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Energimyndighetens titel på projektet – svenska	
Genomförbarhet studie med avseende på etablering av forsknings- och teknikinfrastruktur för uppskalning av batteriproduktion	
Energimyndighetens titel på projektet – engelska	
Feasibility study with respect to establishment of research- and technology infrastructure for battery manufacturing scale-up	
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Executive summary

The purpose of this feasibility study is to investigate the conditions for establishing a national technology infrastructure for battery cell and material production scale-up to support the development of the battery industry. The focus is on infrastructure for research and technology development that enables scaling up to mass production of the battery technologies being researched for an electrified transport sector and energy storage.

Sweden has several areas of strength that give the country great opportunities to become a leading battery nation contributing to future welfare and to the political objectives of the Paris Agreement and Agenda 2030. However, this presupposes that the work is intensified and contributes to resource-efficiency and sustainable circular flows. For batteries, development has only just begun, and rapid progress is being made by independent actors, both in terms of technical solutions and business models. In this context, Sweden has a unique position to facilitate a truly sustainable battery values chain owing to key stakeholders and competencies. Therefore, we see a clear need to concert these efforts, by creating a test and demo environment to address the challenges related to industrial build-up.

*Test and demonstration (**T&D**) infrastructure.*

In this report we define a T&D infrastructure for industrialisation of battery technology (i.e. a *cell pilot line*) as: A system to process battery materials into electrodes, then into cells, according to industry relevant manufacturing techniques, giving rise to state-of-the-art-like products in terms of electrodes and cells. A battery production pilot line must be capable of developing, testing and optimising materials and manufacturing processes to properly adapt those to requested electrodes profiles and cell formats fulfilling industrial procedures. Therefore, a pilot line should consist of flexible, (semi-)automatic and sequential processes.

Market analysis

It is concluded that the *market* development is today driven by transport industry with stationary battery storage on the rise. To summarise the market:

- Electrical Vehicles (EVs) are the transport industries response to climate challenge. Batteries are the key energy storage components that will determine the properties of cars, trucks, construction equipment.
- Batteries in storage applications will be much more prevalent in the electrical grids for various stability services like frequency stability, voltage stability, and peak shaving.
- Growth of EV battery sales have until now been driven mainly by China with Europe and the US following. Fully battery supported electric cars are currently dominating in sales over plugin hybrids.

- The European car and truck industry need battery production in Europe, therefore, battery cell production and development suitable for this market are strategically important.
- The US Inflation Reduction Act (IRA) has incentivised battery manufacturers to prioritize the question of where battery production should be established: i.e. relocation investments to USA.

Industrialisation challenges

In a European context, during the development phase gigafactories it is not unusual that a pilot line is constructed prior to establishing a battery cell factory to serve as a pre-cursor to serial production. This practice is especially implemented by new manufacturers that aim to establish themselves in the battery cell market but do not have access to prior production expertise. For instance, in the case of ACC and Northvolt, start of operation of the pilot line commenced 2 to 2.5 years before the actual factory went into operation. This practice is not adopted by Asian manufactures with well-established production and manufacturing know-how and are able to replicate their Asian production facilities in their European establishment. Therefore, the time from beginning of construction until start of operations of Asian companies can be around 2 years whereas European companies, without prior battery cell manufacturing experience, takes 4 to 5 years on average, and sometimes up to seven years.

To support the growing European battery industry there are several European public and private initiatives attempting to address the industrialisation challenges. Today, many of those initiatives are guided by academic interests due to a fundamental lack of widespread industrial battery know-how. Considering the Swedish landscape, we do conclude that we have internationally successful academic research, several industrial battery leaders as well as world class battery and EV testing infrastructure at RISE/SEEL. However, Sweden is presently lagging behind several European nations considering innovation and industrialisation infrastructure in terms of battery pilot lines.

We conclude from our interviews that the lack of domestic (Swedish) infrastructure impose significant limitations on Swedish cell development. Therefore, actors in the Swedish battery ecosystem wishing to scale up their research must often turn to international suppliers for cell development. The only commercial and *publicly* accessible pilot line presently existing in Sweden have unfortunately technological limitations. This in turn implies that the Swedish relevant industries, e.g. Northvolt, Altris and Enerpoly, all are developing and investing into inhouse pilot line capabilities. While this might have occurred independently of available public infrastructure, these facilities are privately owned and generally neither open for other partners nor accessible for the overall Swedish battery ecosystem. Moreover, these facilities often enjoy public support leading to an uncoordinated duplication of infrastructure and as result a less favourable utilisation of tax fundings.

It was also highlighted in our work that there is at present a discrepancy between the capabilities of European pilot lines and industrial needs. For instance, many of the European gigafactory initiatives are currently focusing on prismatic cells as the preferred cell format. In this context, almost none of the European pilot lines can today fabricate this cell form factor. As a result, the European battery industry struggles to move beyond Pre-A-sample level validation using the available public European infrastructure.

From interviews it was voiced that the Swedish (and European) industry entering the battery value chain are choosing to cooperate with Asian pilot lines in their development and industrialisation work despite the logistical and communicative hinders. This is to high degree motivated by the high and consistent quality provided by the Asian companies as well as competitively priced services.

Proposed infrastructure

We envision that the growing national (and Nordic and European) battery ecosystem is best supported by three types of technological infrastructures:

- Pre-A sample level capable pilot line focusing on education, research and materials discovery,
- A flexible A-sample level capable pilot line able to produce small quantity of industrial quality cells. The purpose is performance and lifetime validation used to close the gap for bringing new materials to market and for training,
- A high throughput B-Sample pilot line focusing on production upscaling and process development, i.e. technology industrialisation. The purpose could also be to process and production optimisation, generate data for electro-thermal modelling, mapping against application requirements, UN38.3, etc.

Since there are three main regional battery clusters growing in Sweden, we believe that an optimal solution (similar to SEEL) is to form a few (3) smaller hubs, being able to support these regional ecosystems. Each of these hubs could consist of <u>one or a combination</u> of the above proposed pilot lines and specialise on the local industrial and academic strengths and needs. The final form of the infrastructure, however, need to be established in forthcoming dialog with potential stakeholders, and in dialogue with other Nordic and European initiatives.

Ownership and implementation process

Based on earlier experiences from the creation of AstaZero and SEEL, we believe that a winning model is risk-sharing between public and private actors. In this context, several Swedish OEMs recently expressed interest into entering partnership toward establishing of an open battery industrialisation infrastructure. However, establishing battery industrialisation infrastructure, regardless of the model discussed above, will require an owner and operator who can take responsibility for the realisation including specifying, building process and operation of the facility. This owner will have to make a business case and it is likely substantial financial support from the public sector will be required. The process to receive such support from the public sector will require a process confirming that all involved stakeholders are convinced Swedish industry and society will benefit from battery industrialisation infrastructure. This goal alignment process is particularly important and needs to involve decision maker from industry, institutes, academia, regional governments and the national government. The national government has an important role in guaranteeing the base support funds to get the stakeholders to make their business commitments so that the owner can include public funding support and stakeholder business and research commitments in the business case. Regional government has an important role in facilitating and supporting local battery hubs with this type of infrastructure. There is a risk that if the public sector i.e., government or an authority, does not take the first steps in a funding commitment, the recommendations to establish battery industrialisation infrastructure will stagnate. In this case, Sweden will be left behind in terms of innovation, which can have disastrous consequences for battery relevant activities in Northern Europe. The next few years will determine the dominant battery centres in Europe and Sweden has a tremendous opportunity to assume that role.

Short term action list

- Identify an organisation willing to lead the process to secure funding and work on detailed planning/design of the above-mentioned infrastructure.
- Detail the infrastructure needed, and create a road-map for its establishment including mapping of potential stakeholders to secure utilization and continuous funding through e.g. membership and or equipment maintenance and upgrading.
- Form a follow-up project, that takes concrete steps to recruit a core team consisting of committed partner organisations willing to undertake risk-sharing for the running costs and utilization. E.g. utilizing the funding model from SEEL and SII-Lab.
- Form a consortium consisting of dedicated private and public stakeholders as well as investments plan to secure:
- Involvement and commitment from government in the financial support/guarantees
- Involvement and commitment of regions and municipalities in the form of an agreement and financial support
- Industrial commitments in the form of an agreement and specification of resources committed.
- Present and debate a national battery infrastructure at relevant venues, such as Almedalsveckan in Visby.
- The short-term goal, beside forming the industrial/public consortium, is to address and highlight the needs for a national battery infrastructure in the upcoming Research Proposition “Forskningspropositionen” for 2025-2029.

Long term goals

- An investment in battery fabrication and innovation infrastructure should be initialised within 2 years.
- Within 3-5 years, the partners should be actively collaborating, and infrastructure being finalised.

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Sammanfattning

Avsikten med denna genomförbarhetsstudie är att undersöka förutsättningarna för att etablera en nationell teknikinfrastruktur för battericell och materialproduktion för att stödja utvecklingen av batteriindustrin. Fokus ligger på infrastruktur för forskning, utbildning och teknikutveckling som möjliggör uppskalning till massproduktion av de batteriteknologier som forskas fram till en elektrifierad transportsektor och energilagring.

Summary

The purpose of this feasibility study is to investigate the conditions for establishing a national technology infrastructure for battery cell and material production scale-up to support the development of the battery industry. The focus is on infrastructure for research, education and technology development that enables scaling up to mass production of the battery technologies being researched for an electrified transport sector and energy storage.

Preface

We would like to give our sincere thanks to the Swedish Energy Agency for funding this work, along with the representatives from Swedish Industry who took their time to participate in interviews. In addition to this, we thank the participants in the four workshops who gave their valuable time in assessing the state of battery production in Sweden today and advising on what a way forward could look like. Thank you also to the participants in this project who placed a large amount of effort in making sure this is the most relevant suggestion for an innovation centre that is specific for Sweden and could increase the future competitiveness of Sweden.

1. Introduction

The aim of this project is to investigate the needs for and formulate an industrialization hub(s) in Sweden that will contribute to building a competitive and sustainable ecosystem for the battery industry in Sweden. The focus here is building up competence and equipment/logistics for battery cell manufacturing as opposed to buying in cells and producing packs. Ultimately, this will be a way for Sweden to be at the forefront of ensuring that Swedish greenhouse gas emissions for domestic transport are at least 70 percent lower in 2030 compared to 2010 levels. Such national infrastructure would contribute strongly to ensure that in 2045, Sweden has zero net greenhouse gas emissions for domestic transport. Only by having this goal in place and working together towards it can we ensure a socio-economically efficient and long-term sustainable transport supply for citizens and businesses throughout the country. We believe that the formulation of a national infrastructure for advanced battery materials and battery production is a key element in making these goals a reality. A dedicated and coordinated battery production centre in Sweden can contribute to faster upscaling of battery production, and growth in the number of industrial actors and available cell chemistries, which can thus help the transport sector to scale up its production of electrified means of transport. This can then reduce greenhouse gas emissions in line with the goal of reducing greenhouse gases from domestic transport. A side effect of such a centre will be to strengthen the competence in the area in both industry and academia, which is needed for faster electrification and sustainability as well as making Swedish industry more competitive.

2. Background

To enable the transition to a carbon-neutral society and a fossil-free transport sector, it is crucial to ensure continued development and production of batteries. According to estimates from the World Economic Forum, global battery production will need to increase by a factor of 19 by 2030 to make the transition to a low-carbon economy.[1] In the EU, transport accounts for around 25 % of greenhouse gas emissions and is the main cause of urban air pollution. Sweden has set a target to reduce greenhouse gas emissions from domestic transport by 70 % by 2030 compared to 2010.[2]

Batteries are the key enabling technology and de facto chosen by the automotive industry for passenger vehicles such as buses and cars. Batteries are expected to be the dominating technology for also electrifying truck transportation in the future. Other transport modes such as regional aviation and ferries are also expected to be

[1] World Economic Forum and Global Batteries Alliance, A vision for a sustainable battery value chain in 2030: Unlocking the potential to power sustainable development and climate change mitigation, 2019.
https://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

[2] Utsläpp av växthusgaser från inrikes transporter
https://www.sverigesmiljomal.se/etappmalen/utslapp-av-vaxthusgaser-fran-inrikes-transporter/

partly electrified by batteries. Batteries are also key to the transition of the energy system. Stationary batteries can be used to stabilize the electricity grid and enable the increased deployment of green but weather-dependent energy sources such as wind and solar power.

