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Editorial

ADVANCING BIOENERGY FOR A GREEN FUTURE

A major pivot in achieving a successful energy transition is the transformation from fossil-based to zero net carbon emission sources. Indeed, modern bioenergy (referred to as the low-impact use of biomass, in contrast to traditional low-efficiency combustion techniques) is a pillar for decarbonization thanks to its near zero-carbon footprint. Modern bioenergy has become the most significant form of renewable energy globally - covering 55% of renewables and 6% of the global energy supply (IEA, 2021a). In addition to its renewability, modern bioenergy provides a series of advantages. Among others, it is able to use existing infrastructures, displays flexibility in assisting hard to decarbonize transportation sectors (such as aviation, marine, and trucking), and embraces a multitude of feedstocks, comprising wastes.

In the current catastrophic climate situation, governments and investors have shown increasing interest in bioenergy, and in July 2022 the European Parliament adopted targets to be achieved by sustainable aviation fuels blended with biofuels from biomass waste and residues. However, these efforts are insufficient to ensure we are on track with the zero-emission scenario, with the IEA indicating the need for a dizzying production growth of 16% per year and expansion from 8 to 45% of total biofuel demand derived from biomass wastes (IEA, 2021b).

In order to yield bioenergy, the chemical energy contained in the biomass needs to be converted to thermal energy (through combustion) or energy carriers. A range of different conversion technologies are currently available at diverse levels of technological readiness and based on different principles - operating at low or high temperatures, based on thermochemical or biological processes, and adapted to different substrates, from wood residues to municipal wastes and sewage sludge.

In general, modern biorefineries are increasingly focused on combining various technologies to produce a mixture of compounds with target properties and impacts, rather than individual substances, to reduce overall production costs and increase plant flexibility. Technologies such as combustion and anaerobic digestion are well-consolidated on the market, while other modern approaches, including gasification, pyrolysis or hydrothermal processes, encounter primary barriers in obtaining cost-competitive, high-quality, and quantity products. The fossil fuel market continues to represent the most convenient option for investors and close-minded governments who tend to avoid investing in arguably risky long-term projects. Increasingly global and synergistic efforts are sorely needed, whilst we, as scientists, are called upon to develop strategies to provide market-ready biomass technologies and bio-based products for industrial implementation.

A list of current, promising conversion processes follows.

Direct combustion

It is largely based on traditional low-efficiency systems (particularly in developing countries) and it is the most widespread technique for biomass conversion worldwide (IEA, 2021a). Modern forms of biomass combustion, including highly efficient domestic pellet boilers and (co)firing in existing coal power stations, remain poorly exploited mainly due to the extremely low cost of coal (50 $/ton in 2020) and scarce attention to the heat sector. The technology is mature and has potential for use in buildings and industries necessitating high temperatures – iron and cement production – and cogeneration plants. Examples of this type of use include the Alholmens Kraft plant in Finland that uses forest residues in a circulating fluidized bed boiler of 500 MW to produce electricity, heat for district heating, and process steam for a pulp and paper mill (Alholmens Kraft Ab, 2023).

Gasification

With the aim of producing syngas, gasification converts biomass through a partial oxidation under high temperatures (600-1200°C) and often without requiring an external heat supply. On a commercial level, this technology is ready for use, but operating plants are mainly present on a pilot scale operating with relatively small volumes. A series of hurdles represented by high operating costs, vague reliability, handling of by-products (tar in particular), and slight substrate flexibility have hampered widespread use on an industrial level. However, gasification offers innovation potential, particularly when integrated with CHP and district heating, and when purpose-designed for a target substrate. The latter is the case of the Alpine Italian region of South Tyrol, which had 46 small-scale gasifiers fed by wood chips in operation in 2016.

Pyrolysis

When performed at fast heating rates (>100°C/s), pyrolysis, occurring under an inert atmosphere of 400-700°C, converts the biomass into a bio-oil, with char and gaseous compounds as by-products. Upgrading processes such as hydroprocessing or catalytic cracking should then be applied to convert the bio-oil into a drop-in fuel as the oil has a very high oxygen content (25-40%), is unstable, has

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a high viscosity, and is corrosive. Pilot and early commercial plants have been set up for heat and power generation, while the full integration of pyrolysis and upgrading in systems that operate in continuous mode is currently at the proof-of-concept stage. Studies aimed at optimizing bio-oil characteristics using catalysts and the scale-up of catalytic reactors are ongoing. The integration of fast pyrolysis with existing petroleum refineries to upgrade bio-oil using petroleum products represents a promising option. For example, the commercial Cote Nord plant in Canada is a 38 ML/year oil facility that converts woody biomass to oil for heating purposes and as feedstock for refinery co-processing. When performed at low heating rates, pyrolysis converts the biomass mainly into a biochar that could play an important role for carbon sequestration through soil application.

