CALIFORNIA
AIR RESOURCES BOARD

Truck Regulation Implementation Group (TRIG) Infrastructure Meeting #5
Future Outlook for Hydrogen

November 4, 2024

Agenda

- Introduction: meeting focus and objectives
- Hydrogen and fuel cell truck presentations
  - Truck dealership perspective – Tom's Truck Centers
  - ARCHES overview – GoBiz
  - ARCHES hydrogen cost and price assumptions – LBNL
  - LCFS status update – CARB*
  - Federal production tax credit and DOE H2 demand initiative – GoBiz
  - Hydrogen producer prospective – Air Liquide
  - Hydrogen distribution via retail truck stops – Pilot Travel Centers
  - OEM updates on FCET commercialization plans*
- Focused Discussion*
- Recap and Next Steps*

* Slides for these presentations in "TRIG 5 CARB slides"

TOM'S TRUCK CENTER

Award Winning Commercial MHD Truck Dealership (since 1949)

HYLA'S PLUG POWER equipment arrives 8-1. Permitted 3.5 MOS. Open 8-12-24.

TOM'S TRUCK CENTER

25-50 trucks day. 35 kg fill. 7-9 mi/kg. $12-15 kg. $1.33-$2.15 mi.

TOM'S TRUCK CENTER

RIBBON CUTTING 9-13. Senator Archuleta & Newman. Permanent Station 2027.

HYLA Modular No. Stations: 2024 = 10. 2025 = 25. Nikola = 2 Million Mi.

City	Address	Hyla or Partner	Fueling Positions	Status
Coolidge, AZ 1	680 E Houser Rd	Hyla	One	Operational
Compton, CA	435 E Weber Ave	Hyla	One	Permitting Expected Operational: Sep '24
Fontana, CA	11053 Catawba	Hyla	Two	Permitting Expected Operational: Oct '24
Long Beach, C 5	2267 W Gaylord	Hyla	One	Operational
Ontario, CA 2	2445 East Guasti Road	Hyla	Two	Operational
Ontario, CA 3	4265 E. Guasti Road	Shell	One	Operational
Port of Oakland, CA 4	Engineer Road	First Element Fuel	Two	Operational
Santa Fe Springs, CA 6	13412 Excelsior Drive	Hyla	One	Operational TOM'S TRUCK CENTER
Stockton, CA	920 Performance Dr	Hyla	Two	Permitting Expected Operational: Dec '24
Wilmington, CA	690 Pioneer Ave.	Hyla	Two	Permitting Expected Operational: Oct '24

CHART

plug

HYDROGEN SERVICE BAY – OPEN 9-17-24

Major Certification Requirements

- Hydrogen ***Leak Detection System*** with Audible Alarm
- ***Ventilation*** to expel any lost gas from the system
- ***Ventilation at high points*** in the celling
- ***Automatic gas detection***
- ***Automatic power-up*** of the equipment to expel the gas
- ***Sealed flooring*** prevents Hydrogen leakage escaping to underground voids

NIKOLA
(SPECS & REBATES)

HVIP-ISEF.
(rebate $240k-$676k)

POLA*.
($75k-$100k)

VIP.
($20K-$520k, 90-100%)

VW.
(>$240k)

IRA Act.
(tax credit >$40k)

TOM'S TRUCK CENTER

TRY-B-4-U-BUY

Avail Purchase, Rental or Lease

TRE - FCEV

ZEV Technology	FCEV
Classification	8
GCWR	82,000 lbs.
Curb Wt.	25,500 lbs.
Wheelbase	182”
Fuel Capacity:	70 kg
Range	500 miles *
Efficiency	7.1 mi/kg *
Fueling	700 Bar
TTC-SRP	~$515k *
HVIP-ISEF	$240k-$676k *
POLA*	$75k-$100k
VIP	$20k-$520k
VW	up to $240k
SAVE	47-90% *
IRA	up to $40k
179	100%

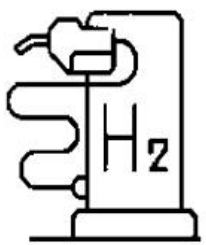
** Subject to change, POLA not eligible in ISEF, 90% Cap*

2023 VOUCHERS = 268 MHD TRUCKS

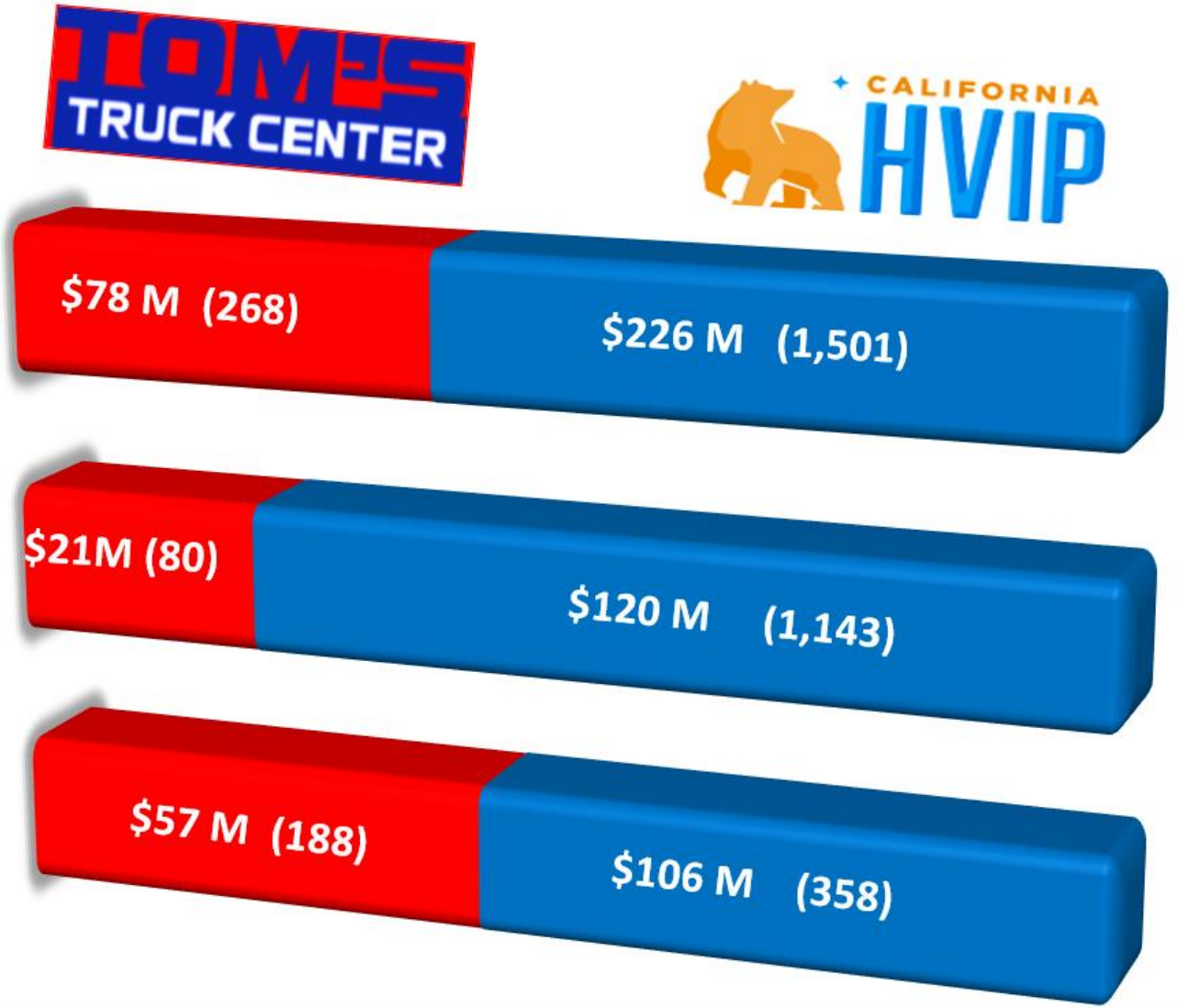
Data thru 12-31-23

Trucks
(class 2b-8)
TTC/$ = 34%

BEV Trucks
(class 2b-8)
TTC/$ = 17%



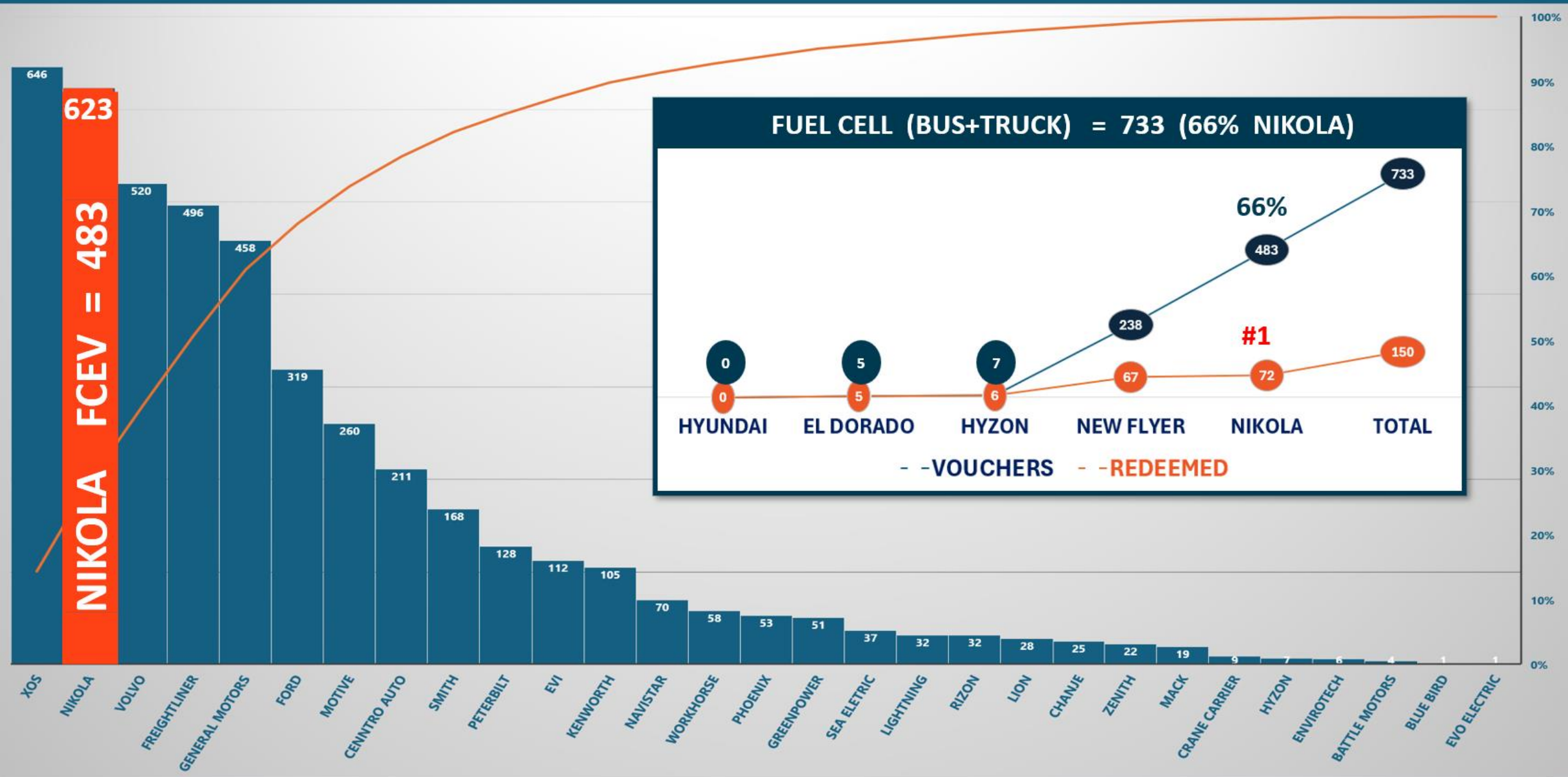
Fuel Cell Tractors
(class-8)
TTC/$ = 54%



Resource: CARB HVIP.org Impact

ZEV HVIP MHD TRUCK REBATES : 4,500 (2011-2024)

