In collaboration with
Accenture and EPRI

World Economic Forum

Unleashing the Full Potential of Industrial Clusters: Infrastructure Solutions for Clean Energies

WHITE PAPER

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Industrial clusters are essential for scaling clean energy infrastructure. By aggregating demand and sharing resources, knowledge and risks, they unlock opportunities to deploy clean energy solutions. This is critical, as the hard-to-abate industrial sector accounts for nearly 30% of global Scope 1 and 2 greenhouse gas (GHG) emissions, rising to nearly 40% when including the hard-to-abate transport sector (aviation, shipping and trucking).[1]

The World Economic Forum, in collaboration with Accenture and the Electric Power Research Institute (EPRI), is committed to improving the cooperation and common vision of co-located companies and public institutions to drive the energy transition, economic growth and employment through the Transitioning Industrial Clusters (TIC) initiative. The initiative is a growing community of 33 signatory clusters spanning 16 countries across five continents, representing a potential for carbon dioxide equivalent (CO_2e) emissions reduction of 832 million tonnes, an amount comparable to the annual CO_2e emissions of a country like Saudi Arabia.[2] In addition, these clusters contribute $492 billion to global gross domestic product (GDP) and create or protect 4.3 million jobs.[3] Since the last World Economic Forum Annual Meeting in 2024, we welcomed 13 new signatory cluster members to the community from countries across the globe, including Australia, Brazil, Colombia, India, the Netherlands, Saudi Arabia, Sweden, Thailand and the United Kingdom.

This white paper examines the current state of clean energy infrastructure and identifies potential solutions that industrial clusters, transport and logistics industries, and the wider clean energy value chain can explore in accelerating its deployment. To successfully deploy clean energy infrastructure, increased collaboration is required, both within and across clusters. There are multiple leading examples of how stakeholders have successfully used clusters to achieve outcomes that would be unattainable in isolation. This collaborative approach must be scaled by government, professional, industry, academic and research and development (R&D) organizations worldwide to meet the Paris Agreement's goals.

By highlighting leading examples, we aim to inspire companies and institutions to enhance their collaborative efforts, thereby scaling the necessary infrastructure for the energy transition. We would like to thank all involved community members, policy-makers and corporate leaders for their time and contributions to this white paper.[4]

Executive summary

To accelerate the energy transition, industry leaders across multiple sectors together with policy-makers have the opportunity to harness the power of industrial clusters and streamline collaboration across the clean energy value chain.

Industrial clusters are key to successful clean energy infrastructure deployment

The rapid deployment of large-scale clean energy infrastructure is vital to achieving the Paris Agreement's goals while balancing energy security and ensuring a fair transition. Advancing towards these goals will require an integrated multi-fuel, multi-modal ecosystem. Coupled with the unprecedented pace of infrastructure deployment required, this multistakeholder ecosystem is complex.

The formation of industrial clusters is an effective strategy for successfully deploying infrastructure. These clusters can offer economies of scale, share risks, aggregate and optimize demand, secure financing and attract capital for clean energy infrastructure. Clusters are also driving the production, distribution and consumption of clean energy, while ports (and port-anchored clusters) facilitate global logistics as key connecting nodes between international markets and regional industries.

This white paper addresses the clean energy infrastructure challenge and presents potential solutions, emphasizing the importance of a multistakeholder approach involving the public, private and R&D sectors. It presents three solution areas within industrial clusters and the broader clean energy value chain:

1

Develop a common vision at cluster level

Building a strong foundation within the cluster to unlock its full potential. This entails achieving effective governance to drive decision-making, expanding cluster-public collaboration and building up a digital core at a cluster level that enables data collaboration to unlock mutual benefits and system value.[5]

2

Expedite the scaling of cluster-level clean energy initiatives

Enhancing collaboration between players across the clean energy value chain from heavy industry, transport and logistics to manage the green premium and facilitating stable and growing demand signals.

3

Strengthen the collaboration across clusters and regions

Creating global networks and partnership initiatives between industry, government and other organizations to facilitate the transport of clean energy between export and import locations in an increasingly multipolar world.

Call to action

Successfully transitioning industrial clusters requires four core components: 1) a balanced focus on economic, social and environmental value; 2) consideration and adoption of technologies and processes that support GHG emissions reduction; 3) cross-sector collaboration among industry, government, financiers, labour and communities; and 4) coordinated, agile strategies across partnership, policy, financing and technology deployment. Together, these elements form the foundation for a sustainable and scalable energy transition for hard-to-abate sectors.

To achieve this, the Forum welcomes action by leaders from government, professional, industry, academic and R&D organizations, supported by Forum initiatives such as TIC and the First Movers Coalition (FMC), to build a global community on the successful deployment of infrastructure for clean energy, with a focus on three areas:

Mobilizing co-located companies

Support the cluster model for co-located companies, thereby optimizing opportunities for scale, sharing of risk/resources, aggregation and optimization of demand.

Strengthening existing clusters and partnerships across the value chain

Enhance collaboration among co-located stakeholders and players across the entire clean energy value chain – spanning energy supply and distribution, heavy industry, transport and logistics – to effectively manage the green premium.

Connecting clusters into a global network

Support the expansion of cluster networks to establish a global clean energy infrastructure model and facilitate a more interconnected world.

Package Centre Börnicke
Image credit: DHL.

1

Clean energy infrastructure is needed at scale and pace

Achieving the energy transition calls for multistakeholder collaboration towards a global build-out of clean energy infrastructure.

The energy transition involves more than just replacing fossil fuels; it demands a comprehensive overhaul of the energy value chain and the coordinated development of clean power and clean fuel infrastructure worldwide. Aligning with the objectives of the Paris Agreement means moving towards a multi-fuel, multi-modal future at pace.

Industrial decarbonization requires looking beyond site operations and into the clean power and clean fuels value chain, including transport and logistics. These decarbonization efforts will rely on a multitude of technologies, primarily energy efficiency, electrification, and renewable power. They will also require clean fuels and carbon capture, utilization and storage (CCUS) for greenhouse gas (GHG) emissions that cannot otherwise be removed.

Medium- to high-temperature industrial heat pump technologies are maturing rapidly and becoming increasingly viable options for hard-to-abate industries. Biofuels such as hydrotreated vegetable oil (HVO) and biogas can also play a role, subject to meeting sustainability criteria in relevant jurisdictions. Other clean fuels, such as clean hydrogen, clean ammonia and sustainable e-fuels, must scale up to meet energy transition goals in the industrial, transport and logistics sectors.

↓ Image credit: Stena Line.

While policy is maturing around the globe, challenges remain, such as the approach to transposing policy into national and regional legislation.

Clean energy infrastructure encompasses a broad range of applications, including the development of gas networks for clean gases, the setup of energy efficiency infrastructure, and the electrification of industrial processes and chemical processing facilities to produce clean fuels. Additionally, transport infrastructure must be enhanced to support both regional and international trade. This will involve the construction of new infrastructure at port facilities, charging stations, storage facilities, refuelling stations, pipelines and interconnectors to link regions of clean energy production and export with import regions.

The current infrastructure, however, falls short of the required scale and pace of growth. For power, there is a risk of its supply being up to 14% short of the predicted demand in Europe by 2030 when there are unfavourable weather conditions, as determined by Accenture modelling.[6] In clean hydrogen production, most announced projects remain in planning or earlier phases. The International Energy Agency (IEA) estimates that for the full clean hydrogen production project pipeline to materialize, the sector must achieve a compound annual growth rate (CAGR) of over 90% annually from 2024 to 2030. Assuming all announced projects are realized, export-oriented projects are expected to account for approximately one-third of clean hydrogen production by 2030, but progress has been negligible.[7]

Effective policy can support long-term stability, facilitating the demand conditions necessary to invigorate the market and drive transformative change for clean energy infrastructure. Over the past year, the clean energy policy landscape has continued to evolve. For example, additional public funding of approximately $100 billion for clean hydrogen projects has been announced, enacted or allocated worldwide. However, it is worth noting that two-thirds of these funds remain at the announcement stage.[8]

Nationally and regionally, support for clean energy infrastructure is being embedded into important clean energy and industrial transformation policies and legislation. For example:

- In the European Union (EU), the Fit for 55[9] package of proposals aims to provide a coherent and balanced framework for reaching the EU's climate objectives while ensuring a just and socially fair transition. Through a range of measures such as the Carbon Border Adjustment Mechanism (CBAM)[10] and the EU's Emissions Trading System (EU ETS),[11] it provides a framework to drive and support the energy transition in heavy industry.

- In the US, the 2022 Inflation Reduction Act (IRA) and 2021 Bipartisan Infrastructure Law[12] put a strong focus on investment initiatives in clean energy infrastructure with measures supporting clean electricity, clean fuels and industrial clusters.

- China's 14th five-year plan (2021-2025)[13] was developed to support the goal of carbon neutrality by 2060. The plan encompasses dimensions across the full clean energy value chain, including generating, distributing and using clean energy. For example, the plan includes advancements of a green, integrated and optimized multi-modal transport system, as well as enhancing connectivity with neighbouring countries.[14]

Focusing on clean fuels, the number of defined and refreshed national strategies and approaches is growing, including India's National Green Hydrogen Mission,[15] Chile's National Green Hydrogen Strategy,[16] the Morocco Offer for green hydrogen,[17] Germany's adapted National Hydrogen Strategy,[18] Japan's Green Growth Strategy,[19] the UK's Biomass Strategy[20] and the US Sustainable Aviation Fuel Grand Challenge Roadmap.[21]

While policy is maturing around the globe, challenges remain, such as the approach to transposing policy into national and regional legislation, ensuring interoperability across regions, navigating new policy at pace and balancing push-pull mechanisms across the value chain. For example, in the EU, truck manufacturers are required to produce low-emission trucks to meet CO_2 reduction targets for heavy-duty vehicles. However, there is no corresponding requirement for companies to purchase them or invest in the necessary infrastructure (such as charging infrastructure), creating a disconnect between supply and demand for sustainable transport solutions.

2

Challenges inhibiting clean energy infrastructure development

Deploying clean energy infrastructure requires navigating various interconnected challenges, including tackling the green premium and facilitating robust demand signals.

Scaling clean energy infrastructure is vital for the energy transition, but it requires robust business cases to attract investment. Despite growing global interest, progress in clean fuel infrastructure development remains limited, as highlighted by the Mission Possible Partnership's (MPP) *Global Project Tracker*[22] and the IEA's *Global Hydrogen Review 2024.*[23]

The green premium creates a challenging hurdle for scaling up investments

When accounting for the infrastructure investments required, clean fuels often come at a higher price than their fossil fuel counterparts. The green premium for clean fuels varies based on several factors, such as the fuel itself, the method of production, storage and transport versus the conventional alternative. The IEA estimates that the production cost of green hydrogen is currently 1.5 to 6 times more than that of producing hydrogen from fossil fuels with unabated GHG emissions.[24] Green ammonia production costs were nearly three times the average cost of production via fossil fuels in 2023. These production costs are only expected to decrease by 30-50% by 2030 in the IEA's Net Zero Emissions by 2050 scenario.[25]

Lack of strong demand signals inhibits deployment of clean energy infrastructure

Global demand for clean energy is increasing.[26] However, this demand is fragmented, with little alignment between the industries and logistics across the clean energy value chain. Without stronger collaboration, achieving the necessary scale to meet climate goals will be unlikely. Uncertainty around demand is not only evident in the current number of clean fuel offtake agreements but is also reflected in disparate demand forecasts for various fuels over the next 25 years.[27,28,29,30] Consequently, investing in clean energy infrastructure involves substantial risk, which can impact the business case, exerting pressure on expected returns and challenging the viability of the investment.

