EXECUTIVE SUMMARY

Electrifying Chemicals

The Cost of Producing Chemicals From Electricity

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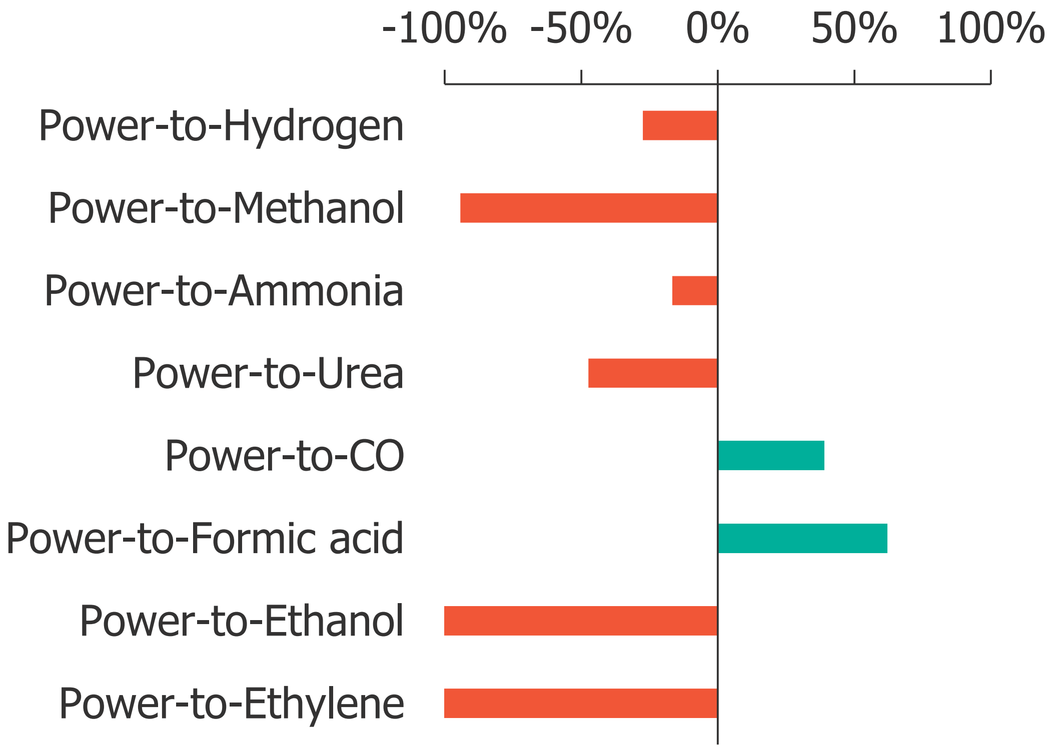
Power-to-chemical technologies are unlikely to pose a threat to the dominance of oil and gas in the chemical sector

The chemical industry will remain firmly linked to the oil and gas sector, but emerging power-to-chemical technologies could change the status quo in niche subsectors:

- Innovations in CO_2 electrolysis will lead to the displacement of natural gas for pure carbon monoxide and formic acid production in 2050.
- Rising carbon taxes will have minimal impact on the electrification of chemicals, as carbon capture and storage (CCS) will become the favored option for decarbonization.
- Only an electricity price below $0.01/kWh has the potential to initiate the widespread electrification of the chemical industry and cause a sharp decline in oil and gas demand.

Relative cost of P2C to CCS

CO_2 tax: $50/ton | Feedstock: Baseline* | Electricity: $0.05/kWh



*See Appendix 1.1 for baseline scenario

Even the most aggressive decarbonization roadmaps foresee a continued role for fossil resources in the chemicals sector…

