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9th Carbon Dioxide Utilisation Summit 2017

Latest advances in routes to renewable fuels and chemicals, reducing global greenhouse gas emissions

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1. Introduction

The Carbon Dioxide Utilisation Summits are held twice per year, alternating between being hosted in a European location and in North America. They are organised by Active Communications International (ACI), Inc. This two-day event was held in Reykjavik, Iceland, on 18th and 19th October 2017. The main aim of this Summit series is to bring together key players from industry, research institutes and universities to explore the ongoing developments in converting waste carbon dioxide (CO_2) into commercially viable opportunities. The summit highlighted the different projects currently in place or expected to happen involving CO_2 capture and utilisation (CCU) across various sectors including transport fuels, chemicals and polymers, from pilot-stage to commercial operation as well as the challenges faced for future deployment. Approximately 100 participants from more than 75 organisations from around the world attended this event, with a high proportion from industry. Universities and research institutes were also represented, providing some of the conference's oral presentations. The key topics of the summit included:

- Getting the industry together to accelerate market deployment of CO_2 utilisation
- CO_2 utilisation's role in a sustainable future
- Policy and regulation
- Life cycle assessment of CO_2 utilisation projects
- CO_2 bio-conversion to renewables
- Electrochemical reduction of CO_2
- CO_2 to fuels
- CO_2 to chemicals and materials.

After each of the main themed sessions a panel of the presenters was formed for questions and answers with the audience.

There was also an opportunity to visit Carbon Recycling International's (CRI) George Olah (GO) renewable methanol plant located in Iceland's Svartsengi geothermal field near Grindavík on the Reykjanes peninsula (**Figure 1**). The plant was first commissioned in 2012 with a capacity of 1300 tonnes per year of renewable methanol and was expanded in 2015 with a current capacity of 4000 tonnes per year. It utilises both captured CO_2 from the nearby Svartsengi geothermal power station and renewable electricity from the Icelandic grid to produce hydrogen *via* the electrolysis of water

Fig. 1. CRI's George Olah (GO) renewable methanol plant located near Grindavík, Iceland

for use in methanol synthesis. By producing the methanol liquid fuel that is used in gasoline blends the GO plant effectively recycles 5500 tonnes of CO_2 a year.

2. Keynote

On day one of the conference the keynote speaker, Damien Dallemagne (GreenWin, Belgium) talked about the creation of a European association dedicated to CO_2 utilisation projects. The mission statement for this was to promote the development and market deployment of sustainable industrial solutions that (a) convert CO_2 into valuable products, (b) which contribute to the net reduction of global CO_2 emissions and (c) increase the diversification of the feedstock base. Once formed, a mixed consortium comprising of industrial, university and research institute representation would look to collectively define a strategic roadmap for CO_2 utilisation and develop a favourable regulatory and market framework. Previously, GreenWin was a leader of the Smart CO_2 Transformation (SCOT) European Seventh Framework Programme (FP7) collaborative project from 2013 to 2016 with an objective to define a Strategic Research and Innovation Agenda (SRIA) for Europe in the field of CCU.

3. Policy and Regulation

Government policies, both nationally and internationally, will influence how fuels and chemicals will be classified now and in the future and will in turn help to stimulate and steer the development of new production technologies that fulfil the criteria.

Peter Hawighorst (International Sustainability & Carbon Certification (ISCC), Germany) talked about sustainability certification of products derived from CCU. ISCC is recognised by the EU and internationally as a voluntary certification scheme for food and bio-based products including biofuels. It is likely that companies exploiting CCU for chemical products or fuels will go through the ISCC to gain certification. The Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) set the framework for the implementation of the renewable energy regulations for the transport sector in the EU. These came into force in 2009 and were amended in 2015, with further changes expected for the new RED II for the period between 2020 and 2030. It is interesting to note that for certification, Life Cycle Assessments (LCA) and greenhouse gas (GHG) emission savings are important for each element of the supply chain for the final product.

The need for a comprehensive LCA that has been developed to allow a fair comparison between competing technologies was reiterated in André Sternberg's (RWTH Aachen University, Germany) presentation. André's work focusses on environmental assessment of 'power-to-X' technologies and CO_2-based chemicals (1); if they are going to help reduce global warming impact an LCA is necessary to quantify this with all energy utilisation defined and accounted for, including that consumed in capturing the CO_2. André also mentioned a novel CO_2-based fuel, oxymethylene ether (OME), produced from methanol, renewable hydrogen and captured CO_2, which is used as a diesel substitute (2). For this fuel, the energy must come from a renewable source to compete with conventional diesel based on the LCA and global warming impact.

