VOLTA CHEM
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Accelerating industrial electrification

VoltaChem in Action
Overview 2020

Join our Shared Innovation Program

www.voltachem.com

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Editorial

At VoltaChem, we believe that the chemical industry can be fully sustainable through innovation, collaboration, and system integration. We focus on using decarbonized energy and circular feedstock for the production of essential products like fuels, fertilizers, and plastics. Since our launch in 2014 we have been working on accelerating industrial electrification together with our community members and collaboration partners, in order to achieve climate neutrality by 2050.

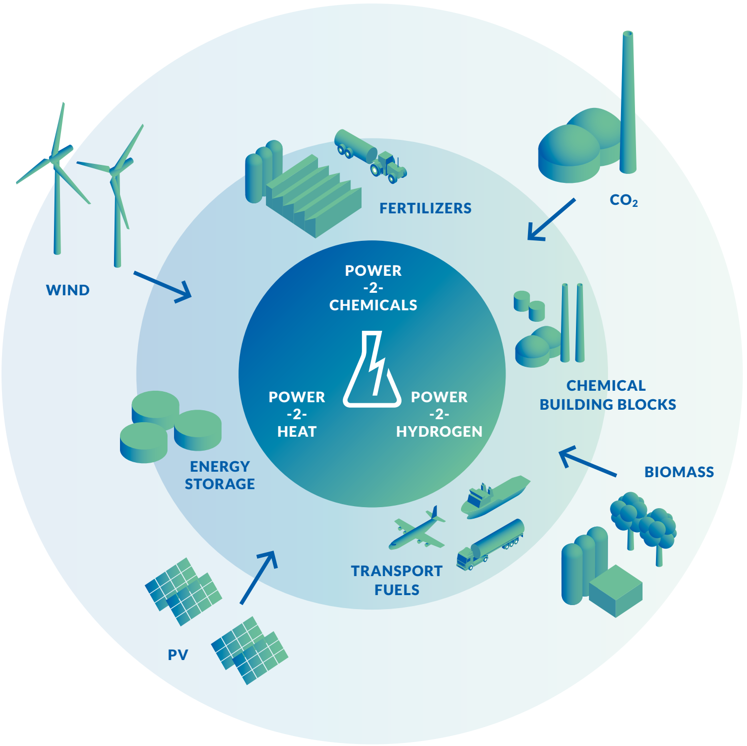
This booklet is meant to give you insight into our Shared Innovation Program and the progress that we made in 2020. Despite the challenges of the worldwide pandemic, we saw considerable growth in projects and partners and we have taken important steps in the development of our program. Together with our partners, we laid the foundation for flagship programs on topics that we believe to be key in a climate neutral chemical industry: International system change and business impact, Electrolyzer industrialization, Integrated CO_2 capture and electrochemical conversion, and Plasma decarbonization of methane.

We hope this booklet will provide you with new insights and opportunities for future collaboration. We look forward to hearing from you and to discuss how we can join forces in further accelerating industrial electrification.

Martijn de Graaff

Business and program director VoltaChem

VoltaChem in short



- Public-**Private Shared Innovation Program** initiated in 2014 by TNO, government, and industry.
- **Accelerate innovation and implementation of industrial electrification options** for reducing the CO_2 footprint in chemicals production, using decarbonized energy and circular feedstock.
- Initiate and facilitate **collaborative development** of technology and associated business models.
- Carry out **studies** and **RD&I** activities, addressing both the indirect and direct use of electricity within the chemical industry, involving stakeholders from **chemicals, energy**, and **equipment supply & licensors**.

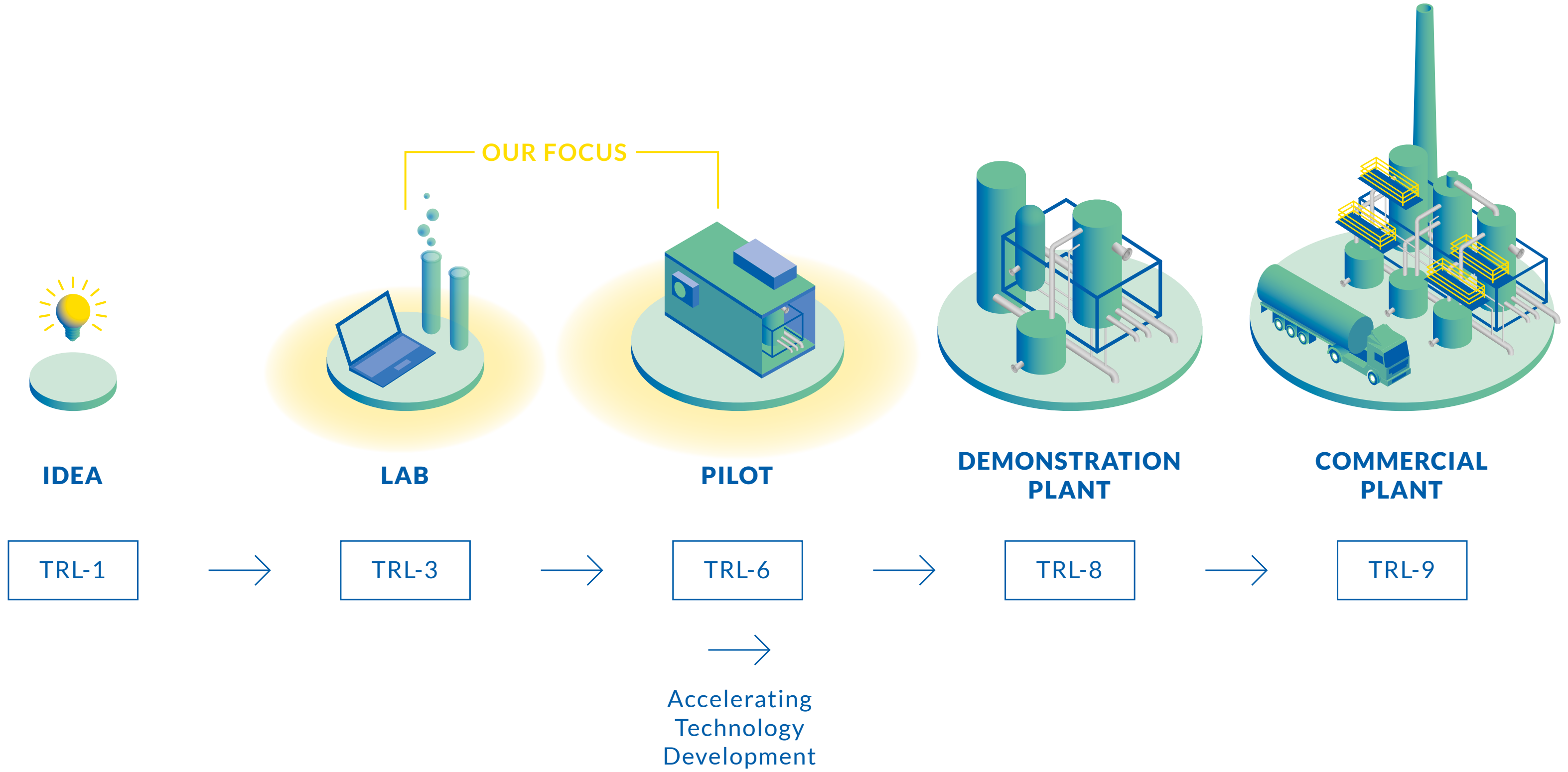
Our mission and strategy

Our mission

It is VoltaChem's mission to support the chemical industry, the energy sector, and equipment suppliers & licensors to move towards a climate neutral future. Finding collaborative business opportunities and addressing their challenges together by linking flexible electricity supply to energy demand in the chemical industry and by using electricity directly in chemical processing, employing novel technologies and business models.

Our strategy

VoltaChem pushes technological developments from TRL 3-5 (research & innovation) towards TRL 5-7 (piloting and demonstration) in a collaborative program. We do this by advancing knowledge through collaboration with top players in the field and by further developing this knowledge into pilots and demonstrators together with industry and regional clusters.



