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Hydrogen in the Golden State

An IHS Markit study considering the potential role of hydrogen in a low-carbon economy

2019

Hydrogen’s Role in the Energy Transition

When considering an energy transition to a low carbon future…

Elements required for a transition to a low carbon economy

- Replacement of most conventional fossil fuels with low- or zero-carbon sources
- Development (or repurposing) of infrastructure to deliver low or zero carbon energy sources
- Development of, and adjustment to, digital, smart and prosumer environments
- Increased energy efficiency
- Well-designed policy that enhances innovation and cost reduction

Source: IHS Markit

The energy transition creates significant investment opportunities, but issues around cost management, stranding of assets and poor progress to date (focus has largely been on the power sector)

…hydrogen may serve as a potential solution…

End use applications of hydrogen for energy use

Transport	Industry	Residential Commercial	Power
			
Displace batteries or fossil fuels	Displace natural gas in pipelines and end uses		Intra-day balancing of renewable generation and power demand
			Seasonal balancing of renewable generation and power demand
			Reduced fossil generation

Source: IHS Markit

…with significant hurdles to overcome

- Hydrogen will have ***competition***—from batteries, demand side management (DSM), and other forms of low carbon heat
- The ***source*** of the hydrogen matters—production from unabated natural gas is carbon intensive
- To play a role in the energy transition ***low-carbon*** hydrogen is essential. Multiple pathways have been investigated:
  - Electrolysis
  - Steam methane reformation (SMR) with carbon capture and storage (CCS)
  - Gasification of biomass waste or coal with CCS, or digestion of municipal solid waste.
  - Methane pyrolysis (also known as methane cracking or thermal decomposition of methane
- Significant ***infrastructure/logistical investments*** will be needed

Key Business Questions: What is the hydrogen opportunity for my company?

Upstream Oil and Gas Companies

- Can hydrogen produced with SMR and CCS offer a long term future for natural gas production?
- What is the competitive threat from hydrogen from electrolysis?

Electric Utilities

- What is the role of hydrogen storage in integrating renewables?
- Is large scale hydrogen power feasible?
- 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 End Users

- Can hydrogen replace conventional sources of process heat?
- How would the hydrogen be produced and delivered to my facility?

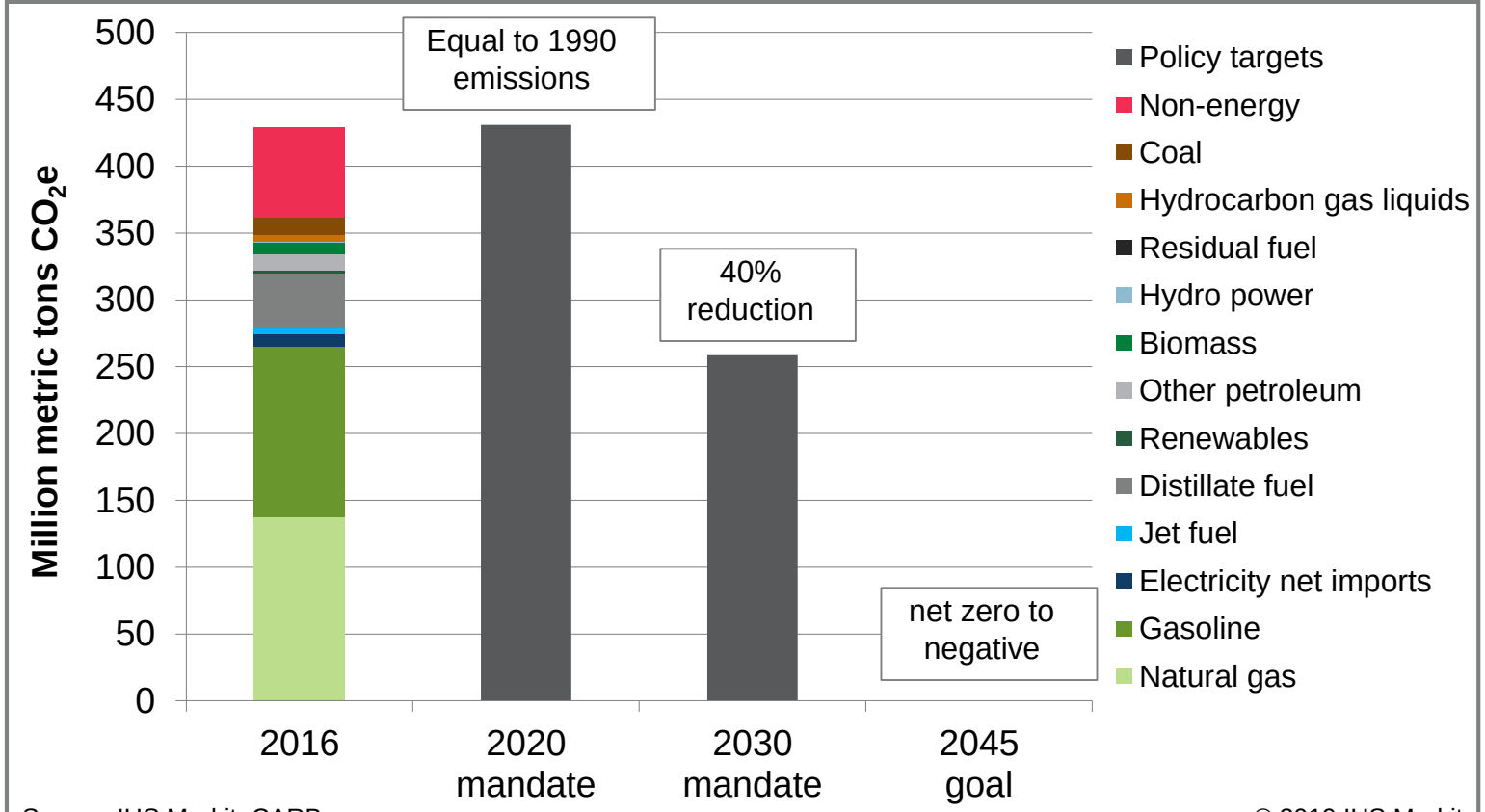
Financial Institutions

- How will hydrogen infrastructure projects be financed?
- Will there be policy support for hydrogen?
- What are the technology and revenue risks?