4. Electrochemical Reduction of Carbon Dioxide

The forecast of a market that capitalises on the availability of inexpensive, surplus renewable energy has driven interest in developing technologies for the electrochemical reduction of CO_2 to chemicals or fuels. This comprised one of the themed sessions at the conference.

Klaas Jan Schouten (Avantium, The Netherlands) talked about the projects and activities that Avantium wishes to focus on. These involve high-value products including a bio-based bottle plastic, polyethylenefuranoate (PEF), made from Avantium's YXY™ process using fructose as a feedstock (now a joint venture with BASF named Synvina), and second generation sugar and bio-based monoethylene glycol (MEG). Avantium is involved in several European funded Horizon 2020 projects utilising CO_2 and electrochemistry, including Oxalic Acid from CO_2 Using Electrochemistry at Demonstration Scale (OCEAN), which involves taking captured CO_2 from the site of an industrial electricity provider to produce formate electrochemically through reduction of the CO_2 (at cathode) and coupling this with glucose oxidation (at anode) to improve the energy efficiency. Further conversion of the formate to oxalate is also a viable transformation. The project will then explore new electrochemical approaches to further convert formate and oxalate to formic acid and oxalic acid, respectively. The oxalic acid can be further converted electrochemically to glycolic acid and other high-value C2-products.

Other EU Horizon 2020 funded projects involving CO_2 electrochemistry include: Recycling Carbon Dioxide in the Cement Industry to Produce Added-Value Additives (RECODE), which uses CO_2 from the cement industry to make added-value chemicals employing ionic liquid based CO_2 capture; Cost-Effective CO_2 Conversion into Chemicals *via* Combination of Capture, Electrochemical and Biochemical Conversion Technologies (CELBICON), which uses CO_2 captured from air, syngas production from electrocatalysis followed by fermentation to high-value chemicals; and Electrochemical Conversion of Renewable Electricity into Fuels and Chemicals (ELCOREL), which carries out fundamental research on electrochemical CO_2 reduction using renewable electricity.

Matthias Jahn (Fraunhofer IKTS, Germany) set the scene of his presentation by talking about the goals of the German government for the share of renewable energy in power generation and emission reduction, concluding that in Germany there would be excess renewable energy available for hydrogen production and then CO_2 utilisation would help reduce emissions leading to the feedstocks for fuels and chemicals. Taking a view that CO_2 capture from air could well be too expensive, at least in the short- and mid-term, Fraunhofer has focused on the concept of using CO_2 rich off-gases from power plants and industry. Its technology uses co-electrolysis of CO_2 and water in a high temperature solid oxide electrolyser cell (SOEC), to form syngas (hydrogen and carbon monoxide) that feeds into the Fischer-Tropsch (FT) synthesis step (**Figure 2**).

The synthesis step comprises small-scale reactors with novel ceramic catalyst support structures for FT reactions to higher alcohols, diesel or waxes. The company has developed its own in-house cobalt and iron FT catalysts with promotors, which are coated on the ceramic support. This work is supported by modelling and process simulation studies. From the techno-economics Fraunhofer has concluded that production costs and economic feasibility are highly dependent on the electricity price and final FT product value, with countries generating relatively inexpensive renewable energy such as Iceland and Norway being favoured for power-to-X processes (3). A technical challenge for deployment would be the necessity for long-term, stable operation of the high temperature SOEC unit.

Roland Dittmeyer (Karlsruhe Institute of Technology (KIT), Germany) talked about KIT's advanced power-to-gas process integrating a SOEC operating in co-electrolysis mode to produce a syngas from water (steam) and CO_2 that is fed to a microchannel methanation reactor. KIT is involved in a German nationally-funded project that started in 2016 and includes this process, called Kopernikus, which aims to produce a prototype system for a 100 kW_{th} methane output. The Kopernikus "Power-to-X" project also looks at producing FT end-products, amongst others, using renewable energy.