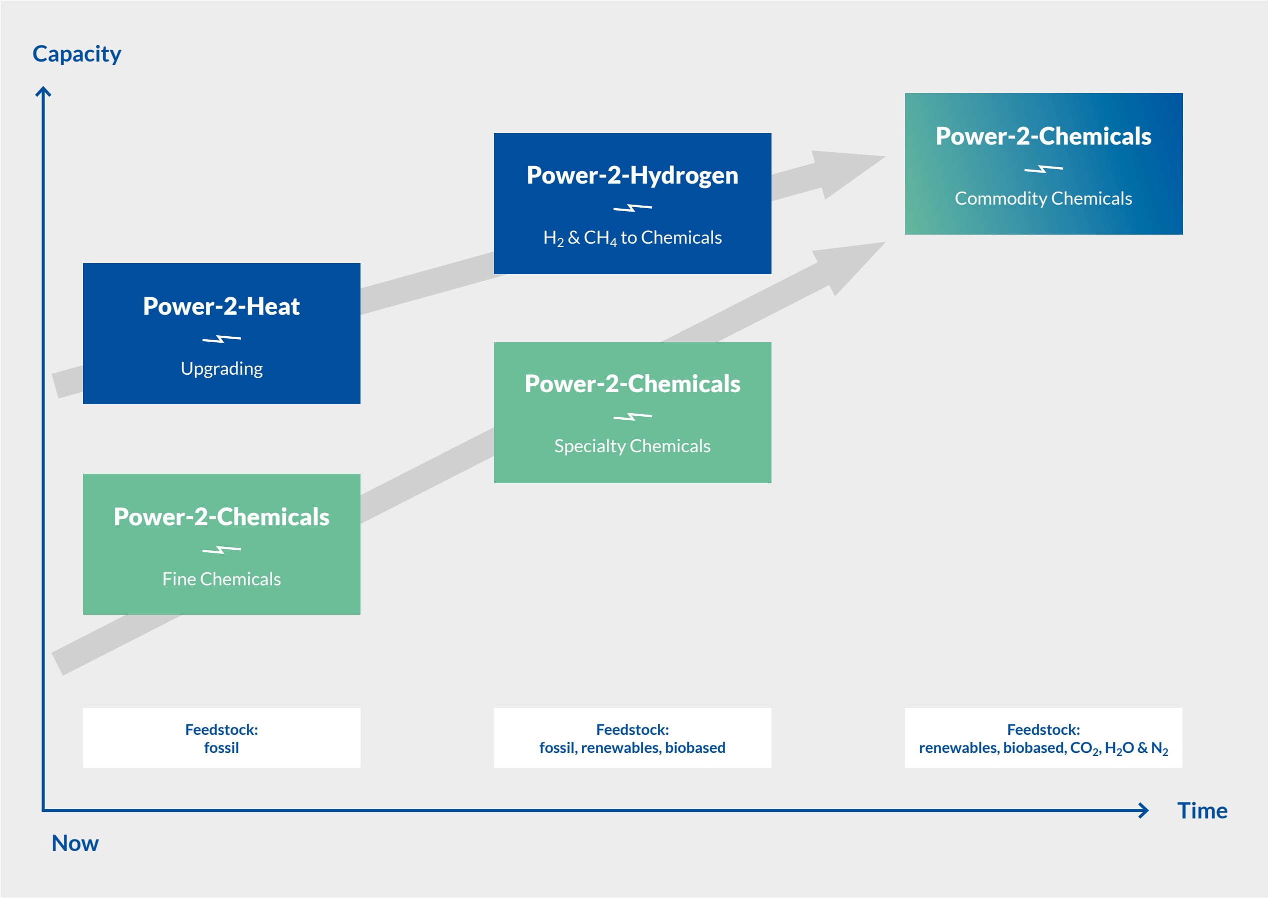
Our approach

We support the chemical industry, the energy sector, and equipment suppliers & licensors to find collaborative business opportunities and address their challenges with respect to energy use, efficiency, and selectivity together. We closely collaborate with industry and academia on:

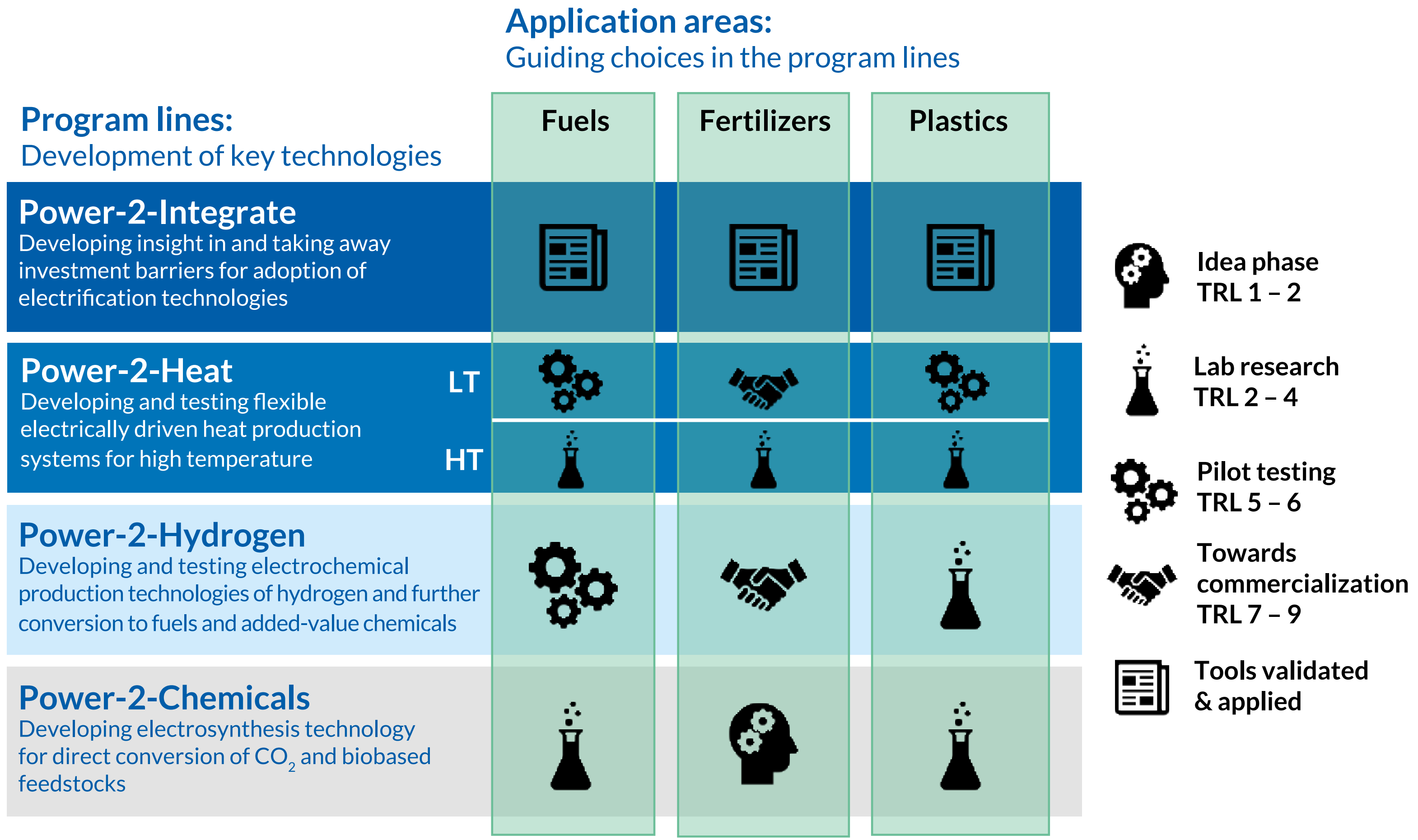
- Bringing stakeholders together to accelerate technology adoption.
- Developing business cases for industrial electrification in the short- and long term.
- Performing collaborative applied R&D in the field of industrial electrification.
- Bringing technologies into industrial practice by initiating pilot/demo activities.
- Addressing fundamental research questions together with top academic players.

The VoltaChem roadmap

We focus our developments in four technology program lines dedicated to specific technological niches. The VoltaChem roadmap, first presented in our electrification whitepaper in 2016, positions these topics and the time before large-scale implementation in industry is expected.