The battery industry is undergoing a rapid development and expansion as an increase in global demand for batteries is expected to go from about 282 GWh in 2021 to about 2623 GWh in 2030.[3] The EU has the ambition to become a world leader in the development and production of future batteries as the battery value chain is of great importance also for the economy, resilience and social development.[4,5] Similar conclusions are drawn in the US.[6] Currently, a large majority of battery production takes place in Asia (84%), compared to the US (10%) and Europe (6%). However, Europe's share is expected to increase over the next decade as more than 40 battery factories are being planned and built in Europe in the coming years.

Sweden currently has a strong position in this value chain and is now ranked number 10 in the world according to Bloomberg NEF.[7] More efforts need to be started to ensure a long-term competitive research infrastructure in the industrialization of large-scale battery production. The rapid development of technology also means that it is necessary to bridge the gap between research and future application, where a national infrastructure is central to quickly bring solutions from research to higher technology maturity.

2.1 Aim and scope

The purpose of this feasibility study is to investigate the needs and opportunities of establishing a national research and development infrastructure for scaling up materials and battery cell production. It is presented how this infrastructure can best support the research and development of a battery industry establishing Sweden as an international leader in the development, production, use and recycling of batteries. Sweden has several areas of strength that give the country great opportunities to become a leading battery nation contributing to future welfare and to the political objectives of the Paris Agreement and Agenda 2030. However, this presupposes that the work is intensified and contributes to resource-efficiency and

[3] Business Sweden, Den nordiska batterivärdekedjan, 2021 https://www.energimyndigheten.se/globalassets/forskning--innovation/affu/dokument/energimyndigheten_den-nordiska-batteriervardekedjan_del-1_final-rapport_2021-02-24.pdf

[4] EU Green Deal: Sustainable batteries for a circular and climate neutral economy, 2020 https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312

[5] Battery 2030+: Sustainable batteries of the future https://battery2030.eu

[6] U.S. Department of Energy, National Blueprint for Lithium Batteries, 2021 https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf

[7] BloombergNEF, China Dominates the Lithium-ion Battery Supply Chain, but Europe is on the Rise, 2020 https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/

sustainable circular flows. For batteries, development has only just begun, and rapid progress is being made by independent actors, both in terms of technical solutions and business models. Therefore, we see a clear need to concert these efforts, by creating a test and demo environment to address the challenges related to industrial build-up.

Presented here are information, knowledge, and insights that can act as a background for informed decisions to be made about how to establish a national battery innovation and industrialization infrastructure. Furthermore, suitable/appropriate locations, financing, synergies with other industrial activities, production technology areas are proposed to ensure the centre is relevant and state of the art for battery cell production.

2.2 Definitions, abbreviations and concepts

To fully understand this report, the following definitions, abbreviations and concepts are important to understand.

Pilot line	Manufacturing line where products are produced in small volume aimed for testing products, product manufacturability, manufacturing processes and/or materials.
UKBIC	United Kingdom Battery Industrialisation Centre
FFB	Fraunhofer Research Institution for Battery Cell Production FFB
WMG	Warwick Manufacturing Group at Warwick University
R&D&I	Research and Development and Innovation
TRL	Technology Readiness Level. A common system to describe the maturity of a new technology. TRL 1 – Principles & research- basic principles observed, TRL 2 – Explore applications-technology concept formulated, TRL 3 – Analytical experiments-experimental proof of concept, TRL 4 – Validation & requirements-technology validated in lab, TRL 5 –Design & performance -technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies),

<table>
<tr><td></td><td>TRL 6 – Model & prototype -technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies),

TRL 7 – Performance & testing-system prototype demonstration in operational environment,

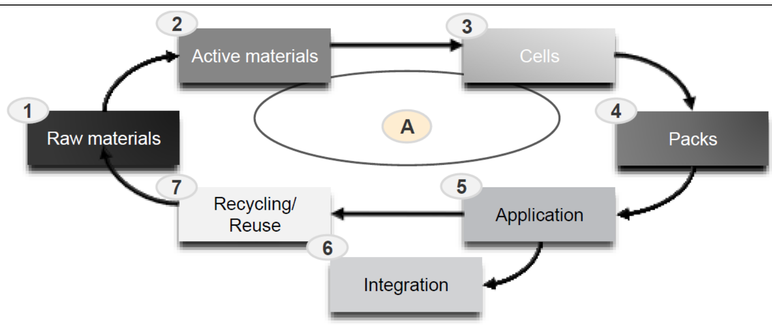
TRL 8 – Test & demonstrate -system complete and qualified,

TRL 9 – Real world & launch- actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).</td></tr>
<tr><td>Cell maturity level</td><td>
<table>
<tr><th>Cell maturity level</th><th>Approximate TRL</th><th>Yearly pilot production</th></tr>
<tr><td>Lab scale</td><td>1-2</td><td>-</td></tr>
<tr><td>Pre-A Sample</td><td>3</td><td><0,1 MWh</td></tr>
<tr><td>A Sample</td><td>4</td><td>0,1-0,5 MWh</td></tr>
<tr><td>B Sample</td><td>5-6</td><td>1-100 MWh</td></tr>
<tr><td>C Sample</td><td>7-8</td><td>1-2 GWh</td></tr>
<tr><td>D Sample</td><td>9</td><td>>6 GWh</td></tr>
</table>
</td></tr>
<tr><td>Form factor</td><td>In this report we discuss battery form factors i.e., the form of the actual battery cell. The common form factors are

coin cell


cylindrical cell</td></tr>
</table>

<table>
<tr><td></td><td>
pouch cell

prismatic cell</td></tr>
<tr><td>EV</td><td>Electrical Vehicle</td></tr>
<tr><td>MWh, GWh</td><td>Wh unit of energy
MWh – Mega Watt hours = 1 000 000 Wh
GWh – Giga Watt hours = 1 000 MWh
GWh/a= Giga Watt hours of production per annum (year)
Size of a battery production site is usually measured in the amount of energy that one year of produced batteries can store.</td></tr>
<tr><td>Steps in the battery value chain[8]</td><td>

1. Mining and extracting + refining and material processing of raw materials into usable battery materials
2. Chemically active materials + production of anodes, cathodes, electrolyte and separator materials</td></tr>
</table>

[8] The Nordic Battery Value Chain

	3. Production of battery cells + stack and roll cells into form 4. Assembly of cells into modules and modules into packs + connect hardware and software, Battery Management System (BMS), into complete packs 5. Producers and users of vehicles and other machinery using lithium-ion batteries to function 6. Integration of the battery application to the energy system including charging stations for EV, other grid solutions and battery storage units 7. Reuse batteries for new purposes or recycle systems, components and materials A. Academia, public organisations, networks. Suppliers of manufacturing equipment, technologies, and digitalisation are key to several steps in the value chain

3. Implementation of this prestudy

RISE is the coordinator of this project (WP1) working with Chalmers University of Technology, Uppsala University and Blue Institute. These partners contributed with their respective areas of expertise within WP 2-4. This has included a quantitative analysis from Chalmers and a social qualitative analysis from Uppsala University w.r.t. the workshops. Blue Institute AB has contributed with information from its industrial network, which is crucial for the activities in WP 2-4, as well as analysing the interview results. The project has contacted parties with special knowledge of specific issues including Business Sweden, selected regions and municipalities, and industrial companies, collecting as broad a perspective as possible. Additionally, four workshops in four different geographic areas in Sweden were conducted to gather relevant actors, knowledge and experience from the entire country.

In WP 2 information from the industries along the entire value chain were collected and the feedback discussed and evaluated. This information helped to form a picture of what the most beneficial implementation could be in Sweden. Presented here are the options of one or more physical facilities with relevant equipment and personnel skills, with a possible neutral networking platform providing support, advice on resources, and key resources not otherwise available.

The next step, WP 3, has involved gathering information and benchmarking with similar facilities internationally, mainly Germany and the UK, and using this information to formulate a centre structure appropriate for Sweden. This includes consideration of resources currently missing for actors in the Swedish value chain, including a description of the challenges being met and what might happen in the future.

The next work package, WP4, has involved defining the necessary business model, partners, components and characteristics that need to be included in such a infrastructure. This work package includes formulating a follow-up project to carry-out and follow-through on the results of this study.

4. Results

Over the course of this project, a group platform has been established with organized storage and access to common documents (Deliverable 1). A kick-off meeting was carried out, a state-of-the-art analysis performed, and four workshops arranged across different geographic locations in Sweden. This allowed us to engage in face-to-face discussions with the stakeholders in Sweden, obtaining an accurate picture of where we stand and what is needed to accelerate the process of making Sweden a major player in the battery production industry. A summary of this information is presented in section 3.

Also included in this report is a summary of the needs of those actors along the value chain in Sweden and a description of the network achieved by the Blue Institute in the section "Interviews". The community analysis carried out by Uppsala University (Deliverable 2) is presented in section 4.

This report also includes a description of the components and parts considered necessary for a possible Swedish battery innovation and industrialization infrastructure. Here there is an analysis performed by Chalmers University (Deliverable 3).

Additionally, presented here is a description of the envisaged structure of the suggested industrialisation centre, challenges, and the proposed way forward (Deliverable 4).

4.1 Business intelligence and market research

Electromobility remains the prime driver for production growth and sales of lithium-ion batteries. In-line with the record sales of more than 10 million electric vehicles worldwide in 2022, the sales of traction batteries increased significantly by 76% compared to 2021. This upwards trajectory continued in 2023. To meet the rising demand, an increasing number of cell production plants and factories for battery components in Europe are being established. Until the end of 2023, the European battery cell production capacity reached approximately 175 GWh/a. This market research highlights the challenges arising from establishing and running cell production plants, and how these might be solved for scaling-up battery production and infrastructure.

As shown in the Global EV Outlook 2023[9], the sales of electric vehicles (EVs) continue to rise quickly. In the past year, more than 10 million EVs were sold worldwide and reached a share of 14% of the total market. After China, where 6 million EVs were sold, Europe comes in second, with 2.7 million units sold. Compared to the total car market, the share of EVs in China is almost 30% and more than 20% in Europe. The rise in sales EV has led to an increased demand for batteries. According to SNE Research[10], batteries with a combined energy capacity of 690 GWh were sold for application in EVs in 2022. This growth amounts to 76% compared to 2021. The market leader in battery cell production is CATL followed

[9] https://www.iea.org/reports/global-ev-outlook-2023

[10] https://www.sneresearch.com/en/insight/release_view/82/page/12?s_cat=|&s_keyword=#ac_id

by LG Energy Solution, BYD, Panasonic, Samsung SDI and SK On. These companies have their headquarters in Asia, but four of the six have production facilities in Europe as well. Along with electromobility, the market for stationary battery storage systems has been developing particularly strongly. According to SNE Research, 122 GWh in battery capacity were sold globally in 2022, corresponding to a growth of 177%. Due to political measures, the high demand for stationary storage will persist in the future. For example, the Chinese government has stipulated that, along with the buildout of renewable energy generation, energy storage systems must be installed simultaneously.

Battery cell production is gaining momentum in Europe with an ever-increasing number of factories starting production. After Northvolt announced the start of cell production in December 2021 and delivery of the first commercial cells in 2022, CATL announced the start of serial production near Erfurt, Germany, in December of 2022. The first phase of Northvolt Ett has a capacity of 16 GWh/a while the CATL factory in Erfurt has a capacity of 8 GWh/a. In May 2023, ACC[11] began battery cell production in Billy-Berclau in Douvrin, France. The company aims to start production before the end of 2023, and the ramp-up is intended to be completed by the end of 2024. In the first build-up phase, the goal is to produce battery cells of more than 13 GWh/a. All mentioned facilities are intended for further expansion in the future. Aside from the recently started operations, South Korean manufacturers LG Energy Solution, Samsung SDI, and SK On have been producing battery cells in Poland and Hungary. LG Energy Solution has presently a production capacity in Poland that amount to 90 GWh/a and is on-track to expand to a total production capacity of 115 GWh/a by 2025. SK On, the battery branch of SK Innovation has operating capacities of 17.5 GWh/a in Hungary. According to company announcements, another facility is planned to start production in 2024, yielding an additional 30 GWh/a. Samsung SDI is producing battery cells for automotive applications in a plant in Göd, Hungary. It is reported to have approximately 30 GWh/a with plans for expansion to 40 GWh/a completed in 2022. In addition to the listed sites with production capacities of more than 5 GWh/a, there are numerous other facilities producing battery cells on a smaller scale, often for applications other than EVs (see e.g. Battery News Germany[12]).