Jan Vaes (Hydrogenics Europe, Belgium) discussed Hydrogenics' involvement in CO_2 utilisation projects that include: power-to-methane in the Power-to-Gas *via* Biological Catalysis (P2G-BioCat) project; power-to-methanol in the EU Horizon 2020 Methanol Fuel from CO_2 ($MefCO_2$)

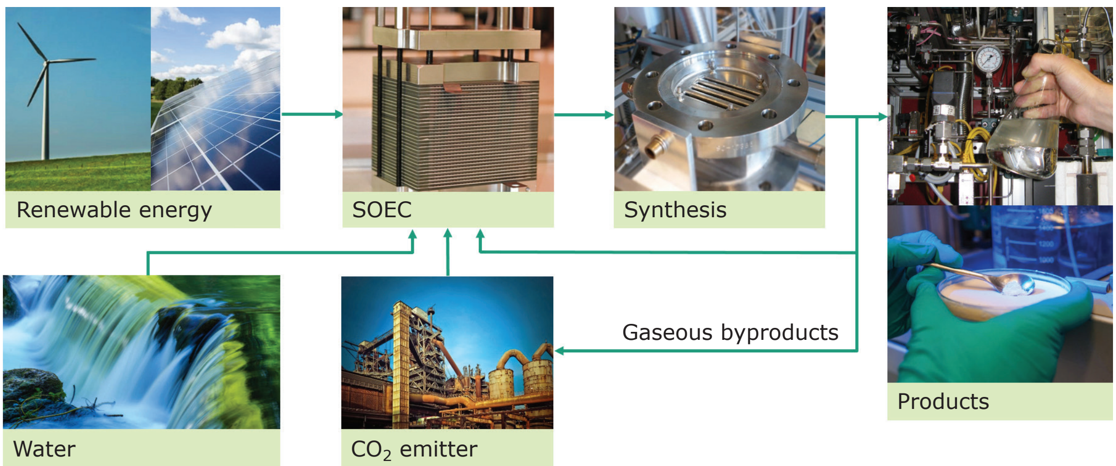

Fig. 2. Production of valuable chemicals from H_2O and CO_2 using co-electrolysis (Fraunhofer IKTS, Germany)

project; and power-to-polymers in a Belgian nationally funded project, all using Hydrogenics' proton exchange membrane (PEM) electrolysers for renewable hydrogen production.

5. Carbon Dioxide to Fuels

Ómar Sigurbjörnsson (Carbon Recycling International (CRI), Iceland) set the scene with what has been commercially implemented using renewable electricity and captured CO_2, this being CRI's renewable methanol plant located near Grindavík, Iceland. The renewable methanol product from this facility is sold under the brand name of Vulcanol™ and is already displacing a small amount of petrochemicals in the transport fuel sector. The methanol is blended in transport fuels for sale into Iceland and other countries including Sweden, The Netherlands and Denmark. The company has agreements with Methanex Corporation, Canada, the world's largest methanol supplier, and Perstorp, Sweden, which uses the methanol to make biodiesel. In 2015 Chinese carmaker Geely Holding, which owns Volvo Cars, became a shareholder in CRI, seeing methanol as an alternative automobile fuel. The renewable methanol product has been certified by ISCC as a fuel without biogenic origin, with GHG savings up to 90% when compared to gasoline. CRI is currently marketing its Emissions-to-Liquid (ETL) technology platform, which utilises captured CO_2 and renewable electrolytic hydrogen to make renewable methanol (**Figure 3**).

Björn Heijstra (LanzaTech, USA) talked about the company's novel gas fermentation technology (employing a proprietary bacterial strain) that uses carbon monoxide rich gases to convert the carbon to fuels and chemicals. The feed gas supplies both the carbon source and energy requirements for the bio-conversion. The gas fermentation platform enables production of a variety of fuels and chemicals, including ethanol, 2,3-butanediol and acetate from feeds containing carbon monoxide, carbon dioxide and/or hydrogen. LanzaTech plans to have commercial scale facilities located in Caofeidian, China, to start up in 2018 (producing 16 million US gallons of ethanol per year) and a large scale demonstration facility using off-gases from an ArcelorMittal steel mill in Ghent, Belgium (EU Horizon 2020 Steelanol project). LanzaTech is also interested in CCU projects that utilise electrochemical CO_2 reduction to carbon monoxide and renewable hydrogen generation by electrolysis, which together form a syngas feed for its fermentation technology (**Figure 4**).