Data thru 9-30-24



TOM'S TRUCK CENTER

R3E

ISUZU TRUCK

Ford

GreenPower MOTOR COMPANY

HINO TRUCKS

A Toyota Group Company

TOM'S TRUCK CENTER

LISA MCGHEE

949-422-8576

LMCGHEE@TTRUCK.COM

WWW.TTRUCK.COM

13443 FREEWAY DRIVE

SANTA FE SPRINGS, CA

LOS ANGELES

909 NORTH GRAND AVE

SANTA ANA, CA

ORANGE COUNTY

Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) – California H2Hub

Tyson Eckerle, GoBiz

Infrastructure Truck Regulation Implementation Group (TRIG) meeting

November 4, 2024

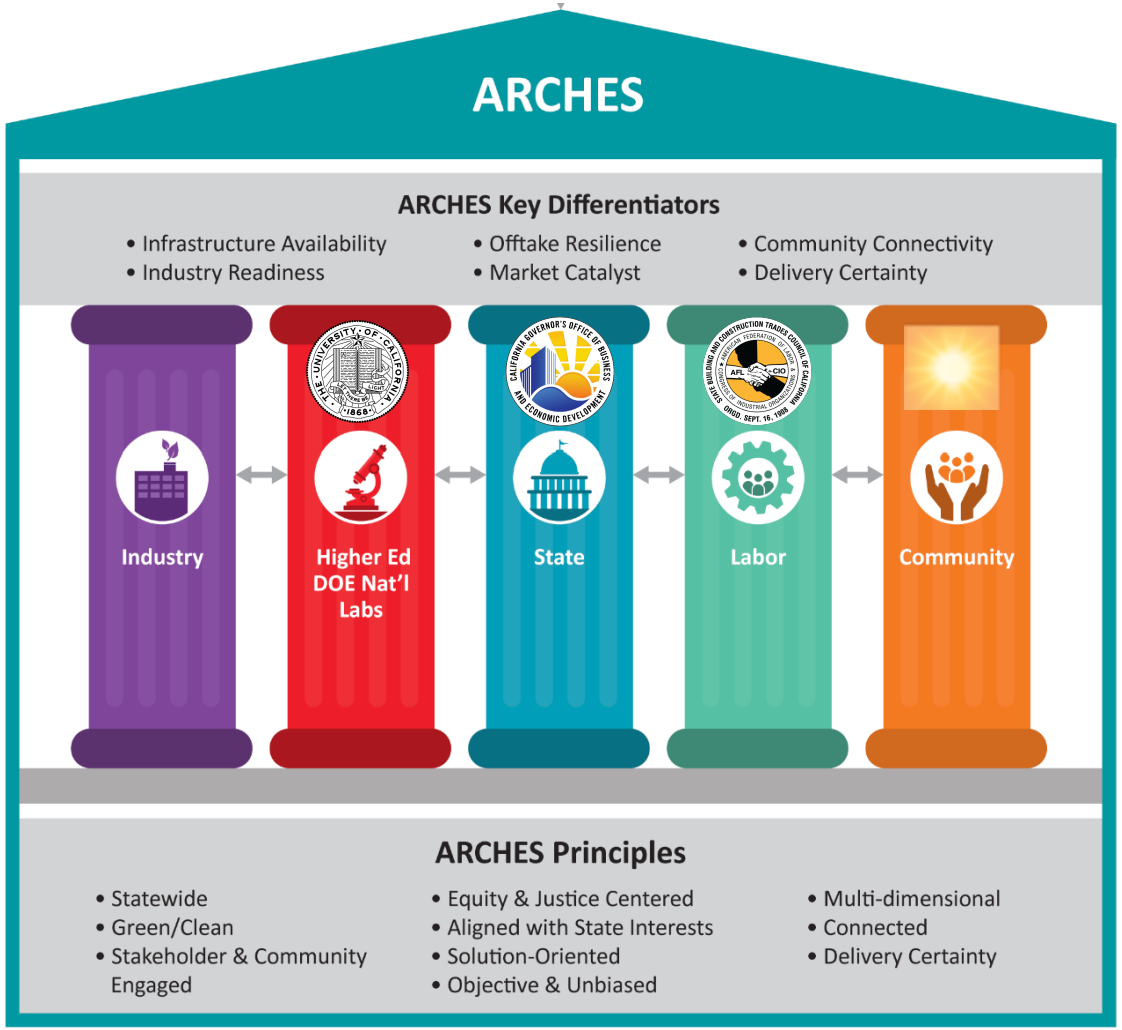
ARCHES Mission

- **ARCHES** is a **public-private partnership** to create a **sustainable statewide renewable, clean hydrogen (H2) market and ecosystem** in California and beyond

- **ARCHES** utilizes **renewable resources** to produce hydrogen with the objective to **fully decarbonize the regional economy**

- **ARCHES** prioritizes
  - ❑ Environmental Justice
  - ❑ Equity
  - ❑ Economic Leadership
  - ❑ Workforce Development
  - ❑ Hydrogen Market Viability

U.S. Department of Energy



Where ARCHES is in the Process

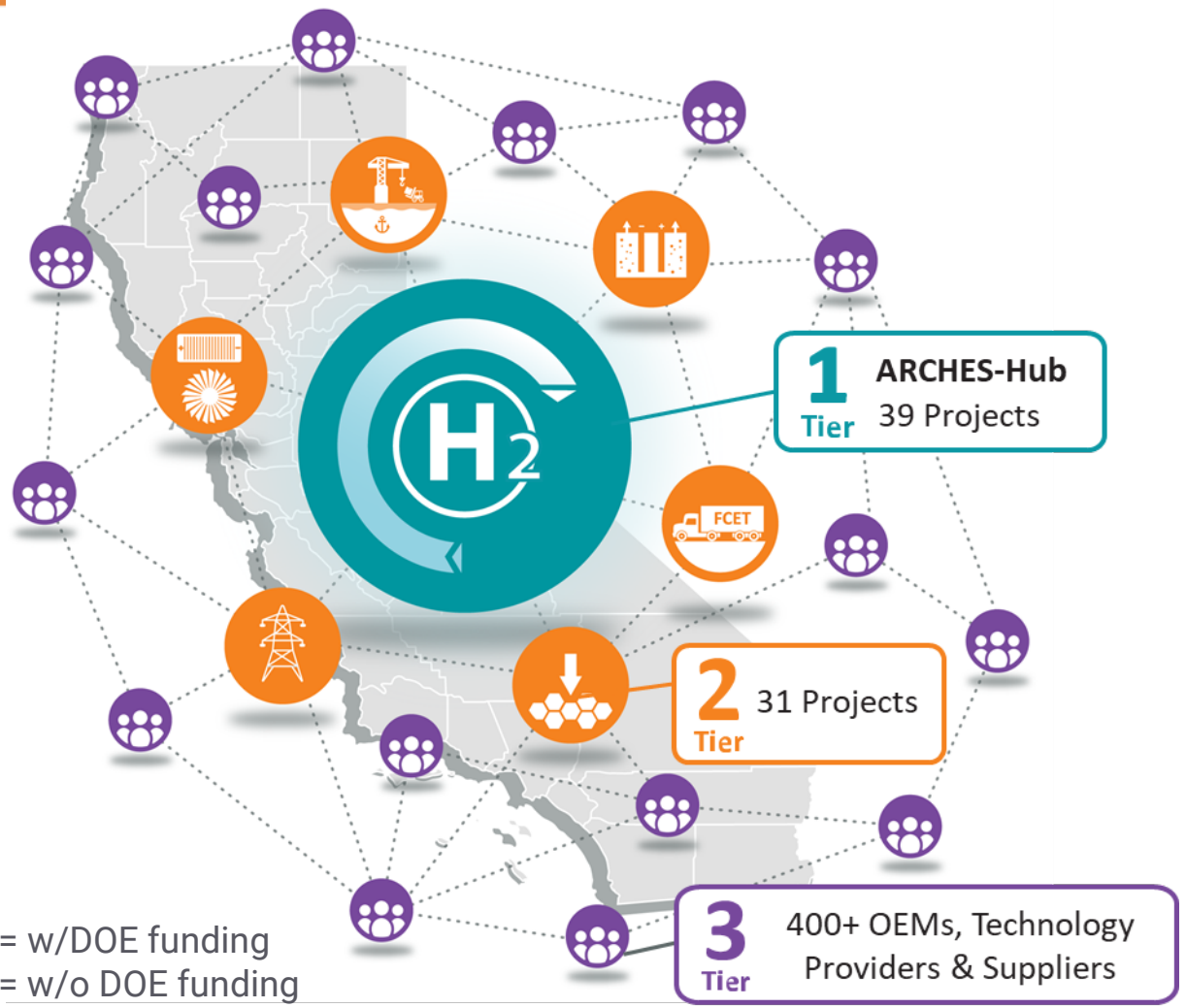
ARCHES is here

Negotiations Conducted

Go/No-Go Decisions

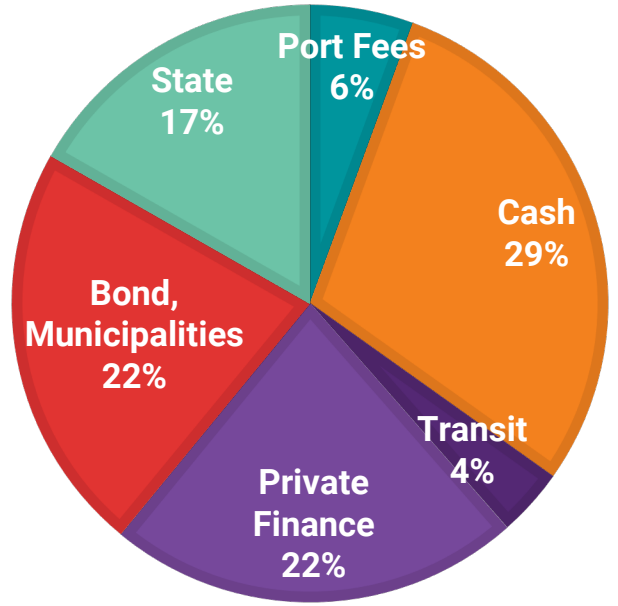
Graphic courtesy of the DOE

ARCHES Projects: A Resilient Hydrogen Ecosystem for California



Tier 1 = w/DOE funding
Tier 2 = w/o DOE funding

$1.2B DOE funds unlocks **$11.7B in matching funds**



Moving from Concept to Reality

Coming Soon:

BERKELEY LAB
Bringing Science Solutions to the World

ARCHES H_2

U.S. DEPARTMENT OF ENERGY
Office of Science

Modeling framework for the assessment of a sustainable hydrogen production and supply chain network in California

