share will increase from 5% to 52% (Observatoire de l'hydrogène Vig'hy, 2021). Combining these expectations with our estimated hydrogen demand of the industry, changing their energy source from natural gas to hydrogen, of around 218,000 tons for the Swiss and French URR alone shows how promising the hydrogen demand in the whole URR appears.

For the German side the hydrogen demand was investigated in the study of the Fraunhofer ISE 2021. The report is still unpublished, but should be available during the year 2022. Until now only a heat map is published for the hydrogen demand on the German side, this shows the hydrogen demand with high certainty today in tonnes per year.

They state a hydrogen need of more than 20 000 tons per year only on the German side. This is not yet turned into calculation for substituting natural gas by hydrogen by the research group at Fraunhofer ISE, as it was done for the Swiss side and the French side, by the research group at FeLis. These calculations still have to be carried out, but it can be assumed that this is approximately in the same range as on the French side. Another study to be published by the Umweltministerium of Baden-Württemberg estimated the yearly industry demand for green hydrogen in the state to be about 100 000 tons, based on data of the year 2020.

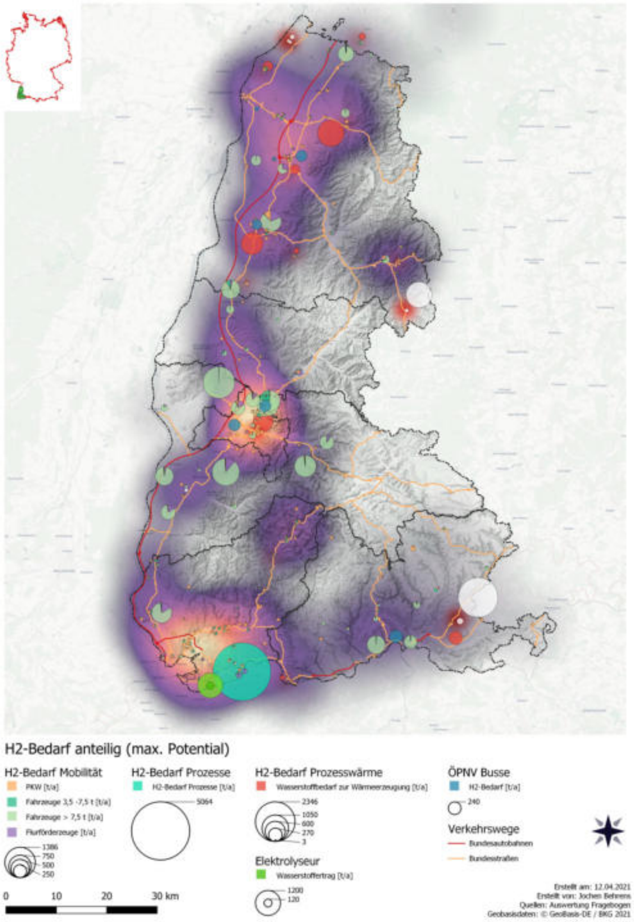


Fig. 5.4: Heat map for projected hydrogen demand on the German side as well as the list for the hydrogen use in 2021 ($H_2$-SO: Wasserstofftechnologien am Südlichen Oberrhein Potentialerhebung –Räumliche Analyse Klimapartner Oberrhein 2021).

| Cluster | Ortenau [t/a] | Breisgau [t/a] | Dreiländereck [t/a] | Waldshut [t/a] | Σ [t/a] |
|---|---|---|---|---|---|
| PKW | 204 | 188 | 79 | 107 | **578** |
| LnF | 57 | 368 | 59 | 8 | **492** |
| SnF | 810 | 6.268 | 541 | 903 | **8.522** |
| FFz | 106 | 315 | 209 | 94 | **724** |
| Busse | 237 | 407 | 0 | 240 | **884** |
| Mobilität | 1.414 | 7.546 | 888 | 1.352 | **11.200** |
| Prozesse | 0 | 0.1 | 5.000 | 0.8 | **5.001** |
| Prozesswärme | 1.320 | 604 | 0 | 2.616 | **4.540** |
| **Summe** | **2.734** | **8.150** | **5.888** | **3.969** | **20.741** |

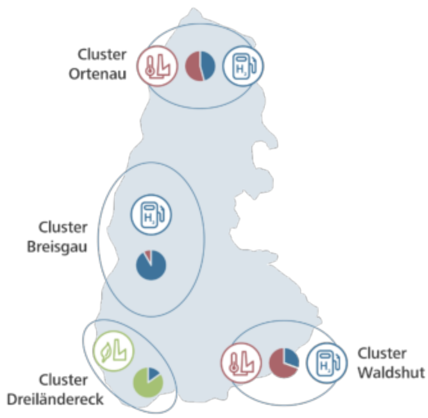


Fig. 5.5: Sectors by Cluster

## 5.4 Pilot Development Based on Potential Industry Use in the Upper Rhine

Currently most of the worldwide yearly produced 120 Mt hydrogen is used for chemical processes, ammonia and methanol synthesis and the refining of crude oil (IEA, 2019). Many industrial facilities are aligned along the river Rhine in Germany and along the French riverside, from Lauterbourg at the border with Germany, to the city of Saint-Louis at the corner of Switzerland and the federal state of Baden-Württemberg. Most of the industrial sites are concentrated around Strasbourg, Mulhouse, Colmar and Cernay. Benefitting from the presence of road and railway connection across the Rhine to Germany, the areas of Chalampé/Ottmarsheim/Neuenburg-am-Rhein and Neuf-Brisach/Breisach-am-Rhein also are characterised by intense industrial activities. Among all industries in the region, those having a current or potential demand for hydrogen like steel, glass, and chemical production are assessed in more detail in the following.

### 5.4.1 Chemical Industries

Hydrogen is an important raw material for various chemical industries: It forms the starting point for important chemical value chains that are based on ammonia or methanol and is used in large amounts for hydration and hydro-cracking processes in oil refinement. Around 12.5 billion cubic metres of hydrogen are already used in Germany every year. This makes chemical industries the largest consumers of hydrogen which is currently mainly produced from natural gas through steam reforming.

For example, BASF in Ludwigshafen produces and processes large amounts of ammonia and MiRO in Karlsruhe as one of the largest oil refineries in Germany needs significant amounts of hydrogen which is currently produced from natural gas through steam reforming. Therefore, it seems reasonable to assess the potential of hydrogen and ammonia use through chemical industries (but also regarding other potential users) in a larger regional context. In the closer region around Fessenheim, particularly Evonik Rheinfelden, BASF but also Linde France in Chalampé, which is already planning a larger electrolyzer, are promising potential users of green hydrogen or ammonia or further derivatives such as methanol. BASF has acquired a polyamide plant at the Chalampé site in France, about 10 km south of Fessenheim. With more than 10 000 t per year large quantities of hydrogen are needed. Currently this need is satisfied with hydrogen conventionally produced, generating typically 100 000 t $CO_2$ annually. These values are in the same order of magnitude as indicated in the $H_2$-SO study for the German side. The estimated costs for this “grey” hydrogen is currently in the order of 1.5 € / kg.

Evonik Industries at the Rheinfelden site produces bleaching and oxidation agents, detergent base materials, filler materials and matting agents, and silane for a very varied range of applications. Many of the initial and intermediate products from which the valuable end products are made, are produced at Rheinfelden itself. Also, hydrogen is used here, however, the specific hydrogen consumption by Evonik in Rheinfelden is not publicly available.

Finally, BASF is evaluating $CO_2$ capture in Ludwigshafen as a way to reduce emissions. Such captured $CO_2$ could be used with the region's green hydrogen for further processing (Fischer-Tropsch Synthesis, Methanol Synthesis, etc.) and then shipped across the Rhine back to Ludwigshafen or other locations.

### 5.4.2 Glass Production

With its high heat requirement - especially for the melting process - the glass industry is one of the most energy-intensive industries. Currently, more than 70 % of the energy is covered by fossil fuels such as natural gas, in addition, $CO_2$ is released due to the process of melting raw materials including carbonates. Up to 80 % of the total emissions are energy-related. With green hydrogen produced from renewable energies, the share of the resulting emissions could be reduced significantly. The use of hydrogen as a fuel in industry is, however, not yet a technical standard, which means that the effects on the very sensitive melting process in glass production, the product quality and pollutant emissions still need to be investigated. First attempts to use green hydrogen in glass production could also be the addition of hydrogen to natural gas as a fuel for the burners. Besides hydrogen, oxygen could also be directly used in glass production. Addition of oxygen in the furnaces increases the process efficiency (oxy fuel burners or oxygen heated melting furnaces) and significantly reduces further air pollutants such as NOx or particulate matter. Besides, the product quality can be increased by directly adding oxygen in the furnace process. Hence, the combination of electrolysis to produce hydrogen and oxygen and to directly use both products in glass production is a promising solution to reduce GHG emissions from glass production. Due to the exhaust heat of the melting processes, also High Temperature Solid State Electrolysers (HT Electrolysis) that require pressurized steam but have significantly higher efficiencies (around 80% based on the LHV) compared to low temperature solutions such as PEM or Alkali Electrolysers (around 65% based on the LHV) could be used in future. The Technological Readiness Level (TRL) of around 7 for HT Electrolysis is not yet at commercial level. In the Fessenheim region, EUROGLAS S.A. in Hombourg is the most important representative of glass industries and a potential user of green hydrogen and oxygen. However, the actual demand for green hydrogen at EUROGLAS SA in Hombourg (3 km south of Ottmarsheim and 8 km south of Chalampe) is about 45 t, based on an energetic scaling and a daily glass production of 580 t[2].

[2] https://www.euroglas.com/uploads/tx_lwgtbrochures/bro_gruppe-glas-troesch_en.pdf

### 5.4.3 Metals and Steel Production

Around 20% of greenhouse gas emissions in Germany can be attributed to different industries (around 200 million tons of $CO_2$ eq/a). The largest single polluter in this sector is the energy-intensive steel and iron industry. Traditional steel production from primary sources (iron ore reduction processes) rely on blast furnaces that run on coal and cause considerable amounts of $CO_2$ emissions. Direct reduction through hydrogen could significantly reduce the GHG emission level of primary steel production. Liquid pig iron is no longer produced here, but a solid sponge iron that is refined into crude steel in an electric arc furnace. The direct reduction of iron ore is by no means new territory: The technology has been used purely on the basis of natural gas for a long time - especially in countries where natural gas is sufficiently and cheaply available. In this way, less $CO_2$ is released than in the traditional blast furnace process with coal. As BSW (Badische Stahlwerke GmbH) in the Fessenheim region only runs electric arc furnaces to produce steel from secondary sources (steel scrap), there is no real potential to use hydrogen at their production site in Kehl. This would require additional production from primary materials (iron ore) through direct reduction to iron sponge materials that could then be processed together with secondary scrap in the electric arc furnaces. However, there are indications that there is a considerable demand for oxygen by BSW to improve the process efficiencies. This could be sourced as a byproduct from a nearby electrolyzer.

### 5.4.4 Heavy Duty Transport

On the other hand, transportation companies have a more homogeneous geographic distribution on the territory. However, the optimization of the costs, and particularly the Total Costs of Ownership (TCO)  is an important criterion for a successful development of those companies. With the rise of the taxes on fossil fuels and on motorway tolls, these companies are looking for alternatives to their conventional diesel-powered fleets of vehicles and some of them already experience the use of biogas for their trucks or electric batteries for their logistic centers. Recently also hydrogen driven, in particular fuel cell electric heavy duty trucks enter the market.

While the technical aspects of this new technology directly compete with the conventional one (large range of vehicles, refueling time, maintenance…), its current costs prevent transportation companies from considering it as an option in the short run. Nevertheless, the fuel cell electric vehicle may become competitive with the diesel vehicle from 2027 onwards, according to the study Fuel cell hydrogen trucks – Heavy Duty´s High Performance Green Solution (Ruf et al., 2020). Moreover, truck manufacturer Hyundai implemented in Switzerland a Pay-per-Use model  for its customers in 2020. This model gives fixed tariffs for transport companies per km,  independent from the maintenance, the driver, and the costs of hydrogen which diminishes the risks. As it was a success in Switzerland, Hyundai or another OEM might replicate this model in several European countries (France, Germany,..). It is also important to note that a significant number of Alsatian trucks drive daily to Switzerland, where the high-duty vehicle tax represents a high cost for them. Switching to a zero-emission technology is a strategic move towards the reduction of their TCO.

If those predictions are true, there will be a significant need for green hydrogen in Alsace within the next years to power the fleets of trucks of the region. Thus, it is essential to start building production and distribution infrastructures, such as electrolysers and fueling stations to provide them with green hydrogen.

A hydrogen refueling station project is currently in development in Ottmarsheim. Developed by the company $H_2V$, the station will be commissioned in two years. At the beginning, about 20 kg per day will be delivered by tankers from Dunkerque and reserved for the heavy-duty vehicles, but the ambition of $H_2V$ is to install a production facility powered by hydropower and solar capacities.

### 5.4.5 River Transport

The transport by barge along the Rhine is also a significant asset for the development of green hydrogen in the region. There are already some initiatives like the Rhine Hydrogen Integration Network of Excellence ($RH_2INE$) of the province of South Holland and the Ministry of Economy, Innovation, Digitalization and Energy of Nordrhein-Westfalen which aims to establish a hydrogen infrastructure along the river with the different actors of the market. Such an initiative could be applied between the region Grand Est and the State of Baden-Württemberg since there is also a high fluvial traffic of barges between the hubs of Strasbourg and Basel.

### 5.4.6 Agriculture

As investigated in the European project HyPErFarm[3] - Hydrogen and Photovoltaic Electrification on Farm, hydrogen may play a central role in de-fossilisation of agriculture. This is especially interesting as agricultural  units/communities might become self-supplying prosumers or even energy suppliers with a well-managed system for electricity and hydrogen, a smart grid on a small scale. This model is supported by farmers, who are typically in favour of developing their sites as self-supplied islands. However, even at a higher level, at an agricultural cooperative for instance, self-supplied schemes in particular for

[3] https://www.ise.fraunhofer.de/de/forschungsprojekte/hyperfarm.html

fuel are well established. So, hydrogen might support the continuation of the cooperatives' business model to act as trading institutions for fuel, energy respectively for agriculture in general.

The DEUTZ Company has already developed combustion engines for the use of hydrogen in agricultural machines. Actually, the required power peaks and robustness with regard to fuel impurities are achievable by combustion engines only (e.g. in deep and muddy soil, on slopes or meadows, highly loaded trailers, etc.). Further alternatives of hydrogen use refer to the conversion of diesel engines in tractors and tractor units. The conversion of existing tractors to hydrogen (combustion over an amount of 70% hydrogen, 30% diesel) can help to decarbonise agriculture in general (e.g. Keyou, 2021). In doing so, the benefits would extend to the entire fleet and upgrade it in parts (performance enhancement). The advantage is that to the understanding of the hydrogen competence group this can be realised with low financial investments in the near future.

### 5.4.7. Public Transport

Public transport is a sector where green hydrogen usage is well developed and demonstrated in several European and national projects. The prices for hydrogen driven buses have considerably dropped and the industry has scaled up production capacities. In July 2019 the European clean vehicle directive (n°2019/1161) was published. It should have been be transposed into a national law in every member state of the European Union on July the 2nd 2021 at the latest. This directive prompts the local communities to renew their bus fleets with cleaner vehicles.

Strasbourg currently has around 275 buses, among which 148 are already powered by biogas and 61 are electric buses. In 2024, the city will not have any diesel buses. Mulhouse has currently around 105 buses, among which 90 are diesel buses. The city wants to have 44 biogas-powered buses in 2024 and the biogas is produced by the muds of a water treatment plant. Colmar has currently 37 buses that use natural gas out of 41 buses. Nevertheless, the natural gas comes currently from fossil sources.

Regarding trains, the region Grand Est has ordered at least 3 hydrogen trains to serve the line Mulhouse- Thann-Kruth. The first tests should take place in 2023 or 2024. Additionally, the president of the departmental council of the Haut-Rhin Brigitte Klinkert is willing to reopen the line Colmar/Neuf- Brisach/Freiburg in 2026-2027 with a fuel cell powered train. Some studies are already in progress.

### 5.4.8 Tourism

Tourism has to also account for its $CO_2$ footprint. The Upper Rhine valley is a very attractive touristic destination, which combines local specialities, such as grape-growing and other touristic activities. The protected nature parks in the Vosgues as well as the Black Forest contribute to the touristic appeal. The geothermal sources offer huge potential for recreational baths already used by the Romans. All these touristic activities should be embedded in a sustainable environment and hydrogen technology may help with this holistic concept. Moreover, the interested tourist may have direct contact with these new clean technologies and learn how they function.

### 5.4.9 Summary of Demand

Industry demand for green hydrogen is the largest in comparison to other demand types. Green hydrogen may directly replace conventionally produced hydrogen. So, the easiest and most economical way to achieve $CO_2$ emission reduction is by a few large investments. Linde France for instance is planning a 40 MW electrolyser on the industrial site of Chalampé to provide the surrounding industries with green hydrogen. The Communauté Européenne d´Alsace recently announced that their ambition was to have a capacity ranging from 200 MW to 300 MW of electrolysis on both sites of Chalampé and Fessenheim. They are working on a "hydrogen network" starting from Neuf-Brisach to Basel.

It is suggested to first support the introduction of green hydrogen at an industrial scale, which intrinsically reduces costs for green hydrogen production. These reduced costs will ease the introduction of more distributed use cases, e.g., heavy duty transport applications on roads and water.

## 5.5 Local Green Hydrogen Production

A green hydrogen hub implies that the production and consumption of green hydrogen should be co-located to the largest economical degree. However, the natural resources of the region might be limited and some pathways for production may not be acceptable due to societal or regulatory constraints, even if they are economically attractive.

Sustainable hydrogen production is based on renewable energy. The Fessenheim region possesses the best conditions for hydro and photovoltaic (PV) electricity because of the river Rhine and its solar profile, (see chapter 4). The combination of both provides the required "additionality" and capacity factors with excess electricity from PV during daytime and from hydro-electricity during the night-time. Generally hydro-electricity is more flexible and valuable as a controllable energy source compared to the more volatile PV electricity. Since the social acceptability of wind turbines and geothermal energy in the Rhine valley are limited, this option is not considered further in this report, but with changing political and regulatory frameworks it might be considered in the next periods.

The strong agricultural background, however, suggests the use of biomass of the 2nd generation and waste of the agricultural processes as an additional and reliable backbone resource for producing green hydrogen. The biomass based hydrogen production might even offer $CO_2$ negative processes.

The potentials of hydro, biomass and PV are described in detail in the study of the Atmo-VISION and RES-TMO report 2022 (Najjar et al., 2022), of which certain parts are integrated in this report.

Fig. 5.6: Fessenheim hydroelectric power station

## 5.5.1. Electrolysis

The analysis of the non-industria non-industrial demand side of the region assuming refueling for 100 buses, 25 heavy duty trucks, 2 trains and 2 ship would require 7.5 t on a daily basis (and 2800 t per year) corresponding to a 20 MW electrolysis operated for at least 7000 h per year (80% capacity factor). The electrolysis should be located closest to the highest hydrogen demand, as electricity transport is cheaper compared to hydrogen transport. Consequently, ship refueling will be placed close to the existing harbor infrastructure in Fessenheim or other Rhine harbours nearby. Furthermore, the grid infrastructure at the former nuclear site is deemed the best suited for collecting distributed PV electricity. Therefore, it is suggested to place the electrolysis farm close to the hydropower plants of Fessenheim or Ottmarsheim.

## 5.5.2 Hydroelectricity

The costs of hydrogen produced by electrolysis are reduced with increasing electrolyser capacity, and is directly related to the price of electricity. Therefore, it is proposed to use the electricity produced by the existing hydropower plants of the region as far as possible from regulatory and contractual aspects.

The power station of Fessenheim in the picture above is historically built on the Grand Canal d'Alsace and it began producing electricity in 1956. With a nominal power of 176 MW generated by four Kaplan turbines it is the most powerful of the 10 hydroelectric plants on the Rhine. This is correlated with a fall of 15.7 metres. Its yearly production of electric energy amounts to 1020 GWh, corresponding to 5800 full load hours or a capacity factor of 66%. It was, right from the start, designed to be more automated than Kembs and Ottmarsheim, which are also potential hydropower plants for scaling up the regional production of green hydrogen.

## 5.5.3 PV electricity

Existing rooftop installations could be integrated in the central PV electricity harvesting for Fessenheim. Solar PV could also be installed in the vicinity of the power plants to provide higher stability.

One possibility would be to add a floating solar panel on the basins upstream from the hydropower plant. During the day, when there is a high demand and pressure on the grid, the floating solar system could provide the electrolyser with electricity, while at night, the hydropower plant could take over the energy supply for hydrogen production. Thus, switching between the two renewable electricity sources helps to reduce the costs of production of green hydrogen. As Fessenheim is surrounded by numerous pit lakes within a few kilometers, in Germany and in France there is a considerable potential for scaling up this solution.

Fig. 5.7: Example of floating PV (1.5 MW electric peak power) plant in Leimersheim near the Rhine

Other PV installation variants could be PV along highways, e.g. integrated in the noise barriers of the A5 on the German side, or installed on airport Sonderlandeplatz Bremgarten (EDTG) only 2 km in the east of Fessenheim.

Finally, AGRO-PV would represent a scalable solution specifically adapted to the profile of the region (see Google Earth for agricultural field dimension). This might be an advantage for farmers because their fields can be better protected against direct sun during dry and hot seasons exacerbated by climate change. Also they can protect their harvest better against heavy storms and hail and finally, they can generate additional income. The AGRO-PV design can be adapted to the needs of the agricultural economy and natural environment.

Fig. 5.8: The AGRO-PV plant in Heggelbach on Lake Constance (Fraunhofer ISE, 2016)

### 5.5.4 Biomass Based Green Hydrogen Production

In the context of renewable hydrogen production, prioritizing biomass is a promising approach, particularly when the unvalorised agricultural bio waste can be used. Several approaches exist, relying on different processes:

- Thermochemical processes – such as gasification processes, pyrolysis, or aqueous phase reforming – are the most advanced and thus most industrially relevant technologies. They often require harsh conditions (high temperature and pressure) and the presence of a catalyst; but lead to high yield in hydrogen production (Jade et al., 2020).
- Biological conversion processes – such as dark fermentation, biological water gas shift and photofermentation – require a lot less energy to occur (temperatures 30-60°, atmospheric pressure). Nevertheless, their level of development is a lot lower (TRLs typically 3-4), the production yields and implementation scale are limited to laboratory proof of concepts (Jade et al., 2020).
- Electrochemical conversions – such as electroforming applied to biomass (also known as biomass electrolysis) or microbial electrolysis cells (MEC) – rely on implementing a bio-electrochemical system where the microorganisms act as catalysts to the hydrogen production reaction. These processes are also at low TRLs, and limited in scale, but pilot-scale implementations of MEC technologies have been reported (Jade et al., 2020).

At the University of Strasbourg, the RePSeM group led by Prof. Barbara Ernst is focusing their efforts on exploring new ways to utilize biowaste through Dark Fermentation (DF), with a particular focus on wine-waste. DF relies on engineering anaerobic microbial communities to produce hydrogen. DF offers better theoretical yields compared to other biological processes, and can be implemented in batches or continuously. Moreover, the process requires very little energy input: to make it fully renewable, we could envision a solar- or wind-powered DF plant. Nevertheless, DF is still considered a relatively low energy efficiency process (with 33% theoretical yield and 21% experimental yield observed on average). Moreover, the scale faces a limit, as most processes are implemented on a 1L reactor volume. Finally, DF co-produces biogenic CO2 – that can be easily trapped in a membrane reactor  (Galkina & Vasyutina, 2018).

In the context of a multimodal $H_2$ hub and considering the scale and efficiency limits DF is facing, it is a relevant technology but with low TRL level. Nevertheless, efforts are currently being pursued to overcome the technological barriers that limit a large-scale implementation of DF.

Recently, more advanced TRL projects have begun in the Upper Rhine region. The project R-HYNOCA is led by Strasbourg energy company R-ENR, with Haffner Energy, Eifhytec, and McPhy. The project aims to install a hydrogen service station in the city of Strasbourg, to power cars. The particularity of this project is that the hydrogen is produced on-site, by compressing wood-waste resulting from forestry activities. The pilot's construction started in February 2021 with the aim of being completed (and of starting the production of hydrogen) in 2023. However, it has to be stated that energetic use of wood waste might not be the future for this valuable material for bioeconomy  (Maack, 2018).

Initial discussions with German agricultural cooperatives have generated strong interest in promoting hydrogen as a new energy carrier and developing agricultural enterprises into producers and consumers of this green energy.

## 5.6. Supply Infrastructure, Import & Export Capacities

Similar to the production, the transport, distribution and storage solutions must cope with the actual local needs. Additionally, it has to bridge the points and times of production and consumption in a suitable way.

### 5.6.1 Hydrogen Storage

Hydrogen may be stored as a pressurized gas, liquefied or in solid storage materials, typically metal hydrides. Compressed hydrogen storage, providing a hydrogen density of about 15 g/l at 20 MPa, has the highest maturity and technologies, including compressors, are available on the market. Large scale storage with compressed hydrogen may be realized in caverns (RES-TMO report, 2022) and in underground pipe systems, similar as for natural gas. Some developments for innovative compression technology are on the way, like electrochemical compression or thermal compression combined with absorbers.

Cryogenic liquid hydrogen $LH_2$ provides a density of 70 g/l at 20 K and ambient pressure, which is even higher than that of compressed hydrogen at 70 MPa (about 40 g/l). Therefore, it is the preferred way to store and distribute hydrogen at a larger scale and on longer distances. Its low system weight makes $LH_2$ the most attractive option for weight critical mobility/transport applications with a high energy demand, in particular aviation but also long-haul heavy duty trucks. $LH_2$ provides implicitly highest purity and therefore is also a good choice for relatively impurity sensitive low temperature fuel cells. Currently, there are only 3 hydrogen liquefaction plants in Europe with a typical daily liquefaction capacity of 1-5 t. All three sites (Rotterdam/Air Products, Leuna/Linde, Sassenage/Air Liquide) are far away from the Fessenheim region.

Solid storage systems are the heaviest hydrogen but the most compact storage option. They are typically operated at ambient temperature and moderate pressure. Classical metal hydrides are using Fe-Ti alloys for storing hydrogen; other materials considered are light metal alloys like boranate or allanates or Metal Organic Frameworks (MOFs). The light metal hydrides, however, need a very sophisticated thermal management system for exothermic charging and endothermal release of hydrogen. Nonetheless, the required heat transfers might be integrated in the sector coupling of the energy system.

For the initial phase compressed hydrogen storage in a buried pipe storage system similar to the one shown in Fig. 5.9 is suggested. This system allows to buffer and equilibrate the hydrogen supply via injection into the gas grid or a dedicated pipeline. Furthermore, a co-located large scale user will benefit from this buffer function allowing to run processes continuously. Additionally, this storage might even serve as a small seasonal storage device.

In the later phase a liquefaction plant (5 t/d) eventually combined with a hybrid LIQHYSMES storage is suggested. The LIQHYSMES, developed at the institute ITES of KIT, storage provides a Superconducting Magnetic Energy Storage (SMES) for fast electricity storage performance. The SMES is cooled by liquid hydrogen providing large energy storage capacities. The $LH_2$ storage implicitly provides best suited interfaces for large scale import and export of green hydrogen. Additionally, $LH_2$ will provide the best basis for supplying large fleet refueling stations for trucks, trains or even aircrafts (Basel Mulhouse) in the region. In addition geological storage capacities have been investigated under the project RES-TMO.

Fig. 5.9: Natural gas tubular storage Urdorf (Jauslin Stebler AG[4])

### 5.6.2 Injection into the Gas Grid

In coherence with the European Hydrogen Backbone initiative, led by a group of European gas operators to design a cross-border gas pipeline grid (30,000 km to 40,000 km by 2050), the Upper Rhine region between three European countries is a strategic place for the injection of green hydrogen. The conversion of the current natural gas pipeline as well as the construction of hydrogen pipes are both planned.

4 https://www.jauslinstebler.ch/VGA/VEM/projekte/erdgas-roehrenspeicher-urdorf.html

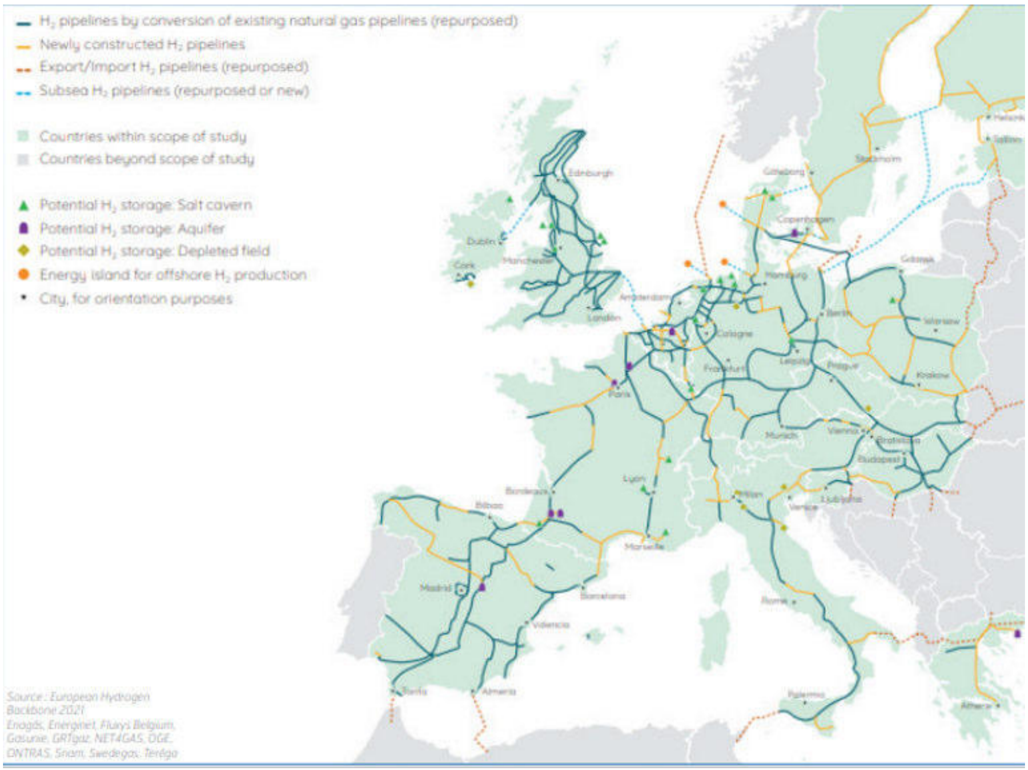


Fig. 5.10: Planned European Hydrogen Backbone[5] (Guidehouse, 2020)

In this illustration (fig. 5.10), one pipeline on each side of the Upper Rhine is foreseen for the transport of hydrogen.