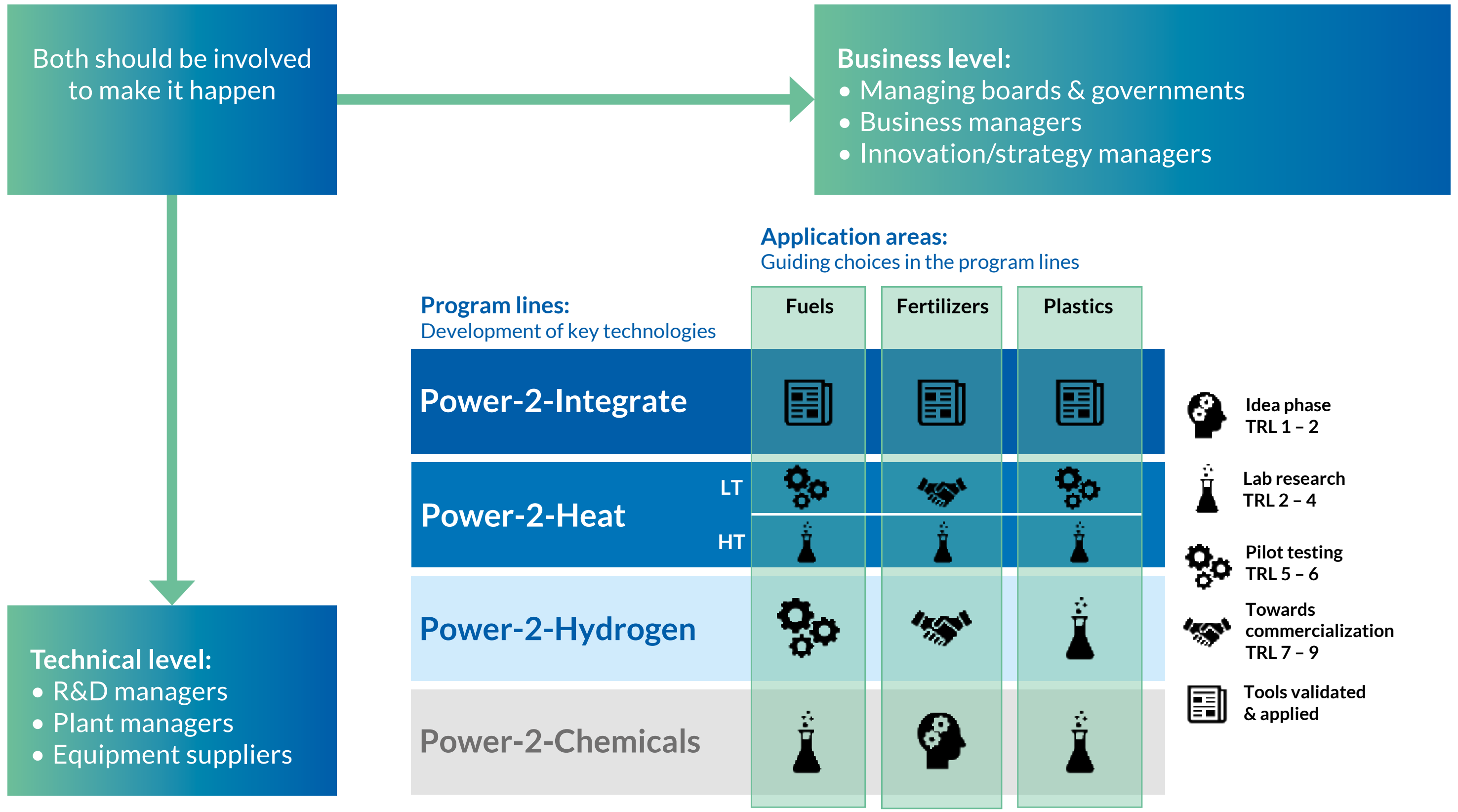


Our program lines and application areas

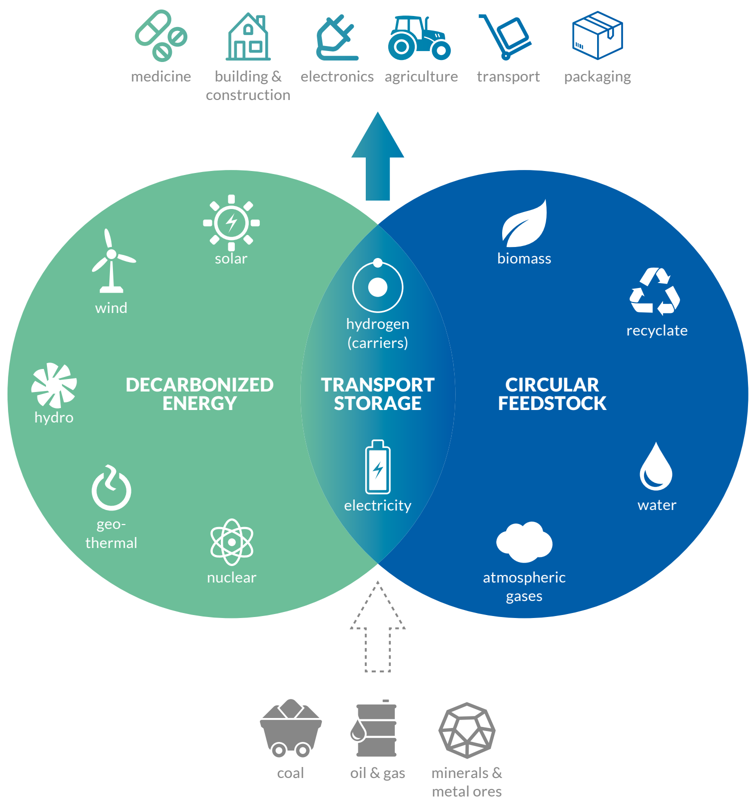


Business and technology combined

The VoltaChem Shared Innovation Program is characterized by its combined business and technology perspective. This is materialized through business related application areas and technology related program lines. Application areas offer guiding choices for the technology development that is performed in the program lines Power-2-Integrate, Power-2-Heat, Power-2-Hydrogen, and Power-2- Chemicals.



Key research areas



Power-2-Integrate
Developing **insight** in and **taking away investment barriers** for adoption of electrification technologies (e.g. business cases, infrastructure, regulations, policy gaps).

Power-2-Heat
Developing and testing **flexible electrically driven heat production systems** for high temperature.

Power-2-Hydrogen
Developing and testing **electrochemical production technologies of hydrogen** and further conversion to fuels and added-value chemicals.

Power-2-Chemicals
Developing **high- and low-temperature electro-synthesis technology** for direct **conversion of CO_2** and **biobased feedstocks** to key chemical intermediates and fuels.

Upcoming Power-2-X technologies
Investigating promising upcoming technologies, like **plasma pyrolysis of methane**.

Example projects 2020

In 2020 our VoltaChem team worked on various projects delivering great insights. We proudly present the highlights.

Power-2-Integrate
- The need for cooperation in trilateral infrastructure
- Power-2-Fuels value chain innovation
- System Supply Chain Model
- Critical Raw Materials
- Merit order of electrification

Power-2-Hydrogen
- Flagship Program Electrolyzer Industrialization
- Income
- GigaWatt Scale Electrolysis
- High-temperature Solid Oxide Electrolysis
- HySpeedInnovation

Power-2-Chemicals
- Flagship Program Integrated CO_2 capture and electrochemical conversion
- Electrochemical DME & Formic Acid production from CO_2
- Paired electrosynthesis of maleic, valeric and adipic acid
- Paired electrochemical CO_2 conversion and chlorine production
- Integrated biogenic CO_2 capture with electrochemical conversion to oxalic acid
- Plasma chemistry for CO_2 free production of hydrogen and ethylene from methane

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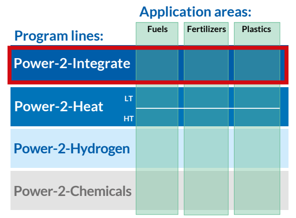
Power-2-Integrate

Industrial electrification plays a vital role in reducing CO_2 emissions. Adoption of electrification technologies using renewable sources can be accelerated when the broader ecosystem and investment drivers and barriers are better understood (in terms of economics, environmental impact, technologies, etc.). In the Power-2-Integrate program line we bring together stakeholders from different sectors who need to work together in the new value chain to accelerate development and adoption of Power-2-X technologies. We both develop and apply economic and system models to better understand national and international electrification opportunities for businesses and offer strategic advice on the drivers and barriers thereof.

We focus on:

- **Entry market** and business case identification.
- (Regional) **system analysis**.
- **Business** and **technology** scouting.
- **Ecosystem development** by means of knowledge exchange and continuous learning.



The need for cooperation in trilateral infrastructure

Context

Northwest Europe (NWE) is a hub for heavy industry of all sectors and for marine logistics. NWE has a well-implemented electricity and natural gas infrastructure. The industry in this cluster needs to move towards a CO_2 neutral footprint, yet there are many uncertainties ahead for this transition. One of these uncertainties lies in the potential for energy infrastructure to flexibly adapt to this new future.

Objective

It is unclear what opportunities there are for using existing infrastructure during the energy transition. Therefore, different stakeholder groups are struggling in decision making processes for investment. In order to stimulate and accelerate the transition to a CO_2 neutral industry, identification of synergies for the existing infrastructure, as well as barriers preventing its cross-sector/cross-border use need to be identified. Central question of this high-level study is what cross-border challenges and opportunities can be identified for the case study 'production of ammonia', a key industry in the Antwerp-Rotterdam-Rhine-Ruhr (ARRRA) region.

Results

- Possible routes towards CO_2 neutrality for ammonia production in the ARRRA region analyzed and implications for individual sites assessed.
- Main finding: Cross-border infrastructure plays a pivotal role in decarbonizing industries.
- A high-level map of transport options for energy and feedstock from changing sources in 2020-2030-2050.

Call for participation

A follow-up study is being prepared, broadening the scope from ammonia to other application areas of the chemical industry, such as methanol and ethylene. Based on the results of this, the consortium will also look into more industrial clusters. Petrochemical companies, energy suppliers, and chemical clusters in the ARRRA region are invited to participate in these follow-up studies.

Core project partners
Dechema, DVGW-EBI, VITO/EnergyVille, TNO

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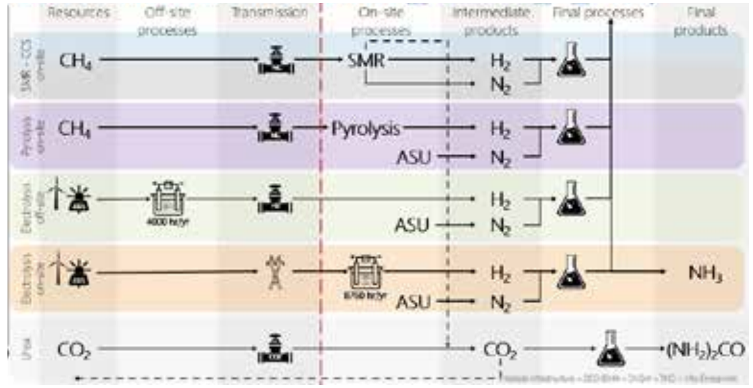

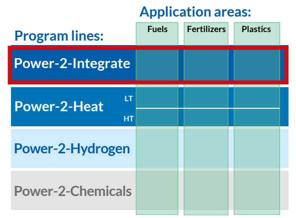

Power-2-Fuels value chain innovation

Context
To realize the targets of the Paris Climate Agreement, drastically greener modes of transport are needed. Electric vehicles can be considered the preferred solution for short distances and light vehicles (e.g. passenger cars, urban mobility concepts). E-fuels have been identified as a potential solution to make heavy duty transport (road, air, water) more sustainable. However, there is a need for more clarity about which e-fuels will be suitable for which modality, and about what is needed to shape such innovations throughout the value chain.

Objective
Enable market parties, knowledge institutes, and governments to take informed decisions about innovation strategies and/or investments around e-fuels.

Results
In terms of costs, the differences between the various e-fuels turn out to be relatively small; hydrogen is the most economical fuel to produce, but higher distribution and powertrain costs level out this advantage. To make heavy, long-distance transport more sustainable, a drastic increase in e-fuel production and associated infrastructure is needed.
This requires steps forward in R&D, production, infrastructure for distribution and fueling, vehicle adaptation, and supporting legal frameworks and regulations. Parties throughout the value chain need to join forces to achieve this.
The results of the Power-2-Fuels project have been published in the whitepaper *E-fuels: towards a more sustainable future for truck transport, shipping and aviation*.

Call for participation
The next phase of Power-2-Fuels is follow-up study CHAIN. This project looks at the international dimension of the transition to e-fuels in the period 2030-2050 and its consequences for large industrial clusters. Companies interested in contributing to CHAIN are invited to contact us.

