Overcoming hurdles for innovation in industrial biotechnology in Europe

Industrial Biotechnology for Use of CO_2 as a Feedstock

Summary

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The BIO-TIC project aims to identify hurdles and develop solutions to the large scale deployment of Industrial Biotechnology (IB) in Europe. IB as a process to use CO_2 as a feedstock is one of five product groups which we have identified to have significant potential for enhancing European economic competitiveness and which have the potential to introduce cross-cutting technology ideas.

This document is a summary of the findings related to IB for CO_2 utilization at the mid-way stage of the project and it has been produced as a discussion piece in order to collect stakeholder's thoughts on the hurdles within this sector and ideas for how these hurdles can be overcome to capture the full potential of IB for CO_2 conversion. This document is a summary of work in progress, therefore, it may not address some topics, which we aim to cover during the forthcoming business case workshop on "CO_2-based chemicals".

Background

CO_2 is widely available from a variety of fossil sources (e.g. syngas production, natural gas sweetening, coal power production…) and bio-based sources (e.g. distilleries and anaerobic digestion). The use of CO_2 as a feedstock for chemicals and materials is attractive for two reasons: 1) CO_2 is the only raw material that Europe has in abundance, and 2) its use is completely outside of the food chain. Utilization of CO_2 is a concept in which CO_2 is considered a valuable commodity rather than a pollutant. Currently, the largest example is the direct use of CO_2 in Enhanced Oil Recovery (EOR). Other direct uses of CO_2 involve the production of carbonated drinks, inert gas for the packaging industry and use as a fire extinguisher and as a cooling fluid e.g. for fridges. CO_2 is also used as a feedstock for the production of e.g. urea, methanol and in the synthesis of acetylsalicylic acid (aspirin). There are many other ways under development, using both industrial biotechnology and chemical catalysts, by which CO_2 can be converted to chemicals and plastics. The industrial biotechnology routes include:

1) **Microalgae technologies**, where microalgae produce biomass and within this biomass chemicals from CO_2 and sunlight,
2) **CO_2 fermentation**, where CO_2 is fermented to a desired molecule using hydrogen as an energy carrier,
3) **Advanced biotechnological processes,** where the abilities of cyanobacteria (a branch of microalgae) to use CO_2 as a *carbon source* and sunlight for energy are merged with the metabolic pathways of known micro-organisms,
4) **Bioelectrical systems**, where enzymes or micro-organisms use CO_2 as a carbon source and electricity as an energy source for their synthesis**,**
5) **Artificial photosynthesis**, where CO_2 is converted to desired chemicals with a (bio)catalyst using photocatalytic water splitting as an energy source.

Market drivers, innovation hurdles and proposed solutions

Currently, the use of IB for CO_2 conversion is in its infancy, with a number of different concepts at different stages of development. The first pre-commercial applications of waste gas fermentation processes to ethanol and 2,3-BDO have been developed. Lanzatech for instance, uses waste gas from coal power and steel mill plants to produce ethanol, acetic acid and 2,3-BDO through CO and CO_2 fermentation. Other companies active in this area include Ineos Bio, Coskata and OPXBIO. Most technology developers are currently aiming to develop drop-in chemicals which have established value chains.

Establishing market projections for the future growth of IB use for CO_2 conversion is extremely difficult given the nascent state of the industry. However, it is possible to develop tentative estimates of the deployment of different technologies by outlining the challenges and limiting factors these will face.

The Vision for use of IB for CO_2 conversion in the EU by 2030

Microalgae technologies will most likely be focused on high value specialties and polymers rather than commodity fuels and chemicals because of their poor efficiency of product recovery and subsequent doubtful economic viability for bulk chemicals, especially in Europe.

