A VISION for Smart CO_2 Transformation in Europe

Using CO_2 as a resource

Enabling European industry to become more resource-efficient, sustainable and competitive

Smart CO_2 Transformation

The Smart CO_2 Transformation (SCOT) project is a collaborative European project focussed on accelerating the market development of carbon dioxide utilisation; it is supported by funding from the European Seventh Framework programme. Carbon dioxide (CO_2) utilisation is a broad term that covers a variety of innovative industrial processes that can transform carbon dioxide into a variety of value added products such as chemical products, synthetic fuels and building materials.

This is the SCOT Vision document, designed to give the SCOT project's vision of why Europe should accelerate the market development of CO_2 utilisation processes and products.

SEVENTH FRAMEWORK PROGRAMME

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Key messages

In a future where carbon dioxide cannot be as freely released to the atmosphere, scientific and industrial progress has enabled us to imagine a solution in which carbon dioxide (CO_2) becomes an increasingly important carbon resource; a world in which we utilise CO_2 to create products. CO_2 utilisation will create new opportunities for economic growth, greater innovation and boost Europe's competitiveness, whilst supporting its transition to a circular, low-carbon economy. CO_2 utilisation can also help to support Europe's decarbonisation and resource efficiency agendas, and provide a route to become less dependent on imports of fossil fuels

By 2030 CO_2 utilisation technologies will enable you to:

- **Buy a mattress from major European retailers, made with foam that uses recycled CO_2.**
- **Construct a truly carbon-negative house from mineralised wastes and CO_2 capturing cements.**
- **Fill a long distance freight truck with CO_2 derived synthetic fuel.**
- **Travel on a plane powered by a percentage of CO_2 derived aviation fuel.**
- **Eat foods produced with fertilizers derived from CO_2.**
- **Live on an island that has a self-sufficient sustainable agricultural industry powered by renewable energy, green urea and synthetic tractor fuels all made from CO_2.**

CO_2 can be transformed into a wide range of products. Over 90% of organic chemicals are derived from fossil carbon, 5-10% of the global demand of crude oil is used in the manufacture of these products. In CO_2 utilisation, CO_2 is used as a carbon source replacing the carbon sourced from fossil fuels. Synthetic fuels can be produced that would directly replace liquid and gaseous fossil fuels, and CO_2 can be used in accelerated mineralisation to create construction materials.

There are three core reasons to suggest why Europe should accelerate the market development of its CO_2 utilisation sector:

- **CO_2 utilisation can be one of the major growth areas in Europe's future low-carbon circular economy**
- **CO_2 utilisation can help to facilitate Europe's energy transition**
- **CO_2 utilisation can contribute to achieving Europe's aims for decreasing carbon emissions**

CO_2 utilisation has the potential to help Europe become less dependent on fossil fuels by becoming more resource efficient, which helps to safeguard the competiveness of its industries. It also provides Europe with a route to decouple economic growth from damaging environmental impacts, and aligns with its aims for a low-carbon circular economy.

Glossary

CCS	Carbon capture and storage
CO_2	Carbon dioxide
DAC	Direct Air Capture
EAP	Environment action programme
EC	European Commission
EOR	Enhanced oil recovery
EU	European Union
GHG	Greenhouse gas
GT	Gigatonne
JAP	Joint action plan
LCA	Life cycle analysis
MSWI	Municipal solid waste incineration
PPC	Polypropylene carbonate
PtG	Power to Gas
PtL	Power to Liquids
SCOT	Smart CO_2 Transformation project
SERIA	Strategic European research and innovation agenda
TRL	Technology readiness level

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Foreword

By 2050, Europe needs to have drastically decoupled its economic growth from its emissions of carbon dioxide. This is a direct response to the compelling evidence from the increasing risks of climate change brought about by the anthropogenic emission of greenhouse gases, and carbon dioxide in particular. Moving from energy systems that are primarily reliant on fossil fuels to those which use greater amounts of lower-carbon energy sources is a broadly accepted policy choice of member states, although the exact technology choices and the speed of the transition vary.

Scientific and industrial progress has enabled us to imagine a future in which carbon dioxide becomes an increasingly important resource; a world in which we utilise CO_2 to create products. By accelerating development in the area of CO_2 utilisation Europe can improve its industrial competitiveness whilst reducing its impact on the planet. However, for this to happen, there needs to be a clearer long-term strategy which itself depends on a stable long-term research and industrial policy framework. CO_2 utilisation also provides a route for Europe to realise its ambition to move to a circular economy. Support for the circular economy comes from a high level, as evidenced by First Vice-President Frans Timmermans statement on the 15th of July 2015:

"Europe should be a frontrunner on the circular economy. I believe passionately in this because the future of the European economy is not in competing on low wages; the future of the European economy is not in competing on wasting finite resources. The future of the European economy is in the circular economy, in reusing, in putting things back into the economic cycle. This means rethinking the way we design, produce, consume and dispose of products."

In this document, we set out a long-term Vision for CO_2 utilisation and put forward why Europe should make it a priority to accelerate its development.

