HYDROGEN FOR PETROCHEMICALS

Prospects

GOOD

This fact sheet is part of an Energy Innovation paper assessing clean hydrogen's value for cutting climate pollution from 12 end uses. The full report includes context, analysis, policy recommendations, and citations—see QR code or link at bottom.

Hydrogen can be paired with captured carbon to build chemicals needed in everyday life.

CONTEXT: The chemicals industry produces more than 100,000 types of chemicals; however, most of them derive from a handful of building blocks: petrochemicals (which contain carbon) and ammonia (which doesn't contain carbon and is covered in a separate overview). Loosely, the former include methanol, olefins, and aromatics; together, they are used to make diverse products such as plastics, pharmaceuticals, cleaning products, paints, and synthetic fibers.

Petrochemicals are almost exclusively made from fossil fuels. In fact, a primary use of hydrogen today (starting from natural gas) is making methanol. However, electrolytic hydrogen and captured carbon can also be used to make "e-methanol," which can in turn make most petrochemicals via methanol-to-olefins (MTO) and methanol-to-aromatics (MTA) processes.

This overview describes how electrolytic hydrogen can obviate the need for fossil fuels in making most petrochemicals. It focuses on the carbon embodied in feedstocks, which get "chemically transformed and become part of the output products," rather than fuels, which are burned for heat or electricity and immediately release carbon as CO_2 (with these functions covered in separate overviews). While temporarily fixed, the carbon in feedstocks eventually is released into the atmosphere (such as when plastics are incinerated); thus, the carbon must ultimately come from a net-zero source rather than fossil fuels.

INFRASTRUCTURE NEEDS: Today's U.S. petrochemicals are made in 312 petrochemical plants and 131 refineries (which make a substantial share of petrochemicals as byproducts from refining crude oil into more useful fuels). In general, these facilities start with fossil fuels and break them into other chemicals, whereas an electrolytic hydrogen-based chemicals sector would start from component parts and use them to build more complex chemicals. Thus, much of today's chemicals infrastructure may be incompatible with this transition—though midstream and end-use assets like pipelines, tanker trucks, storage sites, and manufacturing plants could move and use the same underlying chemicals as-is.

Clean chemicals will require at least five types of facilities: hydrogen electrolyzers, carbon capture plants, e-methanol production plants, and MTO and MTA facilities. Carbon can initially be sourced from fossil fuel combustion (albeit with half the climate benefit) but must eventually come from a net-zero source (e.g., biomass or the air). E-methanol plants use the same underlying technology as conventional methanol plants but with slightly different configurations; based on current projects, this appears to be enough of a change to warrant new production facilities rather than retrofitting existing ones. E-methanol plants can also be smaller and more distributed, supporting better integration with renewables rather than needing to move lots of energy (or hydrogen) to these facilities.

SOCIAL IMPACTS: Petrochemical facilities and refineries are extreme public health hazards, emitting various toxins and carcinogens. Hotspots of these plants have led to "sacrifice zones that disproportionately harm frontline communities of color and low-income communities." A move to electrolytic hydrogen-based chemicals would reduce health risks associated with fossil fuel production and combustion—and could lower the need for refineries when paired with transportation electrification. However, it might not directly mitigate risks associated with synthesizing more complex chemicals from these net-zero building blocks. The transition could make chemicals production more dispersed since it would not have to be clustered in regions of high fossil fuel extraction or ports, thereby relieving pressure from today's hotspots. However, regulations targeting air pollution would be needed to address the biggest risks.

COMPETING TECHS: Two technology classes can also help reduce the need for fossil fuel-derived petrochemicals. First, **biomass** (as a net-zero hydrocarbon) can take less energy to transform into other chemicals relative to making hydrogen, capturing carbon, and building things from the ground up. For example, Brazil makes ethanol from sugarcane and then uses it to produce ethylene (an olefin); the U.S. currently makes an enormous amount of ethanol from corn for blending in gasoline, but this could instead be used to make ethylene—especially as vehicle electrification advances. Biomass can also be symbiotic with hydrogen: biomass gasification or pyrolysis can produce methanol alongside a CO_2 stream that can be paired with hydrogen to make e-methanol. However, biomass faces limitations from being a more complex feedstock than natural gas or refined oil as well as a constrained supply.

Second, some chemical products can be **recycled**, whether mechanically (e.g., plastics being shredded, melted down, and formed into a new product) or chemically (i.e., broken down into component molecules). However, while recycling can be improved, it faces limits due to quality (e.g., mechanical recycling results in impurities), impracticality of collection, or costs.

TAKEAWAY: While the petrochemicals sector is complex, hydrogen can play a large role in cleaning it up by making e-methanol (with a net-zero source of captured carbon), then further developing and using MTO and MTA processes to make most of the sector's building blocks. However, chemical production's huge hydrogen demand potential and its lasting pollution impacts suggest it will be critical to cut total demand, such as by improving material efficiency.

FURTHER READING:

- Jeffrey Rissman, *Zero-Carbon Industry: Transformative Technologies and Policies to Achieve Sustainable Prosperity*, Columbia University Press, 2024, https://zerocarbonindustry.com/#chapter-2, p.37-61
- International Energy Agency, "The Future of Petrochemicals: Towards more sustainable plastics and fertilisers," October 2018, https://www.iea.org/reports/the-future-of-petrochemicals
- IRENA and Methanol Institute, "Innovation Outlook: Renewable Methanol," International Renewable Energy Agency, 2021, https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol
- **Featured story:** Tristan Baurick, Lylla Younes, and Joan Meiners, "Welcome to 'Cancer Alley,' Where Toxic Air Is About to Get Worse," ProPublica, October 30, 2019, https://www.propublica.org/article/welcome-to-cancer-alley-where-toxic-air-is-about-to-get-worse
- **Full report:** https://energyinnovation.org/publication/hydrogen-policys-narrow-path-delusions-and-solutions