A pipeline exclusively dedicated to hydrogen transport already exists and connects the site Linde in Chalampé to its customers Butachimie, EUROGLAS, etc.

### 5.6.3 High Pressure Pipeline

The extension of the existing hydrogen pipeline could be realized with a high-pressure pipeline operated at a pressure of about 100 MPa. Shorter distances between the production site, i.e. the large production electrolyser and a customer with high demand especially for high pressure hydrogen, hydrogen fueling stations for large bus or truck fleet, may be economically bridged by such a pipeline. The high pressure allows for small relatively safe cross sections and might simultaneously turn the pipeline into as an intermediate storage. A prototypical installation may be found at the Infraserv industrial park in Frankfurt Höchst.

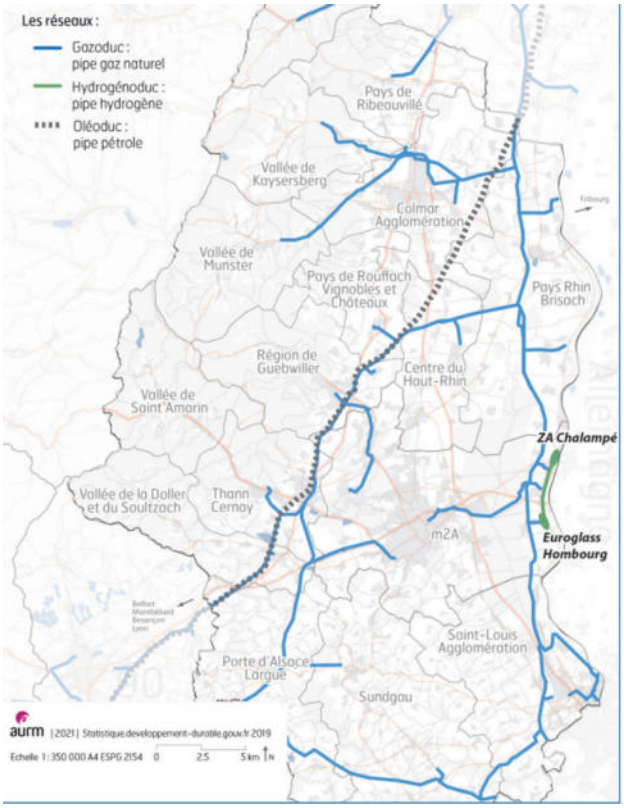


Fig. 5.11: Gas and petrol pipelines in the Mulhouse area (AURM, 2021[6]).

[5] https://gasforclimate2050.eu/ehb/
[6] https://www.aurm.org/uploads/media/6124b2f9011eb.pdf

## 5.7 Pilot Projects

The implementation of the multi-modal hydrogen hub Fessenheim comprises 4 proposals for pilot projects composed of the most important key elements presented above. In the sequence of their realization these are:

- Pilot Project $H_2$_A "Large scale industry supply with green hydrogen"
- Pilot Project $H_2$_B "Virtual pipeline"
- Pilot Project $H_2$_C "Heavy Duty Transport"
- Pilot Project $H_2$_D "Distributed production and use in agriculture"

So, the projects show an early establishment of scales necessary for the economy accompanied by an increasing involvement of the public. The figure 5.12 visualizes the interconnections between the different pilots.

Chalampé region additionally offer unique opportunities for high quality renewable electricity, which allows the use of the production path of green hydrogen via electrolysis.

Thus, the hydrogen produced with locally generated renewable electricity could find immediate lead customers with BASF, Borealis in Chalampé and EUROGLAS in Hombourg. They are all connected to the regional hydrogen pipeline. The huge industry demand, in the order of several 10 000 tons per year, correspondingly requires large scale production plants like industry-scaled electrolyser systems as shown in figure 5.13. The mass of hydrogen $mH_2$ produced in time t via electrolysis can be estimated using the following equation:

$$m_{H2} = \eta \frac{P}{H^u} t$$

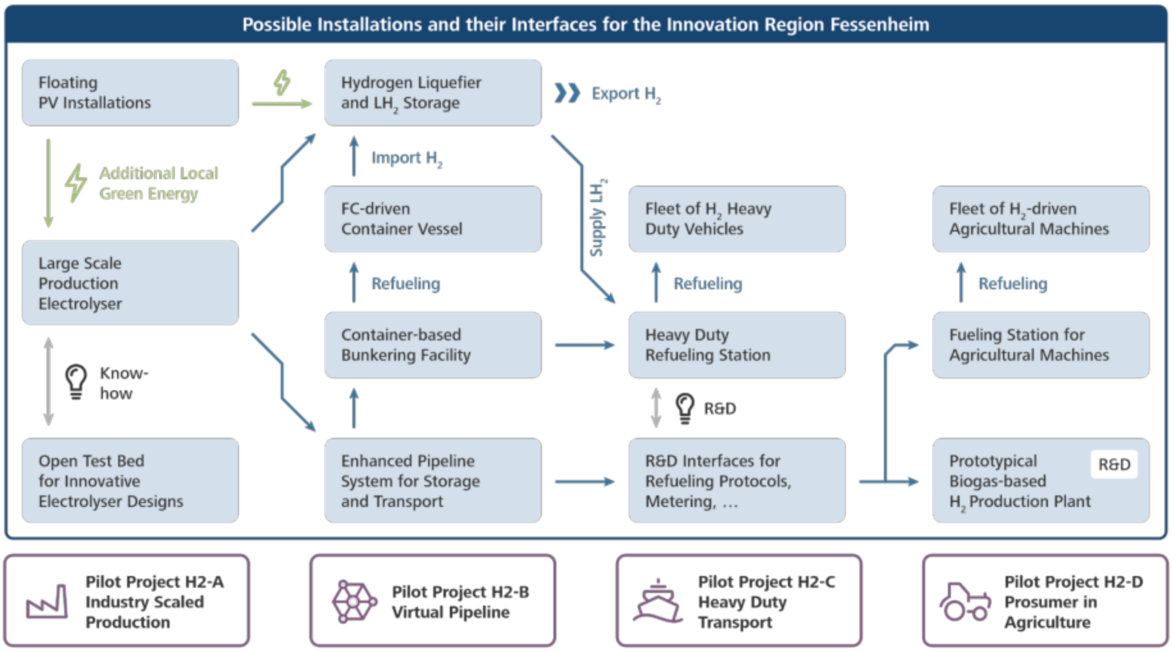


Fig. 5.12: Interrelations between the hydrogen pilots

Although they relate to each other in a complementary way, they might be realized independently as well.

### 5.7.1 Pilot Project $H_2$_A "Large scale industry supply with green hydrogen"

Replacing conventionally produced hydrogen for large industry applications represents a large existing market for green hydrogen. Strong effects in $CO_2$ reduction could be achieved on the large scale at relatively low specific costs, as also existing infrastructures for distribution and storage might be re-used. The Fessenheim and in particular

with η as efficiency, P as the electric power of the electrolyser and the upper heating value of hydrogen Hu=40 kWh/kg. With a capacity factor of 60%, i.e. about 5000 full load hours annually, an 80% efficient electrolyser with a nominal electric power input of 1 MW will produce about 100 t of hydrogen per year.

The potential demand of the mentioned companies amounts to several 10 000 tons per year. Consequently, the electrolysis plant envisioned will be in the order of several 100 MW electric with a capacity factor of about 60-70%.

The actual operator would be either a classical industry gas supplier like Linde France or a company closer to the electricity sector (EdF/Hynamics). The renewable electricity ideally would be generated in a combination of hydroelectric power, mainly for night time and cloudy days and floating PV as an additional renewable electricity source with limited capacity (typically 1000 h/a) at daytime. This is the only way to achieve the high capacity factors required for economic viability and the additionality characteristics.

The hydroelectric power stations at Kembs, Fessenheim and Ottmarsheim provide nominally 500 MW electrical power with a capacity factor of ~ 60%, very close to the required value even without additional photovoltaic installations. The access to this hydroelectricity, however, with the established supply infrastructure and long-term contracts in place would conflict with business models of EdF, the current operator of the concerned hydroelectric power stations. Another critical aspect is the regulatory framework, which may or may not acknowledge those renewable electricity sources as "green" sources eligible for public funding. Current regulation, at least on the German side, would not allow the production of "green" hydrogen with existing hydroelectric power. Additionality and co-location of the green electricity and hydrogen production are required for being eligible for public funding in European and partially in national, French and German regulation.

The investment costs for an alkaline electrolyser of this size amount to approx. 1 M€/MW excluding product gas purification, pressurization and storage. For PEM electrolysers a surcharge of approximately 20% must be calculated. The lower investment costs and the wider experience make alkaline technology the preferred choice at least in the initial phase. However, the cost of electrically produced green hydrogen is driven by the price of green electricity. Therefore it is still significantly higher (~5 €/kg) than grey hydrogen (currently ~1.5 €/kg). So, public support and deduction of grid fees are absolutely necessary to lower green hydrogen costs. A $CO_2$ emission price of 200 €/t might further help making green hydrogen competitive.

Fig. 5.13: Typical large scale electrolyser set-up (Thyssen-Krupp[7])

### 5.7.1.1 Electrolyser Set-up and electricity supply

It is suggested to start with a 30-40 MW initial installation. In a second step, this could be extended with additional electrolyser units to achieve the needed amount for industry. The Communauté Européenne d'Alsace announced recently that their ambition was to have a capacity ranging from 200 MW to 300 MW of electrolysis on both sites of Chalampé and Fessenheim. They are working on a "hydrogen network" starting from Neuf-Brisach to Basel.

The large scale electrolysis should be positioned closest to the large scale user and/or connected to the existing pipeline described above.

For the initial phase, one of the four turbines of the Ottmarsheim power stations should be reserved for electrolysis. For the later phase, additional power from the Ottmarsheim station and from Kembs and Fessenheim should be secured.

For the floating PV,  it is suggested that EdF builds a 20 MW in the basin of the Ottmarsheim hydroelectric power plant in the first half of the project. This reduces interfaces with other potential electricity suppliers. Investment costs will be less than 20 Mio Euro. In the second phase this power shall be doubled by acquiring space on the Rumerheim Ochsengrund and the Kiesgrube Neuenburg-Grießheim. However, for the latter, a dedicated electricity transfer line has to be planned.

[7] https://ucpcdn.thyssenkrupp.com/_binary/UCPthyssenkruppBAISUhdeChlorineEngineers/en/products/water-electrolysis-hydrogen-production/alkaline-water-electrolysis/link-thyssenkrupp_Hydrogen_Water_Electrolysis_and_green_chemicals.pdf

### 5.7.1.2 Additional Features, and opportunities

The Belgian group John Cockerill is building a $H_2$ Gigafactory for electrolysers in Aspach-Michelbach, about 30 km away from Ottmarsheim. So, there is a highly interesting opportunity to establish a test bed for electrolysers in combination with the large scale production electrolysis plant. The test bed for innovative electrolyser designs and grid integration strategies also interfaces with the smart grid competence group. The testing capacity might be initially co-funded by the EC by offering services via an Open Innovation Test Bed model.

The economy the electrolyser operations shall be improved by marketing the side product oxygen (typically used in medical applications, waste water treatment and steel, glass and chemical industry) and by combined use of the off-heat.

Besides, Linde France- the EdF subsidiary Hynamics has declared interest in operating the electrolysers and caring for the electricity supply.

The industry supply with green hydrogen may be complemented, diversified and strengthened by large-scale import via the river Rhine. $LH_2$ is the intrinsically cleanest option for hydrogen transport and offers many other opportunities in using the low temperature, in particular for efficient electricity transport. A liquid hydrogen $LH_2$ landing point for bunkering, loading and deloading $LH_2$ with a large scale stationary cryostat is proposed for the later phase of the project in a separate Pilot Project $H_2$_B (Fig. 5.14). The local availability of $LH_2$ is a key feature for pilot project $H_2$C.

As a contingency plan, importing green energy via green ammonia could be another option. This is supported by a pilot project of Air Products and the Miro refinery in Karlsruhe, where ammonia will be tested as a hydrogen carrier. According to an ESYS study (to be published) ammonia is the cheapest option for long distance transport of green hydrogen, which is, however, only suitable for industrial applications with access to low-cost heat and can cope with relatively low purities of the hydrogen. Fessenheim could line up with the Karlsruhe and form an "extension" of this project.

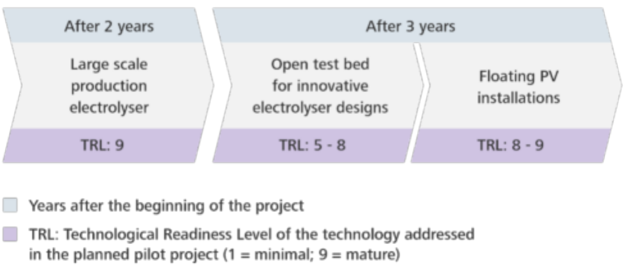


Fig. 5.14: Timeline and TRL for pilot project $H_2$_A "Industry scaled supply with green hydrogen"

## 5.7.2 Project $H_2$_B "Virtual Pipeline"

Currently, it is estimated for Baden-Württemberg that only a fraction of the locally required green hydrogen may be produced with local green resources. Similar limits are supposed for the Grand-Est region. For supplying the larger remaining part, a pipeline transport of green hydrogen from southern Europe for instance would be economically attractive, but the actual implementation will take considerable time. According to the European Hydrogen Backbone report only after the year 2040, the Upper Rhine area might be reached by a hydrogen transmission pipeline for providing the region with larger amounts of green hydrogen. Pipelines represent still huge investments and are in general not a very flexible technology.

Bridging the existing need for the import of green hydrogen to satisfy the larger demands at reasonable costs in the intermediate terms an efficient and scalable batch transport on the river Rhine is suggested. It will compensate the deficiency in supply by aligning the Fessenheim region with many other large industrial demand sites along the river Rhine (Cologne, Ludwigshafen, Karlsruhe,…) and by connecting it with Rotterdam, the central European landing site for LH2. Currently, Air Products operates one out of the three main liquefiers in Europe.

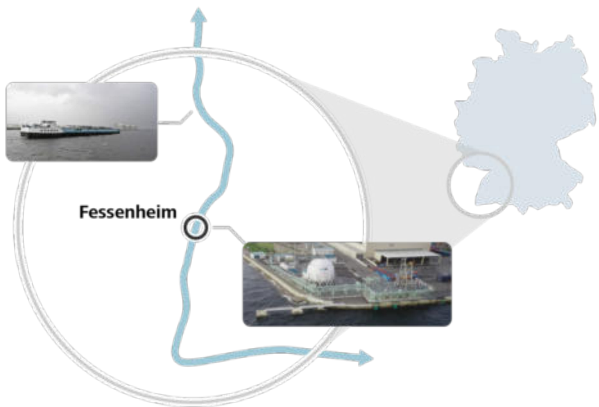


Fig. 5.15: Virtual pipeline for importing and transporting green $H_2$ in the upper Rhine region

### 5.7.2.1 Containers for multi-modal transport

The transport of hydrogen on a national, down to regional scope without the massive investment in a dedicated new hydrogen pipeline may be realized with a standardised (ISO) container solution. The container-based batch transport opens the door for multi-modal transport, which flexibly combines water, rails and street transport. The suggested solution avoids losses caused by transfer between stationary and transport containers and allows for seamless upgrading from high pressure gaseous hydrogen to more dense liquid hydrogen ($LH_2$). With $LH_2$ the capacity might be easily increased by factor 10.


| Key Technical Data | |
|---|---|
| Frame Size | 40ft Container |
| Design | UN Portable Tank |
| Design Pressure | 12 bar(g) |
| LH2 capacity | 3,000 kg (5% ullage) |
| Option | LIN-Shield |

Fig. 5.16 : Hylics UN portable $LH_2$ tank (Linde[8])

### 5.7.2.2 Actual transport of the $H_2$ containers on river Rhine

The ISO container might be directly transported on any conventional container ship. Ideally, those container vessels should be hydrogen fuelled. The strait and less capital intensive pathway suggested is the retrofitting of existing conventional container vessels as realized by Holland Shipyards Group (HSG) for Future Proof Shipping (FPS)[9] see figure 5.17.

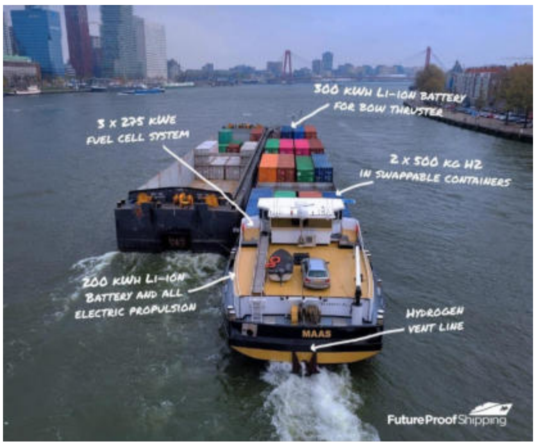


Fig. 5.17 : Hydrogen fuel cell hybrid electric container ship by Holland Shipyards Group (cf. VPO)

MTU has developed suitable drive-trains on fuel-cell technology basis. For the long-term solution the design of a reference vessel could then follow this of Portliner, presented by the Dutch Van Meegen Group in 2019.

Alternatively, $LH_2$ carriers could resemble those currently used for LNG transport. For example, BASF developed a new ship design together with a consortium consisting of the Duisburg Development Center for Ship Technology and Transport Systems e.V. (DST), Technolog Services GmbH and Agnos Consulting, who specialize in various aspects of shipbuilding. For the subsequent detailed development, BASF was able to win over the shipping company Stolt Tankers, which contributed its expertise to the project and will build the ship and operate it exclusively for BASF. On behalf of Stolt Tankers, Mercurius Shipping Group will be responsible for building the vessel. Commissioning is scheduled for the end of 2022 (Fig. 5.18 ).

Fig. 5.18: Modern LNG vessel (BASF)

The vessel provides unique shallow water capabilities and a hybrid Diesel-electric drivetrain, where the genset might be easily replaced by a fuel cell system. However, the flexibility of a container-based solution would be lost and a smooth scale dependent transition from compressed gaseous to liquid hydrogen transport would become more difficult.

### 5.7.2.3 Hydrogen Fuel Bunkering

For the hydrogen-driven container vessel, a refueling infrastructure is required. The fuel supply for this ship will be based on swappable containers. Bunkering with hydrogen should be possible at Ottmarsheim and downstreams in Karlsruhe. The distance between these bunkering sites seems to be economically reasonable. Moreover, bunkering facilities might develop further downstreams, in Ludwigshafen for instance. Finally, the whole river Rhine should have sufficient fueling points that follow the identical standards to allow for a seamless water-borne transport based on hydrogen on this central European north-south transport pathway. AirLiquide will provide a solution for such a container-based fuel supply, which was already tested in a Belgium harbor. MTU has indicated in-

[8] https://www.linde-engineering.com/en/plant-components/helium-storage-un-portable-tanks/index.html
[9] https://hydrogen-central.com/holland-shipyards-group-future-proof-shipping-maas-vessel-hydrogen-power/

terest in providing technologies for all kinds of green harbor equipment and to become a technology provider for hydrogen fuel cell driven transport vessels. For the bunkering of a larger liquid storage container, a stationary cryostat will be required. In the beginning, this storage will mainly serve as a receiver of $LH_2$ delivered. Pressurization and vaporization for filling pressure vessels or feeding the existing gas pipeline will be very economically available.

#### 5.7.2.4 Future options

Additionally, the high-quality cooling capacity with $LH_2$ could be used to make some key superconducting electrical equipment. A combination of the $LH_2$ storage with a superconducting magnetic energy storage (SMES) could open highly attractive opportunities for hybrid energy storage with a close link to the envisaged smart grid solutions. A small hydrogen liquefier with an initial capacity of 1t/d would store and initialize trading of excessive green energy /hydrogen of the region. So, the region might develop into a central trading point for the wider region of southern Germany, eastern France and northern Switzerland (see Fig. 5.19).

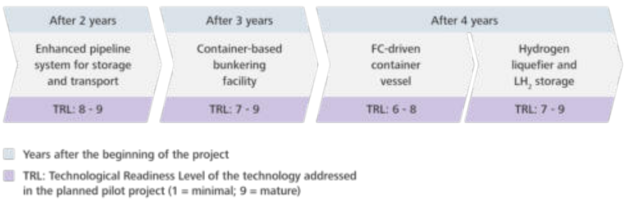


Fig. 5.19: Timeline and TRL for pilot project $H_2$_B "Virtual Pipeline"

### 5.7.3 Pilot Project $H_2$_C "Heavy Duty Transport"

The $CO_2$ reduction required by European regulation will induce the introduction of hydrogen as a fuel for heavy duty transport especially for long distance and demanding services. The infrastructural important location of the southern Fessenheim region, i.e. Ottmarsheim, connecting Northern Switzerland, Grande-Est of France with the South-West of Germany has led to many transport companies to operate branches in this area. Tax law specifics in Switzerland have already allowed an industry-led consortium to commercially operate a fleet of Hyundai fuel cell trucks. The Fessenheim region could be developed as a strategic extension of this project or independently.

#### 5.7.3.1 Supply Infrastructure

The heavy duty transport has to rely on a capable fueling infrastructure, which should be close to the large production or the transport elements described in the pilot projects $H_2$_A and $H_2$_B above. A truck with a daily mileage of 1000 km will need 100 kg/day of fuel. A station shall be able to supply fuel to a minimum number of 10 trucks and should be able to serve 40 trucks and a bus fleet of ~20 buses, amounting to 5 tons/day. As heavy duty fueling implies these capacities in the order of tons/day the advantage of a liquid based fueling infrastructure are obvious.

Transport, compression and pre-conditioning requirements are almost prohibitive for the gaseous pathway on a large scale. Fig. 5.20 compares the supply of a fueling station with 4 tons of hydrogen either with gas trailers or with a $LH_2$ trailer.

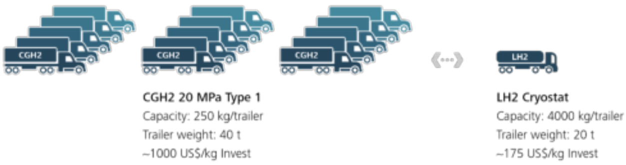


Fig. 5.20: Comparison of hydrogen batch transport variants for 4 t hydrogen; either with trailers for compressed gaseous hydrogen (left) or liquid hydrogen (right)

Moreover, a liquid-based hydrogen station offers widest flexibility for fueling compressed gaseous hydrogen, cryo-compressed hydrogen or liquid hydrogen. The latter will be practically impossible for a gas-based installation. These obvious advantages of liquid hydrogen in the scaling-up have led Daimler Truck to choose $LH_2$ as the onboard storage option for their Gen$H_2$ hydrogen fuel cell truck, which might be entering the market 2027.

Besides the commercial function the fueling station should also serve for the further development and standardisation of the associated technologies. A modular concept should allow testing of critical components (e.g. high pressure coolers, vaporisers, compressors etc.), fueling protocols and of associated measurement techniques (e.g. mass flow, dispensed mass, safety critical parameters, etc.) .

The actual placing should account for the accessibility (highway connection), connection to the large-scale chemical industry supply and for any synergies with ship and/or train transport, wherever applicable, thus commonly labeled as multi-modal.

#### 5.7.3.2 Building the fleet

There are currently a few companies preparing to enter the market with hydrogen fuel cell or ICE driven trucks (Hyundai, Daimler/Volvo, IVECO/Nicola, Toyota etc.). The only company with a larger number in the market is currently Hyundai with their XCIENT trucks.

Fig. 5.21: left: XCIENT fuel cell truck (Hyundai); right: Gen$H_2$ with $LH_2$ tanks of Daimler Trucks (Daimler Trucks)

Daimler Truck already indicated a principle interest to participate and to deliver a considerable number of their Gen$H_2$ trucks to a Fessenheim/Ottmarsheim project.

As it will be easier to negotiate the purchase and organize the operations of a larger number of trucks than to leave the development of the business case to several companies it is suggested to apply a similar concept as for the Swiss Hyundai Hydrogen Mobility (HHM) project, where a central service company manages the fueling station and the fleet of trucks and offers transport capacities to the interested logistics companies on a pay per use basis.

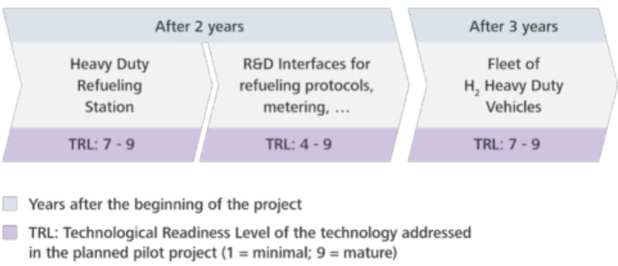


Fig. 5.22: Timeline and TRL for pilot project $H_2$_C "Heavy Duty Transport"

### 5.7.4 Pilot Project H2_D "Distributed production and use in agriculture"

The overall potential of agriculture and forestry in a hydrogen-based economy is although significant, it is often underestimated and complex.

However, with a well thought-out approach, it is possible to demonstrate both utilisation and application possibilities of hydrogen technology as well as synergy effects in demonstration projects in the Fessenheim region. For demonstrating and/or testing valuable pathways and synergetic effects, a concentration on essential core elements and processes would be desirable:

- The use and benefit of biomass for the production of hydrogen
- The use of hydrogen in agriculture
- Synergetic effects and harmony of the use of renewable energy on agricultural land
- Decentralised character in the future image of more independence

The degree of utilisation of biomass for the production of hydrogen, depends on the constitution of the biomass (type, composition, availability, etc.), and on the other hand on the process management for the extraction of hydrogen from biomass. The production of hydrogen from biogas (methane cracking) using renewable energy (e.g. photovoltaics) can be based on established techniques, but should minimise or completely avoid the $CO_2$ footprint (green hydrogen). Specific agricultural waste products from the region can be used in biogas plants. Grape marc extract from wine-growing can also be used, however it has a big disadvantage of only being seasonally available (only available i.e., during the harvest season). The production of biogas is meanwhile conventional on very different industrial levels. However, the production of hydrogen through methane cracking by means of pyrolysis or plasmalysis has only a TRL of 3-5 and thus it is not yet an industrially established technology. A research laboratory (virtual and real) can be established progressively over the forthcoming years to bring these technologies to a higher technological maturity TRL of 6-9 as an alternative to electrolysis. Direct comparisons on laboratory scale between the electrical input and output (energy content of the hydrogen produced) are promising and can significantly reduce the electrical energy demand for hydrogen production. In addition, the intensive use of agricultural residues and waste materials for the production of biogas (primarily methane) and the generation of hydrogen from methane by means of innovative process technologies (e.g. pyrolysis or plasmalysis) represents a potential to highlight Fessenheim region as carbon sink. The resulting carbon quantities derived from methane cracking are significant, but could be deposited on land and forest areas and consequently returned to the natural carbon cycle. Some studies on this specific procedure already exist; the verification must be done for demonstration.

Today's modern agriculture is based increasingly on the use of high-tech machinery and vehicle fleets. Fuel consumption is significant, and simultaneously the energy consumption of chopping and cutting machines, hoisting tools and pumps, etc. To meet the requirements, today's tractors and traction engines have high power. A potential for the use of green hydrogen in agriculture thus lies in the combustion machines, i.e. in the vehicle fleet.

The required robustness and limited cooling capacities for those machines promote the application of hydrogen internal combustion engines, like the TCG 7.8 $H_2$ motor recently introduced by DEUTZ Company10 (see Fig. 5.23)

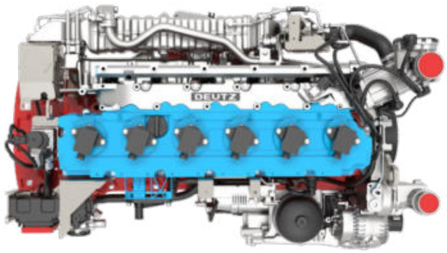


Fig. 5.23: TCG 7.8 $H_2$ is the first hydrogen engine from DEUTZ ready for the market

Further alternatives of hydrogen use refers to the conversion of diesel engines in tractors and tractor units. The conversion of existing tractors to hydrogen (combustion over an amount of 70% hydrogen, 30% diesel) can help to decarbonise agriculture in general[11].

In doing so, the benefits would extend to the entire fleet and upgrade it in parts (performance enhancement). The advantage is that this can be realised with low financial investments in the near future, keeping synergetic effects to be found, for example, in new innovative solar panels and systems (e.g. agrarsolar). Those solar panels work on one side to generate electricity from solar radiation and on the other side could protect high-value crops from indirect consequences of climate change (drought, hailstorms, excessive solar radiation, etc.) (see Fig 5.24).

Fig. 5.24: Potatoes grown under solar panels prototype (Krinner Carport GmbH )[12]

In addition, semi-transparent solar panels are already available on the market but are also under further development (Solarenergie.de 2022)[12].