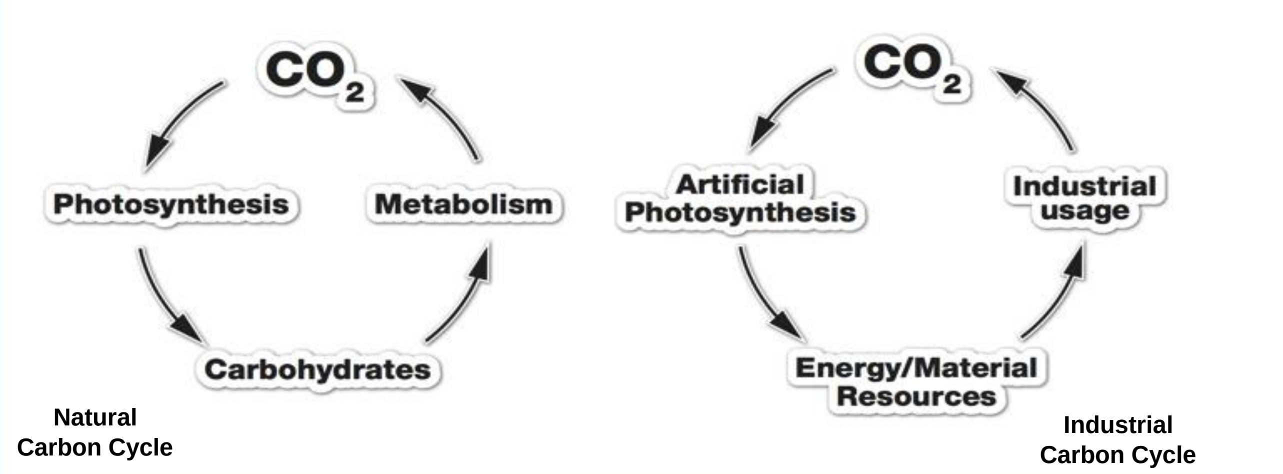
Bacterial CO and CO_2 fermentation will be able to produce a large variety of chemical compounds but will only be cost-competitive where clean low-cost hydrogen and CO_2 are available.

Advanced biotechnological processes are likely to progress at the lab scale and be able to use CO_2 as a direct substitute for sugars while producing similar compounds to those derived from CO and CO_2 fermentation. However, a persisting key challenge is the efficient design of bioreactors.

Bioelectrical systems will probably be in pilot demonstration by 2030 and provide pathways for a great number of compounds (i.e. multicarbon extracellular organic compounds) as well as possibilities for the storage of renewable electricity in chemical form.

Artificial photosynthesis will most certainly not reach large scale production but will remain an intriguing research topic with operating pilot facilities because it offers opportunities for decentralized chemical production using water, sunlight and CO_2.

The true potential of using CO_2 as a feedstock for chemicals production lies in its contribution to promoting the concept of "CO_2 economy". According to this approach, the industrial cycle uses CO_2 as an abundant carbon source along with renewable energy in order to upgrade it to various chemicals and materials which are in turn consumed by industrial usage (see the Figure below).



The efficient capture of CO_2 to enable its reuse as a feedstock is crucial to the long term goal of realizing efficient biorefineries with closed CO_2 cycles. CO_2 is abundant and available cheaply *at source* across Europe; however conventional carbon capture technologies are often costly and energy intensive. This is especially true for heterogeneous waste streams such as those derived from coal fired power stations where CO_2 concentrations may be low and where many impurities exist. As a result, CO_2 is not necessarily a cheap feedstock for chemicals production *at point of use*. Several innovative technologies are under development to reduce the costs associated with CO_2 capture, for example, enzymatic carbon capture technologies have the potential to cut costs significantly compared to conventional CO_2 capture technologies. In the short-term, utilising the exhaust gas from yeast fermentation, for example from distilleries, and from anaerobic digestion plants, may be the most cost effective route to using CO_2 waste streams in many circumstances as these sources have a higher proportion of CO_2 and have fewer impurities. Even though it can assure a high quality of CO_2, Direct Air Capture is currently very expensive and still in the research phase.

The logistics and costs of CO_2 collection and transport from source to the processing plant pose additional hurdles. CO_2 producing industries need to be interlinked by a pipeline system to transport the flue gas to the end user and the further away the end user is from the source, the more costly pipelines are. Alternatively, flue gas could also be potentially transported in compressed form in gas flasks. However, this range of measures appears to be relatively inconvenient and quite expensive for a waste gas such as flue gas. This limits the use of waste flue gas to over-the-fence located consumers. As a result, it is considered that only when flue gas is upgraded to a valuable final product, its distribution over long distances becomes more economically feasible.

For many IB routes for CO_2 utilization as a feedstock, research is still at an early stage and requires substantial funding. Many technical issues need to be resolved. The conversion of CO_2 to chemicals requires energy. CO_2 is an inert, highly stable compound which requires high activation energy for any chemical reaction to occur. In the IB processes discussed in this report, the required energy for CO_2 conversion is obtained either from hydrogen, sunlight or electricity, but it is thought that current technologies are unable to support industrial scale conversion of CO_2 into chemicals because the biochemical reactions are not yet self-supporting in terms of energy requirements.

The final yield of products is still low and needs optimisation. Microorganisms are generally more tolerant of impurities than chemical catalytic processes, but the tolerance of different microorganisms to different impurities can vary significantly and as a result, clean up needs to be matched to the tolerance of different microorganisms. Many of the current technological problems (coating degradation under UV; oxygen release and water decomposition) can be overcome but investment is needed. The costs for the production processes need to be competitive against conversion processes available for non-renewable hydrocarbons. It is crucial for CO_2 technologies to be less energy and material intensive with respect to the on-stream processes that they aim to replace.