California and US Policy Framework

With the first hurdle achieved, California must look towards reducing GHG emissions 40% by 2030 and eliminating them, on net, by 2045

California, total GHG emissions by fuel in 2016 and policy targets, 2020, 2030 and 2045



Source: IHS Markit, CARB

- The first column shows CARB's most recent GHG inventory, which is total included emissions subject to California's policies. Emissions are shown as CO2-equivalent (CO2e).
- California's first GHG emission reduction goal is to return to 1990 emission levels by 2020. The state reached this goal in 2016.
- The next goal is lowering emissions to 40% below 1990 levels by 2030 (Senate Bill 32). Much needs to be done to reach this goal.
- The long-term goal, set by the governor's executive order at the end of 2018, is a net zero GHG emitting economy by 2045.
- Our analysis will focus on the opportunity for hydrogen in a decarbonized California, which will come about from strong policy.

California regulates a majority of GHGs emitted in the state, referred to as "included," but some emission sources are outside the state's scope

California's included and excluded GHG emissions

Included emissions:
429 million metric tons (CO_2-equivalent) in 2016

- Transportation fuels
- Electricity generation and imports
- Manufacturing
- Oil & gas production
- Refining
- Cement production
- Natural gas combustion
- Natural gas storage and transmission
- Chemicals
- Propane combustion
- Agriculture (short-lived climate pollutants)
- Wastewater treatment
- Landfills

Excluded / not specified emissions:
59 million metric tons (CO_2-equivalent) in 2016

- Aviation and marine fuel when destination is outside California
- Some oil and gas production & processing emissions
- Some military sources
- Fugitive emissions from municipal landfills and livestock manure
- Sources below annual minimum thresholds (e.g., 10,000 metric tons CO_2-equivalent)

Notes: Lists do not include every included or excluded / not specified emission source.
Source: IHS Markit, California Air Resources Board (CARB)

California is not alone: many states and municipalities have low carbon ambitions

State and local level climate commitments

State climate goals

20 states now part of the US Climate Alliance, committed to reducing emissions consistent with goals of the Paris Agreement – and 22, plus Washington DC, have GHG targets

10 states currently place an explicit price on CO_2 emissions (and likely to grow to 13)

Municipal targets

Hundreds of cities have declared commitments to stand by the Paris Agreement

Power

29 states have renewable portfolio standards for electricity - representing 55% of total US electricity sales

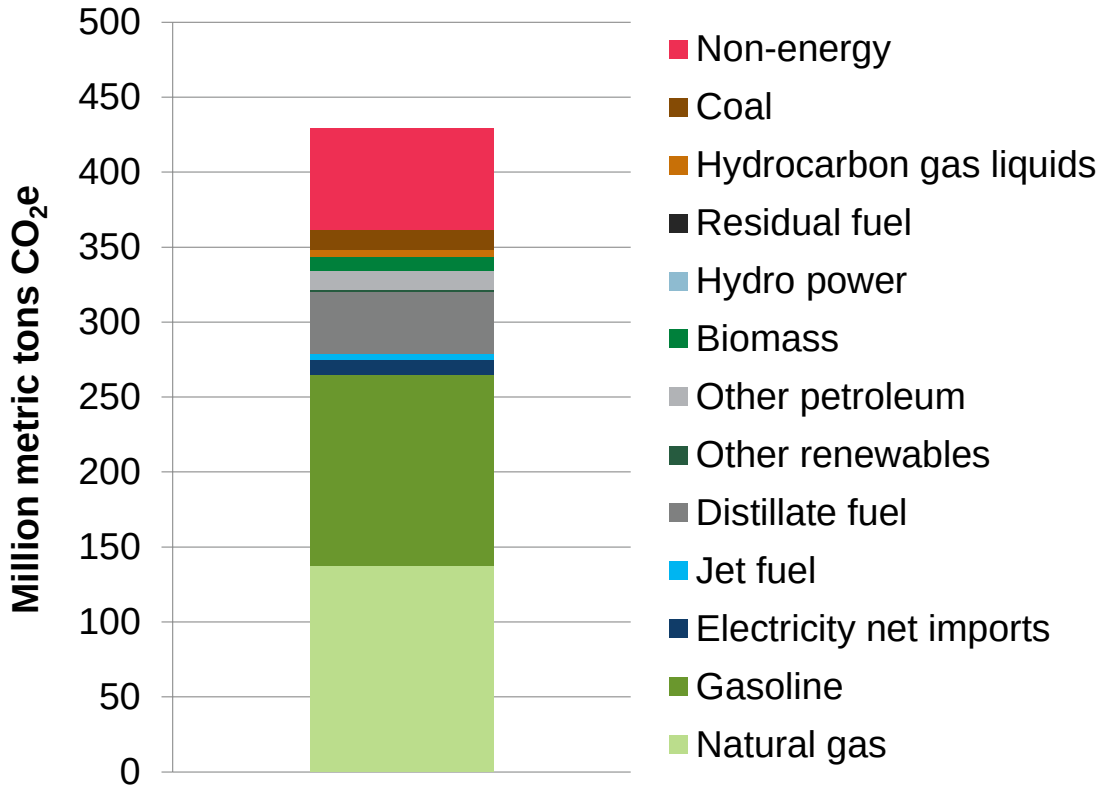
Transport

2 states have clean fuel standards on top of the federal Renewable Fuels Standard. **22 states** have financial incentives for EV or PHEV vehicles. **9 states** currently designing joint cap on transportation emissions.

Source: IHS Markit

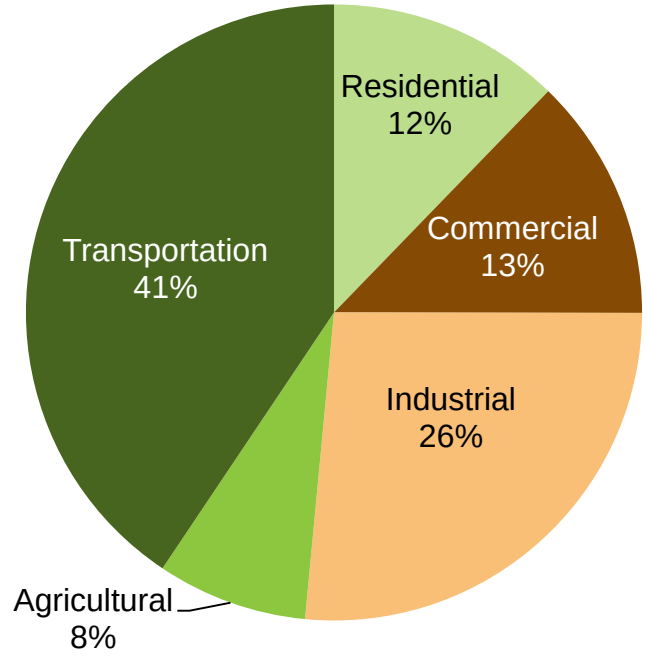
More than 70% of included GHG emissions come from natural gas, gasoline, and diesel; transportation and industry emit two-thirds of included GHGs