Tamim Zaki, PhD
Postdoctoral Researcher

Seongeun Jeong, PhD
Research Scientist

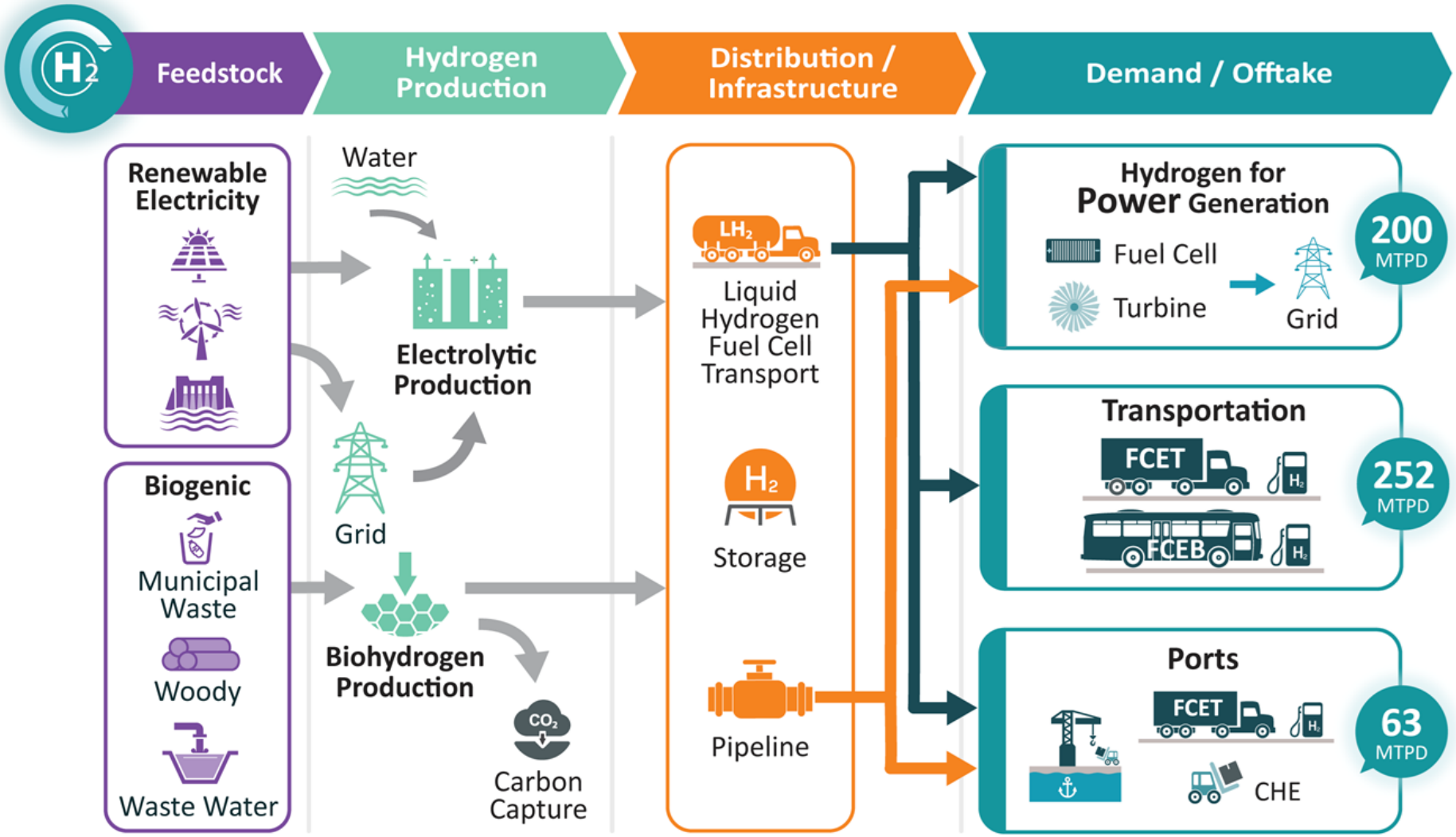
Adam Weber, PhD
Senior Scientist

Hanna Breunig, PhD
Staff Scientist

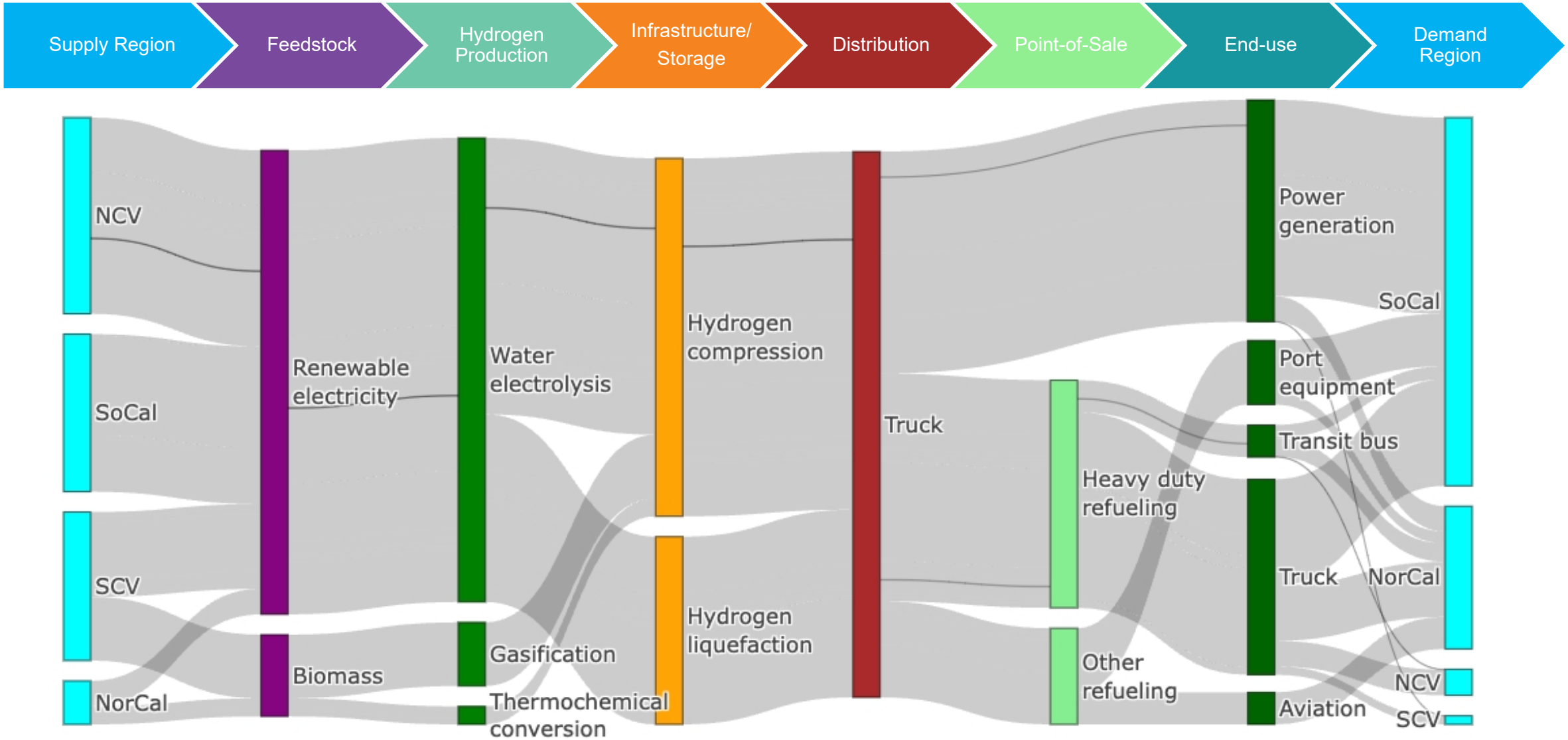
Energy Technologies Area

November 3 2024, Air Resources Board Meeting

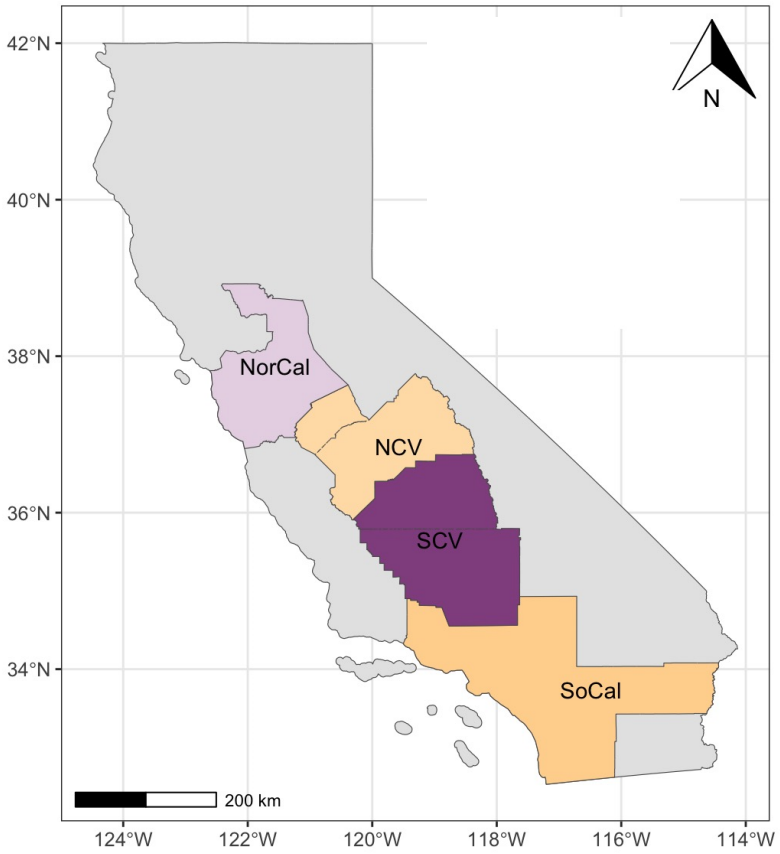
ARCHES Hydrogen Flow



Hydrogen Flow in an Example Scenario



Regions were derived in an iterative process based on counties with projects



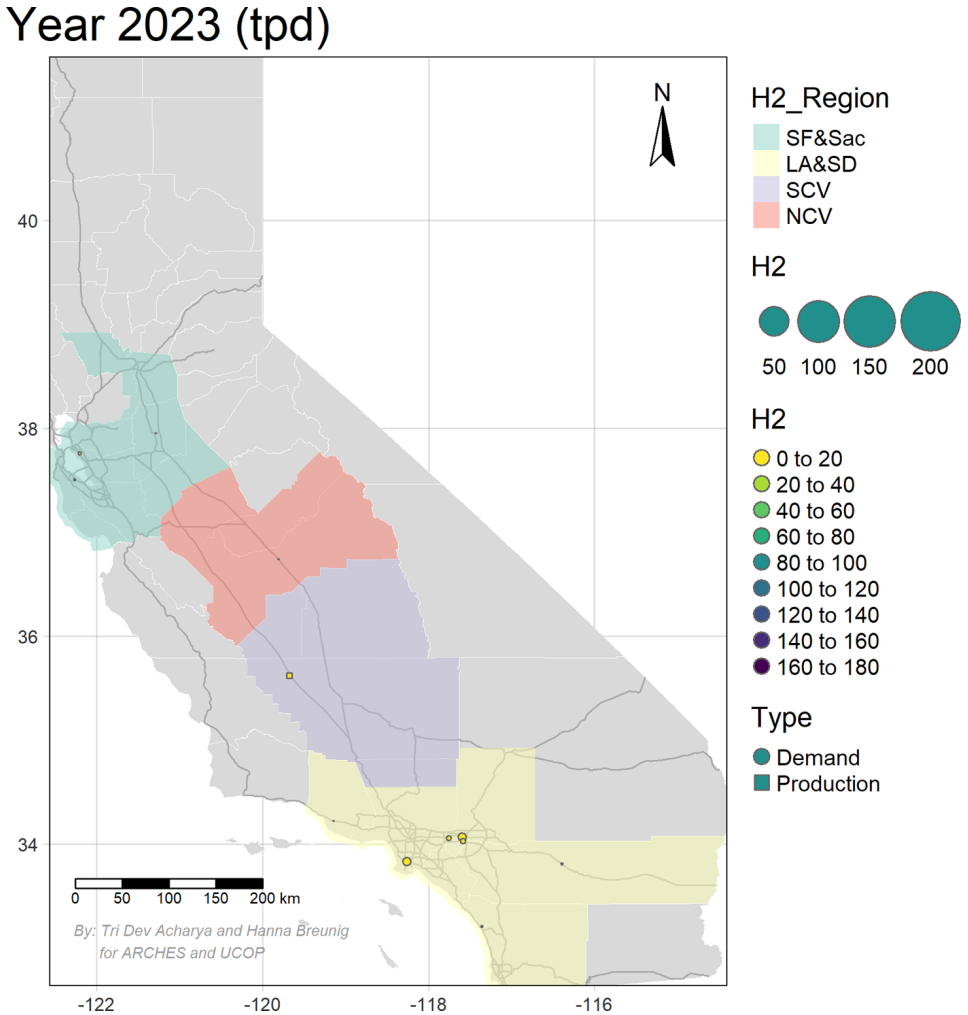
Proposal

- NorCal: e.g. Sacramento, Stockton & Bay Area (down to Santa Cruz)
- NCV: e.g. Merced, Fresno
- SCV: e.g. Lancaster
- SoCal: e.g. Los Angeles, Riverside, Bakersfield, San Diego

Ongoing work:

- Clustering of projects by relevant geographic boundaries
  - county, districts; air quality regions; transportation distances

ARCHES Systems Approach Balances Production and Offtake Over Time



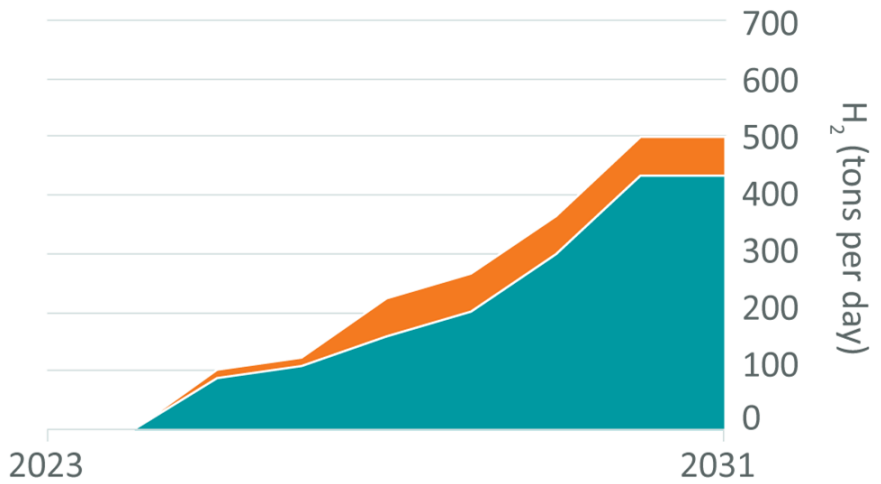
Cost/Emissions from electricity and biomass feedstocks are key tasks for the analysis team

- Projects note type of fuel
- Utility forecasts for cost and emissions gathered: annual average forecasts
- Dedicated solar modeled from DOE
- Biomass pretreatment, cost, and transport gathered or approximated
- Necessary energy storage costs include pumped hydro storage & batteries, approximated via literature values

Production cost assumptions

- Electricity = 0.02-0.19 $/kWh
- Water = 0.021 $/kg

- UC Berkeley Tim Lipman is leading LCA of biohydrogen
- LBNL & NREL leading modelling of grid forecasts
- ARCHES is gathering data from companies



Electrolysis

- Capital and operating costs provided from companies were compared with guidance from DOE H2A models
  - Details include things like catalyst and stack replacements, water, energy, maintenance, labor, construction
- Water consumption derived from company estimates for most producers
- Use a conservative capital charge factor

Production Spec Assumptions

- Electrolyzer (stack and BoP) electricity = 55.04-55.80 kWh/kg H2
- Electrolyzer water = 5 gal/kg H2
- Capacity factor = 0.32-0.90 (depending on electricity source)
- Stack lifetime = 60000-67500 hrs
- Plant lifetime = 20 yrs

