GÄLLIVARE NÄRINGSLIV

Gällivare Green Cluster Pre-Study

Editorial

Commissioned and Published by
Gällivare Näringsliv AB
Centralplan 4
982 36 Gällivare

Funding Provided by
North Sweden Green Deal
Region Norrbotten
European Union

Editing and Supervision
Roger Hansson
roger.hansson@gallivarenaringsliv.se

Authors
Jeremias Finster (Atacama New Vision GmbH)
Máté Rottek (Atacama New Vision GmbH)

Publication Date
June 2023

Roger Hansson
roger.hansson@gallivarenaringsliv.se

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Roger Hansson
roger.hansson@gallivarenaringsliv.se

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Glossary

CO2	Carbon dioxide
DRI	Direct reduction of iron
RFNBO	Renewable fuel of non-biological origin (criteria for renewable hydrogen by the EU)
EIT	European Institute of Innovation & Technology
EU	European Union
HYBRIT	Hydrogen Breakthrough Ironmaking Technology
IPCEI	Important Projects of Common European Interest
LKAB	Luossavaara-Kiirunavaara Aktiebolag
MW	Megawatt
RED	Renewable Energy Directive (EU)
SMEs	Small and medium-sized enterprises
TWh	Terawatt hour

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Executive summary

Context. The Gällivare municipality's economy is primarily driven by the **mining sector**. However, the region is now embarking on a **path towards sustainability** with projects like the **HYBRIT Demonstration**, a hydrogen-based direct reduction of iron set to commence in 2026. This project will generate **substantial residual streams**, including **oxygen** and **heat**. Gällivare **aims** to leverage these streams to establish a **green cluster**, **creating more value domestically**, **high-skilled job opportunities**, and **promoting self-sufficiency** in Norrbotten. This initiative not only **enhances** the **HYBRIT Demonstration** project but also **contributes to** the **region's overall sustainable development**.

Challenges. To date, **sustainability initiatives** in Gällivare have been **focused on specific applications**, such as food production. However, a **more coordinated approach is necessary** to drive an effective transition. By adopting a **cluster approach** and fostering collaboration in efforts, knowledge sharing, and resource utilisation, the municipality **can achieve its goals**. Nonetheless, **several challenges** must be addressed, including **talent attraction**, **availability of housing** for new residents, **permit granting** lead times, and **railroad capacity**. Additionally, as more applications shift to renewable electricity, **energy management** becomes increasingly vital, potentially impacting the region's electricity balance from net-exporter to net-importer.

Approach. Gällivare Näringsliv AB has collaborated with **Atacama New Vision GmbH** to conduct a **high-level pre-study** on the potential cluster and its building blocks. While this pre-study provides valuable insights, a **more detailed study is required** to refine the cluster's design. The pre-study followed a **structured approach**, encompassing **resource** identification, **value chain** analysis, assessment of potential **applications**, and the definition of design attributes. Based on these attributes, four **cluster candidates** were formulated, with a focus on **technology**, **energy-heavy**, and **food** sectors, and a **balanced** approach encompassing all sectors.

Recommendation. Among the cluster candidates, the **balanced cluster aligns best with Gällivare's ambitions**. It strikes a balance between **sectors** (food, energy-intensive, and technology), **job skill levels** (mid-high), **value creation** (mid-high), and **target markets** (cluster-internal and export). Given the initial availability of significant oxygen and residual heat from electrolysis and the requirement for low-medium skill level jobs, we recommend **initiating the development of the food sector** within the balanced cluster. The **next steps** involve **detailed cluster design**, preparation of **marketing activities**, and providing **start-up support** to new entrants.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

1. Introduction

This report highlights the significant potential for creating a green cluster in Gällivare, Norrbotten, leveraging the renewable resources generated by the HYBRIT Demonstration project. With the **ambitious goals** of attracting businesses, high-skilled jobs, and people to the region, Gällivare Näringsliv aims to establish a sustainable and **climate-neutral small town by 2030**[i].

1.1 Context

Norrbotten, located in North Sweden, is renowned for its thriving **mining sector**. In collaboration between LKAB, SSAB, and Vattenfall, the **HYBRIT Demonstration** project[ii] has been instrumental in driving the transition towards fossil-free steel production. By employing green hydrogen in the direct reduction of iron (DRI), the project not only supports Sweden's sustainability goals but also presents a unique opportunity for the Norrbotten region. The construction of a DRI plant in Gällivare, powered by a 500 MW **electrolysis** unit, will generate significant amounts of valuable renewable **oxygen** and **residual heat** streams, starting from 2026.

Capitalising on the renewable resources generated by the HYBRIT Demonstration project, Gällivare Näringsliv envisions the creation of a **green cluster** that fosters high-skilled job opportunities and enhances value creation within the municipality. Currently, the mining sector in Gällivare primarily focuses on upstream activities, exporting primary goods without extensive processing. By diversifying into a green cluster, the region can foster **self-sufficiency** and reduce the reliance on imported goods and services.

The establishment of a green cluster presents an exciting opportunity to stimulate **economic growth** and **job creation** in Gällivare. The cluster is expected to generate a significant number of high-skilled jobs, providing residents with enhanced employment prospects. The aim is to create **2,500 new permanent jobs by 2030**. To support the population growth required for the cluster's success, the municipality plans to construct **1,200 new houses by 2026**. Moreover, the influx of new businesses and professionals will contribute to the overall development of the Norrbotten region, fostering a thriving and sustainable community.

In addition to the HYBRIT Demonstration project, Gällivare municipality is actively pursuing **other sustainability initiatives**. The **ReeMAP** project[iii], led by LKAB, aims to recover and upgrade mine waste from the iron ore mines in Malmberget and Kiruna to produce valuable resources such as phosphorus, rare earth elements, fluorine, and gypsum. The industrial park, slated to commence operations in 2027, will be located in Luleå, the largest city in Norrbotten. This initiative aligns with the region's commitment to circular economy practices and sustainable resource management.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Another promising sector under development in Gällivare is the food industry. The **Arctic Food Arena** project[iv] aims to harness the residual heat generated by the HYBRIT Demonstration project for the food sector. By creating an innovative environment that encourages collaboration between industry, food producers, and universities, the project seeks to develop methods for circular food production. The **Regenergy Gällivare** project[v], a pioneering example of large-scale circular food production in greenhouse horticulture and land-based fish farming, will create approximately 220 permanent jobs and further contribute to the region's economic and environmental sustainability.

This pre-study primarily **focuses on the Gällivare municipality**. However, to gain a **broader perspective** and consider developments and resources in the surrounding areas, projects and infrastructure throughout the **Norrbotten region** have been assessed at a high level. This approach allows for a narrowed scope while still enabling collaboration, resource sharing, and the exchange of best practices. **Further projects** in Gällivare and the Norrbotten region providing resources and influencing the design of the green cluster are listed in Figure 1 below.

Figure 1: Non-exhaustive list of further sustainable initiatives in the Norrbotten region

Project	Stakeholder	Subject	Start	In the Gällivare municipality
Wind Park Storlandet	Vattenfall	Wind power (10 TWh)	n/a	Yes
Mining vehicles	Boliden, LKAB	Electrification	2023	Yes
Per Geijer Deposit	LKAB	Rare earth elements reserve	n/a	No
Vittangi mine	Talga	Graphite mining (for lithium-ion batteries)	2025	No
Green steel mill in Boden	H2 Green Steel	Steel production (5Mt/a by 2030)	2025	No
Green Wolverine	Fertiberia	Ammonia for fertiliser, maritime fuel, and explosives production	2026	No
Bothnia LinkH2	Port of Luleå, Uniper, ABB, etc.	Methanol for maritime fuel production, district heating	2027	No
FReSMe	SSAB, SWERIM, Stena Rederi, etc.	Methanol research & development	2016	No

For example, there are similar plans to utilise residual heat for food production around the H2 Green Steel plant in Boden, presenting opportunities for collaboration and knowledge transfer.

1.2 Challenges

The development of the green cluster in Gällivare is not without its challenges. Several key challenges have been identified that need to be addressed for the successful implementation of the project.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Input Conditions. The transportation infrastructure poses a significant constraint for the cluster development. The **capacity of the railroad**, specifically the Malmbanan, is currently limited due to LKAB's iron ore transport from the Malmberget mine in Gällivare to the Ports of Luleå and Narvik. Plans for expanding the Malmbanan are under discussion to alleviate this constraint. Additionally, the **speed of housing construction** must be accelerated without compromising sustainability standards. **Delays in permit granting processes** can also potentially impact the timeline of projects. It is crucial to address these administrative bottlenecks to ensure timely execution.

Energy Supply. Despite having abundant hydro power and the addition of new power supply from wind parks, Norrbotten's status as one of the EU's largest electricity export regions may change as **widespread electrification** takes place. With the growing energy demands of the green cluster, there is a possibility that the region may transition **from** being a **net electricity exporter to an electricity importer**. This shift in the energy balance needs to be carefully managed and accounted for in the cluster's development plans.

Related and Supporting Industries. The exclusion of another steel mill in Gällivare from the assessment, due to SSAB's electric arc furnace installation in Luleå and H2 Green Steel's greenfield steel mill in Boden, means that **steel is not** considered **a primary resource for the green cluster**. Similarly, Boliden's copper shipments from the Aitik mine in Gällivare to their smelter plant in Skelleftehamn, located over 300 km south of Gällivare, means that **copper is not a primary resource for the cluster** either. The availability of key technologies, such as the electrolyser for the HYBRIT Development project, also presents a bottleneck as plant sizes of 500 MW have not been constructed before and the **supply of electrolysers is limited** in an emerging market.

Business Context. The remote location of Gällivare in Swedish Lapland, above the polar circle, with long, dark, and cold winters, may pose challenges in attracting global talent to the region. To overcome this, it is essential to create an **attractive framework** that encourages professionals to relocate. Additionally, the **integration** of new arrivals needs to be carefully planned and managed to ensure a smooth transition. Furthermore, the **sustainable development** ambition of the cluster should extend beyond its operational phase and consider sustainable technology choices, establishment of value chains, and their timing.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2. Methodology

2.1 Resources

The first step in our methodology is to analyse the **available resources** and streams in order to provide a structured view of their quality and quantity. This assessment will **determine** which **applications** can be **part of the cluster** and **guide its optimal size**.

Mineral Resources:

- **High:** Gällivare boasts abundant reserves of **iron ore** and **copper ore**.
- **Medium:** The region also possesses deposits of **rare earth elements**, **phosphorus** (phosphate rock), **graphite**, and **sand/quartz**.
- **Low:** While **silver**, **gold**, and **lead** resources exist, they are comparatively limited.

Organic Matter Resources:

- **High:** Gällivare possesses ample supplies of **timber**, **wood**, **pulp**, **paper** (although more readily available slightly south of the municipality), **vegetables**, **fish**, and **seafood** (the latter three are upcoming from Regenergy Gällivare).
- **Medium: Residual biomass** from agriculture, forestry, and fish farming can be utilised.
- **Low: Berries** and **flowers** are available but in smaller quantities.