The dual use of agricultural land involves economic benefit, both, for the farmers themselves and for the local communities and municipalities. In a specific European project called "HyPErFarm, Hydrogen and Photovoltaic Electrification on Farm[14]", synergies between using photovoltaic on agricultural lands, options and potentials are investigated and impacts are tested in greater detail.

- Agricultural and forestry land for the use of renewable energy (exploiting synergies)
- Agricultural and forestry products for the production of biogas (from agricultural residues and waste materials, biogenic waste materials from cities)
- Production of hydrogen by means of decentralised plants (methane-cracking by pyrolysis or plasmalysis)

The direct interaction between farmers and municipalities along with its synergies shall demonstrate a win-win situation at different levels and can lead to more acceptance. Basically, it could also be a kind of tourist attraction to launch a demonstration project (e.g. as a hydrogen farm) that demonstrates synergy effects between agriculture and a high technology (photovoltaics and hydrogen technology) and puts its benefits and possibilities in the foreground (showcase). Agriculture can profit from the otherwise lacking acceptance and understanding of the "hydrogen technology", and promotion of renewable energies can benefit the population at large.

It is suggested to install two demonstration plants for this pilot project. The first shall be based on a prototypical

[10] https://www.krinner-solar.com/apv
[11] https://solarenergie.de/solarmodule/arten/gebaeudeintegrierte-photovoltaik/transparente-solarmodule
[12] https://www.ise.fraunhofer.de/de/forschungsprojekte/hyperfarm.html
https://www.deutz.com/media/pressemitteilungen/der-wasserstoffmotor-von-deutz-ist-reif-fuer-den-markt
https://oekl.at/wp-content/uploads/gems/KLRW2012Kraftstoffverbrauch.pdf
https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/struktur-der-flaechennutzung#die-wichtigsten-flachennutzungen

steam reforming process with a relatively high TRL 6-8 (see Fig. 5.25). This installation would follow a past pilot project in the Kaiserstuhl area with a winery. The second installation shall be established using the dark fermentation process.

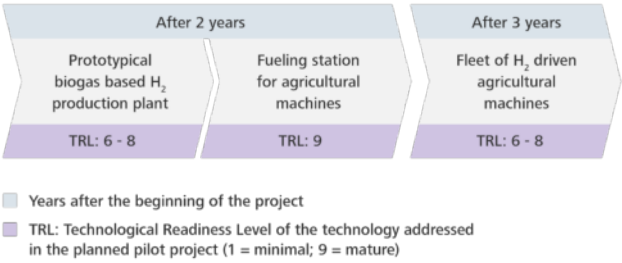


Fig. 5.25: timeline and TRL for the pilots

### 5.7.5 Green hydrogen hub interfacing with the other activities

In a special workshop, the interface of the 4 competence groups and their pilot project elements have been discussed and analysed.

#### 5.7.5.1 Interfacing with the Twin Quarter project

Electrolysis extends the sector coupling in the power to gas (hydrogen) direction. It allows for storing the otherwise lost excess electricity on a large, seasonal scale. They offer broader exploitation of investments in renewable electricity production from volatile sun and wind via larger capacity factors. Besides, electrolysers may be operated as a controllable load for grid stabilising. However, coupling requires smart solutions and appropriate management of production, storage and consumption in particular if competing uses of the electricity and green hydrogen are possible. Besides using distributed rooftop PV for electrolysis, also the use of the electrolysers off-heat has to be integrated for optimising the economies of the twin quarter energy supply. Hydrogen may be re-electrified in fuel cells, motors or turbines or directly used to de-fossilise the heat supply of residential areas. Co-generation is an important element in the demand response mechanisms, which shall optimise the efficiencies and reliability in the energy supply of the twin quarter implementation.

#### 5.7.5.2 Interfacing with the EV Battery Recycling

The complex electricity system actually requires different kinds of storage qualities. This evidently motivates the integration of different chemical energy storages realised with batteries and hydrogen. Second life batteries for fast reactions, high power, but low capacity might be combined with hydrogen-based electricity storage, providing rather large amounts of stored energy for bridging longer phases without renewable input, up to seasonal storage.

Another important link to batteries will be the investigation of their capability to optimise the electricity supply of electrolysers.

Finally, it is intended to complement the battery material and recycling pilot project with similar topics for fuel cells and electrolysers. In many aspects those technologies show commonalities which could be exploited easily.

## 5.8 Summary and Recommendations

In this chapter the main findings are summarized and the recommendations derived from the findings are described.

### 5.8.1. Summary

The Multi-Modal Hydrogen Hub Fessenheim is exploring the application possibilities for green hydrogen as an energy carrier in the Fessenheim Innovative Region. It takes part in the feasibility study and has the goal to develop a forward-looking $CO_2$-neutral economic region which is characterized by its sustainability. The current results of the research show that the use of green hydrogen actually promotes societal transformation and economical changes leading towards a renewable energy supply and a sustainable use of resources. Additionally, new future-oriented jobs will arise.

The hydrogen hub is using a holistic approach which includes all parts of the value chain, beginning with the production of hydrogen, followed by storage, transportation and at last the actual use of the green hydrogen. The Multi-Modal Hydrogen Hub is based on four pilot projects, namely:

- Pilot Project $H_2$_A "Large scale industry supply with green hydrogen"
- Pilot Project $H_2$_B "Virtual Pipeline"
- Pilot Project $H_2$_C "Heavy Duty Transport"
- Pilot Project $H_2$_D "Distributed production and use in agriculture"

The pilot projects are complementary to each other, yet they use different approaches and have different topics to research on.

The success of the broad implementation of green hydrogen technologies is based on two cornerstones: On the one hand, the viability of a business case for the first private up-takers is of utter importance. On the other hand, visibility, public support and public acceptance in the Fessenheim area are crucial. If all these requirements are met, the implementation of a desired sustainable $CO_2$-neutral economic region will be made possible.

### 5.8.2 Recommendations

Heavy-duty transport, which is subject to Pilot Project $H_2$_C, could also benefit from this reduced price for green hydrogen. The use of capable fueling stations, which might be modular with research/testing capabilities for fueling protocols etc. is hereby recommended. Also, the identification of users, for example freight forwarding, shipping companies in the Ottmarsheim region and potential suppliers are to be taken into consideration.

Sustainable hydrogen production is achieved either through renewable electricity or biomass. The use of electrolysis is hereby addressed in the research. The recommendation is to place an electrolysis farm near the hydropower plant in Fessenheim and to use floating PV in order to be able to create green energy in the Fessenheim area. To power an electrolyser of around 40 MW initially, it is proposed to use the electricity which is produced by the hydropower plant of Fessenheim to the greatest extent possible.

Furthermore, already available rooftop PV installations, which are located in Colmar, Mulhouse and Freiburg could be incorporated into a central PV electricity harvesting in Fessenheim. Additionally, PV could be placed along highways or on the Sonderlandeplatz Bremgarten (EDTG) which is located just 2 km from Fessenheim.

The pilot project $H_2$_A also highlights the benefits from combining of hydroelectric power in operation in the area with floating PV: The hydroelectric power plants can be used at night and during days that lack sunlight. PV can serve as an additional renewable electricity source with limited capacity (typically 1000 h/a) at daytime. This is the only working approach to ensure both additionality and the high-capacity factors which are needed to accomodate the economic aspects.

The transport of hydrogen also plays an important role in the research, as it will be necessary in importing and exporting processes. But the construction of pipelines come at big expenses, and they have the disadvantage of not being very flexible. This is where the concept of a virtual pipeline comes into place. The Pilot Project $H_2$_B "Virtual Pipeline" suggests container-based batch transport via pipeline, roads and through the river Rhine. Using the container solution, losses due to transfer between stationary and transport containers can be prevented and seamless upgrading from high pressure gaseous hydrogen to more dense liquid hydrogen ($LH_2$) is made possible. Also, this keeps the costs moderate.

Besides that, using this approach, the Fessenheim region can be coordinated with different industrial demand sites

located along the river Rhine and it can be directly attached to Rotterdam, which is the central European landing site for $LH_2$. This way, the deficiency in supply for $LH_2$ can be compensated. It is also suggested to enlarge the existing hydrogen pipeline by using a high-pressure pipeline which is operated at a pressure of about 100 MPa. The application of high pressure makes small cross sections possible and might be useful for intermediate storage simultaneously. This could be a pilot for a short distance connection between an electrolyser and the industrial area.

The results of the study show that the industry demand for green hydrogen is higher than in other sectors. Conventionally produced hydrogen can be replaced by green hydrogen. The outcome of Pilot Project $H_2$_A "Large scale industry supply with green hydrogen" suggests introducing the use of green hydrogen at a large scale with the industry. This can reduce the production costs of green hydrogen considerably, which in turn, opens the possibility for the introduction of the use of green hydrogen in other fields.

Also, the implementation of AGRO-PV for local green hydrogen production is being discussed within the Pilot Project $H_2$_D "Distributed production and use in agriculture". The use of AGRO-PV on their farmland includes direct advantages for the farmers: Besides the extra income generated for the farmers, AGRO-PV provides protection for the plants against direct sun exposure and also during storms and hail.

The use and benefit of biomass for the production of hydrogen (e.g., methane cracking) is also subject to the Pilot Project $H_2$_D. In the context of renewable hydrogen production, valorising biomass is a promising approach, in particular when non-valorised agricultural bio waste can be used. Various approaches on the use of biomass are available, namely thermochemical processes, biological conversion processes and electrochemical conversions. Also, the use of hydrogen in agriculture (e.g., combustion engine and fuel cells, $H_2$ and $CH_4$) is promoted.

## 5.9 Interested Industry partners

AIR LIQUIDE

AIR PRODUCTS

LINDE France

MESSER

BADENOVA

BOSTIK

VYNOVA PPC

CONSTELLIUM

BOREALIS

GRIESHABER

SCHENKER

JCL Logistics

RHENUS

ADEKA POLYMER

ALSACHIMIE

BASF

BUTACHIMIE

DSM

DU PONT

EUROGLAS

SCA Tissue

STOCKMEIER

WELEDA

WESTRAN

ABOWind

HYNAMICS / EDF

CRYOSTAR

Siemens

DAIMLER TRUCKS

HYUNDAI

A RAYMOND

BOYSEN

BOYSEN

CLARIANT

DANGEL

DIEHL METERING

EFFBE

EIFFAGE E: - CLEM.

FENWICK-LINDE

NEL

THYSSEN-KRUPP

CUMMINS

ITM POWER

MC PHY

JOHN COCKERILL

LIEBHERR

MTU

MAHLE Behr

MHI Mitsubishi

OELTECHNIK

PLASTIC OMNIUM

PSA

SIELEST

## 5.10 Contacts

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# 6. Smart Grids

The transfer towards renewable energies requests new conditions for the electricity network to cope with volatile energy production. In this context, not only the trimming of the existing electricity network is important, but also the intelligent distribution of the produced energy. It is important, especially in the medium and low voltage electricity net to the users for reducing losses linked to energy conversion and to achieve a relatively stable electricity flow. The competence group smart grids was engaged in the development of ideas for pilots testing new intelligent solutions for electricity networks.

## 6.1 Background

Smart grids are intelligent electrical networks that are being developed throughout the world to constitute the future of electrical networks. They are equipped with highly innovative technologies and they optimize the production and consumption of electricity. The objective is to guarantee a secure, sustainable, and competitive supply to consumers. Smart grids integrate new information and communication technologies such as connected objects. Smart Grids are therefore capable of transmitting real-time information on electricity use and consumption to network operators (producers, distributors and consumers) (Butt et al., 2020). The objective of smart grids is simple: they use the collected information to adjust the flow of electricity and guarantee better energy efficiency in the network. The operating principle is based on all the technologies that collect, analyze and transmit information in real time on the electrical circuit. These technologies allow electrical networks to communicate with each other to ensure a balance between supply and demand, to avoid overloading the network and to ensure a more secure supply.

Smart grids identify several characteristics in terms of reliability, and thus offer a continuous supply of energy when needed, along with the ability of collecting and measuring gathered data in order to maintain the full time service.

Another aspect of smart grids is cyber security and privacy protection, which define an important challenge for smart grids deployment with the consideration of multiple systems involved, making it crucial for a robust and standardized security mechanism to be involved.

One of the most interesting characteristics known for smart grids is the ability of self-healing and fast response whenever a problem occurs. This is due to real time communication and other intelligent components that play an effective role in collecting and sensing abnormal behavior in case of such malfunctions by isolating infected areas, rerouting energy flaws etc. This guarantees a full time non-stop energy supply.

Overall, there are three advantages of smart grids:

- **Firstly**, to guarantee the balance between supply and demand:

  Electricity is difficult to store and when we need electricity, the energy producers must immediately inject the quantity of energy equal to our need on the network, otherwise the network overheats. So, preserving the balance is essential for the proper functioning of the grid.

- **Secondly**, to meet the ever-increasing need for electricity:

  The need for electricity is only increasing with the use of new appliances such as heating, air conditioning, cell phones and computers, electric cars, etc. By providing real time information on the energy flow, smart grids allow network actors to check, control, analyze and optimize energy consumption.

- **And lastly** to participate in the energy transition:

  The transformation towards renewable energies, such as wind and photovoltaic, are subject to the vagaries of the weather and their production remains intermittent. At the time of peak consumption, these energies are not always sufficient to meet the immediate needs of consumers. Also, we consider green hydrogen technologies and green batteries which are completely dependent on smart grids for a real time analysis of consumption. The grids allow an excellent knowledge of the state of the network and of the consumption demand in real time. It can be adjusted at any time by integrating other energies such as renewables into the smart grid without altering its efficiency. They allow real-time optimisation of energy use, reduced wastage of energy, electricity and money as well as controlling our electricity consumption. The tool is fully adapted for renewable energy technologies and implicitly it helps to reduce carbon emissions.

## 6.2 Scope of the smart grids competence group

Smart grids are used for different challenges in the region: energy mix, prosumer, measures, and quality. Scope of the smart grid group is to map the existing transmission system in the transnational region linked to the information on the potentials for renewable energy and the development of scenarios including renewable energy and energy storage in the region or the potential of demand-side management. This first needs the identification of possible weak points on energy usage by updating the electricity network connection concept between France and Germany and to display the expansion of the transmission grids. This then allows the comparison of available technical alternatives for grid expansion for more renewables in the grid, to increase and optimize the transmission capacity of existing overhead line routes and to analyze the requirements for renewable energy generation plants about system security.

## 6.3 Potential applications of the smart grids in the region Fessenheim

The challenges behind the cross-border concept for the innovation of the territory of Fessenheim is to integrate the fluctuating electricity generation from renewables in the transnational region and one of the goals is to design and operate the electricity transmission grids, to adjust to other electricity generation plants and demands on the flexibilization of the overall system.

For the smart flexibilisation of the electricity network, the group identified scientific and technical challenges such as: diversity of energy uses, the optimization of systemic energy use in adaptation to the evolution of flexibility needs, the security and usage of the electrical network, the e-mobility and the usage of storage. The group also identifies the economic and societal aspects like the economic model, the social acceptability and the legal and security dimension in a SWOT analysis for the suggested pilots. Among these actions, the Smart Grids group organized a working seminar to define interesting topics with industrial and local authorities.

Based on the input from science, industries and communities, the following objectives were identified:

- To analyse the existing cross-border electricity network and the connector situation between the French-German border in the Upper Rhine
- To develop a cross-border meta-demonstrator in the EcoRhena Innovation parc
- To implement a systemic pilot for different types of city quarters: urban, family-houses or remote village

In the following section we briefly discuss the first objective of analysing the existing cross-border electricity network and the connector situation between the French-German border in the Upper Rhine.

Both Germany and France have dominant electricity production companies in the market, starting with the four companies in the german side: RWE, E.ON, EnBW and Vattenfall also known as "The Big Four" with roughly 82% of electricity production depending mostly on 66% of renewables, and the rest is produced from nuclear, coal and other sources. Other companies share the remaining percentage among them such as *Yello Strom, Ostrom, Eprimo, Lekker Energie* etc.

On the French side, the reigning company EDF produces 91% of the electricity alone, leaving the remaining percentage for other companies, naming few: Engie, Total Energies etc. Most of the electricity production comes from around 60% of nuclear and the rest from renewables and other sources. Although power from nuclear energy is still very dominant, there is a reasonably growing percentage of renewables which indicates an already present "Green thinking" in the region for more sustainable energy in promising a responsible and better future.

All the electricity produced in both countries needs to be distributed both on the national and international level and in doing so, other specialized operators are involved. In France, the EDF's subsidiaries RTE for high voltage and ENEDIS for the end consumer, are responsible for the majority of transmissions. As for Germany, we mention four Transmission System Operators: *TransnetBW, 50 HERTZ Elia Group, TENNET* and *AMPRION*.

The mentioned TSOs among with RTE and 34 other operators from 35 countries are members of the ENTSO-E (European Network of Transmission System Operators for Electricity) former UCTE (Union for Coordination of Transmission of Electricity), which made a grid design agreement in order to transmit electrical energy across borders under a state of a unified protocol, via high voltage lines up to 440 kV and the famous grid frequency of 50 Hz for a secure and stable electricity import/export.

According to the ENTSO-E Grid Map, three substations are shared between the French-German border in and around the region of Fessenheim, Eichstetten substation in the German side and two substations on the French side: Vogelgrun substation and Muhlbach substation.

The Eichstetten substation links the other two French substations directly via two cross-border lines with a 220 kV transmission line with Vogelgrun substation, and a 380 to 400 kV transmission line with the Muhlbach substation as shown in figure 6.1.

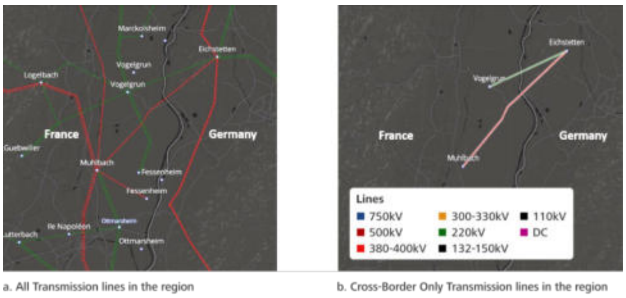


Fig 6.1: Cross-Border Transmission lines in and around the region of Fessenheim (ENTSO-E Transmission System Map).

The change of meter to a smart meter, which transmits gas, electricity and water consumption, follows a European request of 2009 that provides for the deployment of communicating meters in 100% of European homes in 2022. And this implies the replacement of traditional electricity meters by Linky meters in all households connected to its network by 2021.

According to Enedis, the subsidiary of EDF in charge of the management and development of 95% of the electricity distribution network in France, the Linky meter promotes the development of renewable energies, electric vehicles, self-consumption and allows it to act on energy management. It seems to be essential for the energy transition, with an estimated 20 gigawatts of photovoltaic power, 24 gigawatts of wind power, 1.2 million electric vehicles in homes and 100,000 self-consumption customers.

Despite strong local resistance to Linky, France is among the countries well placed to achieve the European objective. The Linky meter has provoked a real revolt from users, for various reasons: the intrusion into private life, the use of data, and fears about wave emissions from these devices. However, some 11 million Linky meters have already been installed. The French territory, i.e about 35 million households should be covered by 2021.

Faced with the similar situation, Germany has opted for limited deployment. The law on the "digitalisation of the energy transition", passed in 2016, only concerns the largest customers. So, Germany decided to make the smart meter mandatory only for households consuming more than 6000 kWh per year with an annual consumption estimated at 3500 kWh in 2021. In France, the consumption is estimated around 4200 kWh in 2021, which is 700 kWh more than Germany.

According to the articles of law, the occupants of the dwelling (tenant or owner) do not have the legal right to refuse the Linky meter, as they are not the owners of the electricity meter. In that case, the Linky meter is mandatory. Its obligation is moreover transcribed in several texts, in Law No. 2015-992 of 17 August 2015 for the energy transition and green growth (Article 29), in European Directive 2009/72/EC of 13 July 2009 concerning common rules for the internal market in electricity, and in Article L322-8 of the Energy Code.

When we look at the interactive map for Linky of Enedis for the year 2021 (Fig 6.2), we can see, that 53,109 Linky meters are already installed in Mulhouse. But when we look at the territory of Fessenheim, we see that the town is managed by a local distribution company which provides electricity and gas around Colmar.

In most of France, the distribution of electricity is done by the national network manager Enedis (present in 95% of the territory), but not in Colmar (in the Haut-Rhin) where it is the an ELD (Entreprise Locale de Distribution), which is responsible for the electricity distribution network. This is because Colmar has a special status in the French energy market and as a result, the historical supplier EDF is not present in Colmar. Most alternative electricity and gas suppliers do not offer their services in this town either. If they want to subscribe to an electricity offer, Colmar residents must contact Vialis, the local distribution company (ELD). It is the only electricity supplier in the region to offer the current regulated rates.

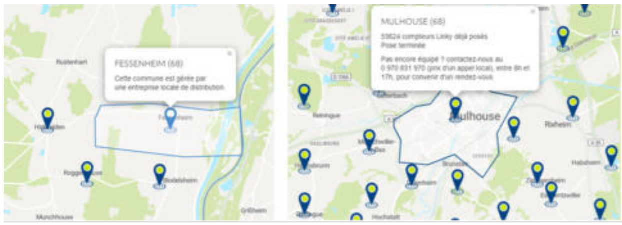


Fig 6.2: Map of Linky installations on the perimeter of Fessenheim and Mulhouse in 2021

- In the following section we briefly discuss the second objective of developing a cross-border meta-demonstrator in the EcoRhéna Innovation parc.

The business park EcoRhéna located in the region of Fessenheim represents a strategic spot for a variety of investments with an already settled all purpose platform. It attracted many companies like Constellium, EDF, Fiberweb, FMC, Knauf, Wrigley, but also many SMEs (Small and Medium Enterprises) like Adecco, Egia, Panthera sécurité, Green Concept etc.

Previously, a company called Européenne de Biomasse initiated feasibility studies at EcoRhéna in order to expand its subsidiary the HPCI (a 100% renewable energy biofuel using wood industry residues) for energy transition in the area.

With such a huge industrial park, energy supply is needed continuously and therefore smart grid installation is mandatory for an efficient, reliable and well managed energy fueling.

- The third objective of implementing a systemic pilot for different types of city quarters: urban, family-houses or remote village is discussed in section 6.5 of pilot project development.

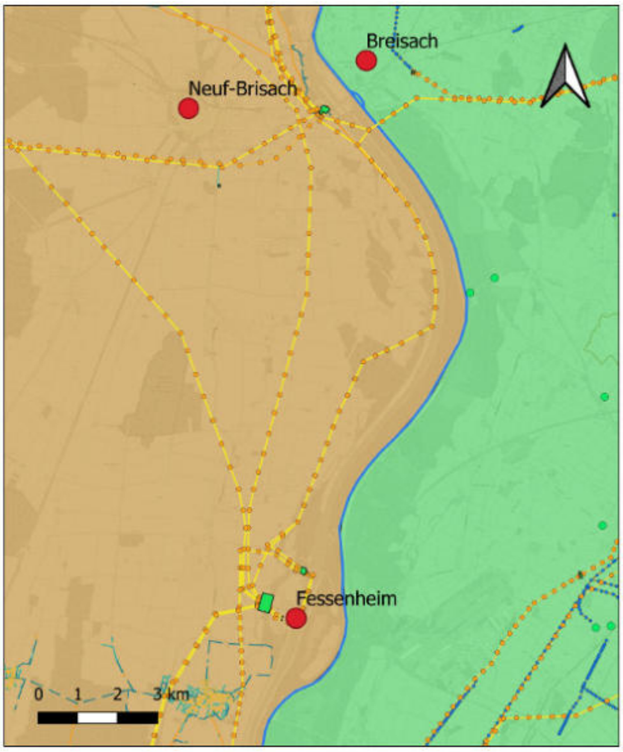


Fig. 6.3: Section of the electricity network in the Upper Rhine region and important transnational connectors

## 6.4 Assets and challenges for the implementation of smart grid in the region

The following paragraphs will identify the assets and the needs:

### 6.4.1 Potentials and demands

For the envisioned installations, companies, communities and funding agencies especially under the EU green deal program need to work together for a pilot role model.

**Systemic overall concept for the regional transformation towards $CO_2$ neutrality and circular economy:**

- Increasing the use of renewable energies such as photovoltaic panels, towards a free carbon-neutral Upper Rhine area
- Showcase of systemic energy flexibility and energy efficiency usage for city quarters and industrial sites to represent the future energy system in a real-world lab
- Revitalization of existing industrial sites and transformation of existing urban city quarters
- Energy management (ISO 50001)
- Modeling grids structures of various types of city quarters and industrial sites in France and Germany
- Constitution of a usage and production database for scenario learning using AI tools

**Status**

In the Smart Grids group, we contacted a lot of companies and local authorities that were interested in energy management and energy sector, where mostly their R&D support wanted to participate in a more effective way to consume energy on-time. The smart grids group wants to propose the development of projects and pilots at a regional scale with the knowledge and scientific expertise of the territory. It is thus then important for the smart grids group to identify the key players, to create contacts and to establish a consortium.

**Potentials**

In the Upper Rhine area, we find all the industrial players from energy production to consumers (energy management, chemicals, automotive, etc.) and all the engineering services necessary for the development of pilot projects.

In addition to having all the technical and scientific skills needed to carry out pilot projects, many local authorities and companies are committed to strategies for modifying industrial sites or neighborhoods in order to reduce their carbon impact, or even to achieve ISO 50 001 certification. All these initiatives are fields of action in which the partners of the feasibility project can intervene in cooperation with companies and local authorities.

**Challenges**

As previously mentioned there is immense interest among the industry players in smart grid technology. However, the lack of conviction of companies to invest in installations in the Fessenheim region poses the biggest challenge so far. For a successful transformation of the region, there is an ardent need for companies that are willing to participate in the building and operation of some of the envisioned installations.

The smart grids group thus proposes research and inno-vation that brings industrial players and researchers together to create a bond of trust for a consortium and to create sustainable jobs.

## 6.5 Pilot development based on potential industry settled in the Upper Rhine

Today, smart grids can support existing industries and companies in the Upper Rhine, so we will explain which sectors or situations we are targeting.

## 6.5.1 Smart Twin quarters

The Smart East Karlsruhe project, performs projects in a mixed commercial and residential area. Existing buildings in the east of Karlsruhe are being transformed into an energy-optimized smart district. The project aims to evaluate and economically assess a renewable and climate-neutral energy supply as well as is testing new business models compatible under these circumstances. The digitalisation of the energy supply, sector-coupled networking, and an integrated optimisation and operating model are being implemented in this project and transferred into practice (Seven2one Informationssysteme GmbH, 2022).

Within this three-year Smart East lighthouse project, a collaboration of research institutes, IT and energy companies aims to realize a smart neighborhood in Karlsruhe East. The existing buildings will be digitized with smart meters and networked in a neighborhood energy management system. The electricity, heating, cooling and transport sectors will be linked and new business models for energy cooperation will be tested. Through this approach, a climate-friendly energy supply for an existing urban quarter with commercial and residential areas is being created as a real laboratory (Seven2one Informationssysteme GmbH, 2022).

Another important core target is a transformation to a smart neighborhood which is economically worthwhile. The project partners are therefore developing new business models that pay off for the various actors. On the basis of practical experience, the project participants are developing recommendations for action that can also be transferred to other neighborhoods.

The goal of the project is to demonstrate how a smart neighborhood can be built and how new business models and marketing opportunities can be realized. In order to ensure the link between the practice and the subsequent transfer of the results, potential users (for example municipalities, the housing industry, real estate developers, commercial park operators or public property operators) are expected to accompany the project (Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg, 2022).

The overall mission is that the Smart East commercial quarter in the Oststadt district of Karlsruhe will become a smart, energy-optimized, climate-friendly quarter (Seven2one Informationssysteme GmbH, 2022).

The Smart East Karlsruhe project is a collaboration of FZI (Forschungszentrum Informatik), Seven2one Informationssysteme GmbH, Karlsruher Institute of Technology (KIT), Institute for Automation and Applied Computer Science and Stadtwerke Karlsruhe GmbH (Seven2one Informationssysteme GmbH, 2022).

Connecting Fessenheim with this quarter in Karlsruhe as well as other innovative quarters like the Fonderie in Mulhouse gives the opportunity to compare different Smart Grids and to gain information about the challenges and opportunities of tomorrow's electricity network.

## 6.5.2 Charging stations (tourism and public transport)

At the end of 2021, the Mulhouse m2A municipality launched a call for private initiative projects, with the aim of increasing the number of recharging stations in strategic sectors of the Mulhouse agglomeration. The aim is to make the electric vehicle users be able to recharge their vehicles in the public domain. The relevant questions raised are the choice of the type of charge (slow, fast), their placement, their connection to the electrical network and the economic model for the use of these charging stations. Solutions do exist, for example a deployment of this type has taken place in Lyon by an EDF subsidiary (IZIVIA), but a lot of work on optimizing the scheduling and economic modeling remains to be done. Such experiments also exist in Germany. The German state of Baden-Württemberg is continuing to support pilot projects for the intelligent connection of underground parking lots to the grid. More than seven million euros are available for the installation of charging stations for the electric vehicles in covered parking lots, parking garages and underground garages. This is done as part of the INPUT 2.0 promotion competition.

In essence, offering the electric mobility solutions between Germany and France by providing charging stations on both sides of the border, would be a beneficial step towards energy transition.