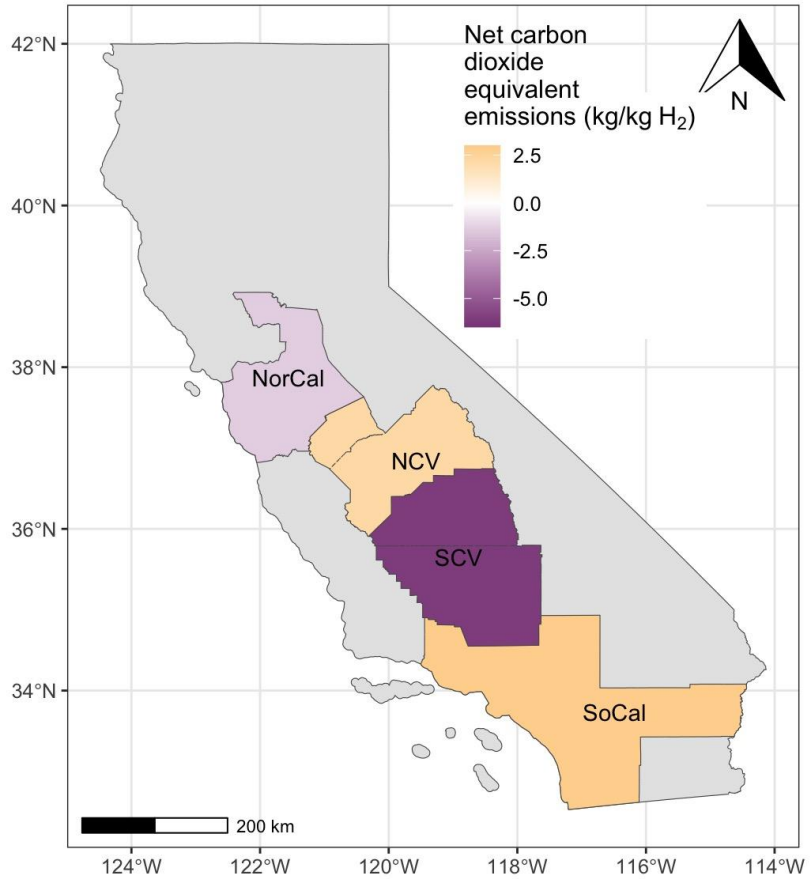
Biogenic conversion

- Detailed company data from gasification of woody biomass
- Literature used to approximate thermochemical conversion of MSW
- Avoided landfill emission using EPA WARM model

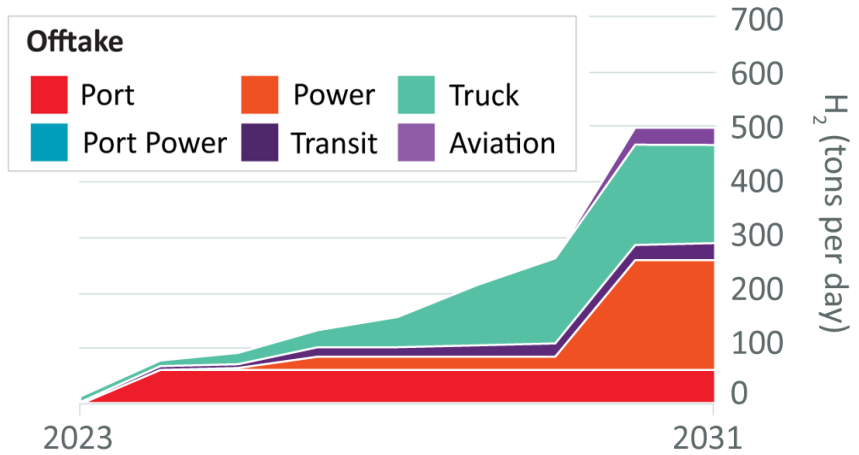
Production Spec Assumptions

- Biomass plant (thermochemical and gasification) electricity = 12-18 kWh/kg H2
- Biomass plant (thermochemical and gasification) water = 0.5-30.0 gal/kg H2
- Plant lifetime = 20 yrs

Net CO_2 emissions from H_2 production



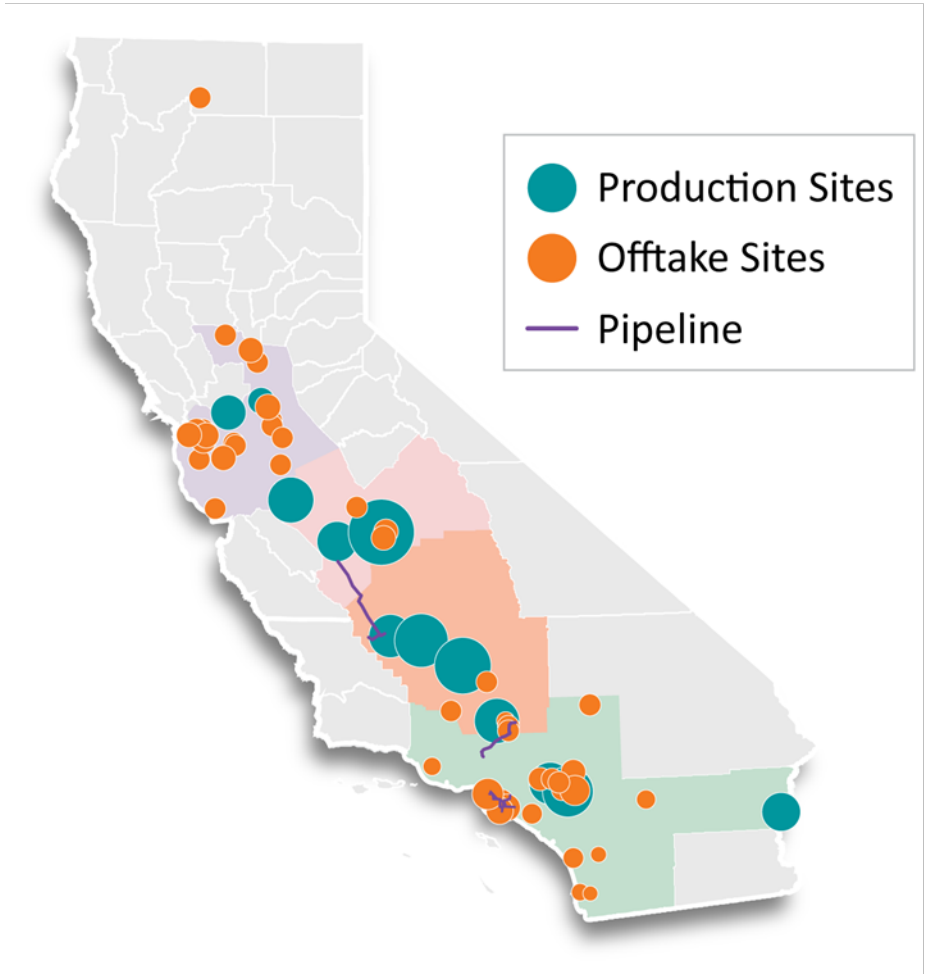
- Coupling of supply and demand informed inclusion of liquefaction, compression
- Assume buffer storage at each project, as well as in key production regions in liquid tanks
- Refueling station & bulk liquid and compressed gas transport models from HDSAM
- Compressed gas bulk storage modeled by LBNL inhouse
- Leakage rates from CA GREET guidance
- Electricity consumption from local grid utility



Processing Assumptions
H2 liquefaction electricity = 9.0-11.3 kWh/kg H2
H2 compression electricity = 2.23 kWh/kg H2

- Pipelines replace compressed gas truck transport or fill need for new projects
- Pipeline selection based on stable supply and demand nodes

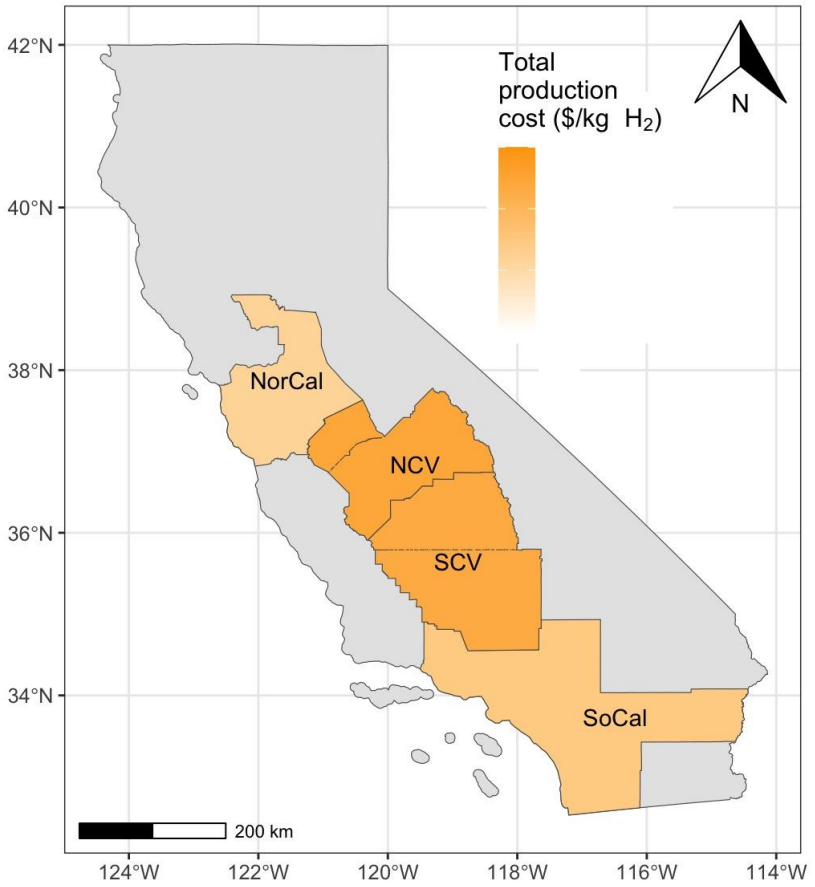
- Diesel vs fuel-cell electric trucks compared
- Bulk liquid and compressed gas transport models from HDSAM to derive a levelized cost per kg-mile transported



Markups evaluated for each key market end use

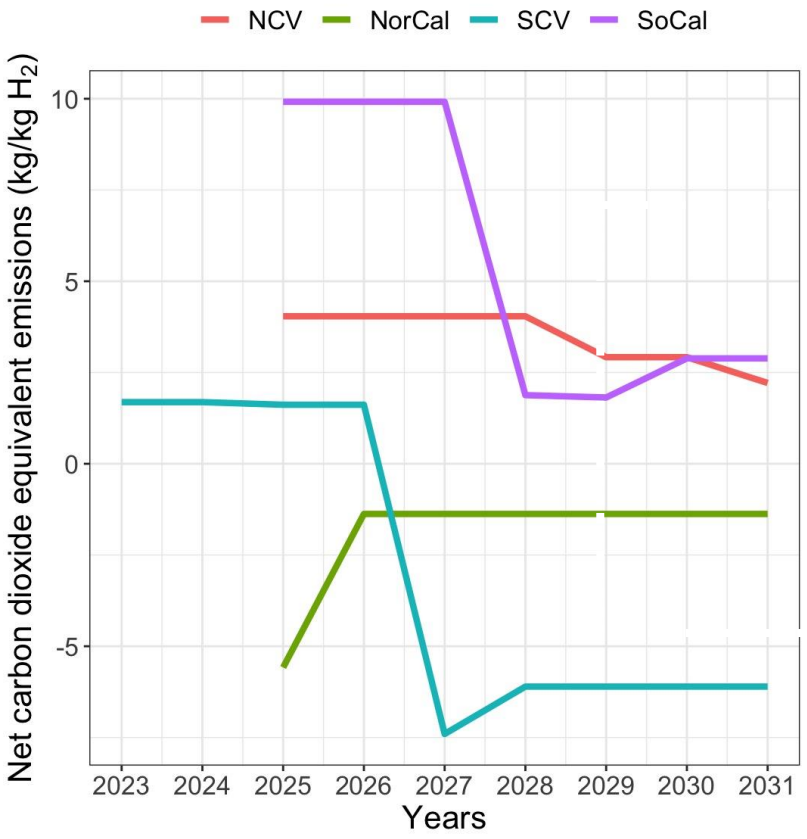
- Hub-wide emissions and cost for each year determined based on the production projects coming online
- DOE H2FAST model used to identify break even cost target for hydrogen at the hub level
  - Based on constraint guidance from industry
  - Reflects goal seek for constraints based on cost of hydrogen production, & matching of regional supply and demand over time

Total cost of H_2 production (no markup)