Core project partners
SmartPort, TNO, Deltalinqs Climate Program, DMT Environmental Technology, EICB, Enviu, Port of Rotterdam, NLR, MKC, Port of Amsterdam, VIV

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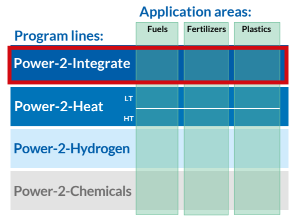

System Supply Chain Model

Context
The potential of the roles that sustainable energy carriers, such as ammonia and hydrogen, could play in the Dutch industry is growing. And with that grows the need to understand the distribution of costs and benefits throughout the global supply chains of these energy carriers.
It is unclear what the future sweet spots for production of chemicals will be globally and how the supply chains will evolve when new technologies mature. Accessible insights regarding the economics of supply chains are required to take well-informed decisions. This also allows for minimizing risks whilst developing individual and collective long-term plans. In addition, it supports establishing new strategic relationships with critical supply chain stakeholders.

Objective
Support strategic decision making of the industry, energy, and infrastructure sector by delivering an easy-to-use and expandable model. In this model, the most relevant features to compare international supply chains for renewable energy carriers (e.g. LH_2, NH_3, LOHC) are included.

Results
The scan of high-potential production locations provided insights on probable supply chain designs in the future.
In 2021, the capabilities of the model are extended even further.

Call for participation
Industrial companies interested in applying (and possibly further expanding) this model are invited to contact us.

Core project partners
VoltaChem Business Community, TNO

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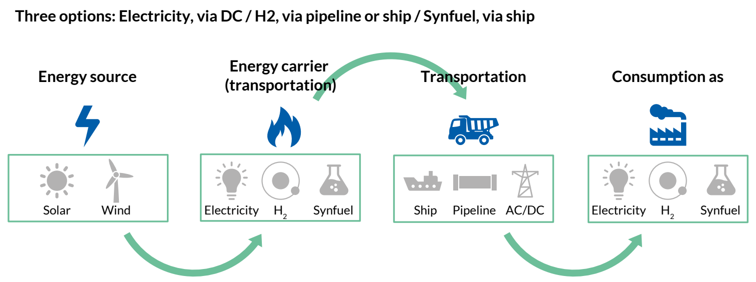

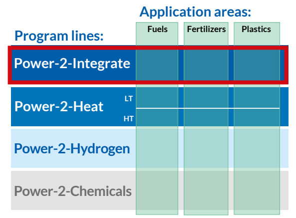

Critical Raw Materials

Context

In 2019, we found that realizing the 2050 "ambitious" hydrogen demand scenario for Europe (FCH JU, 2019) would require large amounts of Critical Raw Materials (CRM) such as iridium and platinum. In the case of iridium, more than the current global annual production (122%) of this metal would be required every year to maintain the hydrogen production facilities. The 2020 project identifies the most feasible technical strategies to mitigate this problem and assess which strategies will be the most impactful.

Objective

Identify and quantify strategies that could help reduce the amount of CRM used in AEL / PEM electrolyzer stacks to make ambitious hydrogen scenarios feasible for Europe.

Results

Iridium and platinum are required in very large quantities by the state-of-the-art technology. Cobalt and nickel are needed in smaller amounts, but there might be competition with other applications. The strategy of reducing CRM amounts (e.g. applying thinner layer) seems the most promising, but requires further research before it can be applied widely.

Call for participation

Industrial companies and equipment suppliers who would like to know how these findings may impact their business and what strategies are relevant for their specific situations are invited to reach out to us.

Core project partners
VoltaChem Business Community, TNO

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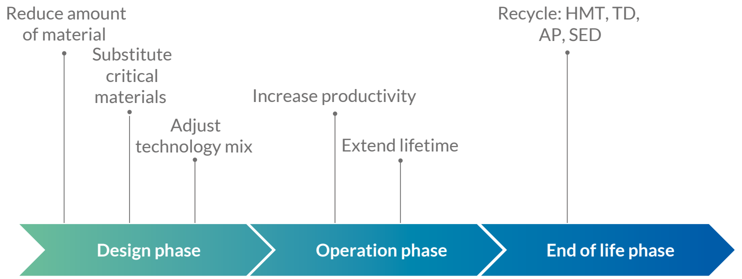

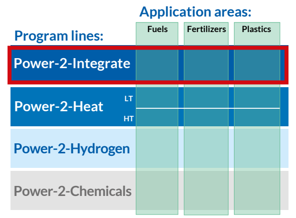

Merit order of electrification

Context

There is an urgent need to take action and reduce CO_2 emissions. Many decarbonization options are available to this end, several of which are centered on electrification and the use of renewable energy. While the Netherlands holds significant potential for developing wind and solar power capacity in the coming decades, the country is not expected to be self-sufficient by 2050. Locally produced renewable power should therefore be treated as a precious commodity and used in the best way possible, in this context in a way that maximizes the reduction of CO_2 emissions.

Objective

- Estimate and rank the CO_2 emission reduction potential (in $kgCO_2$ / MWhel) of different electrification options for the industry, transport, and building sector.
- Rank the CO_2 emission reduction potential (in $kgCO_2$ / MWh_{el}) of different electrification options for the industry, transport, and building sector.

Results

The largest emission reduction potential (in $kgCO_2$/MWhel) is achieved when renewable electricity is used to replace existing fossil fuel power plants, followed by the electrification of passenger vehicles and space heating in buildings. Industrial electrification shows a larger variance, with the largest potential for the electrification of steel using hydrogen-based Direct Reduced Iron and supplying renewable electricity to existing electrified process like Chlorine and Aluminum production.

Call for participation

Industrial companies and equipment suppliers are invited to review the methodology and suggest additional technologies for comparison. In addition, they are invited to reach out to us on how these findings may impact their business and what strategies are relevant for their specific situations.

Core project partners
VoltaChem Business Community, TNO

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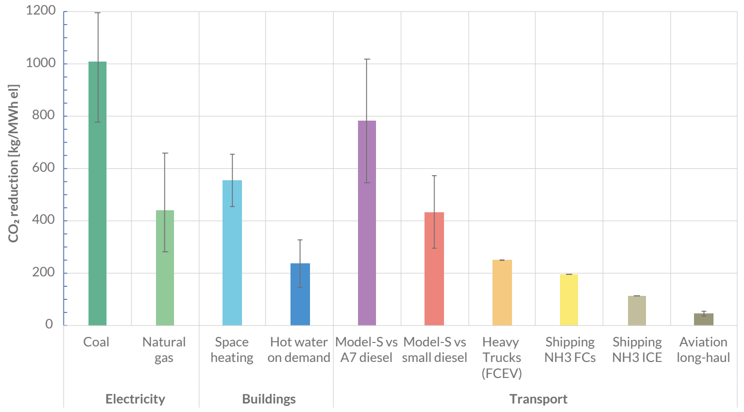


Power-2-Hydrogen

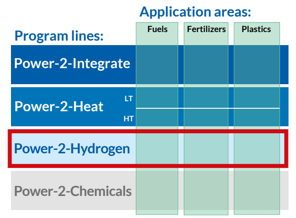
In the Power-2-Hydrogen program line we work on technology to produce green hydrogen from renewable energy and on further chemical conversion of hydrogen towards valuable chemicals (e.g. methanol, ammonia, formic acid). The main challenges we address in this program line are the development of low-cost electrolyzers, low-cost manufacturing and engineering, flexibility (e.g. load following, start-up/shutdown), and the development of financially attractive follow-up chemical conversions.

We focus on:

- **Use of renewable electricity** as energy source for direct chemical transformations via hydrogen, e.g. electricity from wind, solar, and hydro.
- **Use of renewable raw materials** (e.g. water, N2, and CO_2) as feedstock for chemicals & fuels production.
- **Improving the supply chain** through cooperation with component manufacturers.
- New concepts enabling the use of **mass fabrication technologies** (e.g. roll-to-roll manufacturing).
- Identifying **options for demonstration projects** for and with the chemical industry.
- **Developing the next-generation PEM electrolyzer technology** with leading industrial partners.

Power-2-Hydrogen Technology Roadmap

Short term (2017 - 2022)	Medium term (2022 - 2030)	Long term (2030 - 2050)
Electrolyzer concepts • Design of low-cost electrolyzer available; new components tested at bench-scale (TRL4) • Expand the application of existing knowledge into fields like new electrolyzer concepts • World-class facilities for lifetime testing and stack evaluation available and used to provide services to third parties	**Electrolyzer concepts** • Commercialization of low-cost electrolyzers • Improvement of existing electrolytes by advanced fabrication technologies • Replacing scarce materials by more abundant ones in the electrolyzer • Pilot plant demonstration next-generation PEM electrolyzer • Reduce the capital cost of electrolyzers to < 400 €/kWe	**Electrolyzer concepts** • Established industry focused on electrolyzer component manufacturing and system implementation • Electrolyzer plant based on advanced fabrication technologies • Commercialization of next-generation PEM electrolyzer • Reduce the capital cost of electrolyzers to < 300 €/kWe
Downstream conversion with CO_2 • One pilot completed for the production of chemicals/fuels (TRL6) • Develop cost-efficient alternative concepts for hydrogen-based feedstocks	**Downstream conversion with CO_2** • Commercialization of decentralized chemicals/fuels production (DME, methanol, or CH_4)	**Downstream conversion with CO_2** • Commercialization of centralized plants including integration with current assets
Conversion to ammonia • PoP new catalytic NH_3 process • Demonstration SoA technology (10MWe) • Commercialization of decentralized plants • NH_3 produced for 450 €/ton	**Conversion to ammonia** • Pilot of improved indirect NH_3 process • Commercialization of centralized plants including integration with current assets • NH_3 produced for 300 €/ton	**Conversion to ammonia** • Commercialization of improved indirect NH_3 process • NH_3 produced for 200 €/ton



Flagship Program Electrolyzer Industrialization

Context

First-generation PEM electrolysis (PEMWE) technology is progressing towards becoming a mature technology. Currently, the top-3 suppliers of large-scale PEMWE systems have tested their first-generation systems with a power greater than 10-20 MW and are focusing on scaling up their stacks to 2-5 MW as building blocks for hydrogen production on an industrial scale. Several projects in the 100 MW+ scale have been announced worldwide. Such projects will lead to cost reduction, from the current price level (1000-1200 €/kW) to a level where the technology becomes economically feasible at the GW scale (≤ 500 €/kW). At such volumes, with the aid of economics of scale, manufacturers can adopt semi/fully-automatic manufacturing and standardization, further reducing costs. However, to achieve target of < 2 Euros/kg hydrogen, further cost reduction is required.