This Vision document and the subsequent SERIA (Strategic European Research and Innovation Agenda) and JAP (Joint Action Plan) are the product of extensive research and mapping of CO_2 utilisation throughout Europe aimed at understanding the current state of CO_2 utilisation. During this research process the following have been conducted:

- Over **300 interviews** with experts (industry, academia, policy makers) in CO_2 utilisation
- **Over 10 workshops** at (inter)regional level to synthesise and discuss preliminary results
- A comprehensive **regional assessment** to map CO_2 utilisation actors, the existing funds allocated to CO_2 recycling projects and to produce regional SWOT/SOAR analysis
- A comprehensive **socio-economic analysis** to map major CO_2 emitters, energy infrastructures, and assess existing policy and regulations
- An elaborate **desk research** on three CO_2 transformation routes, mineralisation, power to fuels and chemical building blocks
- Extensive **review** of intermediate results by an international and renowned panel of experts and Public Consultation

[1] http://bit.ly/1HJjoEG

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What is CO_2 Utilisation?

CO_2 utilisation is a broad term that covers a variety of established and innovative industrial processes that utilise CO_2 as a source of carbon by transforming it into value added products such as chemical feedstocks, synthetic fuels or building materials. CO_2 utilisation can therefore be viewed as a range of novel technology pathways that utilise CO_2 chemically. During the transformation, bonds between the carbon and oxygen atoms are broken and new bonds are formed with other reactants. Most reactions will also require an additional energy input, which must come from low-carbon energy sources to prevent the emission of further CO_2.

What is CO_2 (carbon dioxide)?

CO_2 is a basic and indispensable molecule for life on earth, but also the primary greenhouse gas emitted through human activities. It is naturally present in the atmosphere as part of the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals. CO_2 is a stable molecule that requires energy to activate it for the majority of synthetic routes to produce chemicals. CO_2 can be activated by the use of catalysts, temperature and pressure, or other high-energy reaction partners.

The SCOT project focuses on CO_2 transformation technologies and processes (Figure 1.1), and therefore other related technologies such as those for capturing and transporting CO_2 for carbon capture and sequestration (CCS) are not elaborated in detail. Direct physical uses of CO_2 without a transformative step are also outside the focus of the SCOT project e.g. enhanced oil recovery, using CO_2 as a solvent, as a plant growth promoter in greenhouses, or in carbonated drinks. However, CCS is nonetheless considered to be complementary rather than competitive in nature, and as such the SCOT project supports the continued development of this and other avenues for the direct use or sequestration of CO_2.

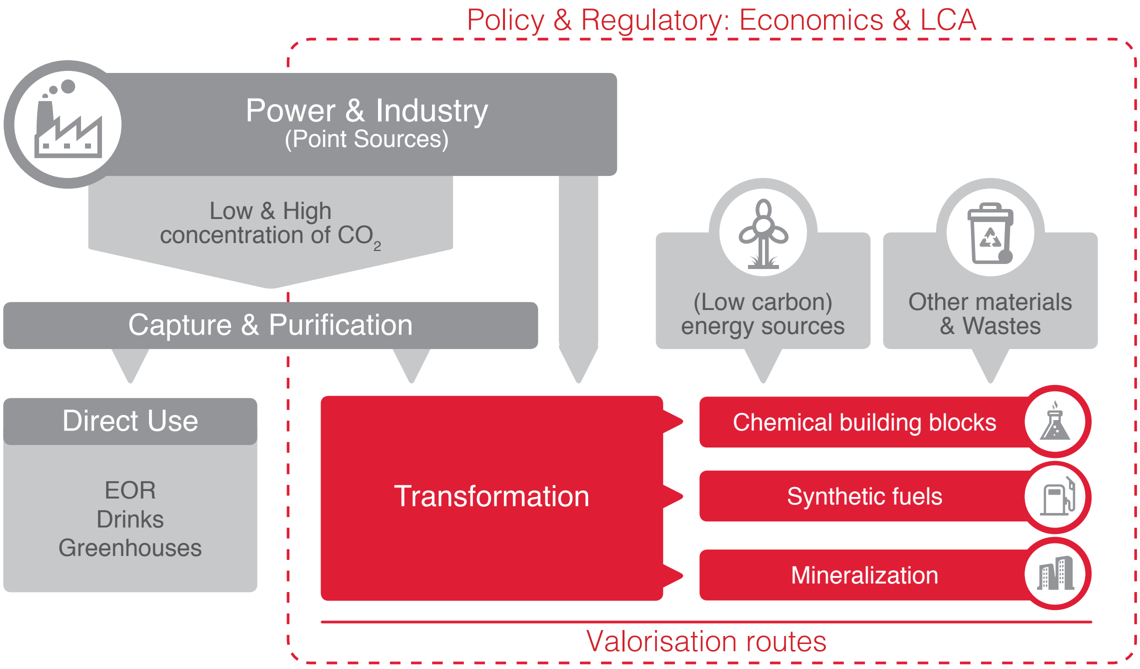

Figure 1.1: CO_2 Value Chain

CO_2 for utilisation can be obtained from a range of differing sources such as industrial gas streams, power generators (flue gas), bio-fermentation, anaerobic digesters, and geological sources or indeed directly from the atmosphere. Each CO_2 source contains differing challenges in terms of its concentration, humidity and other chemicals present as well as the lifetime of the potential source too. Direct Air Capture (DAC) allows CO_2 to be directly collected from the atmosphere, which has a similar overall effect as biomass. DAC allows CO_2 utilisation processes to be sited in any location with access to low-cost low-carbon electricity, its drawback is its energetic requirements to harvest CO_2 at concentrations in the air that are much lower than industrial sources (400 ppm vs 140,000 ppm).

