CO_2 to biofuels at Argos

To address the urgency of the climate crisis, a wide range of CCUS technology pathways are being explored by the cement industry. One of these options is the use of microalgae to capture CO_2 and transform it into valuable products. Over the past 10 years, Argos has been researching and scaling up the use of microalgae. Recently, the company has been testing a group of technologies to capture CO_2 directly from the cement plant smokestack using photobioreactors (PBRs) and transform the resulting microalgal biomass into biofuels.

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Climate change is quickly becoming one of the most crucial challenges we face as a society. As consensus continues to grow, the scientific community, business, community leaders and politicians from across the ideological spectrum agree that the potential consequences of an increase of 1-2˚C in global average temperatures would be catastrophic. Rising temperatures will put our planet in dangerous territory in terms of biodiversity, ecosystems, severe weather events both measured in frequency and amplitude, economic impact and increasingly on human life losses.[1]

Climate change is a complex issue where science does not have all the answers and where we still do not have all the solutions, especially not the technology, today to meet our goals to control an increasing global temperature. However, we understand the relationship between CO_2 emissions, global warming and climate change, and the amount cement production contributes to these emissions globally. Depending on certain variables used in the analysis process, cement production is attributed to around 6-7 per cent of global anthropogenic CO_2 emissions.[2]

Figure 1: current carbon capture utilisation and storage projects (CCUS) around the world[5]

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Future strategies

In general, most cement industry participants are committed to addressing the industry's impact and working to lower or even get to net-zero CO_2 emissions by 2050 throughout the value chain to offer carbon-neutral concrete. Through various global and local groups, associations and individual company contributions, the cement industry has developed strategies to reduce its CO_2 emissions at different stages of the lifecycle of both cement and concrete. These strategies are supported by a range of technologies that are at different levels of development. The International Energy Agency (IEA) forecast that to reach net-zero emissions by 2070, 60 per cent of the cumulative CO_2 emissions from cement production should be avoided thanks to carbon capture, use and sequestration (CCUS) technologies.

To reach the goal by 2070, the global cement industry would need to install a CCUS facility at a cement plant with an average capacity of 2Mta every week. By 2070, 80 per cent of clinker production facilities could have a CCUS unit capturing a total of 40Gt of CO_2[3]. This

Figure 2: CCU pathway from microalgae to biofuels

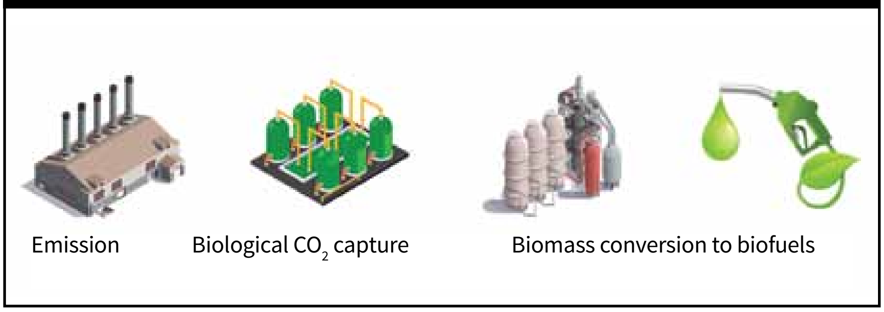

Figure 3: flat panel PBR developed by CarbonBioCapture and tested under real operating conditions at Argos' cement plant in Cartagena, Colombia, using Argos' developed process and growing medium. Tubular PBRs are used for inoculation

Figure 4: microalgae test bench at Argos' Innovation Center located at the campus of the University EAFIT in Medellin, Colombia

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would be an immense challenge for the industry as CCUS technologies are still in development. As of 2020 there were 21 large-scale commercial CCUS facilities, with a combined capture capacity of 40Mta of CO_2 (see Figure 1).[4]

A wide range of CCUS technology pathways have been proposed and investigated, developed and scaled up by various industry players. The magnitude and urgency of the climate change crisis calls for an approach that considers a range of technology options that could be used to reduce industry emissions to target levels. One of these technology options is the use of microorganisms, called microalgae, to capture CO_2 and convert it into useful products.

The microalgae pathway

Microalgae have been the subject of multiple studies and have been of great interest at certain points in time, only to be half-forgotten as the trials did not live up to expected results. As new production, farming and new knowledge has been developed, microalgae are again a suitable option to capture CO_2 and convert the biomass into valuable products at acceptable capex levels and operating costs. Microalgae have the potential to capture CO_2 that is today 10-50 times greater than other plants.[6] Moreover, the biomass they produce can be used in a wide range of products such as plastics, carbohydrates, lipids, proteins, fertilisers and fuels, among others.[7]

Over the past 10 years, Argos has been researching and scaling up the use of microalgae to capture CO_2 and transform it into valuable products from point source locations, such as cement, power generation plants or other concentrated CO_2 producing industries. Recently, Argos has been testing a group of technologies to capture CO_2 directly from the cement plant smokestack using photobioreactors (PBRs) and transform the resulting microalgal biomass into biofuels.

