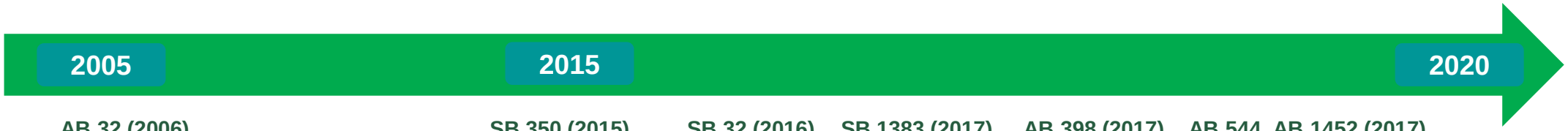
Hydrogen in the Golden State

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

October 2018

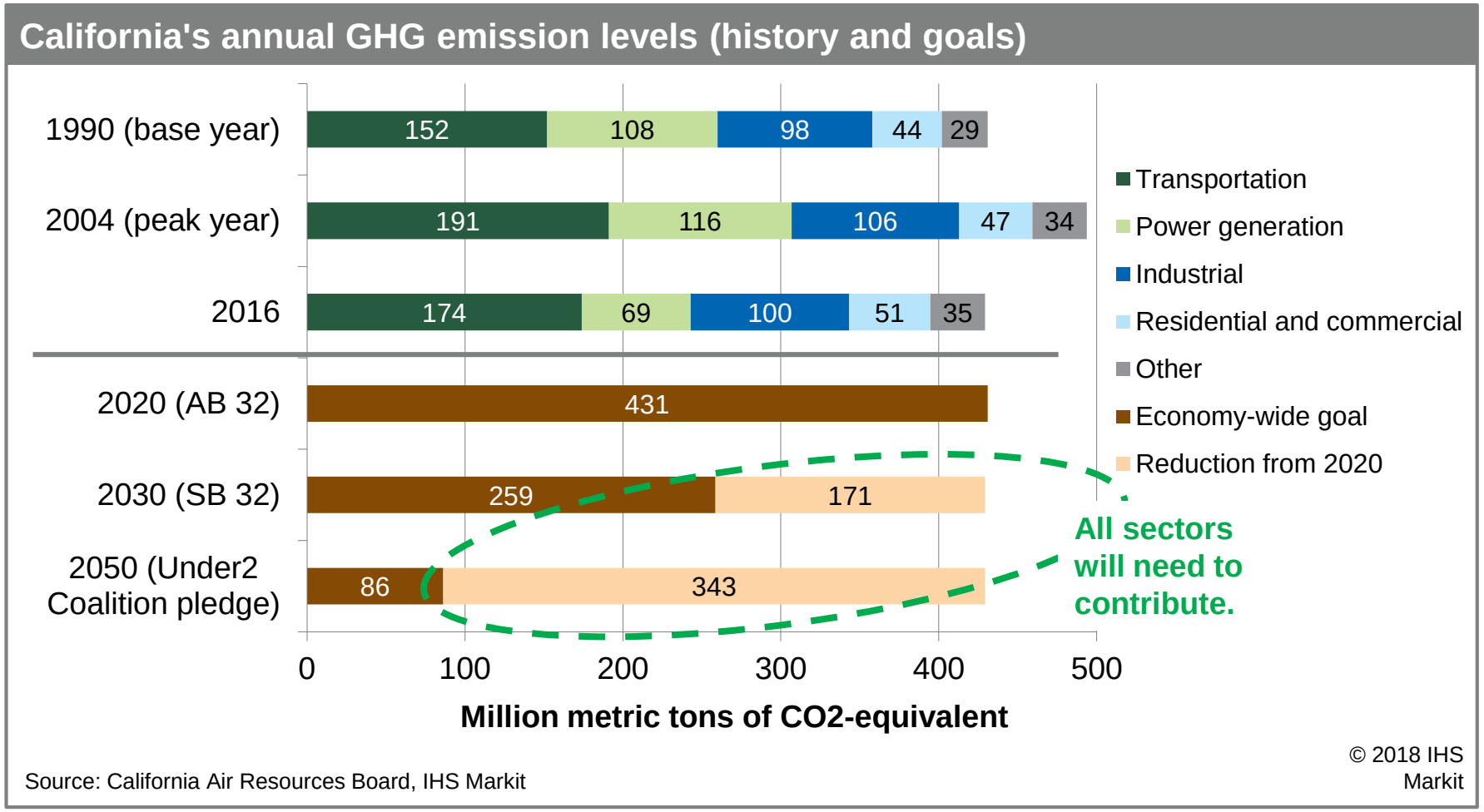
Why an IHS Markit multi client study on Hydrogen in California?

