Hydrogen in the Golden State: Enabling a zero-carbon California economy through hydrogen

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

Study introduction

All eyes are on California, as it aspires to lead the United States to a low and eventually net-zero carbon future. Multiple policy initiatives are driving decarbonization across the state's power, transportation, and natural gas end-use sectors. To meet its long-term greenhouse gas (GHG) reduction goals, California will need new options. Hydrogen is an alternative that could enable the state to rapidly reduce greenhouse gases in the short term while providing a long-term energy storage solution. It can be used in all energy sectors— power generation, heat, industrial uses and transport—using existing natural gas infrastructure. If California is successful in hydrogen adoption, it could serve as a model for the United State as a whole.

Hydrogen is a zero-carbon fuel that can replicate the energy density, the ease of transport and storage, and flexibility in use that hydrocarbons deliver today. As a renewable gas, it has the potential to serve as a key energy source in low carbon future. Like other renewable energy forms, it can be part of the threat to existing businesses posed by decarbonization, but also a significant opportunity both for new investments and for repurposing existing assets. Figure 1 illustrates the motivational forces driving various industries to better understand hydrogen. If the economics work, oil and gas companies can incorporate hydrogen into the portfolio of fuels they produce and supply to customers. Utilities can integrate hydrogen into their operations to balance output from variable renewables and in grid management, and eventually to protect the use of their existing assets in a net-zero carbon environment.

- Hydrogen can be used as a transport fuel – but it is far more than this
- It can be stored, transported and converted to thermal or electrical energy
- It can be used for lower-carbon or zero-carbon heating by injection into, or full conversion of, natural gas grids.

However, before hydrogen can be considered as a significant contributor to the future fuel mix a series of practical issues need to be addressed. Businesses and investors will need to develop business models that offer the prospect of acceptable returns. This is the premise for *Hydrogen in the Golden State.*

Figure 1.

Business strategy: Understanding the hydrogen opportunity for my organization	
Business sector	**Issues and Opportunities**
Upstream oil and gas	• Develop hydrogen produced with SMR and CCS to provide a long-term future for natural gas production. • Understand the competitive threat from hydrogen from electrolysis.
Electric utilities	• The potential role of hydrogen storage in integrating renewables. • Can hydrogen help maintain value for thermal generation? • Is hydrogen electrolysis a major new power demand sector?
Natural gas utilities	• What is the potential for repurposing existing distribution assets to hydrogen delivery?
Transportation	• Could hydrogen be a major means to decarbonize cars, buses and trucks? • What refueling infrastructure would be needed?
Industrial energy end users	• Can hydrogen replace conventional sources of process heat? • How would the hydrogen be produced and delivered to my facility?
Financial institutions	• What is the potential magnitude of hydrogen infrastructure investments? • What policy support does hydrogen need? • What are the technology and revenue risks?

Source: IHS Markit

IHS Markit hydrogen research overview

IHS Markit has commenced a new area of research focused on the role hydrogen can play in enabling economy-wide transitions to a low-carbon future. Organized as a series of geographically-focused multiclient studies, the research is rooted in work that draws on:

- a meta-analysis of the results of over 400 publications in the field
- in-house research work and data sources held by IHS Markit, and
- the results of a series of client workshops for each geographically-focused multiclient study.

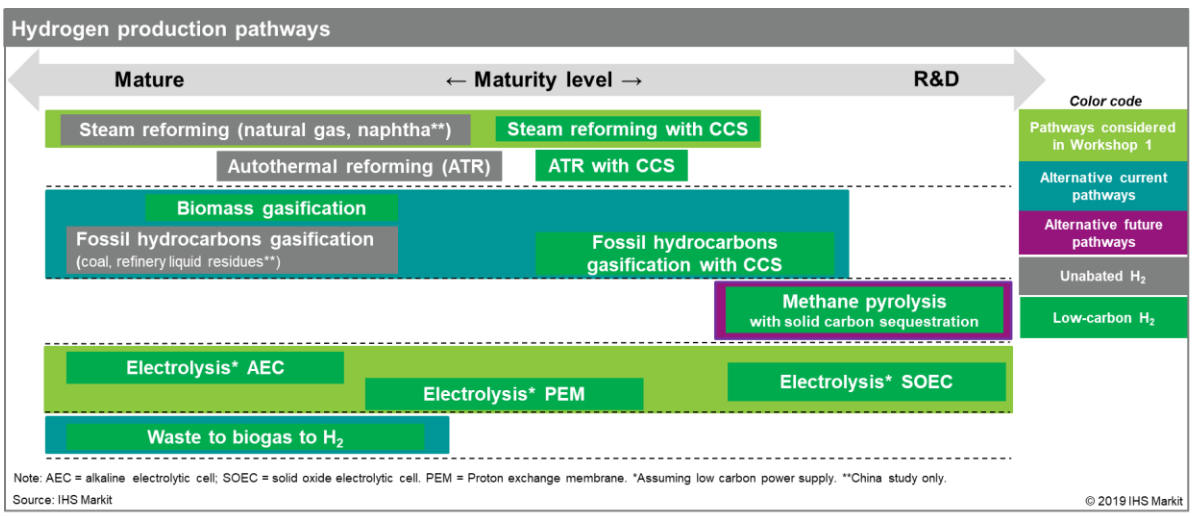
The first three multi-client studies have been focused respectively on Europe, California and China. Each of the studies owe much to the valuable cooperation of our clients in these workshops and to direct dialogue with each of them. We deeply appreciate their contribution and support. IHS Markit is following up this work with the launch of the Global Hydrogen Forum, an on-going retainer-based service which builds on the foundational research developed in the three regional studies.