## 6.5.3. Energy grid consumption comparison mapping between France and Germany to integrate into european grid development

The goal of the smart grid competence group is to map the existing regional transnational transmission system and collect information on the potential of renewable energy and its link to scenario development for the regional energy grids. Additionally, the goal is to study the potential of demand-side management, Hence, it is imperative to identify possible weak points in terms of energy availability. Ideas for updating the electricity network connection concept between France and Germany and for displaying the expansion possibilities of the transmission grids is another focus of this group. Implementing such concepts allows the comparison of the technical alterna-tives available for grid and connector enhancements and supports the expansion towards more renewables. The development of discrete concepts also develops better ideas for optimising the transmission capacity of existing overhead line routes and analysis of the requirements for system security in renewable energy generation plants. One of the main challenges in the cross-border concept is to integrate the fluctuating electricity generation from renewables in the transnational electricity network. Thus, the goal is to design and operate an electricity transmission grid which is both flexible and adapted to different electricity generation plants. For the cross-border innovation concept, the goal is to design and operate the electricity transmission grid in the Fessenheim territory and adjust to the diverse electricity generation plants as well as the demands for more flexibility in the overall system.

The competence group's analysis highlights the technical challenges like diverse energy use, security and usage of the electrical network, and the grid integration of e-mobility and further storage capacity. There are also socio-economic challenges such as suitable economic models, social acceptability, and legal and security constraints.

## 6.6 Local Smart grids application

In order to implement a Smart Grid System, following a set of steps needs to be recognized:

- **Substation Automation**

Electricity substations and central stations need systems that allow automation offering supervision and control, and efficient monitoring, with real-time diagnostics without interfering with its productivity.

- **Advanced Metering Infrastructure**

Smart Meters offer a two-way communication allowing a real-time monitoring and data collection periodically for a better consumption analyzation conducting to a better network awareness.

- **Demand Response**

The key goal of the demand response application is for the utility company management of the consumer-side electrical loads. This is done by enabling the interconnection of all smart grid components (electrical vehicles, micro grids,...) allowing an efficient way to interfere in order to optimize load shifting.

- **Distribution Automation**

The distribution automation system ensures power reliability and availability in the grid by analyzing data collected by utility companies in an automated/monitored way to optimize power grid efficiency.

- **Energy Management System**

It is used to control and monitor the electricity transmission system to avoid any malfunction in the power grid supply.

## 6.7 Pilots projects

The implementation of the smart grids projects comprises 3 proposals for pilot projects composed of:

- Pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"
- Pilot project SM_B "European grid development"
- Pilot project SM_C "Electric vehicles charging stations grid"

These projects need to be accompanied by industries and companies of the Upper Rhine area.

### 6.7.1 Pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"

In the city of Mulhouse there are two possibilities of integration of smart grids. The first one in the Fonderie quarter which includes industrialists and the second one in the DMC quarter with a mix of uses in development.

In Karlsruhe, such a project is ongoing in the East quarter for the energy transition in the city as mentioned in the preceding section. This project is in collaboration with KIT and Seven2one.

For the Fonderie quarter, the city of Mulhouse is planning to set up businesses and the idea is to create a sustainable quarter between already existing smart grid quarters in Karlsruhe and Mulhouse and to create an exchange of expertise between both. The goals of these twin projects are:

- Reducing energy consumption and increase efficiency
- Integrating renewable energy and storage
- Coupling electricity, heat and cold
- Integratinge and developing e-mobility
- Analyzing the uses, creation of learning databases
- Developing respectives business models
- Creating an exportable model (ex: EcoRhena)
- Labellisation ISO 50 001, Energy Management
- Becoming"climate cities"

The next steps are :

- Create a consortium for Mulhouse (already existing at Karlsruhe)
- Define common objectives (sharing of competences and ideas)
- Develop acceptability and an economical model

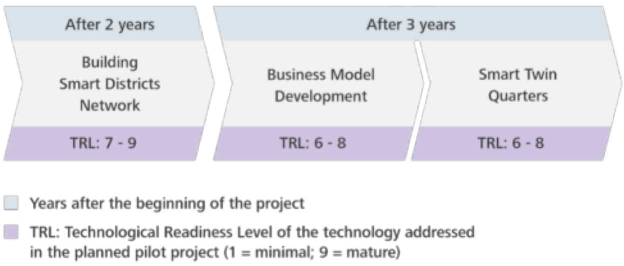


Fig. 6.4: Timeline and TRL for pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"

### 6.7.2 Pilot project SM_B "European grid development"

The objective of this pilot is to solve the problem of stability of electric power distribution including the connection of the German and French networks with electric interconnections development: high level (some GW) middle level (less than 1 GW). The objective is also to tackle the issue of energy mix integration on the grid at an European level.

The specific goals are :

- To ensure a robust stability of the grid, keep the frequency close to 50Hz
- To optimize the energy mix towards decarbonization
- To integrate local grids with transnational grid
- To enhance the commercial transaction balance

The next steps are :

- Collaboration between NetzeBW/TransNetBW and RTE (already existing thanks to the Fraunhofer ISE).
- Define the scientific open questions
- Join grids simulation (ex: RTDS / OPAL-RT)

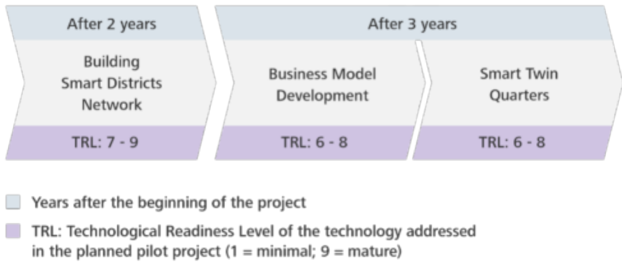


Fig. 6.5: Timeline and TRL for pilot project SM_B "European grid development"

### 6.7.3 Pilot project SM_C "Electric vehicles charging stations grid"

The objective of this pilot is the management of the location of electrical charging stations, charging strategy, storage strategy and development of charging points numbers in cities.

One concrete example is Mulhouse Agglomération (m2A) with 150 new points of electric charging stations. Also, the Black Forest region or the city of Freiburg could be a prototype region to see how e-mobility can be integrated as battery storage in the electricity grid.

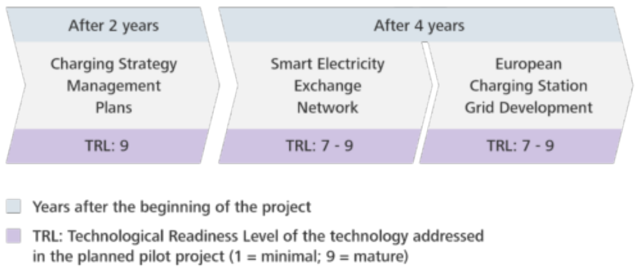


Fig. 6.6: Timeline and TRL for pilot project SM_C "Electric vehicles charging stations grid"

The following table provides an overview on the strength, opportunities, weaknesses and threats for the Smart Grid pilots.

| Strengths | Weaknesses |
|---|---|
| • Experience and knowledge in Energy Management<br>• (ex: ISO 50 001)<br>• Several contacts with local companies | • Data collection (ex: smart meter) |
| **Opportunities** | **Threats** |
| • Revitalization of a neighborhood with new installations towards carbon neutrality (Fessenheim, Mulhouse, Karlsruhe)<br>• Transversality towards the other competence groups (green batteries and hydrogen) | • Local policy<br>• Societal acceptability within the citizens |

Tab. 6.1: SWOT analysis on Smart Grid implementation

The installations, envisioned by the Smart Grids group, have the potential to generate jobs in the Fessenheim region, especially pertaining to battery technology expertise. Also, as the energy consumption control is critical, the installation of smart meters or similar devices will be promoted. Moreover, job potentials can also vary depending on the combination of other technologies that can complement smart grids, such as hydrogen, which can even increase job developments. Due to the universities located in Switzerland, France and Germany that teach relevant competencies, people with the required expertise are already available in the Fessenheim region.

## 6.8 Summary and Recommendations

The following summarizes the findings and provides an overview on the recommendations.

### 6.8.1 Summary

In this feasibility study, the Competence group Smart Grids, suggests possible installations dealing with battery storage options linked to charging stations and also for a controlled and saved electricity consumption with a consumption on demand. The idea is to integrate smart grids in Fessenheim, but also in the perimeter of Mulhouse and Karlsruhe to create areas and districts equipped with smart grids for better energy consumption.

There are a lot of opportunities to install smart meters by innovative quarters in Mulhouse (Fonderie) and Karlsruhe (Smart East), and also with the city of Mulhouse CeA that just launched a call for battery charging stations for vehicles.

However, the biggest challenge for the implementation of pilot ideas is to convince companies to accept and invest in the installation of a smart meter.

In addition, the impact on the electricity grids with increasing renewables shall be investigated by modeling approaches.

### 6.8.2 Recommendations

We recommend following the holistic approach described in this feasibility study by realizing as many of the suggested facilities from the different competence groups (batteries, hydrogen, and smart grid).

The Smart Grids competence group recommends the installation of a smart grid system in two neighbourhoods (Pilot 1) in France and Germany, as testbeds for smart grid management scopes like controlled and efficient electricity consumption on demand. The idea is to integrate smart grid systems in neighbourhoods of Mulhouse and Karlsruhe. The location is selected due to communal level openness available for building such a pilot: in Karlsruhe, the implementation of the smart grid neighbourhood has already started, while the commune of Mulhouse is willing to invest in such an idea. The transfer of the gained know-how from the smart grid systems tested in the two city neighbourhoods to the planned implementation of the French-German innovation Parc EcoRhena, as an example for a cross-border meta-demonstrator is recommended. With this pilot, the following goals will be achieved: a demonstration of how smart grids support the reduction of energy consumption, the integration and intelligent storage of renewable energy, the coupling of electricity sources, heat and cold management, and the creation of exportable models.

The group recommends testing the integration of e-mobility batteries into the smart grid system, along with the implementation of the smart grid neighbourhoods (pilot 2). It will help to understand in an effort to gain knowledge on how this integration can enhance electricity grid management and how technical, economic, and societal barriers can be solved. The goals of this pilot are to improve the understanding of how to optimize the charging station network of a district and the coupling between the charging load network and the distribution network. This will facilitate in reducing power peaks with e-mobility battery storage use, achieving the best profile and usage models, supporting the cross-border standardisation of charging networks. Hence, e-mobility charging stations for cars and bikes need to be included in the design of the smart grid neighbourhoods. It is suggested to start with industrial neighbourhoods by establishing electrical charging stations as test-beds for smart grid applications. As an outcome, it could show how e-mobility charging stations integrated in a smart grid can help save energy and optimize energy distribution in terms of availability as well as accessibility.

Another recommendation is to map out (Pilot 3) the existing regional electricity grid and analyse its weaknesses for optimal cross border electricity exchange. Furthermore, it is recommended to study the ability of regional electricity grids to stabilize under volatile electricity production. The goals of this pilot are based on European Union Energy Policy, which include stabilising the grid by keeping the frequency at 50Hz, optimising and decarbonizing the energy mix, and integrating the local grids with the transnational grid. The capacities of the existing networks and load profile simulations for the different scenarios of renewable installations provided by the RES-TMO study should be part of this pilot.

Therefore, we emphatically suggest that each working group be involved in all these projects because smart grids can be applied to different types of projects. Moreover, working together on the same ideas will greatly enhance the effectiveness and scope of this feasibility study.

## 6.9 Interested Industry Partners

ACTEMINIUM ROMANDIE.

ALSACHIMIE

BUTACHIMIE

CCI ALSACE EUROMETROPOLE

CETIM GRAND EST

COMMUNAUTÉ DE COMMUNES SUD ALSACE LARGUE

CRYOSTAR SAS

EDF - Direction Action Régionale Grand-Est

EIFFAGE ENERGIE SYSTÈMES - Clemessy

ENGIE - Délégation Régionale GE Et Territoriale Alsace

GAUSSIN SA

GROUPE HOSPITALIER DE LA RÉGION DE MULHOUSE ET SUD-ALSACE

GRTGAZ - Délégation Territoriale Nord Est ( Nancy)

$H_2$SYS

HAFFNER ENERGY

HOLCIM HAUT-RHIN

KM0

LAFARGE HOLCIM - Research Center

LIEBHERR-FRANCE SAS

LONZA - CAPSUGEL

MOBASOLAR

MUSÉE ELECTROPOLIS

REISA - Réseau des Entrepreneurs Innovants du Sud-Alsace

RTE- Réseau de Transport d'Électricité (Délégation Est)

SAINT-LOUIS AGGLOMÉRATION

SCHNEIDER ELECTRIC - SITE DE METZ

SHARELOC

SHERPA MOBILE ROBOTICS

SOCOMEC

SOLEA - TRANSPORTS EN COMMUN DE L'AGGLOMÉRATION MULHOUSIENNE

STÄUBLI RACCORD FRANCE AGENCE EST

STELLANTIS

TRION-CLIMATE

VINCI CONSTRUCTION GRANDS PROJETS

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# 7. Territorial Framework

The development of the industrial installations and technologies necessary for a sustainable, circular and de-fossilized economy requires their successful integration on the territory from a societal, environmental, economic and regulatory point of view. The fourth competence group assessed the framework conditions for the implementation of the pilot ideas developed in the feasibility study.

## 7.1 Background

The frame for implementing technical innovation is of high relevance if this implementation is to be a success. The following study analyses this framework of conditions while focusing on the innovation region. This contribution aims to allow the establishment of a baseline "T0" of societal, environmental and regulatory aspects during the feasibility phase - a photograph at time zero of the territorial framework. A close look at these very same issues will be necessary in the implementation phase of technological projects to ensure the prospective monitoring of the evolution of the territorial framework and consolidate the final objective of the project.

## 7.2 Scope of the Territorial Framework Competence Group

Through its network of Franco-German scientific experts, this competence group aims to evaluate concrete ideas related to “Green Batteries”, ”Hydrogen” and “Smart Grids” technologies for the green transformation of the territory Innovation Region Fessenheim (Fig. 7.1). The evaluation was carried out by:

- Identifying the values which citizens and local stakeholders believe in for a better understanding of their perceptions and expectations vis-a-vis these technologies, through acceptability studies;
- Offering an assessment of the environmental impacts of the technologies mentioned, notably through studies of territorial metabolism and life cycle analysis, for the establishment of a viable economic basin and a pilot region in terms of low-carbon energy transition;
- Studying the current regulatory context (French, German and European) in the three targeted areas to give a global vision of the legal framework in which industrials must structurally and technologically fit, through the study of a targeted regulatory and legal compilation.

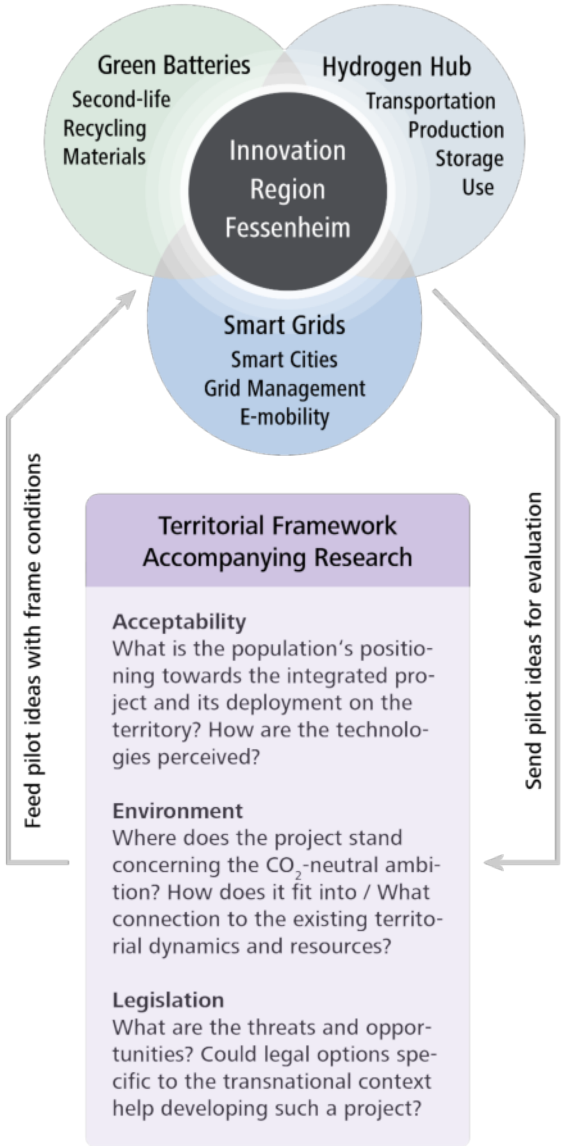



Fig. 7.1: The Interconnection of the Territorial Framework group and the other competence groups.

## 7.3 Social Acceptability

### 7.3.1 Social Acceptability of a Territorial Deployment Project of an Energy Innovation

Feasibility studies often focus on the technical and economic feasibility of a project, yet sometimes fail to consider the potential uses or the perceptions and needs of affected populations near the deployment site. Such an approach may hinder the overall understanding of the issues. Therefore, it is necessary to take a broader look at the question of adoption and acceptability. Societal needs, perceptions and possible changes as well as ethical questions in terms of fairness (e.g., regarding the procedures and distribution of benefits and costs) of the technology by potential users or local residents are to be considered. This work explores the notion of social acceptability as a boost to the implementation of a territorialised deployment project of an energy innovation with the following implicit question: how to obtain the support of the public affected by a project to ensure its sustainability?

Based on an extensive literature review[1], several hypotheses have been put forward regarding the determinants of social acceptability. An exploratory method known as perception-based regional mapping (PBRM) was then used to verify these hypotheses and assess the local residents' perception of a project (Clouet, 2000; Caron et al., 2005). PBRM is a spatial method to support regional development initiatives. It consists of a spatial participative mapping that draws attention to citizens' awareness/sensitivity on a given territory (Saqalli, 2015).

PBRM was performed in the Communauté d'Agglomération de Sarreguemines. This area houses FaHyence, the first hydrogen refuelling station producing its own hydrogen (FaHyence, 2017). The location of this demonstrator has some climatic and geographic common ground with the Fessenheim area (proximity to the German border). Thus, FaHyence could be suitable for benchmarking - in the case of the hydrogen competence group - and a typical comparative study could be performed. It could potentially highlight problems related to the implementation of such demonstration projects and help improve the design of future projects.

The results of our research are compiled in the form of SWOT analyses (Tables 7.1, 7.2 & 7.3) to present factors that are favourable or unfavourable to the territorialised deployment of each type of technology from the perspective of social acceptability.

<table>
<tr><th colspan="2">1 | Green Batteries</th></tr>
<tr><td>Strengths<br>Downstream high acceptability due to a positive environmental image:<br>• Longer battery lifetime<br>• Possibility to recycle battery<br>• Reduction of the depletion of scarce resources (reduced abstraction)<br>Local energy storage (second life of battery) for personal usage.</td><td>Weaknesses<br>Lack of information on the recycling possibility.<br>If technologies on materials used for batteries evolve, uncertainty about continuity of recycling processes may arise</td></tr>
<tr><td>Opportunities<br>Develop a positive environmental life cycle:<br>• Extend lifecycle<br>• Ability to recycle materials</td><td>Threats<br>Upstream weak acceptability due to a rebound effect linked to the exploitation of scarce resources whose availability is by definition limited<br>Energy dependency: threat of blackout due to growing demand for electricity<br>The tolerance for the installation of this type of plant: potential pollution from a battery recycling plant is likely to affect the cost-benefit ratio</td></tr>
</table>

Tab. 7.1: SWOT analysis related to Green Batteries.

[1] See literature with * in chapter 7 references.

| 2 \| Hydrogen | |
|---|---|
| **Strengths**<br>Acceptability is not consumer-dependent<br><br>Little or no NIMBY effect2<br><br>Low risk perception<br><br>Use of a low-polluting asset (no particle emission)<br><br>Storable energy production: act as buffer = compensates for RE intermittency | **Weaknesses**<br>Lack of information on origin / mode of hydrogen production (really green?): green hydrogen might be confronted with criticism if not explained well enough and if it is not part of a holistic concept of energy transition. |
| **Opportunities**<br>Feasibility depends on political will<br><br>Potentially promising: positive environmental image<br><br>Territory attractiveness / ecological trajectory | **Threats**<br>Lack of information<br><br>Lack of trust in project sponsor<br><br>Cost of transportation and grid connection of hydrogen |

Tab. 7.2: SWOT analysis related to Hydrogen

| 3 \| Smart Grids | |
|---|---|
| **Strengths**<br>Acceptability linked to smart management of energy consumption:<br><br>• Bill under control<br>• Energy savings: positive environmental impact as better information helps to involve the consumers behaviour: they lower their consumption accordingly | **Weaknesses**<br>Individual risk perception linked to:<br><br>• Radiations / waves<br>• User and usage tracking<br>• Computer hacking<br>• Fear of bugs<br>• Electricity theft<br>• Control of personal data (ex: of their home)<br><br>Lack of intelligibility in the data use charter<br><br>Lack of vision on the real contribution of smart management in terms of energy consumption reduction. Is the contribution of smart management profitable in terms of cost/benefit ratio? |

[2] NIMBY (Not In My Back Yard): opposition by residents to the development of infrastructure in their surrounding area.

| Opportunities | Threats |
|---|---|
| Trust level<br>• Depends on level of information<br>• Need for data use charter<br>Appropriateness:<br>• Comfort of use / ergonomics (usage "intuit-iveness")<br>• Human / machine interface | Risk perception linked to cybersecurity<br>Will the development of the grids be sufficient to compensate for the growing consumption of electricity in the coming years? |

Tab.7.3: SWOT analysis related to Smart Grids.

### 7.3.2 Psychological Determinants of Social Acceptability

The brakes and levers of social acceptability were also studied from a psychological perspective. The psychological determinants of the social acceptability of the envisioned technologies were identified through previous works (Emmerich et al., 2020; Huijts et al., 2012; Huijts et al., 2014; Tumlison & Song, 2019). They provide support for including variables such as trust, benefit-cost perception, affect, and knowledge as psychological factors accounting for social acceptability. Our measurement strategy consists of a questionnaire (Questionnaire, 2021) to be distributed to the population.

The variables were assessed by selecting specific scales for each. Table 7.4 lists variables and corresponding examples mostly related to hydrogen technology. Questions were also adapted for green batteries and smart grid technologies. Each participant was limited to one technology only.

The questionnaire was distributed to the French population. No specific location was targeted. A dissemination platform was used in order to collect enough data. We primarily focused on the general French population. The study sample was large and slightly mirrors real conditions where the whole population is concerned by the energy transition with the political will to lower/remove the contribution of nuclear sources in the energy mix over time.

The results of our research are presented in the following order. We first compare where all three technologies (Green batteries, Hydrogen, Smart Grids) stand regarding each variable of interest. Second, we detail some of the existing relationships between the different variables and the social acceptability of the technologies considered.

| Variables | Examples |
|---|---|
| Trust (Tumlison & Song, 2019) | • How much would you trust environmental groups to provide reliable information about green technologies? |
| Benefit Perception (Tumlison & Song, 2019) | • What are the new economic benefits that hydrogen may bring to your community ? (e.g., job creation)? |
| Social Acceptability (Batel et al., 2013) | • In general, I accept hydrogen.<br>• To what degree would you agree to the construction of hydrogen dedicated facilities near your community? |

Tab. 7.4: Examples of variables and related scales used for the study.

### 7.3.2.1 Descriptive Study

- **Objective Knowledge**

Objective knowledge was assessed through sets of true/false questions (one set per technology). Each set consists of five specific and factual questions which are related to each technology and were constructed after consultation with the other competence groups. Results show that people have more objective knowledge about Smart Grids than Green Batteries and even less about Hydrogen (Fig. 7.2). The percentage of respondents that got 4 to 5 correct answers out of 5 reveals that they have a relatively good level of knowledge about Smart Grids (51%) and Green Batteries (46%) and a rather modest level of knowledge about Hydrogen (24%).

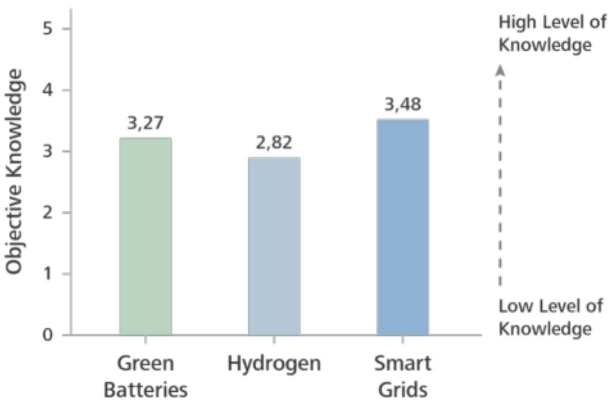



Fig. 7.2: Objective knowledge associated with each technology ("0" indicates a low level of knowledge, "5" indicates a high level of knowledge).

- **Affect**

Participants were asked to indicate up to three words elicited by the technology presented. 'Gas', 'water' and 'energy' were most frequently associated with Hydrogen. 'Recycling', 'ecology' and 'pollution' with Green Batteries and 'electricity', 'economy' and 'technology' with Smart Grids. Elicited words should then be rated as very negative, negative, neutral, positive, or very positive. Of the three technologies, Hydrogen has the best image (positive affect), followed by Green Batteries, and finally Smart Grids (Fig. 7.3).

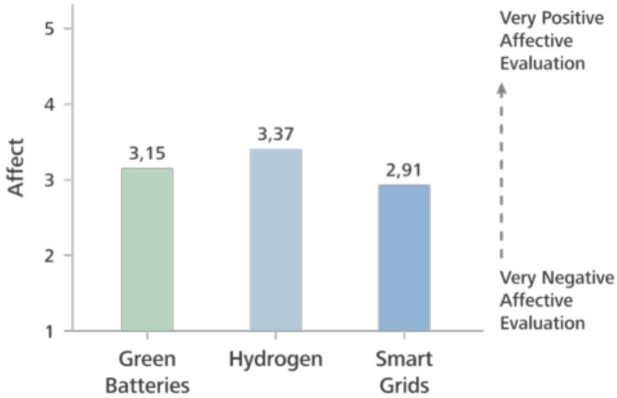



Fig. 7.3: Affect towards each technology ("1" indicates a very negative affective evaluation, "5" indicates a very positive affective evaluation).

- **Benefits and Costs**

Benefits and costs were assessed through a set of height questions (four for benefits, four for costs) covering different topics related and adapted to each of the technologies (territorial, environmental, economic, healthy/safety aspects, etc).

As far as benefits are concerned, Hydrogen is perceived as more beneficial than Green Batteries, and Green Batteries more beneficial than Smart Grids (Fig. 7.4). Irrespective of the technology, the environmental benefit was considered to be the most important.

As far as costs are concerned, Green Batteries are considered to have the highest cost, followed by Smart Grids and then Hydrogen (Fig. 7.4). Irrespective of the technology, the financial cost (infrastructure construction, maintenance, etc.) was considered to be the most important.

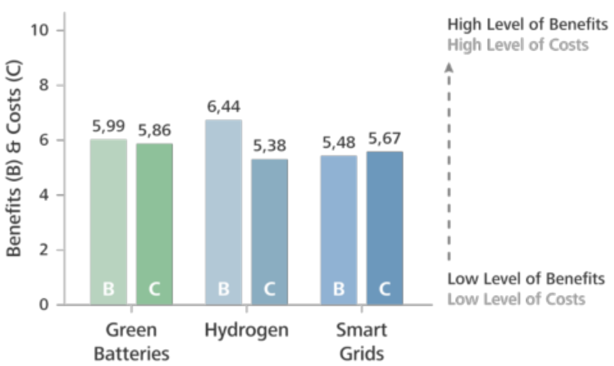



Fig. 7.4: Benefits and costs associated with each technology ("0" indicates a low level of benefits – respectively, a low level of costs, "10" indicates a high level of benefits – respectively, a high level of costs).

Finally, it should be noted that the benefit-cost balance (i.e. the difference between benefits and costs) is positive only for Hydrogen. Hydrogen is perceived to be more beneficial than costly. For Green Batteries and Smart Grids, benefits and costs are in overall balance.

- **Social Acceptability**

Social acceptability was assessed through two questions. One focusing on global acceptability, i.e. being in favour of the development of such technologies in general, the second on local acceptability, i.e., being in favour of the installation of such technologies in the surrounding areas. On average, global acceptability was considered higher than local acceptability, regardless of the technology, and possibly reflecting a NIMBY effect (Not In My Back Yard). Further, responses to both questions were strongly correlated (r = 0.75)3 leading to considering them in a single social acceptability score (Fig. 7.5). In doing so, Hydrogen appeared to be the most acceptable technology, followed by Green Batteries and then Smart Grids.

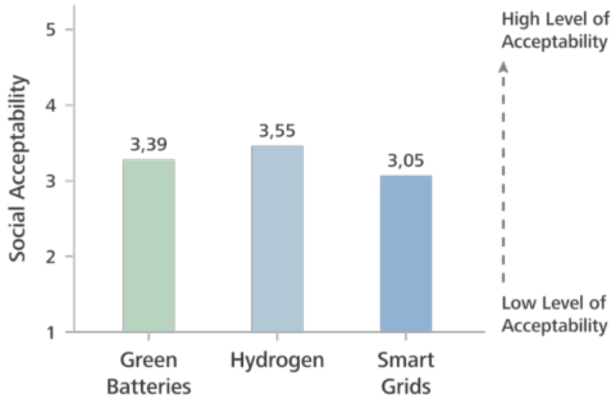



Fig. 7.5: Social acceptability for each technology ("1" indicates a low level of acceptability, "5" indicates a high level of acceptability).

These first descriptive results seem to indicate that Hydrogen is the technology best perceived by the population in terms of image (positive affect), perception of benefits (positive benefit-cost ratio) and acceptability. The level of objective knowledge does not seem to play a role in the way the technologies are perceived.

- **Trust**

Regardless of the technologies, we assessed the level of trust placed in different stakeholders on two topics: reliability of the information provided about new technologies, and "ensuring that production facilities and plants for new green technologies comply with safety rules".

A preliminary analysis showed that the topic does not seem to matter much. The stakeholder itself prevails. We therefore grouped the scores of the two questions into a single score per stakeholder. It then appeared that trust in local representatives, government, and industrials was generally at the same level. These three stakeholders were then grouped into the single entity called "institutions" (political and economic). Participants generally placed less trust in these institutions than in environmental organizations (Fig. 7.6).