California, included GHG emissions by fuel



Notes: Data from CARB's emission inventory program, 2016
Sources: IHS Markit, CARB

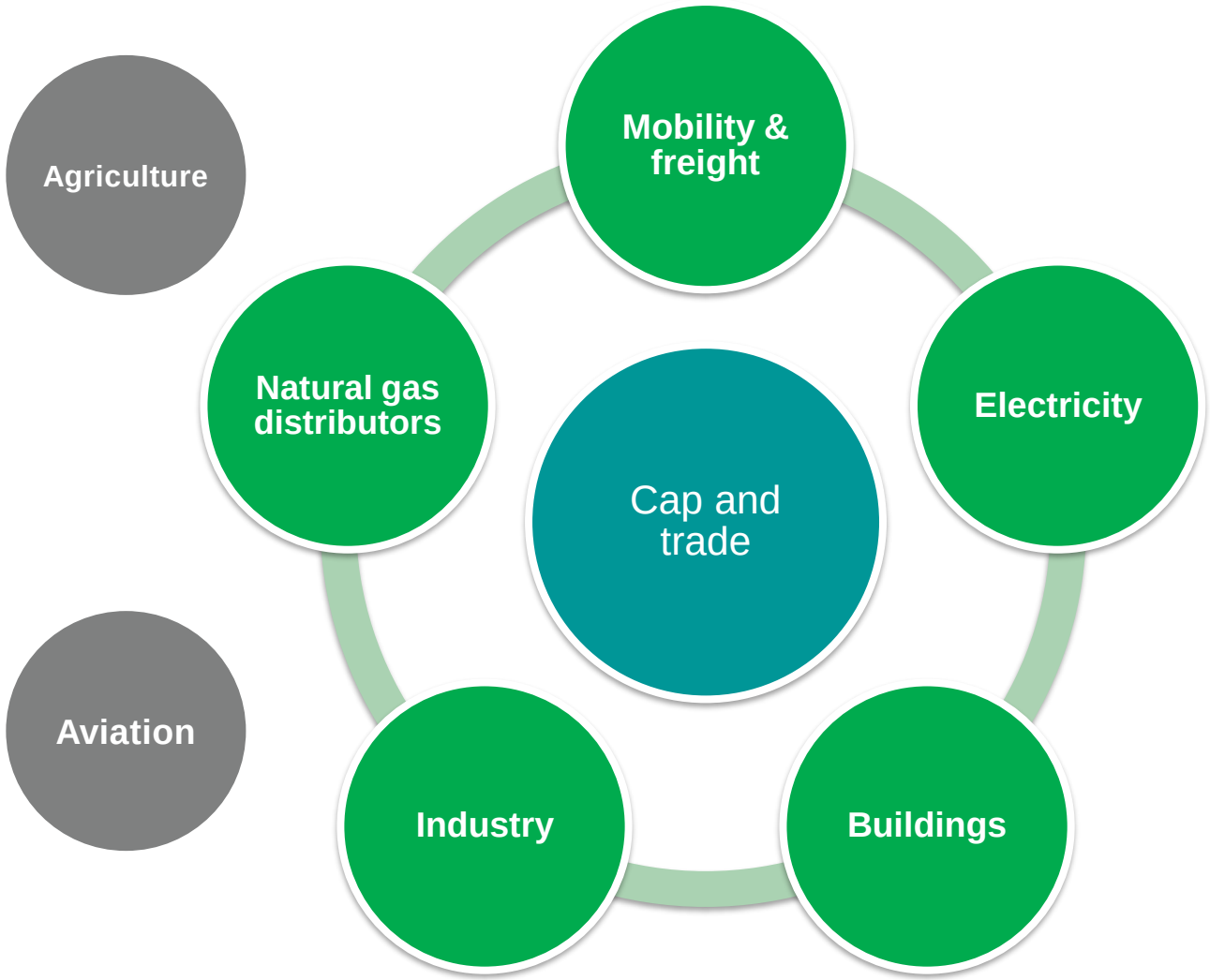
California, included GHG emissions by sector



Nearly 50% of non-energy emissions come from agriculture and 25% come from industry.

Notes: Data from CARB's emission inventory program, 2016
Source: IHS Markit, CARB

