

Public progress report ECHOED project
17/02/2025 – 17/02/2026



Publication date: 13-03-2026

1. Project Information

Dit project is uitgevoerd met behulp van subsidie van het Ministerie van Economische Zaken en Klimaat, landelijke regeling EZ-subsidies, Topsector Energie, uitgevoerd door de Rijksdienst voor Ondernemend Nederland (RVO). De specifieke subsidie voor dit project betreft MOOI-subsidie ronde 2024.

Data project

Project number	MOOI324034
Project title	EleCtrically Heated nOvel rEactor Development
Coordinator and partners	TNO, NEM, TU Delft, TU Eindhoven, Ecomatters, Hybrid Catalysis, Ambrell, Alliander, TotalEnergies OneTech Belgium
Project period	17/02/2025- 17/02/2026

Contact- and availability rapport

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2. Background and objectives

Background

Today the chemical industry is struggling to become climate neutral and circular. According to the Dutch climate agreement (MMIP6), the industrial sector must be climate neutral and at least 80% circular by 2050. As energy and raw materials are intertwined in the process industry, process electrification and reverse water-gas shift (RWGS) technology implementation are poised as attractive solutions for such challenges.

Endothermic reactions i.e. RWGS are largely representative of the processes in the chemical industry which is one of the largest CO₂ emitters in Dutch industrial landscape. RWGS is a promising technology to convert CO₂ and green H₂ into synthetic liquid fuels and industrial feedstock, promoting circularity and a business case for captured carbon and optimal use of green H₂. RWGS reactor offers a predominant route for CO₂ conversion into synthesis gas for synthetic liquid fuels and industrial feedstock. Electrification of RWGS contributes to the circular CO₂ ambitions laid down in MMIP6. Furthermore, the proposed project fits perfectly in MMIP 8 – Maximum electrification and radically new processes.

Objectives

The objective of the ECHOED project is to showcase direct electrification and carbon circularity of chemical processes together with flexibility of operation and prepare for a first commercial demonstration in a follow-up project led by industry partners. ECHOED will pilot an electrically heated RWGS reactor on lab scale based on the learnings from the technology developments of its predecessor projects (THOR, SFINCS and SUBLIME) funded under TSE O&O schemes. The ECHOED project will bring two developments together, electrification of high temperature processes and RWGS reactor development, via multidisciplinary stakeholders approach i.e. bring knowledge from various partners.

Consortium partners

The project is carried out by a consortium of 10 partners: TNO, NEM, Ambrell, Hybrid Catalysis, Ecomatters, TU Eindhoven, TU Delft, VNCI, Alliander, and TotalEnergies OneTech Belgium.

3. Results

Result 1: e-RWGS modelling and design evaluation

Activities

Result 1, reactor modelling and design evaluation, focuses on the chemical reactor modelling, catalyst selection, heat transfer modelling, CFD flow modelling, basic RWGS reactor design, and KPI's definition and reactor design evaluation. This study investigates and compares four heating technologies for the design and expected performance of an e-RWGS reactor: resistive heating, radiative heating, inductive heating, and molten salt heating.

Results

Through a series of workshops, both in person and online, the design specifications, operating conditions (reaction temperature, reaction pressure, and catalyst selection), and preferred reactor configurations for scaled-up implementation have been established for the different heating technologies (see Figure 1).

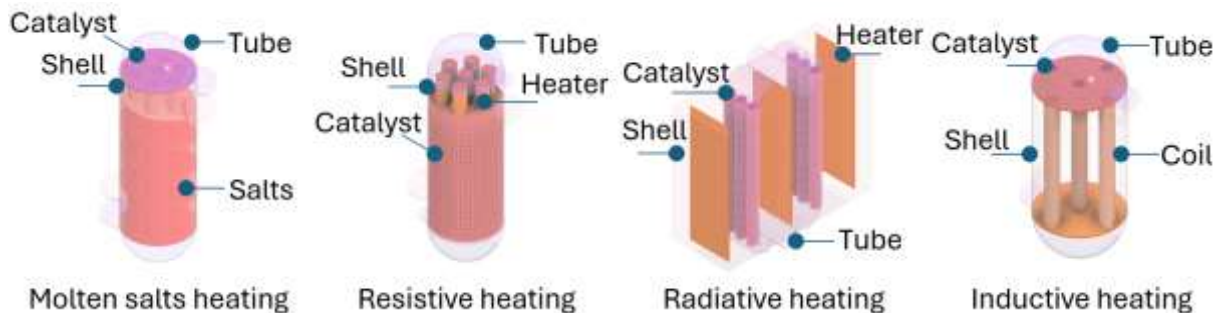


Figure 1. Schematic of the selected configurations for the e-RWGS reactor using different heating technologies, viz., molten salt, resistive, radiative, and inductive heating.