Where would the CO_2 for utilisation come from?

What can be made with CO_2?

CO_2 can be transformed into a wide range of products from chemicals to fuels to building materials, from plastics to memory foams. The CO_2 is used as a carbon source replacing carbon normally sourced from fossil fuels. Over 90% of organic chemicals are derived from fossil carbon and 5-10% of crude oil is used in the manufacture of these products; replacing this fossil carbon with carbon from CO_2 provides new sustainable process routes.

To transform CO_2 into products other inputs are also required. These can be in the form of energy such as heat or electricity or material inputs such as fly ash, hydrogen or epoxides. It is essential that any new CO_2 utilisation process has a lower carbon footprint over its total supply chain than equivalent products manufactured using fossil fuel routes. To achieve this comprehensive Life Cycle Analysis is required, which should also take into account avoided emissions.

1.1 Chemicals from CO_2

In treating CO_2 as a carbon resource, Europe will have the potential to increase the security of supply of high value and commodity chemicals. Utilising CO_2 as a carbon feedstock for the chemical industry opens new routes for added value chemical production that have been previously dependent on petrochemical feedstocks for their carbon and energy.

A vast array of chemicals can be produced using CO_2 as a feedstock. Ongoing research is primarily focusing on methanol, polymers, urea, carboxylates, carbonates, olefins and the discovery of new catalysts and mechanisms for these reactions. Many of the products are also valuable intermediates including synthesis gases and small organic molecules (e.g. formic acid). Methanol is often a key target due to its use as a feedstock in many subsequent chemical processes and as a fuel. Other benefits for the Chemical products sector include the potential of CO_2 utilisation processes to provide less toxic chemical synthesis routes compared to conventional methods e.g. replacing the use of the highly toxic phosgene with products derived from CO_2, and potentially providing a more controllable process environment to create carefully tailored products.

1.2 Synthetic fuels of non-biological origin from CO_2

Synthetic fuels of non-biological origin, also termed synthetic or e-fuels, power-to-gas (PtG) or power-to-liquids (PtL), offer the potential to provide an energy buffer (storage solution) between low-carbon electrical energy sources and energy demands up to bulk energy scales. CO_2 derived synthetic fuels would likely be drop-in replacements for liquid or gas fossil fuels and can directly replace fossil fuels in Europe's existing natural liquid/gas fuels infrastructure without major modification. Long haul transport and aviation are a key target for CO_2-derived fuels as these areas are the most challenging to de-carbonise due to the energy density required from their fuels. The capture of CO_2 from the air or the use of biogenic/biomass sources of carbon will provide carbon-neutral or negative liquid/gaseous fuels and this must be our ultimate 2050 goal. To reach this goal using CO_2 originating from burning fossil fuels may provide initial routes to technology deployment but will only contribute to mitigation via avoided carbon.

1.3 Building materials and stabilised waste products

Accelerated mineralisation is an industrial version of the Earth's natural silicate-carbonate pathway that permanently strips around a billion tonnes of CO_2 out of the atmosphere every year. Materials that can be carbonated include industrial wastes and naturally occurring silicates such as olivine or serpentine. Industrial mineralisation has the benefit of improving certain industrial wastes to create waste streams that are less toxic (improved leaching properties) and chemically stable, whilst at the same time sequestering CO_2. CO_2 utilisation technologies also offer process integration opportunities with the potential to convert low-value materials into useful higher-value products for the building sector (e.g. synthetic aggregate), which also provides a CO_2 utilisation route that can permanently sequester CO_2.

What is CO_2 Utilisation?

Waste management is considered the most immediate opportunity for mineral carbonation to move into a mainstream market. CO_2 transformation provides an opportunity for radical change in order to phase out completely the landfill of certain solid waste streams. Municipal solid waste incineration (MSWI) is an increasingly adopted technology that enables a significant reduction in waste volume but still produces a substantial amount of residue including fly ashes and bottom ashes. These ashes can contain salts, toxic and regulated heavy metals and metalloids; mineral carbonation is a recognised treatment and stabilisation process turning these waste ashes into products.

2 A Vision for CO_2 Utilisation in Europe

CO_2 utilisation will create new opportunities for economic growth, greater innovation and boost Europe's competitiveness, whilst supporting its transition to a circular, low-carbon economy. Carbon dioxide utilisation can also help to support Europe's decarbonisation and resource efficiency agendas, and provide a route to become less dependent on imports of fossil fuels.