The goal of the research is 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 Forum will work from an independent perspective, providing a sound basis for its participants’ business judgments in assessing their potential strategic interest in hydrogen.

Hydrogen in the Golden State

Our starting point in *Hydrogen in the Golden State* was to understand the **costs of producing hydrogen**, from multiple commercial and near-commercial production pathways (see Figure 2). The costs were presented on a levelized-cost basis (the Levelized Cost of Hydrogen, or $LCOH_2$), considering future technological progress, 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 levelized cost of hydrogen.

Figure 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 transport, in generating electricity, in heating and in industrial processes. For each of these sectors, hydrogen is likely to face a very different competitive dynamic in terms of the alternative fuels, the technologies, and future market conditions. The forms of industrial and commercial organization which will be appropriate for effective delivery of hydrogen into these various markets are also likely to be very different.

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 California in 2030, 2040 and 2050.

Hydrogen in the Golden State: Project deliverables

Workshop 1, Los Angeles (PowerPoint)

- Context and study approach: Drivers of interest in hydrogen in the energy transition
- Greenhouse gas policy in California
    - Legislative actions and executive orders
    - California's carbon cap-and-trade market
    - Electric power market regulation
    - Transportation sector regulation
    - Residential, commercial and industrial regulations
- The levelized cost of hydrogen
    - A review of capital costs for steam methane reforming (SMR) with and without carbon capture and storage (CCS)
    - 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 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
- Hydrogen in California's Energy Future
    - An overview of the study's quantitative approach
    - California energy demand and the implications for hydrogen
    - Estimating the demand and supply of hydrogen
    - The natural gas infrastructure context for hydrogen
    - Review of the key results of the Autonomy scenario

Levelized cost of hydrogen production model (Excel)

Excel spreadsheet allowing user to analyse the evolution of the cost of hydrogen through time from multiple production pathways

- Hydrogen production pathways
    - SMR with no carbon capture
    - SMR with five 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 oil and gas productio fields with/without legacy infrastructure and saline aquifers
- Costs of electrolysis provided for range of electricity supplies
    - Grid power
    - Dedicated wind
    - Dedicated solar

Webinar: Hydrogen in the Golden State: California's net zero greenhouse gas economy in 2050 – (PowerPoint and recorded playback)

- California's current energy consumption, greenhouse gas emissions, and policy
- California's path to net zero greenhouse gas emissions by 2050

Webinar: Hydrogen and transportation: Can fuel cells move California? – (PowerPoint and recorded playback)

- Sales of zero emission vehicles in California, and related sales incentives
- Light duty fuel cell electric vehicle economics
- Hydrogen transportation infrastructure and retail prices

Insight special report: Hydrogen in the energy transition: Recent policy measures bolster power-to-gas deployment in Germany; Electrolysis: Status and outlook – (PDF)

A report on two recent developments in Germany which have the potential to profoundly change the global landscape for the use of hydrogen (power to gas) in the energy transition.

- Amendments to the grid expansion acceleration law allowing transmission operators to build and operate large-scale storage facilities, including power-to-gas plants.
- First proposals for Federal legislation to allow virtual generation and consumption sites that would link renewable generation and power-to-gas facilities, bypassing power transmission charges.

Insight special report: Aiming for net zero: UK Committee on Climate Change raises 2050 ambition from 80% reduction to net zero – (PDF)

A report on the UK Committee on Climate Change (CCC) May 2019 recommendations for the United Kingdom's 2050 climate target. The CCC is the official body that provides recommendations to the government on long-term climate targets, including setting the multiannual carbon budgets.

Workshop 2 – (PowerPoint)

- Assessing the cost of producing hydrogen in California
  - An updated presentation of the IHS Markit $LCOH_2$ model with additional product pathways, including biomass gasification, organic solid waste anaerobic digestion to biogas and methane pyrolysis.
  - Assessment of the impact of the California Low Carbon Fuel Standard on hydrogen production pathway costs.
- Transporting hydrogen
  - Methods of transporting hydrogen
  - Main cost drivers for different transportation alternatives
  - How the costs of transporting hydrogen compare among the different methods
  - Strategies for transporting hydrogen as the market grows
  - Comparison with methanation and transporting synthetic methane
- How does hydrogen fit in with California's decarbonized power sector?
  - Balancing power supply and demand on a daily and seasonal basis