Electrochemical Resources:

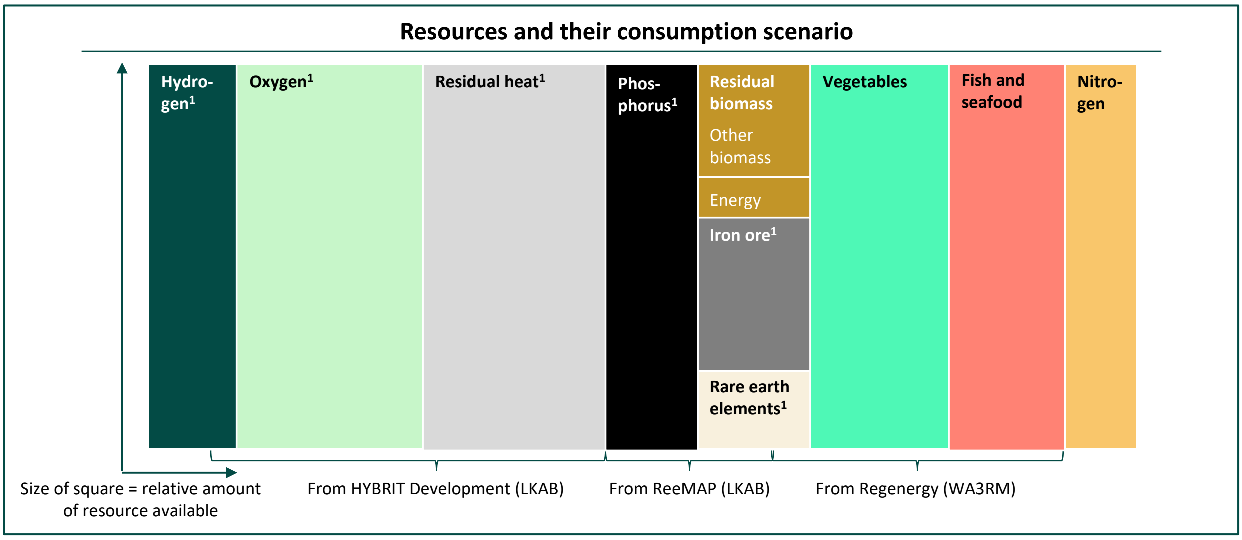
- **High:** The region benefits from significant **hydropower** and **wind power** resources, as well as abundant upcoming supplies of **oxygen**, **residual heat**, and **hydrogen**.
- **Medium: Ammonia**, as a derivative of hydrogen, can be considered a medium-level resource. Additionally, **bioenergy** from biomass and **carbon dioxide** from industrial and biogenic sources can be utilised.

Based on the aforementioned resources, we have identified **11 key resources** for consideration: **hydrogen, oxygen, residual heat, phosphorus, residual biomass, bioenergy, iron ore, rare earth elements, vegetables, fish and seafood, and nitrogen** (in the form of ammonia).

While we have provided indicative quantities for the identified resources, a **verification of specific quantities available for the cluster is still pending**. It is especially important to confirm the availability of resources marked with a "1" in Figure 1 below. We anticipate that LKAB will provide confirmation of these quantities. For now, our **analysis** is **based on the type of resource** that will be available in Gällivare, and the **agreed-upon level of availability** for the cluster as below.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Figure 2: Overview of key resources and their consumption scenario in the future cluster



NB. Please note that the figure presents an overview of the key resources and their corresponding levels based on **available information prior to verification** of specific quantities with relevant stakeholders.

2.2 Value Chains

In the second step of our methodology, we examine the **value chains associated with the identified resources**. This analysis provides valuable insights into the trends and demand for various applications, which will inform the design of the cluster. A detailed overview of the value chains can be found in Figure 17 in the appendix. Below, we outline the **key insights** for each resource's value chain:

1. **Iron Ore:**

- **Hydrogen reduction** enables the production of **iron powder** for powder metallurgy, magnetic material manufacturing, or chemicals manufacturing.
- **Local extraction** of iron ore **is significant**, with **LKAB** holding the **lion's share**. Other potential suppliers include Kaunis and Boliden (as a by-product from copper mining).
- The **EU Carbon Border Adjustment Mechanism** (CBAM) aims to **protect green steel** from carbon-intense steel imports. For its production, the Renewable Energy Directive III (REDIII) mandates a **share of minimum 42% renewable hydrogen (RFNBO)**. LKAB currently caters to 80% of the EU's demand, and there is **growing demand from renewable energy manufacturing**, such as wind turbines (aligned with the EU Green Deal Industrial Plan's target of 85% domestic production).

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2. **Phosphorus:**

- Phosphorus can be **directly applied** (organic fertiliser) or **chemically processed** for food, feed, and chemicals production. A **by-product** of phosphate rock mining is **rare earth ore**.
- While there is minimal use in **semiconductor manufacturing**, efforts to scale domestic production are underway to become more self-sufficient through initiatives like the EU Chips Act.
- Phosphorus is listed as a **critical raw material** by the EU, and EU fertiliser regulations promote the use of organic and **organo-mineral fertilisers**.
- **Growing demand** is observed in **battery and fertiliser production**.

3. **Rare Earth Ore:**

- Besides from mining, rare earth ore can be a by-product of phosphorus extraction and recycling.
- It is listed as a **critical raw material** by the EU, and the EU Critical Raw Material Act emphasises its importance, aiming to **diversify and secure its supply** for the energy transition.
- There is **growing demand** for rare earth elements in **renewable energy technology manufacturing**, such as heat pump manufacturing (aligned with the EU's target of 85% domestic production).

4. **Vegetables (Greenhouse Horticulture):**

- Besides **vegetables** as main product, **residual biomass** can be utilised for **nutrient recycling** and **bioenergy production**, while benefitting from the residual heat generated by HYBRIT.
- Regenerative and urban agriculture practices, nutrient recycling, carbon removal (e.g., biochar), and fertigation techniques are increasingly relevant.
- The EU promotes **organic agriculture and fertilisers**, and Sweden has the third-largest national share of organic agriculture. There is an opportunity for self-sufficiency to **reduce imported CO_2**, as Sweden has one of the highest CO_2 emissions embedded in its trade balance within the EU.

5. **Fish and Seafood (Aquaculture):**

- **Fish and seafood** not only serve as direct products, but their **residuals** can also contribute to **pharmaceuticals, cosmetics, and nutrient recycling**.
- **Sustainable practices**, such as integrated multitrophic aquaculture and recirculating aquaculture systems, are gaining momentum. **Alternative feed sources** like algae and insects are being explored, along with **integrated aquaponics** (symbiosis with greenhouse horticulture).
- There is **growing demand** for seafood, **direct sales** through e-commerce platforms, and an increasing market for **organic premium products** (supported by the EU certification and transparency regulation).

Roger Hansson
roger.hansson@gallivarenaringsliv.se

6. **Residual Biomass:**

- Residual biomass offers **numerous input options** as well as **processing applications** for **upcycling** and **recycling**, such as nutrient management.
- **Circular economy** principles and **waste valorisation** strategies are crucial.
- **Growing demand** is observed in **biochemicals, construction materials, feed, pharmaceuticals, nutraceuticals, and cosmetics**. The EU promotes the use of **organic fertilisers**.

7. **Bioenergy:**

- Bioenergy can be derived from **various inputs**, such as **algae** (one of the REDII listed inputs for advanced biofuels), and its **outputs** are **carbon removal** (biochar), **biofuels**, **biogas** (including hydrogen production), and **biomaterials** (e.g., bioplastics).
- **Advanced biofuels** are expected to **expand**, although a decline is projected in passenger transport from 2035 due to the EU ban on internal combustion engine (ICE) vehicle sales. **Circular economy** principles and **waste valorisation** play a significant role, emphasising the importance of **sustainable management of the CO2 cycle**.
- The EU aims for **about 4.5% advanced biofuels by 2030**, decarbonisation of the **maritime sector** (**6% emissions savings by 2030**), and increased use of **bio-sustainable aviation fuels** (**about 4.8% by 2030**). EU research and innovation initiatives support the development of bioplastics.

8. **Oxygen:**

- Oxygen can be produced through **electrolysis** within the HYBRIT initiative, but other sources such as **algaculture** and **air separation** (for ammonia production) are also viable.
- Oxygen finds **applications in various industries**, including fuel burning (oxyfuel), chemical processes, paper bleaching, water treatment, aquaculture, insect farming, and medical applications.
- The **circular economy** drives the growing market, although **prices may decline** due to increased supply from new applications like electrolysis.

9. **Residual Heat:**

- Residual heat can be sourced from **various industrial processes**, but its **temperature usually remains low** (around 65°C from electrolysis). **Higher temperature applications** are **necessary** to supply +100°C **for district heating** and **industrial processes**.
- **Circular economy** principles, **energy efficiency** regulations, and the adoption of **residential heat pumps** play crucial roles.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

- The RED III targets an **additional 1.1% renewable energy in heating and cooling annually** from 2026 to 2030, utilising residual heat as a key component.

10. Hydrogen:

- Besides **electrolytic**, **biogenic hydrogen** serves as a versatile resource with applications in **energy, chemicals, fuels, industrial feedstock, and food production** (bioreactors).
- **Renewable hydrogen (RFNBO)** is expected to play a significant role, driven by **mandatory REDIII targets** in the **transport** and **industrial sectors**. **Cost reductions** are anticipated through economies of scale, seasonal storage, and balancing renewable energy sources. The **Norrbotten region is well-suited for RFNBO production** as its grid mix is over 90% renewables already.
- The EU has set targets of **1% RFNBO in transport**, **1.2% RFNBO in aviation**, **42% RFNBO in industry by 2030**, and **2% RFNBO in maritime by 2034** (the latter two are conditional).

11. Ammonia (as a Hydrogen Derivative):

- Ammonia can be produced **synthetically** from hydrogen and air-separated nitrogen, or alternatively through **organic recycling** via nitrification (bacteria). It finds applications in **fertilisers, explosives, chemicals, maritime fuels, energy, and steelmaking** (still R&D).
- **Planetary boundaries** indicate that the **nitrogen cycle has already been breached**, underscoring the **need for sustainable management**.
- Renewable ammonia holds potential for **power generation** and as a **maritime fuel**, decarbonising value chains at the Port of Luleå. **Preference** is given to **organic** over synthetic **fertilisers** (EU regulations).

Throughout the value chains of the 11 resources, we have identified a total of **118 applications**. This comprehensive analysis provides a **holistic view** of the potential applications for the cluster. Additionally, the identification of applications participating in multiple value chains allows for the establishment of **circular design links** within the cluster.