Multiple policy initiatives are driving decarbonization in California across the power, transportation, and natural gas end-use sectors



	2005		2015				2020
Existing legislation	AB 32 (2006) Reduce GHG to 1990 levels by 2020		SB 350 (2015) 33% RPS by 2020 and 50% by 2030; Double energy efficiency mandate	SB 32 (2016) 40% GHG reduction below 1990 levels by 2030	SB 1383 (2017) Short-lived climate pollutant reduction strategies	AB 398 (2017) Extend CO_2 cap and trade program to 2030	AB 544, AB 1452 (2017) Authorizes preferential parking and high occupancy vehicle privileges for ZEVs
Mandates / executive actions	Low carbon fuel standard (2007) 10% reduction in transportation fuel CO_2 intensity over 2007-20	Clean vehicle rebates (2010) Rebates to ZEV buyers	GHG Cap and Trade Program (went live in 2013)	Sustainable Freight Action Plan (2015) 100,000 ZEVs (freight) by 2030; 25% increase in efficiency of freight movement ($ value / CO_2) by 2030		Under2 Coalition (joined in 2015) Pledged ≥ 80% GHG reduction below 1990 levels by 2050	Zero emission vehicle goal (2018) 5 million by 2030 (includes battery electric and plug-in hybrids)
Proposed legislation						SB 100 (proposed 2017 and 2018) 60% RPS by 2030; 100% carbon-free power by 2045	SB 1440 (proposed 2018) 32 BCF (2%) of 2030 natural gas demand to be met by bio-methane

California's 2030 GHG reductions will require major contributions from all sectors; meeting 2050 goals requires dramatic reductions and new thinking



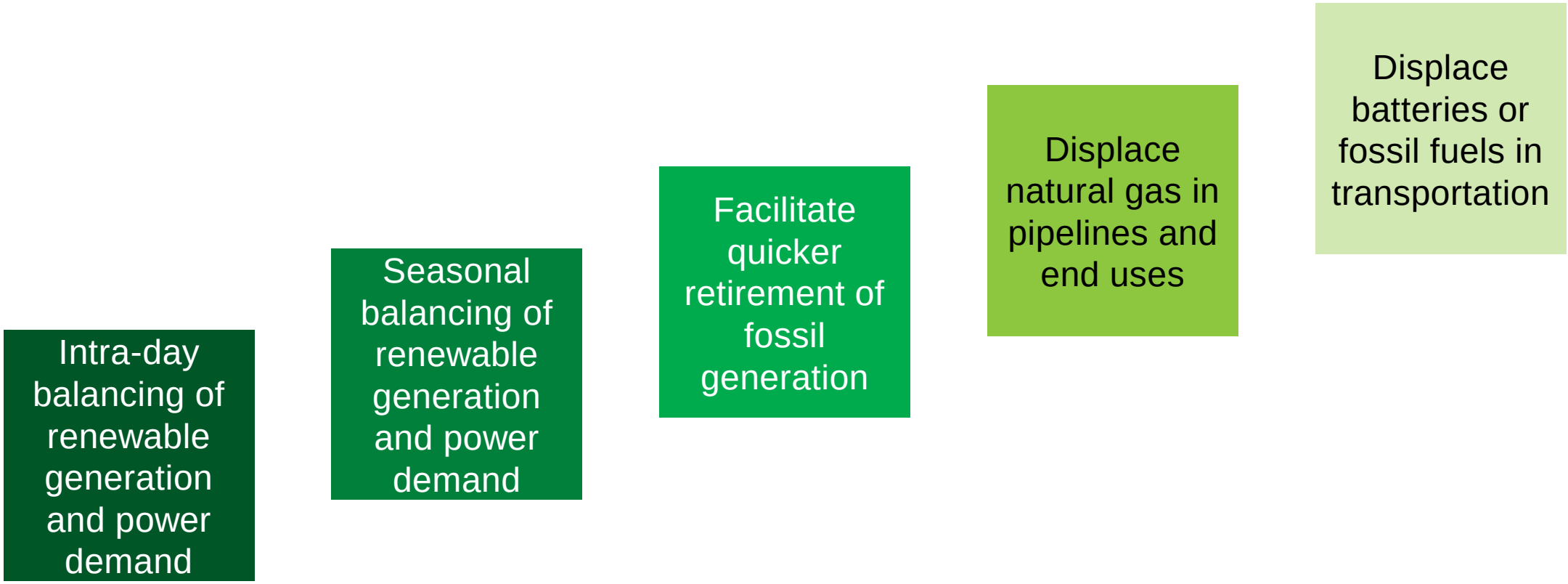
- California met its GHG reduction 2020 goal in 2016, reducing carbon emissions by 13% from its 2004 peak while its economy grew by 26% in real terms.
- But further GHG reductions will require new tools and new thinking; doing "more of the same" will not be sufficient.

