Hydrogen: The missing piece of the zero-carbon puzzle?

An IHS Markit study considering the potential role of hydrogen in a net zero-carbon Europe

March 2019

1. Study overview

Through 2018, IHS Markit undertook a multiclient study about the potential role of hydrogen in a net zero-carbon Europe (see Figure 1). The goal of the study was to produce an objective and balanced assessment of the prospects for hydrogen as part of future energy use. IHS Markit has no interest to promote—we are neither "pro-"nor "anti-" hydrogen. The study presents an independent perspective.

The study is based on work that draws on

- A meta-analysis of the results of more than 400 publications in the field
- In-house research work and data sources held by IHS Markit
- The results of a series of three workshops in the second half of 2018 that involved representatives of 25 interested and expert parties among IHS Markit clients

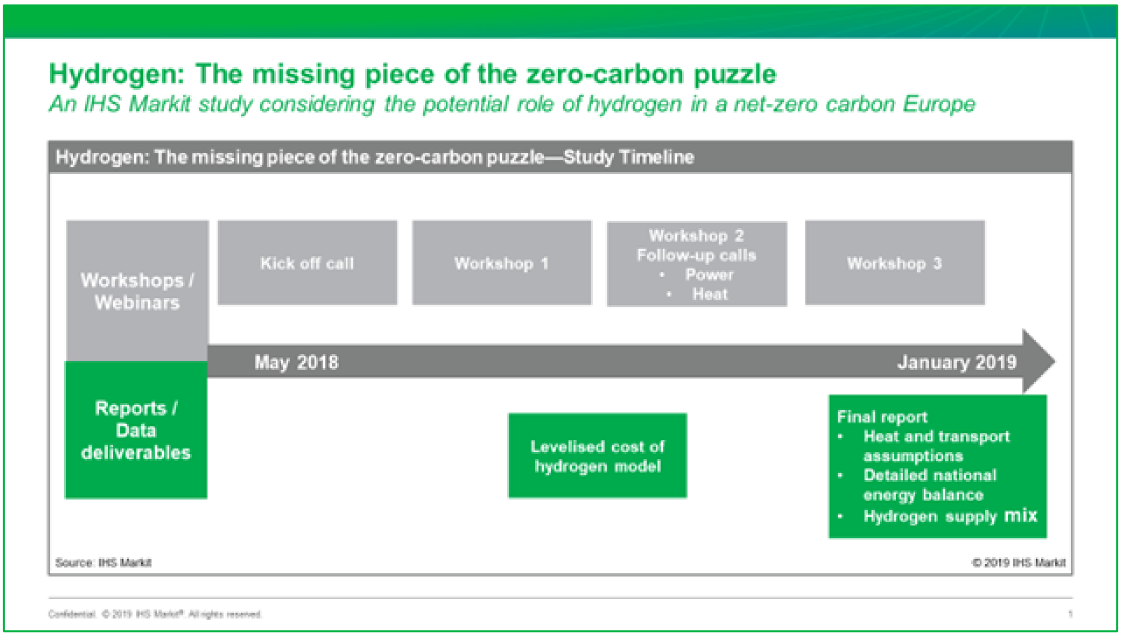
The results of the study owe much to the valuable cooperation of our clients in these workshops and to direct dialogue with all of them. We deeply appreciate their contribution and support.

Our starting point was to understand the costs of **producing hydrogen** from the different technologies that are available. The costs were presented on a levelized cost basis (the levelized cost of hydrogen, or $LCOH_2$), considering future technological progress and possible economies of scale and innovations. In such an area—where innovation and progress are certain to take place, but where the pace of that innovation and its impact on costs are unknown—we adopted an approach based on different learning rates as a way of assessing the future $LCOH_2$.

We then looked at each of the main **sectors of energy use** to assess the potential competitive environment for hydrogen. Hydrogen can be used to supply many different energy needs—in storing and generating electricity, and in transport, heating, and industrial processes. For each of these sectors, hydrogen is likely to face a very different competitive dynamic in terms of the alternative fuels, technologies, and future market conditions. We considered the different forms of industrial and commercial organization that will be appropriate for effective delivery of hydrogen into these various markets.

Finally, the study drew together the costs on the supply side and the market conditions on the demand side to assess a **plausible level of demand** for hydrogen in Europe in 2030 and 2050.

In 2019, we will continue the research effort through the European Hydrogen Forum, which will allow us to deepen the analysis of the 2018 study and broaden the scope of hydrogen-related energy topics in this rapidly advancing field. The format of the Forum is two meetings during the year, including a tour of a hydrogen facility and a workshop day with presentation and discussion of analysis on specific topics. Proposed topics for the first session include comparison of a broader set of hydrogen production options, comparison of transportation costs, and competition with biomethane and synthetic gas. For more details of the European Hydrogen Forum, please see the accompanying slide pack, "Hydrogen Forum: Europe"



2. Deliverables of the 2018 study available to all Forum members

The final deliverables from the 2018 study are now available to all members of the European Hydrogen Forum and are listed below.

Workshop 1: 5 July 2018, London (PowerPoint)

- Context: Drivers of interest in hydrogen in the energy transition
- The levelized cost of hydrogen
  - A review of capital costs for steam methane reforming with and without carbon capture and storage
  - A review of capital costs for electrolysis using alkaline electrolytic cell (AEC), proton exchange membrane (PEM), and solid oxide electrolytic cell (SOEC)
  - Levelized cost of hydrogen from steam methane reforming (SMR) and electrolysis for early-stage, current project, and mass-market deployment
  - An analysis of the learning curves for electrolysis
  - An analysis of the source of the electricity on the cost of hydrogen from electrolysis
- An overview of the quantitative approach for the study
  - Review of the key results of the IHS Markit Autonomy scenario
  - Modeling approach for plausible hydrogen demand and the supply mix

Levelized cost of hydrogen production model: August 2018 (Excel)

The Excel spreadsheet allows users to analyze the evolution of the cost of hydrogen through time from multiple production pathways.