2.3 Applications

In the third step of our methodology, we analyse the **applications** within the identified value chains. This analysis involves **four categories** that provide a comprehensive understanding of each application: **input conditions, demand conditions, resource relations, and business context**. By examining these categories, we can assess the requirements, market potential, value chain connections, and strategic fit of each application. Additionally, we evaluate factors such as job creation potential, technology readiness level, and the utilisation of local resources. This comprehensive assessment helps us identify the **potential for synergies** and the **overall viability** of each application.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

1. **Input Conditions:** Under this category, we consider the following aspects for each application:

- **List of Required Inputs:** We examine the specific resources and inputs necessary for the application's operation.
- **Usage Rate of Local Resources:** We assess the consumption rate of the 11 selected resources by the application and determine the degree to which local resources can meet these requirements.

2. **Demand Conditions:** In this category, we focus on the following elements:

- **Products:** We analyse the output products of each application and their market trends.
- **Market Value:** We evaluate the market value and economic potential of the application's products.

3. **Resource Relations:** Resource relations explore the interconnections and circularity within the value chains. This category involves:

- **Value Chain Connections:** We identify the links between different applications in terms of resource flows, such as outputs and waste products becoming inputs for other applications.
- **Value Chain Enabling Potential:** We assess the potential of an application to be an enabler of a new branch in the value chain.

4. **Business Context:** The business context category considers various factors related to the strategic fit and viability of each application:

- **Job Creation Potential:** We assess the potential for job creation associated with each application.
- **Technology Readiness Level:** We evaluate the readiness level of the technologies required for the application's implementation.

Throughout this analysis, we use a framework that assesses individual factors to determine the suitability and potential impact of each application. To illustrate this assessment, Figure 3 provides an overview that defines the **assessment criteria** of **low, medium, and high** for various factors.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Figure 3: Definition of low, medium, and high for various factors

Definition

Input conditions

Share of local inputs available in Gällivare (of all inputs needed to produce a final product) – objective assessment
- Low: less than a third
- Medium: between a third and two third
- High: more than two third

Consumption rate of selected resources (per tonne of final product) – objective assessment
- Low: less than 1 tonne of resources
- Medium: 1 to 3 tonnes of resources
- High: more than 3 tonne of resources

Demand conditions

Market value (per tonne of a final product) – objective assessment
- Low: less than € 750
- Medium: between € 750-3,000
- High: more than € 3,000

Resource relations

Connected value chains (to an application) – objective assessment
- Low: less than 5
- Medium: 6-9
- High: 10 and more

Business context

Job creation potential (for an average-sized plant) – mixed assessment
- Low: 0-49 jobs
- Medium: 50-249 jobs
- High: 250 and more jobs

Skill level of jobs (for an application) – subjective assessment
- Low: low level of training / risk management
- Medium: medium level of training / risk management
- High: high level of training / risk management

Level of value creation (of application) – objective assessment
- Low: upstream
- Medium: midstream
- High: downstream

2.4 High-Potential Applications

In the fourth step of our methodology, we focus on analysing the **high-potential applications** within the identified value chains. The selection of these applications is based on the **top application(s) per resource**, considering their **synergy and market potential**.

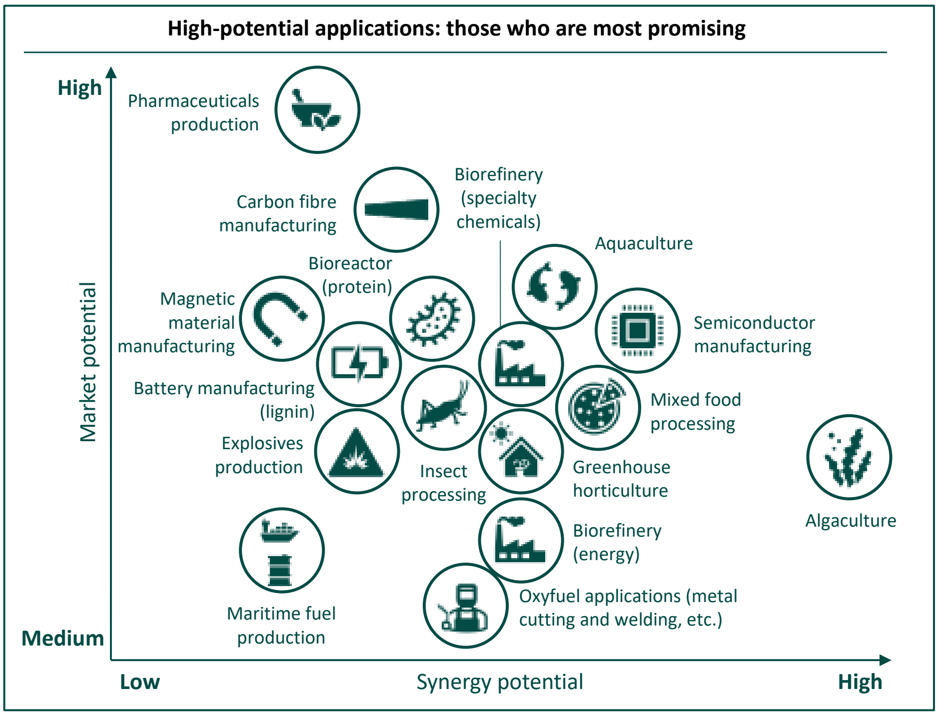
To assess the potential of these applications, we employ a **mapping approach** that considers **two key axes**:

1. **Synergy Potential (x-axis):** The synergy potential of an application refers to the **number of connected value chains** it has and additionally its **potential to enable new value chains**. We evaluate the application's ability to leverage multiple input and offtake applications and create synergistic relationships within the cluster. Applications with high synergy potential can benefit from shared resources, knowledge exchange, and circularity.

2. **Market Potential (y-axis):** The market potential of an application is determined by the **market value of its products** and the **rate of local resource usage** (11 selected resources). We assess the economic viability and market demand for the application's output. Applications with high market potential can generate significant economic value while finding favourable input conditions from local resources.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Figure 4: High-potential application assessment



Based on this analysis, we identify the **highest-potential applications** within the cluster:

1. **Highest Synergy Potential: Algaculture** demonstrates the highest synergy potential among the applications. It benefits from multiple input applications within the cluster and offers various uses for algae, including energy production, food, nutraceuticals, pharmaceuticals, and more. Algaculture can leverage the resources and knowledge available in the cluster to create synergies and contribute to multiple value chains.

    - **Applications Enabling New Value Chains: Carbon Fibre** and **Semiconductor Manufacturing** are identified as applications that have the potential to enable new value chains, particularly within the technology sector. These applications offer opportunities for technological advancements, innovation, and the development of new products and services. Their implementation can drive growth and diversification within the cluster.

2. **Highest Market Potential:** The application with the highest market potential is **Pharmaceuticals** Production. This application stands out due to the high market value of its products, particularly the active pharmaceutical ingredients, which have a market value of about 70,000€ per ton. Additionally, the extraction process for these pharmaceutical ingredients requires a substantial amount of residual biomass, which aligns with the available resources in the cluster.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

By highlighting these high-potential applications, we can **prioritise their development** and explore the opportunities they present for value creation, resource utilisation, and market competitiveness. These applications **play a significant role in shaping the design and focus of the cluster**, ensuring its sustainability and economic success.

2.5 Cluster Candidates

In the fifth and final step of our methodology, we aim to **build different cluster candidates** based on the analysis conducted thus far. The first part of this step involves **establishing guiding design attributes** to ensure the clusters' viability and effectiveness. The main guiding attributes considered in building the clusters are **resources, tactical factors, and strategic considerations**. Additionally, several other design guiding attributes contribute to shaping the cluster candidates. Consequently, **four cluster candidates** are designed: **Technology**, **Energy-heavy**, **Food**, and **Balanced**. Each candidate is assessed based on its resource, tactical, and strategic fit.

1. **Main Guiding Attributes:**
    a) **Resources:** The selected cluster should prioritise a high resource usage rate of **Oxygen, Residual heat, Phosphorus, Vegetables, Fish, and Seafood**. These resources are foreseen to be abundant in the cluster, forming the foundation for various applications and value chains.
    b) **Tactical Factors:** The cluster should incorporate a **medium to high skill level of jobs**, providing opportunities for skilled labour to support the cluster's operations. Additionally, **high infrastructure compatibility** is considered to leverage existing infrastructure and minimise the need for extensive infrastructure development.
    c) **Strategic Considerations:** The cluster should focus on **mid- to downstream applications**, which involve value addition and product diversification. The aim is to move beyond raw material extraction and processing, enabling the cluster to contribute to higher value-added activities. Moreover, achieving **self-sufficiency with some capacity for exports** ensures the cluster's economic resilience and competitiveness.

2. **Further Design Guiding Attributes:**

    a) **Iron Ore:** Due to long-term contracts over most of LKAB's extraction capacity, the utilisation of iron ore is considered **low** in the cluster.
    b) **Rare Earth Elements:** Considering the nascent scaling-up efforts with projects like ReeMAP and the Per Geijer Deposit, the utilisation of rare earth elements is also set to a **low** level in the cluster. This reflects the current status and potential **future developments** in the rare earth elements sector **may change the availability**.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

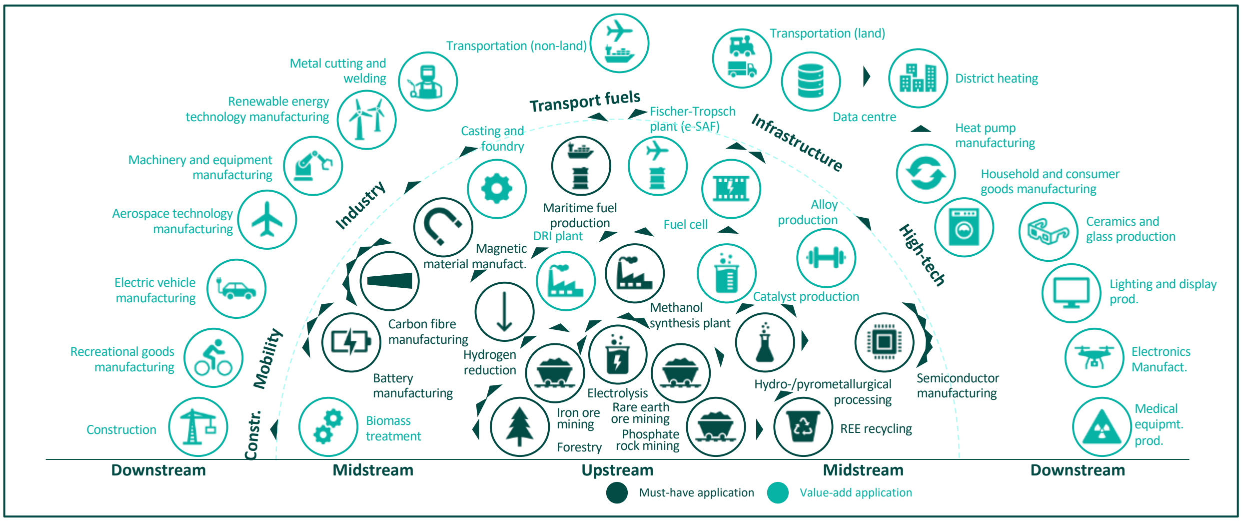
c) **Biomass:** Given the circular design within the food sector, the availability of residual biomass (e.g., for energy purposes) is regarded as **limited** in the cluster.
d) **Hydrogen:** The availability of hydrogen is considered at a **medium** level in the cluster candidates. While the HYBRIT Development project can provide a small portion of excess electrolytic hydrogen, further production of electrolytic or biogenic hydrogen is required to meet the cluster's needs.
e) **Technology Readiness Level (TRL):** The cluster's target applications should have a **medium to high** technology readiness level. This allows room for innovation and the inclusion of applications that can improve their TRL by 2030, aligning with the timeline for development.
f) **Number of Jobs per Application: On average**, the number of jobs per application is considered **medium**, ensuring a balanced distribution of employment opportunities within the cluster.
g) **Carbon removal:** Some applications may focus on carbon removal and be **prioritised**.
h) **Alignment with the EU:** The applications in the cluster should be **well-aligned** with the EU's sustainability goals and initiatives.