In addition to these battery factories in Europe, there is a complete and growing ecosystem supplying the battery cell production industry with necessary equipment, machinery, and components, including mixing, coating, calendaring machines along with cathode active material, separators, and electrolytes. Among others, BASF and Umicore are producing cathode active material in Europe. Umicore opened a factory producing cathode active material in Nysa, Poland, in September 2022 with a production capacity of 20 GWh/a that will expand to 40 GWh/a in 2024. There are plans to increase cathode active material production to 200 GWh/a. Moreover, the cathode active material plant at BASF Schwarzheide is poised to start production shortly. The company Senior Technology Materials is operating a plant to produce battery separators in Sweden. This site is planned in several phases

[11] https://www.acc-emotion.com/media/bbd-press-release

[12] https://battery-news.de/batterieproduktion/

and should reach an annual production capacity of 600 million m² of separator foil by the end of 2024, corresponding to approximately 60 GWh of battery production.

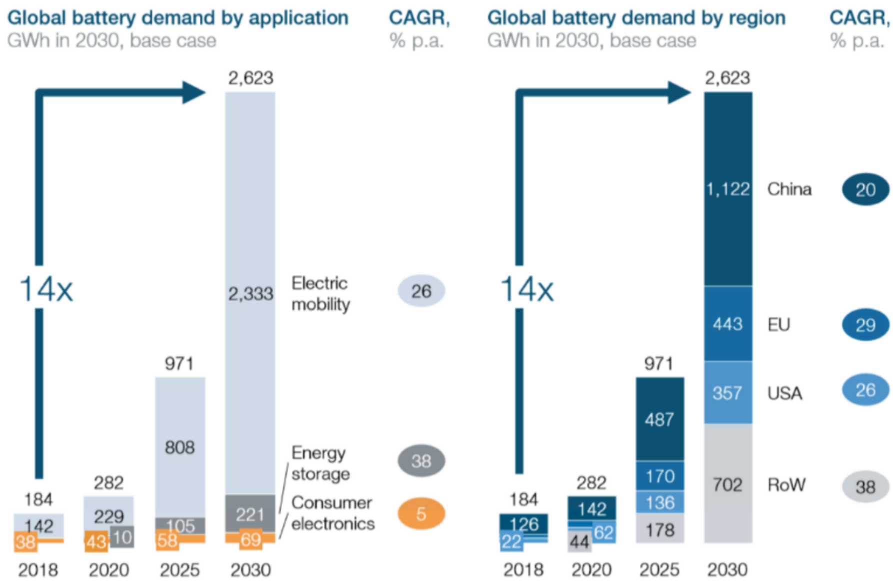


Figure 1. Expected growth in global battery demand by application and region.

Summary:

- Electrical Vehicles (EVs) are the transport industries response to climate challenge. Batteries are the key components that will determine the properties of cars, trucks, construction equipment.
- Batteries in storage applications will be much more prevalent in the electrical grids for various stability services like frequency stability, voltage stability, and peak shaving.
- Growth of EV sales have until now been driven mainly by China with Europe and the US following. Fully battery supported electric cars are currently dominating in sales over plugin hybrids.[13]
- The car and truck industry need battery production in Europe, therefore, battery cell production and development suitable for this market are strategically important.
- The US Inflation Reduction Act (IRA) has incentivised battery manufacturers to prioritize the question of where battery production should be: i.e. relocation USA. For example Freyr Cite: “Establish the U.S. as FREYR’s primary strategic production hub, driving towards first production at Giga America, and maximize the benefits of the U.S.

[13] https://about.bnef.com/electric-vehicle-outlook/

Department of Energy loan program and the tax credits available under the Inflation Reduction Act".

4.1.1 Battery innovation/industrialisation centres in Europe

The ongoing European battery-production capacity build-up is being paired by several EU members states by investments into technological infrastructure. This infrastructure mainly consists of pilot lines and laboratories aimed at supporting this growing industry. The incentive is to support domestic industry and to attract additional investments in their respective countries. The European battery pilot ecosystem was mapped in 2021 by the European battery pilot network LIPLANET, via a structured survey on the subject[16]. The survey is based on several constraints and definitions to avoid oversubscription and ensure a baseline of technical capabilities. In particular, the survey defined requirements that a pilot line should include with detailed features. The survey was completed by 23 organizations within the EU, in which only 12 pilot line facilities fulfilled the eligibility criteria, see Figure 2.

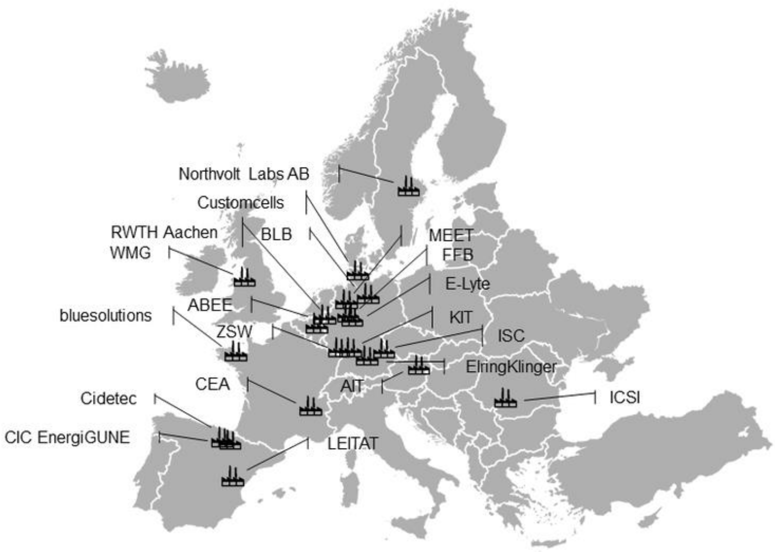


Figure 2. Identified lithium pilot line facilities in Europe 2020-2021.[14]

As observed by the LIPLANET survey, several European countries already have well established publicly funded and/or supported battery industrialisation infrastructures. Examples are Spain, France and Germany with multiple sites and Great Britain with establishments such as WMG and UKBIC, cf. Figure 3. Great Britain is now a front-runner in large scale battery industrialization infrastructure because of their early start in 2018 of £130 million in UKBIC. The UKBIC pilot line is a state-of-the-art facility capable of producing up to 2 GWh cells per year, or roughly C-sample level of production. Presently the facility is being updated by an investment of approximately £48 million into a smaller and more flexible pilot line that will we able produce up to B-samples to increase their customer base.

[14] Report on mapping of EU Li-ion R&D pilot lines

Germany is investing heavily in battery industrialisation infrastructure with the establishment of a new Fraunhofer institute; the Fraunhofer Research Institution for Battery Cell Production (FFB). The investment is €680 million, the facility will host 170 battery experts, and it will have a projected maximal production capacity of 7 GWh/a (electrode), i.e. a roughly D-sample level of production. Similarly to the investments in Great Britain, the Fraunhofer FFB will be accompanied by a smaller and more flexible pilot line, FFB PreFab, capable of producing up to 200 MWh/a (B-sample level); as well as a small A-sample line (CELLFAB). Several European countries are also investing in relevant pilot line infrastructures. For example, the French institute CEA recently invested €40 million in a 3,000 sq. m (including 1,000 sq. m of anhydrous chambers) pilot line facility. In addition to the public German initiatives, there are two commercial initiatives operating in Germany capable of A-B-sample production. These are: CustomCells and UniverCell. In the case of CustomCells, the company has been operating since 2012 and is now investing in a new pilot line to upgrade its capacity from the present 50 MWh/a.

As a part of this study, our consortium arranged a visit at UKBIC in June 2023 to gather hands-on understanding of the necessary machines and equipment for a relevant pilot infrastructure. The visit was open for Swedish stakeholders (both industrial and public) and a total of twenty interested attendees participated. In conjunction with the UKBIC visit, a few project members visited a much smaller but more flexible battery pilot line nearby at WMG. Project members also participated in a battery tour in Germany, visiting different universities and companies in the battery value chain in June 2023. This included visits to pilot lines at Munich University of Technology, Karlsruhe Institute of Technology and BMW. The visit to BMW highlighted the need for a pilot line in battery development. To aid manufacturing process development and optimisation, BMW is building a pilot line with a capacity of a >100s MWh/a to complement the preexisting smaller materials development line.

4.1.2 The Swedish ecosystem and supporting innovation infrastructure

Business Sweden, in a recent report on the battery value chain[8], identified three main regional battery clusters actors along the battery value chain growing in Sweden, see Figure 3. Complete ecosystems are being established in each of these clusters, however, there are also some regional differences. To summarise, we observe that North of Sweden have its centre of gravity in the early stages of the value chain (steps between 7 and 2 according to the Business Sweden value circle definition), having high level academic research and industrial base toward mining, but is also active in recycling, cell manufacturing and development of active materials. The ecosystem around Mälardalen is very much focused around materials innovation startups (steps 2 and 3 in the value chain according to the Business Sweden definition) funded by the excellent research at Uppsala and Stockholm Universities, while Northvolt Labs holds a key position for battery materials production, cell production and recycling. The region is also representing companies downstream in value chain (e.g. Scania). The ecosystem in Western Sweden is to some degree focused on companies downstream in value chain (between 3 and 7 according to the Business Sweden value chain definition) with additional companies acting in the recycling of batteries (e.g. Stena Recycling) as well as chemical industry, but the rapid build-up of NoVo Energy represents a shift of focus to other parts of the value chain. As is clear by this, all three regions cover large parts of the value chain. We would also like to point out that the geographical division does not have any fixed framework; key actors are entering the field, expanding to novel regions, or focusing elsewhere. Also, there are more things in common between these regions, than what separates them, and none is exceptionally unique.

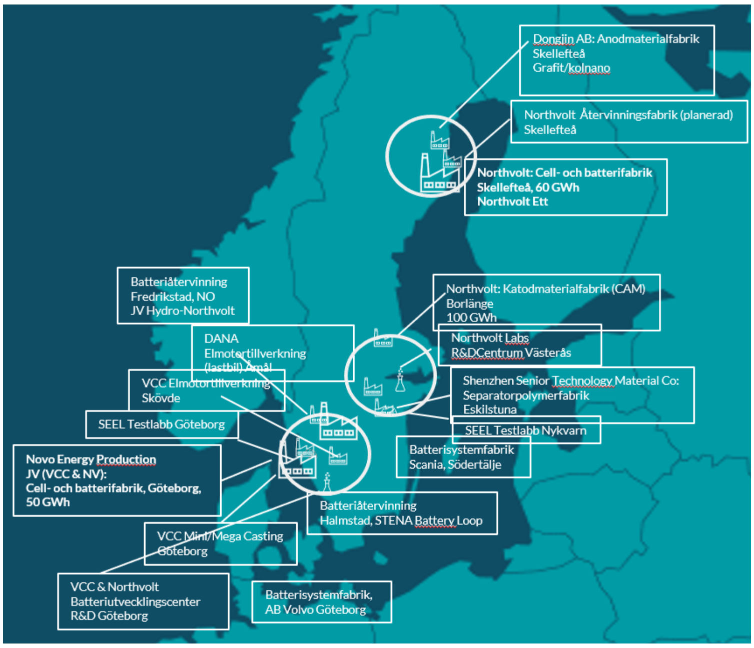


Figure 3. Three main industrial battery clusters forming in Sweden

The Swedish battery research is characterized as being world class. For instance, the battery research environments at Uppsala University and Chalmers are recognized as two of the largest in Europe. However, considering preparation of cells, all Swedish universities have limited facilities for materials coating (above TRL 1-2). Methods used for preparing cell at universities are only suitable for initial materials screening and seldom relevant for further commercialization or industrialisation of the research. This also hampers education in the area. Therefore, important aspects of development cannot be addressed there, including: evaluating challenges related to assessing manufacturability, setting up mass-scale manufacturing, and transferring Swedish research to costumers and market. A battery fabrication infrastructure, if realized, could help accelerate bringing innovations such as material discoveries to market by providing infrastructure for scaling up from research to development for the Swedish battery industry. Today, researchers lack open infrastructure to properly test and validate their research results. This motivates a national infrastructure such as proposed in this report. In this context we allow us to cite Landon Mossburg (the funder of Peak Energy and formerly at Tesla and Northvolt):

-In the battery market, it's not the technology itself that is most sought after, but rather the ability to design for large volumes.

