The PHOENIX Initiative is a collaborative effort supported by the EU Member States, France, Germany, the Netherlands, and the European Chemical Industry Council (Cefic). PHOENIX will function as an umbrella initiative linking national and European RD&I activities with respect to CO_2 valorisation to ensure an optimal use of public funding and private investment. PHOENIX will interact with all relevant stakeholders from industry through research institutions to national governments and the European Commission.

DISCLAIMER: *The following pages reflect the discussion of the PHOENIX Workshop on the 22nd of March in Frankfurt, Germany, and are not a statement of the position of PHOENIX. Whilst the summary aims to present the views of all participants, individual statements might have been omitted for clarity.*

I. Chemicals & Polymers (incl. Artificial Photosynthesis)

What can the PHOENIX Initiative do to support the implementation of related technologies in Europe?

Funding of projects beyond R&D phases was considered by the participants as a critical issue to be addressed by the PHOENIX Initiative. The investment required for the demonstration phase which is essential for market acceptance of the new CO_2-based products by the value chain partners can require support up to the last stage before commercialisation.

The initiative is also expected to contribute to an improved communication on the impact of CO_2 valorisation technologies, including public outreach. According to the participants the PHOENIX Initiative should contribute to ensure that policy makers can understand the potential impact of CO_2 valorisation technologies, and enable a favourable stable regulatory framework. Sustainability assessment related issues, including agreement on LCA, CO_2 sources and criteria to evaluate projects were other points mentioned by the participants.

The PHOENIX Initiative is expected to effectively support cross-national projects. The value of the initiative to facilitate partnership building was also mentioned. The integrated approach could also stimulate the cooperation between ‘similar’ and complementary projects, or at least better communication.

What are R&D needs and TRL of technologies in the scope?

Participants from both small and large companies agreed that public funding measures are available up to the development phase, and that the major funding gap is at demonstration level.
The issue of eligible CAPEX was also highlighted, since for some projects effective support to CAPEX in addition to OPEX would be a decisive element for investment.
Some participants suggested to analyse some existing funding models such as EIT’s KICs, or the approach developed by DECC/BEIS in the UK.

In addition, the PHOENIX Initiative could contribute to making CO_2 valorisation a long-term priority, independent from political changes in member states.

Are there existing large-scale projects in Europe?

Carbon2Chem and the pilot plant from Covestro were mentioned as two major examples in addition to the Power-to-Chemicals projects.
[Remark: An overview of existing pilot and demonstration plants would be valued by some participants.]

Are there approaches towards industrial symbiosis? Which industries are involved?

Companies from the chemical, steel, cement sectors are involved in the development of some industrial symbiosis approach on CO_2 to chemicals.
Carbon2Chem and the Kopernikus projects in Germany as well as some Horizon 2020 projects such as RECO$_2$DE or Carbon4PUR were mentioned as examples.
It was highlighted that the deployment of industrial symbiosis projects requires a joint business model.

What kind of large-scale projects would be necessary, to ensure a swift market implementation in Europe?

New large scale projects are needed to facilitate the market entrance of new CO_2-based products, since risk-sharing at demonstration phase is critical to enable test and approval phases by value chain partners. Companies down the value chains should be encouraged to test CO_2-based products. Support for OPEX and CAPEX of projects up to first production is therefore essential for market entrance.

II. Power-to-X (PtX)

What can the PHOENIX Initiative do to support the implementation of related technologies in Europe?

According to the participants, PHOENIX should give the transition into a fossil free resource system a voice and support companies that are active in it and invest as frontrunners. The PHOENIX Initiative could provide a platform for a completely new type of projects: Projects that include all participants of the value chain and allow for user feedback.

What are R&D needs and TRL of technologies in the scope?

One aspect covered was the need for an introduction of a so-called “systems TRL”. PtX technologies usually combine existing and usually far developed technologies in a new setting or environment. Each component might have a high TRL by itself but the combination, the “system”, needs to be evaluated independently.
R&D needs are predominantly seen in the pre-commercial scale at high TRL. The focus should lie in general on scaling up as there are many small scale applications already.
For fuels the need to develop better and alternative fuels to fossil fuels (“why copy fossil fuels?”) was discussed.
One critical aspect is the improvement of electrolysers. Here, learning curves are mandatory to decrease costs. However, to achieve success, operating times of >30.000 hrs are needed, which are not covered by standard length projects.
A feedback loop from users/customers is also mandatory to improve processes and product quality.

Are there existing large-scale projects in Europe?