Hydrothermal processes

An emerging class of conversion process is represented by hydrothermal processes, which exploit the properties of water under high pressure and temperature to convert biomass to a char-like phase (hydrochar), a bio-oil, and a gas phase, the yields of which vary in line with operating conditions. Hydrothermal processes are suitable for the treatment of wet feedstocks (e.g., organic wastes, sewage sludge, algae), avoiding any drying stage. Hydrothermal carbonization is carried out under lower temperatures (180-250°C) to convert biomass into hydrochar for use as biofuel in coal co-combustion, for advanced carbon-based materials, and soil amendments - and an organic-rich liquid phase containing platform chemicals such as HMF. Thanks to the mild operating conditions and relatively moderate costs, this process has a high potential for integration in existing plants in the waste treatment sector. For example, it enhances biogas production and waste volume reduction in anaerobic digestors and wastewater treatment facilities. A commercial development of the process is underway and recently a plant in Mexico City has been set up to treat municipal biowaste to produce hydrochar for use in a coal-fired power plant (TerraNova Energy, 2023). Hydrothermal liquefaction (at 300-400°C) is the wet version of pyrolysis and produces a lower oxygen content bio-oil, which however still needs to be upgraded, e.g. through hydroprocessing. The technological level is demonstrative and significant research is ongoing, with particular focus on the aviation sector. The continuous pilot plant in Denmark (Aalborg) is a pioneering example of the stage of advancement of this process. Under harsher hydrothermal conditions (400-700°C), biomass undergoes supercritical water gasification forming CH_4 and H_2. However, the industrial implementation remains unlikely in the near future, largely due to high operating costs (Lee et al., 2021).

Anaerobic digestion

In the category of biological conversion processes, anaerobic digestion represents a mature technology which is widely adopted for wet biomass waste to produce biogas. After purification, biomethane is obtained, and an increasing number of policies support its injection into the methane grid and its usage in the transport sector. In this regard, in 2022, a European industrial partnership was launched to support the achievement of targets established by the REPowerEU plan for biomethane production (35 bcm in 2030).

Conclusions

The world has an impelling need for clean energy and a circular development model: the conversion of waste biomass into bioenergy meets this need. A large range of technologies are available for use, each featuring its own strengths and weaknesses. Different technologies suit different substrates and purposes. Combustion can convert very heterogeneous substrates, even municipal solid wastes, and is reliable and consolidated. One big limit is the final product: heat, usable as it is or requiring further conversion stages with their own complexity and efficiencies. From the perspective of bio-oil production, the choice between fast pyrolysis and hydrothermal liquefaction highly depends on the initial substrates – dry biomass or wet substrates, respectively. Hydrothermal carbonization converts wet heterogeneous biomasses into a carbonaceous phase, whose use is still limited by its quality and scarce attractiveness for the market. Finally, gasification is relatively inflexible for the range of treatable biomasses but produces syngas for several purposes. Therefore, technological response to the problems associated with climate change clearly cannot be univocal. Conversely, political response should be immediate and unambiguous with clear-cut and decisive choices supported by technical expertise (of scientists and technologists) and appropriately communicated to the population.

There is no more time to waste: bioenergy represents a decisive path for a better and sustainable future.

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REFERENCES

Alholmens Kraft Ab, 2023. Alholmens Kraft [WWW Document]. URL https://www.alholmenskraft.com/en/home (accessed 6.15.23).

IEA, 2021a. Key World Energy Statistics 2021 – Statistics Report. IEA Publ. 1–82.

IEA, 2021b. Net Zero by 2050: A Roadmap for the Global Energy Sector. Int. Energy Agency 224.

Lee, C.S., Conradie, A. V., Lester, E., 2021. Review of supercritical water gasification with lignocellulosic real biomass as the feedstocks: Process parameters, biomass composition, catalyst development, reactor design and its challenges. Chem. Eng. J. 415, 128837. https://doi.org/10.1016/J.CEJ.2021.128837

TerraNova Energy, 2023. TerraNova Energy [WWW Document]. URL https://www.terranova-energy.com/en/applications/ (accessed 6.15.23).