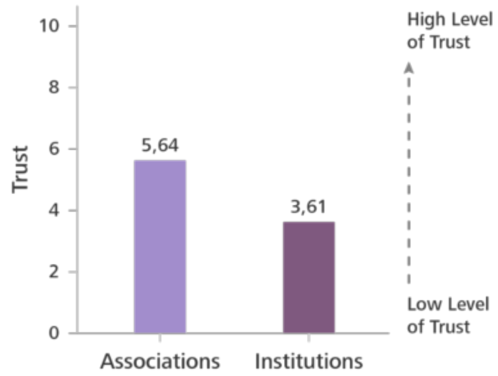



Fig. 7.6: Level of trust according to the type of stakeholders ("0" indicates a low level of trust, "5" indicates a high level of trust).

### 7.3.2.2 Levers for Social Acceptability

In this section, we explore correlation between the variables of interest. In other words, we are interested in the degree to which the abovementioned variables are related to social acceptability. The objective is to identify levers on which it is possible to act in order to improve the acceptability of the technologies under study. The results are as follows:

- The level of objective knowledge appears to be weakly related to both the degree of social acceptability of any of the technologies (r = 0.13) and the other variables (0.05 < r < 0.13). It might indicate that knowledge has a negligible impact on acceptability, but also on the image the technologies convey, or the perception of their benefits or costs.
- The affect towards a technology appears to be strongly linked to both its acceptability (r = 0.53) and the associated benefits (r = 0.49). It is less related to the associated costs (r = -0.11). In other words, the better the affective evaluation of a technology, the more acceptable and beneficial it appears to the public.
- The benefits associated with the technologies are positively and strongly related to their degree of ac-

[3] r indicates the strength of the relationship between two variables. It varies from -1 to +1. The further it is from 0, the stronger the relationship.

ceptability (r = 0.51). The more beneficial the technologies are perceived to be, the more acceptable they are. The perceived costs seem to play a much less important role in their acceptability (r = -0.13).

- The level of trust in associations or institutions seems to play a similar, rather modest role (respectively, r = 0.16 and r = 0.18) in the acceptability. Trusting or distrusting one or the other of the stakeholders seems to be rather secondary to what makes a given technology acceptable (or not).

Among others, the two useful factors which facilitate the acceptability of a new technology appear to be: projecting a good image and highlighting its benefits.

### 7.3.3 Conclusions and Recommendations for Societal Actions

The prospective approach we followed in this study regarding societal acceptability of territorial deployment shows that the public generally supports green technologies. However, several studies show the existence of a "social gap" between opinion polls and the acceptability of a territorialized deployment project: a public may be in favour of a type of energy but opposed to its deployment on its territory. In other words, acceptability does not only depend on the support or rejection of the innovation at a meta-level but also on the way the deployment project is intended in the territory:

- The emphasis on benefits and a fair distribution of benefits and costs promotes project ownership.
- The key is greater transparency and consultation in the project development, which could be implemented through transdisciplinary planning approaches together with discussions and mediations and public meetings with the population.
- The confidence level in the project is affected by the institutional or cognitive distance between the promoter and the locals, which could be lowered by co-construction or in other words by considering place attachment in regional or infrastructural planning and the conceptual involvement of the needs and wishes early in the process.

The psychological determinants of social acceptability study showed that, regardless of the technology, objective knowledge has little to do with the technology's social acceptability, projected image, or associated benefits and costs and their perception. However, the image it conveys, as well as its associated benefits, seems to have a significant impact on its level of acceptability. More precisely, the more positive the public image of a technology and the more it is regarded as a source of benefits (particularly environmental benefits), the more likely it is to be considered acceptable.

Among the studied technologies, Hydrogen fits this picture the most and is ahead of Green Batteries and Smart Grids (without the latters being considered negatively).

We therefore recommend working on the image projected by these technologies (particularly for Green Batteries and Smart Grids) and increasing the perception of their benefits. This will positively impact the population's level of acceptability. Communication is key and has to be worked on (presentation format, graphic illustrations associated with technical elements, etc) (Bostrom et al., 2018; Hoffrage & Garcia-Retamero, 2018; Peters et al., 2006).

## 7.4 Environmental Impact

Life Cycle Assessment (LCA) is a comprehensive and standard methodology used to evaluate a wide range of environmental impacts that a product or service has over its whole life cycle, i.e., from cradle to grave, from raw material extraction, through manufacture and use, to waste disposal or recycling (see Fig. 7.7).

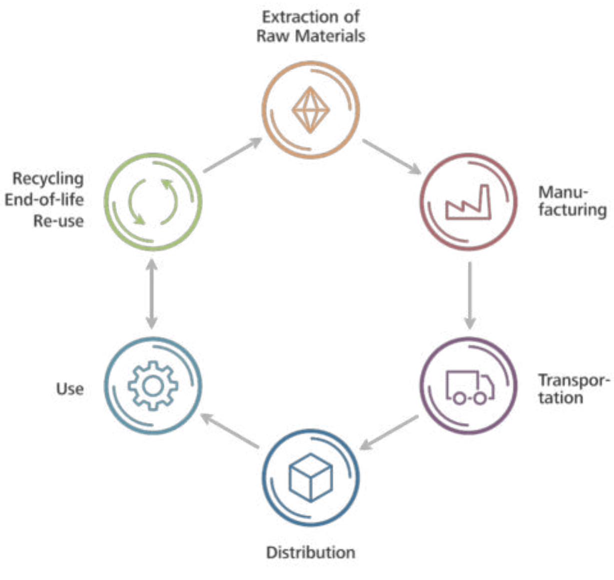



Fig. 7.7: Life cycle of a product

Each life cycle stage can be considered as a separate system and analysed using the LCA methodology. The data concerning the raw materials consumption and pollutants released to various environmental compartments are identified and quantified in the life cycle inventory analysis step. These data are converted into environmental impacts in the Life Cycle Impact Assessment step (LCIA). The purpose of LCIA is to express the impact in terms of category indicator, which is calculated by multiplying the mass of emitted substances measured in the life cycle inventory with the fate factor (defined as the behaviour of the substances in water, soil, air medium and as so-called time residence of the substances) and the effect factor of the pollutants related to the studied system. In the following two studies, the choice was made to focus on the environmental impacts generated by the recycling phase of Li-ion batteries and the production of hydrogen. These two studies are to be linked to the pilot proposals made by the Li-ion battery recycling and the multimodal $H_2$ HUB subgroups. Present social, economic and environmental issues should be analysed for the sustainable development of a territory. It is relevant to quantify the environmental impacts of different Li-ion battery recycling scenarios as well as those of different hydrogen production scenarios in order to define those which are the least polluting and support the decisions of the various stakeholders.

## 7.4.1 Li-ion Battery Recycling

The growth in demand for Li-ion batteries makes it necessary to manage these batteries at the end of their life. This is essential to limit their environmental impacts. The environmental impacts assessment of Li-ion batteries recycling is the major scientific question of this subject; in order to quantify them the methodology of Life Cycle Analysis was used. The most widespread recycling processes on an industrial scale are pyrometallurgy, hydrometallurgy and mechanical processes. These make it possible to extract battery components at more or less basic levels. In many cases, a combination of these different processes is used (Fig. 7.8), but the choice of process(es) depends primarily on the materials to be recovered. The recycling process begins with a pre-treatment consisting of a mechanical process allowing the recovery of the main components (carcass, plastics, electronic components). This is followed by a thermal or chemical process, which will firstly remove the aluminium and copper sheets from the anode and the cathode respectively and secondly, improve the efficiency of the following treatment. This pre-treatment step can be likened to the first pilot planned by the battery recycling sub-group and entitled "Facility for the Dismantlement Batteries”. The treatment of the electrodes promotes the recovery of the elementary components of the latter via pyrometallurgical or hydrometallurgical treatment. The battery recycling step corresponds to the pilot of the recycling sub-group entitled “Pilot Plant for the Recycling of Battery Materials”.

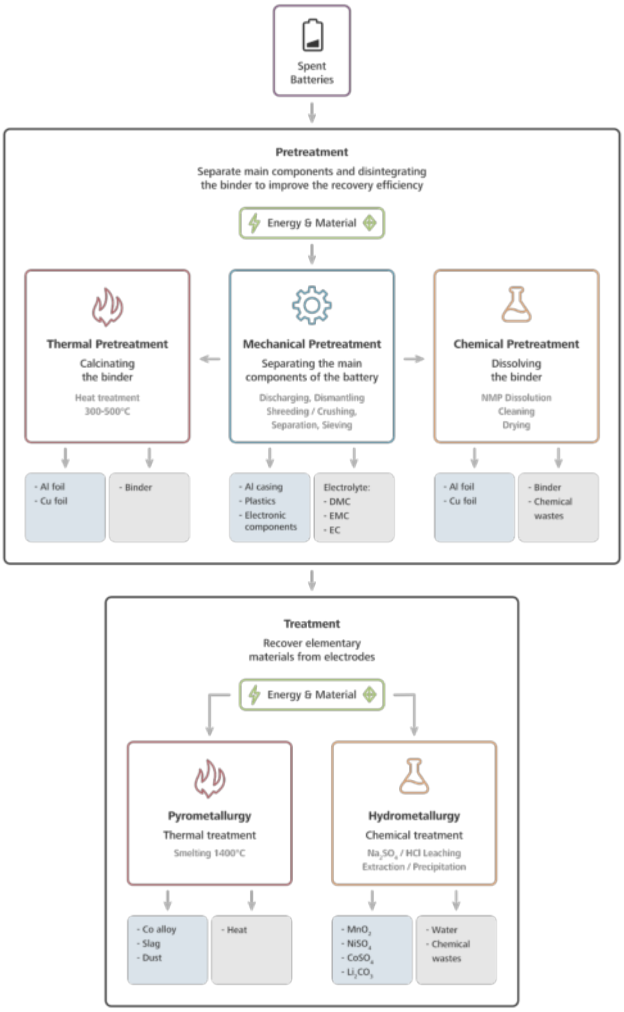



Fig. 7.8: Lifecycle boundaries of the studied system (Kautzmann et al., 2021).

A prospective Li-ion battery recycling LCIA was conducted using literature and the Ecoinvent database. We carried out the LCIA comparison of the recycling processes first independently for each recycling step (pre-treatment and treatment), then through four scenarios representing the possible combinations of elementary processes (Table 7.5). Both Scenario 1 and Scenario 2 consist of mechanical (M) and thermal (T) pre-treatments, but while Scenario 1’s pre-treatment is then followed by a pyrometallurgy (P) treatment Scenario 2’s pre-treatment follow up is a hydrometallurgy (H) treatment. Scenario 3 and Scenario 4, consist of mechanical and chemical (C) pre-treatments followed by a pyrometallurgy treatment for Scenario 3 and a hydrometallurgy treatment for Scenario 4. Evaluation of these scenarios will serve to assess the environmental performance of the recycling process that is envisioned by the Green Batteries Competence Group.

| | PRETREATMENT | | | TREATMENT | |
|---|---|---|---|---|---|
| | Mechanical (M) | Thermal (T) | Chemical (C) | Pyrometallurgy (P) | Hydrometallurgy (H) |
| Scenario n°1 | X | X | | X | |
| Scenario n°2 | X | X | | | X |
| Scenario n°3 | X | | X | X | |
| Scenario n°4 | X | | X | | X |

Tab. 7.5: Different scenarios for battery recycling process (Kautzmann et al., 2021).

The LCA study that was performed showed that (see Fig. 7.9):

- The impact on global warming expressed in equivalent $CO_2$ (the main contributors are Methane, Nitrous Oxide ($N_2O$), CFC-11, CFC-12, HCFC-22, HCFC-141b, HCFC-142b, HFC-134a and Sulphur Hexafluoride) is the most severe. In this impact category, it is preferable to opt for a hydrometallurgical treatment, which generates an impact two times lower than that of pyrometallurgy. The pre-treatment has little influence on the differentiation of scenarios in this impact category.
- On the contrary, pre-treatments have a strong influence on the use of energy from non-renewable sources. The energy required for chemical pre-treatment is up to twice the energy required for thermal pre-treatment. Indeed, the manufacture of the materials used, in particular NMP (N-Methyl-2-Pyrrolidone), in the chemical pre-treatment requires a large amount of energy.
- Regarding the respiratory effects caused by inorganic substances, the thermal pre-treatment shows an insignificant impact compared to the chemical pre-treatment. On the other hand, hydrometallurgical treatment generates an impact two times lower than pyrometallurgy treatment in this impact category.
- The impact on carcinogenic effects and terrestrial ecotoxicity are very low compared to the other categories described above. However, we observe that hydrometallurgy has a greater impact on carcinogenic effects, due to the use of a large quantity of products harmful to human health.

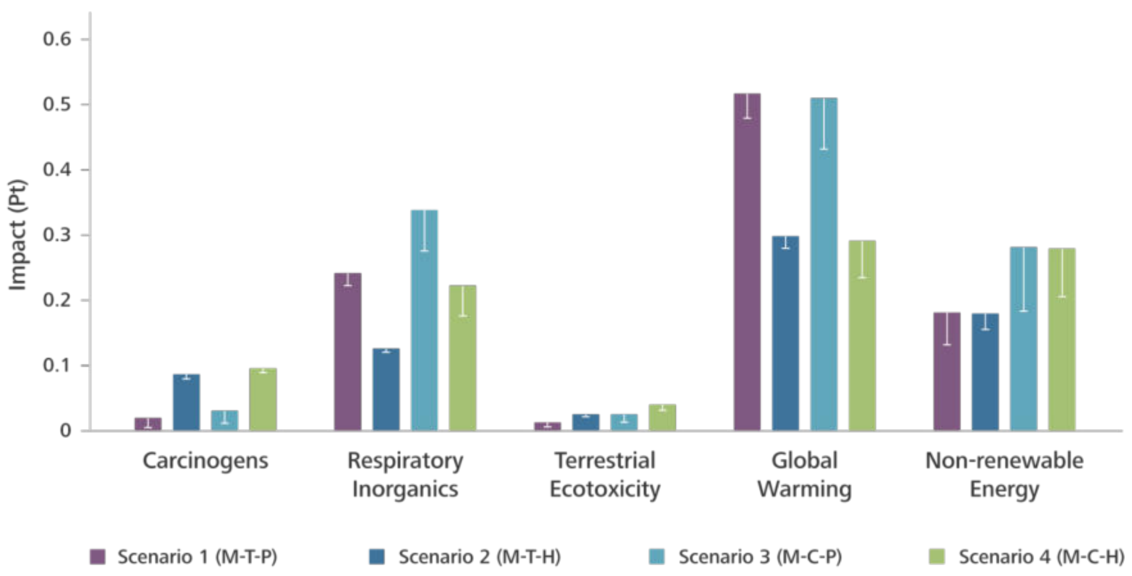



Fig. 7.9: Impacts of the different existing recycling scenarios for each identified category (Kautzmann et al., 2021)

Scenario 2, consisting of a mechanical then thermal pre-treatment and a hydrometallurgical treatment, therefore, seems to be the most efficient scenario from an environmental point of view, in any case, the best compromise given the categories of impacts considered. The detailed version of this study can be found in (Kautzmann et al., 2021).

ment and hydrometallurgical treatment, seems the most efficient from an environmental point of view and probably the best compromise taking into account the categories of impacts considered.

However, to date there is no properly established recycling process that would allow the simultaneous recovery

| **Strengths** | **Weaknesses** |
|---|---|
| The development of recycling contributes to securing the upstream of our industrial value chains in an integrated vision: it allows them to be complete in order to be stronger, more resilient and more competitive (CSF Mines et métallurgie, 2020).<br><br>From an environmental point of view for<br>• pilot 1: "Facility for batteries dismantling", the best pre-treatment is mechanical, then thermal.<br>• pilot 2: "Pilot plan for the Recycling batteries", the best treatment is hydrometallurgy | To date, the profitability of the lithium battery recycling activity is low, even negative. The development of this sector will remain dependent on many factors (recycling profitability, stationary energy storage needs, etc.) (CSF Mines et métallurgie, 2020).<br><br>To conduct a complete LCA, industrial data is necessary but there is a lack of primary data. We consulted 63 papers and only 8 have been used to find data. Moreover, there is also a lack of data collected from companies, because of the problem of confidentiality. |
| **Opportunities** | **Threats** |
| Collaboration with EDF and EURO DIEUZE companies or another recycling company could be an opportunity to implement a recycling unit on the Fessenheim site. A discussion concerning the supply and type of energy could take place and alleviate/compensate the energy-intensive aspect of the pre-treatment and treatment processes | France has the assets to become the European leader in battery recycling, but is left behind by its European partners and its international competitors (CSF Mines et métallurgie, 2020)<br><br>From a scientific point of view, the problem is related to the lack of data for conducting a sensitivity analysis. |

Tab. 7.6: SWOT analysis on Li-ion battery recycling.

## 7.4.2 Conclusions and Recommendations for Battery Recycling

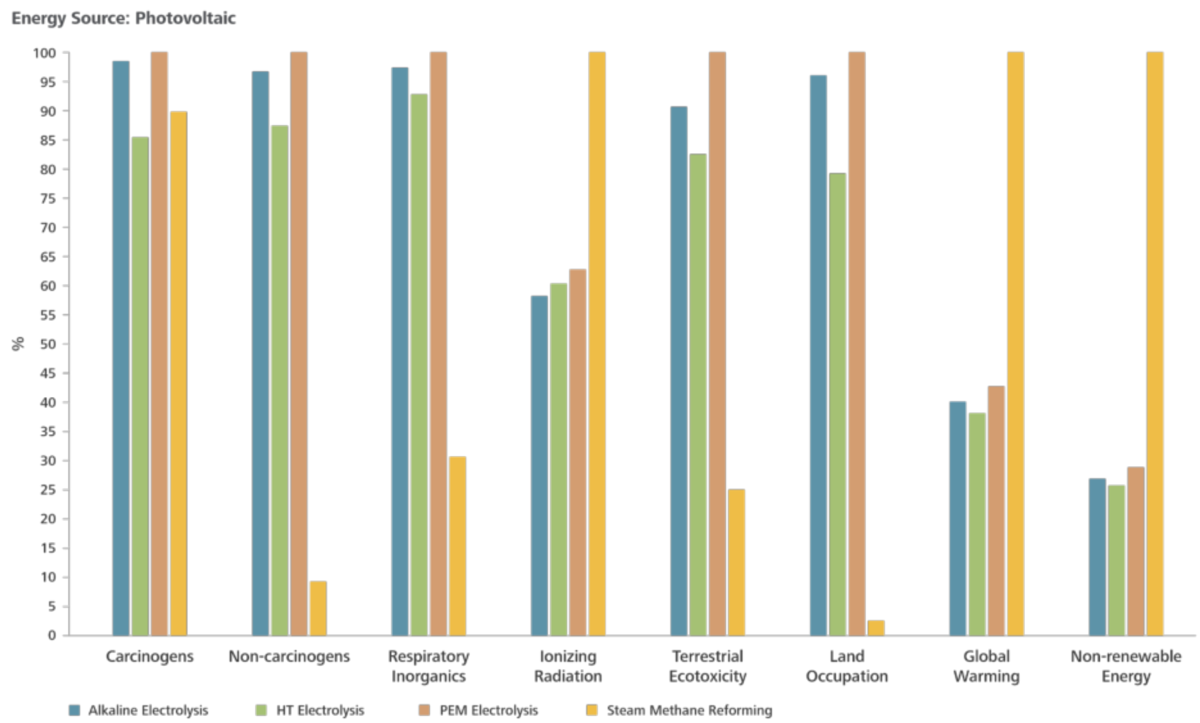
The recycling of lithium-ion batteries is essential, to limit their impact on the environment if disposed of in landfills and to recover and reuse battery materials thus limiting the extraction of new ones. A life cycle analysis based on data from the literature made it possible to determine which scenario, i.e., which combination of these processes, is the most efficient from an environmental point of view. However, very little data is available because of the newness of these recycling processes and the confidentiality of the data (which is not shared by manufacturing companies). Moreover, because of the diversity of the existing processes, these data showed a strong variability which we took into account by using intervals of values for the data concerned. We have observed that scenario 2, consisting of mechanical and then thermal pre-treat- of all lithium-ion battery components at attractive recovery rates (Zante, 2020; Mossali et al., 2020). The recycling processes presented here can be greatly optimised to reduce their environmental impacts. The recovery of the electrolyte could constitute a first major improvement but is to date only applied very infrequently on an industrial scale and the lack of data did not allow us to take it into account in this study. The use of citric acid ($C_6H_8O_7$) as a replacement for sulfuric acid ($H_2SO_4$) in the hydrometallurgy process could also reduce the environmental impacts of this process. However, this choice would be a detriment to the material recovery rate constituting the cathode. Finally, concerning the chemical pre-treatment, it is the production of NMP used in this step which is responsible for almost all of the impacts. The use of an alternative solution, such as sodium hydroxide (NaOH), could also be a solution to limit the impact of chemical pre-treatment, provided that its effectiveness in the disintegration of the PVDF binder is comparable to that of NMP. New recycling technologies are also being developed, such as direct regeneration, which is a method of "repairing" the active material of the cathode (Li et al., 2017; Fan et al., 2021). This technology would thus make it possible to refurbish batteries without going through recycling and then produce new batteries from these recovered materials, which would constitute a shorter loop in the circular economy model. This very promising new technology would guarantee a significant reduction in environmental impacts because it requires lower amounts of energy and less materials than the conventional processes studied here. Finally, to facilitate battery recycling, the design of lithium-ion batteries can be redesigned. Research on the configuration of new “LEGO” type batteries (removable) is currently in progress and would make it possible to simplify the dismantling of these and dispense with the mechanical pre-treatment of crushing and separation (Tarascon et al., 2021).

### 7.4.3 Hydrogen Production

The pilot project developed by the hydrogen group, named Multi-Modal $H_2$ Hub Neuf-Brisach, concerns the global life cycle of hydrogen as an energy vector, from its production to its use. Hydrogen production will be provided by a 20 MW electrolysis plant, located on the banks of the Rhine and close to the Fessenheim hydroelectric plant. This electrolyser will be powered by a renewable energy source, perhaps delivered by a floating photovoltaic panel plant. Previous studies have shown that the operation phase and more specifically the electricity consumption during this stage is the main contributor to environmental impacts. However, gaps exist in these studies and are related to the absence of comparative analysis between the different electrolysis techniques as well as steam reforming over the complete life cycle and using different energy sources during operation.

Therefore, it seems necessary to develop comparative life cycle analyses between these different technologies in order to assess which process will have the least environmental impact. We then carry out a comparative LCA of the three main existing technologies: alkaline electrolysis, PEM (Proton exchange membrane) electrolysis and HT (high temperature) electrolysis.

In order to have a comparison reference, we include in this LCA; on the one hand, the current process mainly used for the production of hydrogen: steam reforming; and on the other hand, an energy source based on the French electricity mix for comparison to the photovoltaic energy source.



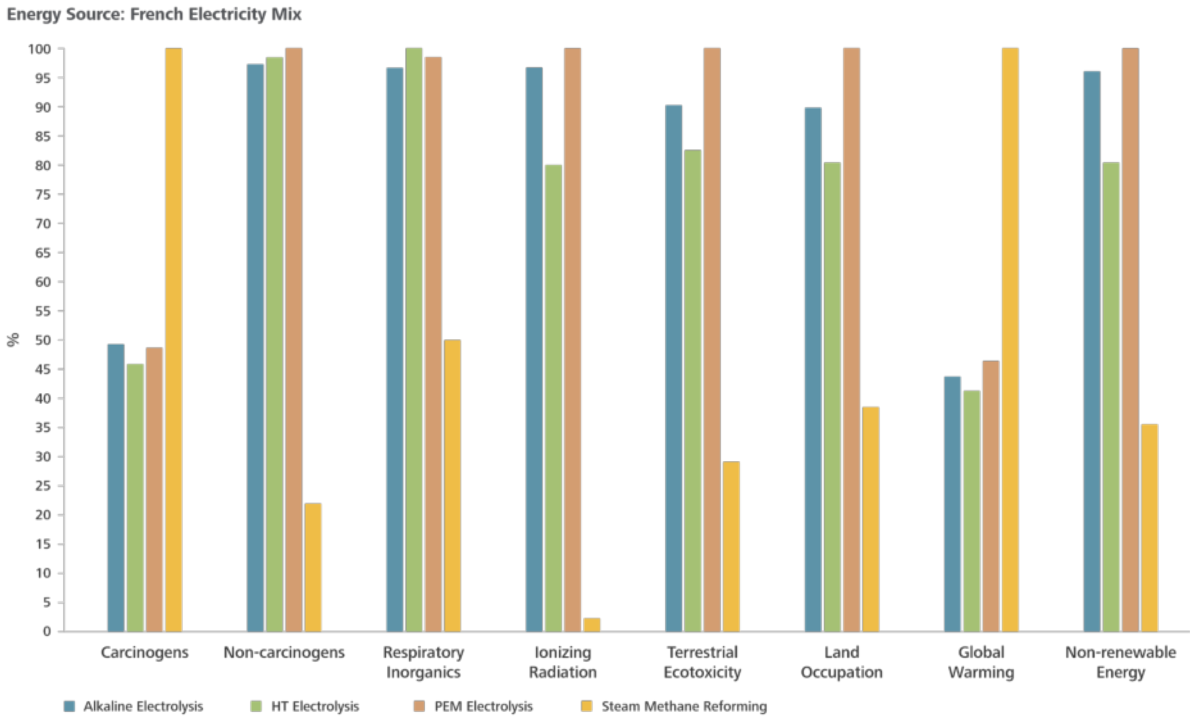



Fig. 7.10: Comparison of relative environmental impacts of steam reforming and electrolysis processes powered by: (top) a photovoltaic electrical source, (bottom) a mix-based on the French electricity mix (Dailland et al., 2021, pp.38-40).

The results, presented in Fig. 7.10 (top), show the comparison between the steam reforming process as well as the three electrolyser technologies: alkaline, proton exchange membrane, and high temperature electrolysis - whose operation is carried out by a solar energy source.

The first point that emerges from this analysis is the similarity of the different electrolysers from an environmental point of view. This equivalence comes mainly from the fact that a very large part of the impacts comes from the operating phase of the processes, which use the same energy source, with yields close to each other. The second point concerns the comparison to steam reforming. It is observed that this process exceeds (between 2 and 3 times greater) the environmental impacts of electrolysers on two indicators: global warming and the use of non-renewable energy. This difference is based on the processes for obtaining Hydrogen: one uses a renewable energy source and produces no pollutants during its operating phase, while the other uses a fossil energy source and emits large amounts of greenhouse gases. Steam reforming has similar or weaker effects on the other impact categories, apart from ionizing radiation emissions because SMR uses electricity for the operation of the infrastructure, based on the French energy mix comprising a large share of nuclear energy (emitting radioactive waste).

The results presented in Fig. 7.10 (bottom) show the same comparison of processes as in the previous scenario; this time the source of electrical energy during the operation of the electrolysers was changed. This comparison shows once again the importance of the energy source for powering the electrolysers. The impacts concerning the use of non-renewable resources or ionizing radiation are reversed compared to the previous scenario in direct correlation with the French mix. Indeed, more than 70% of French electricity production (2019) is based on nuclear energy, directly responsible for the emissions of ionizing rays and the use of resources (uranium as fuel).

There is a very slight increase in the global warming indicator from electrolysers because although nuclear energy is practically carbon-free, there are still sources of electrical energy emitting GHGs in the French mix (8% via combustion natural gas, for example).

| Strengths | Weaknesses |
|---|---|
| The European Union, engaged in an energy transition aimed at decarbonizing the economy, rekindles the hope of a hydrogen society. The recovery plans of France and Germany provide for investments of several billion for the construction of a complete green hydrogen sector, from production to use, intended primarily for mobility<br><br>If the electricity production of dihydrogen is done by electrolysis then this solution meets the climatic challenges, but only if the electricity production is carbon-free (renewable or nuclear) | However, the most widely used technique is steam reforming based on methane ($CH_4$). The mechanism consists of a double chemical reaction initiated at high temperature (between 840 and 950°C) strongly emitting $CO_2$ |
| **Opportunities** | **Threats** |
| Collaboration with GDS and EDF companies could be an opportunity to implement a hydrogen production unit on the Fessenheim site | -- |

Tab. 7.7: SWOT analysis on hydrogen production

## 7.4.4 Conclusions and Recommendations for Hydrogen Production

The results of this study showed that there was some similarity between the impacts of the different technologies, but that high-temperature electrolysis offered a better environmental compromise, especially if the infrastructure is supplied by a network of steam already present on an industrial site. This process is then followed by alkaline electrolysis and finally by PEM electrolysis.

The study also showed the relevance of producing Hydrogen by electrolysers rather than by the traditional process of steam reforming, particularly with regard to greenhouse gas emissions. Indeed, the primary goal of the feasibility study is the development of a carbon-neutral region on the territory of Fessenheim and its surroundings.