Why an IHS Markit multi client study on Hydrogen in California now?

- All eyes are on California, as it aspires to lead the US to a low and eventually net zero carbon future. And at the same time, the nearly universal question is: “how will they do that?”
- A 40% reduction of economywide greenhouse gas (GHG) emissions from 1990 levels by 2030 is required by law. Other policies encouraging the lower-carbon transition are the 50% renewable portfolio standard for electricity by 2030, the low carbon fuel standard for transportation fuels (which requires a 10% reduction in GHG intensity from 2007 to 2020) and programs targeting short-lived climate pollutants (e.g., methane).
- As current clean energy goals near, political aspirations ratchet up. Senate Bill 100, revived in July 2018 by the state assembly, would require all load serving entities to pursue a 100% carbon-free power supply by 2045. Passage by the assembly and the governor’s signature are the only items needed for this ambitious bill to become law.
- Governor Brown has committed the state to doing its part to avoid temperature rises above 2 degrees Celsius by 2050 as part of the Under2Coalition. State policy will likely follow to reduce GHG emissions by at least 80% below 1990 levels by 2050.
- Hydrogen deserves our attention as an option that can both address the short-term need for rapid greenhouse gas abatement and can provide a long-term solution to the difficulties of storing large volumes of energy over long periods of time. Hydrogen can be used in all energy sectors—for power generation, heat, industrial uses and transport.
- Energy suppliers, gas infrastructure companies, consumers and government have all started exploring the advantages of hydrogen. For some energy industry stakeholders hydrogen could be a threat, replacing conventional energy sources, while for other stakeholders it could be an opportunity to re-purpose the substantial natural gas infrastructure already in place while meeting long-term zero carbon targets.
- If conditions are right for widely adopting hydrogen, it can provide a truly transformational opportunity for both California and the US as a whole.