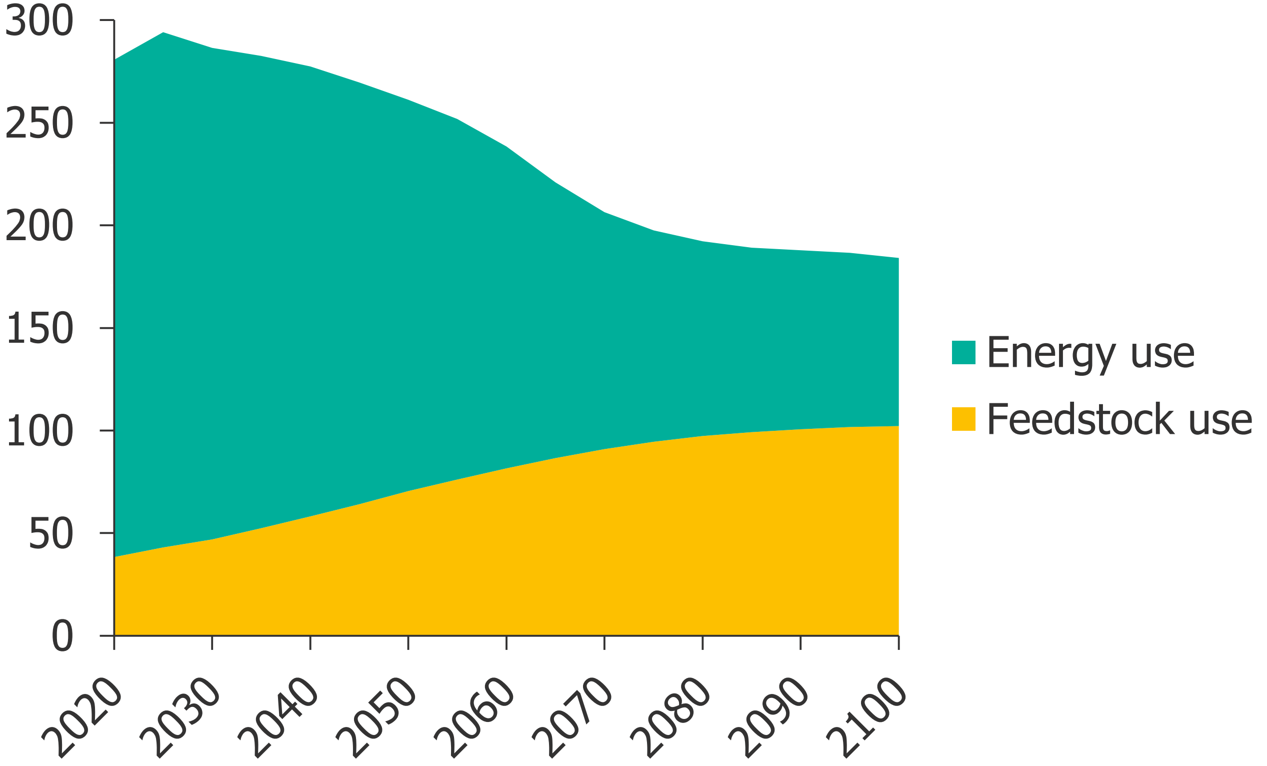
The primary role of the fossil industry today is to provide energy globally, but coal, crude oil, and natural gas are also important sources of feedstock for the chemical industry.

As electrification slowly grabs hold of the global energy system, the majority of energy scenarios forecast that feedstock use will become the primary growth driver of the fossil industry later in the century.

According to the Shell Sky scenario, fossil demand for feedstock applications will overtake energy use in 2080 – the majority of feedstock for the chemical industry will still primarily be crude oil and natural gas.

Global Fossil Resource Use

Energy (Exajoules, EJ)