A summary of the most important specifications is provided below:

- The production capacity is set at 35 kton/year CO₂ (biorefinery CO₂ point source).
- The feed H₂:CO₂ ratio should be approximately 2.25:1 (suitable for Fischer-Tropsch synthesis), combined with gas preheating.
- The investigation is restricted to “surface heating” concepts.
- A packed-bed concept is preferred, with an expected tube diameter of approximately 5 cm and a length exceeding 5 m.
- Two temperature regimes will be considered and compared:

Option 1: Low temperature (~450 °C):

Typically involves a selective catalyst with staged cooling to remove water, combined with interstage heating. The main challenges are the low single-pass conversion and high methane selectivity.

Option 2: High temperature (~900 °C):

Typically involves a non-selective catalyst in a single-stage reactor with internal heating. The main challenges are effective preheating and integrating electrical heating into a high-temperature, high-pressure reactor vessel.

- The catalysts for the above two options are designed and evaluated: a) CsFeCu/Al₂O₃ is highly active for reverse water gas shift reaction at 550 °C, while its CO selectivity is limited due to the CO₂ methanation side reaction. Moreover, maintaining stable activity is

challenging due to coke formation; b) $\text{KCO}_3/\text{Al}_2\text{O}_3$ catalyst demonstrated both high activity and CO selectivity with CH_4 concentrations remaining below 0.04% between 800 to 900 °C.

- The optimal operating pressure is expected to be around 15 bar, balancing reduced coking and reduced methanation ($\text{CH}_4 < 5 \text{ vol.}\%$ in the product gas). Note that 10 bar is the minimum pressure required for CO_2 and H_2O removal in a knock-out vessel with energetic integration of the knock-out vessel and condenser.
- For induction heating concepts, the operating frequency and coil design are determined by the reactor design.

Bottlenecks

Several technical bottlenecks may arise for the different electrically heated reactor concepts:

- **Molten salts reactor:**

- iii) Nitrate and carbonate salts are recommended for low-temperature RWGS based on OPEX and CAPEX KPIs; however, achieving high CO_2 conversions is challenging due to limited catalyst activity at low temperatures.
- iii) Product quality may be adversely affected by increased methane formation at low temperatures.
- iii) Catalyst and salt lifetimes may be critical because of carbon deposition on the catalyst and potential salt decomposition.

- **Resistively heated reactor:**

Heat-transfer limitations between the heating-cartridge surface and the catalyst bed are significant; thermal efficiency is strongly affected when the spacing between heating cartridges is large (for surface-heating concepts).

- **Radiatively heated reactor:**

To avoid electrical breakdown, a relatively large distance must be maintained between the radiative sheet and the reactor tubes. Consequently, the radiative surface must operate at a much higher temperature than the reactor tube to achieve the required heat flux.

- **Inductive reactor:**

- ii) Overall thermal efficiency is strongly influenced by coil cooling, particularly if heat from the cooling system cannot be effectively recovered.
- ii) The spacing between coils must exceed the outer diameter of the coils to prevent electromagnetic field interference of neighbouring coils.

The distribution of eddy currents in large-scale 3D workpieces is not yet fully understood, which may impact overall energy efficiency.

Application perspective

Each of the four heating techniques has distinct advantages and limitations, and all are suitable for large-scale, high-pressure (10-30 bar) RWGS operation. At very high temperatures (e.g. ~900 °C), molten salt heating becomes challenging, while resistive heating using cartridges achieves lower surface temperatures than radiative and inductive heating. Radiative heating requires careful control of the spacing between the heating elements and reactor tubes to prevent electrical breakdown, whereas the energy efficiency of inductive heating can be strongly influenced by coil cooling requirements and workpiece design. Overall, resistive heating offers advantages in energy efficiency and heat management but is limited by heat transfer into the packed catalyst bed, at least for surface-heating concepts. A detailed computational study is currently underway to quantify the identified advantages and limitations and to compare the performance of the different heating technologies for an RWGS reactor.

