# Letter of Intent for participation in the Advisory Board of the Moonshot research trajectory Electrification & Radical Process Transformation

Undersigned, [Company], with registered seat located at [Address], duly represented by [Name of Legal Representative], confirms it is strongly interested in the technology development within the moonshot research trajectory Electrification & Radical Process Transformation (MOT3).

## Research trajectory ‘Electrification & Radical Process Transformation’

In the third Moonshot research trajectory (MOT3), attention is directly focused on CO2 emissions. The net emission of CO2 must be avoided by radical transformation of current processes, in order to achieve a carbon-smart industry. A switch to electrified industrial processes (e.g. cracking installations) and the application of innovative and low-energy separation processes and mild biotechnological conversions (cf. MOT1) is part of the solution. There is also a need for innovation in the conversion of electricity to heat, which is much more efficient than the current traditional conversion via resistance. These large efficiency gains are needed to close the price gap between natural gas and electricity as fuel. Extensive research is also needed into capturing carbon that is emitted as CO2. For example, the industry can be fed with smart carbon (cf. MOT2) or the captured CO2 can be stored (temporarily) (so-called ‘Carbon Capture and Storage (CCS)’). However, there is a high cost barrier associated with capture of CO2. Therefore, the challenge here is to capture CO2 efficiently with new technologies and in an integrated way, to subsequently convert it into usable raw materials (such as monomers for plastics, cf. MOT2) or to store them. Carbon-free hydrogen is essential for these conversions and at the same time offers opportunities for sustainable production of ammonia (from nitrogen gas and carbon-free hydrogen); the current production process of ammonia (from nitrogen gas, water vapor and carbon monoxide) is characterized by significant CO2 emissions. Hydrogen and ammonia can also act as an energy carrier in the transport and storage of energy (cf. MOT4).

The following objectives will be pursued:

1. 60% reduction in ‘CO2 emission/ton produced’ by the (petro)chemical industry (main contribution to be expected from electrification of steam cracking and ammonia production, replacement of distillation by membrane processes, substitution of the traditional chemical processes by biotechnology), for which at least 1 technology will be developed to TRL 6 by 2035.
2. Economically profitable CO2 capture & purification, both capture from point sources (originating from chemistry, steel and energy production) and Direct Air Capture. At least 1 technology will be developed up to TRL 6 by 2025.
3. Economically profitable conversions of captured CO2 as a raw material for the Flemish industry. The most important contribution can be expected from the conversion of CO2 to CO, MeOH and DME; and the subsequent conversion of C1 feedstock into added-value products. At least 1 technology will be developed up to TRL 6 by 2025.
4. Cost-efficient (< €2.000/ton) hydrogen production (either remote or in-situ), characterized by low CO2 emissions. At least 1 technology is to reach TRL 6 by 2025.

Within the precondition that CO2 capture and purification is economically viable for capture at point sources at €20-30/ton and for Direct Air Capture at €50-100/ton.

[Company] is interested in this Moonshot research trajectory because …

*Please describe, as detailed as possible, the interest of your company in this Moonshot research trajectory.*

In addition, [Company] is interested in the following Moonshot cSBO project(s) within the Electrification & Radical Process Transformation research trajectory:

*Please indicate below in which project(s) your company is interested by deleting or removing the project(s) that is/are not of interest to your company.*

* **2CCO2: ‘2 catalysts for CO2‘ - Dual catalysis approach for the carboxylation of aliphatic olefins using CO2 as the carbon source**, full cSBO with a proposed starting date on 1 January 2022 and a proposed duration of 48 months, with partners KU Leuven, UAntwerpen and VUB.
* **CLUE: Clusters for CO2 electrolysers to ethylene**, full cSBO with a proposed starting date on 1 January 2022 and a proposed duration of 48 months, with partners VITO, KU Leuven and UAntwerpen.
* **ICO2CH: Integrated CO2 capture and hydrogen production**, full cSBO with a proposed starting date on 1 January 2022 and a proposed duration of 48 months, with partners VITO, IMEC, VUB and KU Leuven.
* **P2C-2: Power to ammonium nitrate**, full cSBO with a proposed starting date on 1 January 2022 and a proposed duration of 30-48 months, with partners KU Leuven, UAntwerpen and VITO. Follow-up project of the currently running Moonshot sprint cSBO project P2C (https://moonshotflanders.be/mot3-p2c/).
* **CAPTIN-2: Intensification of CO2 capture processes II**, full cSBO with a proposed starting date on 1 October 2021 and a proposed duration of 30 months, with partners VUB, KU Leuven, UGent, UAntwerpen and VITO. Follow-up project of the currently running Moonshot sprint cSBO project CAPTIN (<https://moonshotflanders.be/mot3-captin/>).