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· Live on an island that has a self-sufficient sustainable agricultural industry powered by renewable energy, green urea (as a fertiliser) and synthetic tractor fuels all made from CO_2.

There are three core themes to suggest why Europe should accelerate the market development of its CO_2 utilisation sector:

- **CO_2 utilisation can be one of the major growth areas in Europe's future low-carbon circular economy**
- **CO_2 utilisation can help to facilitate Europe's energy transition**
- **CO_2 utilisation can contribute to achieving Europe's aims for decreasing carbon emissions**

2.1 CO_2 utilisation can be one of the major growth areas in Europe's future low-carbon circular economy

Transitioning to a circular economy is not only a rational response to the eventual end of an era of plentiful and lower cost fossil fuel resources, but also a recognition that economic growth must be decoupled from greenhouse gas (GHG) emissions in order to limit the risks of climate change. This global challenge will continue to grow in importance in an increasingly populated and wealthy world that exerts more stress on the natural environment and its resources.

The SCOT project's Vision is that using CO_2 as a feedstock for chemical products, synthetic fuels and building materials will be a major step towards creating a circular economy in Europe. Gradually, CO_2 as a resource will grow in importance as an input for a wide range of industrial sectors, offering numerous opportunities to increase their resource efficiency, sustainability and competitiveness through innovation. Research and innovation policy should be selectively targeted depending on each industrial context (access to low-cost low-carbon power, skilled workforce, infrastructure, supply chains and access to markets).

Early CO_2 utilisation opportunities are likely to emerge in the European chemical sector as it seeks to replace part of its petrochemical feedstock with CO_2 derived carbon, by exploiting synergies through co-locating carbon users with carbon emitters. This means that Europe could increasingly benefit from developing internal supply chains for CO_2 utilisation processes and products rather than continuing to import fossil fuels and other feedstock. In addition, if Europe secures a lead on CO_2 utilisation development, it seems likely that the technologies developed will be of interest to other regions too. Thus, as well as securing a sustainable supply of inputs and strengthening domestic markets, the technologies to utilise CO_2 could become high added value exports from Europe. CO_2 utilisation technologies are exported abroad further contributing to an industrial renaissance in Europe. The chemical industry is the major supplier to a whole range of other industrial sectors and is at the beginning of the value chain. Replacing the raw materials of this key sector will therefore have a major influence on a wide range of other industries.

By 2020:

· Legislation is in place to further promote industrial symbiosis including potential synergies achieved by recycling CO_2 flows. This means that some incentives are in place to reward the use of CO_2 (e.g. via a targeted carbon price, agreed labelling schemes have been developed to promote CO_2 utilisation with policy makers, specifiers and end-users)

· Industrial research for more economic and scalable capture technologies bears fruit and increases the amount of CO_2 being captured

· A number of success stories using CO_2 are increasing their market share; a number of chemical products will be commercially available (e.g. mattress foams, fuels); some waste flows (e.g. steel industry) are systematically re-used via mineral carbonation to produce building materials

By 2030:

· CO_2 utilisation has contributed to create valuable products and associated services and managed to absorb significant shares of captured CO_2 and thus has contributed to decoupling emissions from economic growth

· CO_2 utilisation technologies developed in Europe are exported abroad further contributing to an industrial renaissance in Europe

· CO_2 is used as a carbon source for the production of many chemicals previously reliant on petrochemical carbon feedstock

By 2050:

· The chemical industry no longer uses fossil carbon as its basis

· 50% of our building material made with CO_2

What should be happening to achieve this and by when…

2.2 CO_2 utilisation can help to facilitate Europe's energy transition

CO_2 utilisation provides a potential route for 'surplus' electricity to be utilised to create CO_2 derived synthetic fuels. This would help to offset fossil fuel demand in other sectors (heat and transport). As the share of low-carbon energy sources in Europe increases, it needs to find robust and economic solutions to manage the balance between energy supply and demands over varying timescales. This is not optional, but a pre-requisite of any secure energy system, and has predominantly been achieved in the past by the use of stored fossil fuels.

There are a variety of techniques that will help with Europe's low-carbon energy system transition such as transmission grid interconnections between differing Member States and demand side management, but it is clear that energy storage will be a critical component too. In addition to the benefits from shorter-term (hours to days) energy storage technologies such as batteries and pumped storage, many regions will continue to require the inter-seasonal storage of vast amounts of energy. The creation of synthetic fuels could be a solution to this inter-seasonal challenge, as they are well suited to providing stored energy at this scale. Interestingly, if synthetic methane is combusted in a gas-power station that has carbon capture fitted the carbon could be utilised more than once. An additional advantage is that these fuels are able to utilise existing transport and storage infrastructure without major modifications.

CO_2 derived fuels may also be an important option for Europe's future low-carbon energy systems as they could help to reduce the CO_2 footprint of hard to decarbonise parts of the energy system such as aviation, long-haul freight and international shipping. These applications require the energy density afforded by existing fuels, and other forms of energy storage such as batteries are not viewed as credible options at this time. However, the CO_2 that is used to manufacture of synthetic fuels is subsequently released (after combustion) into the atmosphere and can therefore not be considered fully carbon neutral. Only when direct-air-capture or bio-sources are used as the source of the CO_2 the process has the potential to be carbon neutral.