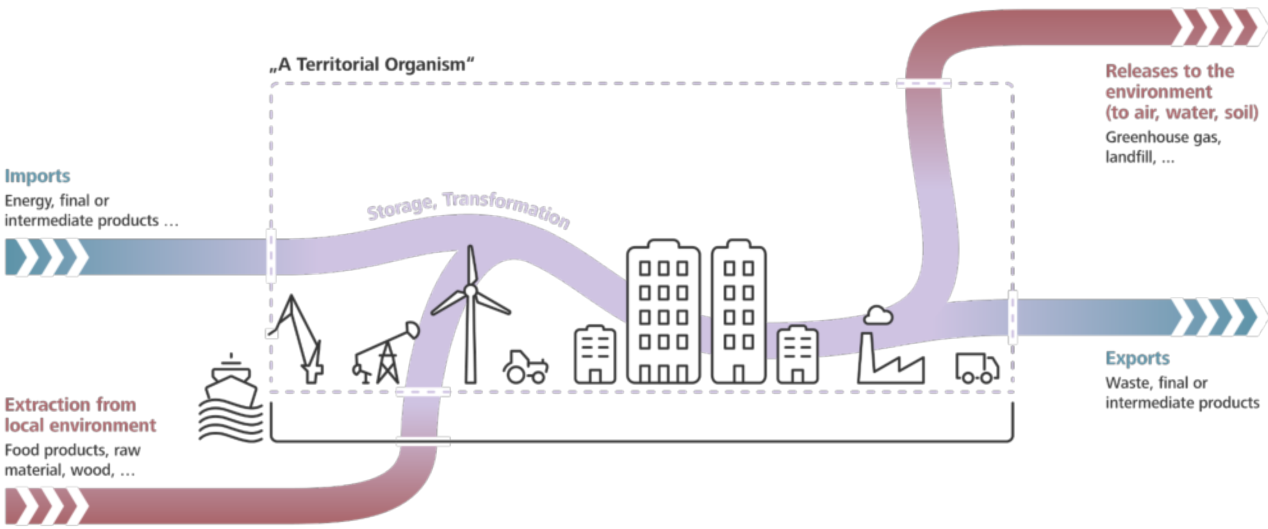



Fig. 7.11: Concept of metabolism applied to a territory – a frame to describe physical flows in link with the economy (Ribon et al., 2018)

## 7.5 Territorial Metabolism

The territorial metabolism approach describes physical flows (material, energy, persons) involved in the economy of a territory (see Fig. 7.11). This approach is complex because it is global and systemic, while the available data is limited, but it opens the way to various applications (Ribon et al., 2018). Among other things, it will allow researchers to identify local resources and needs; supervise energy, mobility, and material flows; assess environmental impacts; build a shared vision of the territory; and improve regional planning. Studying the territorial metabolism of the Fessenheim area will provide a vision of flows linked to the pilot projects, an opportunity to question their relevance and their territorial anchorage.

### 7.5.1 Overview

Five themes relevant to the pilot projects were taken into consideration: mobility, energy and climate, hydrogen industrial ecosystem, raw and critical materials, and land use. Public and area-specific data sets have been collected and analysed to provide an overview for each theme. The purpose is to highlight the issues linked to the territorial flows and resources, in connection with the pilot projects. Key elements of the analysis are summarized in the form of a SWOT analysis for each pilot project (Tables 7.8, 7.9 & 7.10). Each theme is further developed and discussed in the following sections to support our analysis.

| **1 \| Green Batteries** | |
|---|---|
| **Strengths**<br>The growing market of batteries (electrical cars, embedded systems) is high. Managing batteries in their end of life will thus become crucial (from logistic, toxicity and resource preservation points of view). $2^{nd}$-life approach is particularly interesting for efficient resource use, especially regarding critical materials / rare earths (nickel and lithium).<br><br>Carnot batteries seem particularly interesting for reusing Fessenheim power plant infrastructures that already include hydro-systems (cooling, pool, pumps, etc).<br><br>Even with new emerging technologies, Lithium-ion batteries (LIB) are probably the most mature technology standard for the next few years. Massive amounts of end-of-life LIB are thus expectable in the future. | **Weaknesses**<br>Electric cars represent only 0,4% of all cars in 2019 in Haut-Rhin (1743 vehicles). Even with the current high growth rate (+30%/year), that would take years (probably 5 to 10) before having significant amounts of batteries for $2^{nd}$-life or recycling. |

| Opportunities | Threats |
| --- | --- |
| Some of the pilot projects may have synergies to also manage other battery technologies or sizes (thermic car, smartphone, inverter, etc).<br><br>Batteries in their 2nd-life could be associated with a hydrogen electrolyser pilot project for better load-shedding.<br><br>The Fessenheim site may be more interesting for the battery industry than for hydrogen, since the product is much more easily transportable (it does not need the location where it will be used to be close to the production location).<br><br>The Rhine may be used for a low-carbon product transportation. Different components of the green battery industrial ecosystem might be located near the Rhine and connected through it.<br><br>Pilot projects may contribute to reinforcing norms on batteries, especially regarding standard compatibility (functioning point, size, structure). This is necessary to improve reusability and recyclability of the next battery generations.<br><br>Primary resources deposits for battery technologies are available in the territory (for example Nickel deposit around Kruth, or lithium project in Bruchsal). However, the potential synergies between this resource exploitation and the project have not been studied yet. | Upstream weak acceptability due to a rebound effect linked to the exploitation of scarce resources whose availability is by definition limited<br><br>Energy dependency: threat of blackout due to growing demand for electricity<br><br>The tolerance for the installation of this type of plant: potential pollution from a battery recycling plant is likely to affect the cost-benefit ratio |

Tab. 7.8: SWOT Analysis related to Green Batteries

| 2 \| Hydrogen | |
|---|---|
| **Strengths**<br>Neuf-Brisach (FR) / Breisach am Rhein (DE) and Ottmarsheim (FR) / Neuenburg am Rhein (DE) are the best locations for $H_2$ multi-hub development around Fessenheim (especially on the French side) since they offer multiple possible $H_2$ applications: industrial, mobility (truck/boat/train), power-to-gas, high electrical power available for electrolysis.<br><br>Some of the industries already present on these sites are among the highest-$CO_2$ emitters of the territory. Development of a hydrogen solution may result in significant reduction of GHG emissions for these industries.<br><br>Coupling electrolysis with photovoltaic panels may help to reduce the electrical load during some days, in a counter-cyclical way. | **Weaknesses**<br>Since the closing of the Fessenheim power plant, the territory is no longer self-sufficient when it comes to electricity consumption (only 2/3 self-sufficiency in Haut-Rhin). $H_2$ production through electrolysis without associated electricity production means will increase the territorial dependency on external supply.<br><br>The profitability of the electrolysis process depends on a high load factor. Thus, the process is not suitable for regulating intermittent sources of energy. Also, the electrolysers cannot work in only a counter-cyclical way (e.g., during cloudy/winter days, at the 7pm-peak).<br><br>The site of Fessenheim gathers less potential local $H_2$ applications than the two previously mentioned ones. It may not be relevant to focus on it in the project.<br><br>Few industries (at most 10) in Haut-Rhin are currently using $H_2$ in their process. Industries that could benefit from integrating $H_2$ in their process are unknown. Most of the market development will probably lean on mobility usage.<br><br>The economic model of $H_2$ systems and ecosystem remains uncertain, especially with electricity price volatility.<br><br>No mention of coordination with regional strategy. |
| **OPPORTUNITIES**<br>Vynova PPC industry (Vieux-Thann) should be considered in the $H_2$ industrial ecosystem of the territory.<br><br>Services areas are locations designed for a Truck Hydrogen Fuel Station (HFS). Economic and LCA scenarios must identify if it is better to produce hydrogen onsite with electrolysers or to mutualise production capacities (through the pilot) and deliver the stations by truck.<br><br>The Hydrogen train line from Breisach to Colmar could be extended to Metzeral. | **THREATS**<br>Growing market for $H_2$, especially for mobility, is still hard to evaluate. Political incentives and territorial coordination are necessary for securing fast market development.<br><br>Many $H_2$ technologies are using platinum, which is a very rare metal. Availability and price volatility may affect the sector. |

Tab. 7.9: SWOT analysis related to Hydrogen.

| 3 \| Smart Grids | |
|---|---|
| **Strengths**<br>The development of intermittent renewable energies requires more advanced management of the electrical network. | **Weaknesses**<br>Poor current knowledge of the electrical needs of the planned projects. Accurate data (with little time step) is needed to give an overview of the actual consumption and production and to assess the benefits of the project.<br><br>Several storage technologies needed for implementing resilient smart grids over several days (for example through power-to-gas-to-power) are still in development. |
| **OPPORTUNITIES**<br>Green batteries project can offer solutions for electrical network stabilisation.<br><br>$H_2$ production through electrolysis is controllable and contributes to energy storage techniques.<br><br>Project should contribute to open accurate data concerning a real case, to feed other similar projects.<br><br>Electrical vehicles can offer a means of flexibility. | **THREATS**<br>$H_2$ production through electrolysis requires a significant period of operation to be economically viable. This could be incompatible with the high intermittency of solar and wind generation.<br><br>The effectiveness of smart grids also relies on efficient sobriety actions and behavioural changes, which can be difficult to achieve.<br><br>Electrical vehicle development requires more electricity.<br><br>Data communication through the grid is very critical. Protection against malfunctions and hacking is extremely important. |

Tab. 7.10: SWOT analysis related to Smart Grids.

## 7.5.2 Territorial Mobility

Four graphics were used to structure the analysis on the opportunities around Fessenheim for de-fossilised mobility (see Figs. 7.12, 7.13, 7.14 & Tab. 7.11).

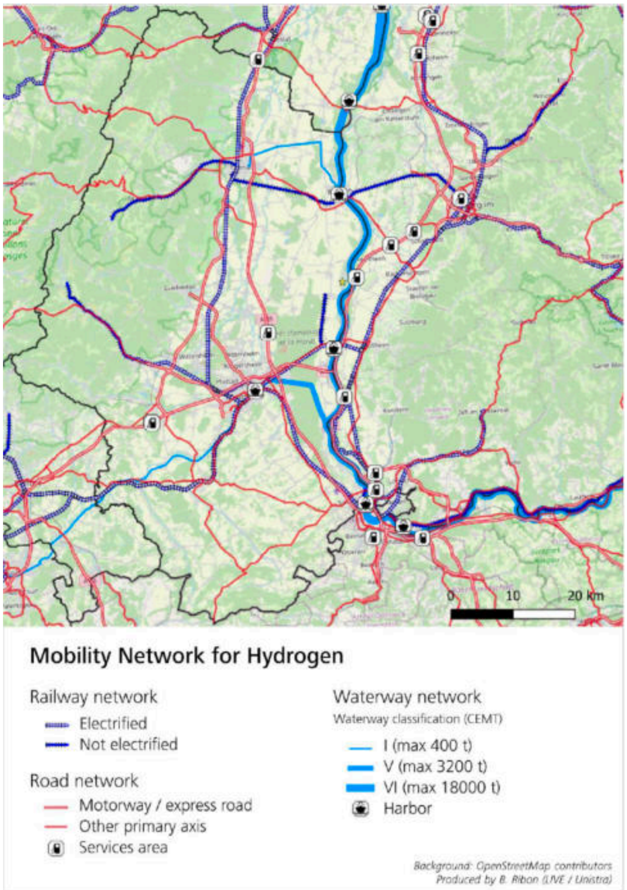



Fig. 7.12: Map of transportation networks: railway, road, waterways. Data sources: SNCF, Deutsche Bahn, OpenStreetMap, Karto-District.

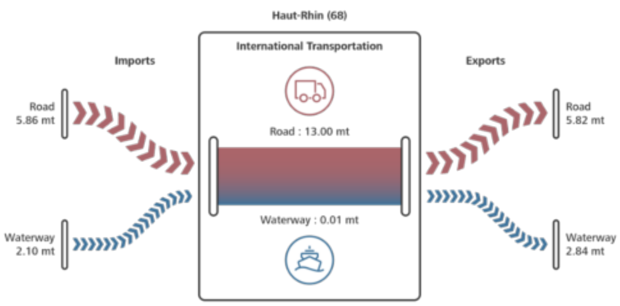



Fig. 7.13: Merchandise transportation into Haut-Rhin (by waterway and road, data for railway are unknown). Source: SitraM 2018 from Ministère de la Transition Écologique.

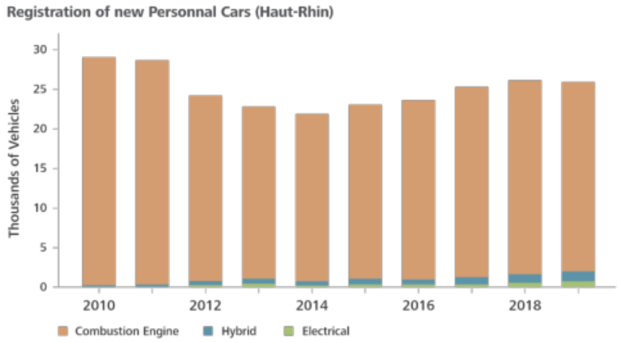



Fig. 7.14: Evolution of the motorisation of new cars in Haut-Rhin. Data source: Données sur les immatriculations des véhicules from Ministère de la Transition Écologique.

| New car registration [vehicles / 1000 cap.] | 2019 | | 2020 | |
|---|---|---|---|---|
| | BEV (% of all cars) | All cars | BEV (% of all cars) | All cars |
| Grand Est<br>5 550 000 cap. | 3 169 (1,8 %)<br>[0,6] | 171.637<br>[31] | 9 034 (7,0 %)<br>[1,6] | 128 177<br>[23] |
| Haut-Rhin<br>761 500 cap. | 635 (2,5 %)<br>[0,8] | 25 829<br>[34] | 1 528 (8,3 %)<br>[2,0] | 18 362<br>[24] |
| Baden-Württemberg<br>11 070 000 cap. | 10 223 (2,0 %)<br>[0,9] | 518 851<br>[47] | 31 367 (7,4%)<br>[2,8] | 425 503<br>[38] |

Tab. 7.11: Evolution of the motorisation of new cars in Grand Est and Baden-Württemberg. BEV: battery (only) electrical vehicle (MTE-DES, Statista).

### 7.5.2.1 Waterway Infrastructure

The Rhine is a structural as well as cultural infrastructure for the territory. A significant amount of merchandise is transported by boat (almost 5 million tons per year), mainly oil products, cereals, gravels, and containers. The Rhine connects the territory directly to neighbouring countries (Germany, Switzerland), Belgium and the Netherlands; this gives access to global maritime transportation. Thus, the Rhine should be considered as a focus for innovation within the territory. However, also a connection to the harbors of Marseille and Genoa is possible in multi-modal mode using railway connection.

As far as the hydrogen hub pilot project is concerned, "hydrogenification" of boats seems to be an interesting specific direction, both for developing the motorisation technology and for installing $H_2$ fuel stations in different harbours along the Rhine.

Regarding the second life battery pilot project, the Rhine can be used for a part of the material logistics - assuming the recycling plant is located close to the river.

### 7.5.2.2 Railway Infrastructure

Few railway lines in the territory are not yet electrified. They are good candidates for hydrogen-powered trains:

- Thann – Kruth (FR): extension of the already electrified line Mulhouse – Thann
- Metzeral – Colmar & Colmar – Neuf-Brisach (FR)
- Freiburg im Breisgau – Breisach am Rhein (DE)
- Freiburg im Breisgau – Elzach (DE)
- Basel – Erzingen (CH-DE)

Additionally, the presence of a train technical center in Mulhouse, where an $H_2$ fuelling station can be located is also noted. There are already plans to run hydrogen trains on the Mulhouse – Thann – Kruth line at the end of 2023 (SNCF, 2021). In parallel, there is a project to electrify the Freiburg im Breisgau – Breisach am Rhein line (Frietsch-Schöneberg, 2019). It could be interesting to consider running an $H_2$-powered train on the other lines and have an $H_2$ fuelling station on the German side as well.

### 7.5.2.3 Road Infrastructure

The development of hydrogen mobility seems to be more adapted for heavy vehicles (trucks) than light ones (cars). Thus, hydrogen fuelling stations are ideally located near main transport axes or industrial areas - service areas being premium locations. There are only 3 on the French side, and 9 on the German side. Hydrogen fuelling stations in industrial areas in synergy with other applications (like in Ottmarsheim and Neuenburg am Rhein) are also interesting locations.

Furthermore, it would be interesting to have a life cycle and economic analysis to compare these two possibilities: producing $H_2$ on-site (on service area) with an electrolyser (for example) or producing hydrogen somewhere else with more capacity (economy of scale) but having to transport it to the service area where the only concerns would be hydrogen storage and truck distribution.

### 7.5.2.4 Electric Mobility

Data on motorisation of new registered personal cars show a slowly growing trend towards electric mobility though this is still limited to a small proportion of vehicles (less than 10 %). Even with a very significant increase in electric cars sold in 2020 (+150% compared to 2019), they will become mainstream only in a few years from now. With an 8-year battery lifetime, we do not expect a significant quantity of batteries to be recycled before at least 2030.

The installation of recycling capacity must take this time horizon into account. However, for a pilot project with a low target capacity (1 ton of battery/day i.e., around 2 or 3 cars) designing innovative recycling infrastructures and testing the process under real conditions is needed. In the long-term (i.e., at least 15-20 years), we evaluate that around 120 000 BEV could be sold each year in the Upper Rhine (~20 vehicles/year/1000 capita). Another study also comes up with similar estimates (Neff et al., 2021). With two battery sets for one vehicle (vehicle lifetime is around two times battery lifetime), that would represent around 250 tons per day of battery to be recycled. These figures are speculative, but still credible and provide a first proposal of a long-term target.

## 7.5.3 Energy and Climate

Energy Production and the associated infrastructure are vital components that must be discussed further with regards to the climate. The transition in energy carriers has a strong impact on the climate and relevant technologies, as well as their usage are at the heart of this subchapter.

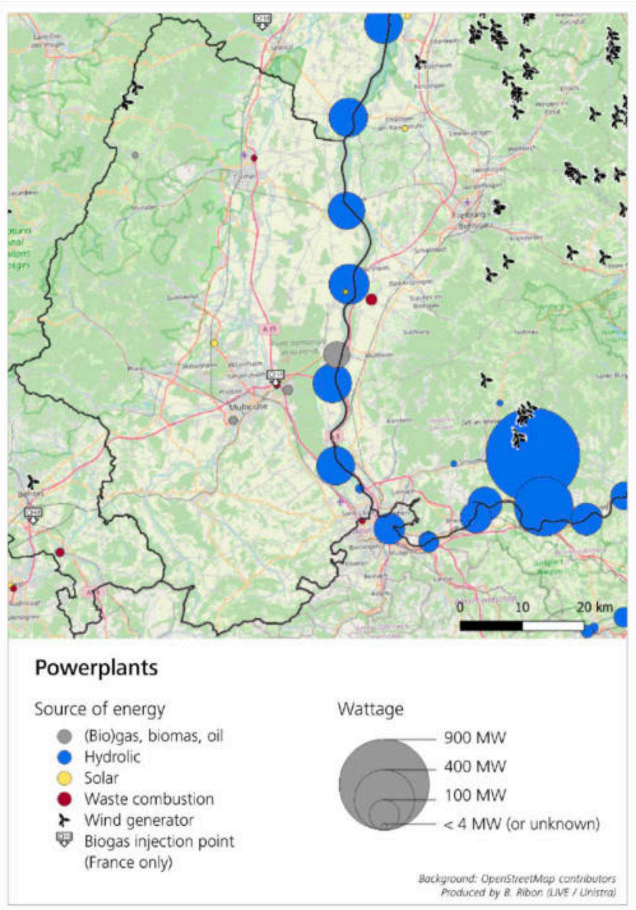



Fig. 7.15: Map of hydropower plants in the area. Data source: OpenStreetMap contributors

### 7.5.3.1 Electricity Production and Consumption

Since the closing of the nuclear power plant of Fessenheim, the main source of electricity in the territory comes from the Rhine thanks to the presence of the numerous installed hydroelectric dams (Fig. 7.15). But this is not sufficient to cover the electricity demand (see Figs. 7.16 & 7.17). Thus, the territory is dependent on other sources and/or external supply. We also show energy price index evolution over the last three decades (Fig. 7.18) to bring more contextualisation elements.

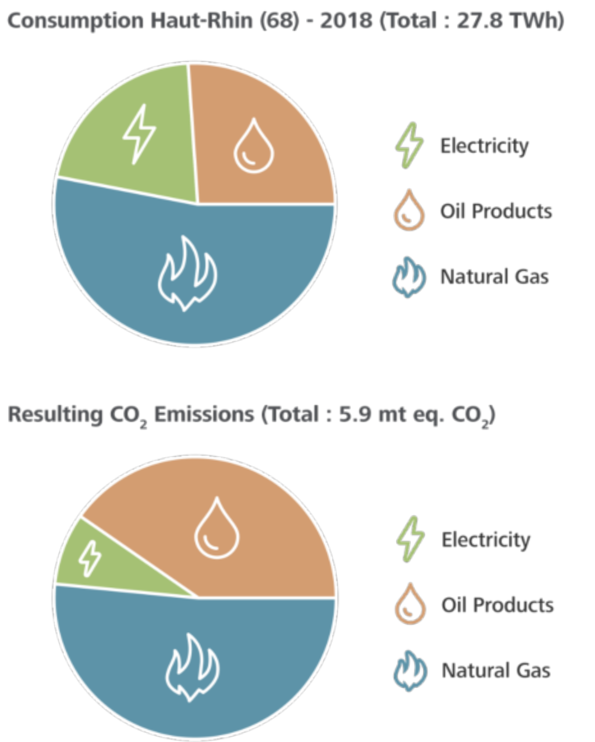



Fig. 7.16: Energy consumption in Haut-Rhin (top), and resulting CO2 emissions (bottom).Data source: Données locales de consommation d'énergie from Ministère de l'écologie.

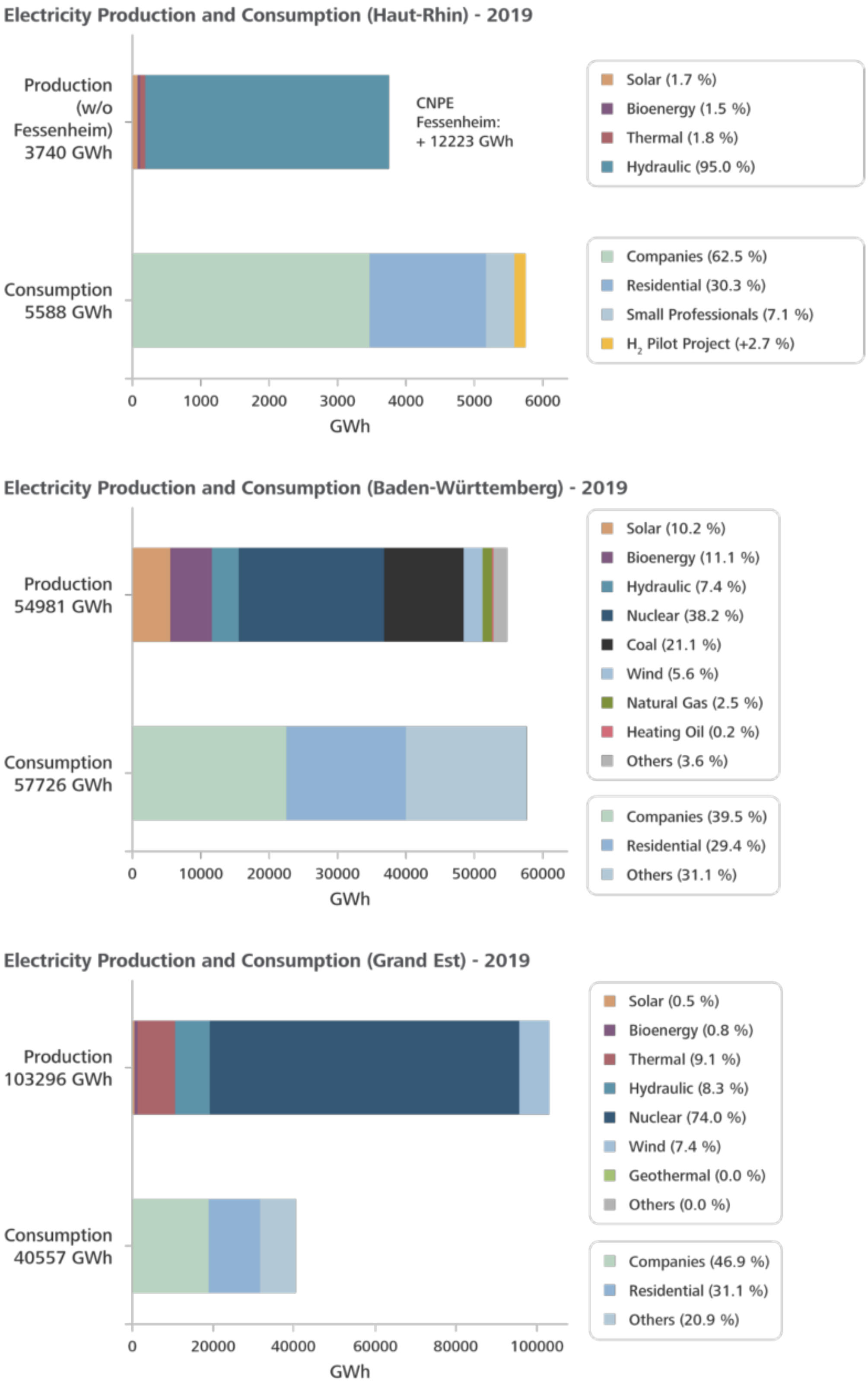



Fig. 7.17: Electricity production and consumption in Haut-Rhin (top), Baden-Württemberg (middle) and Grand Est (bottom). Data sources: Données locales de consommation d'énergie from Ministère de l'Ecologie ; Erzeugung und Verwendung from Statistisches Landesamt Baden-Württemberg ; MUKEBW 2019.

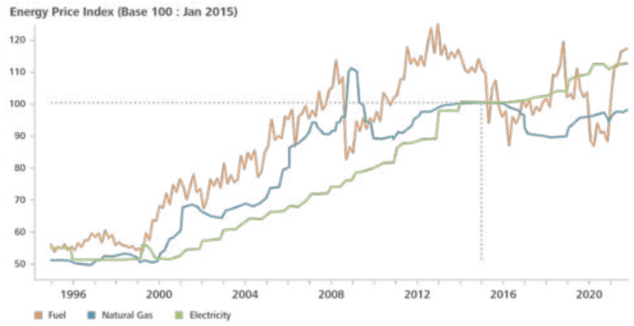



Fig 7.18: Energy Price index evolution in Baden-Württemberg (base 100: january 2015). Source: Erzeugung und Verwendung from Statistisches Landesamt Baden-Württemberg.

Taking into account the fact that there is an energy production deficit in the Upper Rhine region, the production of hydrogen through electrolysis does not look like the best choice, as it would increase external dependency. The complementary installation of photovoltaic panels can, however, contribute to balancing the project in this regard.

In the territory, there is a lot of agricultural activity making it favourable for the production of biogas through methanisation. It thus looks very interesting to explore the possibility of producing hydrogen from biogas. This is already possible with current steam reforming and emerging thermo-cracking techniques, which allow the production of hydrogen with a negative climate impact (see Section 7.5.4). However, biogas production is more space consuming, and around 20 methanisation plants are needed to get power equivalent to that of the $H_2$ pilot project.

### 7.5.3.2 Electrical Smart Grids

The electricity network requires a permanent balance between production and consumption. With the development of renewable energies, this balance is more difficult to achieve because the control of intermittent production means is not possible. A combination of different strategies is therefore needed to ensure the balance. It can consist in building back-up power plants, developing storage installation, as well as shifting and reducing needs.

- Back-up production means are controllable power plants running only when other means are not producing enough. Usually, they are fossil gas power plants. It is possible to use biogas if available to reduce climate impact, but with a low load factor and in a transitional process, even using fossil gas may be worth looking at the given service.
- Storage techniques for electricity are in permanent improvement. Lake dams are currently widely used, but most of the interesting sites are already exploited, thus their future development is unlikely. Thermal and electrical batteries, power-to-gas-to-power (through $H_2$ or $CH_4$), and pressured air are emerging technologies that may reinforce the storage capacity.
- Shifting the need may concern, for example, the use of domestic hot water or the electrical vehicle load: their operation can be shifted from running during consumption peaks without affecting the user (if some precautions are taken). Examples of a few days shifting are more difficult to find. Probably some need could be shifted from the weekdays to the weekend.
- Reducing the need is probably the most important approach to bring resilience and climate neutrality to the electrical networking. It mainly consists of isolating buildings, reducing individual car need, reducing good manufacturing, removing permanent screens, improving light efficiency etc... but this may also concern processes (especially industrial ones) that could come to a halt when demand is much higher than supply.

Based upon these strategies, an advanced control system is necessary to arbitrate which means to operate and which to stop or shift. But this control system is not by itself sufficient. It must be built upon existing energetic installations and adapted social organisations to be efficient. Thus, we suggest including in the project a thorough examination of the technical and social means available to implement the strategies outlined above.

### 7.5.3.3 Reducing $CO_2$ Emissions in Industry

Some of the biggest $CO_2$-emitters in the territory are hydrogen users. Hydrogen is currently produced by natural gas steam reforming, which generates considerable $CO_2$ emissions (see Fig. 7.19). Having low-carbon $H_2$ production for these industries may result in significant reductions of these emissions. Undoubtedly, this study is an important activity to reach the target of a neutral-$CO_2$ territory.

## 7.5.4 Hydrogen Industrial Ecosystem

Electrolysers are not the only technology used to produce green hydrogen, even if other technologies may be less technically mature. Tables 7.12 and 7.13 give an overview of hydrogen production possibilities and applications respectively. Hydrogen plants currently running in Haut-Rhin can be seen in Fig. 7.20 and listed in Tab. 7.14. Based on this data, the current state of hydrogen uses, production, and needs are discussed.