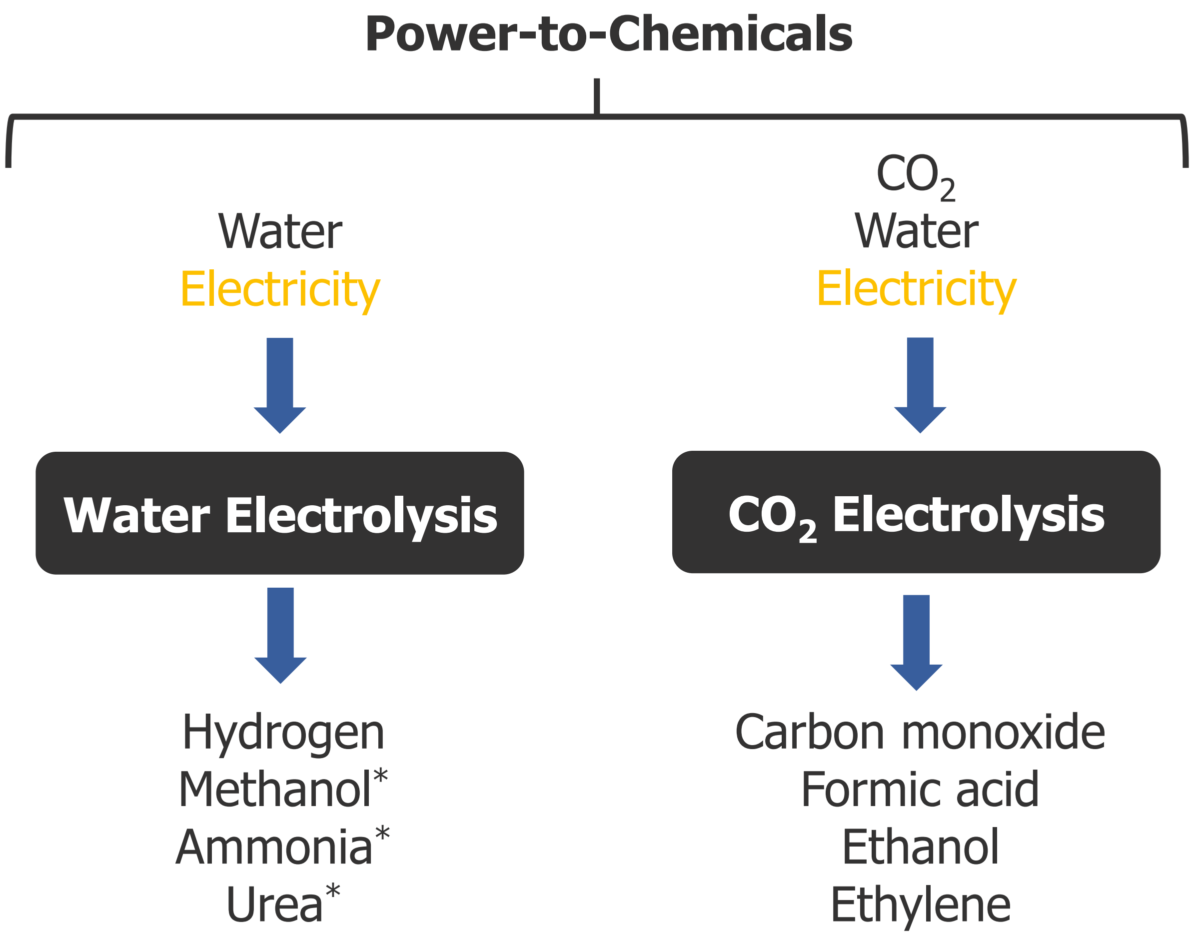
Source: Shell Sky Scenario, adapted by Lux Research

…but forecasts may fail to account for new technologies that threaten the dominance of fossil feedstock in chemicals

The assumption that crude oil and natural gas will never be displaced from the chemical supply chain may be short-sighted due to the emergence of **power-to-chemical** technologies.

Power-to-chemicals is the collective name given to electrolysis technologies that produce chemicals directly from electricity, water, and/or CO_2. The technologies are still at an early stage of development but, if successfully deployed, have the potential to almost entirely displace crude oil and natural gas from the chemicals sector.

For key player analysis, full data, case studies, and more, see our water electrolysis and CO_2 electrolysis Tech Pages.