There is currently a lack of investment in R&D which hinders efforts to overcome the challenges facing this sector. These challenges need to be addressed before scale-up occurs. The scale-up from laboratory to demonstration and from demonstration to commercial production appears problematic as there appears to be no willingness to invest in prototypes. There is a problem to get into current regular funding programs for research and development. At this moment, the price competitiveness is doubtful: there is no real cost-benefit analysis on the implementation of the technology. The inputs needed (e.g. energy) are higher than for conventional chemistry routes, and the yields e.g. for specialty chemicals are still low. There are currently no economic (or other) incentives to use CO_2 as feedstock for chemicals production.

The development of the CO_2 economy will be strongly influenced by policy drivers. There is a need for a policy framework that supports the economic feasibility of CO_2 utilization.

Conclusion

Substantial research into the fundamental process design is required to exploit the full potential of CO_2 technologies and pursue the goal of a CO_2 economy. The R&D and investments towards attaining this objective can be fostered if policy encourages a knowledge-based industrial culture which is less risk-averse and acknowledges the need to shift to a CO_2 economy and decarbonisation of the energy sector. Europe has a significant strength in low carbon technologies, accounting for 35% of IP in this sector. The development of a CO_2 using industry will not only help boost the export of EU technologies and facilities in this emerging field, but it will link Europe's top sectors, the chemical industry, engineering and renewables.

How to get involved

*Stakeholder engagement is crucial in ensuring that actions are developed which best fit the needs of this sector. The BIO-TIC project would greatly welcome any comments you might have on this document, hoping that your valuable input will contribute to setting the groundwork for a targeted workshop dedicated to CO_2-based chemicals through IB which will be held on **24th of September 2014 in Lyon, France**. You can register for this workshop at the following link - http://bio-tic-workshops.eu/carbon_dioxide/.*

We are particularly interested in your views on what the deployment status of different routes for IB conversion could be in 2030, whether we have missed any key hurdles and on any solutions which you could envisage could overcome these hurdles. Please send any comments to bio-tic@europabio.org by end of August 2014.

The table below summarizes the hurdles and some solutions that can be envisaged to overcome the bottlenecks related to using IB for CO_2 conversion. The hurdles that are highlighted in green apply to CO_2 conversion specifically, but are also an issue for IB in general. The white cells apply only to using IB for CO_2 conversion. The cells that have been left blank indicate that no solution has yet been formulated with regards to that barrier. Stakeholders are invited to consider both the blanks and the proposed solutions and send in their feedback to bio-tic@europabio.org

Hurdles	Solution proposed	
	R&D	Non-technological
Uncertain economic feasibility/no incentive to use CO_2		*-Implementation of a carbon tax* *-Reduction of energy prices, making the technology cheaper* *-Increase the CO_2 price in EU ETS trading scheme*
High feedstock cost at point of use due to upgrading costs		
Scale-up is difficult	*- Develop new masters and Ph.D programs and apprenticeships focused on combining chemistry and chemical engineering disciplines* *-develop predictive models for scale-up similar to the computational systems that are already used in engineering fields*	
Cost of Direct Air Capture		
Downstream processing costs		
Process performance is currently poor in terms of yield, productivity and robustness	*-Develop microbes resistant to resistant to byproducts and target products* *-Identify novel, more active and robust enzymes that improve biocatalysis* *-Develop synthetic systems to produce enzymes* *-Develop microbes with an improved ability to convert feedstocks into products* *-Integrated optimization and development of CO_2 capture, bioconversion, product recovery and downstream processing*	
Economic feasibility of algae production for fuels		

Efficiency and product recovery when using algae technologies		
High cost of solar power		
Design of bioreactors for advanced biotechnological processes		
Lack of infrastructure		*-Infrastructure needs to be developed for transportation of CO_2*
Risk of long term investment/access to funding		*-Implementation of funding for feasibility studies for start-ups and special grants for product development and commercialization such as the Small Business Investment Company Program* *-Construction of shared laboratories and improved pilot plant facilities, open to all companies i.e. pre-competitive R&D* *-Allocation of funding for the construction of new large scale facilities and improvement of pilot facilities at interregional/national and EU level*
Limited impact on GHG emissions		
Lack of R&D funding		*-Change of policy towards a knowledge-based industrial culture which is less risk averse* *-Development of new programs for new and sustainable technologies* *-Implementation of a public and private funding scheme* *-Increased R&D funding at EU, national and regional level for pioneering public research in collaboration with the industrial sector in a co-funding scheme*
Low public perception		*-Stress the fact that CO_2 comes from combustion and the importance of - in the long term - shifting to a CO_2 economy (chemistry) and decarbonisation of the energy sector*