European Commission

Study on 'Solar Fuels Research & Invest: Defining and developing the global solar fuel value chain: techno-economic analysis and pathways for sustainable implementation'

Policy Brief

Independent Expert Report

Written by EY and CEPS
October – 2020

EN

Research and Innovation

Study on 'Research and Innovation international cooperation in the field of renewable energy technologies' – Policy Brief

European Commission
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Manuscript completed in 2020.

PDF	ISBN 978-92-76-34355-4	doi:10.2777/482259	KI-09-21-098-EN-N

Luxembourg: Publications Office of the European Union, 2021

EUROPEAN COMMISSION

Study on 'Solar Fuels Research & Invest: Defining and developing the global solar fuel value chain: techno-economic analysis and pathways for sustainable implementation'

Policy Brief

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Clean Planet

2021 EN

Reaching the goals of the Paris Agreement on climate change will require substantial efforts by all countries worldwide to lower, as much as possible, the greenhouse gas emissions associated with their energy consumption. Solar photovoltaic ("PV") is a key component in many countries' plans for reaching their targets under the Paris Agreement. Indeed, the price of PV modules has declined by a factor of 10 in as many years, and is expected to continue declining. Solar PV is now cost-competitive with fossil fuel-based power generation in many jurisdictions, and is expected to be the least expensive form of power generation overall by 2030.

Electrifying end-uses of energy, in particular of passenger road transportation but including a wide range of applications in energy, buildings and transport as well, is another key component in most countries' climate plans. On top of mitigating greenhouse gas emissions, electrification often results in energy efficiency gains relative to fossil fuel-based applications, as is the case for electric vehicles.

Nevertheless, renewable electricity alone cannot address all of the challenges inherent to the decarbonisation of our energy consumption. Firstly, not all energy end-use cases are susceptible to being electrified in the short or medium term, with long-haul air transport being a prime example. Additionally, solar PV and most other renewable energy sources are characterised by a high degree of variability in their output levels. This variability calls for flexible storage capacity to address both short term needs, balancing intra-day fluctuations, as well as long-term needs to balance the seasonal variation in renewable energy production seen in most jurisdictions. On top of temporal imbalance, there is a clear geographical imbalance in the distribution of resources (chiefly wind, sun and land) required for renewable energy production. Many regions that are blessed with an abundance of these resources have relatively small populations and correspondingly low energy consumption, while highly populated regions such as Europe have more limited resource availability.

Solar fuels, i.e. synthetic energy carriers derived from solar energy, can help address the three challenges discussed above, i.e. the resistance to electrification in some applications, as well as the temporal and geographical variability in renewable energy production. Solar fuels can be produced through different technological pathways, including Electrochemical, Chemical, Thermochemical and Biochemical processes, presented in a simplified graphic in Figure 1 below. The most viable pathway for solar fuels production currently is the electrolysis of water for the production of hydrogen, an example of the electrochemical pathway. This pathway combines the production of electricity from solar PV, with water electrolysis in a second stage. A promising, but early stage technology called the photoelectrochemical cell combines both stages in one module, producing hydrogen directly from sunlight energy.