*Methanol, ammonia, and urea are made from the hydrogen produced with water electrolysis

Despite the allure of power-to-chemicals, questions remain

The growing interest in power-to-chemicals brings forth key questions that still remain unanswered:

- What is the cost of power-to-chemicals, and how does it compare to incumbent production technologies?
- Which chemical manufacturing platform will opt for electricity as an alternative to oil and gas feedstock?
- How will rising carbon taxes impact the adoption of power-to-chemicals?

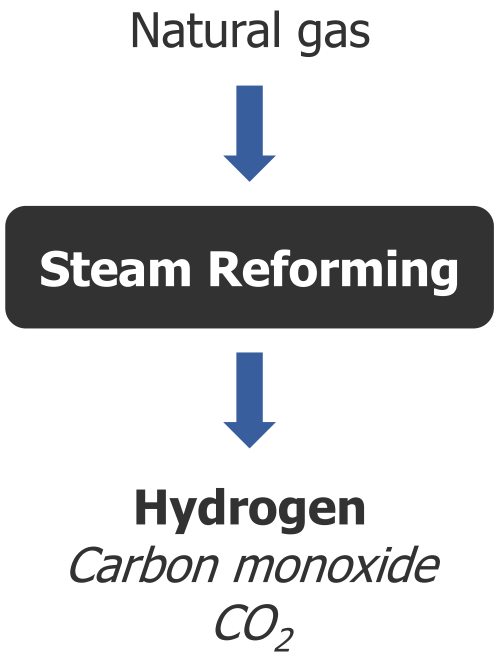
To address these questions, we performed a techno-economic analysis of eight power-to-chemicals platforms: **hydrogen**, **methanol**, **ammonia**, **urea**, **carbon monoxide**, **formic acid**, **ethanol**, and **ethylene**.

HYDROGEN

The incumbent thermochemical platform for hydrogen is steam reforming

INTRODUCTION:
Hydrogen is a highly reactive gas that is today primarily obtained from steam methane reforming. The chief application of hydrogen is for crude oil refining, fertilizer production, and methanol synthesis. The global production of hydrogen averages 70 million tons/year, for an estimated market size of $100 billion.

INCUMBENT THERMOCHEMICAL PATHWAY:
In reforming, methane reacts with steam over a solid nickel-based catalyst to produce hydrogen, CO_2, and carbon monoxide at temperatures of around 800 °C; a water-gas shift (WGS) reactor maximizes production of hydrogen at the expense of carbon monoxide. The capacity of a typical steam methane reforming facility varies between 100,000 tons/year to 500,000 tons/year.



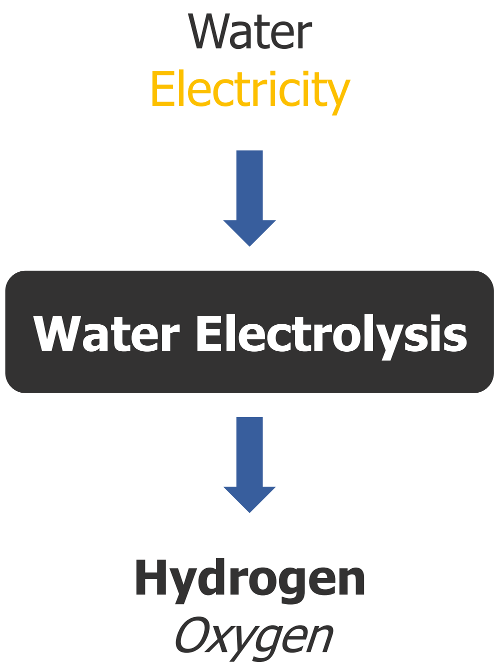
Note: Byproducts are in *italics* and assumed to have zero value