- Carbon policies in California and western North America
    - Zero carbon power in 2050
    - Solar curtailment and seasonal storage
- Is hydrogen an economic route to decarbonize California's space and water heating?
    - Defining the scale of the problem
    - Identifying the uncertainties
    - Identifying the technology options available to provide low carbon heat in California
    - Analysis of the shape of heat demand
        - Evolution of demand through the year, across the day, and by climate zone
        - Relationship of space and water heating demand with current power demand
    - Calculating the cost of decarbonising heat based on the levelized cost of heat for each technology
        - Base case and range of uncertainty
        - Comparison with current default technology—high efficiency gas
    - Options to decarbonize residential space and water heating
    - Implications for the commercial sector
- Hydrogen in the transport sector: can fuel cells move California?
    - A total cost of ownership approach to understanding transportation economics
        - Capital and operating costs
        - Cost of hydrogen refueling
        - Comparison to internal combustion engines and battery electric vehicles
    - Focusing on three major sub-sectors: passenger cars, buses and medium and heavy-duty trucks
- Identifying the plausible demand for low-carbon hydrogen in California's energy transition
    - Synthesizing the study's sectoral analyses (residential/commercial, industrial, transportation and power) to arrive at plausible levels of hydrogen market penetration by 2050
    - Magnitude of sectoral CO2 emission reductions
    - Comparison to other major third-party sturdies
- Supplying California's demand for low carbon hydrogen
    - Assessing the split between SMR with CCS and electrolysers:
        - Establishing the boundaries
        - Arriving at a plausible supply narrative and timeline consistent with electrolyzer cost reductions
    - The risks of the plausible case; what could impede this future?
- Study conclusions
    - Key hypotheses for the future use of hydrogen
    - Hydrogen as part of a net zero carbon California
    - Signposts to watch for if hydrogen is to achieve scale

Executive Summary – (PowerPoint)

Slide deck describing the key results and conclusions of the study, focused on insights and learnings.

California Hydrogen dataset – detailed results – (Excel)

Detailed numerical data for the California Plausible Hydrogen Case in three data tables:

California power outlook. Key assumptions used and the results of the power market analysis delineating the role played by hydrogen.

- Changes in power demand attributed to electrification by sector
- Power supply (capacity) by technology
- Power supply (energy) by technology
- Off-grid dedicated renewable generation and hydrogen electrolysis

California hydrogen supply and demand. Summary of demand by major end use category, and supply by hydrogen production technology.

California energy balance. Full energy balance for California, with historical data plus the Plausible Hydrogen case in 2030, 2040 and 2050.

Levelized cost of hydrogen production model: update – scheduled for July 2019 (Excel)

An updated version of the $LCOH_2$ model provided in December 2018. In addition to improved formatting and ease-of-use, the following features were added:

- Biomass gasification pathway
- A second bio-hydrogen pathway: Organic waste anaerobic digestion to biogas and biogas reforming to H_2 using a small-scale reformer
- Improved CAPEX, OPEX data for coal gasification based on additional data sources, added lower bound and upper bound to reflect data variance
- Thermal Decomposition of Methane (TDM, or methane pyrolysis) pathway. Analysis based on cost-to-capacity exponent for methane pyrolysis plant with the possibility to choose a selling price for the carbon black by-product
- Fine-tuned CCS Cost. Added a 20% contingency to reflect possible delays in permitting and construction as only few commercial projects exist and mostly pilot plants
- Allocation factor for CAPEX and OPEX. Data for CAPEX and OPEX are collected from projects and studies from Europe and North America. This allocation factor allows for an estimate of costs in other locations.
- Oxygen price and electrolysis by-product
- Small scale SMR for direct comparison with similar capacity electrolyzers
- Added transmission fees to wholesale electricity prices

Hydrogen transportation assumptions – scheduled for July 2019 (Excel)

Key assumptions used in the development of the cost of transporting hydrogen. Including:

- Hydrogen pipeline specifications, capital costs and operating costs.
- Hydrogen tube trailer specifications, capital costs and operating costs.
- Hydrogen cryogenic transportation (terminal and trailer) specifications, capital costs and operating costs.

Domestic heat sector assumptions – scheduled for July 2019 (Excel)

Key assumptions used in the comparison of cost of space and water heating with natural gas, hydrogen and electricity. Including:

- Heating system capex
- Heating system O&M
- Heating system economic life
- Heating system shares
- Heating system efficiency

Transport sector assumptions – scheduled for July 2019 (Excel)

Key assumptions used in the total cost of ownership modelling for light duty vehicles, buses and trucks. All figures given for internal combustion, battery electric and hydrogen fuel cell vehicles.

- Vehicle CAPEX
- Vehicle fuel economy
- Vehicle O&M
- Additional infrastructure costs for battery buses-CAPEX and OPEX

The Nexus of Hydrogen and Water: Background on California's water market and implications for hydrogen production – scheduled for July 2019 (PowerPoint)

A characterization of the magnitude of water demand implied by the California Plausible Hydrogen case, and the context of that demand relative to other water end uses.

- Overview of current water fundamentals, supply and demand
- Prices of water
- Background on water policy
- Water requirements for hydrogen production: SMR and electrolysis
- Hydrogen water demand vs. other uses (industry, agriculture)

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