Sector-specific policies drive most of the GHG emission reductions

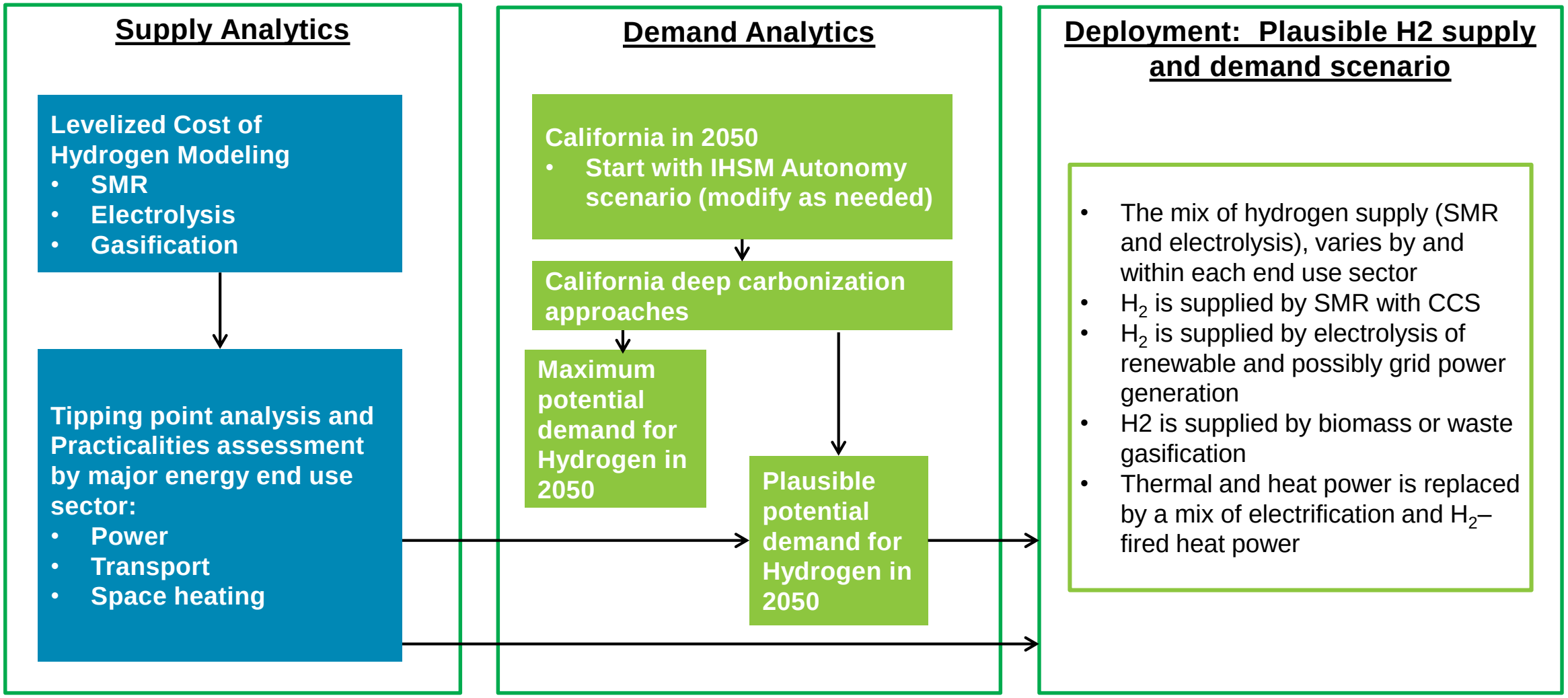


- **Power:** Renewable portfolio standard (60% by 2030), a phase-out of any remaining use of coal, and a 100% carbon-free power supply mandate by 2045
- **Buildings:** Energy efficiency savings in natural gas and electricity end uses, rooftop solar PV requirement, net zero energy buildings goal
- **Mobility & freight:** Low Carbon Fuel Standard, which seeks a 10% reduction in emissions intensity by 2020 and ratchets up to a 20% reduction by 2030 (all relative to 2010); zero emission vehicle requirements; and rebates for electric and hydrogen vehicles.
- **Industry:** Few focused policies implemented to date, but some offset availability under cap-and-trade
- **Natural gas distributors:** Biomethane procurement targets, clean heat market development, methane leakage policies

Source: IHS Markit

Quantitative Approach

Hydrogen in the Golden State: Project analytical framework



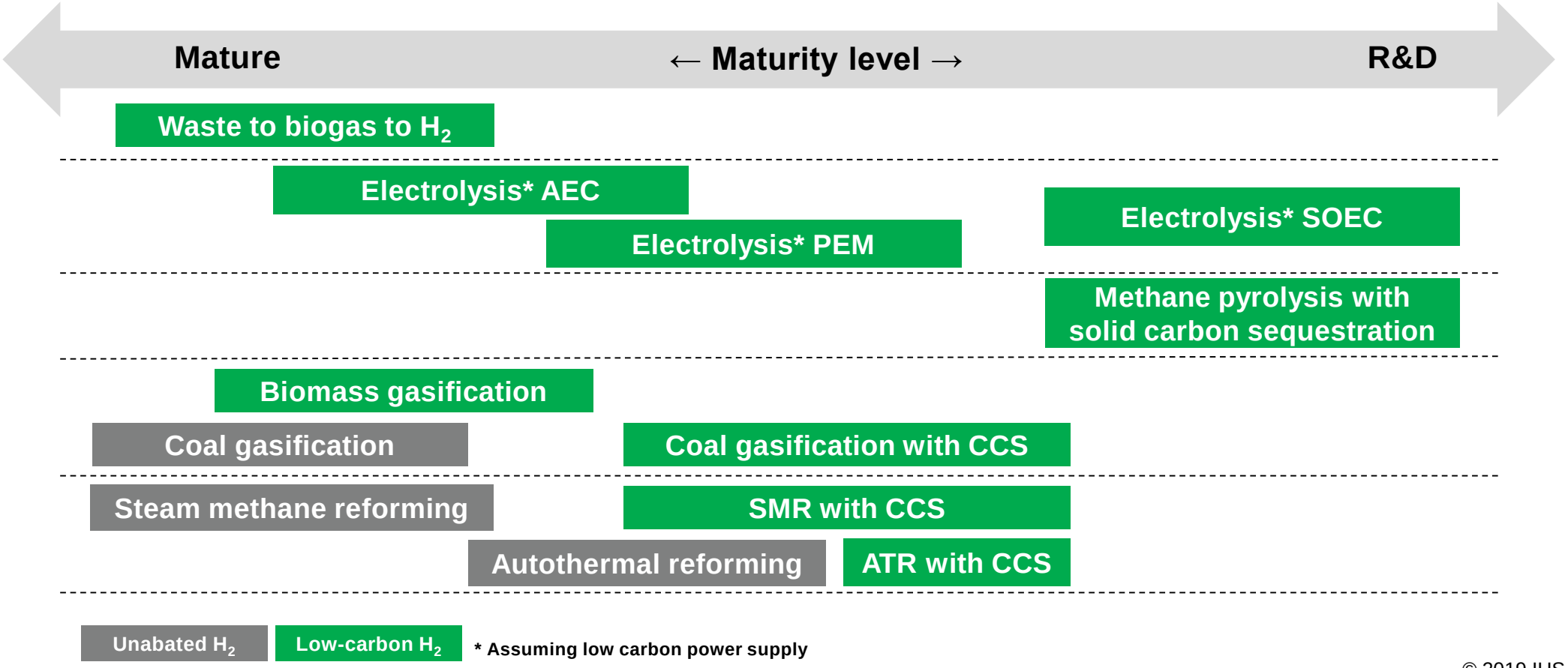
Levelized cost of hydrogen methodology

- The IHS Markit levelized cost of hydrogen (LCOH2) model calculates hydrogen costs at the exit of the production facility, including costs of carbon capture, transport and storage, and CO_2 emissions from the process when applicable. Delivery to end user is considered a separate deployment step.
- The LCOH2 model calculates hydrogen costs via various pathways and multiple scales:
  - Electrolysis (three technologies): alkaline electrolysis cell, proton exchange membrane, and solid oxide electrolysis cell
    - Varying scale and sources of electrolyzer power supply
  - Steam methane reformation (SMR), with and without CCS
    - Varying scale
  - Hydrogen from biomass waste or coal gasification with and without CCS, digestion of municipal solid waste, and methane pyrolysis
- Each production pathway is evaluated to understand the impact of California's Low Carbon Fuel Standard (LCFS) on hydrogen destined to transportation uses