Objective

High-performance 2nd and 3rd generation PEM electrolysis technology is developed together with key materials and component suppliers, focusing on novel materials and mass manufacturing technology. To achieve the required high stable performance at a reduced price and minimal scarce material consumption, innovations by the partners are integrated, interfaces are optimized, and also VoltaChem's own key technology is developed further. The 2nd generation electrolyzer addresses all major bottlenecks in PEMWE technology through innovations in components (membranes, catalyst materials, MEA fabrication, electrodes, etc.), and their integration in the existing stack design. A new innovative design (3rd generation) is targeting even further optimizations in performance, cost, and scarce material consumption required to achieve the GW scale targets.

Call for participation

Companies interested in working on novel materials and/or components for the 2nd and 3rd generation PEM electrolyzer can contact us about opportunities for participation.

Core project partners
Confidential

Milestones
- **2020: Set outline of the program; file patents of breakthrough technology**
- **2021: Launch of the program with international leading partners; high-level technology roadmap; optimized novel PEM stack components**
- **2022 and beyond: Next-generation PEM electrolyzer technology ahead of FCH JU roadmap**

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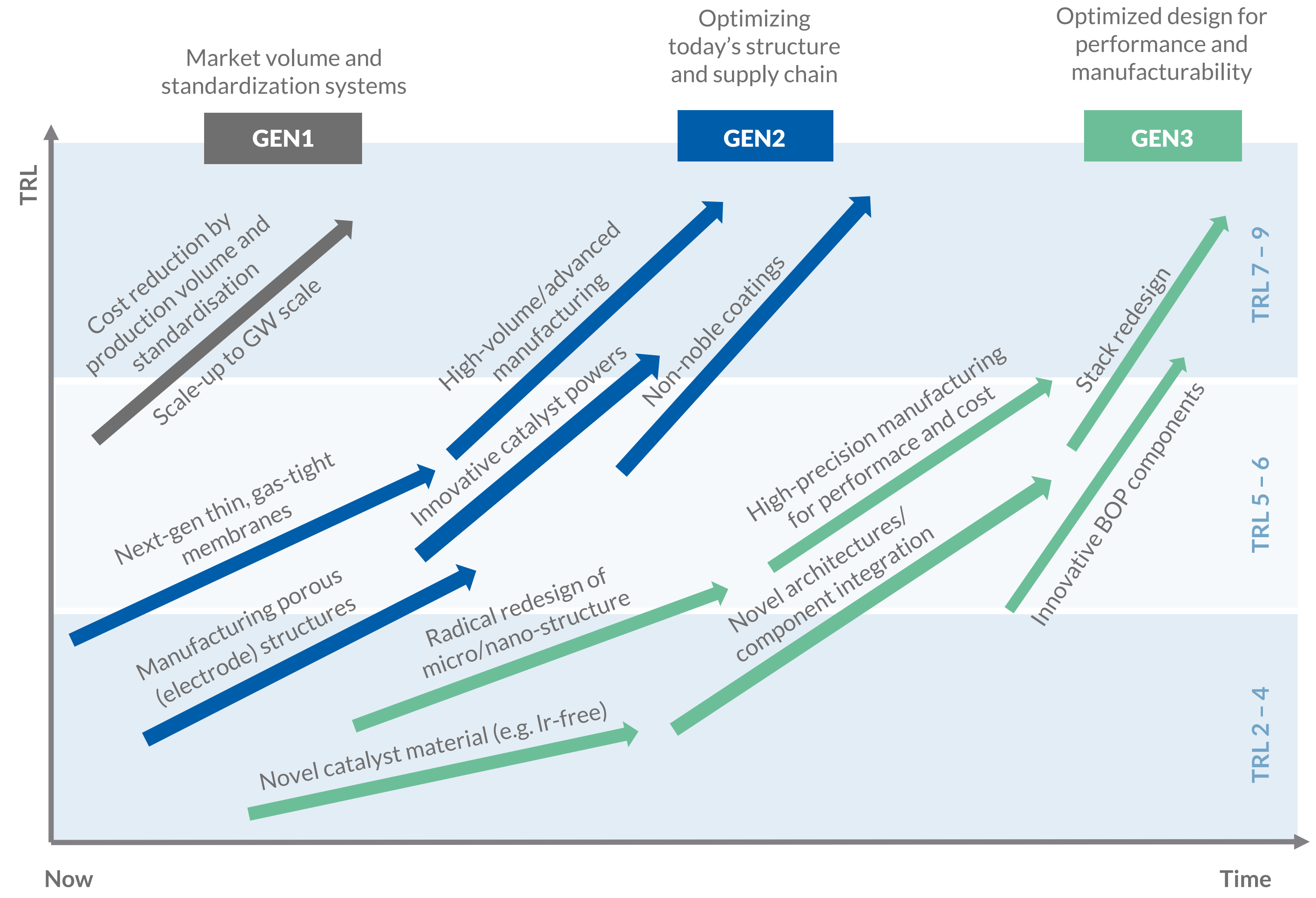

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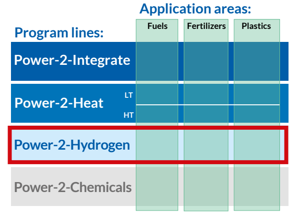

Income

Context
Converting electricity into hydrogen gas via electrolysis of water is seen as one of the most effective options for integrating a wide range of sustainable electricity sources into the energy system. However, electrolysis is still (too) costly; expensive materials are used to guarantee a sufficiently high performance and long life. In particular, the large-scale (GW) implementation of PEM Water Electrolyzers (PEMWEs) has been hampered by expensive components, chiefly among them the electrode/catalyst.

Objective
Active components in PEMWEs, including electrodes and catalysts that make more effective use of materials or use inherently cheaper materials, can make the greatest contribution to the cost reduction. The goal of the INCOME project is to design innovative electrode/catalyst systems to make it possible to achieve the target of < 2 €/kg hydrogen.

Deliverables
- Fabrication of innovative porous transport layer/catalyst layer/membrane system with ultra-low precious catalyst metal loadings.
- Optimization of the performance/durability of the aforementioned system to demonstrate approach towards technical targets.

Call for participation
Companies interested in collaborating on this topic can contact us, such as:
- Chemical suppliers interested in the development of novel catalyst precursors.
- Porous material suppliers.

Core project partners
TNO, Magneto Special Anodes, Hydron Energy

Milestones
2021: PEMWE anode electrode with 10-fold reduction in catalyst loading
2022: 1000 hours performance/durability benchmark against state-of-the-art cell

Contact persons
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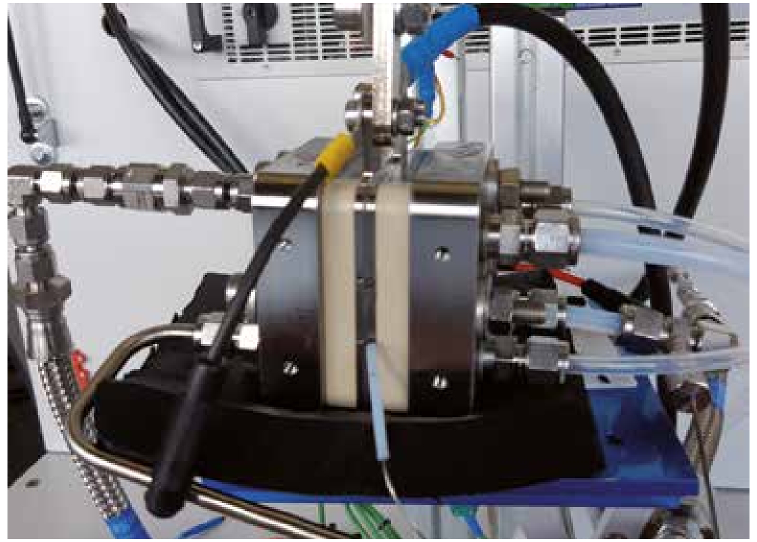

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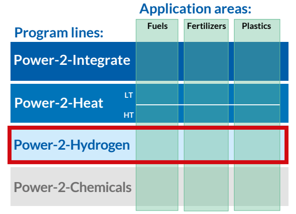

GigaWatt Scale Electrolysis

Context
Using hydrogen as an energy carrier in industry and for mobility requires scale. The ambition of the European Commission is to have 40 GW of electrolyzer capacity installed in 2030. This means electrolyzer systems need to scale up from 5-10 MW current state-of-the-art demo projects to fully functional GigaWatt scale hydrogen factories. To reduce the cost of kickstarting a hydrogen infrastructure, an optimal design of plants on the GigaWatt scale is needed. To come to such an optimized design, it is necessary to look beyond the hydrogen plant itself. The design should be considered as part of a larger system, including the site-specific characteristics and the integration with large renewable energy generation such as off-shore windfarms.