Ulf Herrlett (Air Liquide, Germany) talked about the company's history in methanol production and how Air Liquide is considering more unconventional methanol production that is not based on fossil-fuel derived syngas. The terms 'green' and 'black' methanol were used to describe its feedstock origin ('green' refers to the use of renewable

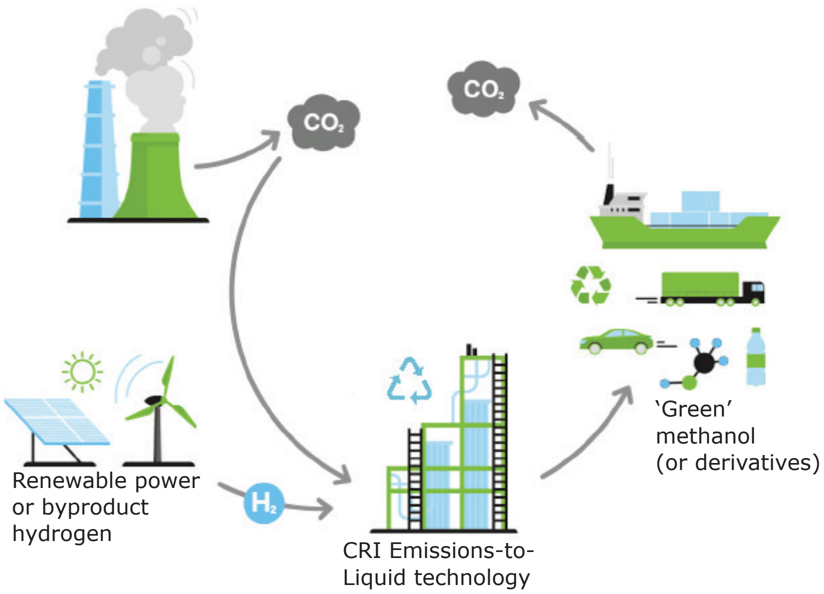

Fig. 3. CRI's utilisation of industrial CO_2 emissions to produce renewable methanol as part of their Emissions-to-Liquid technology

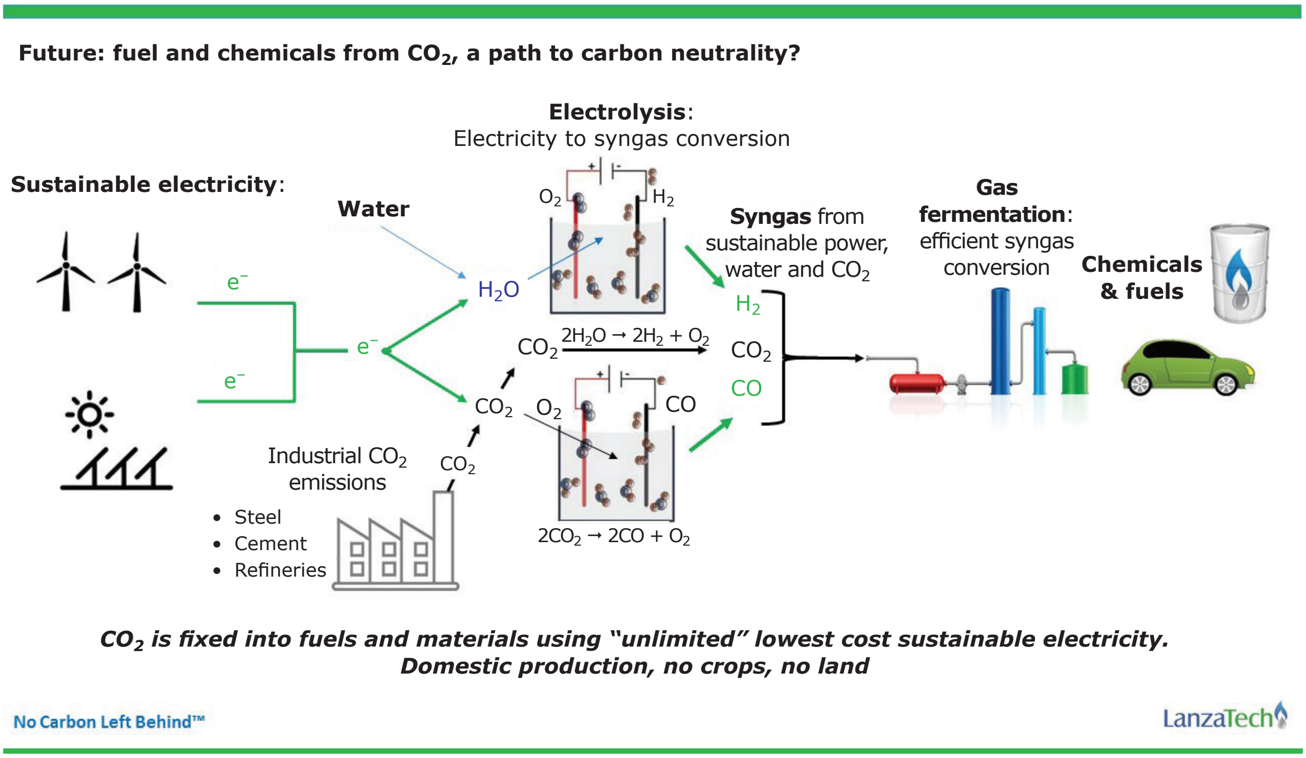

Fig. 4. Fuel and chemicals from industrial CO_2 emissions using electrochemistry and LanzaTech's syngas conversion technology