The future mix of sustainable fuels is far from clear, as the technology development and infrastructure evolution and trade-offs between using hydrogen itself or synthetic methanol, synthetic methane or other synthetic hydrocarbons has a great deal of uncertainty. Any potential net CO_2 reduction of using CO_2 derived synthetic fuels requires robust life cycle analysis to be carefully assessed.

Further benefits from the manufacture of CO_2 utilisation derived synthetic fuels are the potential reduction in import dependency and possibly a reduction in price volatility too. For industries and member states this volatility provides a great deal of uncertainty that is difficult to hedge against over the longer term. Being able to harness increasing amounts of low-cost low-carbon power and combine this with CO_2 and water allows Europe the potential to manufacture its own power-generated synthetic fuels. At scale, this CO_2 utilisation production route may create a more stable price for feedstock for the chemical, energy and transport sectors - especially if longer-term contracts are available for low-cost power and CO_2. If Europe is able to stabilise and increase its energy autonomy, it will also shift resources away from imports to internal low-carbon energy providers thus creating jobs, strengthening economies and energy security, and decoupling economic growth from carbon emissions too. In essence, this seems to be a very rational direction for Europe to be leading in, and one that would benefit from conducting a wider socio-economic research.

By 2020:

· Wider social acceptance for CO_2 derived fuels has been significantly advanced by long-term engagement of different stakeholders to help ensure transparency and due process in decision making

· Regulatory frameworks for fuels such as (Renewable energy directive + Fuel quality directive) provide a market pull for CO_2 derived fuels

By 2030:

· CO_2 utilisation technologies are providing system level benefits to those electrical systems that have reached high levels of renewable energy penetration. The use of CO_2 utilisation technologies is specific to each region's needs e.g. synthetic methane, methanol, other power-to-liquid fuels.

· CO_2 derived drop-in fuels are being used to reduce emissions from the hard to decarbonise parts of the transport sector (aviation, long distance freight and international shipping).

· Power-to-methane is being used to store surplus low-carbon energy at bulk scale for the power sector, the heating sector, the chemicals sector and the transport sector (long distance freight and international shipping)

By 2050

· Direct air capture has made carbon neutral fuels a reality.

What should be happening to achieve this and by when…

2.3 CO_2 utilisation can contribute to achieving Europe's aims for decreasing carbon emissions

In the creation of products from CO_2 utilisation, the utilised CO_2 can be sequestered for a long period as in the case of mineralisation. As well as sequestering CO_2, reduced net emissions can also be achieved such as in the case of polymers. The emission reduction potential is not only dependent on the carbon footprint of the inputs to the CO_2 utilisation process (e.g. energy, heat, hydrogen and CO_2), but also the value given to any avoided emissions.

CO_2 utilisation can contribute towards GHG emissions reduction but this must be put in the context of mitigation plans as a whole. CO_2 utilisation can have a double benefit for emissions reduction: through CO_2 capture and conversion and also potentially through CO_2 emissions avoidance. The latter is a consequence of using CO_2 as the carbon source rather than using additional carbon from underground. Each process will have its own merits and each must be considered separately. Central to this is an honest, thorough, transparent and robust Life Cycle Assessment of the process relative to the conventional or other alternative processes. The SCOT project believes the potential is there to provide CO_2 reductions for Europe, although this is clearly dependent on the nature and scale of CO_2 utilisation development.

Given the mitigation challenges we face, to come to near zero emission around 2050, we see the need for increased efforts to make CO_2 air capture both technical feasible at large scale and an economical viable source for CO_2. Direct air capture enables CO_2 utilisation to deployed in any location removing the need for point sources of CO_2 or CO_2 transportation.

Carbon dioxide utilisation can contribute to a reduction in CO_2 emissions, however the amount of reduction will vary depending on the process and product end use. CO_2 reduction can be described in two ways:

· Reduced net emissions: CO_2 utilisation routes have lower CO_2 emissions than traditional routes, CO_2 is still added to the atmosphere but it is less than before. Carbon avoided needs to be considered.

· Negative emissions: More CO_2 is taken from the atmosphere than is emitted, therefore CO_2 is removed from the atmosphere. Only possible with DAC or bio-sources of CO_2. Carbon avoided may or may not need to be considered.

Understanding avoided carbon is also crucial to understanding the emissions descriptions above, carbon avoided is the emissions that do not now occur due to using a new process route to produce the product, i.e. switching from a fossil carbon source to a CO_2-based carbon source. At its core CO_2 utilisation is using carbon from fossil sources more than once to avoid using more fossil carbon.

In the case of polyurethane foams a 19% reduction in emissions has been observed by Covestro (formally known as Bayer Material Science). In the case of Solidia's process for CO_2 cured concrete a potential 70% reduction from end to end has been observed.

How useful is CO_2 utilisation for CO_2 emissions reduction?