Result 2: e-RWGS development and testing

Activities

Main activities past period have been the coordinating with R1 in order to prepare for the development and testing of a 10 kW scale e-RWGS reactor.

Results

No results yet.

Bottlenecks

NA

Application perspective

NA

Result 3: Radiative heating

Activities

R3.1 Material selection, design and TRL 4 testing of radiative electric heating elements.

Metallic heating elements are being developed in collaboration with TNO and manufactured by NEM. Target design parameters: heat flux @ 150 kW/m², average surface temperature of 1000-1200 °C and supply voltage of 6 kV. TNO has executed material compatibility analyses with SEM/EDX, to study the chemical interaction between the metallic conductor wires and the non-metallic support material.

Ceramic heating elements are being developed, manufactured and TRL3 tested in collaboration with an applied science institute, outside of the consortium. Target design parameters: heat flux @ 150 kW/m², average surface temperature up to 1400 °C, and supply voltage up to 36 kV.

The metallic heating element are being tested at TRL4 level at a 3rd party lab, outside consortium. Additional TRL4 testing capacity for both metallic and ceramic heating elements is being developed at TNO Carnot lab.

R3.2 Design and manufacturing of a 800 kW radiative electric heater prototype

Firstly, a basic process design is being developed under Result 1, for a full scale, industrial RWGS reactor, electrically heated by radiation elements, with support/input from Result 3. The design capacity of this full-scale reactor is not the 100 MW as per project plan, but already downscaled to a more realistic (approx.) 1 MW (see Result 1). Also, the RWGS reactor requires a much lower heat flux (5 kW/m²) from the radiation elements than the target design heat flux of 150 kW/m².

Then, the full-scale reactor design will be scaled down to a 800 kW electrical radiative heater prototype, for TRL6 testing of the radiative heating concept under R3.3, excluding the endothermic RWGS reaction. The heat flux though, will be scaled up to the original 150 kW/m² target, to validate the heater also for applications requiring significantly higher heat fluxes, like Ethylene cracking.

R3.3 Demonstration of the 800 kW heater prototype

Design and construct a -green field- test loop for the 800 kW electrical heater prototype at TNO - FLIE (Field Lab for Industrial Electrification).

Results

R3.1 Material selection, design and TRL4 testing of radiative electric heating elements.

Metallic heating elements: TNO material compatibility analyses have shown that pre-treatment of the conductor wires is required to stabilize the materials for long term, high temperature operation. TRL4 testing has confirmed successful, short time operation (hours) reaching heat fluxes of 100 kW/m² and surface temperatures up to 1000 °C, on low voltage (600 V) power supply. Further design updates and follow up testing in 2026 will aim on long term operation, increased surface temperatures and breakthrough testing at medium voltage.

Ceramic heating elements: material selection done, lab scale TRL3 testing successfully completed on test specimen, with surface temperature @ 1200 °C, on low voltage power supply. Contract negotiations are initiated for next step, for manufacturing of 30 kW heating elements, for TRL4 testing at TNO Carnot lab, in new test box, Q3 2026.

Conceptual design of test box completed by TNO, for long term, durability testing of updated metallic - and the new ceramic heating elements. Testing will be “isothermal, resp. adiabatic”, at low load, but max. operating temperature. Manufacturing & commissioning of the test box to follow in Q1 and Q2 2026.

TNO further acquired a furnace for testing of electrical heating elements for short term, full load testing. The required cooling infrastructure for this furnace still needs to be designed & constructed. Scheduled for Q3 -2026 (modifications) and Q4 2026 commissioning.

R3.2 Design and manufacturing of an 800 kW radiative electric heater prototype

For process design of a full scale RWGS reactor, with electric radiative heating, refer to Result 1.

For the 800 kW electric heater prototype: molten nitrate salt (Na/KNO₃) has been selected as heat transfer medium to cool the heater, respectively to absorb the thermal energy from the radiative heating elements. The main reason being that the most probable test loop for the prototype is an existing molten salt test loop, see results for R3.3. Basic thermo-hydraulic-electric design for the prototype is completed, as well as an 3D model, P&ID and operation & control concept.

R3.3 Demonstration of the 800 kW heater prototype

The total available budget under ECHOED Result 3 was concluded to be insufficient to construct and operate a 500 kW capable test loop at TNO-FLIE and therefore this activity is scrapped. As an alternative, an existing electrical heater test infrastructure was found at an applied science institute, outside the consortium. Contract negotiations have started. This test loop is using molten nitrate salts (Na/KNO₃) as heat transfer fluid.