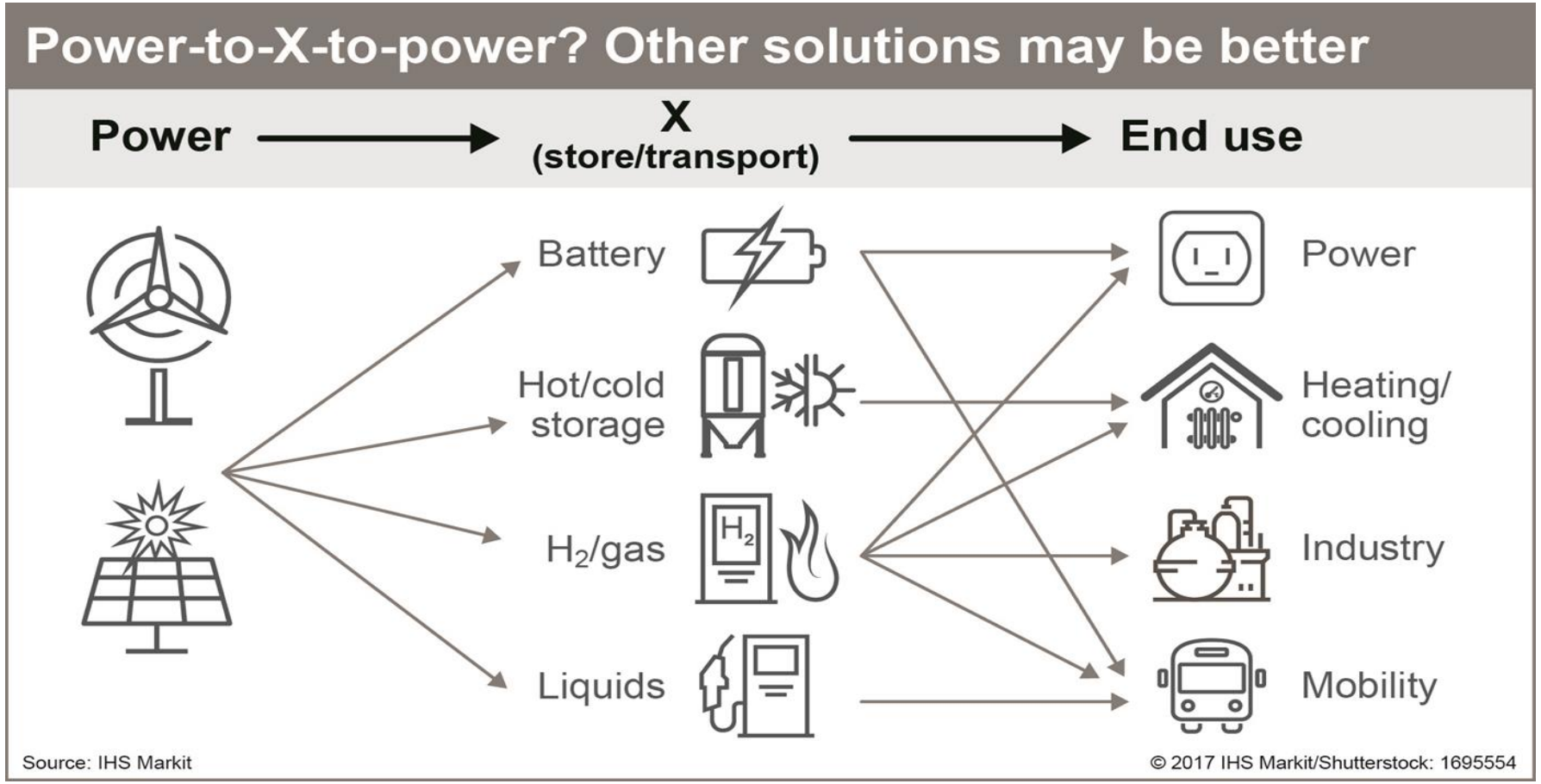
Why hydrogen? Ability to play many roles in decarbonization, although for every application there are competitive challenges

Economy-wide decarbonization via hydrogen



Source: IHS Markit

Why hydrogen? Hydrogen from renewable energy has a potential carbon-reduction role in every end use sector



Power to hydrogen to power is in direct competition with batteries for intra-day balancing