-There are plenty of excellent ideas in research labs and startups, but the challenge lies in scaling up production. This is one of the reasons why very few companies actually bring their "groundbreaking battery technology" to the market .

Currently, a spin-out company from Uppsala University, LiFeSiZE AB (1 employee plus the founder), is the only publicly available organization in Sweden that offers their services for scaling academic materials' innovations to small scale man-made pouch battery cell prototyping. Their contribution has been very important for demonstrating Proof of Concept studies and demonstrating the potential of a novel technology in a functional cell. However, limitations include the lack of dry room and solvent separators excluding the use of organic solvents in prototyping as well as lack of automated assembly of electrodes into cells. Thereby, this is limiting the high-quality assembly that is necessary for studies beyond TRL 3-4. A second important offering by LiFeSize AB has been introductory battery process courses given to e.g. managers from the automotive industry.

This lack of domestic infrastructure imposes significant limitations on Swedish cell development. Therefore, actors in the battery ecosystem wishing to scale up their research must often turn to international suppliers for cell development. Considering the industrialisation and upscaling infrastructure, there is to our knowledge no open pilot line in Sweden able to prototype and facilitate cell development above Pre-A sample level i.e. at or above TRL 4. This implies that the Swedish start-ups; e.g. Northvolt, Altris and Enerpoly; all are developing and investing into inhouse pilot line capabilities. While this might have occurred independently of available public infrastructure, these facilities are privately owned and generally neither open for other partners nor accessible for the Swedish battery ecosystem. Moreover, these facilities often enjoy public support leading to an uncoordinated duplication of infrastructure and as result a less favourable utilisation of tax fundings.

4.2 Competitive intelligence and state of the art

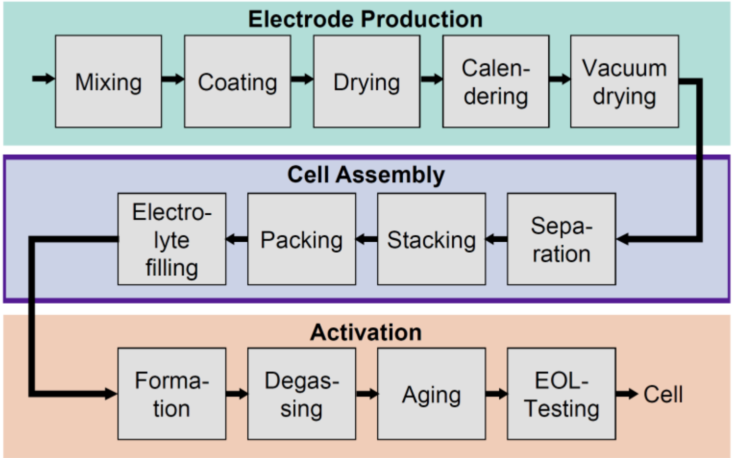


Figure 4. Schematic illustration of typical production steps in contemporary battery processes

4.2.1 Pilot line definition and context

In general terms a lithium-ion battery cell pilot line can be defined as: A system to process battery materials into electrodes, then into cells, according to industry relevant manufacturing techniques, giving rise to state-of-the-art-like products in terms of electrodes and cells[15]. Manufacturing of a (lithium) battery cell consists basically of three main process steps, broadly speaking: (i) Electrode manufacturing, (ii) Cell Assembly and (iii) Cell Finishing, see Figure 2. As pointed out above, a battery production pilot line is capable of developing, testing and optimizing materials and manufacturing process to properly adapt those to requested electrodes profiles and cell formats fulfilling industrial usual procedures. Therefore, a pilot line could be thought of as a flexible semi-automatic sequential process where the manufacturing of the lithium battery cell consists basically of three key manufacturing process steps, namely: 1) Electrode (and solid electrolyte, when applicable) manufacturing, 2) Cell Assembly and 3) Cell Finishing/Activation. Considering *solid state* technology, it is not yet at a stage of maturity for large-scale production that necessitate assessment of its industrial manufacturability. In consequence, a general valid process chain for solid state batteries does not exist; instead, a large number of alternative process chains may be applied. These differ in part from the manufacturing process of a lithium-ion battery. Nevertheless, we believe that futureproofing of any forthcoming battery industrialisation infrastructure is necessary to secure industrial and academic relevance in the internal context.

[15] Luis Colmenares (CIDETEC); Idoia Urdampilleta (CIDETEC); Oscar Miguel (CIDETEC), Pilot line definitions and terms of reference, A LiPlanet report

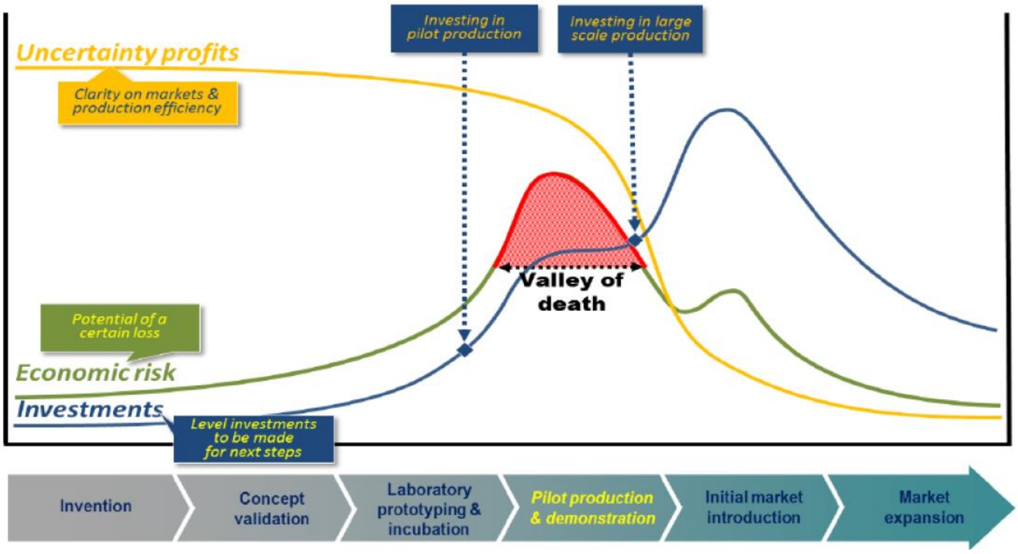


Figure 5. Risk and cost associated with innovation[9].

Following the reasoning above, the primary role of a battery pilot line is to bridge the valley of death and boost the industrial deployment of the battery value chain[16], see Figure 5, while also providing opportunities for research and education. Crossing the so-called valley of death corresponds to the research, development and innovation (R&D&I) activities required to transform a laboratory prototype into a product ready for full-scale production and commercialization. The valley of death is characterized by both high costs and high risks. The approach differentiates three fundamental stages: (1) technological research; (2) product demonstration and (3) competitive manufacturing; from basic research to competitive manufacturing. As shown in Figure 5, investments in pilot can shorten time between technology development and the first commercial market introduction of a product, where the pilot lines are considered as the physical infrastructure and equipment needed to produce small series of pre-commercial but commercial-like products in addition to the activities related to market analysis and engineering to optimize the production process. In that way, one of the key advantages of the pilot line activities is the ability to carefully evaluate each step in the production process to deliver enough output to validate pre-commercial-like prototype products, materials, or manufacturing equipment. This needs minor, but fully operational manufacturing technology infrastructure. These challenges usually imply a need for risk sharing between different stakeholders in terms of industry, academia and the public sector.

[16] http://www.mkpl.eu/fileadmin/site/final/mKETs_brochure_web.pdf

Table 1. Description of Pre-A, A-D samples and approximated corresponding TRL-level[17].

Sample maturity	Corresponding TRL	Definition	Types of work done	Production (volume/year) and application	Example Facilities
Pre-A Sample Electrochemical development	TRL 3	Analytical experiments	Review and screening of cell material performance against design goals, Laboratory-scale cells	10s of cells. Used in early-stage product development and validation activities.	Universities/Lifesize AB
A Sample Electrochemical development	TRL 4	Limited functions prototype batteries	Used for design validation and to demonstrate performance, Commercial-scale cells	<0.1 MWh, 100s of cells. Flexible facility capable of manufacturing several different cell chemistries and formats.	WMG, CustomCells and UniverCell, French institute CEA
B Sample Component production development	TRL 5-6	All functions available	Use for design validation. Final product prototyping. Proof of production concepts at lower production scale	1 MWh-0.5 GWh, 1000s of cells used for product development, validation and industrialisation trials	CustomCells and UniverCell, FFB PreFab
C Sample Cell production development	TRL 7-8	All technical requirements met. Production tools and processes used	Use for product validation. Up to industrial scale production tests.	1-2 GWh, 10000s of cells. Proof of production scalability.	UK-BIC
D Sample	TRL 9	Full production rate	Confirm production flowrate. PPAP sample.	>6 GWh, Complete factory capacity to meet volume demands from customers	Fraunhofer Research Institution for Battery Cell Production FFB

As a result of the innovation and industrialization process used by industry [the three fundamental stages: 1) technological research; 2) product demonstration and 3) competitive manufacturing], the commonly adapted scale for technology maturity consists of the so-called cell sample maturity levels. Cell Sample Maturity is normally defined by the Pre-A, A, B, C, D Sample definitions[18]. Pre-A-sample research is often undertaken using coin cells or small single layer laboratory cells designed to also allow access for instrumentation. The output from fundamental research is essential to finding the next chemistry breakthrough. The cells will have capacities of a fraction of an Ah and limited rate capability. At this stage lots of claims are made that are difficult to validate until the cell has been scaled up in capacity and understood in terms of production processes. However, making 1g of material involves very different processes, thermodynamics and kinetics of the reactions, compared to making 100 kg. This scaling often brings changes to the processes and chemistry. For instance, coating active material onto electrodes at 100 m/minute and maintaining flatness and consistency is a very different process compared to the small size sheet of material made in the chemistry lab. These stages of the cell design and production development are therefore key to the relationship between the cell developer, cell manufacturer and cell customer. The very method is based on the number of cells used for validation protocols used to mature the technology between different maturity levels, for instance, typically 100s of cells

[17] PPAP – Production part approval process
[18] The Battery Component Readiness Level (BC-RL) framework

for A-Sample and approximately 1000 cells for B-Sample maturity validation. To our knowledge, there is no commonly agreed relation between Cell Sample Maturity and TRL-level[19]. However, an attempt to compare the various definitions is presented in Table 1. Finally, we observe that cell development process takes a long time and inevitably overlaps the application development process exist. It is commonly concluded that taking one step at the TRL/sample maturity level takes at least one year of development.

4.2.2 Industrialisation challenges facing the Swedish battery industry

A significant portion of discussions related to pilot lines and Technological infrastructure, as for instance seen in our interviews and workshops, relates to the challenges associated with new technologies bridging the gap to market; via the so-called “valley of death”. However, this discussion misses a critical challenge related to new and expanding industries, such as the Swedish and European Battery Industry. Here, an additional challenge arises during the development of new production sites. During planning and build-up of cell production plants in Europe[20], one of the biggest challenges is the lack of generic knowhow of the very cell production. Reports on the development of battery cell production sites in Europe show therefore that the planning is not always straightforward. During the process, timelines of plans and announcements of milestones can vary[21], deviate from the original plan, or being stopped altogether. Recent examples in Europe have shown that, starting with the announcement of a factory, approximately five years[22] pass until start of operations. It this context, it is evident that the European lead initiatives take around 2 more years compared to the Asian lead initiatives, mainly due to the lack of generic cell production know-how.