Bottlenecks

R3.1: Limited testing capacity at 3rd party lab. Mitigation: additional TRL 4 test box & furnaces at TNO Carnot lab. Complex material compatibility issues at high temperatures for metallic heating elements, and the inclusion of the promising (!) development of new ceramic heating elements to the scope of the ECHOED project, will delay completion of this activity to Q4-2026.

R3.2: Delayed start because of late decision to scrap TNO-FLIE test loop. Expected completion of this activity delayed to Q4-2026..

R3.3 TNO-FLIE green field test loop budget insufficient. Mitigation: using existing 3rd party electrical heater testing infrastructure. This switch will delay completion of this activity to Q4-2027.

Application perspective

For the application of radiative electric heating elements in a RWGS reactor, the achieved heat flux (100 kW/m²) and surface temperature (1000 °C) with the metallic heating elements would already be sufficient. Only the long-term operation, or mean-time before failure, still need to be proven respectively. improved by the discussed pre-treatment, in the second year of the ECHOED project. For electrification of other industrial process, demanding higher heat fluxes and higher surface temperatures, a continuation of the developments of both metallic and ceramic heating elements is required, during the second year of the ECHOED project (and potential other projects) as well.

Result 4: Resistive heating

Activities

R4.1 Material selection, design and TRL 4 testing of resistive electric heating elements.

Metallic resistive heating elements are being developed by NEM and manufactured to NEM specification by a 3rd party, outside of the consortium. The resistive heating elements are tubular-, resp. cartridge type heating elements, to be inserted / placed into a (RWGS-) reactor vessel, similar to a shell & tube type heat exchanger, or into a low-pressure duct to heat a fluid. Target design parameters: heat release of 50 kW per meter tube, surface temperature up to 950 °C and supply voltage up to 15 kV or higher.

The main challenge is to develop an electrical insulator between the metallic electrical conductor coil embedded inside the tube and the tube itself, with sufficient dielectric strength to avoid breakthrough inside the tube from phase to ground, on medium voltage power supply.

The tubular heating elements are being tested at TRL 4 level at a 3rd party lab, outside the consortium.

Results

A new -electrical insulating- ceramic powder mixture, which has been developed by NEM prior to the ECHOED project, was applied in several new design concepts for tubular heating elements as developed during the ECHOED project, and TRL4 tested in the 3rd party lab. Some designs failed because of thermal expansion differences; other designs successfully passed -hot- electrical insulation tests beyond 15 kV and reached operation conditions with heat release of 30 kW per meter tube @ LV power supply. Further design updates and follow up tests in 2026 will aim on long term operation, heat release increased up to 50 kW/m, higher surface temperatures and medium voltage operation as well.

Bottlenecks

The generation, testing and evaluation of the different designs and manufacturing methods, requires considerable time & effort, so that completion of this activity will be delayed until Q4-2026.

Limited testing capacity at the 3rd party lab. Mitigation: it may be necessary to consider additional and dedicated testing capacity for the resistive elements in the Carnot lab as well (i.e., additional to the testing of radiative elements in the Carnot lab, refer to R3.1).

Application perspective

For the application of resistive electric heating elements in a RWGS reactor, the achieved heat release of 30 kW/m is already more than sufficient. Further development and testing in 2026 will be required in the second year of the ECHOED project, to meet all the design targets, both for the RWGS reactor / demonstrator under R1 and R2, as well as for electrification of other industrial process.

Result 5: Inductive heating

Activities

Result 5 focuses on the development and scale-up of the inductive heating reactor technology. Developing and comparing technologies with/without workpieces

R5.1 — Model adaptation

The goal of R5.1 is to extend and improve the induction-heating model (ANSYS Fluent and Maxwell pathway) with temperature-dependent material properties and a temperature feedback loop from Fluent to Maxwell. The consortium is happy to report that the model as finished, with Maxwell and CFD coupling complete, and able to run smoothly. High level validations were performed against theory (e.g., cylinder with coil analytical comparisons) and against lab-type cases (e.g., thin discs/workpieces).

R5.2 — 3D structured internals

The idea of R5.2 is to use the developed model in R5.1 to optimize workpiece geometry and temperature profiles. This will help R5.3 to design the workpiece and make the system constraints. Use the model to design and optimize 3D workpieces/structured internals and operational conditions.