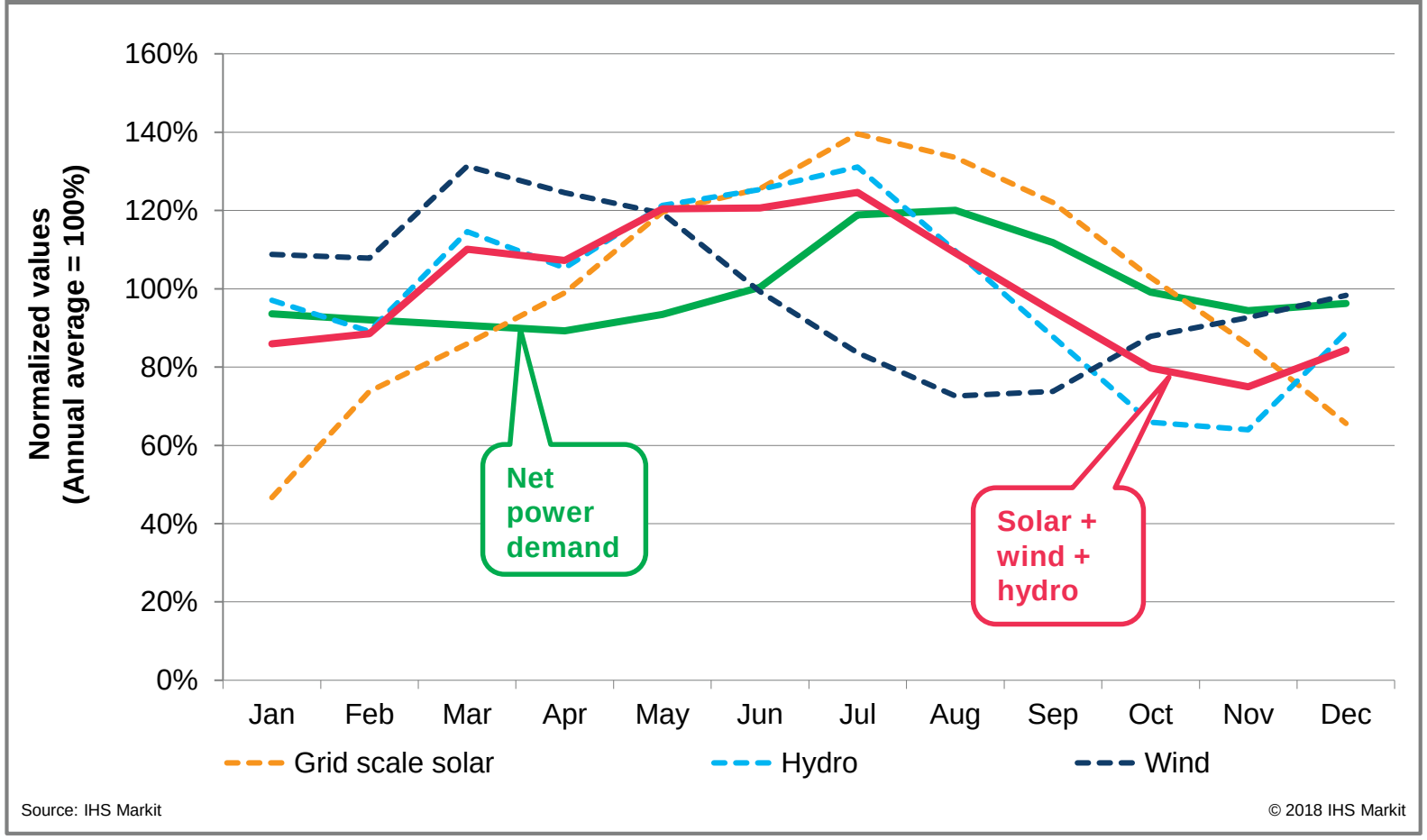
Power to heat requires a heat sink

Power to gas could replace natural gas in industry, where the need is often for its hydrogen content

Power to liquids and power to hydrogen competes with gasoline or diesel

Why hydrogen? The power grid will need a way to seasonally balance renewable energy and power demand

Seasonal variation in California supply and demand



Source: IHS Markit

- While the daily variation in solar generation and the resultant “duck curve” have received much attention in California, the challenge of managing the seasonal mismatch between renewable generation and power demand is still largely un-addressed.
- At current generation levels there is some natural seasonal balancing between California’s solar, wind and hydro generation, although the “shape” of total renewable generation is biased higher than demand in the spring and early summer, and below power demand in the fall and winter.
- This seasonal mismatch will grow profoundly as solar becomes a larger share of total renewable generation.

Why hydrogen? Gas grid owners and operators are looking at ways to decarbonize gas and ensure the future of their assets

- Natural gas is a low carbon fossil fuel, but not low enough for 80% decarbonization by 2050
- Grid operators could consider turning to green gas as a possible supplement or replacement for natural gas
  - To date, biogas is typically used on-site for small-scale power (e.g., landfills in post closure and waste digesters)
  - Californian considering legislation (SB 1440) for a minimum biogas requirement by 2030
  - Biogas and biomethane are constrained by feedstock availability
- Power to hydrogen, or power to gas, may become a much more important source of green gas
- Clean gas from steam reforming of natural gas plus carbon capture and storage could work synergistically with green gas
- A choice may be needed between blending gases in the grid or converting parts of grid to hydrogen