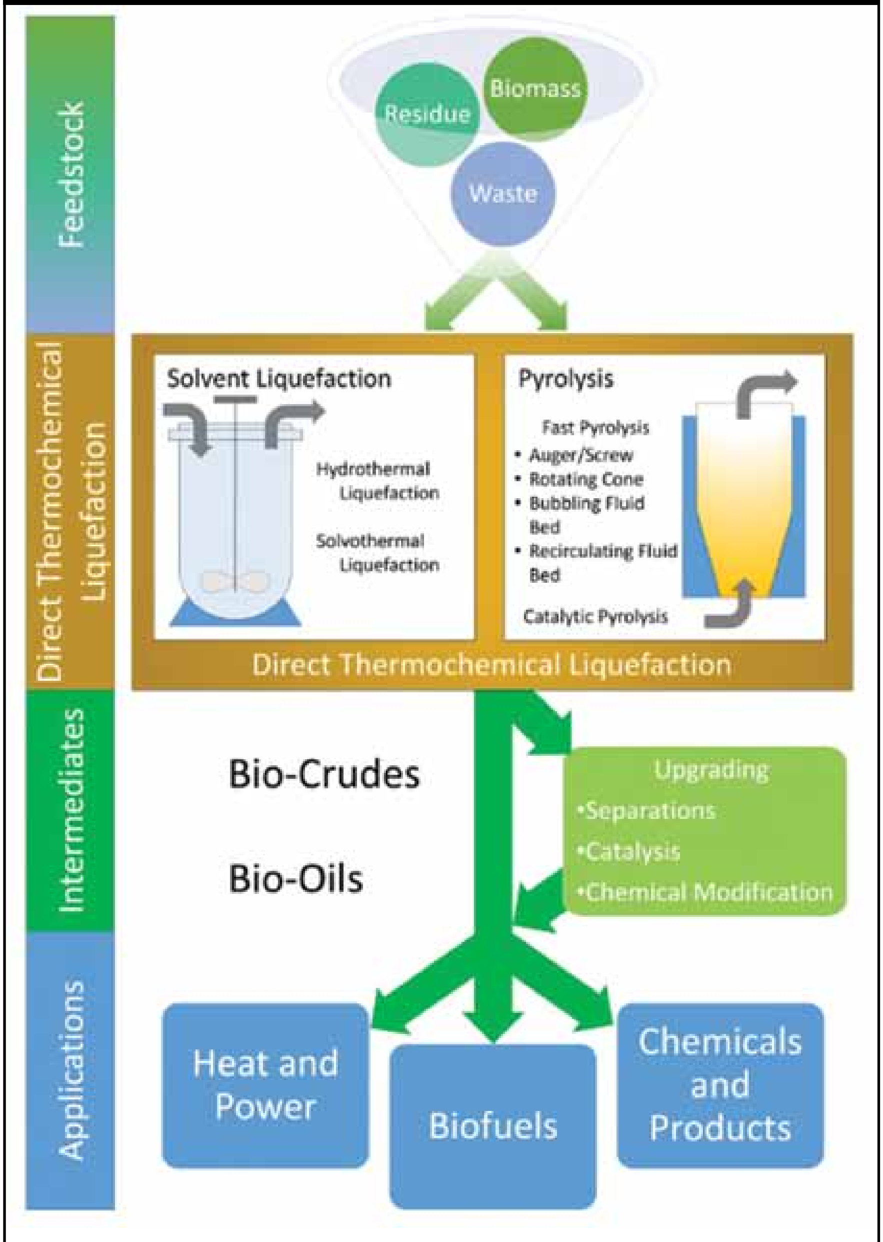
Current focus

Argos's current focus is to use the produced biomass as feedstock for biofuel production. It is driven by two market drivers:

1. Hard-to-decarbonise sectors such as aviation, long-haul trucking and marine industries will grow in demand for renewable energy options, which is likely to include liquid fuels as the required energy density is not met by battery technology.
2. The volume of biomass that must be produced to achieve a tangible impact on CO_2 emissions reduction requires a product line that is of similar size and global reach.