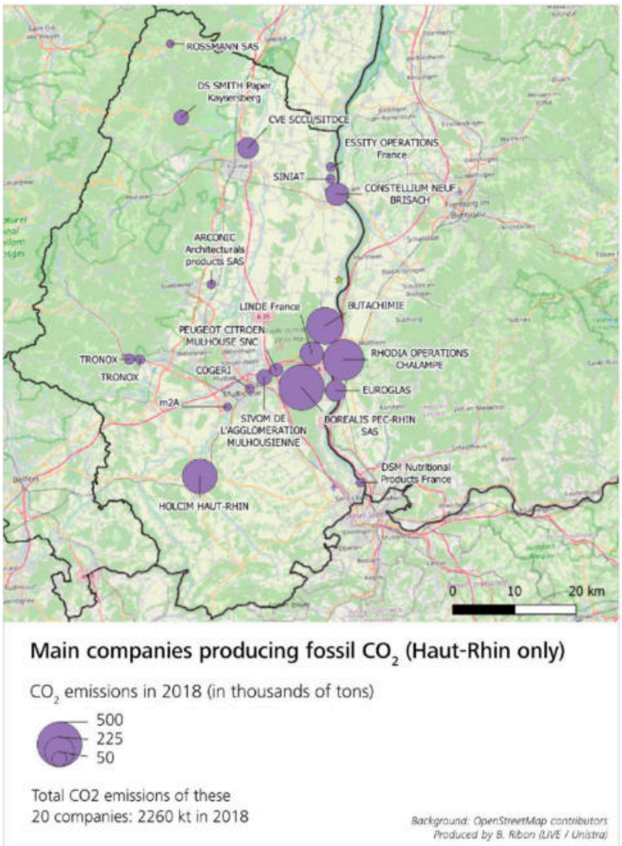



Fig. 7.19: Map of the main fossil $CO_2$ industrial emitters in Haut-Rhin. Data source: IREP-Registre des émissions polluantes from Ministère de l'Ecologie.

| **Process** | **Significant reactant of the process** | **Significant co-product of the process** | **Comment** |
|---|---|---|---|
| Industrial co-product | | | Concerns industrial plant where hydrogen is coproduced in some process. This hydrogen is sometimes released in the air if there is no use. Vynova PPC (in Vieux-Thann) is in the case. |
| Electrolysis | Electricity ; (heat*) ; pure water | $O_2$ | The plant may require high power supply (20 Mw-for pilot project) \| *Heat is needed for high-temperature electrolysis technology (not for all electrolysis technologies) |
| Steam reforming | | $CO_2$ | Biogas can also be used in order to reduce climate impact |
| Biomass thermolysis | | ($CH_4$) ; CO ; biochar | May have a negative climate impact on the life-cycle |
| Production through biological process | Organic waste | | Near organic waste producer See Menia et al. 2019. |
| Thermo-cracking | $CH_4$ | Solid carbon | May have a negative climate impact if biogas is used |

Tab. 7.12: Overview of hydrogen production means.

| Application | Significant co-reactant of the process | Significant product of the process | Comment |
|---|---|---|---|
| Industrial input (refining, fertiliser, …) | | | Few industrial sites are using $H_2$ in their process (around Ottmarsheim, Marckolsheim and Sélestat) |
| Mobility and mobile machines | | | Hydrogen Fueling Station – HFS should be placed near mobility network (main road, $H_2$ railway, river) or be accessible to mobile machines (e. G. For agriculture) |
| Gas network injection | | | Currently limited to 6% of $H_2$ in gas network (in France) but it may increase up to 10 or 20 % in the future |
| Methanation | $CO_2$ | $CH_4$ ; heat | Ideally placed near a gas network, a $CO_2$ producer and a heat network |
| Spacecraft | | | No concern for the project |

Tab. 7.13: Overview of hydrogen applications.

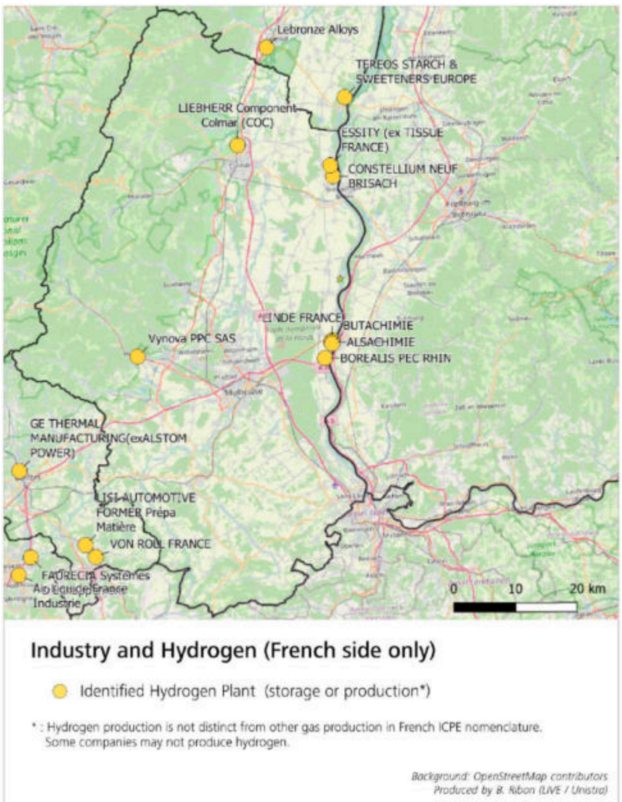



Fig. 7.20: Map of hydrogen plants in Haut-Rhin (storage or production ). Data source: ICPE-Registre des installations classées 2019 from Géorisques.

| Code | Nom | Activity | City | ICPE details | ICPE nomen. |
|---|---|---|---|---|---|
| 0067.0 0433 | Vynova PPC SAS | Fine chemistry of bromine, potassium and chlorine derivatives | Vieux-Thann | $H_2$ production: 6 t/j | Ex-1415; 3420-a* |
| 0067.0 0469 | CONSTELLIUM NEUF BRISACH | Aluminium sheets, coils and strips | Biesheim | $H_2$ storage: 24,5 kg | 1416 |
| 0067.0 0471 | BOREALIS PEC RHIN | Chemicals and fertilizers | Ottmarsheim | Gas production: 775 | 3420-a* |
| 0067.0 0513 | BUTACHIMIE | Polyamide intermediates of the nylon chain | Chalampé | Gas production: 33 | 3420-a* |
| 0067.0 0538 | ALSACHIMIE | Production of polyamide and nylon intermediates | Chalampé | Gas production | 3420-a* |
| 0067.0 0642 | ESSITY (ex TISSUE FRANCE) | Manufacture of toilet paper, single-use tissues | Kunheim | $H_2$ storage: 50 kg | Ex-1416 |
| 0067.0 0643 | TEREOS STARCH & SWEETENERS EUROPE | Processing of wheat and maize into starches and derived sweetening ingredients | Marckolsheim | $H_2$ use or storage max on site: 3 t | 4715-1 |
| 0067.0 0787 | Lebronze Alloys | Casting, rolling, drawing and coating of copper alloys | Sélestat | $H_2$ Storage: 0,45 t | Ex-1416 |
| 0067.0 2200 | LINDE FRANCE | Manufacture of industrial gases | Chalampé | $H_2$ production max on site: 1,16 t | 3420-a |
| 0067.0 5541 | LIEBHERR Component Colmar (COC) | Design of high-performance diesel engines | Colmar | $H_2$ storage: 9,2 kg | Ex-1416 |

Tab. 7.14: Hydrogen plants in Haut-Rhin (storage or production[4]). Data source: ICPE-Registre des installations classées 2019 from Géorisques.

[4] Hydrogen production is not distinct from other gas production in ICPE nomenclature. Quoted companies may not be hydrogen producers.

### 7.5.4.1 Hydrogen Use in the Territory at the Present Time

Currently, hydrogen is used in a few locations in Haut-Rhin (see chapter 5.4). In Vieux-Thann, Vynova PPC is producing $H_2$ as a by-product of its processes. This $H_2$ is currently partially released in the air, but a project is ongoing to recover it. At the other industrial site, $H_2$ is used as a reactant for processes. Currently it is mainly produced from natural gas steam reforming.

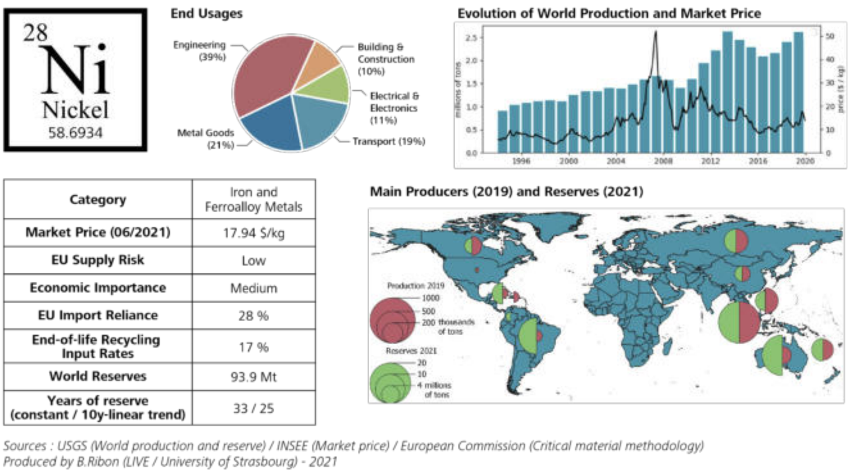
Using biogas could significantly reduce climate impact without the need of new technologies development and costly infrastructure.

### 7.5.4.2 Hydrogen Price

Electricity prices have been particularly volatile in recent months but have also shown a significant upward trend over the past decade (Fig 7.18). These prices represent a significant part of the cost of producing hydrogen by electrolysis. Basic calculation shows that $H_2$ production with current technology would need a carbon price of at least 200 €/ton of $CO_2$ to be competitive. With the price peaks we have seen this winter, the threshold could even be higher.

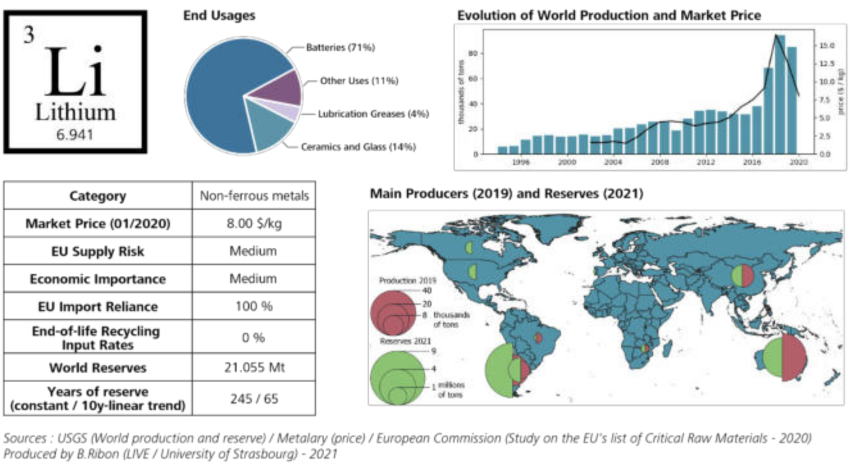
## 7.5.5 Raw and Critical Materials

Raw materials are an important concern for new energy-related technologies. Among these materials, some are common (iron, aluminium, copper) and others are scarcer (nickel, manganese, cobalt and lithium for batteries, platinum for hydrogen electrolyser). Below, you will find some summary elements for a better understanding of the related issues (see Figs. 7.21 & 7.22, Tabs 7.15 & 7.16 and following discussion).




| Category | Iron and Ferroalloy Metals |
|---|---|
| Market Price (06/2021) | 17.94 $/kg |
| EU Supply Risk | Low |
| Economic Importance | Medium |
| EU Import Reliance | 28 % |
| End-of-life Recycling Input Rates | 17 % |
| World Reserves | 93.9 Mt |
| Years of reserve (constant / 10y-linear trend) | 33 / 25 |

Fig 7.21: Datasheet for Nickel. Data sources: USGS (World production and reserve); INSEE (Market price); European Commission (Critical material methodology).




| Category | Non-ferrous metals |
|---|---|
| Market Price (01/2020) | 8.00 $/kg |
| EU Supply Risk | Medium |
| Economic Importance | Medium |
| EU Import Reliance | 100 % |
| End-of-life Recycling Input Rates | 0 % |
| World Reserves | 21.055 Mt |
| Years of reserve (constant / 10y-linear trend) | 245 / 65 |

Fig 7.22: Datasheet for Lithium. Data sources: USGS (World production and reserve); Metalary (price); European Commission (Study on the EU's list of Critical Raw Materials - 2020).

| kg/kWh | Li | Ni | Co | Mn |
|---|---|---|---|---|
| NCA | 0,10 | 0,67 | 0,13 | 0,00 |
| NMC 111 | 0,15 | 0,40 | 0,40 | 0,37 |
| NMC 433 | 0,14 | 0,47 | 0,35 | 0,35 |
| NMC 532 | 0,14 | 0,59 | 0,23 | 0,35 |
| NMC 622 | 0,13 | 0,61 | 0,19 | 0,20 |
| NMC 811 | 0,11 | 0,75 | 0,09 | 0,09 |
| LFP | 0,10 | | | |

Notes: NCA refers to nickel cobalt aluminium oxide, NMC refers to nickel manganese cobalt oxide (numbers indicate the atomic share of each metal), LFP refers lithium iron phosphate oxide. Source: ANL (2018b).

Tab. 7.15: Overview of critical material intensity of key battery chemistries. Data source: IEA 2018b, p. 84 after ANL 2018b).

| Model | Renault Zoe | Tesla Model 3 |
|---|---|---|
| Capacity | 52 kWh | 75 kWh |
| Technology | | NMC 811 |
| Weight | 356 kg | 479 kg |
| Lithium | 7 kg | 6 kg |
| Manganese | 11 kg | 6,6 kg |
| Cobalt | 11 kg | 7 kg |
| Nickel | 34 kg | 56 kg |
| Copper | 85 kg | 85 kg |

Tab. 7.16: Overview of critical material intensity for two commercial cars. Data sources: FranceTV Info, 2020; Daina et al., 2020; ZSW-BW, 2020.

### 7.5.5.1 Increase of Raw Materials Demand

Our research has led us to identify possible supply difficulties for materials used for electric mobility, in particular, nickel and lithium (Gallucci, 2021b). The problem is not really the geological volumes available, but rather the ability to extract them at a satisfactory rate to meet the strong growth in demand in the coming years.

This has two main consequences regarding the green batteries pilot project:

- Its pertinence: it will be very important to have an available recycling process to reuse these materials and reduce dependence on external and primary resource extraction.
- The impact of such supply difficulties on the electric vehicle market development: production cannot be as fast as envisioned. The risk is having a battery volume that grows too slowly in the next 20 years, and thus not having a significant volume to process to justify the implementation of an industrial process.

On the other hand, platinum, a critical and costly material for efficient hydrogen production through electrolysis may also be exposed to a supply risk. Current data suggests a need of 0,8g of platinum per 1kw of electrolyser capacity. The long-term target is around 0,1 - 0,2 g Pt/kW (Durville et al., 2015). This risk on supply also underlines the importance of working on the reduction of our needs (especially personal travel by car), to transform our mobility, and not only on its electrification. However, this need is not explicitly targeted in the innovation study but is targeted in the overall territorial strategy.

### 7.5.5.2 Local Resources

In recent decades, mining materials have been heavily outsourced to less developed countries. But there seems to be an increasing number of voices in favour of exploiting mines in Europe. This appears to be a solution to the supply risks, while operating in better environmental and social conditions. Therefore, we investigated whether there are any interesting geological deposits to exploit in the region, particularly regarding critical materials linked to the pilot projects.

In the Haut-Rhin, the area around Sainte-Marie-aux-Mines was exploited for mining in the last few centuries. Nickel was among many other minerals which were extracted. These mines are no longer in operation and we have no information on the deposits that are still present.

As far as Lithium is concerned, deposits have been found in the geological subsoil of the Upper Rhine Plan. These deposits seem to be exploitable through geothermal installations and with recent water filtration technologies it seems possible to extract lithium (Potier, 2019; Dugamin et al., 2021). We have already identified two sites with ongoing projects relevant to this topic in the Upper Rhine: Soultz-sous-Forêt (Potier, 2019) and Bruchsal (Eggstein, 2020), with significant volume: around 150 t/y of lithium per site (20 000 electrical car batteries ≃ 150 t lithium). This process can be generalised to other geothermal installations in the region. Thus, these projects are worth considering in synergy with the green batteries pilot project.

Lithium has seen a recent sharp increase in price (5-fold by 2021, reaching over $50/kg by early 2022), and production (Fig. 7.22). It has entered the EU's list of Critical Raw Materials (European Commission, 2020) and European countries are completely dependent on external supplies. Thus, the exploitation of the available deposits in the Upper Rhine seems to have a particularly strategic interest.

## 7.5.6 Land Use

In this subchapter we present three land use maps around the main pilot project locations: Neuf-Brisach & Breisach am Rhein; Fessenheim; Ottmarsheim & Neuenburg am Rhein (see Figs. 7.23, 7.24 & 7.25). These maps can be used to discuss the best place for the implementation of the pilot.

### 7.5.6.1 Location of the Hydrogen Plant around Ottmarsheim

Land use data reveal a free space between Borealis and the group Alsachimie-Butachimie-Linde, that are the current hydrogen users of the area. This could be a good and close location for the hydrogen pilot project. Some other areas are also free, but they are farther away from the industrial plants and closer to the residential areas, which is less desirable as regards acceptability concerns.

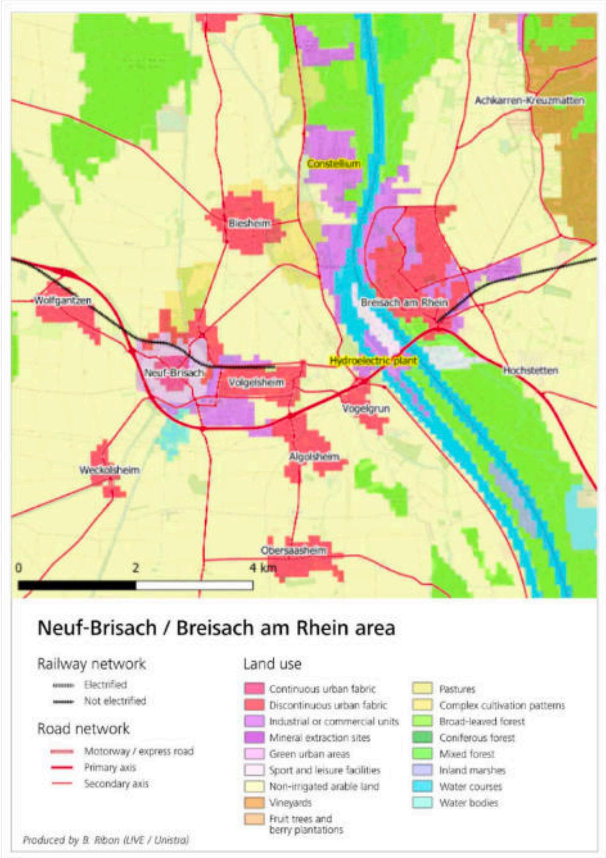



Fig. 7.23: Land use maps: Neuf-Brisach & Breisach am Rhein. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

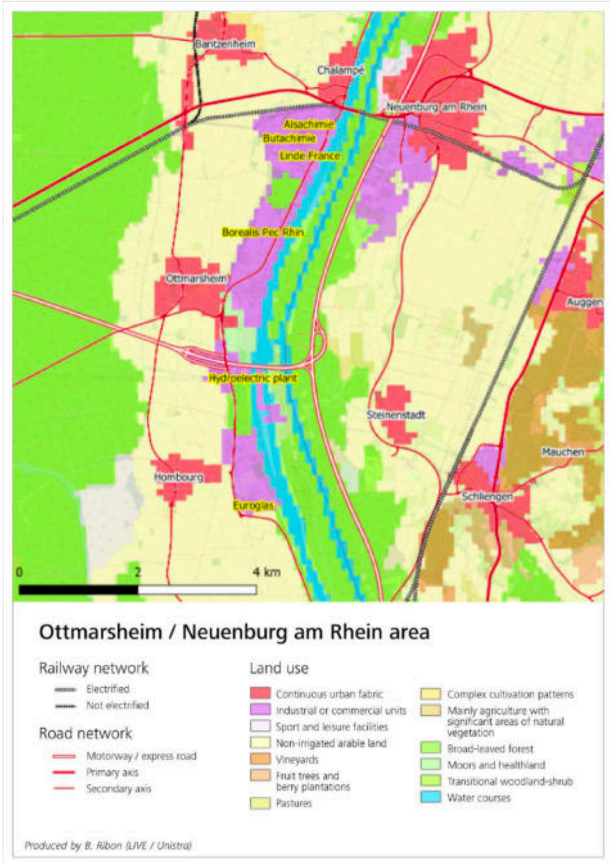



Fig. 7.25: Land use maps: Ottmarsheim & Neuenburg am Rhein. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

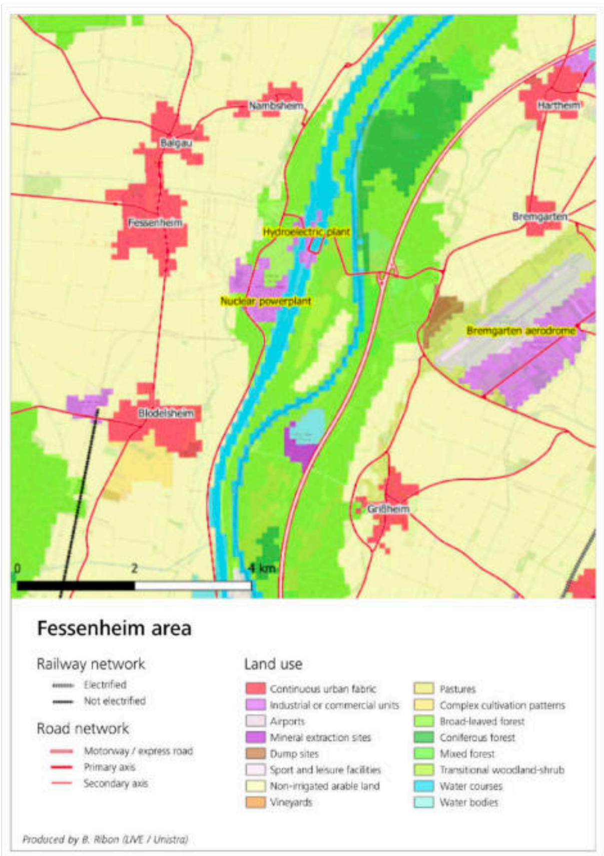



Fig. 7.24: Land use maps: Fessenheim. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

### 7.5.7 Conclusions and Recommendations for Territorial Anchoring

**Green Batteries Pilots**

The current trend, where the electrical vehicle market is growing quickly, will require an efficient end-of-life solution for batteries in a few years (probably five to ten years). The pilot tackles this issue with a large overview: it highlights interesting opportunities for a complete and circular economy of batteries.

The Green Battery project considers a large variety of technologies, with different readiness levels and development timelines. It results in potential synergies but also in interferences or dependencies that should be more clearly highlighted. Some technologies (lowest maturity or with high economy of scale) should consider gathering partners (industrials and politics) beyond the Upper Rhine Region.

Battery recycling techniques are still emerging, subject to technological developments and the pilot project is open to the idea of experimenting with different approaches (manual, mechanical, chemical, biological). The installation site selected - which may consist of several sites - must therefore be designed to evolve and offer the necessary spaces for this experimentation.

The processing capacity of the pilot project (1 tonne of car batteries per day) seems to be adapted to the volume currently available in the territory. In the long-term (15-20 years), we believe that the volumes of electrical car batteries to be recycled will be around 250 tons per day in the Upper-Rhine.

The question of primary resources should also be addressed as it is closely linked to battery issues. The Upper Rhine has deep and significant deposits of Lithium which could be recovered through geothermal energy. Deposits of other minerals, in particular Nickel, also exist in the territory but are no longer exploited. The (re-)exploitation of these deposits deserves to be studied given the importance of these materials in batteries, and the criticality of batteries for electric mobility development.

**Hydrogen Pilots**

The two proposed locations (NB/BR and OT/NR) and Vieux-Thann are interesting for developing a territorial $H_2$ ecosystem because of the synergy potential. However, due to a lack of data, it was not possible to evaluate if the pilot project production (3000 $tH_2$/year) corresponds to the current and future needs.

We note that electricity production capacities are limited, especially in the studied territory. Producing $H_2$ through electrolysers may add a significant and almost permanent (for economic profitability) load on the electrical network. There are suitable proposals by the hydrogen competence group to overcome these challenges. Associated PV infrastructures may compensate for some of the load. On the other hand, the territory has significant biomass resources that could be used to produce hydrogen and a better realisation of the technical potentials in the areas needs more intensive discussion.

**Smart Grids Pilots**

The Smart Grid project mostly relies on energy optimization. “Energy sobriety” should also be underlined for the effectiveness of smart grids.

It is generally quite rare to have detailed data (temporally and spatially) on the energy consumption of a territory. The Smart Grid project should make their data publicly available as scientific contributions to support similar projects elsewhere. This project presents an opportunity to build and disseminate consumption data (with the necessary statistical anonymization) of the considered experimentation field in order to support other projects.

**Global Territorial Strategy**

The stated objectives of the feasibility study around the Fessenheim region are to reduce greenhouse gas (GHG) emissions and move towards a $CO_2$ neutral region, make Fessenheim an innovative region, and support employment affected by the closure of the nuclear power plant. It examines the importance of developing technological pilot projects around hydrogen technologies, battery recycling and the development of smart grids.

The examination of the project through the territorial metabolism approach raises questions about the coordination between the pilot projects and the territorial project (Projet de Territoire). While the pilots are interesting in themselves for their contribution to the reduction of GHG emissions, their integration into a coherent territorial policy, including other territories in the vicinity, needs a more thorough examination.

This is particularly noticeable for the production of hydrogen by electrolysis. If technically the project has interests in the two identified favourable sites (Ottmarsheim & Breisach), the interaction between the policies and the economy of the territory is not really clear. Finally, apart from these two sites, there are few other interesting sites for developing hydrogen technologies. Moreover, the production of hydrogen by electrolysis is not particularly innovative and the local production of electricity is currently insufficient to cover these new needs. It would have seemed more appropriate to focus on different (but perhaps less mature) technologies for the production of hydrogen (from biogas, thermolysis, thermo-cracking). This does not prevent the development of electrolysis solutions in the short-term in order to quickly start the development of the hydrogen ecosystem, but this development should also be accounted for in a medium and long-term development plan.

Clarifications regarding the territorial development strategy for the studied fields is needed instead of a succession of pilot projects. The rapid deployment of these new sectors seems to require:

- A shared consensus of the public and private stakeholders and players concerned and/or involved in the development of the sectors,
- Significant and explicit public support to limit the additional costs associated with emerging technologies,
- Greater participation by private stakeholders, particularly in sharing their information. It is crucial to have a better understanding of current and potential needs (e.g., for hydrogen) in order to develop appropriate facilities,
- A more explicit coordination of public policies at different territorial levels and with the surrounding territories.

## 7.6 Legal Framework

The pilot projects are developed in the Franco-German border region. As law is based on the national territories it is important to establish the general principles of German and French law. This comparative description establishes the convergence and differences of both sets of rules to assess both the legal constraints and opportunities for the development of battery production and recycling plants, hydrogen production and smart grids along the Franco-German Rhine. A focus will be made on the possible legal exemptions that can be obtained in French and German law. Possible cross-border pilot projects will be analysed to assess possible legal strategy, especially in the context of the Aachen Treaty.

### 7.6.1 Battery Production and Recycling

Germany and France both have markedly different legislation regarding battery handling sites. The relevant regulations are listed and explained briefly here.

#### 7.6.1.1 Under German Law

Battery recycling plants are typically plants requiring a permit according to BImSchG – Bundes Immissionsschutzgesetz (Federal Immission Control Act), which, if the threshold values are exceeded, are subject to a formal immission control procedure according to § 10 BImSchG with public participation. The plants are likely to fall into the catalogue of plants named in the 4th BImSchV according to No. 8.11.1 or No. 8.11.2.

Technically, the following typical operating units are likely to be covered by the permit: storage areas (indoor and outdoor storage for both primary and secondary batteries), a sorting facility, crushing facilities for primary batteries, separation facilities, cooling storage, dismantling facilities for the various battery types, filter facilities for the dismantling and processing facilities (dust and activated carbon filters) as well as workshops, scales and a transformer station.

In this configuration, the plant is not likely to fall under Appendix 1 (especially No. 8) of the UVPG – Gesetz über die Umweltverträglichkeitsprüfung (Environmental Impact Assessment Act), and an UVP – Umweltverträglichkeitsprüfung (EIA - Environmental Impact Assessment) would probably not be required in this respect. However, this would still have to be checked on the basis of the technical specifications.

In this respect, reference can be made to the elements presented above.

#### 7.6.1.2 Under French Law

The production unit requires a series of administrative authorisations which need careful preparation and have a clear cost. Such a plant can be considered as an ICPE (installation classée) according to the Code de l'Environnement. The obligation to declare the activity or to authorize it is clearly described on the ministry website (AIDA1810 2015). It is important to have a precise description of the project to follow the classification procedure.

A single course of action which establishes a unique authorisation procedure (AE 2017, p.4) to the national authorities in charge of the control of the ICPE (L 181-1 du Code de l'Environnement)[5] has been in place since 2017. A specific dossier must be set up, and the authorities must conduct a public inquiry. The advantage is that a unique control is made on all environmental effects of the projects (on water, Natura 2000 zones, Habitats directive, etc) and other effects. This unique authorisation is a simplification, but a "permis de construire" should also be required from the local authorities. An authorisation to exploit the plant may be requested in a separate procedure before the Préfet.

Both sets of rules require an authorisation to avoid serious threats to the environment. These authorisations are costly and time-consuming; this must be taken into ac-

[5] For a checklist in the Région Grand Est, see ref. DREAL-GE.

count before any concrete actions. A deeper analysis of the administrative practices is needed to assess the differences of content between the French and German legal approaches.

No specific regulation exists concerning storage of batteries under French Law which constitutes a serious legal risk for the recycling of batteries. One of the questions is the legal treatment of Lithium, which is considered a dangerous product:

- The storage building must be adapted to the danger which varies with the age and condition of the battery;
- As a dangerous product, the transport of Lithium is also regulated through providing adequate information about its handling to the carrier.

## 7.6.2 Hydrogen Production

Like battery handling which is subject to many restrictions, hydrogen is a similarly regulated commodity, with varying legislation across borders.