To initiate design thinking on candidate geometries and manufacturability: consideration of helical workpiece as best-performing for temperature distribution based on TU/e experience and internal interpretation.

R5.3 — Design & duration testing lab-scale validation TRL5

The core intent of R5.3 is an experimental lab-scale validation of 3D-structured internals and design/duration testing of an inductive-heater prototype in the ~100 kWe range.

Currently a practical execution strategy is emerging:

- Non-reactive flow testing (air), with smaller-scale (10 kWe) experiments at TNO Petten before ramping up the electrical power to move toward larger electrical input (100 kWe).
- Instrumentation and safety planning: magnetic-field safety boards/shielding, temperature measurement approaches (IR camera, fiber optics, thin thermocouples).

Results

R5.1 — Model adaptation

The team established a clear direction for theory replication and validation: comparisons indicate a good match at low frequency, while discrepancies emerge in the mid- to high-frequency regimes. Early simulations using iron and copper discs reached the correct order of magnitude and revealed distinct differences in field and heating distribution—copper showing a more concentrated pattern and iron a more distributed one—yet a recurring observation is that the total heating power is still underpredicted.

R5.2 — 3D structured internals

Currently, a working design heuristic is forming which aims for an isothermal workpiece (temperature uniformity), and previous TU/e results suggests a helical shape. Such a shape can provide favorable behavior due to continuous edges and improved distribution compared with stacked discs.

A practical boundary condition is becoming explicit for experimental tests: the pressure-drop limitation within the experimental system from available blowers in R5.3, which directly constrains geometry choices (surface area vs pressure drop tradeoff).

R 5.3 — Design & duration testing lab-scale validation TRL5

No results yet.

Bottlenecks

R5.1 — Model adaptation

Overall, while the Ansys Fluent and Maxwell coupling was done in a relatively straightforward manner, the material-property remains the central challenge, since the temperature dependence of magnetic properties (i.e., permeability) is both critical and nontrivial. Moreover, the analytical approximation used no longer holds in the same way when skin thickness becomes comparable to geometry,

R5.2 — 3D structured internals

No parametric optimization is possible for the workpiece for the given budget and time. A parametric/topology optimization was acknowledged as “a project on itself,” i.e., not feasible as a full-blown optimization campaign within current constraints.

R 5.3 — Design & duration testing lab-scale validation TRL5

The main bottlenecks revolve around the following issues: first, heat transfer to a flowing gas remains the central technical limitation, because transferring heat to air make it difficult to determine what power density is actually achievable; in other words, the setup is fundamentally “power driven,” so drawing 100 kW electrical does not automatically mean 100 kW is transferred heat into the flow. Second, measurement uncertainty directly undermines validation, since IR-based approaches only measure external surfaces and require careful emissivity calibration, fiber sensors are both fragile and expensive, and thermocouples can be influenced or even heated by the electromagnetic field produced by the induction heater depending on geometry and frequency. Third, frequency and hardware inflexibility slows down iteration: changing generator frequency typically implies hardware changes (capacitor, coil, and/or workpiece), making systematic testing across frequencies both time-consuming and operationally costly.

Application perspective

The activities and results within R5 are about making induction heating a viable “contact-less” electric heating option for chemical reactor and thereby supporting the electrically heated RWGS (e-RWGS) pilot at lab scale within ECHOED, in line with the project’s broader aim of demonstrating direct electrification plus operational flexibility and preparing for a follow-up commercial demonstration.

Result 6: Molten salt indirect electric heating

Activities

Result 6 focuses on the study of molten salts as storage and heat transfer fluid. This enables a decoupling of supply and demand of electricity, an important factor in the viability of the electrification of the RWGS process, and of industry in general

R6.1: Desk research for existing and new molten salt mixtures

The goal is to select the molten salt(s) suitable for the indirect heating of the RWGS process, with an eye on other applications in industry as well. This comprises a literature study and collection of properties of available molten salt compositions, including an overview of suppliers.