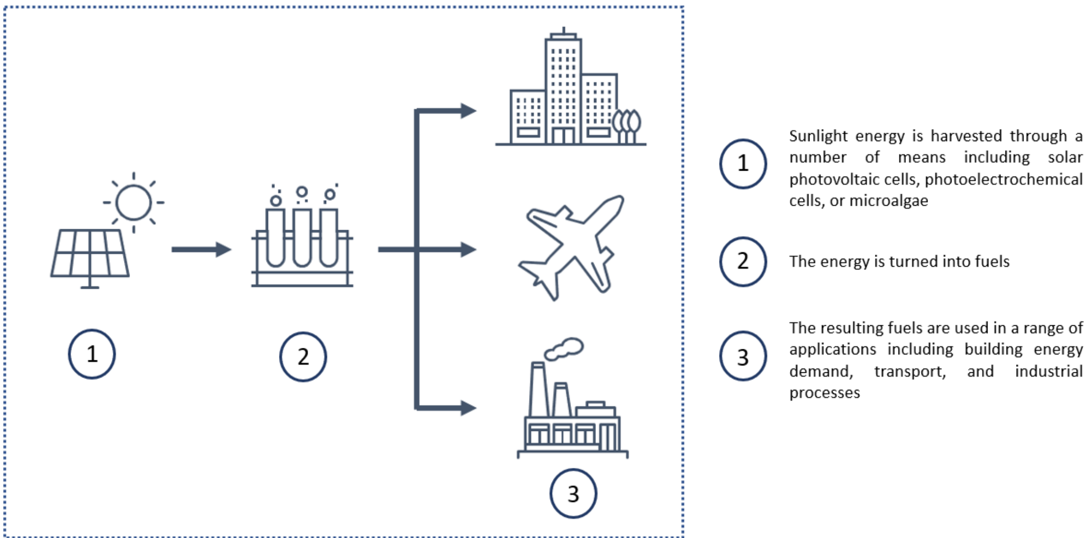

Figure 1 – Solar Fuel Value Chain

A techno-economic analysis was carried out for a number of solar fuel pathways as part of the "Solar Fuels Research & Invest: Defining and developing the global solar fuel value chain: techno-economic analysis and pathways for sustainable implementation" commissioned by DG RTD. The analysis reveals that energy input costs, namely the cost of solar PV, accounts for the majority of the costs for producing solar fuels. The cost of solar PV modules is expected to continue its decline, suggesting a future where solar fuels could potentially become competitive with comparable fossil fuels. The question becomes: what is the cost performance of solar fuel technologies over time, and at which point in time do they overcome the cost advantage enjoyed by their fossil counterparts, if at all.

The forward-looking analysis reveals three main pathways of interest to our energy needs in industry, transport and buildings. The first is a form of electrolysis of water using a proton exchange membrane electrolyser cell, for the production of hydrogen. The second is the production of methanol through CO_2 hydrogenation, using green hydrogen produced through e.g. solar-powered PEMEC, and CO_2 captured directly from the air, or through carbon capture and utilisation[1]. The third is power-to-methane, which consists in the production of methane from green hydrogen and CO_2, similarly to CO_2 hydrogenation.

The analysis reveals that water electrolysis could compete with fossil-based hydrogen production before 2040, with a possible accelerated time to market depending on factors such as solar irradiance or synergies with local industry. E-fuels[2] could follow suit in the short term, with methanol produced through CO_2 hydrogenation expected to reach cost parity with the price of motor gasoline, factoring in a carbon price of approximately €178 per tonne of CO_2, by the early 2040s. Power-to-methane, on the other hand, would reach cost parity around 2060.

A number of factors are expected to impact the uptake of solar fuels worldwide, including:

- Costs of solar fuels, which are primarily driven by the price of solar electricity at first vs. costs of comparable fossil fuels,
- Costs of adapting end-use systems to solar fuels, such as changing from coal to hydrogen in steel manufacturing,
- Infrastructure costs,
- Demand for carbon-neutral industrial products, vehicles and transportation services, and heating and cooling technologies in buildings, and
- Supportive regulations and policies such as carbon pricing mechanisms.

Industry, in particular, could potentially become early adopters of solar fuel technologies in certain applications. As industries are increasingly considering carbon capture and storage schemes, CO_2 may become more readily available, and could serve as an input to solar fuel production. These solar fuels could be produced and used on-site to power the same CO_2-emitting industrial processes, thereby closing the carbon loop. Such schemes, with the right incentives, could prove attractive to industries, driving them to invest in early-stage technologies.

1 In that case, for CO_2 hydrogenation coupled with CCU to be truly carbon neutral, the fuel resulting from the fuel's combustion would have to be captured again to close the carbon loop.

2 E-fuels are synthetic fuels, either gaseous or liquid, produced through the use of electricity to produce hydrogen, which is combined with carbon dioxide to produce hydrocarbon fuels.

Solar fuels could contribute approximately to approximately 4 to 6 percent of worldwide energy needs in 2050, and 6 to 10 percent in 2100. A concerted effort by stakeholders in energy supply chains, in sectors where energy end-use cases could transition to solar fuels, and by policymakers and consumers will be required to ensure that targets for solar fuel supply matches demand targets. Policymakers, in particular, should consider the following:

- Early and significant investments in solar fuel technologies, through e.g. subsidies for capital expenditures or fiscal incentives,

- Demand-side policies mandating minimum shares of carbon-neutral fuels, such as solar fuels, in the energy mix in specific sectors in e.g. industry or transport,

- Fair, and increasingly strict carbon pricing, and

Given the challenges related to infrastructure, in particular for hydrogen, a concerted policy is needed to prioritise applications where infrastructure needs are minimal, e.g. by developing solar fuel production capacity within the same facility as existing large scale industrial plants to leverage synergies between CO_2 derived from carbon capture and solar fuel production.

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This European Commission funded study provides a techno-economic analysis of global solar fuel value chains and pathways for sustainable implementation. It is structured around four key tasks providing: a techno-economic analysis of worldwide solar fuel value chains; a technological development roadmap for 2030 and 2050 and economic roadmap to 2100 as well as a market outlook mapping the full potential of solar fuels for 2050 and 2100; the International Solar Fuels Forum; and the organisation of an international conference on solar fuels. The study aims at identifying the key technological bottlenecks that need to be overcome to allow for the large-scale industrial production of solar fuels. Based on this, the cost competitiveness of a number of solar fuel technologies is assessed, together with their potential time-to-market to replace comparable fossil fuels. By forecasting the potential demand for solar fuels through 2100, the study gives an outlook on what role solar fuels could play in our future energy systems. The investments required to build capacity to meet this demand are also discussed. The report also describes the development of the International Solar Fuel Forum that was used as communication channel to disseminate study results and to encourage discussion between solar fuels experts.

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