By incorporating these guiding design attributes, the cluster is designed to **optimise resource utilisation**, **promote skill development**, **enhance infrastructure compatibility**, and **strategically position itself within the value chain**. The alignment with EU objectives further strengthens its relevance and competitiveness.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2.5.1 Technology Cluster

Figure 5: Technology Cluster map



The technology cluster has the potential to **capitalise on the existing mining and forestry sectors** and can contribute to **significant value creation**. It offers numerous applications in construction, mobility, industry, transport fuels, infrastructure, and high-tech.

Figure 6: Technology Cluster assessment

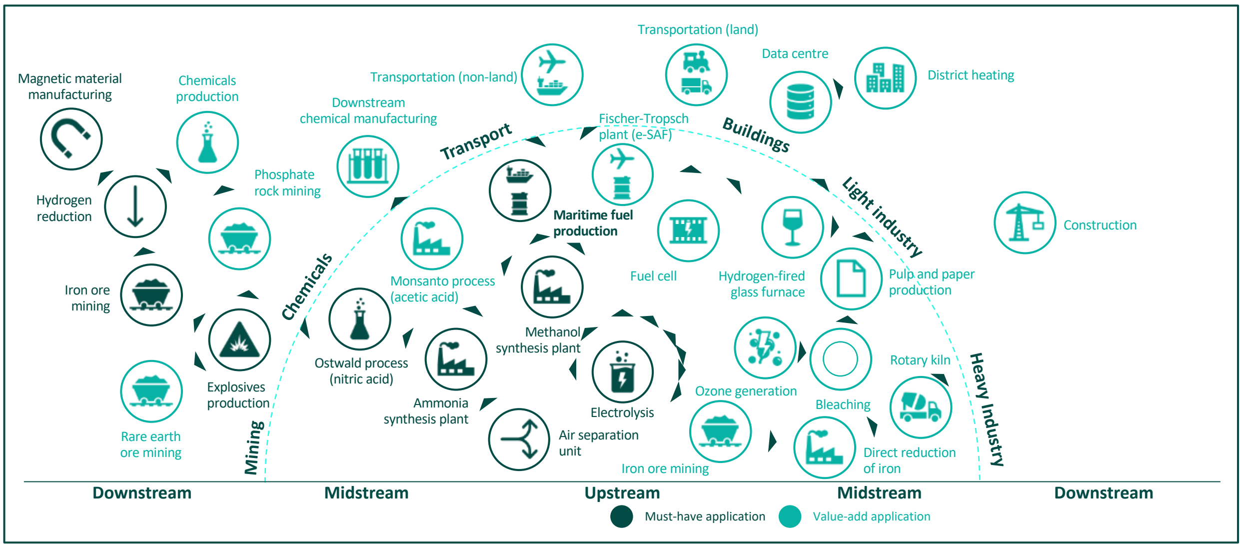
Category	Attribute	Comment	Fit
Resources	**Phosphorus**	Minimal use in semiconductors	✗
	Vegetables	No use	✗
	Fish and seafood	No use	✗
	Oxygen	Some remaining oxygen	✓
	Residual heat	A lot of remaining residual heat	✗
Tactical fit	**Skill level of jobs**	Too high for immediate development	✗
	Infrastructure compatibility	Building on existing mining and forestry sectors, but significant export needed	✗
Strategic fit	**Position in value chain**	Downstream	✓
	Target market (both domestic & export)	The export market may be even more dominant than the domestic market	✓

However, the cluster may face **challenges in terms of resource fit**, as the identified resources may not align seamlessly with the cluster's requirements. Additionally, the **initial skill level of jobs** in the technology sector **may be too high**, presenting a short-term challenge that can be addressed through skill development initiatives. The establishment of **additional export infrastructure** may also be necessary to support the cluster's growth.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2.5.2 Energy-Heavy Cluster

Figure 7: Energy-Heavy Cluster map



The energy-heavy cluster focuses on **new applications** such as **electrolysis** and **air separation**, supplying **midstream and some downstream applications** in mining, chemicals, transport, buildings, light industry, and heavy industry.

Figure 8: Energy-Heavy Cluster assessment

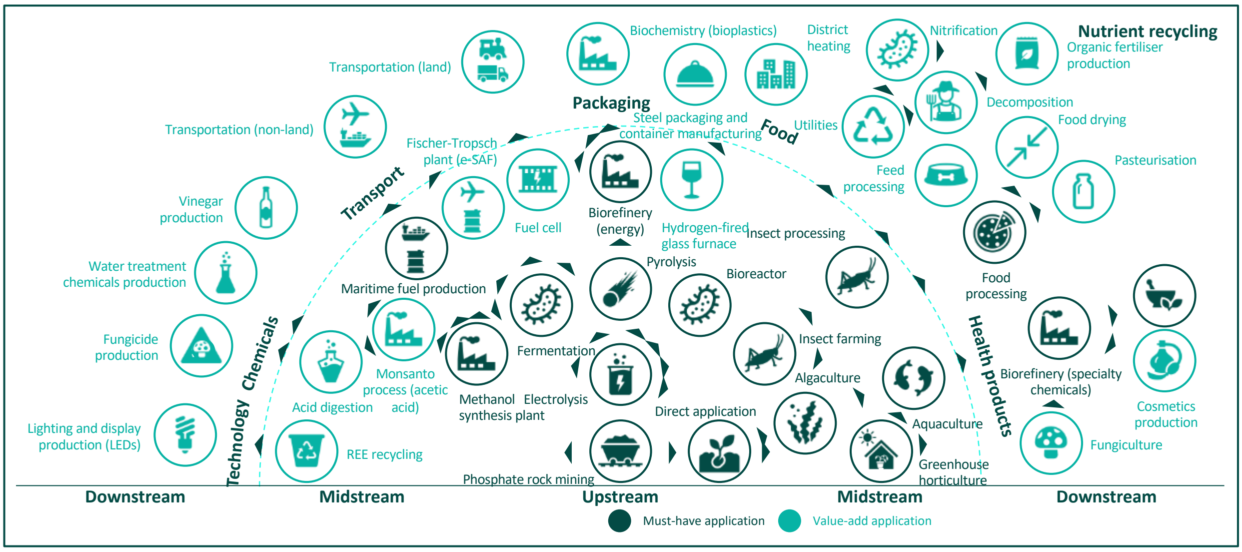
Category	Attribute	Comment	Fit
Resources	**Phosphorus**	Minimal use in chemicals production	✗
	Vegetables	No use	✗
	Fish and seafood	No use	✗
	Oxygen	Some remaining oxygen	✓
	Residual heat	A lot of remaining residual heat	✗
Tactical fit	**Skill level of jobs**	Gradual increase of skill level	✓
	Infrastructure compatibility	Integrating new sectors within the existing economy, but further exports	✗
Strategic fit	**Position in value chain**	Midstream	✓
	Target market (both domestic & export)	The export market is more dominant than the domestic market	✗

As there are **additional sources of oxygen and residual heat generated**, fully consuming these resources poses challenges. Moreover, the **products** generated by energy-heavy applications are primarily **geared towards export markets**, which may **not align well with** the cluster's **infrastructure constraints** and target market.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2.5.3 Food Cluster

Figure 9: Food Cluster map



The food cluster **capitalises on the timely introduction of electrolysis** through HYBRIT and **phosphate rock recovery** from ReeMAP. It holds **significant value creation potential for mid- and downstream applications** in technology that support plant growth, chemicals, transport, packaging, food, and health products.

Figure 10: Food Cluster assessment

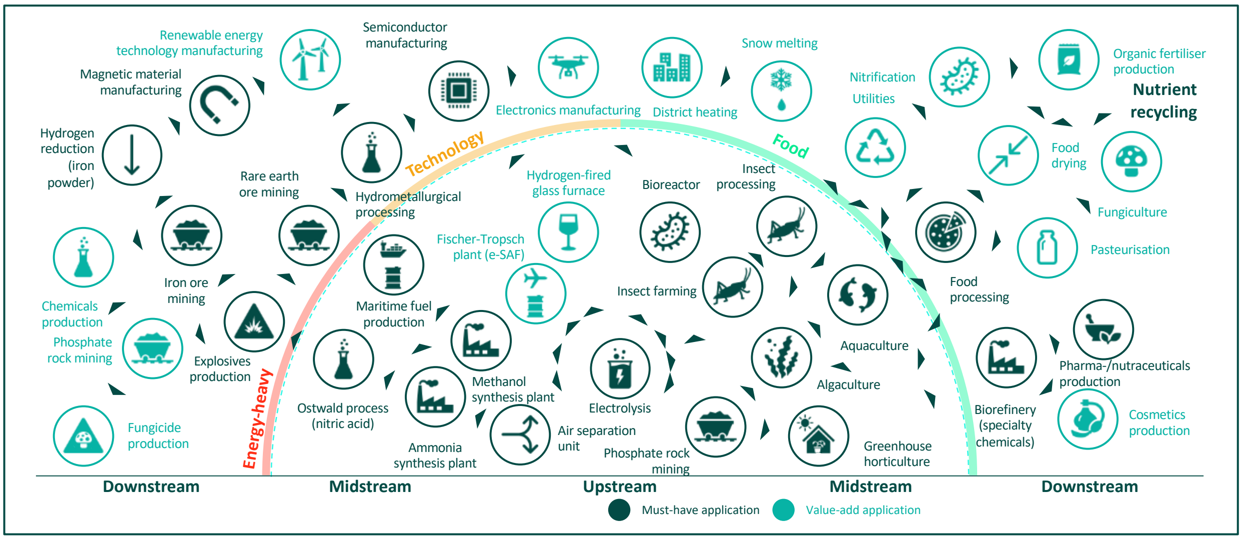
Category	Attribute	Comment	Fit
Resources	**Phosphorus**	High use	✓
	Vegetables	Full use	✓
	Fish and seafood	Full use	✓
	Oxygen	High use	✓
	Residual heat	Full use	✓
Tactical fit	**Skill level of jobs**	Gradual increase of skill level	✓
	Infrastructure compatibility	Integrating new sectors within the existing economy, but further exports	✗
Strategic fit	**Position in value chain**	Mid- to downstream	✓
	Target market (both domestic & export)	Increasing self-sufficiency while offering export opportunities	✓

The cluster benefits from a **high level of resource and strategic fit**, with abundant resources such as vegetables, fish, and seafood enabling the production of large volumes of food. However, those cannot all be consumed locally, creating **infrastructure compatibility challenges** on export capacity.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

2.5.4 Balanced Cluster

Figure 11: Balanced Cluster map



The balanced cluster leverages the **timely applications** (as the Food Cluster) as well as **air separation** (as the Energy-Heavy Cluster). It offers high **value creation potential in mid- and downstream applications** across the technology, energy-heavy, and food sectors.