In a European context, during the development phase it is not unusual that a pilot line is constructed prior to establishing a battery cell factory to serve as a pre-cursor to serial production. This practice is especially implemented by new manufacturers that aim to establish themselves in the battery cell market but do not have access to prior production expertise. For instance, in the case of ACC[23] and Northvolt, start of operation of the pilot line commenced 2 to 2.5 years before the actual factory went into operation. We see also the same process being repeated by newcomers and startups in the materials development companies such as for instance Altris and Enerpoly. By means of the pilot line, the cell production processes are developed, and cell designs tested, and the resulting preproduction series – or null series – serve as a basis for the serial production. During pre-production, product samples are produced that can be inspected, characterized and tested by potential customers.

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[19] Scale-Up of Pilot Line Battery Cell Manufacturing
[20] https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/market-updates/2023-07-BZF_Kurzinfo_Marktanalyse_Q2-ENG.pdf
[21] https://www.transportenvironment.org/discover/two-thirds-of-european-battery-production-at-risk-analysis/
[22] https://www.faraday.ac.uk/wp-content/uploads/2022/07/Faraday_Insights_2_update_July_2022_FINAL.pdf
[23] https://www.electrive.net/2023/05/30/acc-eroeffnet-batteriefabrik-in-frankreich/

PowerCo[24] designated its first factory in Salzgitter, Germany, as a blueprint in terms of sustainability and innovation and uses it to accelerate the build-up of further factories. This practice is not adopted by Asian manufactures with well-established production and manufacturing know-how and are able to replicate their factories in Asia with new European ones. Although the start of operations of the production equipment is tested in pilot lines, scale-up by a factor of 20 (example Northvolt Ett) is far more complex than expected and requires close collaboration between process engineering, quality management, cell design and software. Therefore, the dimensioning of a factory is adjusted over the course of the planning stage and laid out for several stages of capacity increases. In summary, the time from beginning of construction until start of operations of a copy & paste factory can be 1 to 1.5 years, whereas a factory with an entirely new production and without prior battery cell manufacturing experience, takes 4 to 5 years on average to start production, and sometimes up to seven years in Europe.

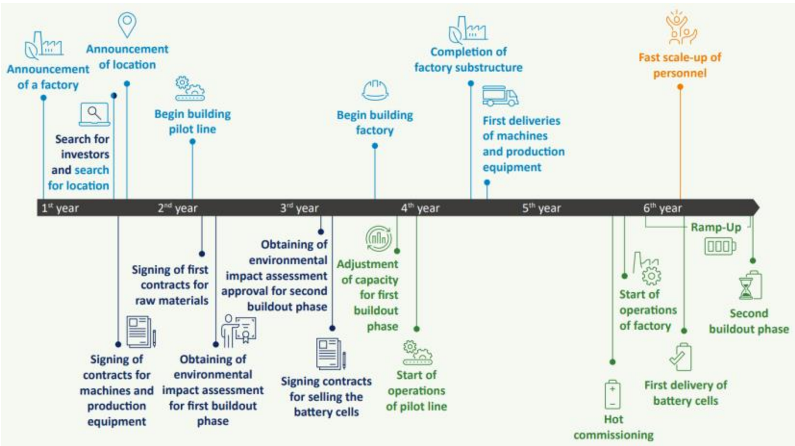

Figure 6. ***The build-up of a battery cell plant: Northvolt Ett. The site is not a copy and paste factory and was built without prior battery production expertise. In particular, the processes and production equipment were developed and tested at Northvolts pilot line: Northvolt Labs.***

In addition to the challenge related to establishing and development of new European cell production industry, there is still a need to bridge the techno-economical barrier for maturing new technologies for market introduction. The European Battery industry is therefore hampered by two challenges: one related to technological maturity and one related to production scale-up maturity. It is therefore important that there is a continuity in the battery value chain. Development of cutting-edge technology and new innovations and future material and systems development is essential in a battery ecosystem. Equally, the large-scale processes and equipment are essential for the success of new innovations. To take new incremental and disrupting technologies that originate in the academic lab environment and implement them in commercial products, a support system must exist where these technologies can be produced and tested in increasingly larger scales and in different formats. This requires a flexible makers space with resources,

[24] https://www.volkswagen-newsroom.com/de/pressemitteilungen/grundsteinlegung-in-salzgitter-volkswagen-startet-mit-powerco-ins-globale-batteriegeschaeft-8050

knowledgeable staff, and modular equipment. Sweden has the academic infrastructure working on tomorrow's battery technology and the large-scale production of state-of-the-art Li-ion technology that is being built up with Volvo and Northvolt and Scania for example, but this support network to bring new technologies to market as well as scaling up manufacturing and production technology is currently missing. Sweden runs the risk of falling behind in innovation.

4.2.3 The role of an open innovation infrastructure

As discussed in previous sections; to foster innovation and commercialization of research results in the battery value chain, availability of pilot production infrastructure can increase scale-up possibilities. Privately owned pilot production facilities are, naturally, primarily dedicated to support the battery manufacturers' own product development, rather than that of potential competitors. Moreover, as the pace of production ramp-up is so rapid in the EU, there is little capacity in these facilities to support suppliers' material or process qualification requirements. That means that the existing infrastructure is pretty much closed for all projects not prioritized by the battery manufacturers.

While it is not unique to the battery value chain that innovation is inefficiently under-provided in private markets[25,26], there are reasons to expect that the social returns to innovation are especially high in batteries, in the EU, and in Sweden. That would support the establishment of publicly available infrastructure, possibly through public funding, as it would benefit the development of the entire ecosystem in several ways:

- **Collaboration**: Publicly available infrastructure enable collaboration among research and businesses by sharing knowledge, data, and expertise in joint projects. Start-ups and scale-ups can benefit from publicly funded incubators and accelerators, which provide community, mentorship and resources. Established manufacturers can use the infrastructure to test developments without interrupting their production process in their own facilities. Collaborative networks foster resilience by sharing best practices and lessons learned.

- **Resource Augmentation**: Access to state-of-the-art equipment and facilities can accelerate R&D for both the academic community, research institutes as well as businesses. Open data platforms enable private companies to analyze trends, validate hypotheses, and make informed decisions. Production infrastructure can pilot products and qualify materials and processes, to show to investors that the technology is viable for future financing. For instance, think of a materials company who wish to enter the battery manufacturing market. They need to prove their product will work

[25] https://journals.sagepub.com/doi/pdf/10.1177/87569728231189989
[26] https://www.cambridgeblog.org/2022/06/private-entrepreneurs-can-elevate-public-innovations-but-they-also-need-better-governments/

in a battery before the battery manufacturer will be willing to invest integrating the product into their specific manufacturing process.

- **Risk Mitigation**: Publicly available infrastructure can mitigate risks associated with innovation. Availability of production infrastructure reduces financial risk of innovators, as capital investments are deferred.
- **Education and Training**: Real-world settings enhance the quality of education and vocational training. Well-trained professionals contribute to private innovation by bringing expertise, creativity, and fresh perspectives to companies.

In summary, publicly available innovation infrastructure complements privately owned infrastructure by providing knowledge, resources, regulations, and collaborative and training opportunities. Together, they create an ecosystem that drives sustainable and impactful innovation as well as industrial growth and competitiveness. Furthermore, the availability of open innovation infrastructure will increase the attractiveness of the country/region for foreign investments.

4.3 Results from the Workshops

General overview of discussions from the workshops

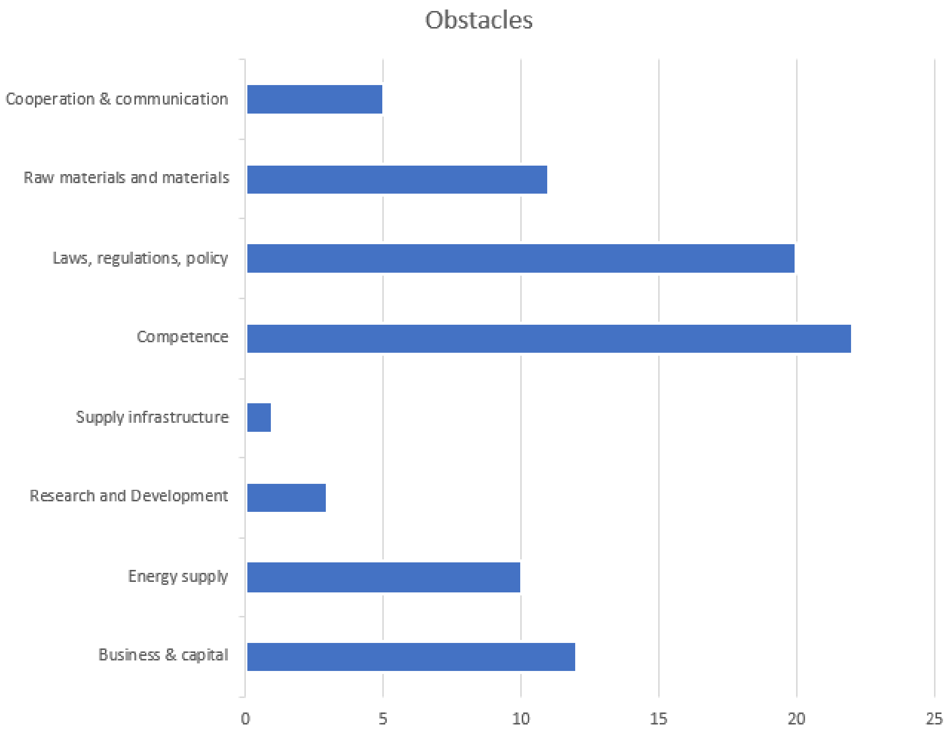

Figure 7. Obstacles in the battery sector in Sweden from workshop participants.

As a part of the information gathering, the project together with The Swedish Energy Agency, arranged four national workshops. The theme of the workshops was "How can we build a leading battery industry in Sweden?" with the aim to gather the Swedish actors including academia, industry, small and medium companies, students, and the public sector; to obtain a very fundamental understanding to the challenges of working within the Battery production value chain on a grassroot level. There were 175 participants taking part in the workshops, as detailed in the Appendix. The workshops were held in Stockholm, Skellefteå, Gothenburg, and Västerås.

Below, a general summary of the workshops is presented, followed by a more in-depth discussion, followed by dissemination of the interviews.

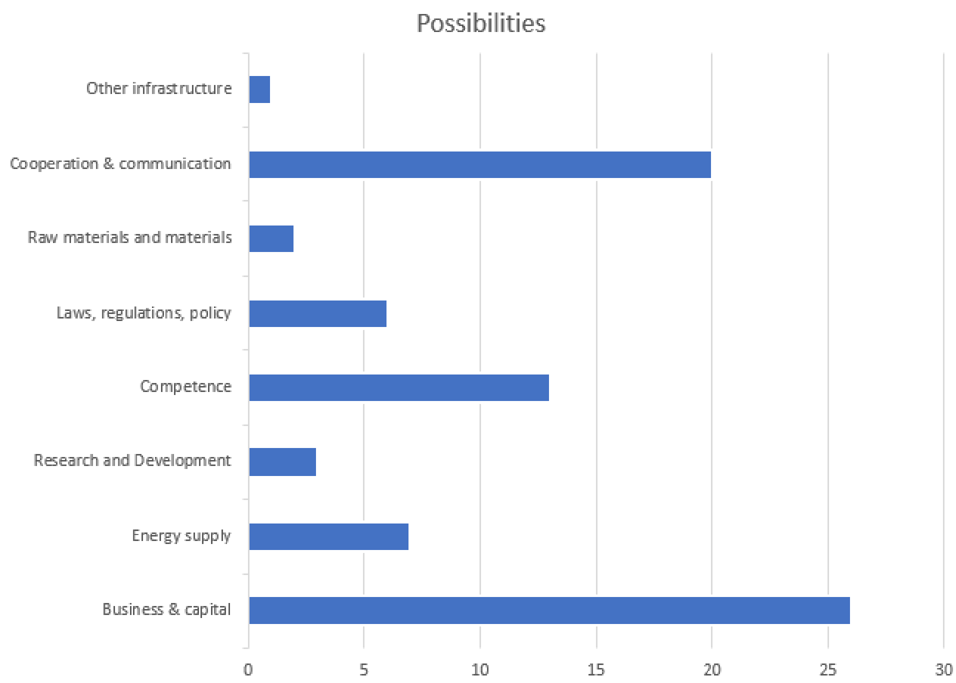

Figure 8. Possibilities in the battery sector in Sweden according to the workshop participants.