Study considers a wide range of hydrogen production pathways

Pathways differ in terms of technologies, feedstock, scale, commercial availability and maturity

Hydrogen production pathways



Source: IHS Markit

Key cost drivers for hydrogen production

Cost drivers for hydrogen

SMR	Electrolysis
Size of SMR	Electrolysis technology
% of CO_2 captured	Deployment/learning rate
Deployment/learning rate for CCS	Efficiency improvement
Natural gas price	Electricity price
Carbon price	Electricity supply: curtailed or dedicated?

Source: IHS Markit

Drivers of the competitiveness of retail hydrogen

Drivers of the competitiveness of retail hydrogen

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Capital cost of the downstream infrastructure

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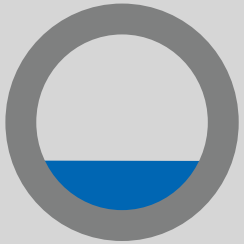
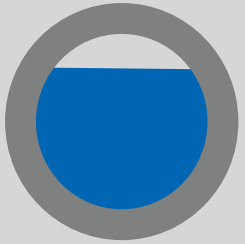
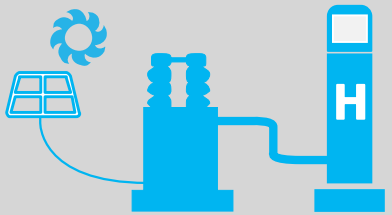


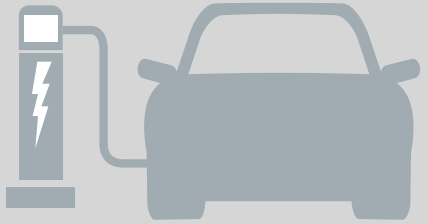
Utilization of the downstream infrastructure



Trucked supply vs onsite production



Price of competing fuels

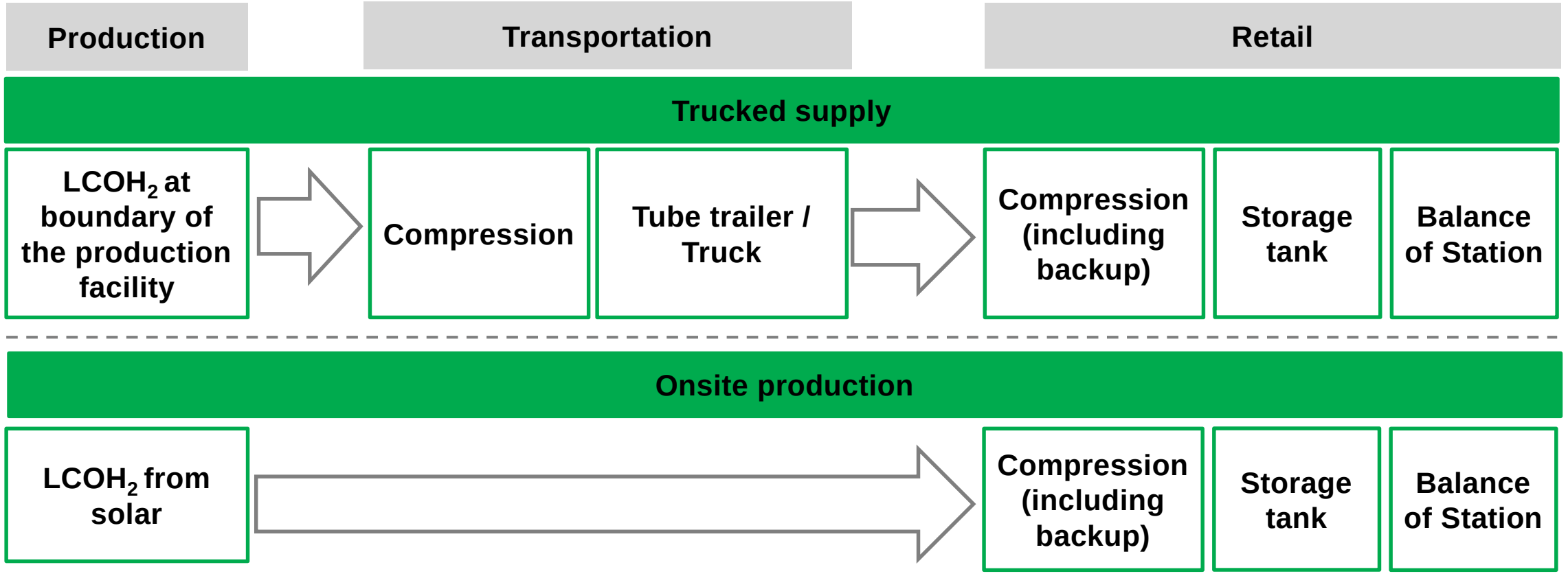


Notes:
Source: IHS Markit

There are two options for the medium-term supply of H_2 for transport use

Tube trailer or onsite production

Build up of hydrogen delivery costs (2020)