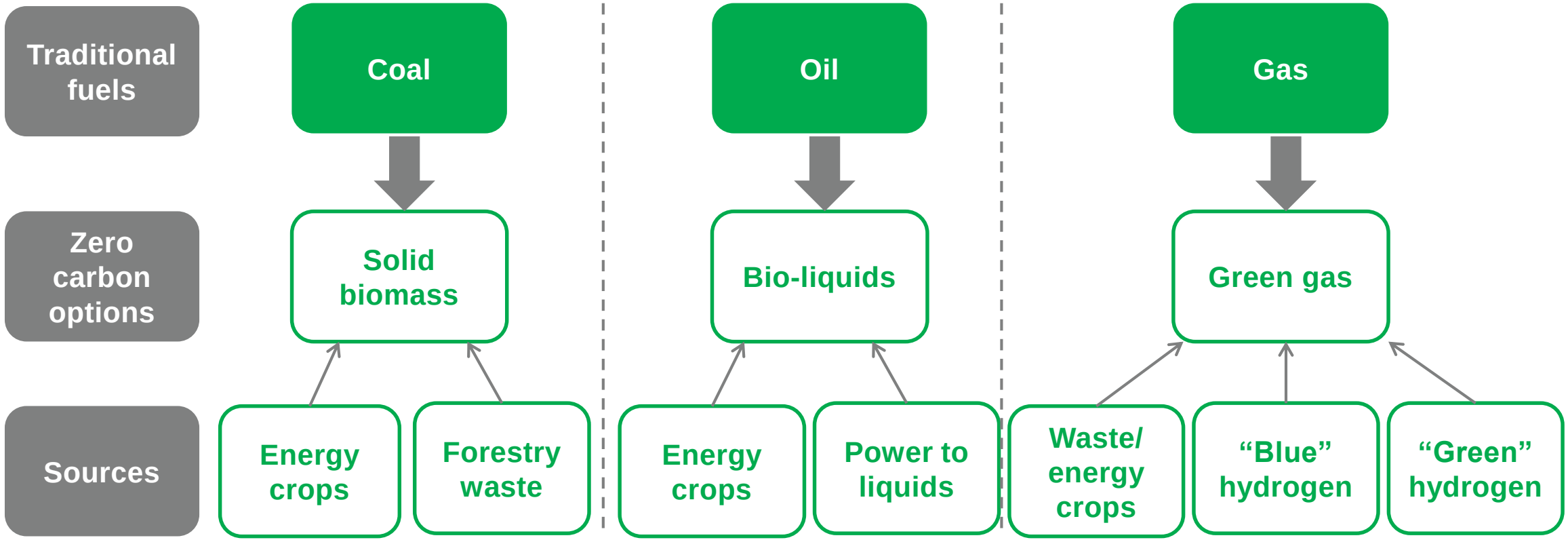
The power sector value proposition: An “80 by 50” world enabled by hydrogen presents many risks and opportunities for the power sector

Sector	Opportunity	Risk
Decarbonizing transportation	• Power demand growth from transport electrification. • Power demand growth from Hydrogen Fuel Cell Vehicles (HFCVs) if fueled by Green H2.	• Blue H2 used in HFCVs could limit power demand growth.
Decarbonizing space heating	• Power demand growth from electrification of space heating.	• Delivery of Blue H2 to today’s natural gas end users could limit power demand growth .
Decarbonizing industry	• Green or Blue H2 feedstocks could allow some industries to survive, safeguarding other industrial power demand.	• Blue H2 could compete with electricity in some industrial high heat applications.
Decarbonizing power generation	• Green H2 to enable daily and seasonal grid balancing. • New capital investments in renewables, storage and power delivery infrastructure.	• Write-offs of existing assets unless they can be retrofitted to use either Blue or Green H2.

- In addition to California, 17 other US states have made pledges for dramatic GHG reductions by 2050, and over 500 cites, universities and private business support the US Paris Agreement pledges.
- While difficult for many to imagine today, the US could move to a national commitment to an 80% reduction in GHG emissions by 2050
- If that scenario happens, the power sector could see tremendous demand growth from electrification, which could be facilitated by Green or Blue H2.
- **Power’s Blue H2 Paradox:** while it could enable the repurposing of fossil generation, it is also a significant competitive threat to the electrification of other sectors.