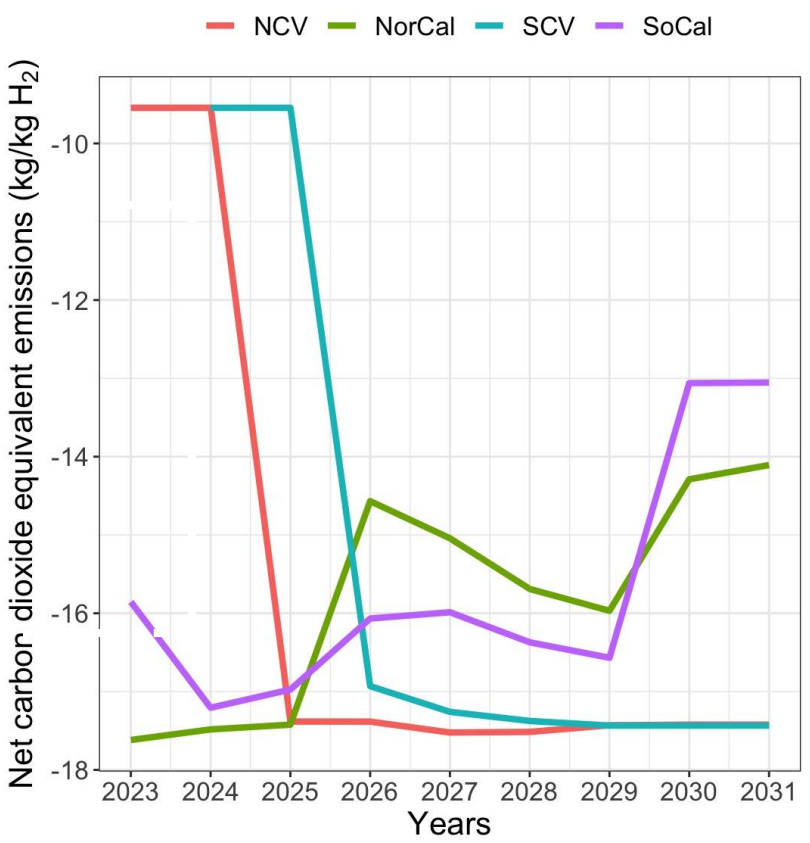


Temporal Environmental and Economic Impacts

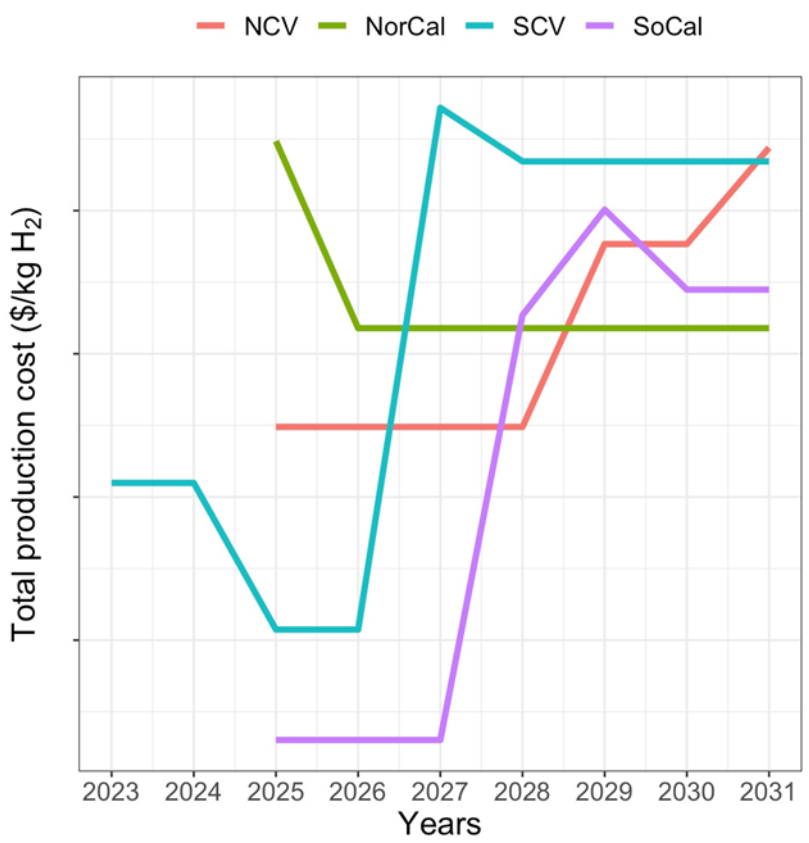
Net CO_2 emissions from H_2 production



Net CO_2 emissions avoided by H_2 end-users

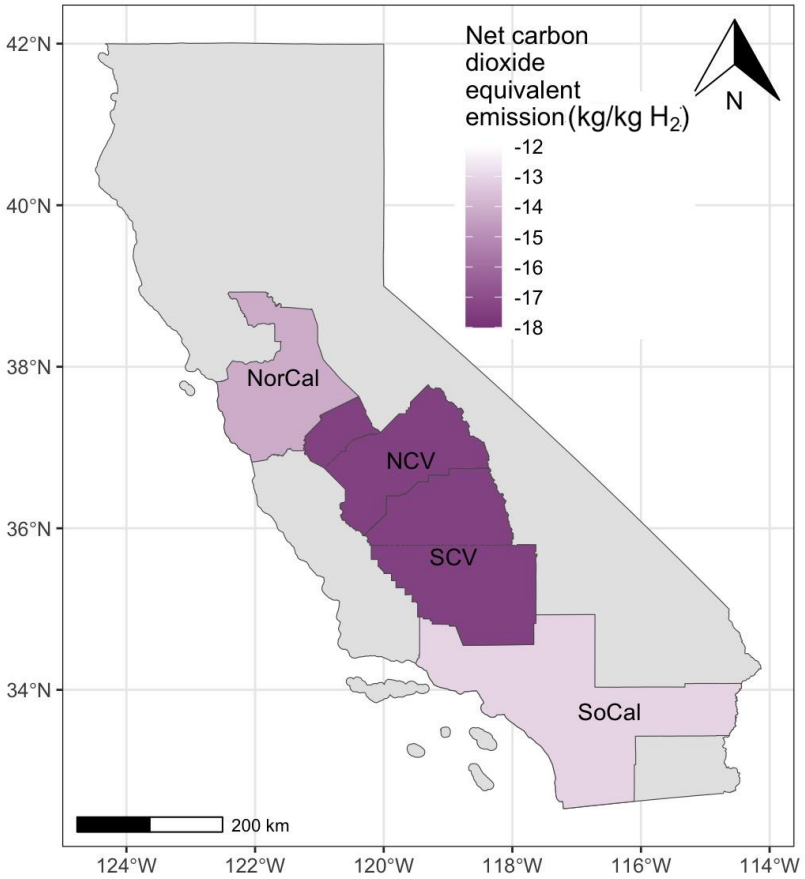


Total cost of H_2 production

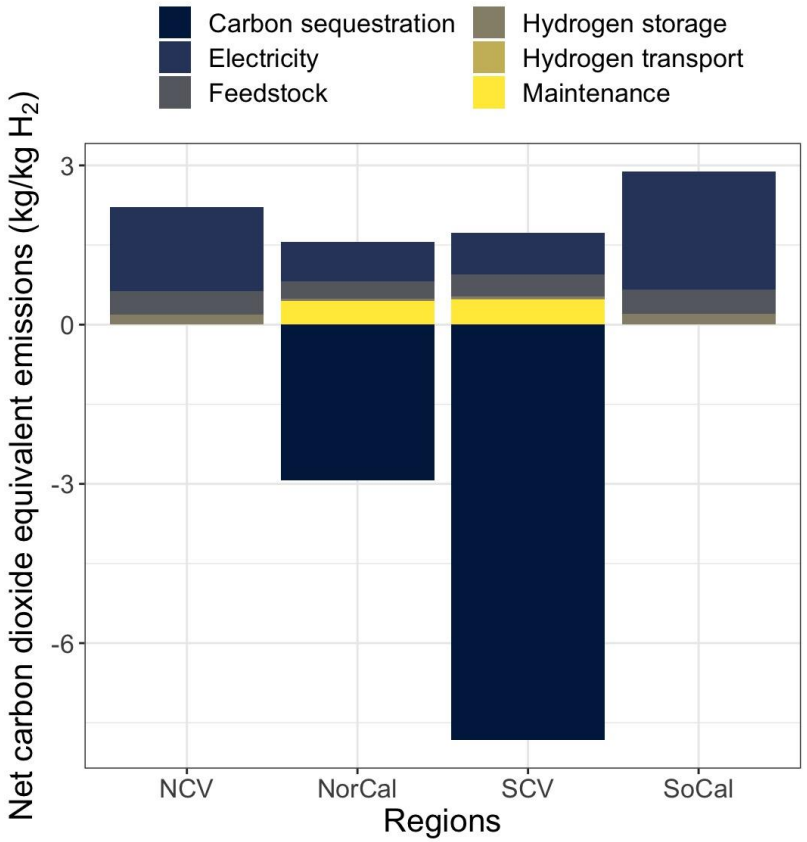


- Costs for refueling stations, trucks & buses from CTE, UCDavis and UC Berkeley, energy efficiency and emissions from GREET
- Cost for turbine and fuel cells from proposals, emissions from literature
- Port equipment from ports by equipment type and mobile refuelers. Energy efficiency and emission from GREET, EPA (for truck class and generation)

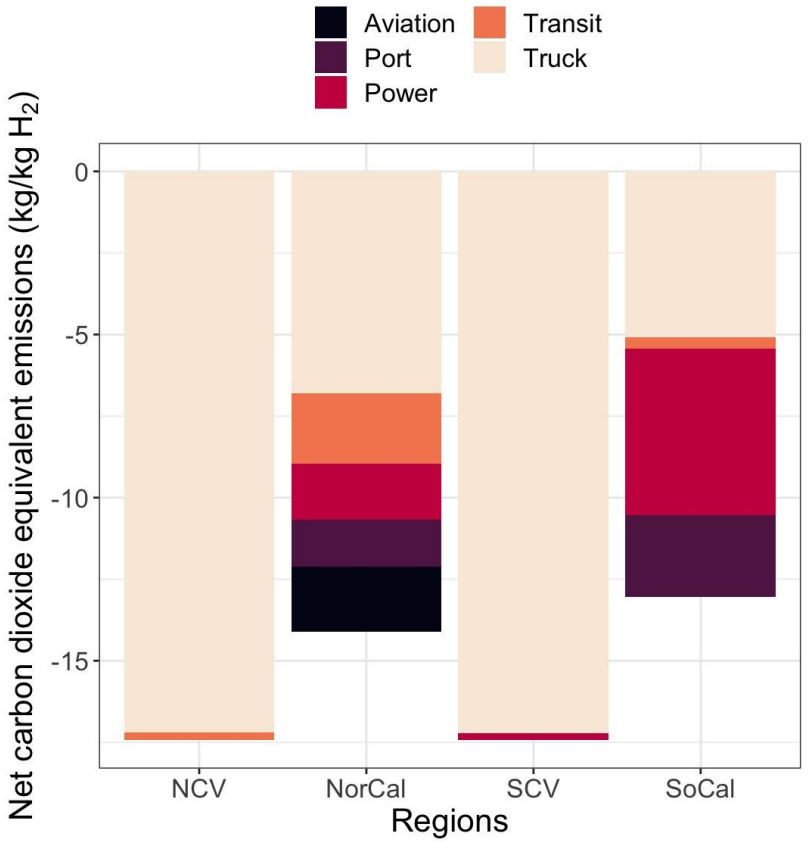
Net CO_2 emissions avoided by H_2 end-users



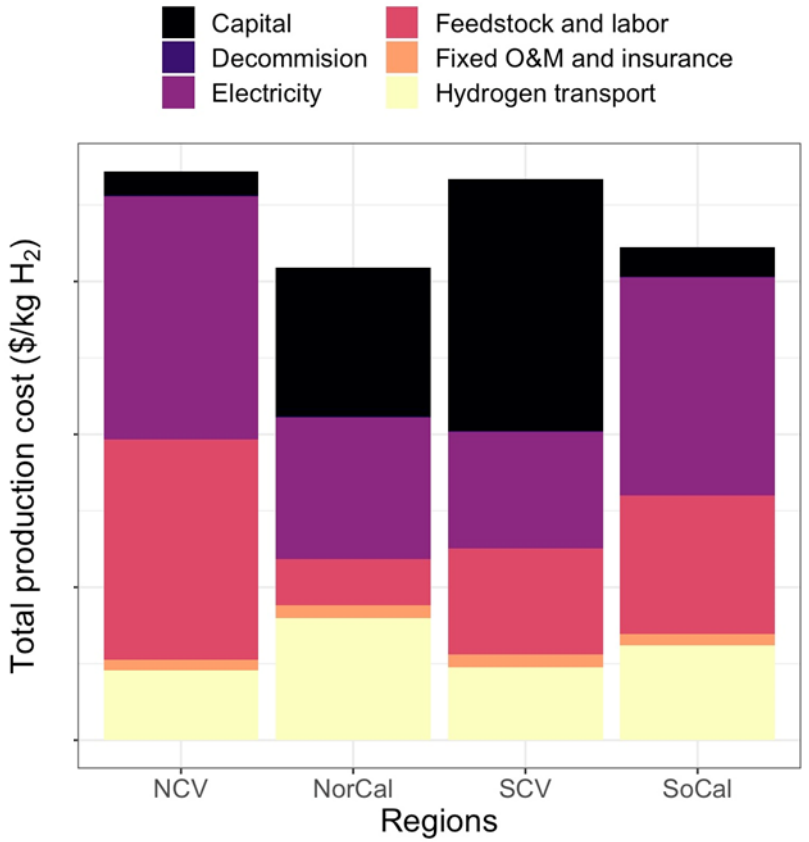
Net CO_2 emissions from H_2 production



Net CO_2 emissions avoided by H_2 end-users

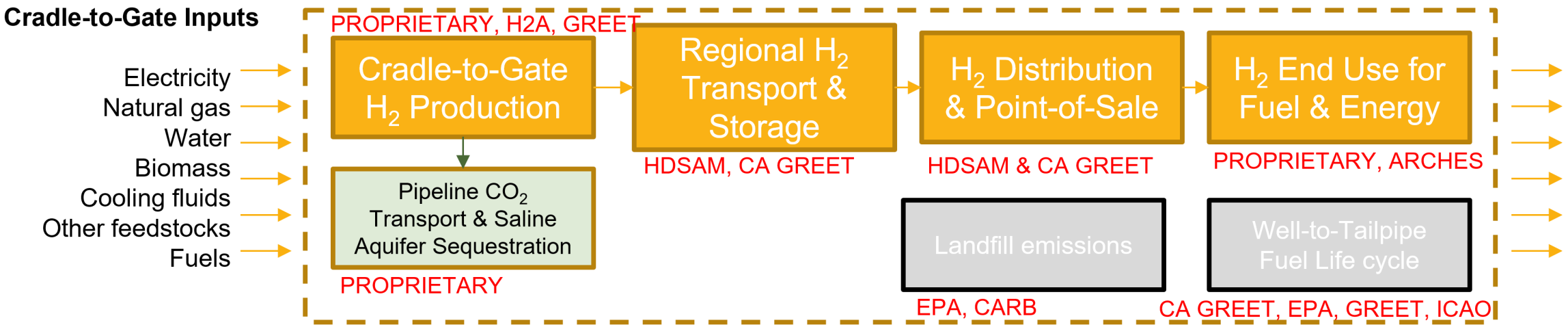


Total cost of H_2 production



Modeling Framework

Data Management and Flow of the Life cycle assessment and Techno-economic analysis