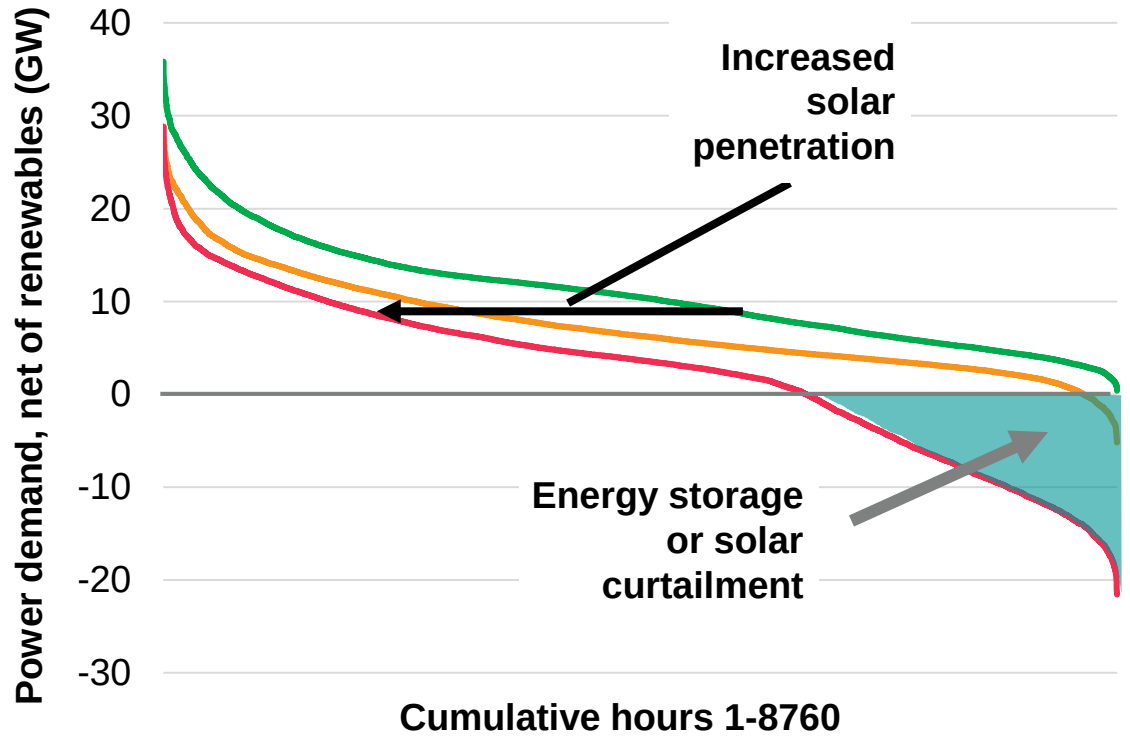


Notes: In the long-term hydrogen could be delivered via pipeline, but this is likely to require the deployment of hydrogen for energy use in the wider economy
Source: IHS Markit, US DOE

Energy storage is needed to match variable renewable generation with load

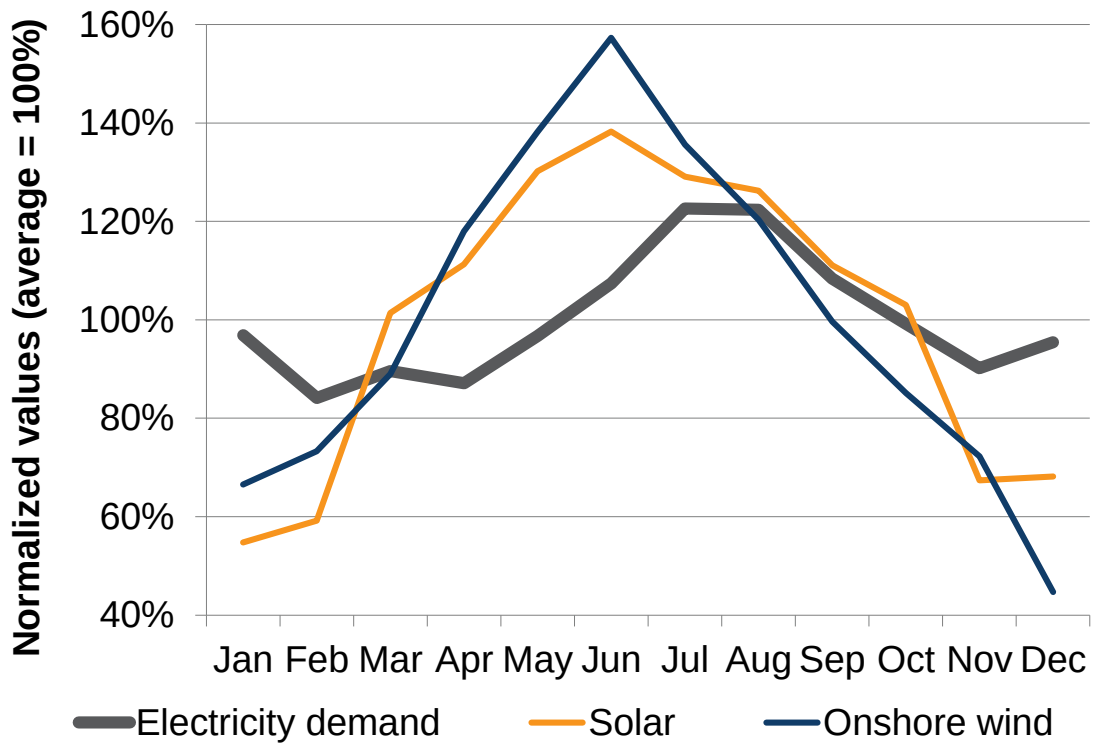
Mis-matches exist across hours, days, weeks, and months. Storage may also be necessary for year-to-year variations in climate.