### 7.6.2.1 Under German Law

The legal framework for hydrogen uses in Germany is currently still incomplete (Langstädtler, 2021).

For the production of hydrogen, i.e., the construction and operation of electrolysers, reformers or separation plants, a formal immission control approval procedure with public participation is regularly required. The legal basis for this procedure is § 10 BImSchG. In principle, this is always applicable if the plant is named in Appendix 1 of the so-called Plant Ordinance (4th BImSchV) and which is marked there with a "G" (cf. Dietlein, in: Landmann/Rohmer, Umweltrecht, 81st EL 2016, § 4 BImSchG Rz. 7f.).

Electrolysers, reformers or separation plants may be covered by No. 4.1.12 of Appendix 1 of the 4th BImSchV. This covers "installations for the production of substances or groups of substances by chemical, biochemical or biological conversion on an industrial scale [...] for the production of gases such as ammonia, chlorine and hydrogen chloride, fluorine and hydrogen fluoride, carbon oxides, sulphur compounds, nitrogen oxides, hydrogen, sulphur dioxide, phosgene."

The facility must also produce hydrogen on an "industrial scale." The specific threshold for this is, on the one hand, legally unclear (Bringewat, 2017), and, on the other hand, actually unclear (size of the pilot).

Hydrogen storage facilities are also operating sites or other stationary facilities according to § 3 para. 5 no. 1 BImSchG and thus facilities according to the BImSchG.

It must also be examined whether the pilot falls within the scope of § 23b BImSchG and the Major Accidents Ordinance (12th BImSchV), where limits on hydrogen quantity are imposed in number 2.44.

Characteristic for the procedure according to BImSchG is the concentration maximum, according to which in principle all necessary official permits are granted in this procedure (§ 13 BImSchG). Within this framework, the relevant requirements under building planning law (such as Section 35 (1) No. 3 of the German Building Code (BauGB)) must also be taken into account.

The construction of new hydrogen transport networks is not covered by the EnWG – Gesetz über die Elektrizitäts- und Gasversorgung (Electricity and Gas Supply Act). The situation is different for the rededication of existing (underground) gas pipelines. However, the exemption from the UVP pursuant to Section 43 f (2) EnWG does not apply there either. Incidentally, this also applies to the conversion of natural gas storage facilities.

In all cases, it must still be checked whether the threshold values of the UVP are exceeded (§§ 4 ff. UVPG).

### 7.6.2.2 Under French Law

**A Future Major Component of French Energy Mix**

The « Loi relative à la transition énergétique pour la croissance verte (2015) » is designed to reduce greenhouse gas. It is based on a national low carbon strategy (2015) wherein greenhouse gas emissions are to be cut by a factor of four by 2050 on the basis of the 1990 levels of emissions and national energy dependence with the objective of 32% of renewable energy on the French energy mix in 2030. After the Paris Agreement (2015), a second low carbon strategy was agreed upon, in 2020, to achieve a reduction of greenhouse gases by a factor of six - and thus abide by this international agreement.

The 2020 strategy establishes the objective to achieve a carbon neutral economy by 2050 based on biomass resources, carbon-free electricity and heat from the environment. Low-carbon hydrogen is more specifically promoted by the “Loi relative à l’énergie et au climat (2019)“, with the objective to achieve 20% to 40% of total consumption of industrial hydrogen in 2030. The “ordonnance n° 2021-167 (2021)“ and national strategy dedicated to low-carbon hydrogen (2020)[6] are adopted to develop low-carbon and renewable hydrogen.

[6] Hydrogen can be produced by water electrolysis from decarbonized electricity or renewables. Such hydrogen is called “decarbonized” as neither its production or usage emits $CO_2$.

### The French General Legal Framework

Hydrogen production, transport, storage and traceability is governed by the new livre VIII of the Code de l'énergie which has been introduced by the " Loi relative à l'énergie et au climat (2019)" and the " ordonnance n° 2021-167 (2021)". Hydrogen is considered as a vector of energy carrying certain dangers from production to storage. Its production, distribution and storage are therefore governed by the ICPE regulation and require a unique environmental authorisation (see supra)[7].

The «arrêté sur les stations d'hydrogène» describes the legal obligations imposed on the conformity process of hydrogen plants or unit of distribution (stations d'hydrogène), the exploitation of such installations, the respect of security, water management, waste and noise regulations[8].

Some disposals are specifically dedicated to:

- The injection of hydrogen in the natural gas networks is guaranteed (art. 49 de la loi énergie climat 2019)
- Legal regime of the underground storage of hydrogen. The Mining Code (Code Minier) has been changed to allow the holder of a fuel gas or natural gas storage concession to store hydrogen without any new mining licence.

### Definition of Hydrogen

The Code de l'énergie emcompasses the definition of the different types of hydrogen: renewable, low-carbon and carbon hydrogen. It defines the rules of traceability and the various subsidies to the production of hydrogen available to develop a French hydrogen capacity.

Hydrogen is considered as a major energy vector for the development of renewable energy resources and low-carbon economy. It is therefore a strong incentive for the development of hydrogen production by the end of 2023 if it is:

- Renewable Hydrogen[9],
- Low-Carbon Hydrogen[10],
- and Carbon Hydrogen[11].

A guarantee of origin is provided for renewable and low-carbon hydrogen mixed with other types of gas in natural gas networks; a market of these guarantees has been created by the Code de l'énergie.

A system of traceability is also provided for non-mixed renewable and low-carbon hydrogen to recognize this type of production on the energy market. Both instruments are managed by a national registry under the supervision of an independent administrative body.

The Région Grand Est has adopted a Hydrogen Strategy for the time span of 2020 to 2030 (Fig. 7.26). Two major objectives are emphasised:

- a low-carbon offer in road and river transports,
- decarbonised industry.


Fig. 7.26: Five axes of the Grand Est hydrogen strategy for 2020 - 2030 (adapted and translated from GEW 2020, p.5)

[7] Decree No. 2018-900 of October 22, 2018 created section 1416 "Storage or use of hydrogen" in the nomenclature of classified installations (ICPE).
[8] Order of October 22, 2018 on the general requirements applicable to installations classified for environmental protection subject to declaration under section 1416 (hydrogen gas distribution station) of the nomenclature of classified installations and amending the order of November 26, 2015 on the general requirements applicable to installations using hydrogen gas in an installation classified for environmental protection to supply hydrogen gas carts when the quantity of hydrogen available in the facility falls under the declaration regime for section 4715 and amending the order of August 4, 2014 on the general requirements applicable to installations classified for environmental protection subject to declaration under section 4802.
[9] Renewable hydrogen: produced from renewable energies whose production process respects a $CO_2$ threshold per kilogram of hydrogen. These processes are electrolysis using electricity from renewable energy and any other process using renewable energy and "not conflicting with other uses allowing their direct recovery".
[10] Low-carbon hydrogen: subjected to the same $CO_2$ threshold per kilogram of hydrogen as renewable hydrogen, but produced from non-renewable energy sources, which makes it possible to integrate electrolysis of nuclear origin.
[11] Carbon hydrogen: does not meet either of the other two definitions, it includes steam reforming of natural gas or RE production exceeding the $CO_2$ threshold.

Hydrogen is a key element in the regional energy mix. Industry must provide for the production and transport of hydrogen and the regional policy is aimed at decarbonising the industrial uses. Many objectives correspond to the products and services proposed for the post-Fessenheim project. Many subsidies are available, but Hydrogen must be developed with public subsidies opened for the production of hydrogen by electrolysis of water.

From a legal point of view, the French ecosystem is safe and well-developed. A build-up of French low-carbon hydrogen capacity is considered to be necessary by the French legislator for a low-carbon industry and the development of heavy-mobility using carbon-free hydrogen (as a complementary storage medium for electric batteries). It appears that the legal framework is designed to develop pilot projects and to foster innovative projects. These innovations allow for possible legal derogations.

#### 7.6.2.3 Provisional Legal Derogations for Hydrogen

Article 61 of the "loi relative à l'énergie et au climat" provides for regulatory sandboxes (bac à sable réglementaire). This mechanism allows for experimentation with new technologies or innovative services for energy transition by using specific and provisional legal derogations. The experimentation is strictly delimited for the achievement of the objectives of the Hydrogen strategy and the Code de l'énergie. The Commission de Régulation de l'énergie (CRE) can authorise temporary derogations from the legal conditions of access and use of energy networks. Such an incentive is supposed to boost innovations without waiting for a change of regulatory frameworks.

The conditions of eligibility of sandboxes are the following. The project must:

- Contribute to the achievement of article L100-1 of the Code de l'énergie (energy transition)
- Have an innovative dimension
- Be faced to a clearly identified legislative or regulatory obstacle
- Have a potential future development
- Present a benefit for the society on a long-term basis.

If the project is eligible, a three-month period of in-depth examination by the CRE begins. If the feasibility of the project is confirmed, a specific derogation will be provided by the CRE on a four-year basis. After this period, a report on the derogation will be submitted and a modification of the legislation or the regulation may be decided upon.

It must be underlined that sandboxes already accepted by the CRE meet the following criteria:

- The derogation is possible to solve a specific and well-defined legal obstacle
- The project is clearly an innovative solution or process
- The derogation is targeted to solve the legal obstacle and is provisional

The French Administrative Commission of Energy Regulation has so far accepted considering as legal obstacles the rules governing the injection of gas on an existing public network. It shows the limited possibilities to negotiate sandboxes under French law. The innovative character of hydrogen pilots may allow the identification of other legal obstacles. The legal obstacles only involve a legal derogation from French law. A Franco-German pilot project which requires crossing the border may require a more comprehensive derogation which must be encompassed either in an EU regulation or in the Aachen Treaty. An interesting solution could be to apply French rules as they provide for a more complete legal framework than the German ones.

### 7.6.3 Smart Grids

With regard to both pilot projects, it must be pointed out that the main aspects in the area of planning and licensing law depend on the specific location of the plant.

In view of the infrastructures that can be used within the framework of the pilot projects, the smart connection of already existing infrastructures such as ports, rail connections, hydropower plants or gas pipelines is recommended rather than developing a new concept.

Concerning the Smart Grids pilot project, the main legal question concerns the legal protection of personal data. This protection is harmonised in the EU by the GDPR (general regulation on the protection of personal data). It means that a common protection of personal data exists in the EU and therefore no major differences exist between France and Germany.

The collection, treatment and storage of personal data must respect the common rights defined by the GDPR (GDPR chapter 3, 2016) and must be respected. It is important to develop the necessary technical tools to guarantee an effective protection of these rights - for example, smart meters (Petrlic, 2010).

It is also very important to underline that a common governance of data also derives from the GDPR and must be considered to build the economic model of smart grids. Two principles are of major importance: privacy by design (Antignac et al., 2014) and privacy by default. These principles have a direct impact on the economic model of smart meters.

The development of smart grids must take into account the balance with individual freedom such as the freedom of movement of citizens (the balance results from the principle of proportionality). It is important to respect this balance, to avoid the rise of social acceptability concerns of such projects.

### 7.6.4 Further Aspects

It is interesting to consider the law applicable for the pilots in the innovation region as a bilateral innovative zone along the Rhine. Such a development is promoted by EU energy law and may include the possibility to use the derogation clause existing in the Aachen treaty.

**A Favourable European Context to Develop Cross-Border Energy Zone**

In terms of European law, it should be noted in particular that a corresponding deviation through the innovation zone must not violate the various prohibitions of discrimination in EU primary and secondary law. Whether the prohibition of state aid has been violated must be examined on a case-by-case basis.

The Green Energy package is promoting a new market design for electricity and a central role for consumers. It consists of 4 directives and 4 regulations.

- The EU Regulation on the Governance of the Energy Union and Climate Action (Regulation 2018/1999): The Governance Regulation sets out how Member States will cooperate with each other and with the European Commission to achieve the targets for renewable energy, energy efficiency and $CO_2$ emissions. It also provides for monitoring mechanisms to ensure that the targets are met and that all the measures proposed by the Member States are coherent and coordinated. In particular, the regulation sets a 15% interconnection target in relation to installed generation capacity in each Member State by 2030.
- Renewable Energy Directive (Directive 2018/2001): The new text sets a target of 32% for the share of energy produced from renewable sources at EU level by 2030. This new target follows the political agreement that was reached in June 2018 between the Council of the European Union and the European Parliament.
- The Energy Efficiency Directive (Directive 2018/2002): The revised directive sets the target of improving the EU's energy efficiency by at least 32.5% by 2030. It also introduces an obligation to achieve annual energy savings of 0.8% of final energy consumption between 2021 and 2030.
- The Energy Efficiency in Buildings Directive (Directive 2018/844): This directive encourages cost-effective building renovation, introduces a building intelligence indicator, and simplifies inspections of heating and cooling systems.

It is interesting to note that the 2019 directive on new market design comprises specific mechanisms for cross border cooperation to develop decentralised production of electricity based on renewables. Regional management of the supply of electricity is considered as being more effective for consumers and network stability.

Moreover, Article 61-2 of the 2019 directive provides that Regulatory authorities shall cooperate at least at a regional level to:

- Foster the creation of operational arrangements in order to enable an optimal management of the network, promote joint electricity exchanges and the allocation of cross-border capacity, and enable an adequate level of interconnection capacity, including through new interconnection- within the region and between regions-to allow for development of effective competition and improvement of security of supply, without discriminating between suppliers in different Member States
- Coordinate the joint oversight of entities performing functions at regional level
- Coordinate, in cooperation with other involved authorities, the joint oversight of national, regional and European resource adequacy assessments
- Coordinate the development of all network codes and guidelines for the relevant transmission system operators and other market actors
- Coordinate the development of the rules governing the management of congestion
- Give regulatory authorities the right to enter into cooperative arrangements with each other to foster regulatory cooperation (EEA 2020, MOT 2019).

(Berrod et al., 2016, HBF 2017, HBF 2018, PASSAGE 2018, Pescia et al., Carlin et al., 2018)

### 7.6.5 Legal Opportunities to Benefit from Derogations to Build an Innovation Zone

With regard to the question of the extent to which a type of special "legal innovation zone" in the area of tax law or urban development planning, plant approval law or the regulatory regime under which plants operate, would be permissible for such a cross-border project, reference must be made to the constitutional framework of the Member States as an imperative legal basis.

#### 7.6.5.1 German Approach

Insofar as such an innovation zone is to take place based on the existing legal framework, this would be inadmissible due to the constitutional principle of the lawfulness of administration (Article 20 (3) of the Basic Law) in the absence of corresponding exemption provisions already standardised by law. Insofar as such an innovation zone is to be established on the basis of new statutory exemption regulations yet to be created, it should be noted that a general - i.e., overlapping various specialised laws - general clause-like exemption regulation would be inadmissible under constitutional law due to the expected infringement of the rule of law principle of Article 20 (3) GG in. Individual case and special law-related exemption regulations would also have to be subordinate to the constitutional prohibition of discrimination under Article 3 (1) of the Basic Law - provided they satisfy the principle of definiteness. Unequal treatment of this innovation zone would have to be justified by factual reasons that are appropriate to the differentiation objective and the extent of the unequal treatment. This would have to be examined in depth on a case-by-case basis (Missling et al., 2016).

It should be noted that there are various activities by the German government to establish real-world laboratories and corresponding legal exemptions (Reallabore, 2021). This includes initiatives to provide a legal basis for such exemptions, which are also part of the coalition agreement of the new federal government (Koalitionsvertrag, 2021).

There has also been work on the practical design and implementation of such regulatory experiments (Bauknecht et al., 2021) that can be the basis for implementing such experiments in the Upper Rhine region.

#### 7.6.5.2 Under French Law

The principle of equality of article 1 of the Constitution prohibits any differentiation unless it is justified by a general interest or if it is necessary to treat different situations. Two such situations can used as an illustration:

- Differentiation of competences between regions gave birth for example to the Collectivité Européenne d'Alsace, by application of the law of 2 August 2019, which is competent for example on the management of national roads and local highways (which is normally the competence of the French state). The importance of the road transport along the Rhine explains the need for a differentiation
- Differentiation is possible to define specific modality of exercise of certain competences such as the obligation to guarantee in each town at least 20% social housing (loi du 13 Décembre 2000, dite « SRU »)

The current debates on the loi 4D show the limited possibility of differentiation that can be foreseen with this law. The project presented by the government encompasses a specific provision to develop differentiated approaches. A report of the Assemblée Nationale proposes an interpretation of this new approach of differentiation (Jacquier-Laforge 2021) which means that differentiation is possible and may even be maintained after an experimental period of time. It nevertheless appears that derogation is possible only in relation with the competences or rules of functioning of competences belonging to the "Départment Français". It is not the case for fiscal competences for example and therefore the ambit of possible differentiation is limited.

### 7.6.6 Possibilities Opened by the Aachen Treaty (2019)

Insofar as the Treaty of Aachen, in particular the so-called experimentation clause of Art. 13 Par. 2, is cited as a conceivable lever, it must be pointed out that the possibilities mentioned there only exist "with due regard for the respective constitutional rules of the two states and within the framework of the law of the European Union". In this respect, this does not change the framework described above.

Article 13 does allow for a derogation if no other instruments can solve the specific obstacle to cross-border projects. Such an obstacle must be defined before any demand for derogation. In many cases a correct application of national rules or a solution provided by EU law or Council of Europe convention is sufficient to solve the obstacle. It means that the derogation clause is used only if the application of EU or national law is not sufficient to solve a specific obstacle. It is not possible to deduce from the Aachen treaty a general derogation from national laws. This interpretation is in line with the sandboxes approach existing in France (see above).

There exists a limit to the possibility of application of a derogation, to avoid any normative dumping: the derogation must comply with the preservation of strict rules of environmental and social protection. The derogation clause of the Aachen Treaty also implies a political will of both French and German states.

This also needs to be seen in the context of developments on the EU level, such as:

- EU Council Conclusions on Regulatory Sandboxes and Experimentation Clauses 13026/20: Regulatory sandboxes can provide the opportunity for advancing regulation through proactive regulatory learning, enabling regulators to gain better regulatory knowledge and find the best means to regulate innovations based on real-world evidence, especially at a very early stage, which can be particularly important in the face of high uncertainty and disruptive challenges, as well as when preparing new policies.

- Horizon Europe: Mission Approach: Missions are by definition 'experimental'. They provide a learning lab for policy experimentation

## 7.7 Summary

Innovative ideas are always prone to technological challenges and although cross-border scientific expertise in the Upper Rhine region is an asset for tackling those challenges, the main challenge left to overcome is the territorial one. The territory is very complex, and its complexity is increased by its transnational nature. Therefore, a framework of multiple dimensions in which the overall project has to be adopted is required.

Green technologies are generally supported by the public. Hydrogen appeared to be the most acceptable technology, followed by Green Batteries and then Smart Grids. The two most promising identified levers with positive impact appear to be the image conveyed (affect) and the associated benefits as both are positively correlated to the level of acceptability. Therefore, we recommend careful communication. The more positive the image (positive affect), the more likely it is for the project to be considered acceptable.

In addition, a territory is a living entity whose metabolism can be studied in order to analyse the mobilised resources and question the territorial anchoring of a project. The installation of manufacturing plants for hydrogen or batteries should be quite feasible due to a large number of equipped business development sites in the territory and land availability. Some of them are located along the Rhine, which is an undeniable logistical asset. Moreover, some sites host industries that are already linked to hydrogen or batteries, which allows the development of positive industrial ecology conditions. Building on the existing industrial fabric and creating synergies through sectoral coupling is a win-win strategy that, in the long run, will not only provide alternative and decarbonized energy sources but also de-fossilize the production methods of existing industries.

However, the transformation of Fessenheim into a sustainable and innovative region raises legal issues linked to the existence of two, French and German, legislative systems across the border from each other. There are innovative solutions within these legislations but, they need to be identified and applied in order to develop this project. Cross-border cooperation could be the key to developing an attractive legal framework that would favour the concretization of the project. If legal obstacles were to be identified for the envisioned cross-border coupling of green technologies or the implementation of specific facilities etc., cross-border cooperation could act as a legal tool that enables territories facing the same problems to experiment with and develop solutions together. Existing French legal options for innovative projects could be applied and possibly extended to Germany and vice-versa or new-for-both solutions could be implemented.

In conclusion, it is also worth underlining the marked interest of national, regional and especially local authorities that can support the development of the pilot projects. The Upper Rhine regional assets such as high population density, high standard of living, leading universities and research centers, industries of interest, and support from local and national authorities provide the perfect conditions and strengthen the feasibility of the project.

## 7.8 Recommendations

**Social Acceptability**

First, regarding the psychological determinants, one of the objectives of the study was to conduct a comparative analysis between the general French population and the local population in Fessenheim and its surroundings. The idea was to highlight potential specificities (if any) for the local population which is directly affected by the project and already transitioning. Several local associations were contacted, most of them very active in the territory and willing to contribute to the decision-making process. However, none of them followed up. The questionnaire was also sent to local groups via social networks. It also proved unsuccessful. No local data was collected to date. Our final sample was therefore made up only of respondents from the general French population. The next interesting step would be to conduct the same study within the general German population for comparison.

From a more general perspective, we propose using a transdisciplinary approach in planning and implementing the three proposed innovative technologies at the specific sites chosen. Based on other experiences in planning and implementation of contested infrastructures (eg. deep geothermal energy or nuclear energy facilities), the participation of the various regional players is a very important factor for the integration of different perspectives and knowledge as well as the adjustment of the different planning and implementation processes to suit the perceptions and needs of local residents (Ejderyan et al., 2020; Krütli et al., 2012; Mbah & Krohn, 2021; Mbah & Kuppler, 2021). A transdisciplinary approach is suitable to foster collaborative project design and knowledge production (Lam et al., 2021; Lutz & Bergmann, 2018; Newig et al., 2019; Pohl et al., 2017). Here, the real-world laboratory format might be a promising format - maybe in an adopted way - to accompany and design the planning and implementation process (Bergmann et al., 2021; Parodi et al., 2018; Schäpke et al., 2018; Wanner et al., 2018). In this format, selected stakeholders, called practitioners, are directly involved in developing a solution, here a collaborative planning and implementation process design for the three proposed innovative technologies.

In this respect, the first step will be to identify the relevant local stakeholders which should be selected and integrated in the collaborative process. As far as the cross-border region is concerned, practitioners from both sides need to be integrated, as not only do legal and institutional frameworks differ in the two national contexts, but cultural and historical experiences do so as well. (Enserink et al., 2007; Llewellyn et al., 2017; Knaps, 2021; Mbah & Kuppler, 2021). The second step is to arrive at a common understanding of the problem framing and the aim of the project. Basis for the identification of the most relevant issues which should be addressed in the planning and implementation process is a context analysis which might be either collaboratively developed with the practitioners involved or beforehand, based on the findings of the feasibility study. Accordingly, specific issues will be identified for further analysis. The aim could be the development of technological and socio-technical criteria which need to be met in implementation scenarios. Criteria and scenarios need to be jointly developed. It is expected that the scenarios will cover recommendations for communication and participation in the planning and decision-making process as well as specific recommendations for technical adjustment.

**Environmental Impact**

Many steps in the life cycle of a product could be integrated into a life cycle analysis. We recommend including either the transportation, redistribution and/or end uses for both Green Batteries and Hydrogen projects in the next step. As for hydrogen production, in order to reduce its environmental impacts, it seems necessary to focus on the energy source that powers the electrolyser during its production phase, rather than specifically on the choice of a type of electrolysis as the electrical source impacts the environmental aspects over the entire life cycle. We recommend comparing different sources of renewable and/or carbon-free energy (hydraulic, wind, nuclear (French side), etc.) including safety and economical aspects.

**Territorial Metabolism**

For accompanying the pilots in their developments on the territory, we recommend the following sets of tasks:

- First Set: (i) Analysis of additional critical materials in relation to the projects: Cobalt / Manganese / Platinum (similar to the Nickel and Lithium analysis already provided); (ii) Analysis of the climatic conditions of the territory and the consequences on the intermittency of energy production; (iii) Consolidation of the energy analysis and the inventory of production means on the territory (electricity, biogas, biofuels)
- Second set: (i) Issues and opportunities in sharing data within the industrial ecosystem; (ii) Study of the necessary logistics on the territory for battery recovering
- Third set: (i) Prospective study of the battery market (all types of batteries and in all stages: 1st-life, 2nd-life and end-of-life); (ii) Green battery/ hydrogen projects benchmarking in other close territories; (iii) State of the technology of the different reuse and recycling techniques; (iv) State of the technology of the different hydrogen production means and applications, interference and synergies on the electrical network (power-to-gas-to-power, high-power electrolysers); (v) Evaluation of the current and future hydrogen market in the territory, evolution of hydrogen capacities, production means and usage; (vi) Political and territorial coordination for innovation

**Legal Framework**

From the point of view of competence group 4, the development of integrated and cross-border integrated spatial development concepts in border areas, especially in the Trinational Metropolitan Region Upper Rhine, poses numerous highly interesting research questions in the legal and administrative fields, both in the area of basic research and in the area of application-oriented research.

The complementarity extends both externally to other, for example, technical or economic research areas, as well as internally between the regional players, who are jointly in the situation to research the legal-administrative area in energy and environmental law from the International and European legal to the municipal level, both basic and application-oriented cross-border.

The technical pilot projects can be used to identify legal and regulatory issues and barriers and develop new legal and regulatory approaches that are needed to upscale the technical solutions in a sustainable way.

The development and operation of regulatory innovation zones, in cooperation with the technical pilots, can be further used to test such new legal and regulatory approaches.

### 7.9 Contacts

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# 8. Conclusion

The feasibility study has demonstrated that the Innovation Region Fessenheim is endowed with a number of assets (see Chapter 2) that could help it develop into a European cross border regional innovation system (CBRIS). In order to effectively use the proposed ideas for its development, the selected pilots need to be further elaborated on to concretize and clarify the ideas proposed and to construct for each one discrete implementation plans. For more detailed planning of the pilots or a selection of pilots, a consortium needs to be established with communal and European level stakeholders and industrial partners that possess scientific and administrative knowhow as well as legal competences. The selected pilots from different fields can demonstrate how the transformation towards sustainability is linked with the different technological innovation fields. For example, the generation of renewables is on one hand linked with the capacity of producing green hydrogen through electricity and, on the other, with smart grid systems to achieve optimal and timely electricity distribution with minimal losses. Equally important is the link between the stabilisation of the electricity grid and battery storage capacity as well as the link between battery storage and the need to recycle batteries for protecting the environment/climate and lessening the dependency on imported raw materials. Keeping the interdependencies in mind, a holistic approach of the interlinked pilots and their implementation in a region is essential to learning about the overall transformation process towards sustainability.

Choosing the Upper Rhine region with its energy intensive industry clusters around Basel, Chalampé and Karlsruhe is an optimal way to demonstrate the benefits of regional cross-border innovation hubs towards more sustainability. Furthermore, it provides the chance to demonstrate, after the decommissioning of a nuclear plant (Fessenheim), how a cross-border region can be transformed into a prospering future-oriented innovation region within a relatively short time frame by joining the resources of both sides of the border. Above all, decreasing dependence on fossil and nuclear energy sources is symbolic for an area that previously hosted a nuclear plant on its grounds and especially for its citizens who lived in the vicinity of this plant and feel strongly about the issue.

Besides, the benefits of cross-border hubs are many: overcoming administrative and legal barriers, providing regional expertise that transcends national borders, and accelerating knowledge transfer between companies, societies and science organisations. Cross-border hubs increase cross-border flexibility for employees and multiply the resources for joint investments. Likewise, cross-border hubs advance intercultural understanding, join political visions, and strengthen by joint activities Europe's position in the world. A number of economists have even proved that value addition in cross-border hubs is significantly large (EC study on the quantification of cross border effects, EC, 2017).

The Feasibility Study Innovation Region Fessenheim outlines preliminary possible pilot projects developed based on the identified regional strengths. The most feasible option is to implement these pilots in the same region as they can not only provide best practice examples of how an innovative transformation towards sustainability is put into action but can also demonstrate how nations on both sides of a border can benefit from cross-border joint activities. As a matter of fact, feedback provided by industry partners during several workshops confirmed that the proposed pilot projects are in line with their future plans. In the workshops, the partners also highlighted the pressure for a timely implementation of such pilots in order to gain the know-how and to scale-up for industrial facilities.

According to a statement by Frans Timmermanns, Executive Vice-President for the European Green Deal (2022): "The green transition will free us from our dependence on energy- and other resource imports. The circular economy more specifically will allow us to reduce our demand for primary resources, and use a lot less energy for our production and consumption". All the proposed pilots in the feasibility study comply with this statement and help to achieve this demand. Moreover, all pilots can be further investigated by the reader and are described in the form of a pilot sheet in the folder attached to this document. The pilot sheets will provide a basis for the concretization of the pilot ideas. Finally, the pilots' implementation requires large investments which must be mainly secured as start-up funds and through public funds from a European to a regional level that can be used for refining and detailing the plans. Mixed public-private partnerships could provide the investments required for the pilot infrastructures.

For the acceleration of the above mentioned process, the next steps need to be implemented in a timely manner as per statements of industry members:

1. Formation of a management group to coordinate and administer activities (including public relations) for the innovation region with the goal of pilot implementation
2. Concretization of the pilot ideas by detailing the implementation requests, like the compilation of interested consortia members from science and industry, administrations, and society stakeholders for each pilot
3. Elaboration of the pilot's details and execution plans
4. Formation of a steering group for all decision levels related to politics, industry, and societal as well as regional stakeholders
5. Formation of a territorial framework group to accompany the implementation planning related to environmental, societal, and regulative matters
6. Implementation of investor approach activities and an investment plan for companies and public and private investors
7. Determination of a start date for the pilots along with the public relation activities

In conclusion, it is imperative that the abovementioned steps be executed within a tight time frame. As mentioned previously, feedback from the workshops with industry members has indicated that time is of the essence for taking the lead in the innovation field and creating an impact in this decade.

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