HYDROGEN

The emerging electrochemical platform for hydrogen uses water electrolysis

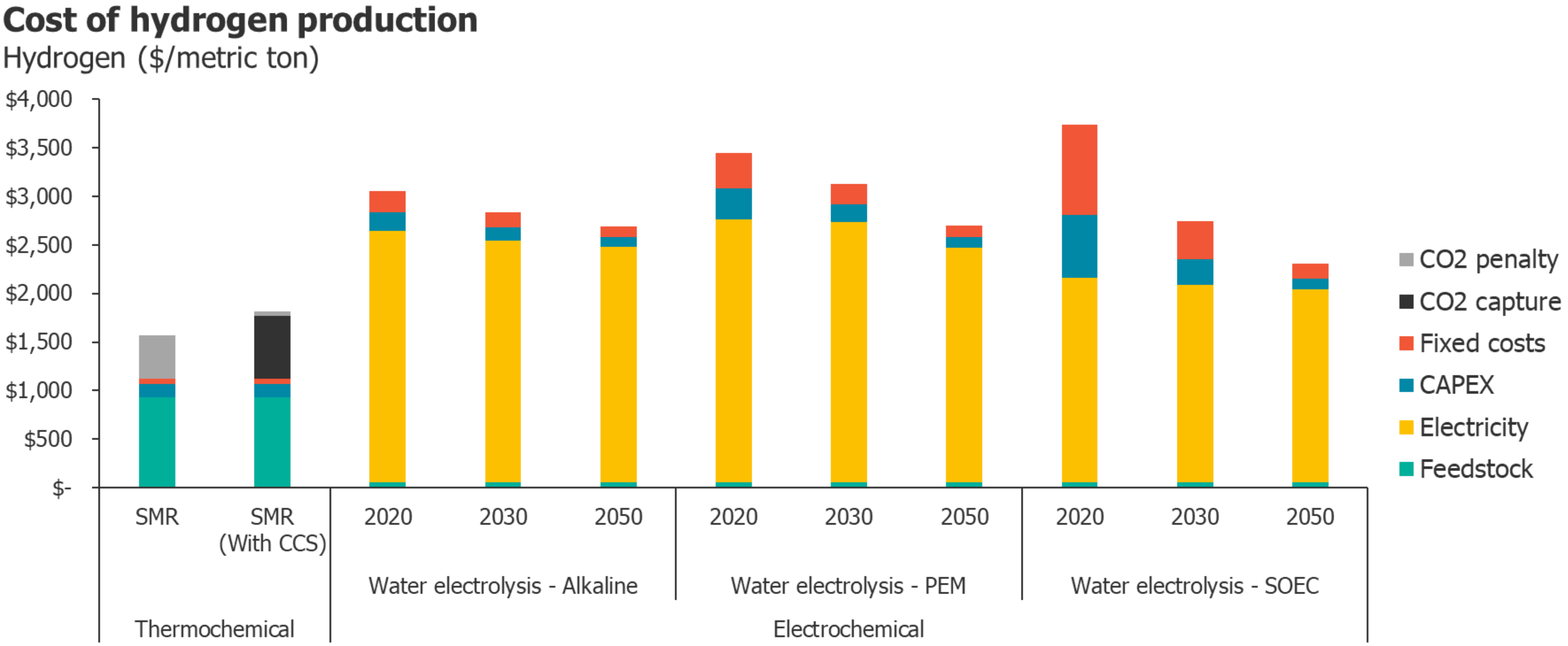
EMERGING ELECTROCHEMICAL PATHWAY:
A water electrolyzer produces hydrogen directly from water using electricity – oxygen is a coproduct of the reaction. Water electrolyzer units can be deployed in stand-alone facilities or integrated in refineries and chemical plants.

TECHNOLOGY & COMMERCIAL STATUS:
Hydrogen production from electrolysis is at various stages of development. Alkaline electrolyzers (AEC) are commercially ready and deployed at scales greater than 10 MW. Polymer exchange membrane (PEM) electrolyzers and solid oxide electrolyzer cells (SOECs) are emerging technologies boasting higher efficiencies but currently more expensive and deployed at a sub-10 MW scale only. For more information on the current and projected performance of water electrolysis technology for hydrogen, see Appendix 2.1.