GREET, UTILITIES, EIA, eGRID

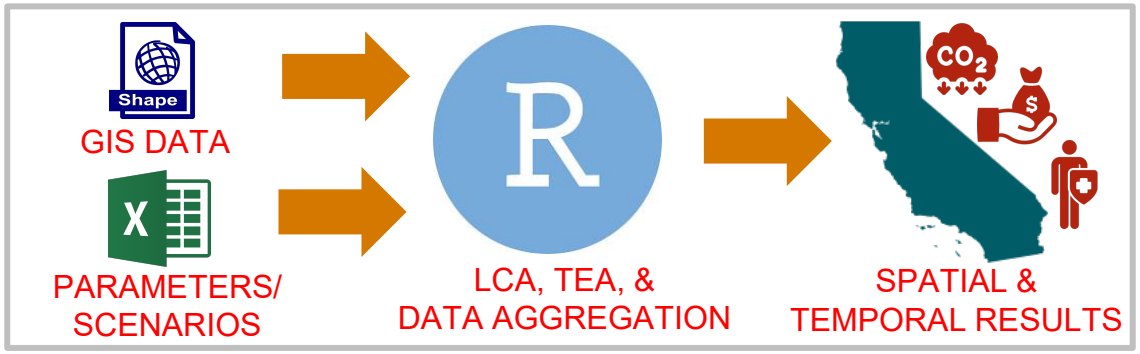
BenMAP, ARCHES

Legend

- H_2 hub
- CO_2 End of Life
- Offset

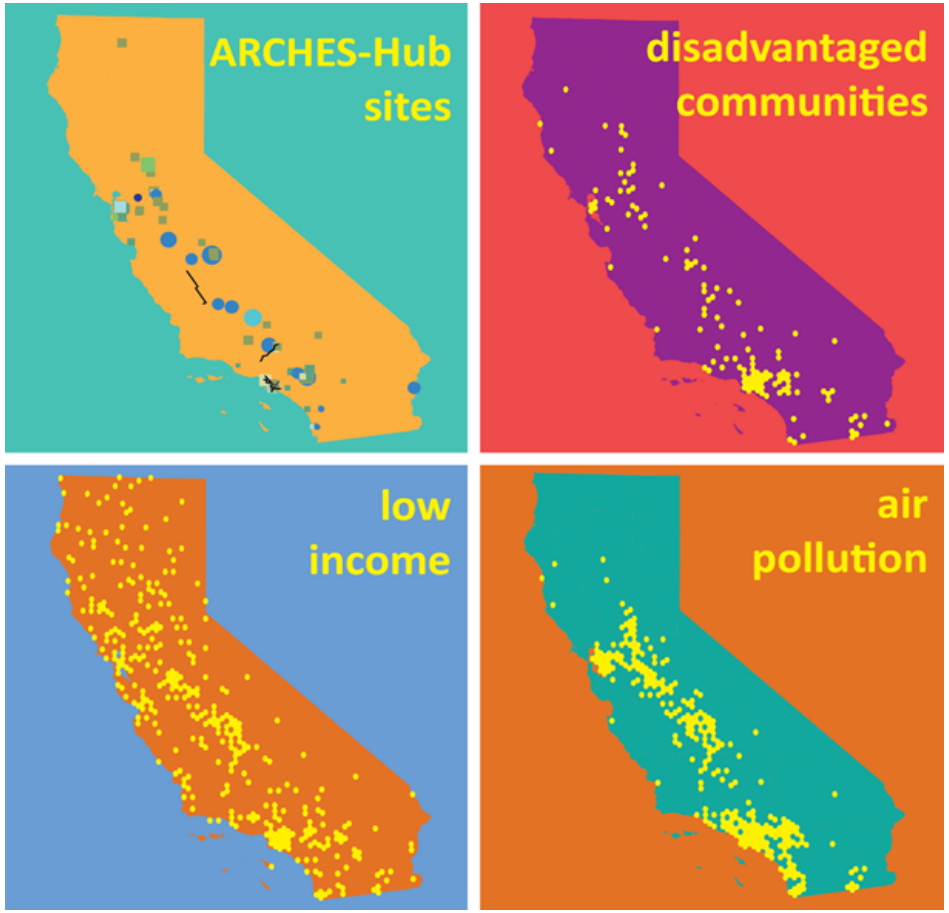
PRIMARY MODEL/ DATA SOURCE

Model Framework

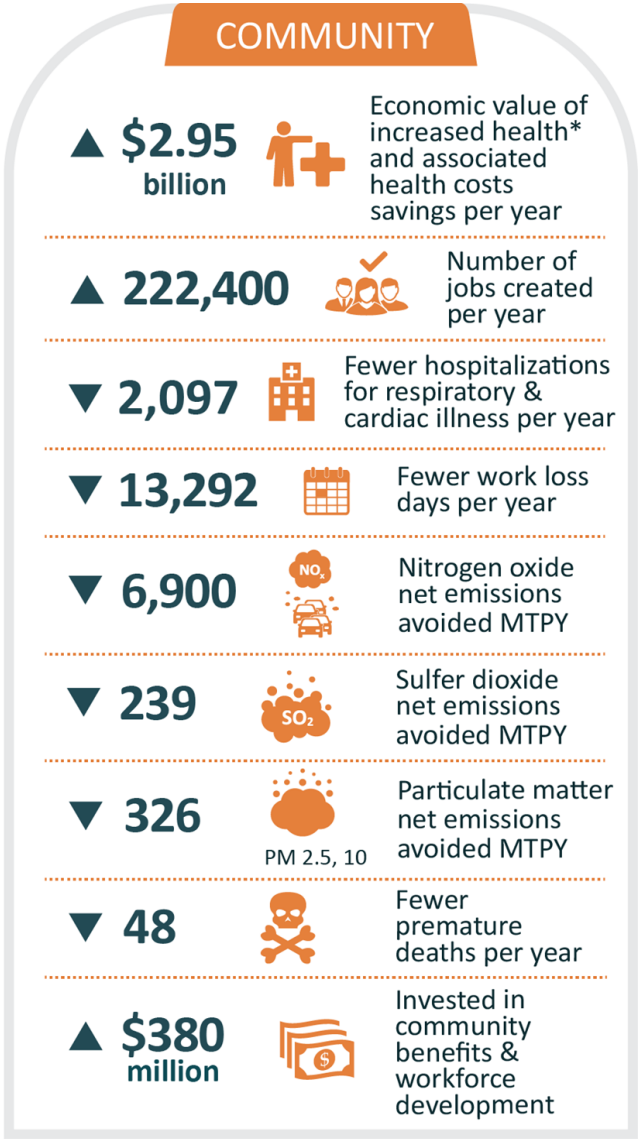


BERKELEY LAB ENERGY TECHNOLOGIES AREA

Disadvantaged Communities Will Benefit



*EJ40 database and CalEnviroScreen



BERKELEY LAB
Bringing Science Solutions to the World

ARCHES

U.S. DEPARTMENT OF ENERGY
Office of Science

Questions?

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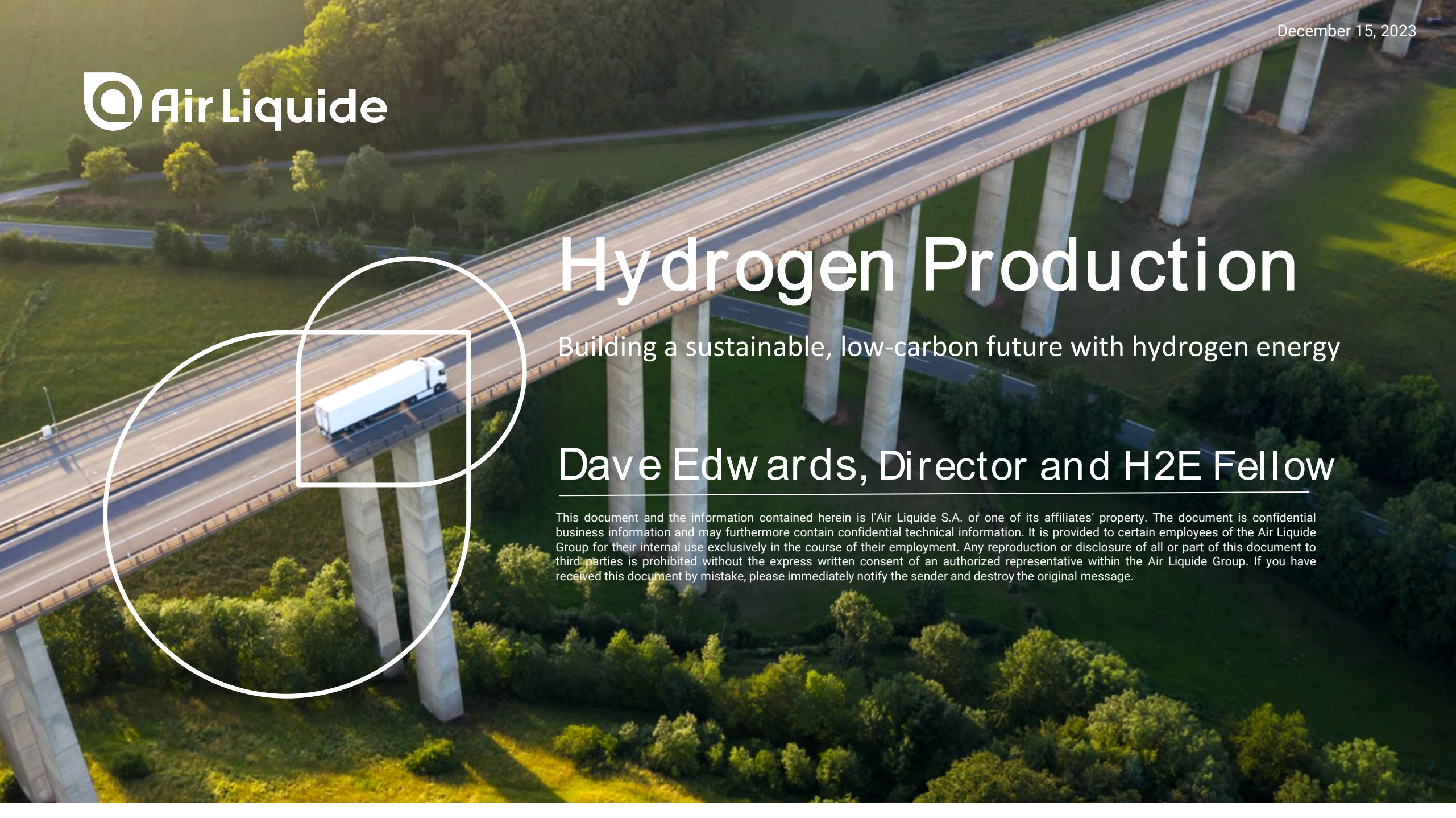
45V and Clean H2 Initiative Updates

Tyson Eckerle
Sr. Advisor for Clean Infrastructure and Mobility
Governor's Office of Business and Economic Developent

Federal Hydrogen Supply Initiatives

- US Dept. of Energy's (DOE) Clean Hydrogen Production Tax Credit – 45V
  - Up to $3.00/kg 10-year incentive based on carbon intensity
  - Public Comment Letters for Section 45V
- Hydrogen Demand Initiative
  - Consortium set up to support US H2 Hubs with demand-side support measures to facilitate clean hydrogen purchases
  - Goal to enhance early commercial viability of H2 Hubs across US

December 15, 2023



Hydrogen Production

Building a sustainable, low-carbon future with hydrogen energy

Dave Edwards, Director and H2E Fellow

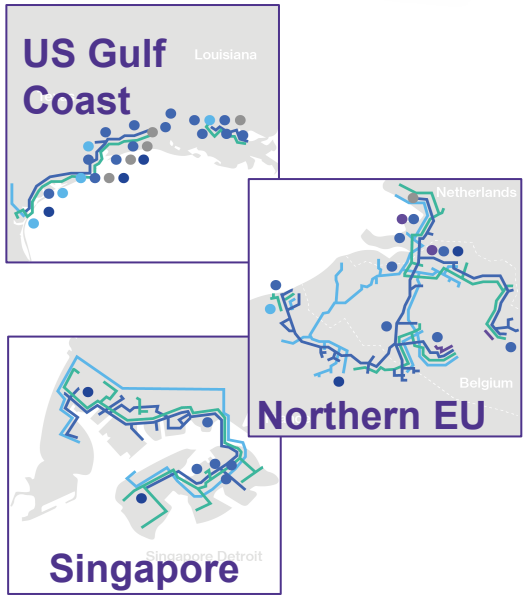
Air Liquide has nearly 60 years of hydrogen development for industries

Production & Supply chain

Production

Supply chain

Distribution Networks

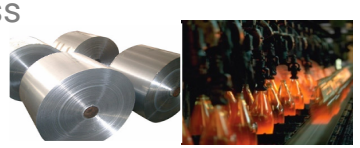


Markets Segments

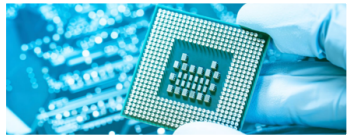
Process industries

Oil & Gas

Steel, Glass



Electronics



Transportation

Space

Key Figures

14 Bm^3/yr

1,850 km H_2 pipeline

46 large H_2/CO plants

40 electrolyzers in operation

2 B€ sales

Low-Carbon Hydrogen Production

Thermocatalytic Processes
Reformers

Hydrocarbon + Carbon Capture, Usage and Storage (CCUS)

Reformer-based hydrogen with carbon capture and storage.