Objective
The objective of the GigaWatt Scale Electrolyzer project is to design a large-scale electrolyzer plant with a hydrogen cost that is competitive with fossil-based hydrogen including CCS by integrating scientific, business, and engineering progress. This includes the required infrastructure and the hydrogen demand at potential locations.

Deliverables
- 2020: Baseline design for both large-scale Alkaline and PEM electrolyzer systems.
- 2021: Advanced design based on 2030 technology.

Call for participation
Industrial companies interested in developing GW scale electrolysis systems for green hydrogen generation can contact us.

Core project partners
ISPT, Nouryon, Yara, Ørsted, Gasunie, Dow, OCI, TNO, Imperial College, Utrecht University, Eindhoven University of Technology

Milestones
2021: A public version of the advanced GigaWatt scale design will be published

Contact persons
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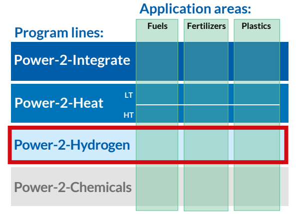
High-temperature Solid Oxide Electrolysis



Context

Solid Oxid Electrolysis (SOE) is a technology with a large potential to accelerate industrial electrification because of its high conversion efficiencies and the possibility for direct electrochemical conversion of steam, carbon dioxide, or both, into green hydrogen, carbon monoxide, or syngas respectively. SOE technology can be thermally integrated with a range of chemical synthesis processes, enabling the re-use of captured carbon dioxide and water into green fuels and chemicals, like gasoline, methanol, and ammonia, at even higher efficiencies.

Objective

The main development objectives for SOE are lifetime extension, cost reduction, and scaling up of cells and stacks, as well as techno-economic and business case analysis on industrial integration options. The translation of the technology towards high power levels (> 1 MW) is crucial for the application of the SOE technology on a large industrial scale. The manufacturing of SOE single cells with planar dimensions > 20 x 20 cm^2 and higher active surfaces based on more complex cell design is a necessary step towards MW-scale SOE systems.

Deliverables

- Fabrication of multi-layer ceramic cells.
- Demonstration of generation of syngas for methanol synthesis from water and carbon dioxide.

Call for participation

- (New) material or component suppliers and system integrators who are or want to become active in the field of SOE.
- Industrial end users who are interested in piloting and demonstration projects focused on site integration.

Core project partners
FCH JU NewSOC project consortium, consisting of 16 major European industrial and research partners

Milestones
2021: Solid Oxide Cell capable of CO_2-electrolysis with high C-resistance
2021/2022: Scale-up of Solid Oxide Cell dimension to 30x30 cm^2

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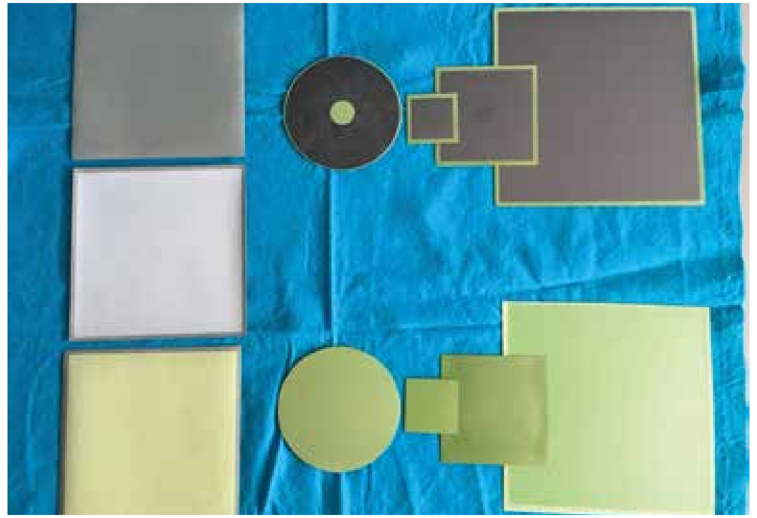
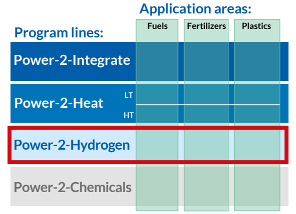


HySpeedInnovation



Context

The European Hydrogen Strategy and several national hydrogen strategies of EU member states set clear, yet ambitious goals when it comes to installed electrolyzer capacity. But much remains to be done before we can produce this clean energy carrier on an industrial scale and at an acceptable cost. Europe has good trump cards to achieve this. At the initiative of VoltaChem founding partner TNO, a number of leading European Research and Technology Organizations (RTOs) have launched proposals to strengthen cooperation aiming to take electrolysis up a notch, fast

Objective

In order to enable EU policy makers, governments, and knowledge institutes to take the right approach when it comes to meeting the targets from the hydrogen strategies, the RTOs decided to write a position paper: *HySpeedInnovation, a joint action plan for innovation and upscaling in the field of water electrolysis technology.*

Results

The position paper describes the upscaling challenges that lie ahead and how the knowledge institutes can come together to tackle these challenges in order to make Europe a leader in the field of electrolysis. In order to reach the 2x40 GW renewable hydrogen targets from the EU Hydrogen Strategy, a strong acceleration of the technology learning curve is needed. Recommendations to achieve this are:

- Connecting the hydrogen research labs to build a stronger R&D ecosystem.
- Setting clear performance and environmental standards to build out our European position as electrolyzer technology leader.
- Monitoring performance of subsidized pilots and next-generation data sharing.

Call for participation

RTOs and industrial partners who are interested in collaborating on these topics are invited to join and support the HySpeedInnovation Initiative.

Core project partners
Fraunhofer (IFAM and ISE), Forschungszentrum Jülich (IEK14), SINTEF, CEA, TNO

Milestones
2020: HySpeedInnovation paper released
2021: Further develop roadmap and implement actions

Contact persons
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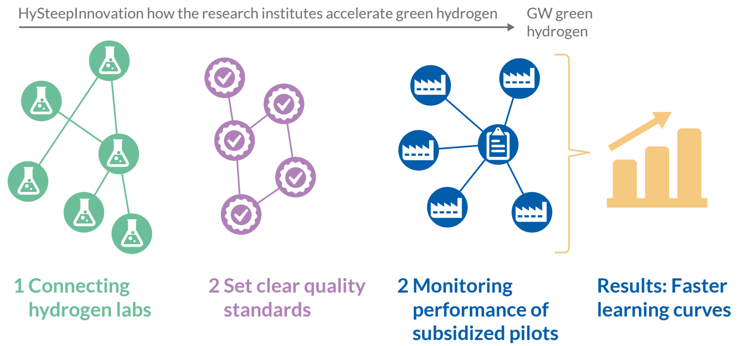

VOLTA CHEM
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Power-2-Chemicals

In the Power-2-Chemicals program line we work on the direct electrosynthesis of chemical building blocks and higher value products using conventional and sustainable feedstock (e.g. CO_2, biomass-derived). The main challenges that are addressed are the development of electrochemical routes, reducing capital costs for electrochemical cells, increasing energy density and selectivity, choosing & using catalysts, and downstream processing.

We focus on:

- **Electro-organic synthesis** using electro-oxidation and electro-reduction as means to efficiently convert renewable feedstock (e.g. bio-based furfural, HMF, alcohols) to key chemical building blocks.
- **Electro-reduction of CO_2** to C1 building blocks, focusing on Formic Acid, CO, and Ethylene as key products.
- **Paired electrosynthesis** in which product is produced at both cathode and anode of the electrochemical cell.
- Alternatives for electrochemistry in conversion with electricity as energy source, e.g. **photochemistry** and **plasma chemistry**.

Power-2-Chemicals Technology Roadmap

Short term (2017 - 2022)	Medium term (2022 - 2030)	Long term (2030 - 2050)
Bio-based feedstocks • Expand toolbox with c-c coupling, electro-oxidation, and electro-amination • Pilot demonstration of FDCA and lactic acid production • Electrochemical test street from fundamentals up to pilot demonstration • Paired electro-synthesis proof of concepts	**Bio-based feedstocks** • Commercialization of FDCA and lactic acid production • Pilot plant demonstration for paired electro-synthesis • Development of new chemistries and reactor concepts • System design for integration with bio-refinery plants	**Bio-based feedstocks** • Established industry in the Netherlands focused on electrochemical engineering and system implementation • Commercialization of paired electro-synthesis processes
CO_2 conversion • Catalyst screening and selection • System evaluation • Evaluation of integration of CO_2 capture with electrochemical conversion • CO hydrocarbons, formic acid, oxalic acid	**CO_2 conversion** • Pilot plant demonstration (CO, FA) • Integrated CO_2 capture pilot for electrochemical CO, FA, OA production • Concept development for paired electro-synthesis system • 2nd generation co-electrolysis lab demonstration • CO produced for 500 €/ton	**CO_2 conversion** • Commercialization of decentralized plants • Commercialization of centralized plants including integration with current assets • CO produced for 400 €/ton • Current density target
Ammonia • Route identification and scouting	**Ammonia** • Proof of principle	**Ammonia** • Demonstration

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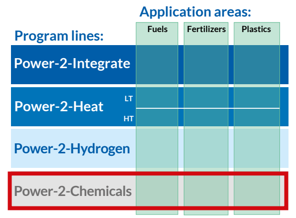

Flagship Program Integrated CO_2 capture and electrochemical conversion

Context

A chemistry based on CO_2 as feedstock will open up new routes for chemicals production and valorization of CO_2. From this wide landscape of possibilities, our VoltaChem team dedicated its efforts to identifying and pursuing some of the most promising business cases.