R6.2: Experimental determination of molten salt degradation & associated corrosion rates to TRL3

The goal is to investigate experimentally (with physical or theoretical tests) missing parameters of the molten salt system. The initial focus is on the well-known nitrate salts. The experiments comprise

- Experimental determination of the primary & secondary chemical degradation reaction kinetics of nitrate salts
- Experimental determination of associated metal corrosion rates as function of (among others) concentration of degradation products for nitrate salts.
- Development of physical/mathematical models, based on derived reaction kinetics and corrosion rates, to simulate decomposition of the nitrate salt and metals corrosion of the components in contact with molten salt. Development of an industrially applicable model (reduced order model) to optimize the molten salt heaters with respect to minimizing the degradation rates at maximum allowable operating temperatures for the selected molten salt(s).

R6.3: Lab scale testing of electric molten salt heater prototype to TRL4

The goals are:

- Selection of most suited electrical heater principle for molten salt heating, either radiative, resistive, or inductive, following outcome of R3 through R5.
- Conceptual design of an industrial scale molten salt heater, in 100 MWe power range, operating at medium voltage and at maximum molten salt operating temperatures as per activity 6.2.
- Scale down of the full-size molten salt heater to a 50 – 200 kWe prototype.
- Detailed design and manufacturing of the 50 – 200 kWe prototype molten salt heater.
- Operation of the electric molten salt heater prototype in brownfield molten salt test loop at TNO.

Monitoring of associated molten salt degradation and metals corrosion and validation of the mathematical model as developed under activity 6.2.

Results

R6.1: Desk research for existing and new molten salt mixtures

Potential molten salts were categorized in 4 families, nitrates, chloride, carbonates and fluorides. For the RWGS reaction, two representative operating temperature regimes were defined, low temperature (~500 °C) and high temperature (~900 °C), based on expectations on catalyst development. The two levels can also give options for other applications. A comprehensive study was carried out to evaluate candidates on temperature limits and selected KPI's (based on storage volume, storage mass, OPEX, CAPEX). The result for the Low-temperature RWGS is a preference for Solar Salt (nitrate) and ternary carbonate salts (LiNaKCO₃), with Solar Salt offering the best overall performance among nitrates while the carbonate salt gives the best overall performance. The result for the Low-temperature RWGS is a preference for Ternary carbonate (LiNaKCO₃). Binary carbonate (NaKCO₃) is an attractive low-cost alternative but carries a significant operational risk due to its high melting point.

R6.2: Experimental determination of molten salt degradation & associated corrosion rates to TRL3

- After literature studies and consulting experts in the field it is concluded experimental determination of secondary chemical degradation kinetics for nitrate salts is not possible within the allocated budget of ECHOED wp 6, experiments are aborted. Primary reactions kinetics are considered known. Degradation kinetics of carbonate salts were studied from literature.
- It is decided to investigate metal corrosion in 3 steps, going from general to specific in the nr. of metal types and salts: A) testing 10-20 alloys under stagnant salt conditions for both nitrate (Solar Salt) and carbonate (ternary LiNaK) salts, atmosphere controlled. B) a smaller selection of alloys in an agitated salt test, for both nitrate and carbonate salts, atmosphere controlled, C) a flow test with only one metal alloy and nitrate salt only, where locally higher temperatures can be reached at the heater wall than in test A) and B), leading to more realistic corrosion rates. Potentially non-corrosion related phenomena could be investigated here as well. Planning of all experiments is in progress.
- Models were developed by TUD for heated nitrate salt inside round tubes, describing (development of) momentum and thermal boundary layers. Inclusion of the reaction kinetics of the primary reaction for nitrate salts was implemented as a source term in the mass conservation. First results are available on local concentrations of different species inside heater. Emergence of bubbles due to oversaturation of oxygen is being studied.

R6.3: Lab scale testing of electric molten salt heater prototype to TRL4

No results yet.

Bottlenecks

R6.1: None

R6.2: Budget for the three parts of the corrosion testing, as well as testing. If it is deemed a significant effect, modelling bubble formation and transport is challenging.

R6.3: Too early to judge

Application perspective

The planned tests will enable a much-improved material selection of heated and non-heated components in plants employing nitrate or ternary carbonate salts, as well as give insights on operation that avoids decomposition of salts and lead corrosion. Electrical heaters can be designed at maximum energy densities, leading to more cost-effective designs. For a RWGS reactor specifically, good integration with the catalyst is needed, configurations still to be detailed in the remainder of the ECHOED project.