CO_2 utilisation processes and product pathways should clearly aim for reduced net emissions (otherwise they will increase atmospheric CO_2) or be carbon neutral, but negative emissions are the best scenario resulting in CO_2 removal from the atmosphere. However, negative emissions routes are dependent on taking carbon from the atmosphere, which means they are dependent on DAC or bio-sources of carbon. The treatment of avoided CO_2 emissions in comparison to a traditional production route (e.g. where the system boundaries are set) should be made clear in any LCA undertaken.

By 2020:

· A broad range of stakeholders (including politicians and affected publics) are aware and supportive of the wider benefits of carbon dioxide utilisation technologies and products

· Benchmarking framework including a widely accepted LCA is in place to compare CO_2 utilisation processes

By 2030:

· CO_2 utilisation is decreasing net emissions via avoided emissions and permanent sequestration

· Wastes are mineralised to provide long term CO_2 storage within commercial building materials

· CO_2 utilisation synthetic fuels' lower net emissions have reduced transport emissions

By 2050:

· CO_2 utilisation has grown to such an extent that it is significantly reducing Europe's CO_2 emissions

· Direct air capture is helping to reducing net emissions in all sectors by removing CO_2 directly from the atmosphere, thus allowing CO_2 to be fully recycled without the need for additional carbon from underground

CO_2 utilisation is contributing upto 5% of the 40 GT CO_2 reduction target

What should be happening to achieve this and by when…

3

What would help accelerate the market development of CO_2 utilisation?

In common with other industrial processes, CO_2 utilisation market progress is ultimately influenced by a combination of scientific advances, technological developments, policy agendas, market frameworks, wider social acceptance and also, crucially economics,. Europe's industrial sector will be the main actors for the growth and investment in CO_2 utilisation processes and product development, and understanding the policy commitments that would enable them to make major investments will be a critical factor to allow the sector to scale-up i.e. industrial investments stand a better chance of being made if it provides an attractive rate of return given the perceived risks and alternative investment choices. Establishing credible, coordinated and long-lasting policy frameworks is extremely important to transition Europe towards a future in which the profitability of industries is more and more correlated to its environmental impacts. This would continue the broad policy direction of the EU over recent decades.

As shown in Figure 4.1 there are a wide range of TRLs for CO_2 utilisation processes, which suggest a different approach is required for different areas. These will be examined in greater detail in the SCOT project's Strategic European Research and Innovation Agenda to understand where support could be targeted to accelerate some of these advances.

In general it is felt that all areas of CO_2 utilisation would benefit from the technological learning and cost reductions driven by scale-up that follows larger-scale investment. However, this is thought to be especially true for the mineralisation sector that is rapidly moving from pilot scale to full-scale manufacturing plants, and initial policy should encourage this scale-up and investment to take place within Europe.

· Advances in plasma and co-electrolysis CO_2 utilisation processes to allow competing routes to conventional Fischer-Tropsch and Sabatier processes to produce syngas and hydrocarbons

· Advances in modular reactors that allow CO_2 utilisation processes to be operated under a flexible part load regime rather than under steady state conditions; this allows the CO_2 utilisation process to better follow variations in low-carbon low-cost electrical generation

· Advances in carbon capture technology (including air-capture technology) to lower costs and energy use

· Advances in CO_2 utilisation processes based on photochemistry, utilising primary energy from the sun directly (without being transformed into electricity) by mimicking photosynthesis to generate fuels and chemicals from CO_2

· Advances in catalyst development e.g. catalysts based on earth abundant materials; catalysts allowing the direct use of flue gases of varying composition; catalysts that are able to be recovered economically

Technological developments that would help the CO_2 utilisation sector

· Agreement on appropriate life cycle analysis techniques for the CO_2 utilisation sector

· A systematic investigation of the social facilitators and barriers to CO_2 utilisation products being successfully introduced to various market sectors

· Access to low-cost CO_2, hydrogen, low-carbon electricity and heat.

· Favourable policy incentives to reduce the cost gap between fossil fuels and CO_2 utilisation derived synthetic fuels

· An association that can continue the work of the SCOT project

· An increase in education and training to allow greater understanding of the benefits of CO_2 utilisation

· Availability of suitable infrastructure; industrial symbiosis

Other developments that would help accelerate the CO_2 utilisation sector

There is a need for enhanced coordination and a coherent European funding strategy for CO_2 utilisation. In the absence of such a strategy, countries fund individual projects and create their own networks of actors. This is sub-optimal and as such, a supra-national coordination would highly be desirable.

It is felt that Europe would benefit from a greater number of pilot and demonstrator projects to help bridge the gap and accelerate market development. Crossing the 'valley of hope' – taking research outputs into the market – is an area where more effective policy support will be necessary.

Many of these developments will be further explored in the Strategic European Research and Innovation Agenda document – the next phase of the SCOT project.

4

Why is Europe the right place to accelerate the market development of CO_2 utilisation?

4.1 Europe has a world leading science base in CO_2 utilisation

Most regions in Europe are funding research on CO_2 utilisation at various technology readiness levels (TRLs)[2]. In general, Europe has a high concentration of innovative research that is taking place in universities and research centres that are actively involved in co-design, collaboration and knowledge exchange. The CO_2 utilisation sector is attracting an increasing level of investment to start-ups such as Econic Technologies (UK), Carbon8 Systems Ltd (UK), Recoval (Belgium), Sunfire (Germany) and is complemented by investment within Europe's established multinational industrial leaders such as BASF and Covestro (formally Bayer Material Science).