Apart from already mentioned projects during the workshop, the following projects were collected as examples (no complete list):

Denmark: Haldor Tospoe, large scale project for CO formation, aim for TRL 8 in 2020, will be 300-400kW scale when commercialised (comment: CO is competitive even on smaller scale)
Denmark: 1 MW biological valorization in Kalundborg
Germany: MefCO_2 (SPIRE-project), CRI, Hydrogenics and others in Niederaußem
Germany: Energiepark Mainz, focus on Hydrogen
Sweden: FRESME, Follow up project of MefCO_2 and STEPWISE in H2020, CO_2 to Methanol in Lulea
Netherlands: Power-to-Formic Acid, supported by VoltaChem, City bus run on Hydrogen in Eindhoven
Netherlands: OCAP project (ports of Rotterdam and Amsterdam) *[Comment PHOENIX: OCAP transports CO_2 to greenhouses.]*
Norway: Nordic Blue Crude in Heroya

Are there approaches towards industrial symbiosis? Which industries are involved?

Industrial symbiosis is seen as key to success for PtX projects. Ultimately the whole value chain needs to be involved, e.g. also cities and local authorities for piloting of new fuels.

Sectors involved are providers of feedstocks, converters of CO_2, and users. This includes for example chemistry, steel, cement, car manufacturers, petrochemical companies (which should be involved more).

What kind of large-scale projects would be necessary, to ensure a swift market implementation in Europe?

The participants agreed that more large scale demonstration projects along the whole value chain with showcase character are needed to demonstrate viability to decision makers. Often technologies are commercially ready but not competitive without the appropriate framework. This can be changed by demonstrating on large scale that the technologies work and have an impact. Projects should always include partners from the whole value chain, including customers for testing of products, and would allow for combination of different funding sources/investments. Projects should involve economic and ecological evaluation.

A short survey of the participants showed that many project ideas are already existent and could be realised with appropriate support in a short timeframe.

III. Mineralisation/Carbonation

What can the PHOENIX Initiative do to support the implementation of related technologies in Europe?

The participants agreed that product labelling or certification/standardisation is needed for new CO_2 based products from carbonation/mineralisation to assure the technical performance. The main concern from the customer's point of view is the technical performance of a new material with different chemical specification.

What are R&D needs and TRL of technologies in the scope?

a. Are these R&D aspects covered in existing initiatives?
b. Where are funding gaps?

Classification of carbonation/mineralisation technologies by TRL:

- low TRL: new processes need support to improve R&D
- high TRL : processes are already demonstrated, the need is to support the technologies by regulatory policies or standardisation to act as an impulse for commercial scale projects to facilitate the market entrance of the CO_2 based products.

The participants emphasized the difference of carbonation technologies as compared to other CO_2 valorisation technologies: the technologies could be developed now because there is no need to have high quantity of cheap renewable energy.

Mineralisation/carbonation as other CO_2 valorisation technologies needs to demonstrate the CO_2 emissions reduction. LCA could be a good tool to assess the environmental benefits (GHG emissions reduction) of products from mineralisation/carbonation.

Are there existing large-scale projects in Europe?

There are already large-scale projects in Europe even at commercial scale as in the UK with Carbon 8. The main issue is the price of CO_2. Bringing a technology to commercial scale requires a reliable business model and it depends mainly on the CO_2 source and its price.
Other issue is the regulatory aspect. There is not one unified "end-of-waste" regulatory framework in Europe and each country has its specificity. This could be an obstacle for the development of the technology.

Are there approaches towards industrial symbiosis? Which industries are involved?

To have a better efficiency and lower cost, the industries should stay closer. To do that, a long-term strategy from EU is required to encourage industries for more synergy. With cross sectorial symbiosis, allocation of the benefits of each actor of the value chain needs to be defined.

However, it is not only industries; public authorities need to be involved by pushing products with better environmental footprint. For example, public tendering should include environmental criteria to support products with low carbon footprint and so to create demand. The assessment of these new products will be challenging, a standard is needed for the carbon footprint or the environmental evaluation (LCA).

It is important to note that industries are already in standardisation process with PEF (Product Environmental Footprint) or with "World Green Building Council". To develop these new technologies, the main driver of the supply will be the demand.

What kind of large-scale projects would be necessary, to ensure a swift market implementation in Europe?

a. What would be the requirements for first-of- a-kind plants?
b. What would be the added value of new large-scale projects as compared to existing initiatives?

For mineralisation, the main issue is not a technological obstacle/barrier but the certification of the end product and so the end use. Generally, the product is new and properties not fully known and therefore it is difficult to compete with alternative or conventional products (e.g. building materials), especially in term of certification of the properties and quality. Low prices of the targeted products are also seen as an obstacle for large-scale projects. Several pilots/demonstrators are needed to demonstrate the relevance of these new technologies in Europe.

Several propositions were made by the participants:

- Guidelines for standardisation of LCA: to demonstrate the CO_2 emissions reductions from carbonation/mineralisation technologies.
- Large scale projects (demonstrators) exist already: need to do pilot/demonstrator project in different countries to assess the implementation of this technology: need to define a proper regulatory framework as well as incentives to promote low carbon footprint building materials (public tendering) to enhance the market
- Carbonation/mineralisation: large capacity to store CO_2 emissions (order of Gt/year) with a wide range of products (some even don’t exist for the moment) so there is a need to develop new business models and to open new markets.