Figure 12: Balanced Cluster assessment

Category	Attribute	Comment	Fit
Resources	**Phosphorus**	High use	✓
	Vegetables	Full use	✓
	Fish and seafood	Full use	✓
	Oxygen	High use	✓
	Residual heat	Full use	✓
Tactical fit	**Skill level of jobs**	Gradual increase of skill level	✓
	Infrastructure compatibility	Integrating new sectors within the existing economy, less export-driven	✓
Strategic fit	**Position in value chain**	Mid- to downstream	✓
	Target market (both domestic & export)	Increasing self-sufficiency while offering export opportunities	✓

With a **strong alignment** in terms of resource, tactical, and strategic fit, the balanced cluster incorporates a **diverse range of high-potential applications** compared to other candidates. By effectively utilising the identified resources, this cluster can optimise resource utilisation and value creation. It also aligns well with the tactical attributes, including a suitable skill level of jobs and infrastructure compatibility.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

In summary, while the **technology and energy-heavy clusters** may face **limitations in resource fit and infrastructure compatibility**, the **food cluster** exhibits a **strong resource fit but** encounters **challenges in exporting** food products. The **balanced cluster** emerges as a promising candidate, offering a **high level of resource, tactical, and strategic fit**, along with a **diverse range of high-potential applications**.

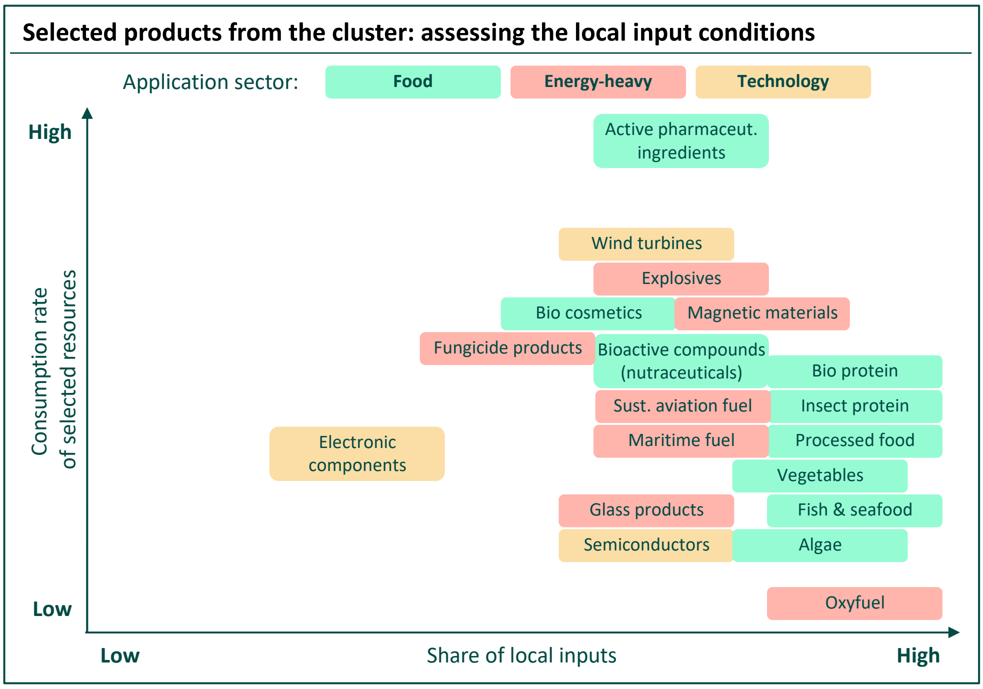
3. Recommendation

To maximise long-term benefits and ensure sustainability, it is recommended to develop a **balanced cluster** in Gällivare. The cluster should **initially focus** on utilising the oxygen and residual heat from the HYBRIT Development project in the **food sector**, forming and activating the cluster. **Over time**, the cluster can be upgraded to **incorporate the energy-heavy and technology sectors**.

3.1 Products

Assessing the **local input advantage** is a crucial step in cluster development, as it provides valuable insights into the resources available in Gällivare. This assessment allows us to identify and leverage the **unique strengths of the local area**, which can serve as a foundation for building a thriving and sustainable cluster. By evaluating the **share of local inputs** and the **consumption rate of selected resources**, we can determine if Gällivare has optimal input conditions. A high share of local inputs and a high consumption rate of selected resources indicate favorable input conditions for selected products.

Figure 13: Local input advantage assessment



Roger Hansson
roger.hansson@gallivarenaringsliv.se

In terms of **local input advantage**, Gällivare holds the largest advantage for the following products:

- **Food: bio protein (bioreactor)** - All required inputs for bio protein production are available within the future cluster. The consumption rate of resources such as ammonia (nitrogen), hydrogen, phosphorus, and residual heat is also beneficial. Some bioreactors even utilise oxygen as an input.
- **Energy-heavy: explosives** - Except for packaging, all required inputs for explosives production are available within the cluster. The consumption rate of resources such as hydrogen, nitrogen, and oxygen is above average.
- **Technology: wind turbines** - Wind turbines within the cluster consume selected mineral resources like iron ore (e.g., magnetic materials) and rare earth elements. Additional local inputs include copper, zinc, and potentially carbon fibre (lignin) sourced from neighbouring forestry.

3.2 Value creation

The balanced cluster accommodates a significant number of **both mid- and downstream applications**, fostering **increased value creation** within Gällivare. This shift towards a more **self-sufficient economy** allows for the creation of value domestically and reduces reliance on factor-driven export models.

3.3 Target markets

With numerous value chain relationships within the cluster, products and services are likely to find ready **markets within the cluster itself**. As self-sufficiency is achieved in the Norrbotten region, there are **opportunities to supply neighbouring regions with essential goods** like food and the **broader European market with high-tech products** such as wind turbines and semiconductors.

3.4 Jobs

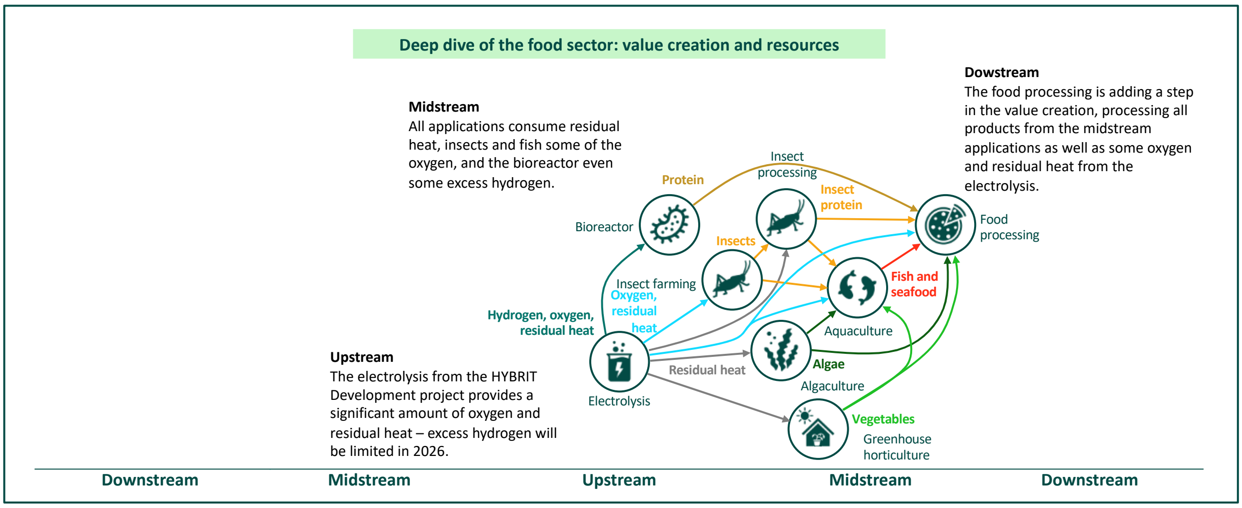
The development of the balanced cluster is expected to create a range of **medium- to high-skill jobs**. The **job creation potential spans across multiple applications** within the cluster, ensuring a diverse employment landscape and fostering economic growth.

3.5 Resources

Efficient resource utilisation is a key aspect of the cluster's operations. The cluster **effectively utilises available resources**, with particular emphasis on the plentiful applications for oxygen and residual heat. Some applications even make use of residual biomass, iron ore (excluding steel production), and rare earth elements, further optimising resource utilisation. An example of a resource stream is in Figure 14 below.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Figure 14: Value creation and resource flows in the food sector within the balanced cluster



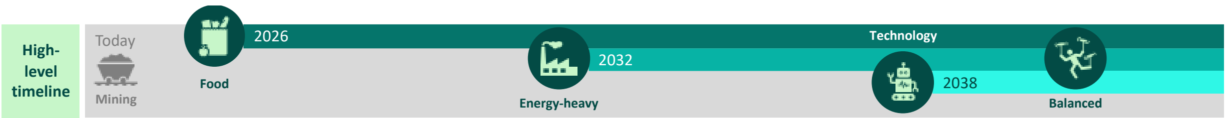
The development of a balanced cluster, comprising sectors such as food, energy, and technology, holds significant advantages for sustainability and economic growth. This approach allows for the **gradual expansion of the local economy** and **infrastructure upgrades** to meet future export demands. By leveraging the available resources and value chains, Gällivare can establish a thriving and sustainable economy that optimises value creation, job opportunities, and resource efficiency.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

4. Cluster Building Blocks

Building a successful and sustainable cluster requires careful planning, coordination, and management. To ensure the smooth and efficient formation and activation of the cluster, it is essential to establish a dedicated **cluster management team**. This team will play a pivotal role in guiding the cluster's growth, overseeing its various components, and driving collaboration among stakeholders. Their expertise and strategic vision will be instrumental in navigating the complexities of cluster development and realising its full potential. In the last section, we will explore the key building blocks for establishing and managing the cluster, including a **detailed cluster design**, marketing activities to **attract firms and talent**, and **start-up support** for new entrants.