Limited availability of clean power supply in the near future restricts clean fuel supply growth

An additional challenge is access to clean power. This is because many clean fuel pathways rely on significant quantities of renewable power. According to the International Renewable Energy Agency's (IRENA) 1.5°C Scenario, total global renewable power generation capacity will need to triple while energy efficiency improvements double by 2030.[31] This challenge relates to both the availability and delivery (grid infrastructure) of clean power.[32]

Additionally, the current pace of clean energy infrastructure capital project delivery for electricity and gas,[33] for example, is too slow to meet the timelines needed for the industrial energy transition and global climate goals. For instance, the planning and permitting of infrastructure have long lead times relative to the total development time for these projects.[34]

Fragmentation of standards, certifications and policies for clean fuels persist

The rise of international clean fuel trade and its mass application also depends on the establishment of global standards and certifications. Different regions are developing varying standards and certification schemes, complicating a unified approach. Definitions of clean molecules across jurisdictions are still evolving, inhibiting international trade. For example, the EU has developed relatively strict standards for the definition of green hydrogen. To add to the complexity, there are 34 certification schemes for hydrogen and its derivatives (e.g. ammonia) globally, which vary on factors such as GHG intensity and the scope of emissions that should be included.[35]

> **The green premium for clean fuels varies based on several factors, such as the fuel itself, the method of production, storage and transport versus the conventional alternative.**

Policy barriers include imbalances in supply and demand measures, slow translation of clean energy national strategies into legislation, challenges around the transposition of policy across countries and varying criteria for clean fuels between jurisdictions.[36]

Clean energy technology adoption requires a step change

To meet the growing global demand for clean fuels, significant advancements in production, storage, transport, and distribution technologies are required. Examples include the improvement of electrolyser efficiency, the deployment of circular economy technologies, and the integration of electron and molecule-based systems. The momentum of scaling clean fuels will ultimately rely on shifting their innovation curves with new disruptive technologies across various dimensions, including materials, manufacturing techniques and general-purpose technologies (i.e. technologies that can affect an entire economy nationally or globally, such as the internet or the steam engine) – a challenge that is unprecedented in scale and pace.

Digital technology must be rapidly deployed to accelerate the pace and efficiency of clean energy infrastructure scale-up and operation

Digital technologies such as artificial intelligence (AI) possess the transformative capacity to significantly enhance speed, productivity and efficiency within infrastructure development, operations and supply chains. However, adoption is lagging, particularly in industrial clusters. Key challenges include unclear articulation of the value case, data-sharing barriers and difficulties in crafting cluster-level digital roadmaps. Consequently, digital initiatives within clusters remain isolated, missing the benefits from broader coordination in the planning, deployment and operation of shared infrastructure.

Challenges in governance and data sharing hinder collaboration within and beyond clusters

Gaps in governance, data protocols and controls to ensure confidentiality, and the appropriate application of data are persisting. Without data-driven insights, players within and beyond clusters cannot drive commercial and wider system-value benefits for all players.

A more collaborative way forward is needed to overcome clean energy infrastructure challenges

To reach global climate goals and advance the energy transition in the transport, logistics and heavy industries, the expansion of clean energy infrastructure must occur at an unprecedented rate. However, this expansion faces many challenges, fragmenting the landscape and slowing efforts among stakeholders in the clean energy value chain.

Overcoming existing challenges is not straightforward; it requires a multistakeholder approach that individual companies cannot achieve on their own. Therefore, collaboration within and beyond clusters is essential. This is evident in the transport and logistics industry, particularly maritime, which operates across industrial clusters in different geographies, introducing additional complexity to interoperability.

> **One of the challenges is that the maritime industry is largely a regional industry supported by hundreds or thousands of companies of relatively small- and medium-sized operators around the world, most of whom do not have the financial strength to make large upfront investments. It is vital that the maritime industry aligns and collaborates with larger-scale industries such as steel and power generation to work out such challenges.**
>
> Takeshi Hashimoto, President and Chief Executive Officer, Mitsui O.S.K. Lines

↓ Image credit: Mitsui O.S.K. Lines

3

Strategic solutions within and beyond industrial clusters

Industrial clusters can accelerate the deployment of clean energy infrastructure by collectively aggregating demand, mitigating risks and streamlining collaborative efforts.

Strong policy signals provide a fundamental basis for the acceleration of clean energy technologies and infrastructure, particularly in the early stages of emerging technologies. The establishment of long-term policy frameworks supports investors in de-risking business models and deploying capital. However, industry players must act in parallel, innovating and collaborating to share risk and advance new business models.

Industrial clusters provide a natural foundation to facilitate this collaboration, stimulate the flow of capital, and expedite the development of clean power and clean fuels infrastructure through economies of scale, shared risk, and aggregation and optimization of demand. Each cluster offers unique benefits driven by local context, location and the makeup of its members – whether specializing in the production of clean power, specific clean fuels, serving as pivotal global trade hubs (port based and/or inland) and/or hosting major heavy industries.

Beyond industrial clusters, addressing the infrastructure challenge requires collaboration among various stakeholders across the entire clean energy value chain. This encompasses critical nodes such as production sites, port ecosystems and industrial clusters, as well as the logistics between them. Solutions should be explored at local, regional and international levels, with clusters and their value chains eventually integrating into a global clean energy network. For example, initiatives such as the First Movers Coalition (FMC) have kickstarted a drive to aggregate demand across industrial and transport sectors, generating $16 billion in demand for near-zero-carbon goods and services. This will help scale the next generation of emission mitigation solutions for carbon-intensive sectors by 2030.[37]

“ Each cluster offers unique benefits driven by local context, location and the makeup of its members.

↓ Image credit: Brightlands Chemelot Campus

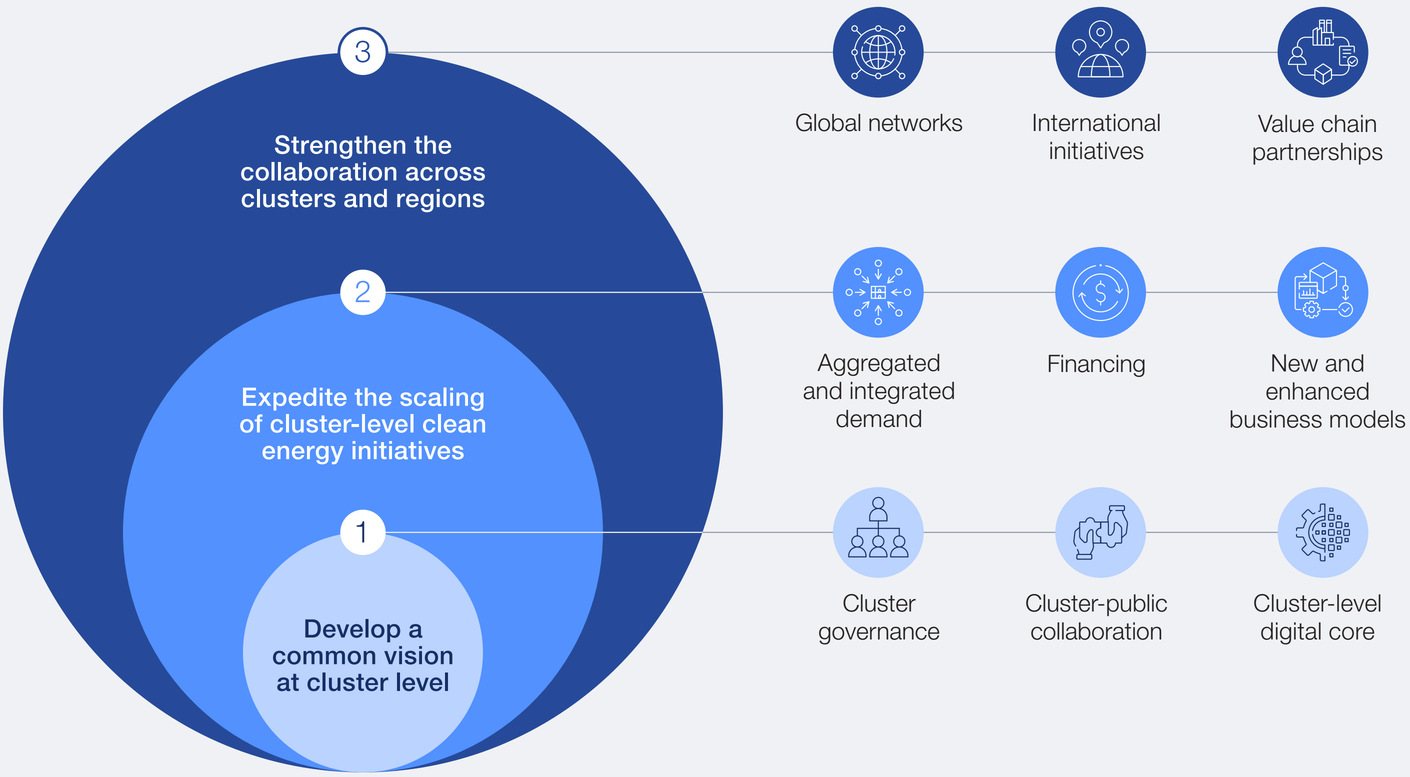
Through comprehensive engagement with the Forum's community of participants from government, professional, industry, academic and R&D organizations globally, three impactful solution areas have been identified. The following section of this paper explores these solutions and outlines examples of how clusters and players along the value chain are accelerating action:

1. **Develop a common vision at cluster level**: Building a strong foundation within the cluster to unlock its full potential. This entails achieving effective governance to drive decision-making, expanding cluster-public collaboration and building up a digital core at a cluster level that enables data collaboration to unlock mutual benefits and system value.

2. **Expedite the scaling of cluster-level clean energy initiatives**: Enhancing collaboration between players across the clean energy value chain from heavy industry, transport and logistics to manage the green premium and facilitating stable and growing demand signals.

3. **Strengthen the collaboration across clusters and regions**: Creating global networks and partnership initiatives between industry, government and other organizations to facilitate the transport of clean energy between export and import locations in an increasingly multipolar world.

FIGURE 1 **Three solution areas for industrial clusters and their ecosystems to solve the clean energy infrastructure challenge**



> **Industrial clusters provide a foundation for accelerating the energy transition, particularly as infrastructure emerges to support new energy flows between clusters. As a specialist in shared infrastructure solutions within clusters, we optimally design, operate and maintain infrastructure. For instance, our expertise enables the repurposing of existing assets for sustainable energies and feedstocks, while optimizing land use in ports. Consequently, shared infrastructure solutions within clusters contribute to reliable and efficient flows of sustainable energies and feedstocks.**
>
> Dick Richelle, Chairman of the Executive Board and Chief Executive Officer, Royal Vopak

3.1 Develop a common vision at cluster level

A unified cluster vision allows companies and public entities to maximize economic, social and environmental value, facilitating an integrated energy system. To achieve this vision, cluster members must build mutual trust and align on a roadmap to reach their common climate goals, often expedited by government support. The following levers are key to forming a cluster and ensuring its effective operation:

- **Cluster governance**
- **Cluster-public collaboration**
- **Cluster-level digital core**

Cluster governance

A well-structured governance framework enables cluster members to make decisions, translate a vision into action, unlock operational and commercial cooperation, and compete together to secure public and private funding sources.

Defining the most effective governance model for an industrial cluster will depend on their convenor (government, corporate or community advocate) and their focus (e.g. innovation or capital project development). Regardless, robust governance structures are supported by clear cluster-level key performance indicators (KPIs), shared objectives and targets and a cluster-level transition roadmap. Building trust through deep collaboration in the early stages of establishing the cluster governance model is fundamental to the enduring success of the cluster as an entity. In turn, the right governance model can facilitate long-term collaboration and trust between players in a cluster.