Note: Byproducts are in *italics* and assumed to have zero value

Power-to-hydrogen is projected to reach $2,310/MT by 2050; hydrogen synthesis with CCS is $1,810/MT



Note: For assumptions used in baseline scenario, see Appendix 1.1

Power-to-hydrogen requires electricity at $0.02/kWh for cost parity with incumbent technologies

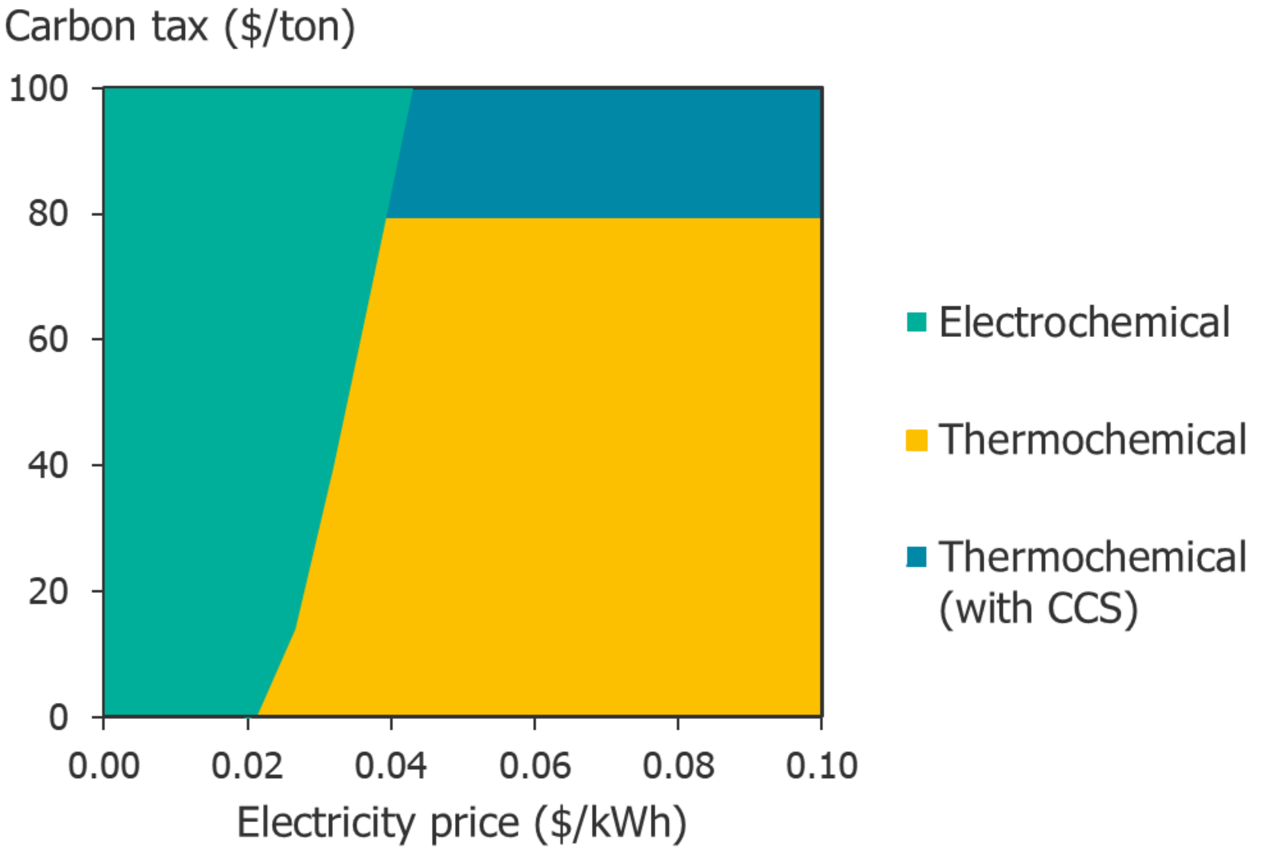
BREAKEVEN COST OF HYDROGEN

Power-to-hydrogen will be the most cost-competitive mode of hydrogen production with electricity prices below $0.02/kWh.