A common thread in the feedback is the lack of an independent actor who can take the lead in terms of coordination of battery activities. This has led to small, scattered and fragmented activities. Businesses have to search internationally for resources and services in the area. There is a need to ensure that there is capital for smaller companies, especially needed when there is an industry being built up.

Other main obstacles that were voiced were the lack of availability of workforce/competence, slow processes for formulating/updating laws and regulations and the risk that they are unclear, lack of access to raw materials due to supply chain issues for example, and lack of access or too expensive capital, or lack of green electricity (Figure 7). These areas are discussed more in-depth below.

In terms of possibilities, it was expressed that if businesses, authorities and capital along with cooperation and communication can be exploited, success rates will increase. (Figure 8). These topics are also discussed more in-depth below.

From the workshops, the following discussion topics were discussed.

4.3.1. In-depth discussion from the workshops- Infrastructure

An established battery industrialisation infrastructure could provide opportunity that comes with a large industrial establishment of battery manufacturing that strengthens the potential in various parts of Sweden. Based on the feedback, there was wide agreement among the workshop participants that there is a lack of R&D infrastructure for mass production of battery cells. Pilot plants spanning TRL 4/5-7 are missing in Sweden today. Currently, no such centre, with corresponding infrastructure, is available and accessible to academia and industries. The development and implementation of the new materials and technology in battery mass production is slow and the resources is insufficient because of the lack of critical infrastructure. The pilot scale testing equipment are not affordable to purchase and operate by universities, small companies and even the regions. Although the large battery manufacturer for example Northvolt has a pilot line, they are designed and established with the dedicated purpose to serve the development of Northvolt's mass production of battery cells. Thus, it is generally not open to academia nor start-ups and sub-suppliers to the battery cell manufacturers.

A flexible battery manufacturing technology with the support of the various and flexible infrastructure is highly demanded to adapt to the new battery technology and battery chemistry. Such infrastructure could bridge research to industrial benefit. For the electric vehicle market, battery manufacturing needs to be developed continually, with flexible and open infrastructure, to match with the ever-increasing demand of the battery market. This could also provide the opportunity to create a sustainable battery ecosystem with Nordic neighbours. Generating jobs, new knowledge and competence. As an outcome, it is expected that a large industrial establishment of battery manufacturing strengthens potential in various parts of Sweden.

4.3.2 In-depth discussion from the workshops-Raw Materials

Raw materials and energy (electricity) supply were observed as an obstacle. Some critical materials used for the battery cell production rely heavily on supply from outside of Europe. There is a critical shortage of raw materials and lack of conditions for applied research. Therefore, funding is required for high-risk projects for this type of development and research. The entire ecosystem should be developed from natural resources to renewable energy, infrastructure, production and end users. As alternative to the current widely developed electrode materials system, new sustainable materials need to be investigated and eventually implemented in battery production. An example of this is removal of toxic Cobalt from cathode materials, the use of cellulose based separators, and production of synthetic graphite from biomaterials using a low energy consumption method. Sweden has competence and resources in bio-based materials, which could be raw materials for new electrode materials (iron for lithium iron phosphate) and new battery chemistries from example sodium ion battery (biomaterial derived carbon-based anode). However, Sweden also faces challenges in sustainable extraction of raw material and legislation, e.g., the mining issue.

4.3.3 In-depth discussion from the workshops-Energy

This area should be addressed by politicians with green energy management solutions being a priority. The example of the green steel initiative taking place in the north of Sweden could be followed by other initiatives. Further, production processes and next generation materials should be streamlined and obtained from reliable sourcing. A system analysis is highly demanded to address the issues and provide the possibility to test those new sustainable materials at large scale for mass production of the next generation batteries. This includes mining resources and having the facilities and trained personnel to be able to independently offer electrification solutions. In line with this, a risk assessment of the energy storage and supply should be done, and mitigation plans should be in place in all cases where production will be taking place.

4.3.4. In-depth discussion from the workshops-Competence

It is observed that competence is high on the list of obstacles, and it is therefore important that any kind of battery innovation centre works closely with universities and that training on different levels is implemented. We have difficulty supplying the industry with the skills and labour it needs, especially where the needs are large (geographically).

The complexity of taking an innovation and scaling-up and going to pilot testing from lab level to industrial level was emphasized. That this requires knowledgeable people, resources and reliable infrastructure and testing.

There is a lack of long-term and lasting resources for research, training, development, implementation, etc. A training center where both academia and industry are involved could provide training at all levels, reskilling, and upskilling for industries affected by the transition.

4.3.5. In-depth discussion from the workshops- Laws, Rules and Policies

Further, laws, regulations and policy were also seen as an obstacle. This included “slow legislation”. Knowledge in battery passport legislation should be considered. This legislation is already enacted and dictates what can and cannot be done in the arena of materials, reuse and recycling. Workshop participants stated this is largely due to the lack of a clear strategy that Sweden has in comparison to other countries in Europe. What participants wished for is a long-term battery strategy similar to Finland and Norway. The cooperation of the authorities during the establishment of such a centre and the clarification of the state’s role linked to the economy and infrastructure should be addressed.

It was remarked that there were far too many silos, not only in each field, but also in politics, public administration, business, research, and education. There is a high level of ambition, but a lack of coordination. If there is a goal that Sweden will be a leading battery nation, then this goal can collectively be worked towards. Participants commented that Sweden spends only a fraction of resources on research in comparison to other countries, leading to a lack of sufficient resources for research over the entire battery value chain. Further, with the economy in a strained state, there is a risk of a capital investment shortage leading to a lack of investors and a stagnation of development. This legislation criticism included “*Lacking the long-term political leadership for a long-term plan for: Batteries Energy Permitting processes”* guidelines should be established within legislation making this a transparent area for business in Sweden.

4.3.6. In-Depth discussion from the workshops-Cooperation and Communication

Sweden is an innovative nation and if we work across academics, industry, research institutes and authorities, this should provide even more synergy. There was discussion of the need for an accessible platform for coordination and contact creation. This would provide infrastructure to bridge research and benefit industry.

This may allow industrial partners to build up their own initiatives within this platform with membership programs for example. Additionally, it was suggested to clarify different geographic competence hubs that are that are the driving force behind the innovation and development accelerators in close partnership. This could be achieved by regular workshops and study visits. There was a strong desire for more testing and pilot resources.

4.4 Feedback via Interviews

To further deepen the understanding of what needs and requirements that businesses have regarding research and innovation infrastructure for battery manufacturing, in-depth interviews were carried out. Respondents were selected to gain perspectives from all parts of the value chain, from material supply to OEMs integrating batteries in their applications, as well as recycling.

In total, 23 interviews were conducted (Table of participants in Appendix). The interviews were semi-structured, using a jointly developed questionnaire with questions concerning company operations in relation to batteries, how R&D for such operations is handled currently, perspectives on using open test and demo infrastructure and expectations concerning the requirements and capabilities of such an infrastructure. Respondents were furthermore asked if and how they would consider contributing to the setup of and/or running such infrastructure. They were also asked to elaborate freely on their perspective on the emerging battery value chain and what they perceived as possibilities and obstacles to their operations.

Even though the interview study only covers a fraction of companies engaged in the battery value-chain, it can provide insights into industrial demand and requirements for an open test and demo infrastructure.

4.4.1 Interviews-Companies at the core of battery manufacturing

The most positive views come from companies engaged at the core of battery manufacturing – active and passive materials suppliers, cell/pack manufacturing, as well as suppliers of production technology and automation solutions. Furthermore, OEMs with applications dependent on batteries, but who mainly source them, are positive, although in many cases they have adequate supplier interfaces already – in these cases, many see advantages in using such infrastructure for testing and for providing general competence surrounding battery manufacturing. Companies that are more remote from battery manufacturing, such as raw material suppliers, were less concerned with the establishment of an open test and demo infrastructure.

4.4.2 Interviews-Material suppliers

Among active material suppliers, as well as cell- and pack manufacturers, various factors motivated their interest. Among smaller start-up companies, production infrastructure and pilot lines are considered important for validation and for initial production runs – mainly concerned with novel/alternative chemistries and form factors.

For manufacturers a bit further along, “scale-ups”, the usefulness was less pronounced since they have/are in the process of investing in their own production lines with adequate capabilities. However, they were positively inclined for such infrastructure providing training and contributing to a larger network of people/companies in the industry as well as allocating more of their capital to market development.

More established battery manufacturers, as well as OEMs with significant involvement in development/manufacturing of batteries (mainly automotive companies) obviously have the requisite infrastructure in-house. However, they saw much needed opportunities for an open infrastructure to provide their existing and future suppliers with needed production capacity to validate materials, components, and production techniques. There are not many opportunities to conduct such activities in existing production facilities, where production is ongoing. For the same reason, some of these companies saw a use for an open test and demo infrastructure for materials characterization and testing, as well as for employee training.

4.4.3 Interviews-Application providers

Application providers (including those that do not produce cells, or even packs, but integrating them and designing products) have various perspectives concerning their potential participation. This could include testing, developing for others and not themselves, and/or collaborative development with battery suppliers. Testing and techniques for latent cell fault issues is also of increasing importance since this is a problem when sourcing batteries. Many application providers are using the same or similar infrastructure because they must be outsourced to Germany, Japan and Korea.

Application providers value capabilities such as IPR handling highly. The ability to guarantee confidentiality and the ability to guarantee the separation of users is essential. Further, the ability to handle non-typical chemistries and formats (e.g. prismatic cells) and unique or seldomly used equipment is a challenge and very valuable. Being an available infrastructure to provide an environment for training purposes is also very important. We have heard from others about the situation of current sites where this is possible, that they are overwhelmed with demand, are booked up for the foreseeable future and have quality issues because there is such a rush on these facilities. There is high personnel turn-over because of the high demands placed on these knowledgeable and trained workers so that these facilities have a difficult time retaining labour.

Production technology providers likewise emphasize the value of a facility in terms of training, as well as the ability to demonstrate and test solutions together with customers.

In terms of cost considerations, a potential facility must be competitively priced compared to other options in Europe, that some are using currently. There must be a reliable reputation where deliveries can be promised and then delivered promptly, which may not always be the case with universities.

4.4.4 Overall Industrial perspective and needs

In general, businesses operating in the battery value chain would welcome publicly available infrastructure where they can test new products and production methods, without the need for costly infrastructure investment. This requires testing capabilities, knowledgeable staff, flexible equipment and labs, along with strong IP protection. They are also looking for skilled workers who they can employ along with a training ground where they can increase the competence of their current workforce. This is no small task where there are only academic and large-scale facilities in the current battery value chain in Sweden. Therefore, a range of business models and infrastructure models could be considered.

4.5 Academic perspective and needs

4.5.1 Material perspective

Several universities and research institutes in Sweden are carrying out materials research for battery applications, e.g. Uppsala University, Chalmers, KTH, Stockholm University, RISE, Linköping University, Mid-Sweden University and Luleå University of Technology. Several of these also have had successful spin-off companies, producing materials and cell concepts. These involve both lithium-ion batteries and next-generation battery chemistries. Research and development are being done at Swedish academia on all battery components: electrodes, electrolytes, separators, binders, current collectors, additives, etc. Hundreds of researchers are active in battery materials and cell research at Swedish universities, from PhD students to professors.

Since research work and scientific activities at the universities generally are further away from commercial products and industrial production than in the companies that has been interviewed during this pre-study, the need for this type of centre might be slightly different from an academic perspective. Research is usually done on a small lab scale, but some smaller battery fabrication pilot lines do exist within academia in Sweden (still targeting cells of 0.1 Ah capacity and 10-20 mm size). Nevertheless, several academia-industry projects are also targeting larger commercial cells, and test capabilities for such cells exists locally or at SEEL, also or academic use. Having access to a demo centre will enable a smooth transition from academic lab scale to upscaling, and the possibility to perform larger-scale experiments, also regarding production and process technology. It will also be useful for spin-off companies from the universities to take the next step towards upscaling and commercialization.