CASE STUDY 1

A governance model to maximize innovation at Brightlands Circular Space

Brightlands Circular Space, part of an industrial innovation cluster in the Netherlands, has emerged as a model of effective governance, facilitating collaboration across sectors to develop and scale up innovations for a circular economy. The founding partners within the cluster, including Brightlands Chemelot Campus (an innovative ecosystem for green chemistry, circular materials and biomedical applications), the Netherlands Organization for Applied Scientific Research (TNO) and Maastricht University, enable collaboration among researchers, chemical industry third parties (SABIC, Fibrant, Dow, BASF via the Global Impact Coalition, Chemelot Industrial Park), engineers and entrepreneurs. The core partners also contribute to funding the cluster annually, with additional support from the EU and Dutch governments via the National Growth Fund for structural and durable economic growth.

There are no additional governance layers within the Brightlands Circular Space beyond the founding partners. Instead, individual sustainability initiatives are developed through the cluster, each with unique governance structures created by the respective investing corporates and R&D groups, ranging from Dutch small- and medium-sized businesses (SMEs) to multinational corporations. This innovative governance approach has catalysed cooperation across the value chain, with members such as researchers, cross-industry partners, brand owners, entrepreneurs, students and designers collaborating on shared infrastructure planning and development. This shared infrastructure, owned by Brightlands Chemelot Campus, exists to catalyse innovation across industries housed on campus, with input from the likes of government and society. Cluster members also collaborate for shared commercial projects, cross-industry funding, knowledge sharing and reskilling the workforce. The Brightlands Circular Space's governance structure has enabled the alignment of diverse stakeholders around a shared vision, advancing sustainable infrastructure, commercial projects and cross-industry development in pursuit of a circular economy.

The governance structure at Brightlands Circular Space has successfully facilitated collaboration among industry, academia and government, driving innovation and sustainable practices in the region. This inclusive model has resulted in increased investment, business growth and a skilled workforce, positioning the region as a leader in the circular economy.

Lia Voermans, Director, Innovation Strategy, Brightlands Chemelot Campus

CASE STUDY 2

A regional fuel study helping a cluster identify its primary value propositions

The Greater St. Louis and Illinois Regional Clean Hydrogen Hub industrial cluster in the US brings together a network of industries, businesses, community groups, and academic institutions to drive regional decarbonization. The cluster is following a corporate-led governance model convened by Ameren, a major regional utility player. Through this governance model, the cluster constituents are collaborating towards advancing both individual company and collective GHG emissions reduction goals by 2035. The vision for the cluster encompasses the region's diverse industrial sectors – energy, steel, manufacturing and transport – alongside its existing infrastructure and natural resources. The governance model has supported review and communication of the vision by cluster constituents through a series of partnership meetings supported by the Forum's Transitioning Industrial Clusters (TIC) initiative.

Building upon the cluster's common vision, a recent study by EPRI's Low Carbon Resources Initiative (LCRI) programme helped the cluster to identify its primary value propositions related to a broad set of low-carbon fuels (including eSAF, eMethanol, eMethane and renewable diesel) that can use the region's transport infrastructure and agricultural feedstocks. Capitalizing on an established ethanol industry and the potential to use curtailed wind power for electrolysis, the cluster shows strong promise for locally produced renewable fuels, which would support regional aviation, maritime and energy needs, as well as opportunities for domestic and international exports. The renewable fuels regional model has the potential to create more than 1,100 jobs, add \$635 million to gross domestic product (GDP), and reduce carbon dioxide (CO_2) emissions by 1.4 million tons (approximately 1.27 million tonnes) per year.[38]

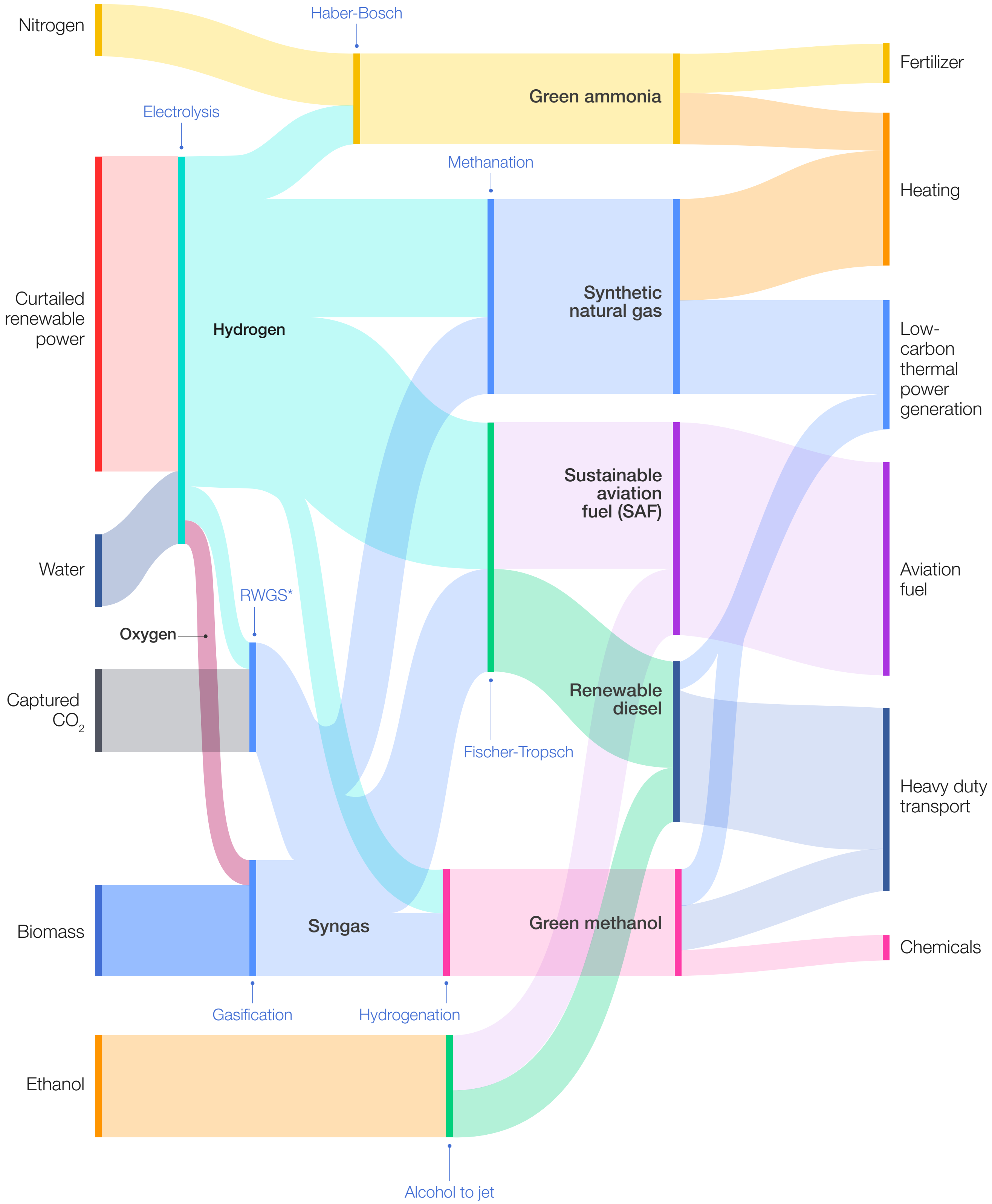
The next step in the cluster's collaboration is to move from vision to execution by continuing to identify and develop key strategic partnerships for economical, low-carbon projects within the cluster. This will be driven by bilateral discussions between the corporate leadership of the cluster and key companies from the regional low-carbon fuels value chain. Orchestrating a robust governance foundation with the aim of developing low-carbon fuel production for domestic and international consumption will create system value benefits – including CO_2 emissions reduction, jobs, GDP and energy security – for players in the cluster, their value chain and wider local region.

This study is critical for our shared vision as a cluster, supporting new low-carbon fuel infrastructure for carbon reduction and regional economic growth.

Mark Fronmuller, Senior Vice President, Corporate Development, Environmental Strategy, Innovation and Enterprise Data, Ameren

↓ **Greater St. Louis and Illinois Regional Clean Hydrogen Hub**
St Louis, Missouri and Illinois, US

Greater St. Louis and Illinois Regional Clean Hydrogen Hub clean fuel sankey diagram



Notes: Flows are conceptual, not necessarily to scale. *Reverse water gas shift.

Source: EPRI renewables fuels programme analysis

CASE STUDY 3

A strong governance structure aligns the priorities in the Humber region

The establishment of the Humber Energy Board has significantly enhanced collaboration across the Humber cluster. By providing a cohesive platform, the board enables companies to collectively voice their priorities and concerns to policy-makers and decision-makers, strengthening the region's influence on its key role in meeting the UK's net-zero ambition. The cohesive partnership approach developed by the Humber Energy Board has helped align a range of projects within an overarching framework, making it easier to attract public and private investment for the decarbonization of Humber's industry. This work has galvanized communication activities across Humber, working with a range of partners to provide clearer messaging of the potential of the region – within the UK and overseas – and reducing duplication of efforts. This is most clearly evidenced in the Humber 2030 Vision,[39] which demonstrates the Humber has scope to be one of the largest circular economies in the world. Innovative decarbonization technologies have the potential to spur a more symbiotic relationship between businesses and projects in the region, maximizing efficiencies and delivering sustainable economic growth.

With millions of pounds invested in preparatory design and investigative studies, businesses in the Humber now stand ready to work with the UK government on its hydrogen and CCUS allocation rounds. They are also prepared to support the further expansion of offshore wind capacity and invest over £15 billion to decarbonize industry and power generation across the region.

The board brings together the entire Humber energy ecosystem, ensuring that projects aren't working in isolation but instead are part of a coordinated effort to build a more sustainable, low-carbon future for the region.

Jonathan Oxley, Senior Manager, Confederation of British Industry (CBI)

↓ **Humber Bridge**
Image credit: Future Humber

Humber Cluster

Humber, United Kingdom

Including **Zero Carbon Humber** Signatory Cluster

Source: Humber Energy Board. (2024). *Delivering the Vision: The Humber's Roadmap for Industrial Decarbonisation*.

Cluster-public collaboration

Clusters can expand their collaboration with public authorities to inform strategies, policy frameworks, enabling measures and funding aligned with industry needs and the energy transition.

Industrial clusters, as important centres of industrial activity and trade nodes, could further their collaboration with public bodies in support of achieving their energy transition roadmap.

For example, cluster procurement practices could incorporate environmental, social and governance (ESG) or system-value criteria and could be supported by governments to help address the green premium in the short- to mid-term. Conversely, public procurement of goods and services can also assist in creating demand signals to advance the development of supply and trade infrastructure, which is often within an industrial cluster.

CASE STUDY 4

The government-led Net-Zero Basque Industrial Super Cluster working effectively through a collaborative framework

The Net-Zero Basque Industrial Super Cluster (NZBIS) aims to accelerate the path to net-zero emissions in the Basque Country in Spain while creating market opportunities by scaling up new technologies and innovative services. To achieve this, it brings together the efforts of both the public and private sectors, represented by industrial cluster associations that encompass both energy demand and technological solution providers.

Driven by the Basque Government, particularly through the Basque Business Development Agency (SPRI) Group, the cluster plays a key role in facilitating the energy transition. It aligns business needs with technological supply, encouraging investment in infrastructure priorities. What sets NZBIS apart is its collaborative framework, which unites public institutions, industry leaders, research and technology organizations and energy providers, building on over 40 years of cooperation between the local government and industry structured through industrial cluster policy.