By-product hydrogen recovered from other industrial processes.

Biomethane (Renewable Natural Gas- RNG)

Reformer of waste streams including landfill and agri-waste digesters

Electrochemical Processes
Electrolyzers

Electrolysis

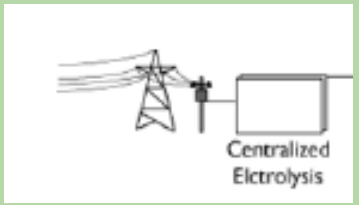
Water electrolysis using low-carbon electricity (e.g., nuclear, solar, wind)

Hydrogen Transportation Fuel - Production and Distribution

Centralized Production

Feedstocks

Electricity

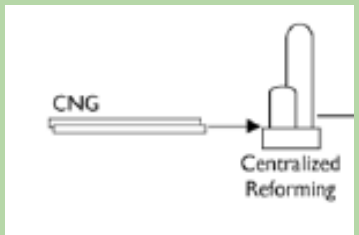


Electrolyzers

Water

Reformers

NG, RNG



CO2 (Capture)

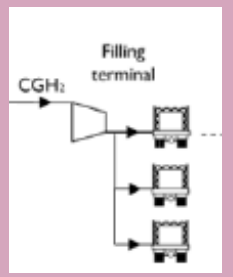
Waste

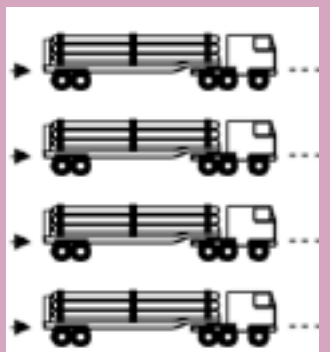
Transfer Station (Trailer Filling)

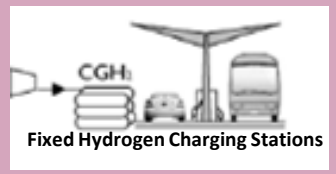
On Road Distribution (Trailers)

Retail Fueling (Stations)

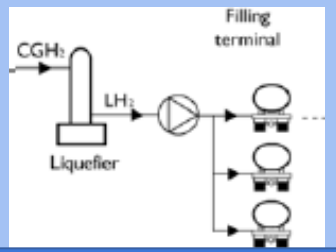
Gaseous (GH2) Pathway

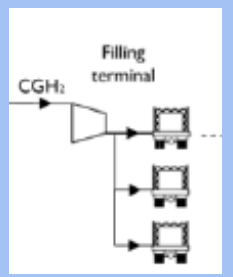


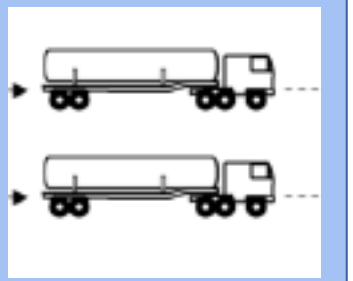




Liquefaction







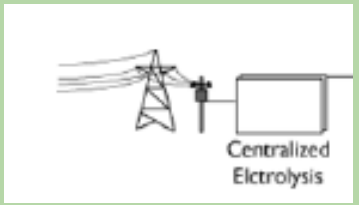
Liquid (LH2) Pathway

Hydrogen Transportation Fuel - Production and Distribution

Centralized Production

Feedstocks

Electricity

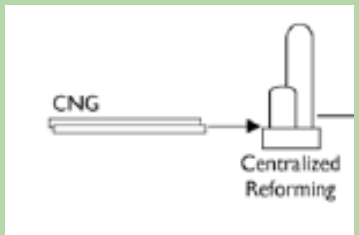


Electrolyzers

Water

Reformers

NG, RNG



CO2 (Capture)

Waste

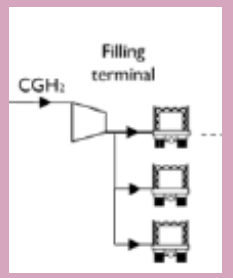
Fuel Price at the Pump is Driven by these three Boxes

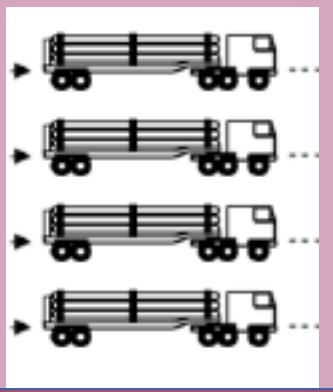
Transfer Station (Trailer Filling)

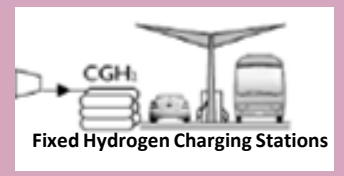
On Road Distribution (Trailers)

Retail Fueling (Stations)

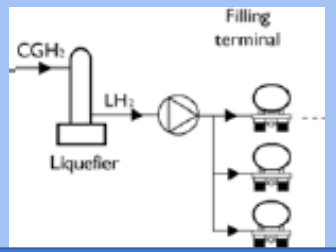
Gaseous (GH2)Pathway

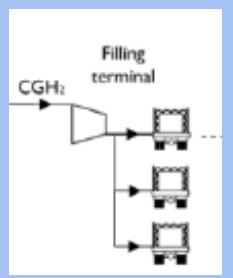


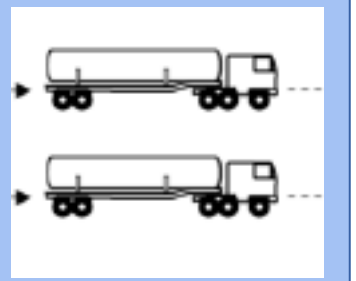




Liquefaction







Liquid (LH2) Pathway

North Las Vegas - Production and Liquefaction

Steam Methane Reformer (SMR)
Liquid Hydrogen (LH2) Distribution

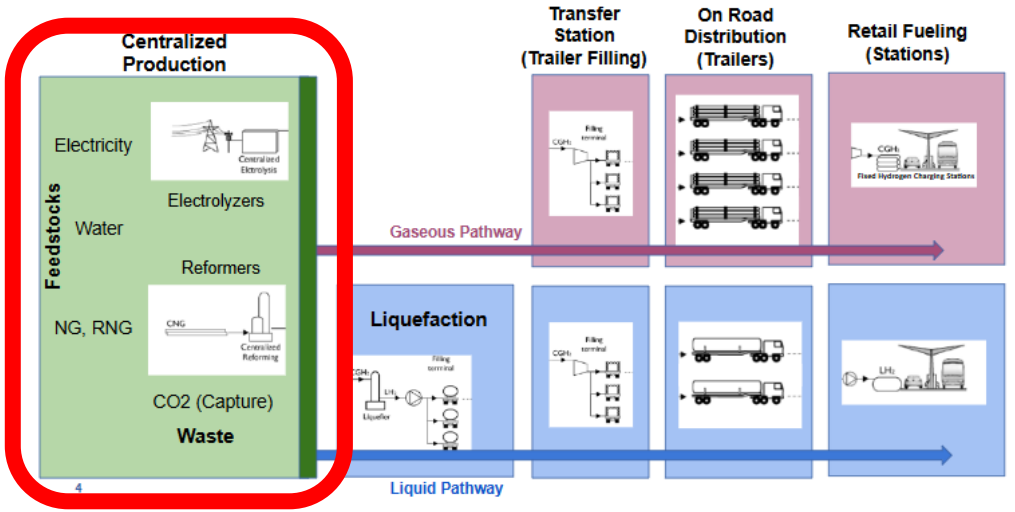
Becancour, Quebec - Production and Liquefaction

SMR, Electrolyzer, Waste H2 Recovery
Pipeline, Gaseous and Liquid H2 Distribution

Hydrogen Costs - Production

Cost = OPEX + CAPEX

ELY =	50/50	OPEX/CAPEX
SMR =	75/25	OPEX/CAPEX



OPEX is driven by feedstock costs

- ELY driven by electric power rates and access
- SMR driven by NG rates
- SMR CO2 cost/value is uncertain and very location dependent
- Cost of EAs to offset carbon intensity applies to both SMR and ELY but not equally

CAPEX is driven by project size

- ELY processes scaleup by increasing numbers of modules - linear cost increases
- ELY cost reductions driven by supplier manufacturing scale up
- SMR & CCS processes scaleup by increasing capacity of a single train - 0.6 rule chemical facilities

Economy of scale can significantly impact these costs

- ELY manufacturing scale up drives down cost of modules
- SMR project size drives down cost of construction
- May provide access to low cost energy

Hydrogen Costs - Distribution

Cost = OPEX + CAPEX

GH2 - driven by Fleet OPEX

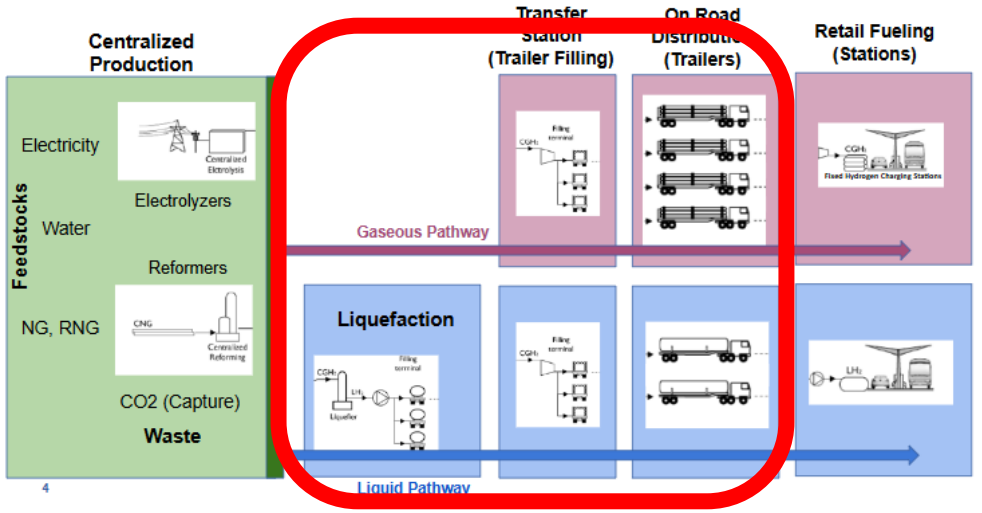
LH2 - driven by Liquefier CAPEX & OPEX

GH2 distribution is much less efficient

- More deliveries
- More trailers

LH2 is more equipment intensive

- Liquefier OPEX - up to 25% additional electric power
- Liquefier CAPEX - 50% adder to production facility cost
- Trailers are more expensive but carry much more product (5X to 10X compared to GH2)
- Liquefiers need to be fully loaded



Economy of scale can impact these costs but not as much as production

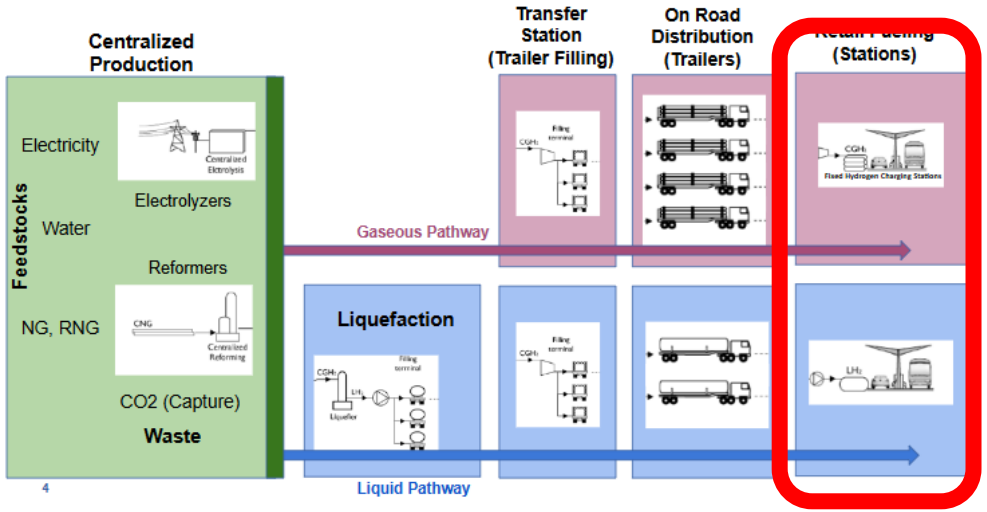
- Scale up of supply chains to reduce CAPEX
- May provide access to low cost energy

Hydrogen Costs - Stations

Cost = OPEX + CAPEX

CAPEX driven by station size

OPEX driven by energy costs and maintenance



Economy of scale can impact these costs but not as much as production

- Scale up of supply chains to reduce CAPEX
- May **NOT** provide access to low cost energy
- Maintenance support costs improve with network size

Hydrogen Costs - Needs

Economy of scale is the solution, but not a single approach

- Promote larger production facilities - drives down facility costs
- Invest in scale up of electrolyzer manufacturing
- Enable access to low cost power (electricity for electrolyzer and liquifaction)
- Increase station network size to improve OPEX and supply chain CAPEX