Why hydrogen? Provides one of many fuel options for a zero-carbon future

Storable energy: From high to zero carbon options

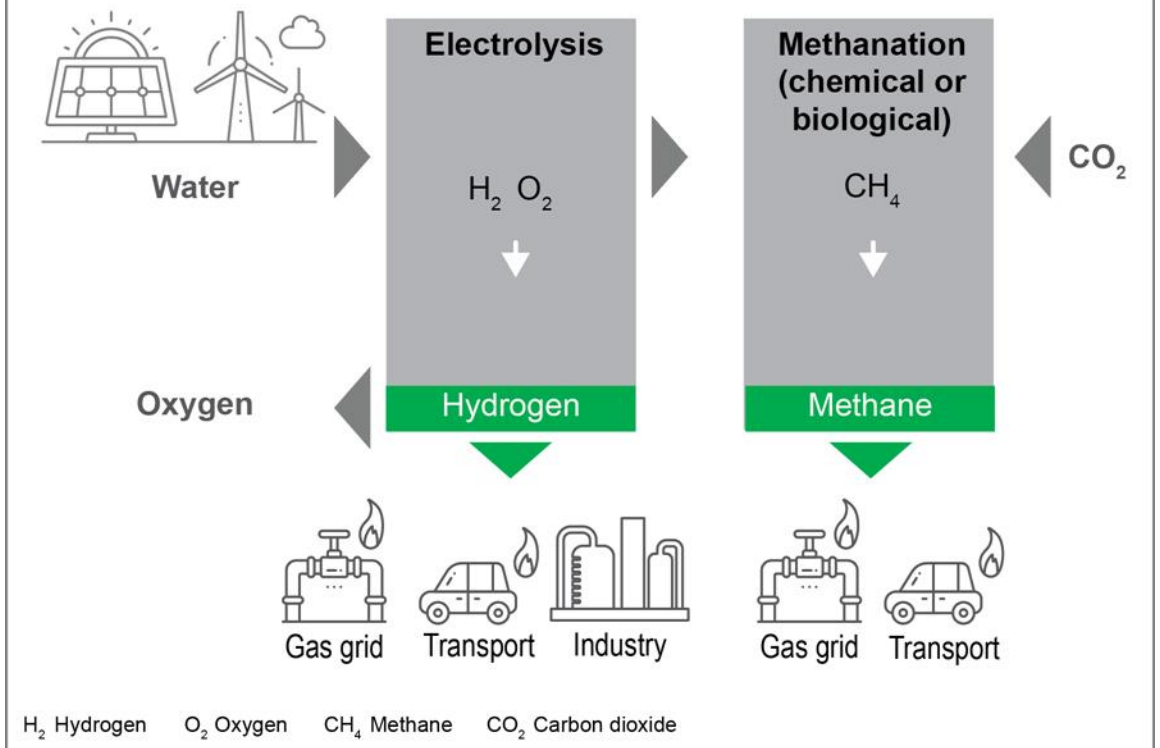


Note: "Blue" hydrogen is hydrogen created from steam reforming of natural gas combined with CCS. "Green" hydrogen is from electrolysis with the electricity provided by renewable sources

Source: IHS Markit

Technology options: Hydrogen from power to gas or steam methane reforming plus CCS to store electricity and decarbonize the gas grid