Result 7: TEA, LCA and market analysis

Activities

R7.1: Techno-economic analysis TEA

Within the techno-economic analysis a comparative assessment is made for the application of the different heating technologies considered in the project, applied on the RWGS process. Here carbon dioxide and hydrogen are converted into syngas, and the heating technologies are used for feedstock heating and providing the heat for reaction. The syngas can be used for various downstream applications, the specification for the syngas selected is that for Fischer-Tropsch synthesis towards fuels. First, a Basis of Design (BoD) document was created listing all the assumptions on the process and electrification technologies evaluated. The assumptions were provided and are reviewed by the respective industrial partners. The framework for the TEA was created that consists of 3 phases: (1) process design and analysis; (2) electrification technology technical evaluation; (3) economic analysis. Phases 1 and 2 main results are available and phase 3 is about to begin.

R7.2: Market analysis

This task has only just begun. The script has been developed to interview make industrial stakeholders to identify the strategic ambitions, needs and the trends in the market

R7.3: LCA

The system boundaries and functional unit for reporting the LCA results have been defined for each of the four reactor heating technologies, as well as for the overall syngas production system. Relevant background documentation (scientific paper, product category rules, etc.) has been reviewed, and a data questionnaire has been developed covering all heating technologies and the overarching production system. Data has been collected from the project partners and has been verified for radiative and resistive heating, while the data check for inductive heating and molten salt systems is currently in progress. The development of the initial LCA models, results, and the accompanying report will take place in 2026.

Results

R7.1 TEA

The main insights from the process analysis is that is that of the two reaction temperatures considered, the low-temperature RWGS operation (450 °C) requires a selective catalyst that sufficiency supresses methane formation. It also requires a two-step reaction with intermediate water knock-out. Results show a lower specific energy demand compared to the high temperature process (900 °C). A potential improvement to the high-temperature process is the use of a special alloy high-temperature recuperator, which could make the heat demand higher than that of the low-temperature process.

Four heating options have been evaluated, addressing the total power demand for electric heating. Comparing the four heating options, it is found that the highest efficiency is from both radiative and resistive heating. Molten salt heating is slightly below that. The losses in inductive heating are significantly higher, leading to a lower efficiency. Consequently, the forthcoming economic analysis needs to focus on potential benefits for inductive heating in capital cost to compensate for the higher energy costs.

Bottlenecks

R7.1: The relevant plant size still needs to be selected. The decision has been delayed by the fact that the constraint on the limited feedstock availability shifted the discussion into a small-scale operation which needs to be revisited as it clashes with some of the ambitions.

The budget is very strained at the moment, so the economic analysis needs to be finished within a limited effort.

R7.2: None.

R7.3: None.

Application perspective

The results of this study will provide direct input to Result 9 – Full-scale plant design and Roadmap development. A closer interaction with Result 7 is anticipated short-term to define the plant size. The insights generated within Result 7 will lay ground for the follow-up projects.

Result 8: Electrical system integration and operational flexibility

Activities

Result 8 focuses in system integration and operational flexibility. A discussion with partners within the consortium was set up, in order to understand technical aspects of the system to be modelled, including the heating technologies and the power grid. Further assessment of the boundaries of the system is to be made in the following months.

Results

No results have been produced yet, as discussions on the system to be modelled are ongoing.

Bottlenecks

None

Application perspective

The modelled cases to be modelled will allow for a better understanding of the impact of the rest of the system (e.g., energy supply) on the grid, and vice versa.

Result 9: FS design and development roadmap

Activities

No activities yet

Results

No results yet

Bottlenecks

NA

Application perspective

NA

Result 10: Dissemination activities and societal studies

Activities

A few dissemination activities have been carried out, see below

Results

A project pitch has been given at “Projecten op het podium”, see chapter 6. In addition, a LinkedIn account has been setup to disseminate ECHOED results that can be shared in public.