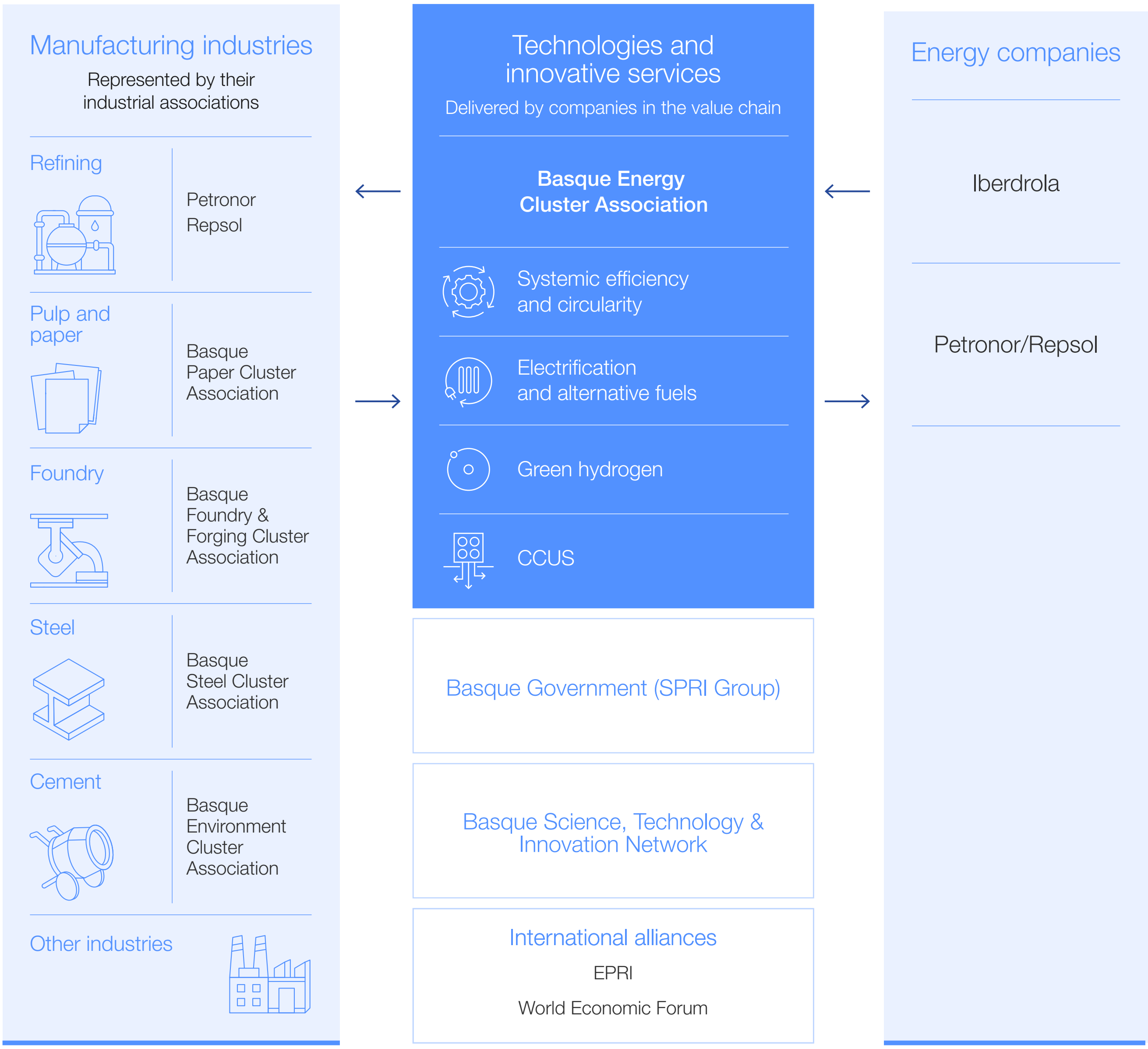
Focusing on five major industries (pulp and paper, cement, refining, steel and foundry) that account for 68% of the region's GHG emissions, the cluster has developed sector-specific roadmaps for emissions reduction. It emphasizes innovation in green hydrogen, energy efficiency and digitalization while promoting systemic efficiency and circularity across industries. Notably, companies like Repsol (a global energy company, through its Basque subsidiary Petronor) and Iberdrola (a global utility company headquartered in the Basque Country) play key roles, using the cluster's coordination to advance the region's initiatives on hydrogen and electrification. One of the NZBIS' key achievements is the establishment of the Industrial Decarbonization Forum, which brings together technology providers and industrial leaders to identify opportunities and drive collaborative decarbonization projects. According to SPRI Group, the NZBIS anticipates net-zero industrial emissions by 2050 and expects to generate €2-3 billion GDP and 20,000-30,000 jobs for the Basque Country.

"The Basque cluster exemplifies how strong regional government leadership can drive the creation of clean energy hubs. By collaborating with key partners like Iberdrola and Petronor/Repsol, we streamline priorities and align business needs, accelerating infrastructure investments in electrification and hydrogen. Our role as public facilitators enhances coordination among stakeholders, enabling us to address urgent clean power needs while fostering innovation and sustainable growth.

Cristina Oyon, Deputy Director General, Technology, Innovation and Sustainability, SPRI Group

NZBIS governance model

The NZBIS aims to develop a robust, innovative industrial ecosystem where technology innovations serve as key driver of the energy transition and decarbonization



Source: SPRI Group

CASE STUDY 5

Over 1,280 organizations unite to advocate for policy change in the Antwerp Declaration

Launched in February 2024, the Antwerp Declaration calls on European Commission President Ursula von der Leyen to strengthen the business case for investing in Europe. Backed by over 1,280 organizations across 25 industries, it presents 10 key actions to revitalize European industry, focusing on clear policy frameworks, legislative enhancements and initiatives to boost demand for low-carbon products.

The Port of Antwerp-Bruges in Belgium is central to these efforts. Beyond its role as a major logistics and petrochemical hub, the port hosts large-scale infrastructure projects, including the development of a CO_2 grid aimed at cutting CO_2 emissions at the port by 50%, as well as hydrogen and ammonia infrastructure to support clean energy transitions. The port also provides concessions on its NextGen site for investors in recycling and clean technology at both commercial and demonstration scales.

With extensive experience and resources, the Port of Antwerp-Bruges is uniquely positioned to support and amplify initiatives like the Antwerp Declaration, offering policy-makers critical insights into what is needed to retain and attract investments in Europe.

The Antwerp Declaration exemplifies how industry can come together to offer policy-makers a clear and well-informed framework, leveraging the knowledge and experience of industrial stakeholders to outline crucial actions for boosting Europe's prosperity by protecting its industrial competitiveness and sustainability.

Jacques Vandermeiren, Chief Executive Officer, Port of Antwerp-Bruges

↓ **Port of Antwerp-Bruges**
Image credit: Port of Antwerp-Bruges

Cluster-level digital core

Data collaboration, underpinned by a strong digital core, is a critical foundation to enable clusters to unlock system value benefits for the cluster, their constituents and local stakeholders.

Trust among players in a cluster is key to enabling transparency and data collaboration via a robust cluster-level digital core in a secure environment. In turn, digital technologies can harness and integrate complex information to produce valuable insights at the cluster level. Building upon the core, digital applications enable operational and commercial benefits and unlock related system value benefits (e.g. energy security). These digital tools not only facilitate secure data collaboration but also set the foundation of resilience and reinvention[40] to help clusters innovate and incorporate new digital technologies such as AI.

> **Clusters achieve the greatest impact when digital technology providers are deeply integrated in the collaborative process. As trusted partners within industrial clusters, we are positioned to craft digital solutions that unlock significant value, driving performance, sustainability and innovation. This symbiotic relationship ensures that our technology underpins a resilient, transparent and efficient ecosystem, benefiting all stakeholders involved.**
>
> Thomas Leurent, Chief Executive Officer and Co-Founder, Akselos

CASE STUDY 6

Zero Carbon Humber uses digital twins for decarbonization pathways modelling and infrastructure planning

Zero Carbon Humber is part of the Humber Cluster in the UK. This cluster includes one of the UK's two main steel production centres, two oil refineries, two major chemicals clusters, and manufacturers of biofuel, cement, lime and glass.

Microsoft and Accenture's joint venture Avanade and the Advanced Manufacturing Research Centre (AMRC) at the University of Sheffield are supporting the Zero Carbon Humber partnership in developing the foundation for a digital test-bed for the cluster, starting with a digital twin of the hydrogen infrastructure and local market. By digitally modelling the hydrogen value chain with both real and synthetic data, it will encompass the production of blue and green hydrogen, as well as its storage, transport and consumption within and beyond the cluster. This digital twin will facilitate the modelling of decarbonization pathways and scenarios, providing insights into risk, carbon abatement potential, hydrogen market evolution and the development of the UK's hydrogen supply chain. The solution will be built in the cloud and will apply open data principles and cross-sector digital twin data standards. Given that clusters are inherently collaborative endeavours, the intention is that this digital twin technology will serve as an invaluable decision-supporting tool to facilitate the envisioning, shaping and building of clusters from policy-makers to investors and operators.[41]

> **The project's output demonstrates the potential of digital models in solving complex supply chain problems in industrial clusters. The product-level digital twin showcases the benefits of connectivity between hydrogen producers, industrial emitters and various cross-sector actors. It also includes embedded financial modelling of different supply and demand scenarios, providing investors with visibility of potential order volume and related return on investment.**
>
> Victor Guang Shi, Lead, Supply Chain Resilience, Advanced Manufacturing Research Centre (AMRC), University of Sheffield

CASE STUDY 7

Digital technologies enable low-carbon industrial clusters, underpinning the energy transition

As the energy transition accelerates, digital solutions are vital for managing complex infrastructure and underpinning low-carbon products and services from industrial clusters.

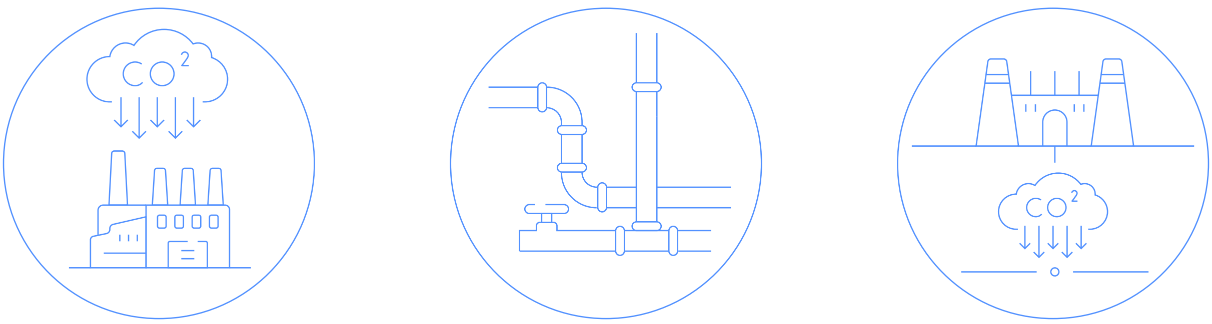
In CCUS, digital platforms enable end-to-end monitoring, reporting and verification across the capture, transport, utilization and storage stages. These platforms ensure seamless data integration, operational alignment, and performance assurance for both equipment and products.

For instance, in the Wabash Valley Resources' (WVR) low-carbon ammonia project in the US, digital tools and solutions, provided by Baker Hughes, enable the measurement, monitoring and verification of CO_2. These tools offer real-time data, tracking and management capabilities across multiple facilities and stages, ensuring compliance and verification for permanent underground storage.

This capability not only provides WVR with detailed oversight of the equipment performance and emissions reductions associated with its products, but also creates opportunities to expand its storage site into a regional infrastructure solution for a cluster of emission sources identified under the US Government's CarbonSafe Initiative. Digital solutions like these are vital for advancing industrial decarbonization efforts and have the potential to be applied globally across diverse regions, industries and regulatory jurisdictions.