4.2 Europe has world leading industries and engineering capability in key sectors

European industry operates across the full CO_2 value chain and has an engineering capability that is a key strength for CO_2 utilisation development. Europe has a long established chemical products sector with world leading industrial gas companies coupled to an extensive knowledge base with broad and deep supply chains. The high levels of integration and the existence of powerful networks and hubs that could support the creation of new CO_2 utilisation value chains within Europe should not be underestimated.

[2] http://bit.ly/1eyekDh

4.3 Europe has strong networks of innovation actors with breadth and depth

Europe has strong networks bringing together CO_2 utilisation stakeholders. CO_2Chem operates worldwide but with the majority of members in the UK, ClubCO_2 and CO_2 Forum operate in France and CO_2Net in Germany. Activities by CEFIC have brought together key stakeholders in CO_2 utilisation for roundtable discussions leading to new partnerships and initial road-mapping. Europe also hosts a number of major annual and biannual conferences on CO_2 utilisation. Overall the breadth and depth of CO_2 utilisation stakeholders in Europe is advancing, not only in the technological areas, but also the areas of social-acceptance and public perception too.

4.4 Accelerating CO_2 utilisation development is aligned with Europe's long term policy objectives to move to a circular economy

Most countries in the EU are aware of the need to move towards a decarbonised more resource efficient and circular economy. The 7th Environment Action Programme (EAP) set by the EC in 2013 identified the need to turn the Union into a resource-efficient, green and competitive low-carbon economy (Objective 2). Transforming surplus low-carbon electricity into different energy carriers and chemical products aligns with Europe's resource efficiency agenda and moving towards a circular economy. Furthermore, CO_2 utilisation processes will support meeting these objectives by enabling innovative regional supply chains for chemical products and fuels, supporting the energy transition and reducing to some extent GHG emissions.

4.5 Europe is a strong leader in decarbonising its energy systems

With its targets for a 20% share of renewable energy by 2020, rising to at least 27% by 2030, the EU is a strong leader in promoting the use of renewables and use of low-carbon technologies. Such policies have already successfully triggered important transformations in the European energy sector, where renewable energy has already become a mainstream choice. In 2013 electricity generated from renewable sources contributed 25.4% of the EU-28's gross electricity consumption[3], providing significant employment and economic opportunities. The large-scale deployment of renewables creates new opportunities in balancing the electrical network over different timeframes.

All in all, the co-design, collaboration and knowledge exchange strengths mentioned above constitute a highly favourable foundation for CO_2 utilisation development to be accelerated in Europe. However, it is also important to note that many of these strengths are not unique to Europe. The USA and China also have strong industrial bases, engineering capability, and are developing research and development activities in the CO_2 utilisation space. Given Europe's experience with encouraging the renewables sector to move into the mainstream, it has the proven ability to lead in this area; however to do so requires the multiple stakeholders to better understand the benefits of CO_2 utilisation, which is part of the remit of the SCOT project.

4.6 How advanced is CO_2 utilisation today?

The figure below broadly shows the range of Technology Readiness Levels (TRLs) of promising applications categorized into the three major CO_2 utilisation pathways: mineralisation, chemical products, and synthetic fuels. Even within the different kind of pathways, the TRLs may differ over the whole sector therefore the figure shows the levels that the majority of the effort is concentrated around. Some CO_2 utilisation technologies are close to the market, however, there is a wide array of processes to transform CO_2 into products that still require more research and/or changes in the regulatory framework to become commercial. SCOT's vision for 2030 is to have increased significantly the TRLs of the promising CO_2 utilisation routes, which can have a positive effect on resource efficiency and decoupling the economy from CO_2 emissions.