Access to large-scale battery fabrication infrastructure is also useful for educational purposes. Universities educate engineers and researchers, often with a focus on materials science and chemistry, that will work within the battery and battery relevant industry in Sweden in the future. Relevant training equipment and hands-on possibilities to understand fabrication processes and production techniques within this type of centre would constitute a useful tool in their education and training. The lack of such training possibilities today constitutes a gap in Swedish engineering education. One example of an educational programme that will benefit from such infrastructure is the master program in battery technology and energy storage at Uppsala University, but several chemical and materials engineering programs around Sweden can be foreseen to utilize these resources.

Furthermore, materials development is related to processing of the battery cell. Today, the process chemistry that follows materials fabrication is not researched sufficiently in Sweden, and there is a lack of academic faculty. This part of the value chain is locally sub-critical in academic research. To recruit and build up faculty in battery fabrication, relevant infrastructure will be necessary.

From a materials perspective, it is vital that the planned facility is flexible in terms of what materials, cells and techniques that can be used. Since research in the battery field is constantly developing into novel materials, components and cell chemistries, it is necessary to be prepared and adaptive in the production line for next-generation chemistries. This includes for example novel sensitive electrode materials, other type of solvents, extrusion processes, or the possibility to fabricate solid-state batteries using high-pressure techniques. To adapt for new lithium-ion battery materials or adopt to sodium-ion batteries is comparatively easy, while preparing for solid-state batteries is considerably more challenging. These considerations will require versatility in both production equipment as well as in working atmosphere (dry room, clean room, inert atmosphere, etc.). Another concern is the choice of cell type, where different types are differently useful for different type of cell chemistries. While academia mostly works with smaller pouch cells or coin cells, there is a growing interest to also work with cylindrical and prismatic cells.

This type of centre would likely accelerate the collaborations between academia and industry, promoting materials development into functional battery cells. Better access to battery fabrication infrastructure would stimulate the scaled-up production of materials, since the barrier to testing in real cells would be lower. This could result in more rapid exploration of novel materials resulting from research projects, where industrial standards can be met.

4.5.2 Production perspective

Sweden as one of the main players in the battery manufacturing in Europe, has competence in cell assembling from module to pack and mass production of battery cells (with one operational gigafactory and plans for a few more). However, battery cell manufacturing still suffers from high costs with large capital investments needed, high energy consumption, time intensive processes, with safety and environmental issues. Therefore, innovative, sustainable, and competitive battery manufacturing technology is in high demand.

Although several Swedish universities, institutes, and industries are developing in this area, there is still a gap between lab scale cell fabrication and Gigafactory scale cell production. Companies hesitate to implement new technologies developed by Universities and Institutes in the production line before validation on a larger scale. This gap involves manufacturing of kilograms and hundreds of kilograms (pilot scale) of electrode materials for cell manufacturing that needs to be tested. The infrastructure, energy supply, space, investment, skill and knowledge for this are needed to validate the technology and meet the requirements for next level mass production.

All the related sectors in Sweden have identified and agreed that scale-up infrastructure is a critical component. An example of this is lack of a dry room for testing large-scale battery cell manufacturing for validation of new technology. A national centre will facilitate manufacturing of systems to develop and scale-up the capacity for current and future battery concepts, from R&D labs to Gigafactory production, from cell manufacturing to packs. It will meet industrial needs of requiring verification before testing on their equipment and provide a platform for academia to carry out scientific excellence in cross-disciplinary projects, accelerating the evolution of critical technology in the battery manufacturing industry.

From a battery cell manufacturing perspective, the current challenge of the battery manufacturer in Sweden is to address all aspects of sustainability in the process while building a strong international position within research. A national infrastructure would allow for efficient academia-industry collaboration, creating a highly attractive environment for recruitment of young researchers and engineers. Such a centre could also establish Sweden as a hub for the Nordic countries as an incubator for international research and innovation projects.

4.6 Conclusions

To support the growing European battery industry there are several European public and private initiatives attempting to address the industrialisation challenges, as detailed in Section 4.2. Today, many of those initiatives are guided by academic interests due to a fundamental lack of widespread industrial battery know-how. This includes for instance the development processes adopted globally by battery industry. Considering the Swedish landscape, we do conclude that we have internationally successful academic research, several industrial battery leaders as well as world class battery and EV testing infrastructure at RISE/SEEL. However, Sweden is presently lagging behind several European nations w.r.t. innovation and fabrication infrastructure in terms of pilot lines.

It was also highlighted in our interviews, international visits and discussions with industrial organisations, that there is a discrepancy between the capabilities of European pilot lines and industrial needs. For instance, many of the European gigafactory initiatives are currently choosing the prismatic cell as preferred cell format. In this context, almost none of the European pilot lines can fabricate this cell form factor. As a result, the European battery industry struggles to move beyond Pre-A-sample level validation using the available European infrastructure. This is the case, even though some pilot lines can manufacture GWh's of batteries.

From interviews it was voiced that the Swedish (and European) industry entering the battery value chain are choosing to cooperate with Asian pilot lines in their development and industrialisation work despite the logistical and communicative hinders. This is because <u>the small number</u> of European pilot lines that can qualify cells from the A to C process have not been able to demonstrate cell fabrication with the <u>consistency</u> and <u>quality</u> required.

5. Recommendations

As stated in previous chapters, there are about 40 production sites being built or planned for in Europe with three major gigafactories in Sweden. Alongside these production sites there is a supporting ecosystem growing. We believe that there is an opportunity for Sweden to establish itself as a leader in this area due to the national development pace set by Northvolt, as well as the large number of inventions occurring in Swedish institutions, not least academia. However, as the battery industry is establishing itself in Sweden, very little competence and technology infrastructure exists that could aid cross-pollination of competences and technology development between an ecosystem of actors. To best support the growing battery ecosystem, a technical infrastructure that can bring academic research results into commercial products in an organised platform must be established. Such an infrastructure can also be used for teaching and for research, which is necessary to build Swedish research excellence also in battery production. Sweden lacks however the technical infrastructure where new battery technologies can be developed and verified for mass production, and to do high-level battery process research. Without such an infrastructure, actors risk working blindly in silos and building small initiatives, unaware of similar efforts in their own backyard. It also leads to a lack of trained workers and a lack of innovation. To avert this risk, and to facilitate establishing Sweden as a leader in this area while remaining internationally competitive, a technology infrastructure for a battery ecosystem should be a national priority.

5.1 General considerations

As discussed earlier, it is important that what is developed in the academic world, typically TRL 1-3, can be produced on a pilot production scale in a seamless way regardless of the chemistry. The TRL scale and what is implied in terms of battery production are detailed in Table 1. To bring emerging technologies and chemistries closer to market it is essential that the pilot production plant is flexible enough for these possibilities and developments.

It should be possible for researchers and engineers to work together on open equipment to modify and streamline processes, to tune and make more efficient new products and to test new active/passive battery in connection to the infrastructure materials. There should be knowledgeable staff who can suggest modifications that would ease production at a Pre-A to A Sample level which requires the pilot line to be flexible. Scale up to B Sample is used for determining if chemistries and processes are scalable in speed and automation and related challenges and require a more rigid and fine-tuned pilot line.

It is envisioned that a national industrialisation infrastructure could have both a physical infrastructure and a network platform. The network platform could supply resources for partners along the battery production value chain and allow for an increased exchange of information, accelerating innovation and promoting entrepreneurship. A battery industrialisation infrastructure could also be linked to existing centres such as Battery Sweden Vinnova Center, (BASE) as well as initiatives that may result from e.g. WISE, to ensure a well-functioning ecosystem for the value chain from basic/applied research to demonstration and support for industrialization. This platform could act as a point of contact with education programs and academic partners.

The overall objective of any future battery industrialisation infrastructure physical infrastructure is to support the growing Swedish innovation and production ecosystem by offering battery cell pilot production line(s). This will enable the Swedish industrial stakeholders in their market access within the cell manufacturing ecosystem. Moreover, a battery industrialisation infrastructure will also reinforce the position of Sweden in the Li-ion cell manufacturing market, identifying knowledge and equipment gaps, creating common training and standardization initiatives, carrying out research projects on battery processing and manufacturing, and ultimately jointly developing strategies for scaling up the impact of the network. Although the present proposal is based on the LIB technology, it is crucial that a battery fabrication infrastructure is secured toward post-lithium-ion technologies, especially activities related to R&D&I pilot line configuration. In the latter, the matter of choice would depend on the adaptability of the conventional Li-ion cell production line and the final battery targets.

Providing infrastructure supporting industry activities also has a positive effect on industrial companies scouting for suitable countries and areas to establish R&D centres as well as manufacturing subsidiaries.

As observed from the interviews, the need for small companies is mostly a one-stop-shop where all testing, trials, and quality control can be performed. This includes education and research. For larger companies, system testing (RISE/SEEL-capacity) as well as access to a flexible and a larger pilot production line will be critical for their possibility to quickly screen promising technologies that do not fit their own pilot activities. From a market perspective, industrial partners have expressed a lack of cell sample capacity in Europe, in the quality and consistency of the production. This means that at a minimum, a supporting infrastructure is necessary for Sweden to maintain a presence in competitive battery production innovation (see section 5.2 below).

To fill these needs, an **automated** pilot line that allows for a **continuous** process able to run over a longer period is desired. It should also be **flexible**, in that certain parts can be changed out for other types of equipment, for example to allow for different chemistries and form factors. Price estimates vary based on sourcing of equipment, which could be of Asian or European origin. UKBIC has advised that it is advantageous to invest in European equipment for safer and faster updating and effective on-site support. In even the smallest suggested infrastructure, it will be important to have dry rooms, clean rooms, solvent recycling/solvent scavenging systems, large halls with production equipment (slurry and calendaring), along with packaging (sealing equipment).

5.2 Suggested Infrastructure

Based on our interviews, workshops, results from our state-of-the-art studies and previously discussed international investments, together with our visits to companies and institutes in the USA, Germany, and Great Britain, we envision that the growing national (and Nordic) battery ecosystem is best supported by three types of technological infrastructures:

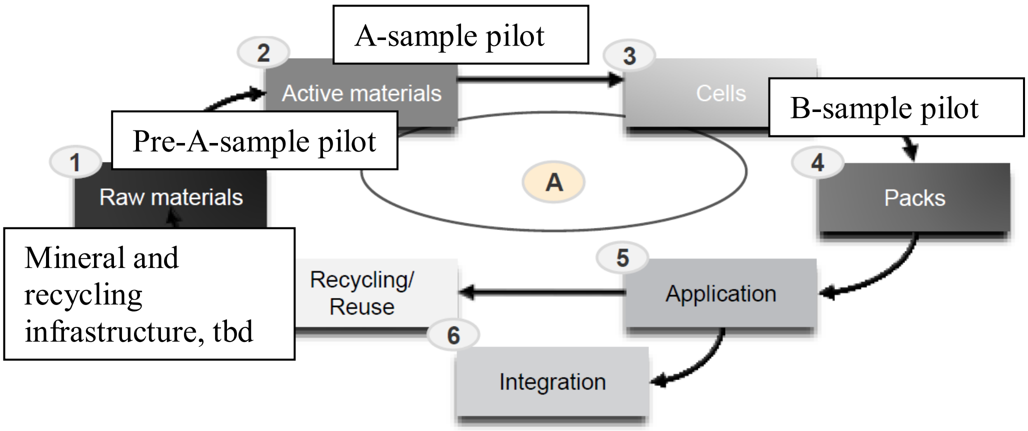

Figure 9. Roll of various pilot lines in the battery value chain.