> **At Baker Hughes, we believe digital solutions enable existing and new infrastructure to reach their full potential. The many benefits that digital can unlock are improved performance and value, better project management, increased transparency, safer and more reliable services, and more sustainable practices. We do this using innovative software to help solve our customers' toughest challenges and make energy safer, cleaner and more efficient for people and the planet.**
>
> Lorenzo Simonelli, Chairman, President and Chief Executive Officer, Baker Hughes

End-to-end digital solution for CCUS operations, Baker Hughes



CO_2 capture	CO_2 transport	CO_2 storage
Cost optimization	Pipeline health	Regulatory compliance
Asset performance	Flow assurance	Injectivity optimization Revenue realization

End-to-end digital solutions

Source: Baker Hughes

3.2 Expedite the scaling of cluster-level clean energy initiatives

Clusters can act as conduits for new projects by supporting collaboration between constituents and pooling resources throughout project planning, coordination, delivery and operation. There are three areas where collaboration through a cluster has the potential to significantly accelerate clean energy infrastructure development:

- **Aggregated and integrated demand**
- **Financing**
- **New and enhanced business models**

Aggregated and integrated demand

Creating mechanisms that allow clusters to aggregate and/or integrate their demand can present a compelling case for suppliers to scale investment in clean energy production and infrastructure.

By developing offtake agreements aggregating demand within a cluster, cluster members can provide suppliers with the confidence to commit to long-term investments. Additionally, players in a cluster can work together to integrate their energy requirements and optimize the distribution of their demand over time (e.g. for clean electricity). In turn, this allows for the optimization of sizing and operation of the clean energy technologies in a cluster, such as solar, batteries and electric vehicles (EVs). This creates system-wide efficiency, reduces GHG emissions and costs, and optimizes system value benefits (e.g. energy security).

↓ **Gothenburg, Sweden**
Image credit: Shutterstock

CASE STUDY 8

Aggregating clean energy demand at the largest port in Scandinavia via the Tranzero Initiative

Pooling demand for a new product or service is an effective strategy to mitigate risks associated with the upfront investment needed to scale supply. The Tranzero Initiative is a prime example of co-located companies – some of them traditionally being competitors – collaborating to create synergies for their energy transition. This initiative comprises Stena Line (one of Europe's largest ferry companies), the Port of Gothenburg in Sweden and world-leading providers of transport solutions Volvo Group and Scania. It aims to establish a unified demand signal for clean energy, initially focusing on the decarbonization of the 1 million truck transports annually passing through the Port of Gothenburg, the largest port in Scandinavia. As concrete results of the Tranzero Initiative, charging infrastructure for electric trucks has been established, comprising a total of 14 charging stations at strategic locations in and close to the port. In the meantime, the number of electric trucks in the port area has increased from less than a handful to over 100. Also, in October 2024, a hydrogen filling station was inaugurated in the middle of the port area, specially designed to cater for trucks and port terminal equipment.

Having identified the supply of green electricity as a crucial factor for scaling up the green transition, the partners of the Tranzero Initiative will now widen the cluster collaboration to focus on the aggregated demand for a larger industrial area shifting all sectors into renewable power. Under the name Tranzero Energy, the cluster will also understand how the demand will affect prices and availability of electricity at a certain place and point in time and how any negative effects can be mitigated. This can be achieved by flexible power consumption customized for the industry cluster, helping to reduce costly peak-hour electricity demand (peak shaving), which in turn stabilizes the grid by alleviating power constraints during high-demand periods. Due to this, potential negative effects on the willingness to shift to electrification in the transport industry due to unpredictable cost and availability can be reduced. The initiative will provide local and national policy-makers and utility companies with insights into the current and future demand for renewable power to be able to make informed investment decisions.

The Tranzero Initiative sends a strong message that collaboration is both essential and achievable in tackling future sustainability challenges. Joint efforts are crucial for overcoming barriers to accelerating availability of non-fossil energy and finding innovative ways to utilize existing resources. Initiatives like this pave the way for ongoing investments in cutting-edge solutions, as availability of non-fossil energy is a requirement for any vessel design.

Niclas Mårtensson, Chief Executive Officer, Stena Line

At the Port of Gothenburg, we are proud to support the Tranzero Initiative by providing the necessary infrastructure and access to fossil-free fuels. Our collaboration with industry leaders to aggregate demand for clean power and fuels was essential in creating clear demand signals for this infrastructure. Together, we will provide comprehensive demand signals for clean fuels and power to fuel producers, utility providers and government.

Göran Eriksson, Chief Executive Officer, Port of Gothenburg

↓ Gothenburg harbour, Sweden

Tranzero

Gothenburg, Sweden

Stena Line, Volvo Group,
Scania, Port of Gothenburg

- **1,2** 2 charging stations with 14 E-charging points for trucks
- **3** Hydrogen filling station
- **4** Priority lane roll-on roll-off terminal
- **5** Priority lane container terminal

* Retail facility

Please note infrastructure projects displayed (points 1-5) have been developed by the Port of Gothenburg and Stena Line. Volvo Group and Scania plan to be involved in future infrastructure developments within the cluster.

CASE STUDY 9

Ordos-Envision Net-Zero Industrial Park transforming the industrial ecosystem

Envision, together with the city of Ordos, co-built the world's first net-zero industrial park. The Ordos-Envision Net-Zero Industrial Park in Ordos, Inner Mongolia, in China, demonstrates a strategic approach to managing power demand within an industrial park setting. The Ordos-Envision Net-Zero Industrial Park will integrate the supply chains of several industries, such as EV and battery manufacturing. Ordos is the world's largest city economy reliant on coal, currently generating about 16% of China's coal production. Consequently, the city faces immense pressure to shift towards clean energy sources.

The industrial park will feature a comprehensive clean energy solution, powered by the latest wind, solar and hydrogen power technologies. A new renewable energy system powered by the internet of things (IoT) will dynamically manage the aggregate power demand based on solar/wind energy generation, battery storage charging/discharging and grid power usage. With the battery industry as the core, the park attracts upstream and downstream companies to establish their presence within its grounds. By linking new energy and new industries, Envision is building the infrastructure for a new industrial revolution. This transition, powered by 5 TWh/year of locally sourced renewables, is designed to achieve full net-zero operations while setting a clear example for further clean energy investments. The park aims to reduce carbon emissions by tens of millions of tonnes annually by 2025, all while creating tens of thousands of jobs in green technology.

'Helping humanity solve the challenges of a sustainable future' – we have never wavered from this mission. As we grow our roster of partners to fight climate change, we remain firm in our commitment to a brighter, boundless future for all mankind.

Lei Zhang, Founder and Chairman, Envision

↓ **Ordos-Envision Net Zero Industrial Park**
Ordos, Inner Mongolia, China; Image credit: Envision

An integrated concept for the Ordos-Envision Net Zero Industrial Park

Source: Envision. (n.d.). *Home.* https://www.envision-group.com/case-study/ordos-industrial-park.

Financing

Clusters can accelerate funding by coordinating net-zero investment opportunities and analysing impact across the cluster and regional players, resulting in more compelling business cases.

The formation of clusters can save costs (e.g. lower overheads through shared infrastructure) and achieve economies of scale. For example, cluster financing allows them to act as legal entities that manage funding for multiple projects.[42] This approach can optimize debt structures and strategically use leverage, boosting economic growth and creating positive spillover effects. In some cases, governments can take a more active role in convening clusters through the financing of energy transition projects.

CASE STUDY 10

HyNet North West industrial cluster decarbonizing the North West of England and North Wales

The UK government and Eni are working on one of the world's first asset-based regulated carbon capture and storage (CCS) business models at the HyNet North West industrial CCS cluster, providing carbon transport and storage for hard-to-abate CO_2 emissions in the North West of England and North Wales. This is part of the UK government's CCUS commitment, which includes £21.7 billion of support for CCUS projects, as announced in October 2024. Through this business model, the government de-risks significant infrastructure projects by providing funds and creating vital certainty for large-scale private investment. Kickstarting with HyNet North West, a UK industrial cluster with carbon capture facility will be created, removing approximately 10 million tonnes of CO_2 annually after 2030 and contributing significantly to the UK's target of storing 20-30 million tonnes of CO_2 annually by 2030.[43] The HyNet cluster as a whole is estimated to provide £17 billion in economic value in the UK until 2050.[44]

The project will transform one of the UK's most energy-intensive regions into one of the world's first low-carbon industrial clusters, by reusing the depleted reservoirs operated by Eni in Liverpool Bay. HyNet will not only guarantee local employment, supporting the decarbonization of hard-to-abate industries, but will also be able to maintain the UK's industrial competitiveness in the long term by creating new production chains and jobs. Moreover, Eni is expanding its CCS investments with the Bacton Thames Net Zero project in the South East of England, which aims to contribute to the decarbonization of the South East and the Thames regions.

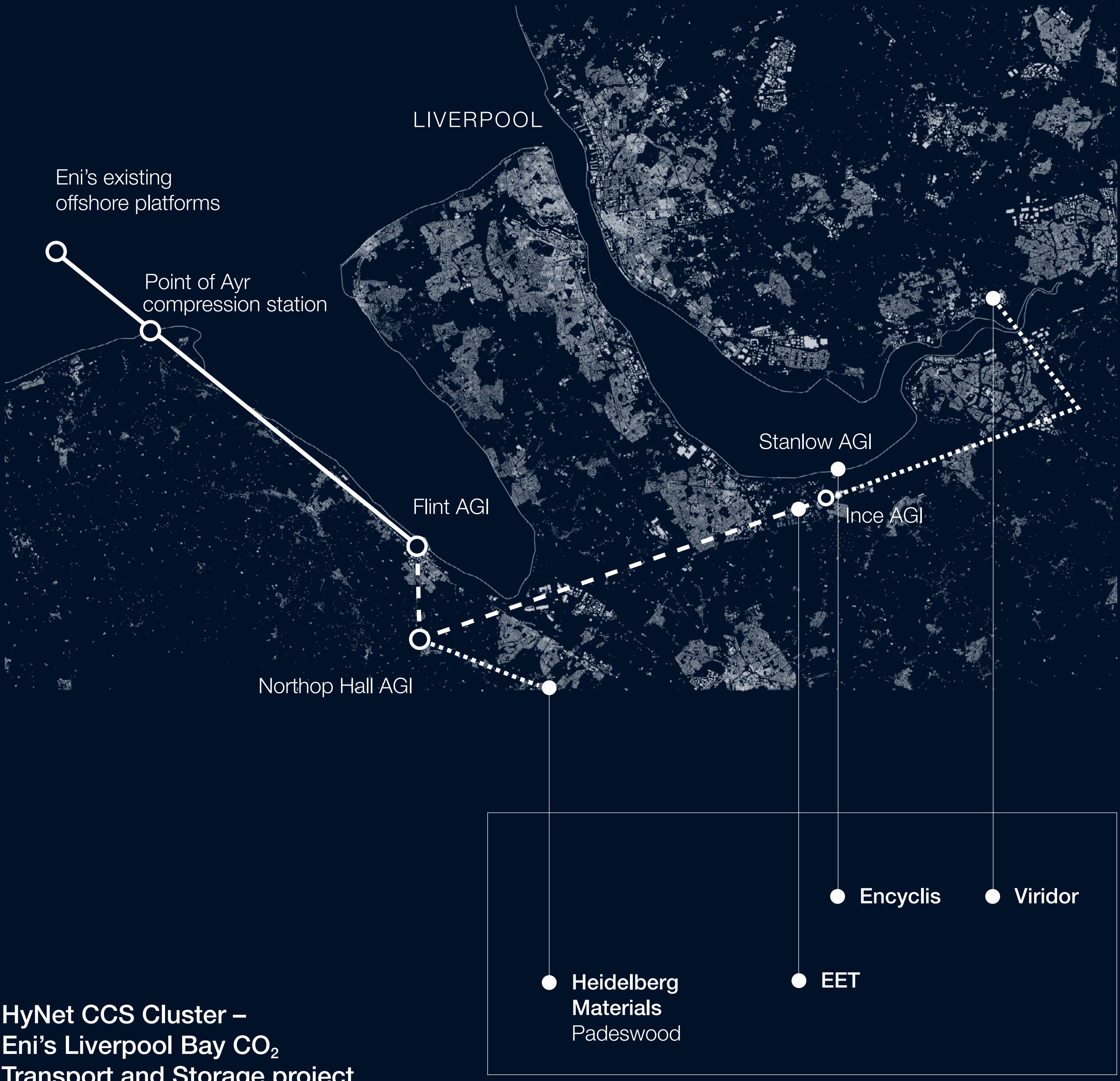
> **The UK government's design of the funding mechanism has been instrumental in scaling the CCS industry by offering the certainty needed to de-risk clean energy infrastructure investments for the private sector. This strong public-private collaboration is crucial for driving the innovative projects that will power the energy transition and it reaffirms Eni's role as a key partner with the UK in enabling its journey towards net zero.**
>
> Claudio Descalzi, Chief Executive Officer, Eni