The approach that we are taking is the integration of novel technologies in the development of a technological chain from a CO_2 emitter and utilizing renewable electricity to a versatile chemical building block.

Combining the expertise on the CO_2 capture technologies and the electrochemical CO_2 utilization technology, we defined a platform technology based on the CO_2 capture directly integrated with the electrolysis to produce chemical building blocks. This technology has the potential to decrease both the capital costs by reducing the number of operational units as well as the operational costs for the process as compared to the decoupled CO_2 capture and CO_2 conversion.

Objective

The goal of this Flagship Program is to develop breakthrough technologies that will make it possible to integrate CO_2 capture and electrochemical conversion processes. We will start with the "simple" molecule formic acid (the 'red' route) and based upon experience and knowledge gained will continue to develop other chemicals for the chemical industry (the 'yellow' route).

Core project partners
Confidential

Milestones
2020: Set outline of the program; filed patents of breakthrough technology
2021: Launch of the program with international leading partners; deliver high-level technology roadmap
2022: Evaluate technical feasibility of the main selected business cases
2023: Proof of system in the Fieldlab for one of the selected business cases
2025: Demonstration under relevant conditions (TRL 5) of one of the selected business cases

Contact persons
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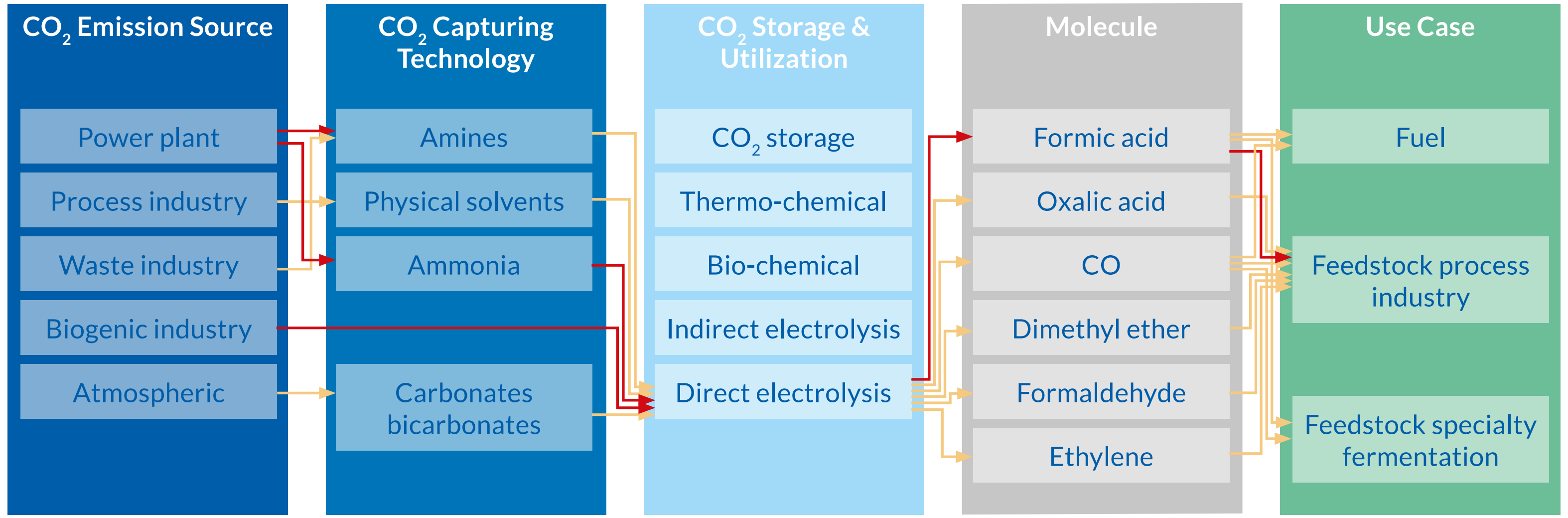
Erwin Giling



Call for participation

To develop this Flagship Program we would like to work with:

- Technology developers and equipment manufacturers interested in developing electrochemical processes:
  - Anode, cathode, and electrolyte manufacturers and producers.
  - Electrochemical reactor developers.
- Technology developers with a focus on CO_2 capture processes.
- Companies active in the process industry and companies in terested to develop fermentation processes.
- CO_2 emitting companies (power generation, process industry, waste industry).

VOLTA CHEM
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Program lines:	Application areas: Fuels	Fertilizers	Plastics
Power-2-Integrate			
Power-2-Heat LT HT			
Power-2-Hydrogen			
Power-2-Chemicals			

Electrochemical DME & Formic Acid production from CO_2

Context

Partners from the 2 Seas region joined forces from 1 July 2018 in the interregional project “Electrons to high-value chemical products” (E2C). The cross-border project focuses on the conversion of CO_2 into chemicals and fuels, using renewable electricity. The aim of this consortium - consisting of 7 research partners and 29 industrial observers from the Netherlands, Belgium, France, and the United Kingdom - is to accelerate the development and implementation of the Power-2-X and CO_2 conversion technology. The project has been granted by the Interreg 2-Seas Program and will run for 3.5 years. It will result in two pilot installations demonstrating the possibilities of Power-2-X technologies.

Objective

Stimulate and support companies, especially SMEs, to further invest in the development and implementation of innovative Power-to-X technologies. And by doing so, accelerate the transfer of innovation to the market while focusing R&D on one of the major societal challenges facing the 2 Seas region today.

Deliverables

The main deliverable will be the establishment of a European Centre of Excellence for the development of Power-to-X technologies, which currently does not exist in the EU. Two pilots will be realized for the Centre, demonstrating technology for the conversion of CO_2 to chemicals using green electricity.

Call for participation

Industrial companies and equipment suppliers are invited to join the observer partner group.

Core project partners
VITO, Delft University, University of Exeter, University of Sheffield, University of Lille, University of Antwerp, TNO, Industrial observer partner network, INTERREG 2-SEAS

Milestones
2020: Electrochemical bench-scale installations have been realized
2021: Commissioning of Power-2-FA pilot and Power-2-DME pilot installations
2022: Research results from pilots

Contact persons
Willem Frens
Erwin Giling

Program lines:	Application areas: Fuels	Fertilizers	Plastics
Power-2-Integrate			
Power-2-Heat LT HT			
Power-2-Hydrogen			
Power-2-Chemicals			

Paired electrosynthesis of maleic, valeric and adipic acid

Context

Process industries in the EU are at a tipping point and now have the opportunity to strengthen and expand their competitive position by moving to electrochemical biomass as a feedstock. This will not only lead to a low carbon footprint, but also has advantages over thermochemical processes. Such advantages include higher selectivity and elimination of the harsh operating conditions required for conventional processing. These advantages have led to a growing interest in the electrochemical processing of bio-based feedstocks and new innovative chemistries, but scale-up of these technologies, as done in this project, is still a hurdle that needs to be overcome. This H2020 project Perform started in 2019.

Objective

The construction of a highly flexible pilot plant incorporating advanced integrated electrochemical technologies which allow for, among others, the valorization of biomass and efficient use of fluctuating electricity supplies in the production of performance materials. Two showcase processes will demonstrate how electrochemistry will lead to a highly improved position of European chemicals companies through increased process selectivity, low carbon footprints, and decreased overall costs.

Results

- Advanced electrochemistry materials, electrodes, electrolytes, and reactors.
- Advanced processes and system integration.
- TRL6 pilot with two showcases.

Call for participation

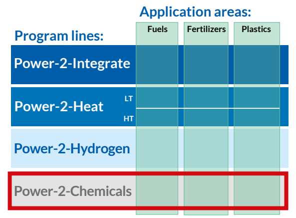
The project is closed but interested industrial or equipment parties can reach out to get connected.

Core project partners
VITO, Avantium, INSTM, HYSYSTECH, Vertech, SI Europe, Perstorp, Radici Chimica, AVA Biochem, Novamont, University of Hohenheim, TNO, EC-H2020

Milestones
2020: Single cell electrochemical reactors constructed
2021: Integral bench-scale system developed and tested
2022: Perform pilot platform commissioned and tested

Contact persons
Reinier Grimbergen
Erwin Gieling

Paired electrochemical CO_2 conversion and chlorine production



Context

Electrochemistry is a powerful method of synthesizing organic products, and is ideal for decentralized plants. However, in most cases, the chemistry that occurs at the counter electrode yields a waste product, which holds little economic. To overcome this issue, we are developing the concept of paired electrolysis, where useful products are produced at both electrodes without consuming more electricity. The paired CO-chlorine electro-synthesis concept involves the electro-oxidation of HCl together with the electro-reduction of CO_2, giving rise to valuable chemicals in a highly efficient manner from essentially waste materials.

Objective

The goal of the e-Couch project is to develop a continuous electrochemical process (paired electrolysis) using waste materials (CO_2 and HCl) to produce two valuable chemical products simultaneously by combining two large electrochemical processes: CO_2 reduction to CO and chlorine production from HCl in one electrochemical reactor. This process will be demonstrated up to TRL4.

Deliverables

- Investigation of performance of catalysts and optimization of reaction conditions.
- Integration of both reactions in a single electrochemical cell.
- Demonstration of a bench-scale continuous paired electrolysis of CO_2 and Cl.
- Evaluation of economic impact.

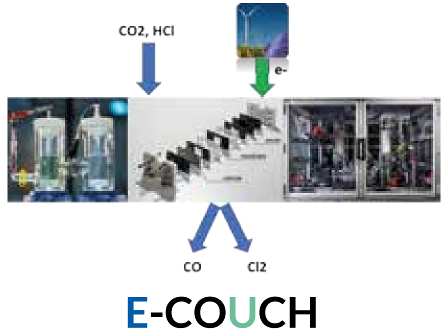
Call for participation

Interested industrial companies are welcome to participate in the development as end user.