Power system impact of increased solar penetration



Source: IHS Markit

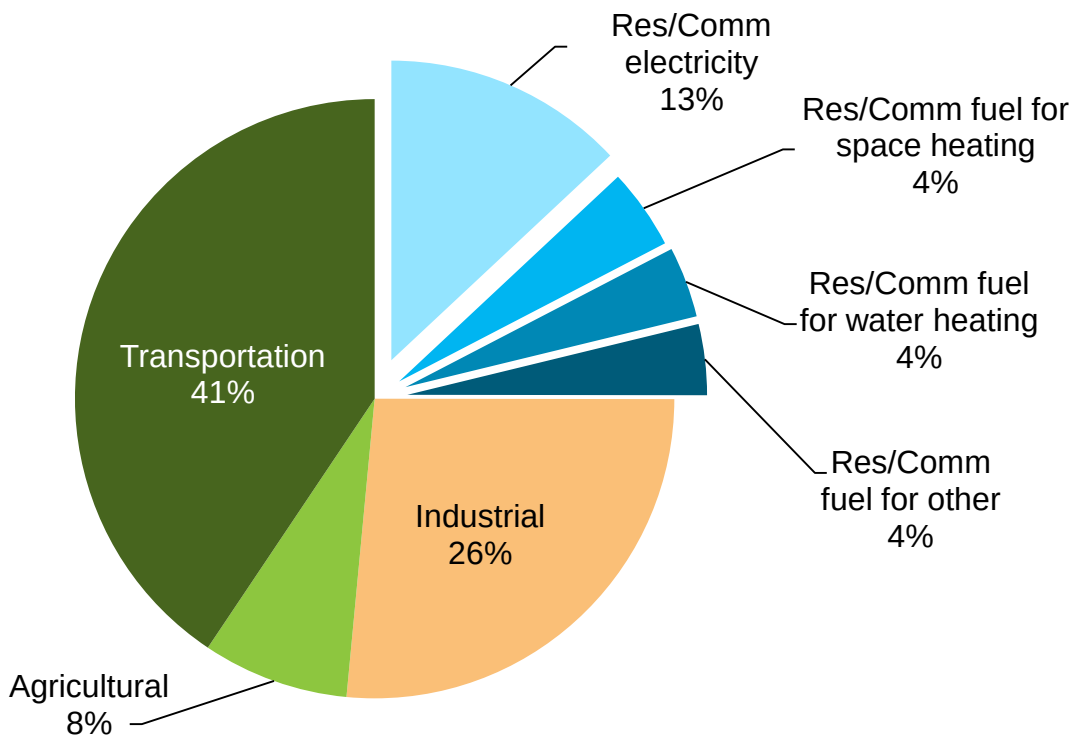
CAISO, demand and generation profiles



Source: IHS Markit, ABB Velocity Suite

Residential and commercial direct GHG emissions dominated by natural gas used for space and water heating end uses

California, residential and commercial GHG emission details

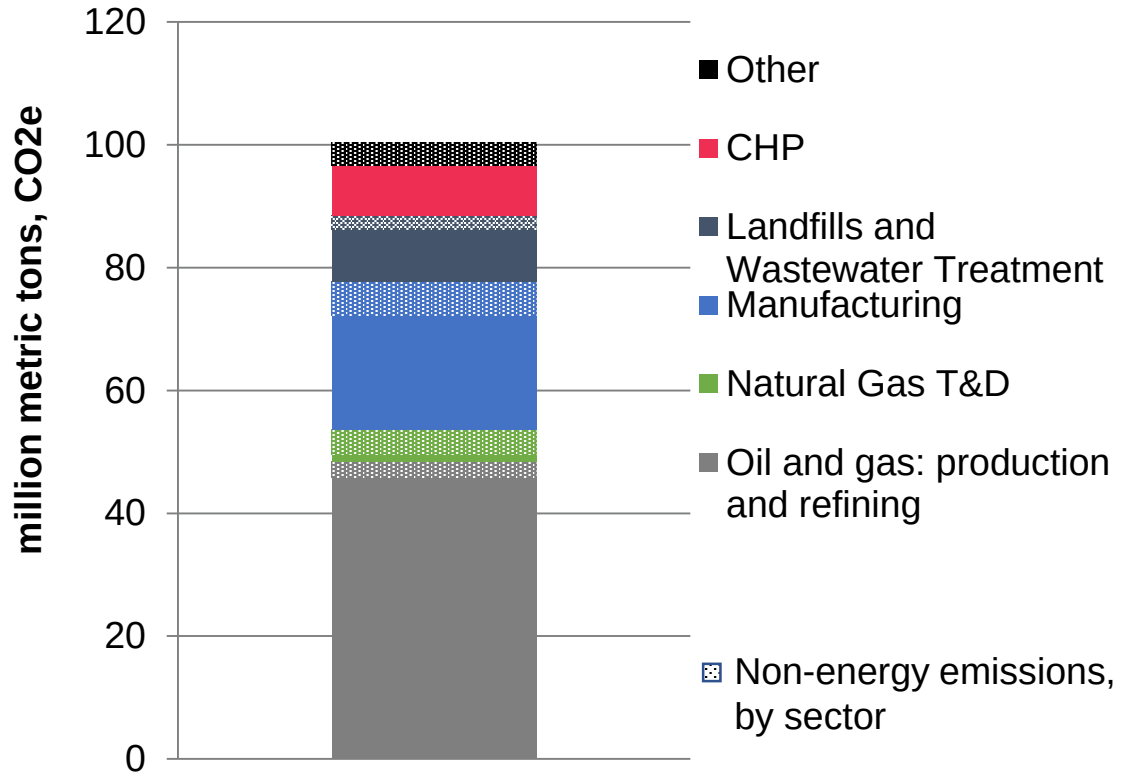


Source: IHS Markit, CARB 2016 Emission Inventory

- Potential options for the high decarbonization of residential and commercial sectors are:
  - Electrification or
  - Gas grid conversion to hydrogen
- Our analysis is considering the practicality and costs associated with each, including the challenges of managing peak heat demand in the case of electrification, and the implications of large scale gas grid conversion

Industrial emissions are split across many sectors – fossil fuel production represents about half