↓ **Workers at Eni's Point of Ayr Gas Terminal in North Wales, which will be repurposed for CCS.**
Image credit: Eni

HyNet North West

North West England and
North East Wales, United Kingdom

Signatory cluster



HyNet CCS Cluster – Eni's Liverpool Bay CO_2 Transport and Storage project

Eni CCUS Holding, EET, Heidelberg Materials, Encyclis, Viridor, Progressive Energy

- Existing CO_2 pipelines
- New CO_2 pipelines
- Proposed spur pipelines

Note: AGI = above ground installation

CASE STUDY 11

Public players and government deploy low-emission energy infrastructure and derisk use for private players

Porthos – a project among the Port of Rotterdam Authority, Gasunie and EBN in the Netherlands – showcases how effective financing can drive low-emission energy infrastructure deployment by supporting both supply and demand. Porthos has received over €100 million in grants and subsidies from the EU for the development of CCS infrastructure.[45] Through the Sustainable Energy Production and Climate Transition Incentive Scheme (SDE++), the Dutch government has committed €2.1 billion to support four major industrial players (Shell, ExxonMobil, Air Liquide and Air Products) in reducing their CO_2 emissions by capturing and storing them under the North Sea. This is achieved through a 15-year operating subsidy from SDE++, enabling industries to cost-effectively reduce their emissions by bridging the cost gap between processes with and without CCS.[46] Porthos aims to capture approximately 2.5 million tonnes of CO_2 annually, drawn from industrial companies in Rotterdam's port area, which is estimated to result in 37 million tonnes of CO_2 being captured over a 15-year period.

This project is a vital step towards our ambitious goal of reducing CO_2 emissions in the Rotterdam port area by 55% by 2030 and transforming into a carbon-neutral port by 2050. As one of Europe's leading energy hubs, we're dedicated to building the CO_2 infrastructure and international connections needed to drive down emissions across European industry and foster a sustainable future together.

Boudewijn Siemons, Chief Executive Officer, Port of Rotterdam

↓ **Port of Rotterdam, Botlek**
Rotterdam, Netherlands; Image credit: Shutterstock

Port of Rotterdam

Rotterdam, Netherlands

Signatory cluster

Connections from CO_2 capture locations to pipeline

Porthos CCS project

Port of Rotterdam, EBN, Gasunie

CO_2 pipeline route

New and enhanced business models

Exploring new and enhanced business models that address the green premium is key to incentivizing electrification and the adoption of clean fuels.

These models include creating new green products and markets underpinned by digital certificates. As highlighted by Accenture's 2023 report, *Powered for Change*, 51% of heavy industry executives plan to launch or expand products and services with a lower carbon footprint in the next 3-5 years.[47] These new products and services will be critical to unlocking demand across the clean energy value chain. New business models could also include a shared economy, allowing users to utilize infrastructure without requiring upfront investment (e.g. via subscription-based services and pay-per-use models). For example, the Port of Rotterdam Authority, as part of a consortium with Wärtsilä, the ING Group and Engie, established a pay-per-use model for battery containers to reduce upfront investment in clean technologies for users.[48] Business models based on vertical integration and circularity provide another option, as they lower the green premium on clean fuels by reducing costs through supply chain control, economies of scale and process efficiency.

CASE STUDY 12

Vertical integration across the green hydrogen value chain and circular economy business model in the Mundra cluster

In the Mundra cluster, one of India's largest green hydrogen hubs is currently being built by strategically applying vertical integration to drive down costs and enhance the efficiency of the production of green hydrogen and its derivatives. By managing all aspects of the supply chain – from renewable energy equipment manufacturing and generation to electrolyser manufacturing and green hydrogen production – the Mundra cluster minimizes reliance on external suppliers, streamlining operations and reducing expenses. This approach allows to capitalize on economies of scale, while enabling circularity and integrating cutting-edge technologies. Regarding circularity, CO_2 captured from cement production is combined with green hydrogen to produce low-carbon methanol.

In addition, the proximity of the industrial cluster to the country's largest commercial port facilitates the transport and export of green hydrogen and its derivatives, further lowering logistics costs. By combining large-scale production capabilities with the adjacent industrial ecosystem, decarbonization within the cluster is supported, while enabling the trade and export of green hydrogen and its associated derivatives. This comprehensive vertical integration not only supports cost reductions but also aligns with India's broader goals of achieving energy security and reducing reliance on imports of energy, fertilizer and chemicals.

> **We have implemented a vertically integrated model at our Mundra industrial cluster to achieve economies of scale and reduce the cost of green hydrogen production. By controlling every stage of the supply chain – from renewable energy equipment manufacturing and generation to electrolyser manufacturing and green hydrogen production – we minimize reliance on external suppliers to facilitate the large-scale production of low-cost green hydrogen.**
>
> Karan Adani, Managing Director, Adani Ports and Special Economic Zone

↓ **Mundra cluster, Mundra Port**
Gujarat, India; Image credit: Shutterstock

CASE STUDY 13

Indo-Pacific Net-Zero Battery-Materials Consortium forms to harness collective strengths for the development of the EV supply chain

The Indo-Pacific Net-Zero Battery-Materials Consortium (INBC), comprising the Bakrie Group (an Indonesian conglomerate), Envision (a Shanghai-based energy company) and Glencore (a Swiss natural resources company), is leading efforts in vertical integration within the EV supply chain.

This collaboration spans the entire supply chain, from mining raw materials and generating renewable energy to producing and distributing batteries. When launched, the INBC aimed to process approximately 94,000 tonnes of nickel annually – equivalent to 140 gigawatt hours (GWh) of nickel-based batteries, sufficient to power 2 million passenger EVs. The consortium also plans to develop 1 gigawatt (GW) of renewable energy capacity through a combination of onshore wind farms and natural gas-based combined-cycle power plants.

Each consortium member brings its expertise to the initiative allowing to create synergies at different points of the supply chain:

– Bakrie Group and Glencore: Oversee nickel mining and processing, contributing approximately 27% of the supply chain.

– Envision and Bakrie Group: Lead clean energy generation, the establishment of a net-zero industrial park, and cathode and battery cell production, collectively accounting for around 44% of the supply chain.

This collaboration is supported by the Indonesian and UK governments, aiming to secure low-carbon battery materials for gigafactories in the UK, France and Spain while establishing Indonesia's first net-zero industrial park in Sulawesi. The initiative is expected to boost trade between Indonesia and the UK by over 30%, driving economic growth and advancing sustainability. In recent years, the battery industry landscape has undergone significant shifts, prompting INBC to revisit and refine their original intentions and strategies.

Following initial studies, a change in EV adoption, influenced by macroeconomic and geopolitical challenges, has impacted their approach to this initiative. As a result, INBC is currently reviewing their original capacity plan to better align with the evolving industry dynamics.

> **By forming the INBC consortium alongside Envision and Glencore, we've harnessed our collective strengths and mitigated risks. This partnership positions us to play a pivotal role in the global EV supply chain while accelerating the development of battery gigafactories across the G7.**
>
> Anindya Novyan Bakrie, Chief Executive Officer, Bakrie Group

↓ Indonesian Nickel Ore

3.3 Strengthen the collaboration across clusters and regions

The challenge of clean power and clean fuel infrastructure demands collaboration beyond the cluster, across their value chains, and within and across regions. Reducing costs and logistical barriers across the value chain and increasing electrification and clean fuel demand require a global interoperable distribution network. A cluster can use the following methods to strengthen collaboration both within and across regions:

- **Global networks**
- **International initiatives**
- **Value chain partnerships**

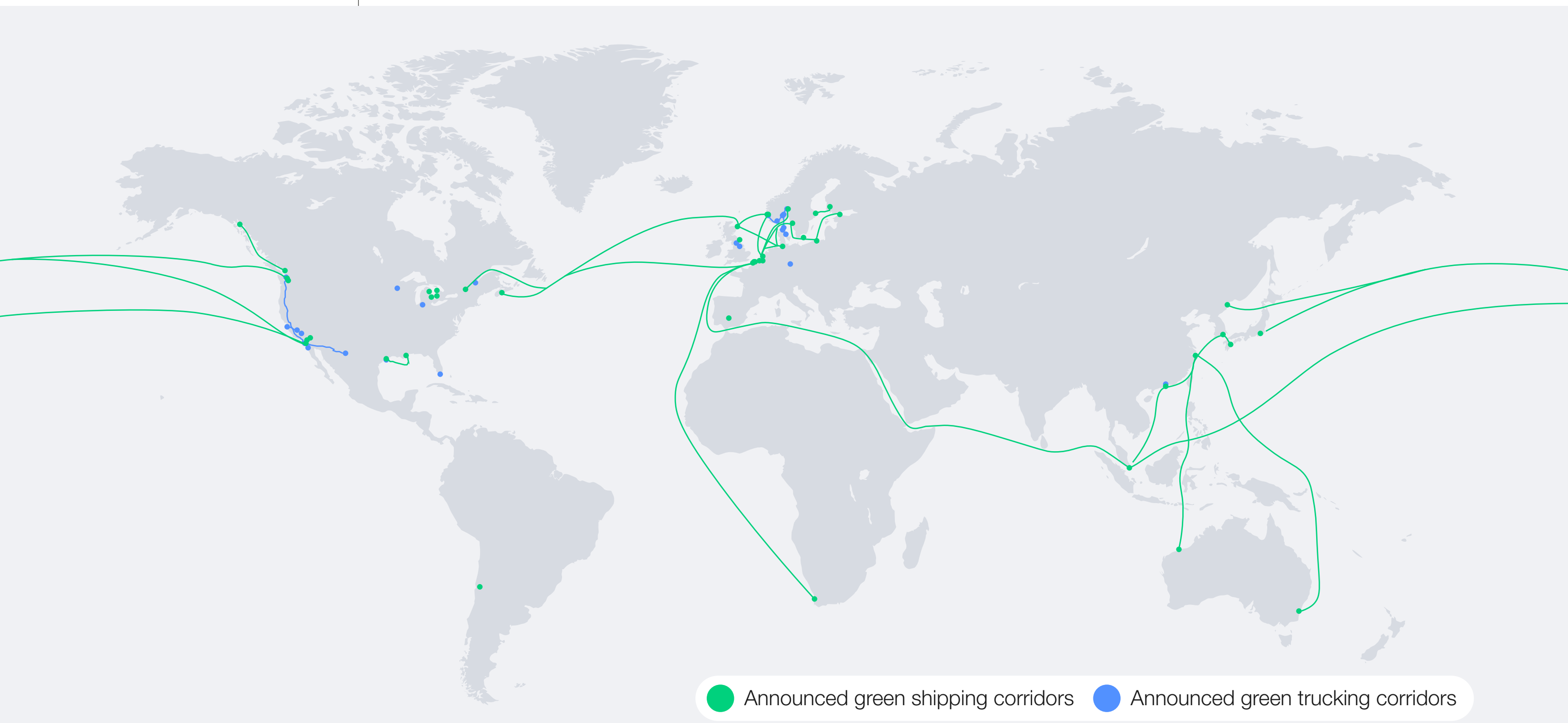
Global networks

Connected clusters serve as conduits for energy carriers, sustainable trade flows and knowledge sharing.