A deep discussion took place about the definition of the needs to support the implementation in Europe. Some participants pointed the uselessness to have several pilots/demonstrators in different countries. One large scale and flexible project should be enough to demonstrate the benefits of the technology. One proposition was to develop a flexible demonstrator with smart combination of different wastes and CO_2 from different sources to get different products that could be characterize to identify the best use/application. One main advantage of mineralisation is the possibility to use CO_2 without purification or with low concentration. This project could run across different industries.

The discussion concluded on the main hurdles that PHOENIX could tackle:

- Regulatory aspect: the non-existent coherent “end of waste” directive is the main hurdle to the deployment of successful projects in Europe (example: carbon8 technology)
- Public funding: mineral/carbonate products are very low-priced/cheap products so there is a need to support these new technologies (CAPEX/OPEX).

IV. General Discussion

LCA for CO_2 valorisation

The value of LCA as method for determining the impact of various CO_2 valorisation approaches was questioned – the outcome is a theoretical number that depends on assumptions and system boundaries (no general agreement/standard here) and cannot be statically evaluated. However, alignment of the associated impact of CO_2 utilisation is desirable at the same time. The studies on LCAs for CO_2 valorisation should be brought together, with the aim of a common agreement on the impact of various CO_2 valorisation technologies on environmental protection. PHOENIX's role could be to facilitate an alignment process. Moreover, there is a need for more LCA applications in semi-industrial scales within the boundaries of entire value chains.

It was argued that the CO_2 footprint is the most important parameter for CO_2 valorisation industry. Looking at the future, understanding company carbon footprint will be essential. PHOENIX could become the standardized interface for industry to "compare" CO_2 footprint processes. However, there is a general understanding that the actual process remains proprietary information of the company (see company's profit and loss).

How to get CO_2 valorisation to the market? – policy instruments (ETS, alternative instruments and uniformity) to build confidence and to incentivise industry and investors

If there is a willingness to pay for a product with a lower carbon footprint, or if there is regulation that compensates additional OPEX, or indeed regulations that enforce or advertise specific products, this would drive a market. Linking to these challenges is the PHOENIX target to improve investor trust. Regulations are key, e.g. linking regulation to the laws of physics: CO_2 emitters pay and CO_2 reducers get paid. However, reduction of CO_2 emissions is not clearly defined: avoidance as reduction measure, retention time of the CO_2 (see fuel sector and storage for a few days vs. CO_2 mineralisation). The keywords interplay of different instruments/measures is required, e.g. quota targets, pull from the product side and ETS/penalties in parallel were mentioned by some of the participants.

Alignment in European countries is important (uniformity). PHOENIX could potentially harmonise between the different DGs of the EC (DG RTD, DG GROW, DG ENER, DG CLIMA). Furthermore, it should convince about and advocate for CO_2-based products with a lower carbon footprint.

However, this is always depending on policies, that need to be adapted to new situations (both new governments or new price levels, societal developments etc.). A stable policy framework is beneficial, but adaptation is a fact of life.

A number of participants mentioned that subsidies for demonstration plants in the 30% range and the additional administration will not convince decision makers in industry. Even 40% will have no influence on a company's decision making in favour for a demonstration project. Subsidies should have some flexibility (e.g. public infrastructure funding from the German Federal Ministry of

Transport and Digital Infrastructure, BMVI; the claim was that rules are much simpler there). And the OPEX is the real problem.

At the same time, there was consensus that large demonstrations (>10 mEUR, >TRL 6) are needed. These would be in the tens-hundreds million euro range. These demonstrations will need public money.

For large companies, steering in an unsuccessful direction is the nightmare. Public authorities should understand the long-term (10-20 years, esp. for chemicals, steel and cement) perspective there. Some participants suggested that PHOENIX could play the role of a guarantor in the near-/mid-term.

Cross-sectoral projects and CO_2 allocation in the value chain

How to implement co-siting, what is the joint business case? As a chain is as strong as its weakest link, there is a challenge. Everyone in the chain should gain something: sharing profits and losses across the value chain (margin expectations need to be transparent).

The structure of ETS, where CO_2 emission allowances should be paid by the organisation taking in the fuel is not a real problem for CO_2 valorisation, according to some of the participants. The ETS cost in principle adds to the price of that CO_2 for the client. If there is sufficient market pull for the product produced from recycled CO_2, the producer of the product will be able to pay.

Educate and clarify about CO_2 valorisation

CO_2 valorisation is a hoard of technologies, difficult to grasp for policy makers. There is a need for clear communication. Participants frequently mentioned an IEA GHG paper on CO_2 valorisation. The story must be made as simple as possible. PHOENIX should address (irrational) fears by teaching about technologies.

Other themes (brought to the table, but not discussed)

a. Circular economy (in the steel industry)
b. CO_2 capture – carbon looping
c. Certification requirements in the building industry for new CO_2-based products (see also the section on Mineralisation)
d. What is the role of a facilitator?