Figure 15: Balanced Cluster building blocks



Cluster formation & activation

Building blocks	0 Set up governance	I Prepare detailed cluster design	II Attract firms & talents	III Support start-up
Activities	I. Establish a core cluster management team steering the development II. Establish a marketing task force, coordinating all marketing efforts III. Establish a support team for new entrants and a network management team for existing stakeholders of the cluster *Cluster upgrading:* facilitate information and technology exchange, foster cooperation and coordination (innovation)	• Quantify the availability of key resources (e.g., residual heat, land, mines for refrigeration, etc.) • Establish healthy boundaries for the cluster development (i.e., regenerative level of resource flows) • Learn from other region's best practices (e.g., ice free streets in Iceland) • Obtain stakeholder input and feedback	• Identify the targets: firms, talents, and their needs • Develop a value proposition for them: benefits of the cluster in Gällivare, additional incentives to attract them (e.g., EU funding) • Develop a marketing mix to attract potential investors, businesses, and talent (e.g., presentations, workshops, website, etc.) and implement it (e.g., at industry events, universities, etc.)	• Offer administrative support for new businesses (e.g., permit granting) • Offer integration and housing support services for new talent • Implement tools and standards monitoring the sustainability of cluster participants
Results	• Strong network, common standards, joint action, shared beliefs and agenda • Capacity to upgrade the cluster and leverage the benefits for its participants	• Well-designed cluster: maximised resource efficiency and minimised environmental impact	• List of firms to contact and investment guide to the cluster • List of talent profiles and compelling narrative to attract them	• Satisfied new entrants to the cluster • Transparency about the sustainability of the cluster towards its stakeholders (e.g., customers, government, etc.)

Governance. To effectively steer the development of the cluster, a dedicated **cluster management team** should be established. This team will play a crucial role in **overseeing the detailed cluster design** and coordinating various aspects of cluster development. Additionally, the team should establish a **marketing task force** to promote the cluster's firms and attract talented individuals. Furthermore, a **support team for new entrants** during the start-up phase will be essential to provide guidance and assistance.

Detailed Cluster Design. A comprehensive and detailed study is required to determine the **optimal configuration** of different applications within the green cluster. This study should delve deeper into **understanding the available resources** and **establishing the healthy boundaries** of the cluster. The principles of systems thinking, circular economy design, and efficiency considerations should guide this process. **Quantifying the available resources** is a crucial aspect of effective cluster planning. It is essential to assess sources like from HYBRIT, natural resources such as water, and non-conventional

Roger Hansson
roger.hansson@gallivarenaringsliv.se

resources like mines for cooling. The **primary objective** should be to achieve **self-sufficiency** for essential needs like food and hygiene products, **considering exports as an opportunity rather than the sole focus**. One potential approach to **maximise resource utilisation** is exploring the integration of greenhouse horticulture and aquaculture through aquaponics. This innovative method allows for resource sharing, such as residual heat. Excess resources can be strategically utilised to enhance the region's attractiveness through initiatives like creating ice-free streets or undertaking restoration and regeneration projects. By implementing sustainable resource management practices, **clear boundaries** can be defined to ensure long-term viability while avoiding unsustainable growth. Infrastructure needs should be aligned with these boundaries to support the cluster's operations effectively. Drawing **inspiration from best practices in other regions**, such as Iceland's district heating and ice-free streets, Finland's 'hot heart' for district heating, or Italy's use of caves for cooling fruits, can provide valuable insights.

Firm & Talent Attraction. Studying **funding and incentives** is vital to attract firms. National initiatives, such as tax benefits and IPCEI for SMEs, along with the General Block Exemption Regulation ceiling for aid to SMEs, can provide financial support. EU programs like the InvestEU Programme and the Innovation Fund offer funding opportunities for various areas such as battery technologies, critical raw materials recycling, hydrogen propulsion technologies, and advanced manufacturing technology equipment. Private funding sources should also be explored to supplement public support. Monitoring the supply and demand of talent is crucial for the cluster's success. Participating in initiatives like the European Year of Skills 2023 and the European Pact for Skills can facilitate **talent development**. Collaboration with organisations like Net-Zero Industry Academies and the Academy on Sustainable Construction can further strengthen the talent pool[vi]. Leveraging existing networks like EIT Food can also provide additional opportunities for talent development at institutions such as the Technical University of Luleå. To set Gällivare apart from other regions, it is important to differentiate its talent attraction campaigns and highlight unique selling points. Emphasising the cluster's commitment to sustainability, innovation, and its contributions to the transition towards a net-zero industry can form the basis of a **compelling narrative**.

Start-Up Support. Establishing one-stop-shops for permitting processes related to battery, wind turbine, heat pump, and electrolyser manufacturing facilities can streamline procedures and facilitate **administration**. **Integration and housing support** services will also increase the willingness to relocate for global talent. **Transparency** is crucial, enabling customers to make informed choices based on reliable information regarding the sustainability, durability, and carbon footprint of products and demonstrate the cluster's sustainable impact towards stakeholders such as the government.

By effectively implementing these cluster building blocks, Gällivare can foster the development of a thriving, sustainable, and innovative cluster that attracts firms and talent.

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Authors

Jeremias Finster
Co-Founder
Atacama New Vision GmbH
LinkedIn

Máté Rottek
Co-Founder
Atacama New Vision GmbH
LinkedIn

Roger Hansson
roger.hansson@gallivarenaringsliv.se

Appendix

Figure 16: Frequently asked questions on applications and products

FAQ on applications and products

Applications

Q: How about applications such as rocket fuel, do we punish them for their simple value chains and low synergy potential?

A: Applications such as rocket fuel do not fit the idea of a cluster that creates a strong network, where resources are shared and additional value is created. Shipping hydrogen and oxygen to the space station is corresponding to an export of valuable resources that will be missing at another part of the cluster. Before those resources are used as rocket fuel, the demand of more valuable participants in the cluster should be fulfilled and the remaining excess resources can be used for products such as rocket fuel.

Q: Why is the direct reduction of iron (DRI) not part of the proposed cluster?

A: Similar to the case of rocket fuel, the produced sponge iron is a resource that is exported away from the cluster. LKAB has long-term contracts with its European off-takers and there is only limited room for the expansion of mining capacity. Furthermore, there are no plans to install an electric arc furnace in Gällivare. The electrolysis supporting the DRI, however, is a key pillar of the cluster as many applications depend on the residual streams (oxygen, heat) other than the hydrogen that is mostly planned for the DRI.

Products

Q: Why do vegetables and algae not find all inputs in the future cluster as other food products?

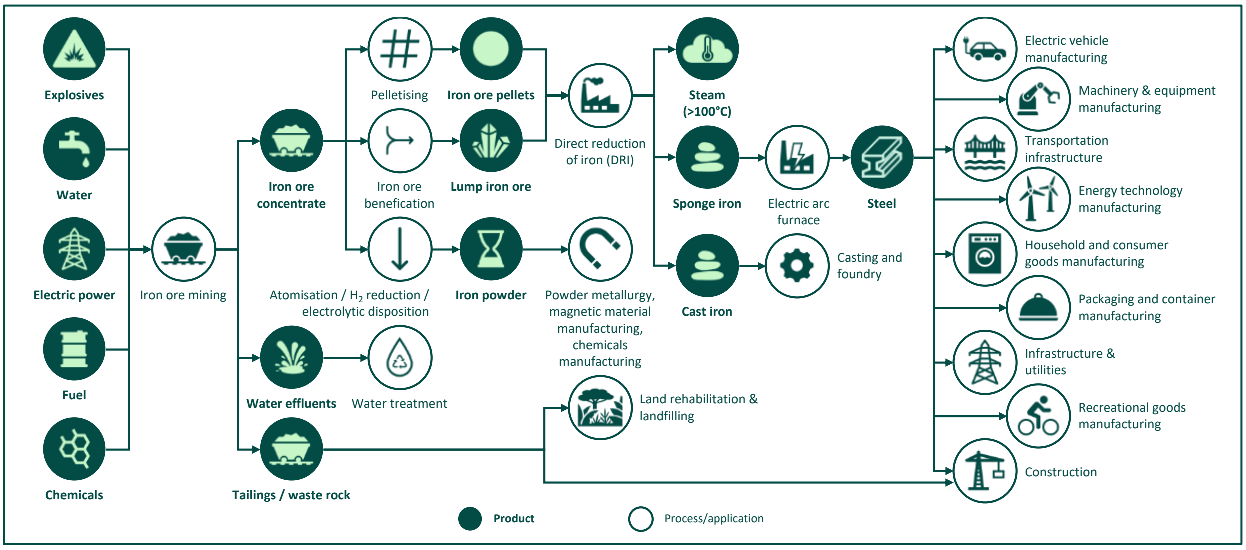
A: Their constraint is the supply of light. During the dark winter months, there is a lack of natural sunlight. Therefore, artificial light sources such as LED – which could even be produced with local resources such as rare earth elements – are needed.

Q: How come that wind turbines find most of their inputs in Gällivare?

A: Currently, not all inputs may be produced in Gällivare. Until the technology sector is developed within the balanced cluster, however, there is an opportunity to pull those inputs together. Already with the energy-heavy sector, magnetic materials will become available. Other inputs such as steel and carbon fibre (from lignin) also do not need to be produced in Gällivare if the logistics can still be managed reasonably (e.g., steel from Luleå).