Power to hydrogen and power to gas

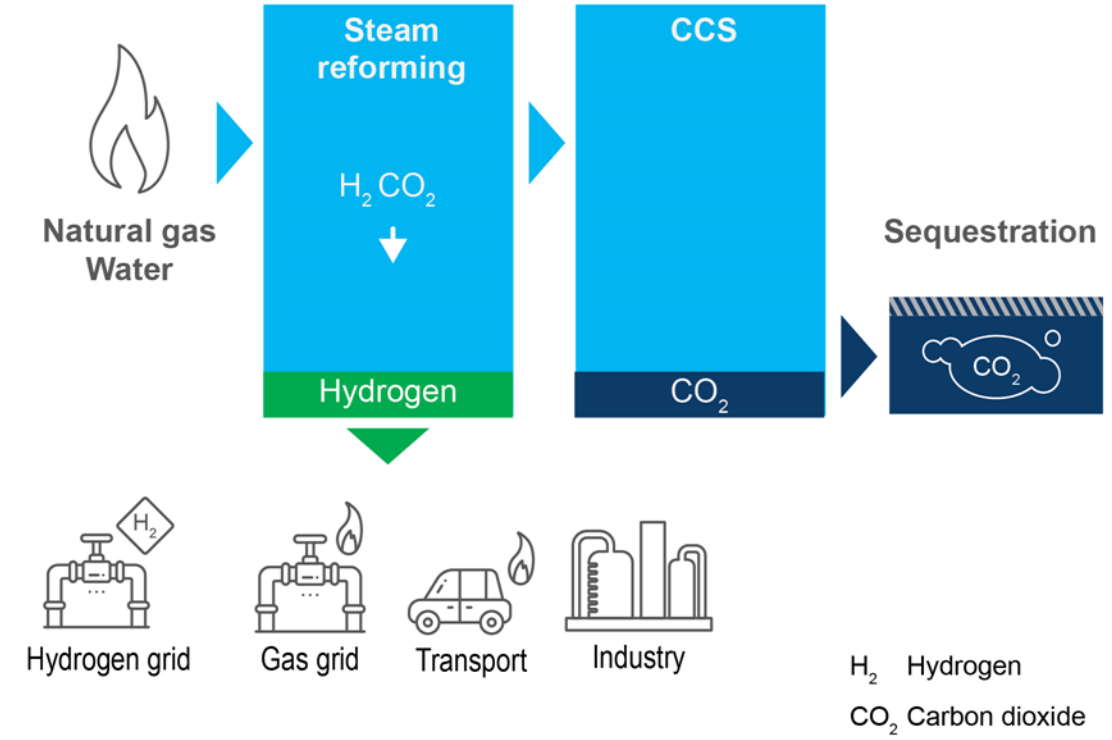


H_2 Hydrogen O_2 Oxygen CH_4 Methane CO_2 Carbon dioxide

Note: CHP - combined heat and power

Source: IHS Markit

Steam reforming of natural gas plus CCS



H_2 Hydrogen

CO_2 Carbon dioxide

Source: IHS Markit

Overall quantitative approach

Putting together costs and opportunities

Supply cost analysis: Green, blue and other hydrogen production technologies analysis

Levelized cost of hydrogen under various technology starting points

- Green H_2 (electrolysis)
- Blue H_2 (SMR, SMR with CC&S, other)
- Other H_2 technologies (coal, etc.)

Market potential

Maximum likely demand for hydrogen in each major end use given favorable costs and policy

- Power
- Space conditioning
- Industry
- Transportation

Tipping point analysis by end use sector

Identify the netback value or cost of hydrogen in each major end use under various sensitivity cases of future costs and policy.
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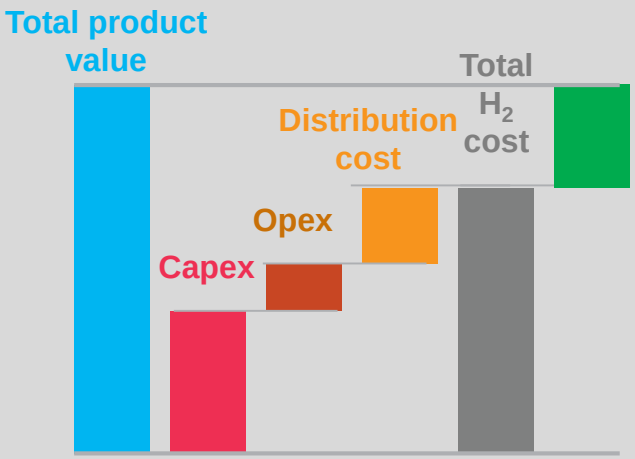

H_2 netback value = total product value – H_2 costs (could be negative)

- Power
- Space conditioning
- Industry
- Transportation

Source: IHS Markit

Project timeline and deliverables

Study Kick-off
October 2018

- **Study kick-off**
- **Introduce the study participants.**
- **Overview of the project timeline and scope.**
- **Discuss the first workshop agenda and logistics.**

Intermediate Workshop and Presentation Materials
Los Angeles
30 October 2018

- **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 for green and blue hydrogen.
- **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.

Final Workshop and Presentation Materials
San Francisco
April/May 2019

- **Practicalities:** understanding the technical and policy issues impacting the potential role of hydrogen (from both "green" and "blue" sources) 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 maximum potential demand for hydrogen in California if it is economic.

Sample agenda for First Workshop: Why Hydrogen, and Why California Los Angeles - 30 October 2018

9:00 – 9:15	Breakfast and registration
9:15 – 10:00	Introduction – why now for hydrogen? • Context for California • Context for global markets
10:00 – 12:15	Hydrogen Production Cost Comparison • Calculating a levelized cost of hydrogen using electrolysis or steam methane reforming
12:15 – 1:15	Lunch
1:15—2:30	Long-term Energy Outlook for California • Scenarios for primary energy demand • Scenarios for power generation • Implied CO2 emissions and comparison to official targets
2:30 – 3:30	First steps to quantifying Hydrogen's role in the energy balance • The sector opportunities – power generation, transport, heating and residential/commercial grids, industry • 'Niche' demands and scale production—is there a business out there in the next five to ten years? • Can niche demands grow to global scale?
3:30 – 4:00	Next steps for workshop 2
6:00 -	Dinner

A community to be joined by other organizations before the first workshop

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