Increasing carbon taxes will improve the cost-competitiveness of the electrochemical pathway at higher electricity prices, up until a carbon tax of $80/MT is reached. At this point, steam methane reforming combined with CCS will be the most economical source of hydrogen.

For carbon taxes below $80/ton of CO_2 and electricity prices above $0.02/kWh, stand-alone steam methane reforming will remain the dominant option for hydrogen production in 2050.

Preferred technology for hydrogen



SCENARIO ANALYSIS & OUTLOOK

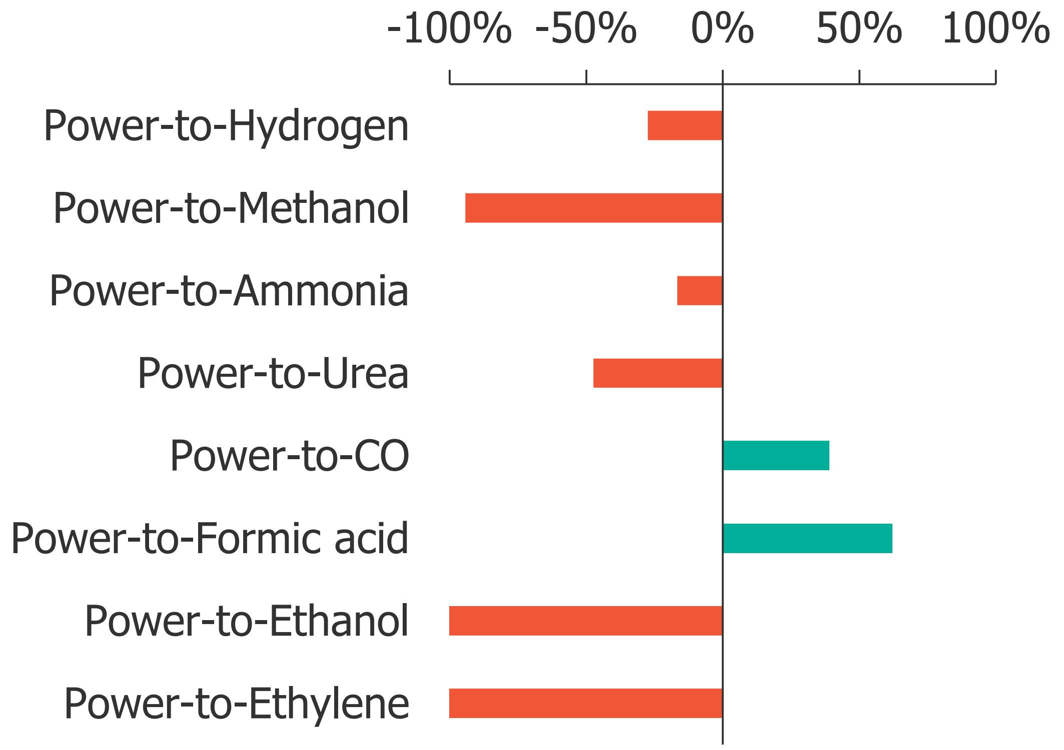
We analyze three potential market scenarios and their effect on the cost-competitiveness of power-to-chemicals

In this section of the report, we will project our cost model in three scenarios and compare the cost-competitiveness of power-to-chemicals platforms versus their incumbents combined with CCS. All scenario data are for 2050.

- **Scenario 1: High carbon taxes**
  In this scenario, the carbon tax increases from a baseline of $50/ton of CO_2 to $150/ton of CO_2.
- **Scenario 2: High feedstock prices**
  In this scenario, feedstock prices for natural gas, ethane, and corn increase by 100% from their baseline values.
- **Scenario 3: Low electricity prices**
  In this scenario, electricity price decreases from a baseline of $0.05/kWh to $0.01/kWh.

Relative cost of P2C to CCS

CO_2 tax: $50/ton | Feedstock: Baseline* | Electricity: $0.05/kWh



*See Appendix 1.1 for baseline scenario

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