[Company] is interested in this/these Moonshot project(s) because …

*Please describe, as detailed as possible, and for each of the projects in which you are interested individually, how this project fits in your company’s innovation roadmap. Additionally, please describe how the project results could contribute to your company’s present and future activities.*

The next steps after this/these Moonshot project(s) are …

*Please describe step-by-step, as detailed as possible, and for each of the projects in which you are interested individually, how your company will organise follow-up activities for implementation and valorisation of the project results.*

[Company] engages to actively follow up on the Moonshot research trajectory and/or the project(s) of interest and to take part in Advisory Board meetings.

The Moonshot operational team can deliver information about and invitations for these Advisory Board meetings, as well as all other relevant communication related to this Letter of Intent, to [Name of company employee] ([employee email address]), who will act as [Company]’s main point of contact within the framework of this Letter of Intent.

Sincerely,

[Signature]

[Name, Function, Company]

[Date]

## Abstract 2CCO2

**‘2 catalysts for CO2‘ - Dual catalysis approach for the carboxylation of aliphatic olefins using CO2 as the carbon source**

This project aims at producing **chemicals that incorporate a high fraction** (  50 weight %) **of CO**2.The strategy is to reduce CO2 to CO with H2 and a solid catalyst at moderate temperatures (< 200°C), and to immediately consume the CO by coupling it in the same liquid phase reactor to other reactants, typically olefins like butadiene or ethylene. The equilibrium of the CO2 reduction (a.k.a. the ‘Reverse Water Gas Shift Reaction’, RWGSR) is unfavourable at low temperature; we can circumvent this limitation by withdrawing the CO from the equilibrium and coupling it to an olefin in a homogeneously catalysed reaction. Comparing with other routes for CO2 incorporation, our concept:

1. needs **only one H2 per CO2**, while e.g. CH3OH production requires 3 H2 per CO2;
2. works at much **lower temperature** (< 200 °C) than ‘classical’ CO2 hydrogenation.

Success in this **high-risk approach** will depend on (i) design of shape-selective catalysts for the RWGSR (KULeuven), (ii) use of innovative homogeneous catalysts that are efficient even at low CO pressures (UA), (iii) thorough insight of concentrations and traffic of CO2, CO, olefins ... in the system (VUB).

This strategy offers new routes, with highly improved CO2 footprint, to chemicals like for instance:

* **adipic acid** and its ester derivatives: adipic acid produced in this way will contain **60 mass% CO2**;
* **acrylic acid**: coupling of CO2 to ethylene (via CO) gives propanoic acid, which in a subsequent step can be dehydrogenated to acrylic acid, containing again **61 mass% of CO2**.

Such a concept can be highly appealing for

* **producers of adipic acid, acrylic acid**, other carboxylic acids, looking for routes valorizing CO2;
* producers of **polyamidefibers** (e.g. Nylon-6,6): they can get access to CO2 based feedstock;
* producers of an array of **polyesters**, **polyols** (and **polyurethanes**) that are adipate based; etc.

*For substantive questions about this project proposal, please contact MOT3 representative Luc Van Ginneken (**lvanginneken@catalisti.be**; +32 477 979 947).*

## Abstract CLUE

**Clusters for CO2 electrolysers to ethylene**

CLUE aims to develop the **next** **generation CO2 electrolyzers** for **sustainable production of ethylene** with reduced carbon footprint by designing novel, selective and highly robust electrocatalysts using an innovative approach based on **Cluster Beam Deposition (CBD) technology**. For electrochemical conversion of CO2 to ethylene, stimulating results have recently been obtained mainly on copper-based catalysts, yielding relatively high Faradaic efficiency (FE ≈ 60-70%) and current densities (100-200 mA cm−2) by using a flow cell with a gas diffusion electrode. Although the prospects for electrochemical ethylene production are promising, several challenges need to be overcome before industrial implementation: the full-cell energetic efficiency (EE) for ethylene production is ≤30%, operation window is narrow, electrocatalyst lifetime is poor (<200 hours). Achieving high selectivity for ethylene production with low energy input (**EE > 30%)** at **high production rates** (j > 300 mA cm-2) for a **long-term operation** (> 1000 hours) remains a major challenge. Moreover, the capability of CO2 electrolyzers to **utilize captured CO2** has not been assessed so far, introducing additional uncertainties for industrial implementation given the limited **insights in electrocatalyst degradation and deactivation**. Within CLUE, CBD technology is used to deposit size-selected bi- and multimetallic clusters with a very high and controllable homogeneity and desired morphology on adequate electrodes. This allows for **steering electrocatalyst functionality** and hence **enhancing electrocatalyst performance** (selectivity, production rate and stability). Moreover, extensive **(*in situ*/*operando*) structural characterization** will enable to fundamentally **understand the structure-property relations** **during electrochemical operation under realistic conditions** (i.e. at high current density and with industrially-relevant CO2 streams). The obtained insights will guide the cluster production to design electrodes with **improved stability** that will allow **avoiding, circumventing or minimizing electrode degradation or performance deterioration** in next generationCO2 electrolyzer systems. A prototype electrolyzer will be fabricated for **long term operation** and durable and **cost-effective production of ethylene** from **captured CO2** and renewable energy.