Energy can be transferred from production hubs with low costs (often due to abundant renewable resources or supportive policy incentives) to energy-intensive industrial centres as well as establishing sustainable trade routes for vessels powered by clean fuels. Interoperability across the end-to-end network will be key to the integration of clean energy pathways and the cohesive scale-up of infrastructure. Beyond facilitating clean energy flows, these networks can strengthen international collaboration and act as proving grounds for clean energy technologies and shared expertise across clusters.

> **“Our global project tracker provides a holistic view into the decarbonization for heavy industry and transport – and the rising ambition of industry is clear. But there is no hiding from the challenges ahead, we’ve reached a stalemate between producers and buyers. Collaboration across industrial clusters and regions is vital to developing a global network for international trade of clean energy. MPP is committed to addressing the collective action needed, working with businesses and governments, and we urge all stakeholders to contribute to opening up the next wave of green industrial projects.**
>
> Dick Benschop, Chair, Mission Possible Partnership (MPP)

FIGURE 2 **Global project tracker, green corridors for shipping and trucking**



Source: Mission Possible Partnership (MPP). (n.d.). *Global Project Tracker*. https://www.missionpossiblepartnership.org/tracker/.

CASE STUDY 14

The maritime corridor connecting the Andalusian Green Hydrogen Valley with demand in Northern Europe

A green hydrogen valley in southern Spain that will connect to Northern Europe via a maritime corridor is laying the foundation for the continent's clean energy future through decarbonizing industry as well as heavy transport. The Andalusian Green Hydrogen Valley, led by Spanish multinational energy company Moeve, will have an electrolysis capacity of 2 GW and produce up to 300,000 tonnes of green hydrogen per year by the end of this decade. The valley will also include a green ammonia plant and a green methanol plant with an annual production capacity of up to 750,000 tonnes and 300,000 tonnes, respectively. Tying it all together is Moeve's "green hydrogen ring", which draws on diverse supply sources, including renewable solar and wind power and biogas, to ensure the most optimal supply of green hydrogen at any time for final users. Altogether, green energy output from the valley can reduce CO_2 emissions by 7 million tonnes per year.

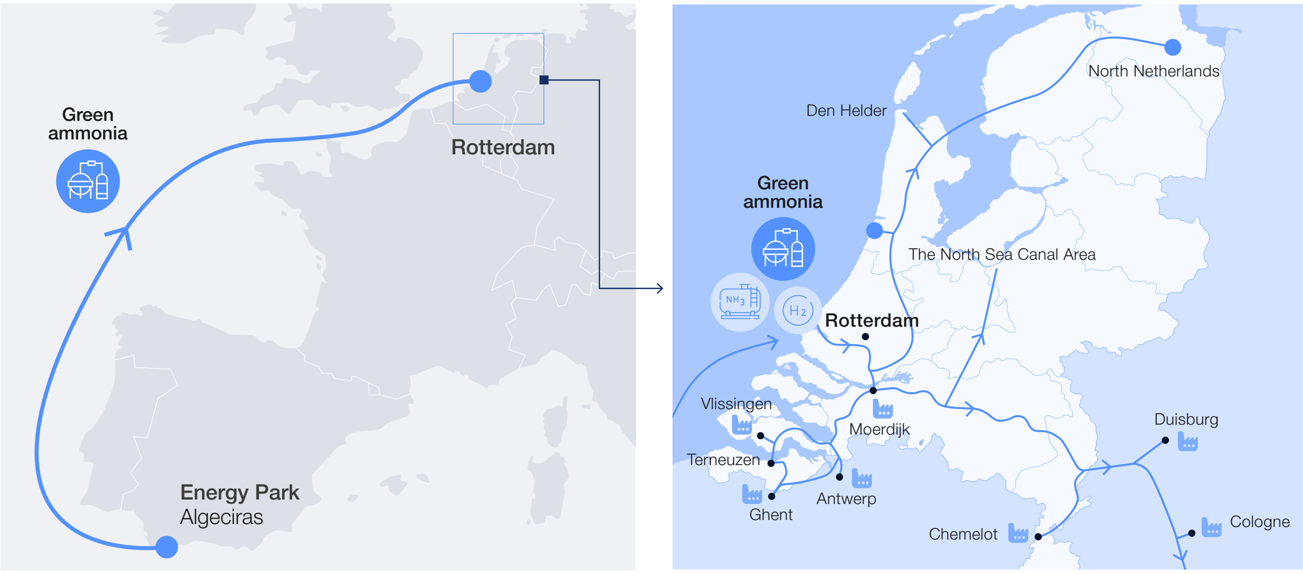
To enable the flow of green energy produced from the facilities in southern Spain into Northern Europe, Moeve has teamed up with the Port of Rotterdam to create a maritime corridor from the nearby Andalusian port of Algeciras. This strategic partnership uses Spain's low-cost renewable power to produce green hydrogen and the Port of Rotterdam's central role as a major logistics hub in Northern Europe, ensuring efficient distribution to energy-intensive nearby industries. Through the maritime corridor, the Andalusian Green Hydrogen Valley can support Rotterdam's goal of supplying 4.6 million tonnes of green hydrogen to Northwest Europe by 2030. Adding to the logistical ecosystem, Moeve has also partnered with Yara Clean Ammonia to enable the transport of green hydrogen with ammonia as a carrier. Once in Rotterdam, the ammonia can either be used as a clean fuel for maritime transport or cracked back into hydrogen and distributed for use by heavy industry.

This inland distribution will occur thanks to Moeve's agreement with Gasunie, an energy infrastructure company involved in the Delta Corridor project linking Rotterdam with industrial clusters in Germany, Belgium and the Netherlands via pipelines.

This collaboration exemplifies how global networks can efficiently connect regions with renewable energy resources to energy-intensive industrial areas, fuelling Europe's energy transition.

> **The green hydrogen corridor between Algeciras and Rotterdam marks a major milestone in Europe's energy transition because it provides an opportunity for significant levels of decarbonization in the very near future. It is the first step in establishing a network of global networks that will connect regions with abundant renewable resources, like southern Spain, to high-demand industrial hubs across Central and Northern Europe. The ecosystem of partnerships behind the corridor, as well as the Andalusian Green Hydrogen Valley, will accelerate decarbonization in the maritime and industrial sectors and also serve as a model for future collaborations that bridge the gap between supply and demand for green fuels. These partnerships are a critical step towards building a truly sustainable energy infrastructure for Europe.**
>
> Maarten Wetselaar, Chief Executive Officer, Moeve

Andalusian Green Hydrogen Valley – Port of Rotterdam maritime corridor



Source: Moeve

CASE STUDY 15

Port of Houston to Port of Antwerp-Bruges connected clusters to distribute low-cost clean hydrogen to Europe

A clean maritime corridor between the Port of Houston in the US and the Port of Antwerp-Bruges in Belgium is creating a transatlantic link for clean hydrogen. Enabled by a unique set of dedicated hydrogen pipelines, three of six clean hydrogen storage assets, the largest portfolio of renewable plants in the nation and access to renewable and low carbon natural gas, the US Gulf Coast can harness low-cost clean hydrogen production to meet European demand. The Houston clean hydrogen ecosystem is using over 900 miles of hydrogen pipelines, representing 32% of global hydrogen pipeline infrastructure. The corridor will support the export of clean hydrogen, reducing emissions across sectors like transport and industry. This corridor also aims to facilitate the exchange of knowledge, best practices, and innovation. It connects two of the world's largest chemical clusters, supporting shared decarbonization goals and advancing clean energy trade between the US and Europe.

> **The Texas Gulf Coast is well positioned to produce clean hydrogen at globally competitive costs. By establishing this corridor, we are able to leverage this strong position and fulfil the growing need for secure clean hydrogen supply in Europe.**
>
> Brett Perlman, Managing Director, Hydrogen Program, Center for Houston's Future

Port of Houston – Port of Antwerp-Bruges clean maritime corridor

International initiatives

Accelerating electrification and the clean fuel agenda requires robust international collaboration and partnerships among industries, governments and global bodies.

International initiatives serve as a crucial platform for stakeholders to converge, facilitating shared benefits ranging from infrastructure deployment across different geographies to the advocacy of enabling policies. These international efforts can effectively reduce trade barriers, establish reliable markets and stimulate investment in clean energy infrastructure across borders.

CASE STUDY 16

Green Balance Mechanism to incentivize the maritime sector's energy transition

The Green Balance Mechanism or feebate was proposed by industry leaders such as A.P. Møller-Maersk, an integrated logistics company, to the International Maritime Organization (IMO), through the World Shipping Council. It aims to mitigate the green premium associated with clean fuels in the maritime industry, which will enable an uptake in demand of these fuels while establishing a net-zero fund for R&D projects and climate mitigation initiatives. This innovative approach incorporates a GHG fuel-intensity standard and establishes a fee on fossil fuels, redistributing the collected funds to support clean fuels. By doing so, it creates a strong incentive for fuel providers to invest in clean energy, accelerating economies of scale that will lower production costs and drive down prices.

The time to act is now if we are to meet our ambitious net-zero by 2050 target. The IMO stands at a pivotal juncture, where the decisions we make will define the future of decarbonizing the shipping industry. What's needed is a mechanism that bridges the green premium, rewarding early adopters by compensating truly green vessels for their emissions reductions.

Vincent Clerc, Chief Executive Officer, A.P. Møller-Maersk

↓ Image credit: Maersk

CASE STUDY 17

Competitors join forces to electrify Europe's heavy-duty trucking sector via Milence

Milence, a joint venture between the TRATON GROUP, Daimler Truck and the Volvo Group, exemplifies how competitors can unite to mitigate individual risks while advancing mutual goals. With a €500 million investment, Milence is set to establish at least 1,700 high-performance public charging points across Europe by 2027, supporting the shift to zero-emission heavy-duty vehicles. This collaborative approach enables each partner to contribute without bearing the full financial and operational risk individually, pooling resources to accelerate sector-wide electrification.

Strategic hubs like the Port of Antwerp-Bruges and Able Humber Port in the UK – scheduled to open in 2024 – are key to Milence's network, offering essential connectivity to and within the European market. Milence conducts extensive regional research when selecting locations, ensuring charging stations align with the logistical needs of Europe's freight sector, which carries nearly 80% of the EU's land freight.[49] By providing sustainable energy solutions for battery-electric trucks and coaches regardless of brand, Milence demonstrates how cross-industry cooperation, even amongst competitors, can create scalable infrastructure solutions that might otherwise be unattainable individually, driving the continent's transition to cleaner, high-capacity transport.

> **We've come together with Daimler Truck and the Volvo Group to take a bold step towards the commercial vehicle industry's transition to sustainable energy. Through this important collaboration, we harness shared strengths, drive impactful synergies and share risks in developing clean energy infrastructure for all to use.**
>
> Christian Levin, Chief Executive Officer, TRATON GROUP

↓ **Charge Hub Varberg**
Image credit: Milence

Value chain partnerships

Establishing novel value-chain partnerships is essential to accelerate clean energy adoption and infrastructure development within industrial clusters.