Air Liquide
Thank You
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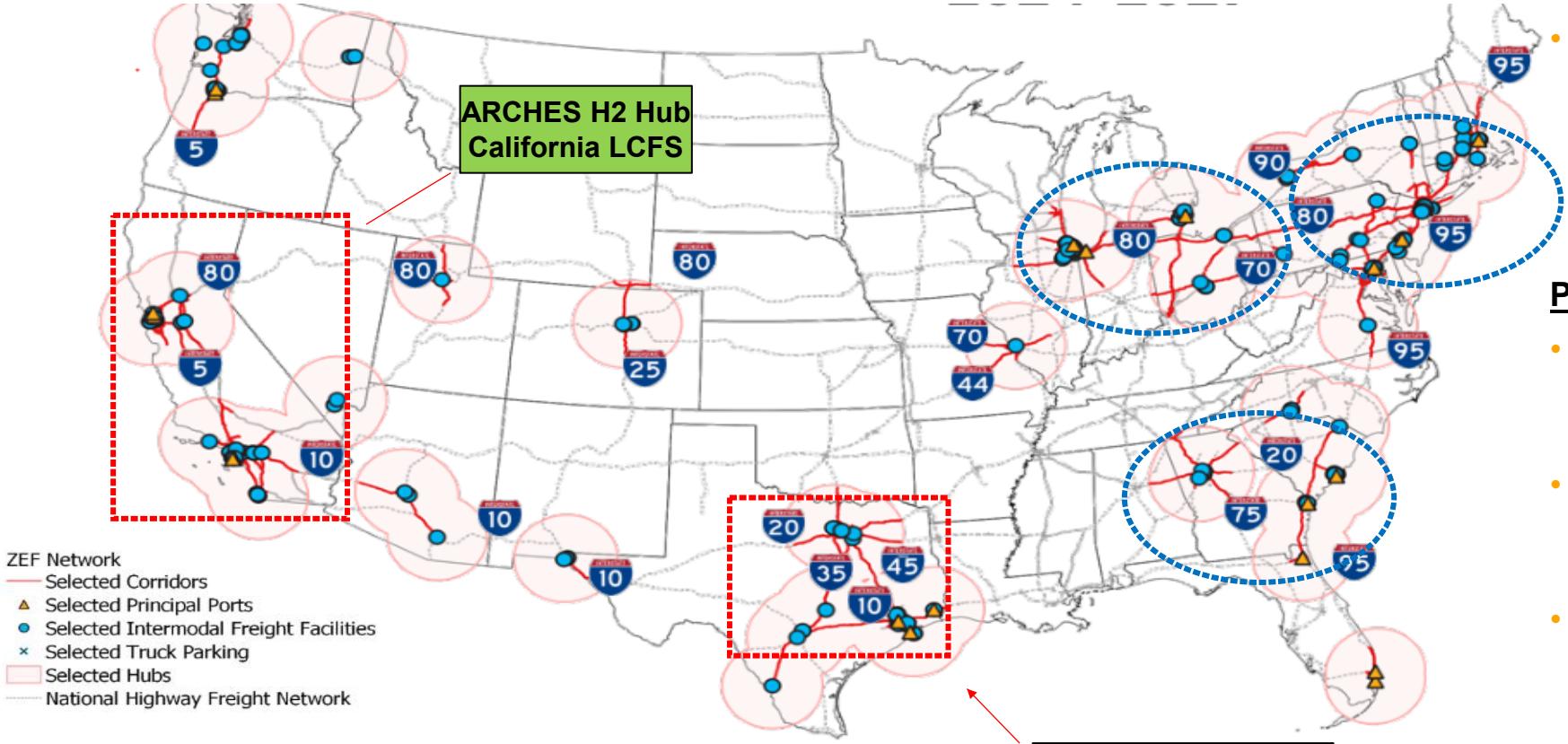
CARB TRIG Meeting

November 4, 2024

Map: Joint Office of Energy and Transportation National Zero Emission Freight Corridor Strategy Pilot's Priority Regions for MHD HRS Deployments



Pilot Primary Regions

Pilot Secondary Regions

Opportunity:

- A H2 ecosystem is developing with billions in government funding.
- H2 is a zero-emission fuel and a strong candidate to decarbonize long-haul heavy-duty (HD) trucking. Integration of H2 fuel into the transportation sector supports commercial shipper's goals to reduce transportation emissions and GHGs.

Policy Driven Energy Transition:

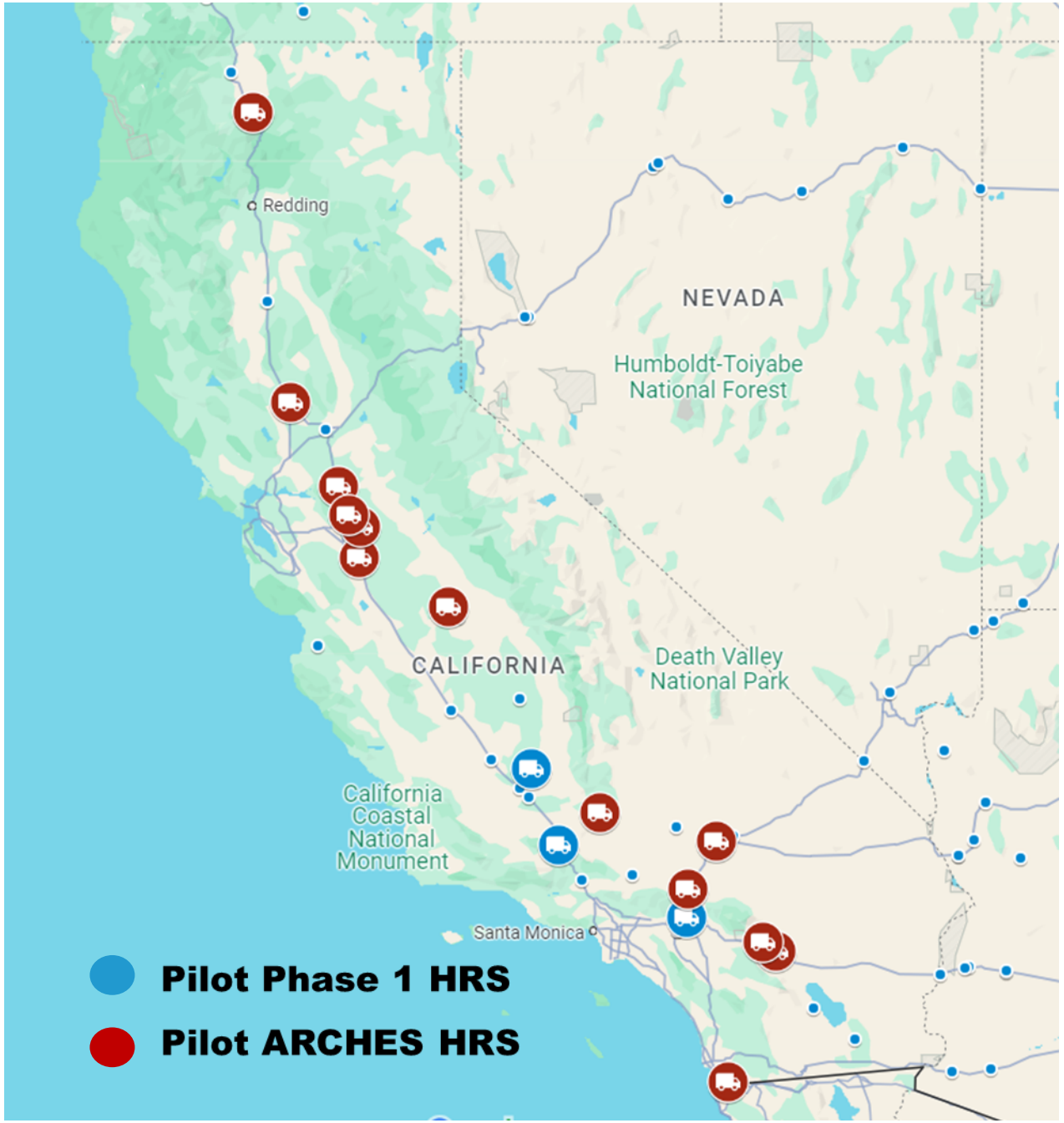
- The transition to zero emission transportation is policy driven, not economic.
- Success depends on sustained government policies that provide a bridge to an "economic" energy transition.
- Federal and state policies are supportive of H2 in transportation today, does this shift with a new administration? If so, how?
- Market participants need to be committed to enable a sustained transition.

Pilot's H2 Engagement:

- Government policy, direct and indirect grants are driving Pilot's development priorities and timeline.

PILOT COMPANY

Pilot Travel Centers Potential California HRS Locations



CARB

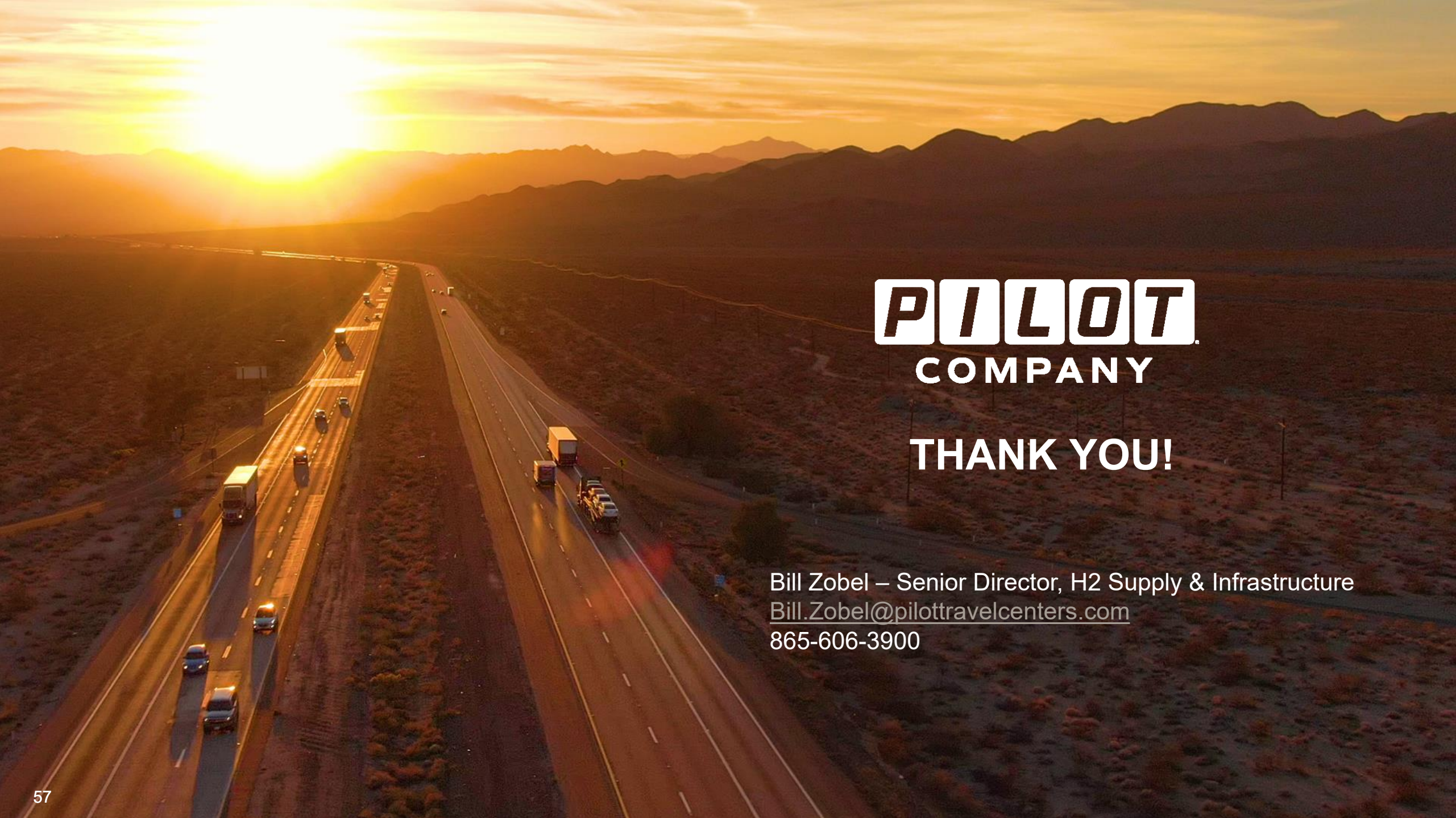

Pilot
Pilot
Pilot H2
PILOT LH2 TANK - 45
LIQUID H2

Grant Timeline

Pilot H2 Refueling Station (HRS) Grants	Amount	Agency	Capital Deployment and Expected Commercial Operations 2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
State Programs														
Energiize H2 Lane (Bakersfield, #613)	$4m	CEC												
SCAQMD MSRC, Moyer (Rilato, #1328)	$7m	SCAQMD												
CEC MHD Blueprint (Lebec, #616)	$5m	CEC												
Federal Programs														
Ca. ARCHES H2 Hub (10 locations, $5m/HRS)	$50m	DOE												
Tx. Clean Fuel Infrastructure (5 locations)	$70m	FHWA												

What's Needed to Reach Final Investment Decision (FID)

- Regulatory Certainty for Commercial Investment
  - Flexible 45V
  - Commercially Effective LCFS Program
  - California Waiver Resolution
  - HVIP Funding for Trucks



THANK YOU!

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865-606-3900