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## Abstract ICO2CH

**Integrated CO2 capture and hydrogen production**

In the ICO2CH project, an integrated concept is investigated for the **low-cost capture** from CO2 point sources with alkaline KOH-based media and **renewable H2 production**. The innovation is on the level of the water electrolyser, which is fed by a CO2-rich, post-capture (bi)carbonate solution, that enables isolation of a 80:20 % CO2/O2 gas mixture from the anolyte during operation. This eliminates the need for dedicated ‘stripping’ energy, since CO2 liberation is a consequence of OH- consumption during O2 production. Simultaneously, KOH is regenerated in the H2 evolution reaction, avoiding further capture utility costs. The **high-purity CO2 stream** can be valorized, in combination with H2 to produce e.g. synthetic fuels, next to O2 in (partial) **oxy-fuel combustion**, after a final CO2/O2 separation step.

The scientific goals are related to performance targets that enable low electrolyser cost levels (CAPEX ~current density, AWE: 600 - 1200 €/kW) with minimal impact on OPEX (electricity use/efficiency ~cell potential). This will be pursued by the development and stacking of 3D-thin-film components (VITO – Imec), to (1) compensate decreased ionic conductivities compared to typical KOH-based electrolytes and (2) maximize the effectiveness of pH change at the anodic side. Therefore multiphase models are used to link electrochemical reactions and transport phenomena to the bulk chemistry, while process modeling and application testing is involved in the evaluation of CO2/O2 separation (VUB) and integration with an oxy-fuel combustion step (KUL). The project is supported by research-directive models and advice (VITO), based on techno-economic principles and benchmark analysis.

The key exploitable results encompass devices and process-based innovations, addressing producers of electrocatalysts, electrodes and membranes, next to process developers, for valorization. The end users of such capture technology are present in the refining, chemical, steel and energy sectors, having unavoidable CO2 point source emissions and optionally interest in (partial) oxy-fuel combustion. This also involves companies (or clusters) interested in CCU/Power-to-X applications with access to high-purity CO2 and H2, as produced in one intensified system.

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## Abstract P2C-2

**Power to ammonium nitrate**

Ammonium nitrate is a bulk chemical produced worldwide in large quantities especially for fertilizer applications. With the growing population the market is predicted to grow substantially in the next decades. State-of-the-art ammonium nitrate production proceeds by a combination of the Haber-Bosch process producing ammonia from nitrogen and hydrogen gas, and the Ostwald process in which nitric acid is produced from ammonia. Ammonium nitrate is obtained by the acid-base reaction of ammonia and nitric acid. Ammonium nitrate production is globally responsible for a significant share of greenhouse gas emission of CO2 and N2O (a molecule with 310 times stronger global warming potential than CO2).

We propose a new ammonium nitrate production scheme, combining plasma technology producing NOx from air with electrocatalytic reduction of the NOx to produce ammonium nitrate. This integrated process avoids the corrosive nitric acid and anhydrous ammonia intermediates as well as N2O by-product formation. By combining the formation of ammonium and nitrate in one process, separation and purification processes are minimized. The process is applicable at different scales (small- medium-large) and can fully cope with intermittent green energy supply.

*For substantive questions about this project proposal, please contact MOT3 representative Luc Van Ginneken (**lvanginneken@catalisti.be**; +32 477 979 947).*

## Abstract CAPTIN-2

**Intensification of CO2 capture processes II**

In this follow-up project, we aim at the further development of new and more efficient, sustainable and economically viable CO2 capture and separation technology with focus on point sources.

Different routes will be continued to achieve this goal:

1. Intensification of mass and heat transfer processes in CO2 capture is aimed at, using a vortex unit and an aerosol reactor for liquid phase CO2 absorption.
2. Electrification of the CO2 capture processes using inductive heating (IH) will be implemented in order to develop faster and more efficient separation cycles.
3. The integration of CO2 capture and conversion is envisioned using alkali-mediated capture combined with electrochemical conversion of CO2 into chemicals.

The experimental test devices that have been developed in CAPTIN will be used to further investigate these new concepts. The already built models will now be fully exploited for the assessment of the new technologies in terms of efficiency. The main challenges that were identified in CAPTIN will be tackled: combining intensified absorption and stripping; enhancing efficiency of the inductive heating process; improving adsorbent energy absorption; process cycle optimisation; evaluating operating window and effect of operating conditions; process control. A roadmap analysis will be carried out to define technical and valorisation-related milestones and identify technical, economic, environmental and market-related hurdles.

To tackle this challenge, a multidisciplinary team has been built with experts in process intensification, separation processes, functional material development, electrochemistry and techno-economical assessment.

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