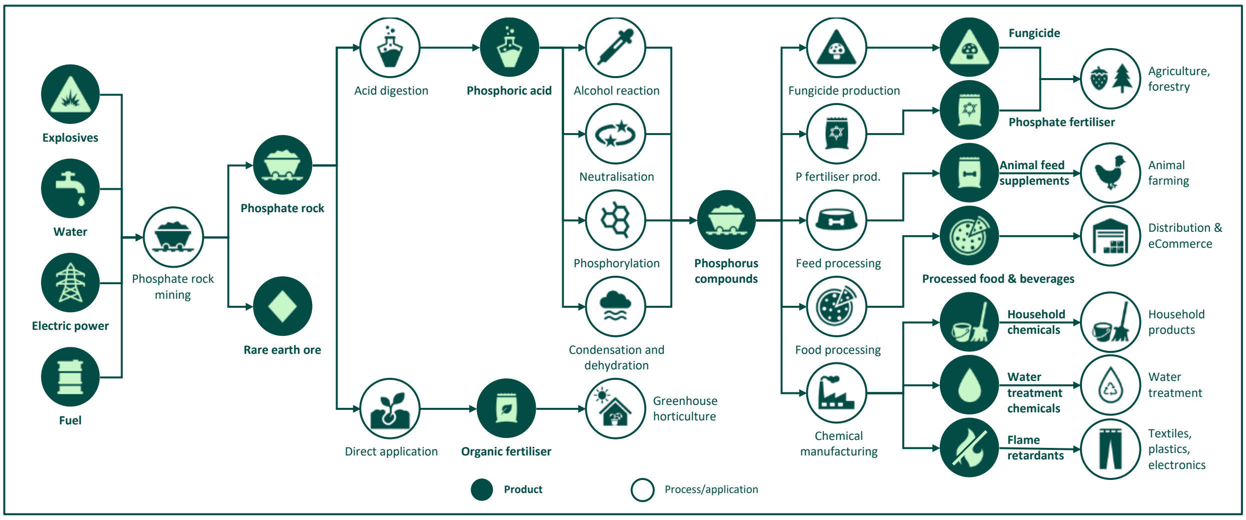
Figure 17: Value chains of the selected resources