Industrial emissions by end use, 2016

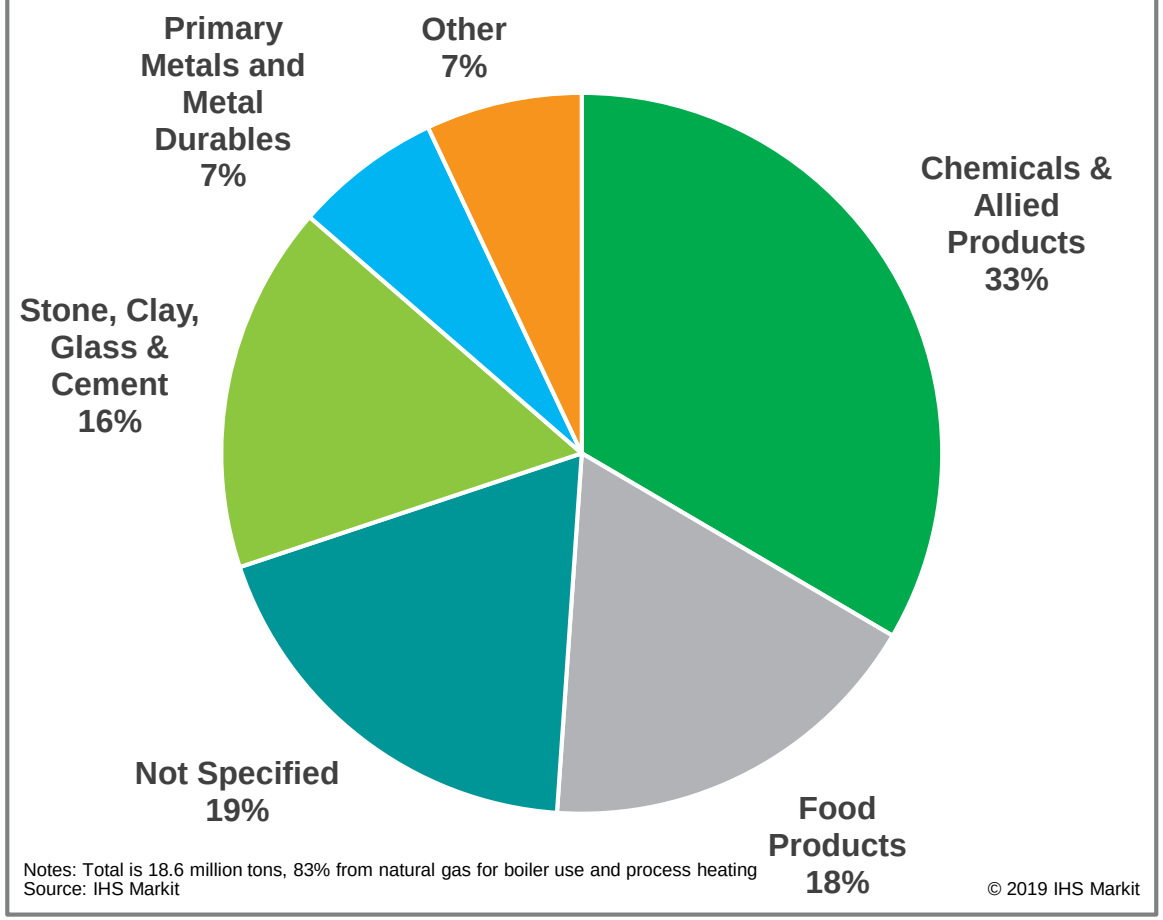


Notes:
Source: IHS Markit

- Manufacturing, waste management, and combined heat and power represent 43% of industrial sector emissions and 10% of statewide emissions
- Offsets is one way to manage these emissions, but some degree is likely addressable via direct emissions reductions through fuel switching and efficiency improvements
- Landfills and wastewater treatment to be primarily addressed via capturing emitted or flared gases

Manufacturing is diverse; most emissions are from fuels used for heat

Manufacturing combustion-related emissions, 2016



Notes: Total is 18.6 million tons, 83% from natural gas for boiler use and process heating
Source: IHS Markit

- Of the 18.6 million tons of combustion-related emissions in manufacturing, 83% are from natural gas
- Most manufacturing emissions are from boiler fuels and process heat
  - Process heat used across industrial sectors for metal and non-metal melting, calcining, metal heat treating and reheating, coking, drying, and more
- Early policies to encourage alternative fuel adoption could include:
  - Codes and standards
  - Cap and trade offsets
  - Small scale injection into existing infrastructure

Hydrogen deployment focuses on the intersection of supply, demand, policy and logistics to arrive at a plausible future

- Practicalities
  - The practical issues surround the rollout of any new technology or fuel into the energy mix.
  - For hydrogen these issues include
    - The suitability of existing infrastructure for hydrogen use: e.g., gas distribution system, power generation, and consumer appliances
    - Transportation refueling network requirements
    - Storage cost and suitability
    - Safety
- Tipping points
  - Identify factors that can trigger a take-off of hydrogen from niche fuel into a more significant part of a zero- or ultra-low carbon future
- Models of production and delivery
- Assessment of hydrogen's plausible future for each sector
- Identification of inter-sectoral synergies

Two models for hydrogen deployment

Models of hydrogen deployment

Centralized	Decentralized
Large scale production	Local production close to end use
Transmission / distribution grid connected	Small scale
Integrated system planning required	Ring-fenced integrated products possible
Policy / government initiatives necessary	Local government mandates

Source: IHS Markit

Decision makers, timing, risk profile, end use for each route are significantly different

Hydrogen in the Golden State: The IHS Markit Muticlient Study

Hydrogen in the Golden State: Project timeline and deliverables

Initial Workshop and Community introduction
Los Angeles
30 October 2018

Intermediate presentations: Community calls
November 2018 – May 2019

Final Workshop and Presentation Materials
Chicago, 14-15 May 2019

- **Why hydrogen now:** an overview of policy initiatives supporting hydrogen development in California.
- **Hydrogen supply analysis:** presenting the results and insights from the IHSM Levelized Cost of Hydrogen ($LCOH_2$) modeling and analysis.
- **Developing the project quantitative approach:** review of the components of the IHSM Autonomy scenario and a how to assess hydrogen's role in a deeply decarbonized California.

- **Intermediate community calls:** validation of the modelling and intermediate results, sectorial deep-dive, etc., in a webinar format.
- **California net zero greenhouse gas economy in 2050.** Provided the policy backdrop for the project's analytics
- **Status of Analysis of the Transport Sector.** Quantification of transportation costs for hydrogen fuel cell vehicles and competing technologies.

- **Practicalities:** understanding the technical and policy issues impacting the potential role of hydrogen in power, industry, transport and heat in California.
- **Identifying the tipping points:** determining the triggers and conditions required for hydrogen to be used more widely
- **Costing:** quantifying indicative costs needed to move hydrogen from demonstration to commercial success in each principal end use.
- **The market potential for hydrogen:** quantification of the plausible and maximum potential demand for hydrogen in California.

Inviting you to join the IHS Markit Hydrogen Community

- Over 40 organizations have joined as members of one or more of IHS Markit's Hydrogen multiclient research projects.
- For more information on IHS Markit's global hydrogen research activities please refer to the IHS Markit website
  - Global perspective: https://ihsmarkit.com/products/hydrogen-global-market.html
  - US/California: https://ihsmarkit.com/products/hydrogen-in-the-golden-state.html
  - Europe: https://ihsmarkit.com/products/europe-hydrogen-forum.html
  - China: https://ihsmarkit.com/products/hydrogen-facilitator-china-energy-needs.html

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