- Hydrogen production pathways

    - SMR with no carbon capture
    - SMR with four alternative configurations of carbon capture and storage
    - Electrolysis: AEC, PEM, and SOEC
    - Coal gasification with and without carbon capture and storage
- Impact of changing scale for each production pathway
- Cost of carbon transport by ship and by pipeline
- Cost of carbon storage in depleted fields with and without legacy infrastructure and saline aquifers
- Costs of electrolysis provided for a range of electricity supplies at a member state level
    - Base-load electricity
    - Distributed electricity
    - Offshore wind
    - Nuclear

Workshop 2: 19 October 2018, Pennyhill Park, UK (PowerPoint)

- Curtailment and green hydrogen: understanding the interaction
    - Availability of curtailed electricity in Europe—including price/volume curve
    - Supply cost curve for hydrogen from curtailed electricity
    - Impact of grid charges on competitiveness of hydrogen from curtailed electricity
- Assessing the potential scale of hydrogen use in the heating sector
    - Breakdown of the landscape for space and water heating in Europe
    - Review of technology options for residential space and water heating
    - Peak demand for heat
    - Case study: Great Britain. Detailed modeling of the levelized cost of heat and the avoided cost of carbon for a typical home using a range of heating technologies:
        - Natural gas based: gas boiler, hybrid system: natural gas and an air-source heat pump (ASHP)
        - Hydrogen based: hydrogen boiler, hybrid system: hydrogen and ASHP
        - Electricity: direct electricity, ASHP
    - Analysis includes cost of upgrading the electricity grid and conversion to hydrogen
    - Implications for the transformation of heat across Europe
- Follow-up presentations provide more detail on modeling approach and assumptions

A discussion of developments in reforming of natural gas: 19 October 2018 (PowerPoint)

A presentation by Johnson Matthey

Workshop 3: 28 November 2018, London (PowerPoint)

- Tipping points for the transportation sector
  - > Total cost of ownership modeling for buses and trucks
  - > Costs for three stages of the development cycle: current, early adopter, and mass market
- The plausible demand case: Outlook for hydrogen demand in Europe
  - > Sector narrative and results
  - > Share of primary and final energy demand
  - > Impact of hydrogen deployment on fossil fuel demand
  - > Reduction in carbon dioxide emissions from hydrogen deployment
  - > Comparison of hydrogen outlook with a range of external sources
- Matching hydrogen production with demand
  - > Boundary cases for supply—all natural gas based / all renewables / all nuclear
  - > Plausible supply case
  - > Location of hydrogen supply
  - > Implications for power supply and natural gas demand
- Hydrogen deployment
  - > Key questions for hydrogen deployment
  - > Direct and indirect costs of carbon
  - > A road map for hydrogen deployment
- Conclusions of the study

Electrolysis: Status and outlook: 19 October 2018 (PowerPoint)

A presentation by NEL Hydrogen

Final report: 15 January 2019 (PowerPoint)

A 136-slide deck covering each theme of the study. Includes a textual description of the main results for each section.

- Context
- A review of the cost of low-carbon hydrogen supply
- An analysis of the business opportunity for curtailed electricity
- The role of low-carbon hydrogen in space and water heating

- The tipping points for the use of hydrogen in transport
- Defining the plausible demand for low-carbon hydrogen in Europe
- Matching low-carbon hydrogen production to demand
- Study conclusions

Executive summary: 15 January 2019 (PowerPoint)

A 21-slide deck describing the key results and conclusions of the study

Domestic heat sector assumptions: 15 January 2019 (Excel)

Key assumptions used in the comparison of the cost of space and water heating with natural gas, hydrogen, and electricity. All figures given for condensing gas, hybrid gas, condensing hydrogen, hybrid hydrogen, ASHP, and direct electricity.

- Heat demand for United Kingdom dwelling
- Heating system capex
- Heating system operations and maintenance (O&M)
- Heating system economic life
- Heating system shares
- Heating system efficiency
- Electricity storage assumptions
- Residential energy prices for gas and electricity

Transport sector assumptions: 15 January 2019 (Excel)

Key assumptions used in the total cost of ownership modeling for buses and trucks. All figures given for diesel, hybrid, battery electric, and hydrogen fuel cell.

- Vehicle capex
- Vehicle fuel economy
- Vehicle O&M
- Additional infrastructure costs for battery buses capex and opex
- Transport fuel prices: France and Germany
- Carbon dioxide emission factors: France and Germany

European energy balance—detailed results: 15 January 2019 (Excel)

Full energy balance for each European member state, Norway, and Switzerland, and aggregate data for the EU28+2. Figures provided for 2000 and 2017, as well as for Autonomy and the plausible case in 2030, 2040, and 2050.

- Electricity demand split by sector including electrolyser consumption (TWh)
- Power generation capacity split by fuel (MW)

- Power generation split by fuel (TWh)
- Unused electricity generation by low-carbon source prior to electrolysis, split nuclear, and renewables (TWh)
- Hydrogen demand split by sector (ktoe)
- Installed SMR capacity (mn m3/h)
- Installed electrolysis capacity (GWe)
- Hydrogen supply split by technology (ktoe)
- Primary energy demand split by fuel (ktoe)
- Power and heat sector fuel inputs—split by fuel (ktoe)
- Hydrogen sector fuel inputs—split by fuel (ktoe)
- Final energy demand by fuel (ktoe)
- Demand by sector by fuel (ktoe)
    - Residential, commercial, industry, feedstock, transport, other)
- Carbon dioxide emissions (million metric tons of carbon dioxide)