1. Iron Ore

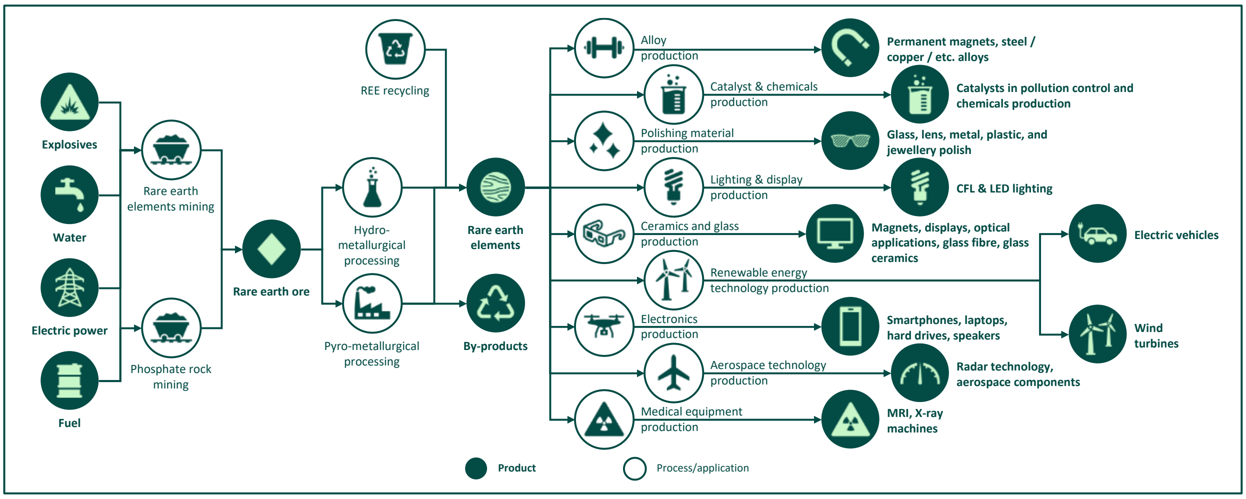


Roger Hansson
roger.hansson@gallivarenaringsliv.se

2. Phosphorus

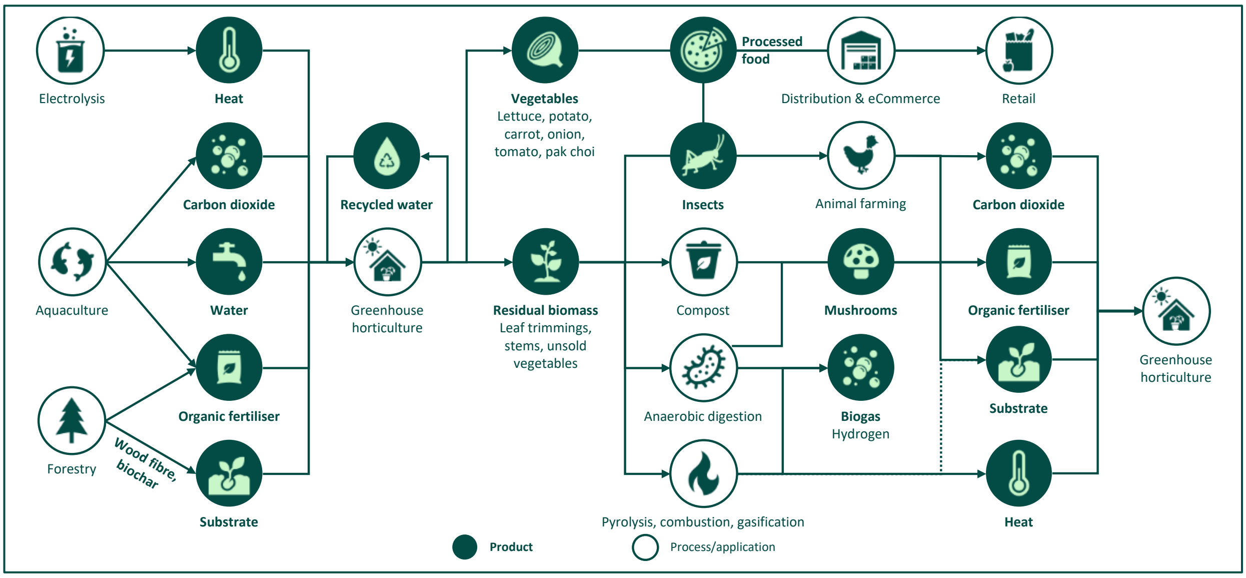


3. Rare Earth Elements

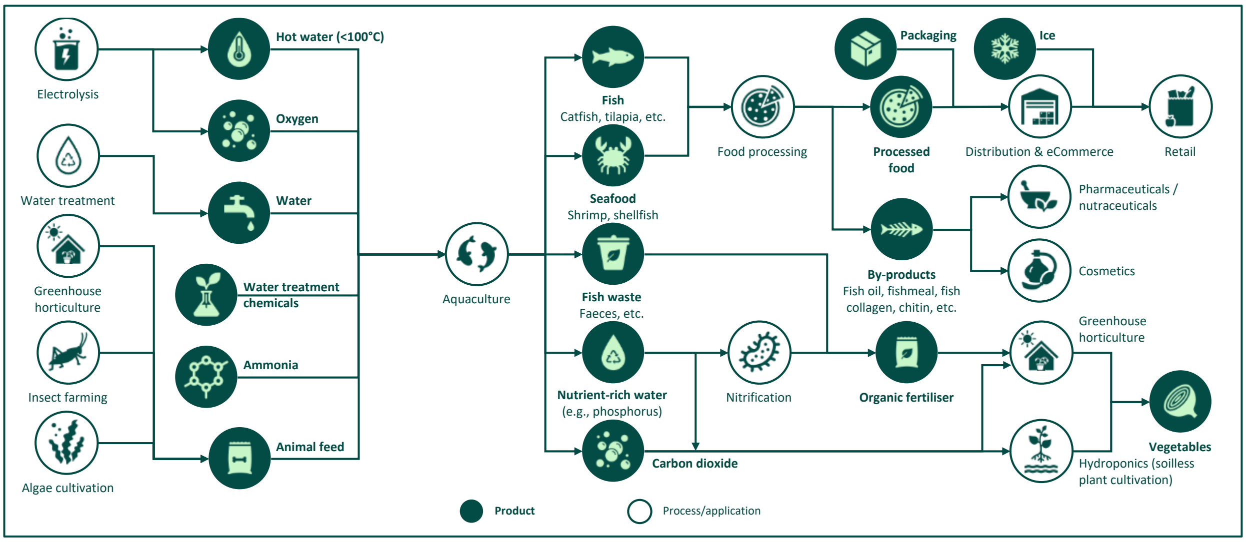


Roger Hansson
roger.hansson@gallivarenaringsliv.se

4. Vegetables (Greenhouse Horticulture)

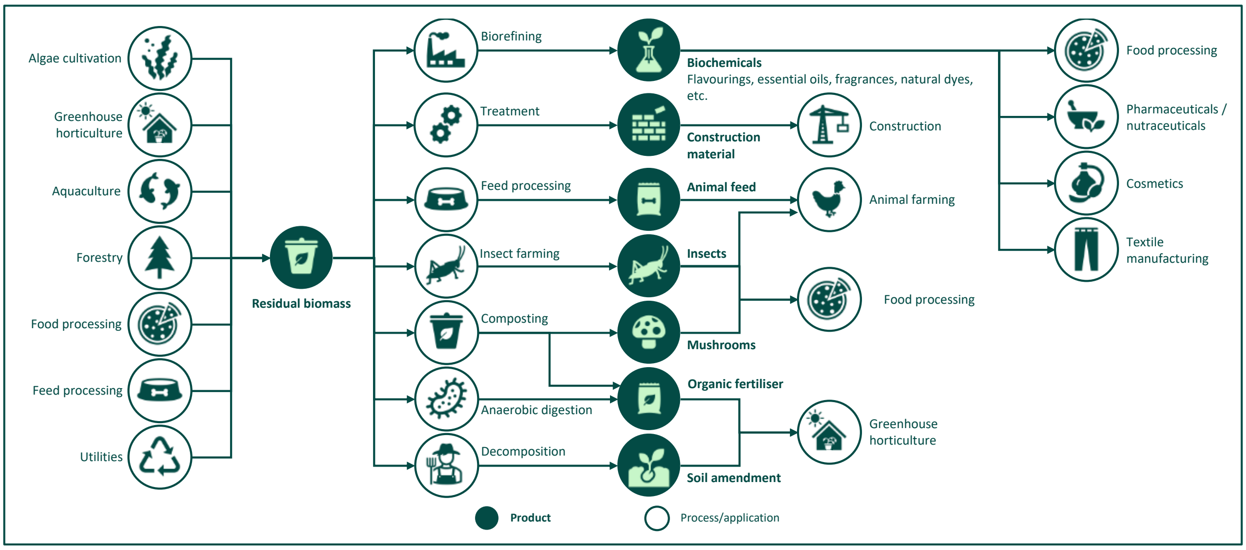


5. Fish and Seafood (Aquaculture)

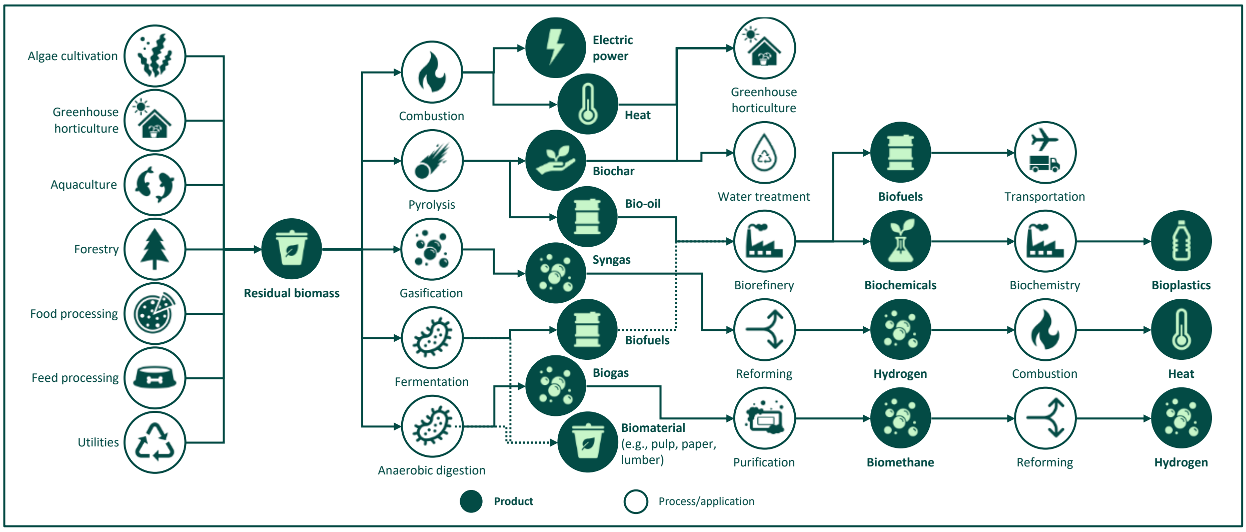


Roger Hansson
roger.hansson@gallivarenaringsliv.se

6. Biomass

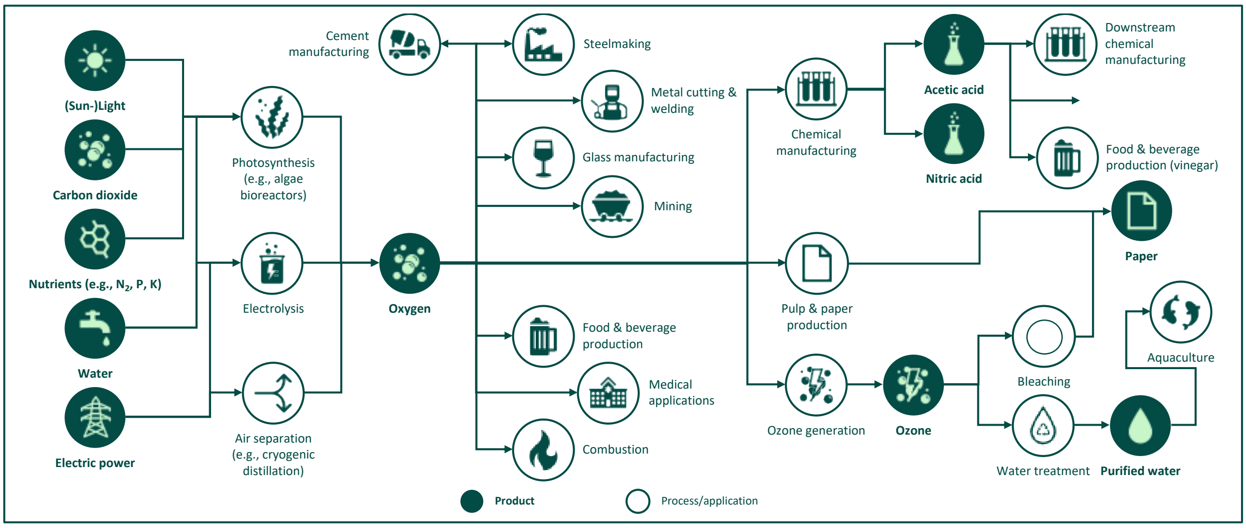


7. Bioenergy

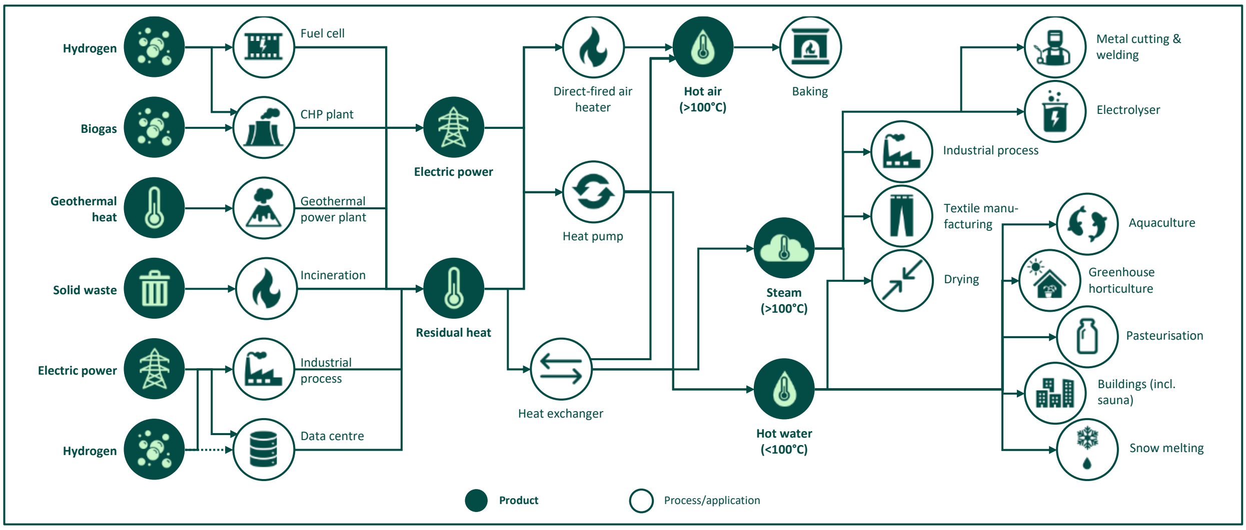


Roger Hansson
roger.hansson@gallivarenaringsliv.se

8. Oxygen

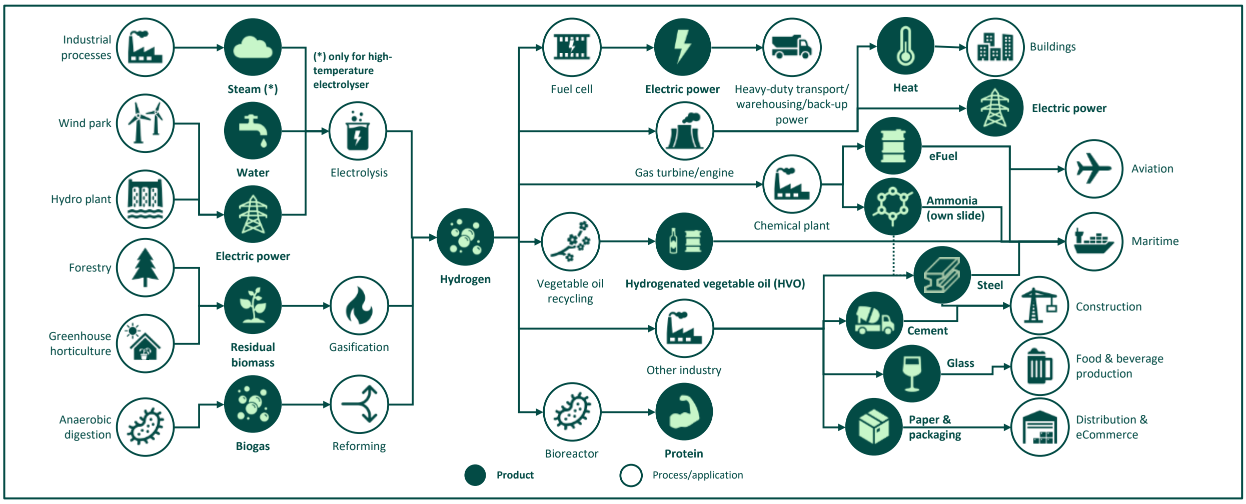


9. Residual heat

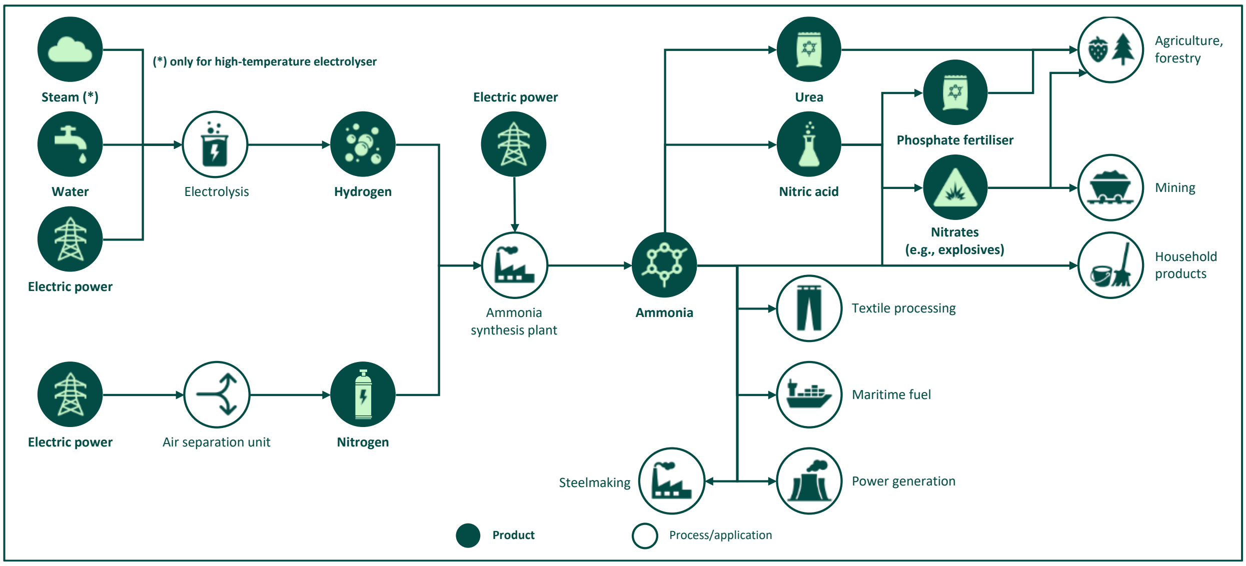


Roger Hansson
roger.hansson@gallivarenaringsliv.se

10. Hydrogen



11. Ammonia



Roger Hansson
roger.hansson@gallivarenaringsliv.se

Endnotes

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[i] Gällivare Kommun, "Hållbarhet", accessed June 2023
[ii] HYBRIT, "HYBRIT Demonstration", accessed June 2023
[iii] LKAB, "About ReeMAP", accessed June 2023
[iv] Gällivare Näringsliv AB, "Multi-million Investment in a Testbed for Food Production in Gällivare", accessed June 2023
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[vi] European Commission, "A Green Deal Industrial Plan for the Net-Zero Age", accessed June 2023