Bottlenecks

None

Application perspective

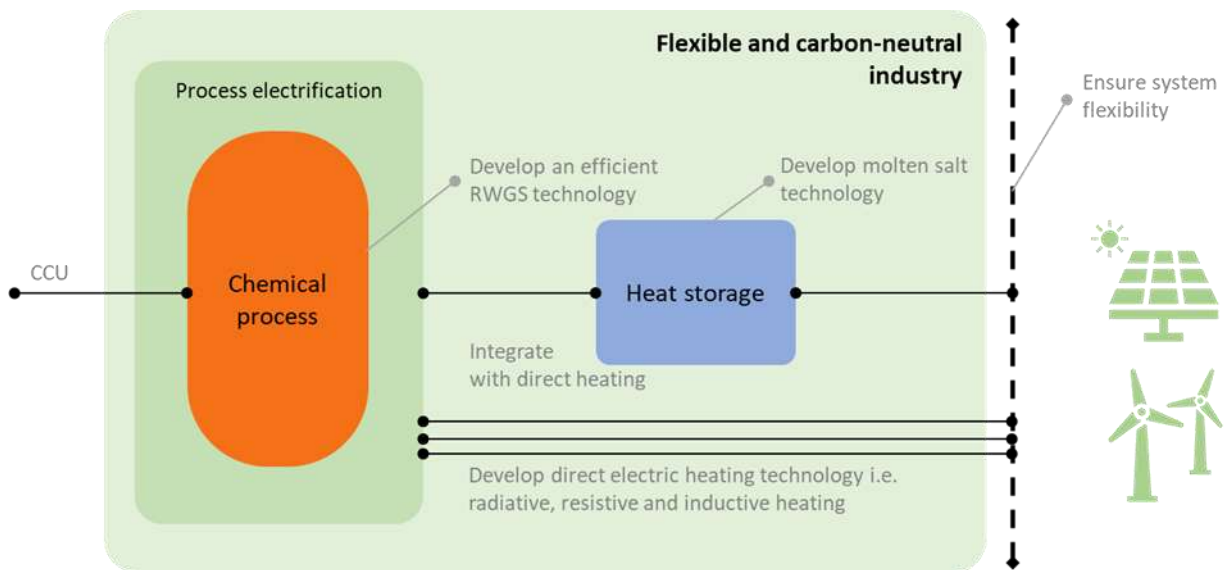
NA

4. Contribution to objectives Topsector

The objectives of the Topsector are aimed at the energy transition towards 2050. Specific for industry, a climate neutral industry is targeted that makes maximum use of renewable sources and operates in a circular way. At the same time, this industry is competitive in a global economy.

The project objectives directly contribute to the MOOI mission Industry and target two innovation themes simultaneously. The project is focused on development of a new cost-efficient electrical process (innovation theme 1), while focusing on a use case of utilizing CO₂ emissions for sustainable production of synthesis gas (innovation theme 2). State-of-the-art RWGS process requires substantial amount of heat to operate at temperatures above 800 °C. Successful execution of the project will take a step forward to electrified RWGS (e-RWGS) technology implementation and reaching MMIP7 i.e. 50% electrification of all high-temperature heat while supplementing it with a flexibility factor for robust operation based on fluctuating renewable electricity.

In parallel, electric heating technologies will be developed and tested as a generic technology for high-temperature heating applications. This allows electrical heating to be applied in multiple sectors across industry.



The ECHOED project has the ambition to pursue innovations in several fields simultaneously contributing to the fast development pace required by the time-pressing sustainability targets:

- Validation of four, distinctive or hybrid, e-heating reactor technologies with defined preferred window of operating conditions and a list of chemical processes that would match with the certain technology type
- Flexible RWGS process development in connection to fluctuating supply of variable renewable electricity and reduction of local grid congestion
- Formulation, fabrication and upscaling of catalyst customized for each of the electrically heated technologies including low-temperature operation (below 500 °C)
- Scaling up the envisaged integrated solutions to industrial capacity (100 MWe range) and high power density heaters.

- Medium voltage-based operations, in the order of tens of kV resulting in less complex and possibly expensive electric power supply, while enabling high-power density
- Increase of the temperature operation window up to 1000 °C, to enable high temperature endothermic reactions
- Electric heated furnaces at a COP (ratio of heat generated and the electricity consumed) and energy efficiency (ratio of energy in the syngas product and the electricity consumed) as close as feasible to one.

5. Spin-off

NWO and Nationaal Groeifonds have granted 45 M€ subsidy for the HYCARB project. This project will develop technology for production of carbon based chemicals with hydrogen, renewable electricity and carbon dioxide. Part of this project concerns electrical heating technologies to be applied in chemical processes. Some of the partners involved in ECHOED are also part of the HYCARB consortium (being TNO, TUE, NEM).

6. Publications

The following activities have been carried out during the first year of the project.

- A project pitch has been given at the TKI event “Projecten op het podium” on 16 September 2025 in Utrecht.
- A [LinkedIn](#) account has been setup to disseminate information from the ECHOED project.