CO_2 and hydrogen feedstocks, 'black' is derived from fossil fuels). Air Liquide also has its own commercial cryogenic CO_2 capture technology named Cryocap^{TM}. A techno-economic study for a methanol process using electrolytic hydrogen and captured CO_2 was presented, concluding that for favourable process economics a high on-stream factor of the plant is required. Efforts to improve the efficiency of the electrolytic hydrogen generation step, together with a lower capital cost of the electrolyser and a lower electricity price, would help drive the deployment of this technology.

6. Carbon Dioxide to Chemicals and Materials

Presentations from Christophe Gürtler (Covestro, Germany) and Peter Shephard (Aramco Performance Materials, USA) were looking at using CO_2 to make building block polyols for everyday applications ranging from automobile seats to building insulation materials, with coatings, adhesives, sealants, elastomer and foam products. Richard French (Econic Technologies, UK), talked about their catalytic technology for using low-cost CO_2 and epoxides to form polycarbonate and poly[ether]carbonate polyols that can be used to make polyurethanes with up to 50% less petrochemical feedstock.

Laura Nereng (3M, USA) talked about low cost, high current electrolysers and 3M's involvement in developing materials for low temperature PEM water electrolysers, operating at very high current and with a low precious metal catalyst content in the electrocatalyst, for commercialisation in 2018. 3M is also involved in a Joint Development under a US Department of Energy Advanced Research Projects Agency-Energy (ARPA-E) research and development contract with Dioxide Materials, Inc, USA. This collaboration encompasses the development of membranes and membrane electrode assemblies (MEAs) for low temperature anion exchange membrane (AEM) CO_2 electrolysers (operating at relatively high current) and low temperature AEM alkaline water electrolysers (operating at relatively high current and without precious metal based electrocatalysts) for commercialisation in 2020. The drive of their research is to reduce the capital and operating costs of the electrolysers to promote the commercialisation and deployment of these technologies. Laura discussed the PEM and how 3M employs an iridium nanostructured thin film (NSTF) catalyst, using a vacuum sputtering coating technique, stating that the NSTF electrode is over

20 times thinner than a conventional precious metal dispersed electrode, exhibiting a thickness of less than ~0.4 μm. The use of iridium-NSTF based MEAs allows for high power operation up to 50 W cm^{-2} with current densities approaching 10 times (i.e. 20 A cm^{-2}) that of conventional PEM electrolysers. It was noted that efficient cooling design in the cell stack will be required to accommodate high power operation. For their CO_2 electrolyser materials 3M and Dioxide Materials are using imidazolium-containing polymers to eliminate mass transfer limitations in the cell and improve lifetime. As a result, they have reduced the necessary overpotential for cell operation, requiring significantly less electrical energy than before.

7. Conclusions

The 9th Carbon Dioxide Utilisation Summit was an enjoyable and informative event that brought together the right representation from industry and academia to facilitate networking and further developments in the exciting and relevant area of CCU. This short conference review is intended to give an overview of some of the sessions and presentations given at the event and it should be noted that not all these have been covered by this article.

It is evident that there is a significant amount of activity happening in the area of CO_2 utilisation with universities and industry all looking to develop their low carbon technologies, some of which have already been demonstrated and commercialised, the latter being exemplified by the CRI renewable methanol plant in Iceland. The array of technologies that were presented at the conference utilise captured CO_2 and renewable hydrogen to produce a variety of products including methanol, FT fuels and polyols for the plastics and polymers industry. The research and development behind these technologies is often supported through collaborative projects and there is much progress happening in this field. The future deployment of these new technologies will invariably be influenced by the process economics, including any government incentives, with certification required for renewable fuels. The LCA will form a key part in establishing the overall CO_2 utilisation and energy consumption of the new processes to enable a fair comparison with those conventionally derived from fossil-fuel feedstocks.

The next European edition of this Summit series, 11th Carbon Dioxide Utilisation Summit, will be held in Manchester on the 26th and 27th September 2018.

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The Reviewer

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