- Pre-A sample level capable pilot line focusing on materials discovery and verification, supporting start-ups and other companies that do not yet have battery production infrastructure themselves above small-scale testing. These can also be used in academic research projects on battery processing and production. The goal of this facility would be to proof of concept for new materials and processes to determine generic battery performance and thus facilitate market introduction. We believe that such infrastructure is best suited to support R&D&I upstream the value chain (steps 1-2 according to the Business Sweden definition). A recent quotation indicates that cost for such an infrastructure for a ~0,5 MWh/a pilot is in the region of SEK160 million and include the necessary ancillary equipment.
- A flexible pilot line capable of producing A-Sample level quantity and quality of cells per year (~1 MWh/a), supporting start-ups and other companies that with internal R&D capability that need industrially quality cell samples for performance and lifetime validation. The goal of this facility would be to bring new materials (such as high voltage cathodes or solid-state batteries) to market. We believe such infrastructure is best suited to support R&D&I within materials and cell development (steps 2-4 according to the Business Sweden definition). An insight into recent national and international investments as well as information from equipment suppliers indicates that such pilot line cost in the region of SEK500 million, including the necessary ancillary infrastructure.

- A high throughput pilot line focusing on production upscaling capable of B-Sample level quantity and quality of cells, supporting companies that that need industrially quality cell samples to establish the key parameters and behaviour of the final product. The goal here would be to focus optimisation and scale-up of present manufacturing and production technologies (e.g. solvent free electrode manufacturing) including assembly of cells to modules. We believe such infrastructure is best suited to support R&D&I midstream the value chain, i.e. cells to product development (steps 3-5 cording to the Business Sweden definition). According to the information available to us, a 250 MWh/a pilot line costs about SEK1.7 billion; including costs for buildings, the necessary ancillary infrastructure and a fundamental analytical laboratory. At present however, we struggle to justify such an investment specifically in Sweden. A more appropriate investment for the Swedish and Nordic ecosystem seems to be a pilot line capable of 5-25 MWh/a. Unfortunately, the cost doesn't scale linearly, resulting in an investment of over SEK 600 million.

Note that, the cost indications above (around SEK1.3 billion in total) depends highly on the equipment manufacturers country of origin, the amount of ancillary and complementing analytical equipment needed to be invested in, as well as real estate costs. These costs need to be further elaborated on in the future work on detailed planning/design of the facilities, while all larger investments (i.e., B-Sample facility) need to be carefully planned with other development plans in the close regions outside of Sweden. From an economical point of view, the most appealing proposition would be to co-locate all the above-described infrastructure. This would allow for saving on, for instance, buildings and ancillary infrastructure as well as the very battery production equipment.

There are three main regional battery clusters growing in Sweden. In our view, it is important to support all the three national geographic battery clusters. Therefore, we believe that an optimal solution (similar to SEEL) is to form a few (3) smaller hubs, being able to support these regional ecosystems. Each of these hubs could consist of one or a combination of the proposed pilot lines and specialise on the local industrial strengths and needs. The final form of the infrastructure, however, need to be established in forthcoming dialog with potential stakeholders.

The volumes required, up to 100 MWh/a, necessitate a certain amount of space for industrial production lines, with at least a few thousand square meters for operation where equipment can be moved in and out of the focused working area. Facilities envisioned would be those for testing including analysis labs, coating, formation, stacking, slurry production and handling, and training. Also, both A and B samples levels pilots should ideally be able to produce different form factors including prismatic and cylindrical cells, while the Pre-A pilot line would primarily focus on pouch cells. This proposed infrastructure must be in-sync with industry adopted development processes, where a small line is dedicated to functional prototypes using pouch cells, a larger flexible line is suitable for A-sample maturity levels and a largest pilot is suitable for B-sample maturity and validation processes and should be further elaborated upon in future work.

Finaly, it is also evident from our dialog with industry, academia and the authorities in Sweden, that there is also a pronounced need for infrastructure toward *materials synthesis, upgrading and refining higher* up the value chain related to the mining businesses as well as down streams value chain related to *recycling*. Moreover, Swedish industry of battery producers would greatly benefit from such a broad infrastructure with expertise and resources existing close to the customer and contributing to the strong export market that currently exists in Sweden.

5.3 Possible owners

Based on earlier experiences from the creation of AstaZero and SEEL, we believe that a winning model is risk-sharing between public and private actors. SEEL for instance was made possible due to governmental support that led to industrial commitments resulting in a IPCEI application and that RISE together with Chalmers made the investments in taking ownership, building and operating the facilities. Thereby, SEEL can operate independently and openly to the financing bodies and industrial stakeholders. Another example of a successful testbed is SII-LAB (Stena Innovation Industry Lab) hosted by Chalmers with base funding from the STENA foundation. In SII-Lab companies are invited to place equipment and software which is the jointly utilized (by industry, institute and academia) to perform research and showcase development and results. RISE and Chalmers have experience from hosting and co-owning this type of independent technological infrastructure and could do so also for the proposed battery-relevant industrialisation infrastructure, regardless of its geographical location. One possibility is a more geographically and functionally distributed model, where different owners of different facilities in different part of Sweden. The major disadvantage of such model would be the lack of coordination between the various hubs compared to coordination offered by a single ownership. Note that the above ownership discussion is speculative and not a recommendation. The final form of organisational structure of any future industrialisation infrastructure need to be established in the future work.

5.4 Future work and implementation process

Establishing battery industrialisation infrastructure, regardless of the model discussed above, will require an owner and operator who can take responsibility for the realisation including specifying, building process and operation of the facility. This owner will have to make a business case and it is likely substantial financial support from the public sector will be required, possibly at least 50% of the investment and/or providing governmental loan guarantees (similarly to SII-LAB and the IPCEI process adopted for SEEL). The process to receive such support from the public sector will require a process confirming that all involved stakeholders are convinced Swedish industry and society will benefit from battery industrialisation infrastructure. This *goal alignment process* is particularly important and needs to involve decision maker from industry, institutes, academia, regional governments and the national government. The national government has an important role in guaranteeing the base support funds to get the stakeholders to make their business commitments so that the owner can include public funding support and stakeholder business and research commitments in the business case. Regional government has an important role in facilitating and supporting local battery hubs with this type of infrastructure. There is a risk that if the public sector i.e., government or an authority, does not take the first steps in a funding commitment, the recommendations to establish battery industrialisation infrastructure will stagnate. In this case, Sweden will be left behind in terms of innovation, which can have disastrous consequences for battery relevant activities in Northern Europe. The next few years will determine the dominant battery centres in Europe and Sweden has a tremendous opportunity to assume that role.

Short term action list

A necessary first step is to form a team and to identify an organisation willing to take the role of a leader for this investment. The ambition should be to have, as soon as possible, a clear path forward with the most realistic financing strategy aligned in due time for upcoming Research Proposition "Forskningspropositionen" for 2025-2029, and a strategy for the prioritization of what infrastructure to build. In addition, to secure financial support from industry and regions we propose the following action list to be activate immediately.

- Identify an organisation willing to lead the process to secure funding and work on detailed planning/design of the above-mentioned infrastructure.
- Detail the infrastructure needed and create a roadmap for its establishment including mapping of potential stakeholders to secure utilization and continuous funding through e.g. membership and or equipment maintenance and upgrading.
- Form a follow-up project, that takes concrete steps to recruit a core team consisting of committed partner organisations willing to undertake risk-sharing for the running costs and utilization. E.g. utilizing the funding model from SEEL or SII-Lab.
- Form a consortium consisting of dedicated private and public stakeholders as well as investments plan to secure:
    a. Involvement and commitment from government in the financial support/guarantees
    b. Involvement and commitment of regions and municipalities in the form of an agreement and financial support
    c. Industrial commitments in the form of an agreement and specification of resources committed.
- Present and debate a *national battery infrastructure* at relevant venues, such as Almedalsveckan in Visby.
- The short-term goal, beside forming the industrial/public consortium, is to address and highlight the needs for a national battery infrastructure in the upcoming Research Proposition "Forskningspropositionen" for 2025-2029.

Long term goals

- An investment in battery fabrication and innovation infrastructure should be initialised within 2 years.
- Within 3-5 years, the partners should be actively collaborating, and infrastructure being finalised.

6. Dissemination

Initial findings and insights from this study were presented at the conference Energiutblick arranged by the Swedish Energy Agency in December 2023. This topic will be actively discussed at Almedalen 2024 and a summary will be presented in various forums (Energy Agency workshops, academic arenas for example Battery Sweden (BASE), SEEL, Swedish Electromobility Center (SEC) and Swedish Electricity Storage and Balancing Center (SESBC).

Appendixes

Workshop participants

Göteborg	Stockholm	Västerås	Skellefteå
AB Volvo	ABB Electrification Sweden AB	ABB	Arctic Center of Energy
AB Volvo - Mariestad Industrialisation Project	Blue Institut	Addiva AB	Automation Region
AFRY	Business Region Skaraborg	Alstom	Blekinge Tekniska Högskola
Alelion	Chalmers Students	Altris AB	Blue Institute
Alelion Energy Systems AB	EBA250/ Innoenergy	APR Technologies AB	Business Sweden
Batixt AB	KTH	Blue Institute	Chalmers
Business Region Borås	Naturvårdsverket	Invest Västerås	Chalmers tekniska högskola
Business Region Göteborg	Nilar AB	Mälardalen University	Hitachi Energy
Business Sweden	Regal Components AB	Mälarenergi AB	
CEVT AB	Region Dalarna	Nilar AB	luc norr
Chalmers Industriteknik	Scania CV AB	Region Dalarna	IVL Svenska Miljöinstitutet
Chalmers students	Siemens Energy AB	Region Dalarna /Invest in Dalarna Agency	LTU
Chalmers tekniska högskola	Talga AB	Uppsala universitet	LTU Business / LTU
China Euro Vehicle Technology (CEVT)	UPPström Racing (vid Uppsala Universitetet)	AB Volvo	Luleå tekniska universitet
CIT Renergy AB	Volvo Car Corporation	Volvo Group Trucks Operations	ACE # Arctic Center of Energy
Cling Systems	Volvo Energy		Luleå tekniska universitet
Compular	WSP		Luleå University of Technology
DSV	Zparq AB		Northvolt
E.ON Energidistribution AB	Östersunds Kommun/The Power Region		Skellefteå kommun
Energimyndigheten			Skellefteå Kraft AB
Experis			Skellefteå Kraft Elnät AB
Göteborgsregionen			Skellefteå Science City
Hitachienergy			SPGA
Högskolan Väst			WSP
IDC West Sweden AB/ASSAR			
IF Metall Göteborg			
Insplorion			
Invest in Skåne			
IVL Svenska Miljöinstitutet			
Lex Energy North AB			
LexEnergy			
Lindholmen Science Park AB			
NOVO Energy			
Odette Sweden AB			
Polestar			
Position Väst Företagsetableringsservice, Fyrbodals kommunalförbund			
Pratexo			
Provexa			
Provexa Technology			
Scania CV			
Siemens			
Skaraborgs kommunalförbund			
Skaraborgs Kommunalförbund			
Svenljunga Kommun			
Swedish Electromobility Centre, Chalmers			
VCC			
Volvo			
Volvo Group			
Volvo Group Trucks Operations			
Volvo GTT			
Volvo Trucks			
WireFlow AB			
Öresundskraft			

Interviewed companies and representatives

Company	Representatives
ABB	Anna Andersson/Shiva
Alstom	Peter Mellgren
Altris	Kristina Von Fieandt, Tim Nordh, Björn Mårlid
Boliden	Erik Ronne, Anna Medvedeva
Business Sweden	Jessica Olsson, Robin Petersson
Elektrolux	Ulrik Danestad
Enerpoly	Mylad Chamoun, Samer Nameer
Festo	Stefan Johansson
Husqvarna	Sören Kahl
Nilar	Stina Starborg
Norsk Hydro ASA	Johan Fridner
NorthVolt	Martin Karlsson
Nouryon	Mats Wildlock, Magnus Paulsson, Lauren Mulqueen
Novo Energy Manufacturing	Oskar Falk, Pooyan Seddighzadeh
Novo Energy R&D	Eerik Hantsoo, Reza Younesi, Peter Norin
Polestar	Hanna Bryngelsson
SAFT	Daniel Nilsson
Stena	Fredrik Övergaard, Björn Hall
Stora Enzo	Walter, Stephan
Sthlm Universitet	Gunnar Svensson
Talga	Anna Motte
Volvo Cars	Annika Ahlberg Tidblad, Therese Granérus, Henric Rhedin, Fredrik Edgren
Volvo Group	, Klas Sandren, Robert Gorner, Michael Balthasar