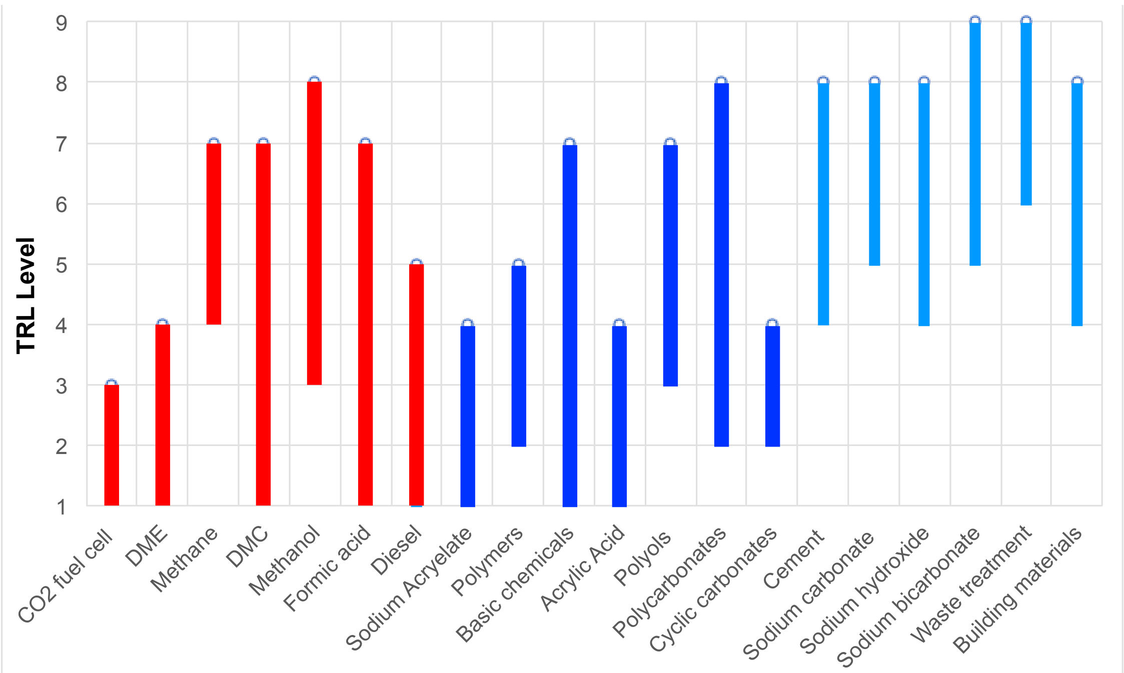

Figure 4.1: Range of TRLs of the different CO_2 utilisation technologies

[3] http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics

Today the scale of profitable business opportunities is a major barrier for companies to further engage in CO_2 utilisation commercialisation. However, a few innovative companies are already seizing opportunities related to CO_2 utilisation, and new and better processes are emerging. Therefore, CO_2 utilisation products are already entering certain niche markets on a commercial basis, examples of this are:

Carbon 8 Systems in the UK uses accelerated carbonation technology (ACT) to manufacture a high quality lightweight aggregate – C8Aggregate (C8A). The ACT process permanently captures more CO_2 than is generated during its manufacture, making the aggregate carbon-negative.

Carbon Recycling International (CRI) is disconnecting the methanol economy from fossil fuels via producing methanol from CO_2, hydrogen and geothermal power. The CRI George Olah plant in Iceland produces 4000t/yr methanol and is at TRL9 whilst a pilot plant project in Germany at the Steag Lünen coal-power plant will produce 400t/yr at TRL7-8.

CCm Research in the UK are producing a range of products from industrially seperated CO_2. A fibrous fertiliser material has undergone agricultural trials and a pilot plant is in development.

Covestro. As part of the 'Dream Production' project at **Covestro**, the production of CO_2-based polyols for polyeurethanes has been demonstrated at pilot scale and now a production line for 5,000 tons/year (TRL9) is being built at their Dormagen, Germany site.

The **Audi E-gas** project in Germany is pilot-scale demonstration (TRL7-8) of Power-to-Gas technology. It is links renewable electricity with car mobility and the natural gas network.

Novomer (USA) are using CO_2 in the co-polymerization of epoxides to make polycarbonates. Their PPC polyol is available at a commercial scale and adopted into a formulation for polyurethane hot-melt adhesives by Jowat AG.

Recoval in Belgium have demonstrated the recycling a fine fraction of steel slags into construction materials at pilot scale. These products meet The Netherlands & Belgium standards required for construction materials.

Integration of process steps leading to flexible turnkey solutions for different markets is key to the approach taken by **Sunfire** to produce power to liquids in Germany. The Sunfire pilot plant (TRL7) uses renewable energy, water electrolysis, CO_2 conversion processes and Fischer Tropsch chemistry to create blue-diesel which can directly be used in cars.

5

The Next Steps

CO_2 utilisation has the potential to significantly change the way in which we view and control CO_2, switching it from an unwanted by-product with little value to a valuable resource. The development of CO_2 utilisation technologies will require investment but will result in lower environmental impacts and an opportunity for industrial redevelopment in Europe, while reducing fossil fuel import dependence. However, for that to happen, there needs to be a clear longer-term strategy involving research and industrial policy.

The SCOT project will promote the implementation of CO_2 utilisation technologies throughout Europe via the creation and advocacy of several documents:

- The Strategic European Research & Innovation Agenda (SERIA), where we will outline the research and innovation agenda to make CO_2 utilisation a European success story. The SERIA will give guidance for future coordinated action at the EU level.
- The Joint Action Plan (JAP) will define the short to mid-term actions that need to be done collectively to achieve the SERIA and ultimately the Vision presented in this document.

The SCOT project believes that CO_2 utilisation will enable European industry to become more resource-efficient, sustainable and competitive. This document, the Vision, together with the SERIA and the JAP aim to accelerate the market development of CO_2 utilisation in Europe, to help Europe realise the potential of CO_2 utilisation to achieve Europe's industrial renaissance and to help decouple its economic growth from its emissions.

If you would like to find out more about this vision and how to become involved with the SCOT project, please visit

www.scotproject.org

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Smart CO2 Transformation

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