Value chain partnerships connect players across the value chain down to the end consumer, both within and beyond clusters. In this way, it becomes easier to recognize willingness to pay across products and sectors, enabling the spread of the green premium across the value chain. As the value chain gets close to the end consumer, the green premium from a given clean fuel can be diluted and simultaneously directed to customer segments with higher willingness to pay. Forming such partnerships can innovative new business models and drive demand for clean energy.

CASE STUDY 18

Avelia, the blockchain-powered book and claim solution for scaling SAF demand

Developed jointly by Shell, Accenture, Energy Web Foundation (EWF) and American Express Global Business Travel (Amex GBT), Avelia is one of the first blockchain-powered book and claim solutions for aviation that has proven results in scaling sustainable aviation fuel (SAF) demand. Since Avelia was launched in 2022 to September 2024, Shell Aviation has injected over 18 million gallons of SAF into the existing fuel network, helping to abate[50] more than 165,000 tons of carbon dioxide equivalent (CO_2e), the equivalent of over 290,000 passengers flying from London to New York.[51] Over 35 airlines and corporations[52] have purchased environmental attributes through Avelia.

The platform has successfully demonstrated the credibility of the book and claim model by enabling more stakeholders from the aviation value chain to use and benefit from SAF. Thanks to the use of blockchain technology, Avelia enables the secure, reliable and transparent tracking and allocation of SAF's environmental attributes to companies and airlines. By aggregating global business demand for SAF through its platform, Avelia helps create the market demand signals that very well could attract the required investments to scale SAF production and infrastructure and contribute to the aviation industry's journey to net zero.

> **SAF is a key scalable in-sector solution for decarbonizing aviation. Avelia was developed to help generate the scalable demand necessary to help the sector transition to net-zero emissions by 2050. Through its book and claim chain-of-custody model and blockchain technology, Avelia helps to enable broader value chain participation to unlock SAF demand at scale. By making the environmental attributes of SAF accessible to corporations and airlines, it is possible to aggregate global business demand for SAF, which will help drive SAF investment and production scale, contributing to reducing emissions from air transport.**
>
> Raman Ojha, President, Shell Aviation

Note: The views presented in this white paper do not necessarily reflect the views of all of the member organizations of the Transitioning Industrial Clusters initiative.

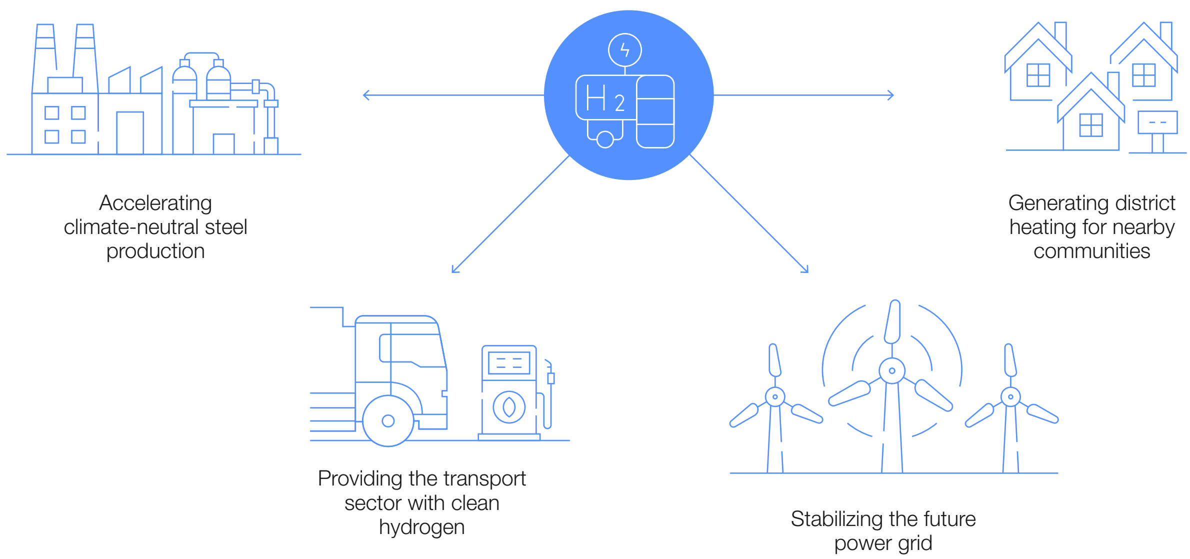
CASE STUDY 19

Pioneering clean hydrogen production for sustainable steel and transport

Steel manufacturer Ovako, Volvo Group and key partners, including Hitachi Energy, Stegra and Nel Hydrogen, with support from the Swedish Energy Agency, have launched a groundbreaking initiative to significantly reduce CO_2 emissions and develop local industrial hydrogen production. Ovako's new hydrogen plant in Hofors, Sweden, is the first in the world to use hydrogen for heating steel prior to rolling, advancing climate-neutral steel production. The surplus green hydrogen produced will power Volvo Group's fuel cell vehicles and be used at a new hydrogen filling station adjacent to the plant. This collaboration enhances cost efficiency by recycling hydrogen by-products into energy, playing a vital role in Volvo Group's shift towards electrification for long-haul and heavy duty applications while also serving as a fossil-free fuel for combustion engines.

> **Collaboration is key, and we need a new form of collaboration. Partnership is the new leadership – this is not just a belief; it's a proven strategy. We know this approach works.**
>
> Martin Lundstedt, President and Chief Executive Officer, Volvo Group

Local industrial clean hydrogen production



Source: Ovako

Each of the above case studies demonstrates how collaboration within clusters and their broader clean energy value chains function as a method to overcome the infrastructure challenge, achieving outcomes that would be unattainable in isolation.

> **At DHL, we are strongly committed to partnerships that drive the energy transition. Our recent collaboration with Envision, which focuses on innovations such as sustainable aviation fuel and the development of Net Zero Industrial & Logistic Parks, is a testament to this commitment. However, the energy transition requires an even more comprehensive collaboration across the entire energy value chain, focusing on energy demand as well as energy supply and optimized grid management to further drive the decarbonization of our transports. These partnerships are essential to advancing sustainable energy solutions and we are committed to fostering many more.**
>
> Tobias Meyer, Chief Executive Officer, DHL Group

Conclusion and call to action

Several challenges are hindering clean energy infrastructure scale-up

To achieve global climate goals and advance the energy transition in transport, logistics and heavy industries, clean energy infrastructure must scale up rapidly. However, this involves overcoming challenges, such as the green premium, fragmented demand coupled with limited supply, a lack of a cohesive policy framework and inconsistent standards and certifications.

Industrial clusters can play a key role in overcoming the challenges

One strategy to overcome these challenges is to form industrial clusters – geographic hubs where firms are co-located. These clusters can offer economies of scale, share risks, and aggregate and optimize demand, playing a vital role across the clean energy value chain. This paper outlines three key solution areas through engagement with the TIC and the Supply Chain and Transportation communities. Industrial clusters can collaborate within and with their wider value chains to:

1. **Develop a common vision at cluster level**

2. **Expedite the scaling of cluster-level clean energy initiatives**

3. **Strengthen collaboration across clusters and regions**

Call to action

The examples and case studies outlined in this white paper illustrate how industrial clusters and their respective value chains have catalysed efforts to develop clean energy infrastructure. While these examples mark significant progress, they remain insufficient to meet the objectives of the Paris Agreement. Greater collaboration is needed at local, national and international levels.

Successfully transitioning industrial clusters requires four core components: 1) a balanced focus on economic, social and environmental value; 2) inclusive adoption of technologies and processes to reduce GHG emissions; 3) cross-sector collaboration among industry, government, financiers, labour and communities; and 4) coordinated, agile strategies across partnership, policy, financing and technology deployment.

To achieve this, the Forum welcomes action by leaders from government, professional, industry, academic and R&D organizations supported by Forum initiatives such as TIC and the FMC to build a global community on infrastructure with a focus on three areas:

– **Mobilizing co-located companies**: Support the cluster model for co-located companies, thereby optimizing opportunities for scale, sharing of risk/resources, aggregation and optimization of demand.

– **Strengthening existing clusters and partnerships across the value chain:** Enhance collaboration among co-located stakeholders and players across the entire clean energy value chain – spanning energy supply and distribution, heavy industry, transport and logistics – to effectively manage the green premium.

– **Connecting clusters into a global network**: Support the expansion of cluster networks to establish a global infrastructure model and facilitate a more interconnected network.

Appendix: Glossary

Term	Definition
Biofuel	A class of renewable fuel derived from biological sources and processes. Minor modifications are possibly required to accommodate refuelling. Based on EPRI definition[53]
Biogas	A mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. Biogas includes landfill gas and sewage sludge gas, and can be upgraded by removing non-methane constituents, principally CO_2. Based on IEA definition[54]
Blue hydrogen	Hydrogen produced from natural gas by a process of steam methane reforming (SMR), in conjunction with CCS. Based on World Economic Forum definition[55]
Clean (energy) technology	A technology that has the potential to help increase the uptake of clean energy. This includes any device, component of a device or process for its use dedicated to producing, storing or distributing energy with low CO_2 emissions intensity. Alternatively, it can mean a device that provides an energy service or energy commodity that enables users to minimize their contributions to atmospheric CO_2 concentrations, in line with net-zero emissions globally. It also includes technologies that reduce the cost or improve the performance of manufacturing other clean energy technologies. Based on IEA definition[56]
Clean energy	An umbrella term that groups energy sources, infrastructure, applications and related assets that are compatible with a net-zero emissions energy system. Based on IEA definition[57]
Clean fuel	Clean fuels/low-emission fuels can be grouped into gaseous fuels (biogases, hydrogen and synthetic methane) and liquid fuels (liquid biofuels, ammonia and synthetic liquid hydrocarbon fuels). They can be produced from plants, which absorb CO_2 from the atmosphere as they grow, or through industrial processes powered by renewables or other clean energy sources. Based on IEA definition of low-emission fuel[58]
Clean hydrogen	An umbrella term for both green and blue hydrogen. Based on World Economic Forum definition[59]
e-fuels e.g. eSAF, eMethane, eMethanol	Short for electrofuels, a class of synthetic fuels produced from captured CO_2 and renewably sourced electrolytic hydrogen. Based on EPRI definition[60]
Green ammonia	Ammonia that is produced from renewable energy and derives its hydrogen from water and its nitrogen from air. Based on World Economic Forum definition[61]
Green hydrogen	Hydrogen produced from water by electrolysis, powered from renewable sources. Based on World Economic Forum definition[62]
Green methanol	Methanol that is produced from low-carbon sources such as biomass, or via carbon capture. Based on from the World Economic Forum definition[63]
Green technology	A technology that has the potential to help increase the uptake of green energy – renewable power or green fuels such as green hydrogen, green ammonia or green methanol. **Note:** this term was brought in via a case study, the definition is based on understanding utilizing the clean technology definition
Low-carbon fuel	A category of fuel that when burned, provides thermal energy with lower net emissions compared to fossil fuels. Based on a definition provided by Greater St. Louis and Illinois Regional Clean Hydrogen Hub Industrial Cluster
Renewable diesel	A low-carbon, renewable fuel produced from vegetable oils, animal fats and food waste. It is treated to be a similar quality to fossil fuel. Based on EPRI definition[64]
Renewable fuel	A type of low-carbon fuel produced from renewable sources, such as biological (plant matter, animal waste), organic waste, captured CO_2 and renewable electricity. Based on definition provided by Greater St. Louis and Illinois Regional Clean Hydrogen Hub Industrial Cluster
Sustainable aviation fuels (SAF)	A low-carbon alternative jet fuel produced from renewable sources (biological, synfuel and others). Could be blended with conventional fossil-based fuels or used directly if it meets aviation standards. Based on EPRI definition[65]

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