Using microalgae to capture CO_2 and turn it into biofuels relies on various technologies to achieve the required techno-economic performances for successful implementation. A key element in biomass production is the system to grow the microalgae and achieve an efficient biological CO_2 capture. Different technologies of PBR are currently available in the market and have been tested by Argos. For the last two years, Argos has tested a flat panel-type PBR (see Figure 3) at its Cartagena cement plant in Colombia. The flat panel system is designed to stimulate photosynthesis performance and increase biomass yield, ie, CO_2 capture rates, growth-driving nutrients availability and growing medium heat distribution. Cement production exhaust gases are injected into the panels designed to maximise CO_2 capture and biomass growth by optimising internal fluid dynamics, light absorption at all points of the PBR and algae use of nutrients for fast growth.

Figure 5: the larger field that studies the conversion of biomass into renewable energy is known as bioenergy. The figure shows the direct thermochemical pathway[8]



At the Cartagena plant, the PBRs are directly connected to the smokestack flue gases and used directly without treatment. Microalgae strains and handling developed by Argos have shown impressive adaptation to direct flue gas exposure, having obtained average biomass productivities of 32g/m^2/day, which in terms of CO_2 capture equates to around 290t/ha/year. For comparison, 1ha of trees captures up to 10t of CO_2 per year. This productivity has been achieved by combining the growing conditions (light, temperature, humidity), PBR design, microalgae strains and growing process and medium developed by Argos and its research partners, ie, Universidad de Antioquia Universidad EAFIT and others over time.

Biomass to biofuels

Further developments to reach commercial viability are focussed on the conversion of biomass into biofuels. To reach this point, Argos has teamed up with the University of Antioquia, Colombia, to develop a process based on direct thermochemical liquefaction and, particularly, a process for solvent liquefaction of the biomass (see Figure 5).

So far, based on batch-scale trials, optimum conditions of temperature, pressure, time, solvent compositions and solvent to biomass proportions have been defined to obtain a biocrude with good quality and at a cost in line with expected projection from institutions such as the Bioenergy Technologies Office at the Department of Energy of the United States[9]. These optimum conditions have delivered a biocrude yield of 0.63, which in CO_2 terms equates to 2.9 biocrude barrels per tonne of CO_2, placing our results in the upper levels of productivity reported in available literature.

Further, the obtained biocrude was successfully upgraded, obtaining 30 per cent of light fraction and 40 per cent mid-fraction, yielding high-value liquid fuels through well-known refining processes and facilities.

A cradle-to-gate lifecycle assessment for 1kg of diesel was developed. System boundaries included in the assessment are: biomass production, solvent liquefaction and biocrude upgrading. The resulting Global Warming Potential has a value of -3.11g CO_2/g of diesel, showing the positive CO_2 capture potential for this technology pathway for the cement and other concentrated point emission industries.

Testing, integrating and upscaling technologies

Argos continues to work with research and industry partners on testing, integrating and upscaling the technologies with a view of reaching commercial scale and cost feasibility in the near future. ■

BIBLIOGRAPHY

[1] GATES, B (2021) *How to avoid a climate disaster*. New York, USA: Alfred A Knopf, 256p.

[2] SCHNEIDER, M (2019) 'The cement industry on the way to a low-carbon future' in: *Cement and concrete research*, 124, p1-19.

[3] IEA (2020) 'Energy Technology Perspectives 2020' *https://www.iea.org/reports/energy-technology-perspectives-2020* [Accessed 12 September 2020].

[4] IEA (2020) 'CCUS in Clean Energy Transition' *https://www.iea.org/reports/ccus-in-clean-energy-transitions* [Accessed 20 July 2020].

[5] IEA (2021) 'About CCUS' *https://www.iea.org/reports/about-ccus* [Accessed 22 July 2021].

[6] ROJAS, D, VARGAS, G AND MORALES, JG (2017)'La alternativa biotecnológica para mitigar los gases de efecto invernadero procedentes de la industria cementera,' in: *Cemento y Concreto de Iberomaérica y el Caribe*, 4, p50-56.

[7] HEPBURN, C, ADLEN, E, BEDDINGTON, J, CARTER, EA, FUSS, S, MAC DOWELL, N, MINX, JC, SMITH, P AND WILLIAMS, CK (2019) 'The technological and economic prospects for CO_2 utilisation,' in: *Nature*, 575, p87-97.

[8] IEA (sd) 'Task 34: Direct Thermochemical Liquefaction' *https://task34.ieabioenergy.com* [Accessed 21 July 2021].

[9] US DEPARMENT OF ENERGY – OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY (2019) 'Bionergy Technologies Office 2019 R&D State of Technology' *https://www.energy.gov/eere/bioenergy/downloads/bioenergy-technologies-office-2019-rd-state-technology* [Accessed 28 May 2021].