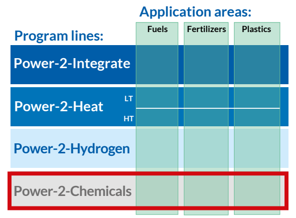
Core project partners
Avantium, University of Amsterdam, TNO, RVO

Milestones
Accomplished: Design and optimization individual and paired routes
Accomplished: Electrochemical reactor design
2021: Conceptual process design and economics, final report

Contact persons
Willem Frens
Erwin Giling



Integrated biogenic CO_2 capture with electrochemical conversion to oxalic acid



Context

One of the emerging ways of utilizing CO_2 is based on the conversion of CO_2 into value-added chemicals produced via an electrochemical reaction. The Bio-cel project focuses on the integrated capture and electrochemical conversion of biogenic CO_2 to oxalic acid. As around 2 kg of CO_2 is consumed per kg of oxalic acid, this process will help reduce the CO_2 emissions of fossil-based production methods.

Objective

The goal of the Bio-cel project is the development of new electrochemical processes and reactor concepts for integrated capture and conversion of biogenic CO_2 towards oxalic acid. Focus is on the development of new electrolytes and the scale-up up of the electrochemical flow reactor in terms of current density and production rate. The CO_2 mitigation achieved with this approach can become a major contribution towards reaching climate goals.

Deliverables

The overall result of the project will be to deliver a test setup comprising of a capture unit, an integrated pressurized reactor, and a solid - liquid separator. Additional results include the data from a series of experiments evaluating combined solvent-electrolyte solutions, a computer model of an elevated pressure CO_2 electrolyzer, and the results of an environmental and economic analysis of a full CO_2 value chain with oxalic acid as the added-value product.

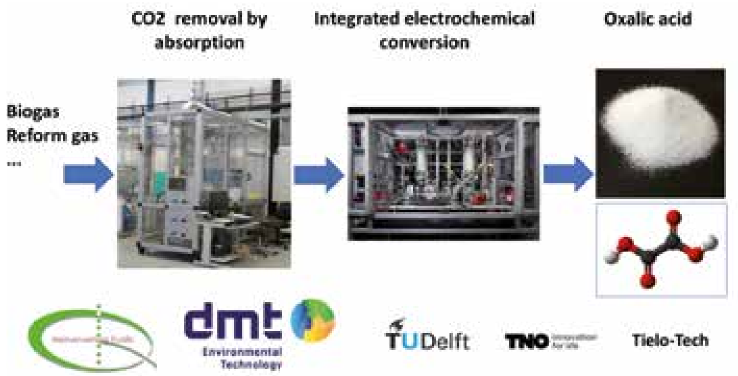
Call for participation

Interested industrial companies are welcome to participate in the development as end user.

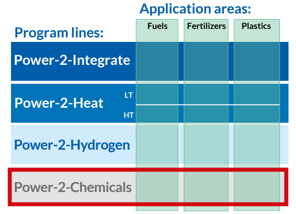
Core project partners
TU Delft, DMT, Mestverwerking Fryslan, Tielo-Tech, TNO, RVO

Milestones
2020-2021: New solvent/electrolytes developed
2021: – CO_2 electrolyzer models developed
– Test setup with integrated capture unit and pressurized CO_2 electrolyzer

Contact persons
Willem Frens
Erwin Giling



Plasma chemistry for CO_2 free production of hydrogen and ethylene from methane



Context
The chemical industry drastically needs to reduce GHG emissions. Plasma pyrolysis is a promising innovative electrical conversion technology for methane valorization and nitrogen activation. It will enable both the reduction of process emissions and the use circular feedstock.

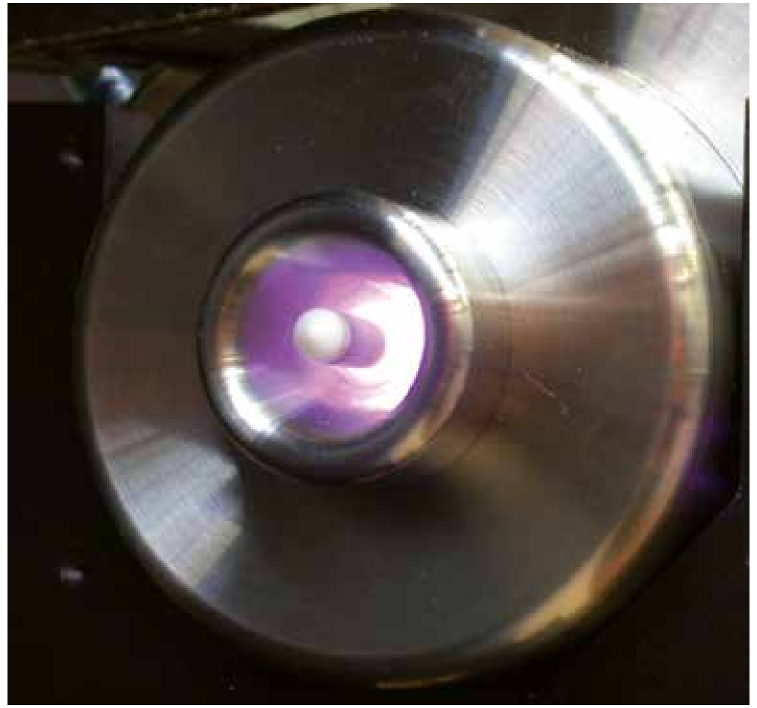
Objective
Our long-term objective (2030-2050) is commercialization of plasma technology for the chemical industry, and commercialization of high-tech plasma equipment. In the short term (2017-2022) we focus on determining the feasibility of plasma technology for the chemical industry, building an ecosystem of companies and knowledge partners, and realizing a plasma lab at Brightsite (Chemelot). We will also establish a baseline process for methane plasma pyrolysis based on existing technologies (Hüls), followed by hydrogenation. In the medium term (2023-2030) we will work on optimizing the plasma pyrolysis processes based on methane, develop high-tech plasma equipment, realize the first demo plant, and design criteria for the first large-scale commercial plant.

Deliverables
- 2021: Techno-economic analysis of plasma technology, joint commitments for development and scale-up of projects, start design & construction of plasma lab facilities.
- 2022: Brightsite plasma lab fully operational at Chemelot.

Call for participation
Industrial companies interested in the development of plasma technology, equipment, or facilities can contact us.

Core project partners
TNO, Sitech, Brightlands Chemelot Campus, Maastricht University/Differ, Chemelot site users

Contact person
Reinier Grimbergen



Collaboration models

1 Business community membership
Exclusive discussion group, roadmap updates, high-level results, and (inter)national events.

2 Multi-annual shared R&D
Pre-competitive R&D within a collaborative program with a duration of 2-4 years. Participants get rights to the results and determine the scope of the program along the way.

3 Co-funded R&D
Pre-competitive linear development; small projects with predefined scope/time/budget. Participants get certain rights to the results and scope is determined upfront.

4 Bilateral project (consultancy, contract R&D)
Exclusive bilateral consultancy or contract R&D project with predefined scope/time/budget.

5 Subsidized research collaboration
VoltaChem participates in publicly funded consortium projects (e.g. RVO, EU) and fundamental research programs (e.g. NWO). The funding rules of the specific programs determine the rights to the results and the scope is determined upfront by partners together.

Our facilities

At VoltaChem we have various state-of-the art lab facilities at our disposal, with unique equipment.

TNO labs Delft

Research facility for small- to medium scale R&D on electro-chemical conversions. Equipment: small-scale electrochemical test stations, bench-scale low pressure electrochemical setups, high-pressure CO_2 electroreduction test rig for batch and continuous operation, single cell reactors/electrolyzers, stacks, analytical equipment, processing-purification and separation units, and much more.

TNO labs Petten (Faraday lab)

Hydrogen research facility, small- to medium scale R&D on PEM, SOE, and alkaline electrolysis. Small cell research, screening, and validation up to 50 KW, 500cm^2 single cell area. Equipment: electrolyzer test stations, hydrogen separation and conversion long-term test rig, high-pressure conversion test rig, and much more.

External facilities

Hydrohub MegaWatt Test Center Groningen

Fieldlab Industrial Electrification Rotterdam

Brightsite Plasma Lab Geleen

Our current members and partners

Process industry

Equipment supply & licensors

Energy sector

Policy, knowledge and industry organizations

Join our VoltaChem Program

Do you want to find out more about our Shared Innovation Program VoltaChem and how your company can participate and benefit? Please contact us!

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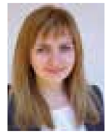
Scientist technological value chain integration



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Scientist novel business models and financing

Octavian Partenie
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Leonie Beekman
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Lead scientist Power-2-Hydrogen

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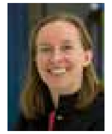
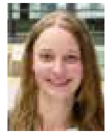
Frans van Berkel
Scientist Solid Oxide Electrolysis

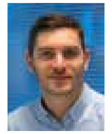


Claire Ferchaud
Scientist Solid Oxide Electrolysis



Maartje Feenstra
Scientist Solid Oxide Electrolysis integration

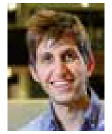
Earl Goetheer
Lead scientist Power-2-Chemicals



Roman Latsuzbaia
Scientist Electrochemical Reactor and Process Development

Anca Anastasopol
Scientist electrochemical engineering

Elena Perez-Gallent
Scientist electrochemical CO_2 conversion



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Francesc Sastre
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Let's energize innovation together!