

# CA Hydrogen Hub and Advanced Electrolysis R&D at LBNL

Benchmarking Workshop, ASU, Los Angeles | June 11, 2024

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Chief Technology Office  
Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)

# Hydrogen @ Lawrence Berkeley National Laboratory

Systematic research to solve applied problems informed by technoeconomic, life-cycle, and energy analysis

Have been working on hydrogen technologies for over 3 decades

Hold leadership levels in major applied and fundamental R&D DOE consortia

Focus holistically on the issues and advance the science and technology to establish innovation pipelines

Operate as an honest broker in examining different technologies, pathways, and materials for strategic RDD&D



**MAKE**

**STORE**

**USE**

**ANALYZE**

PRODUCTION

STORAGE/DELIVERY

UTILIZATION/APPLICATION

SYSTEM ANALYSIS

TRL: Technology Readiness Level

# Hydrogen @ Lawrence Berkeley National Laboratory

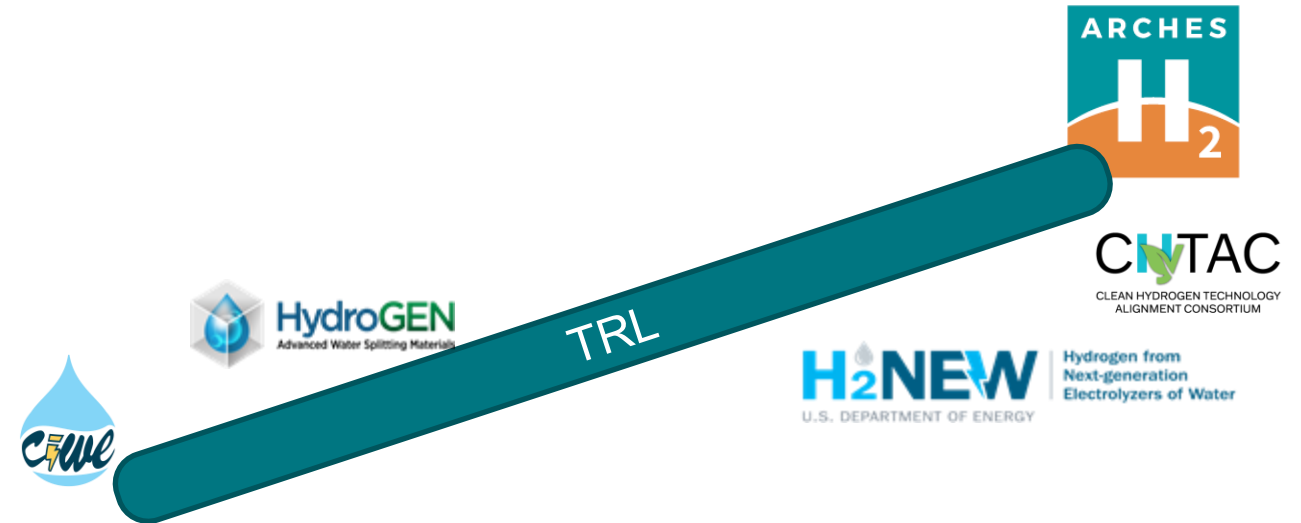
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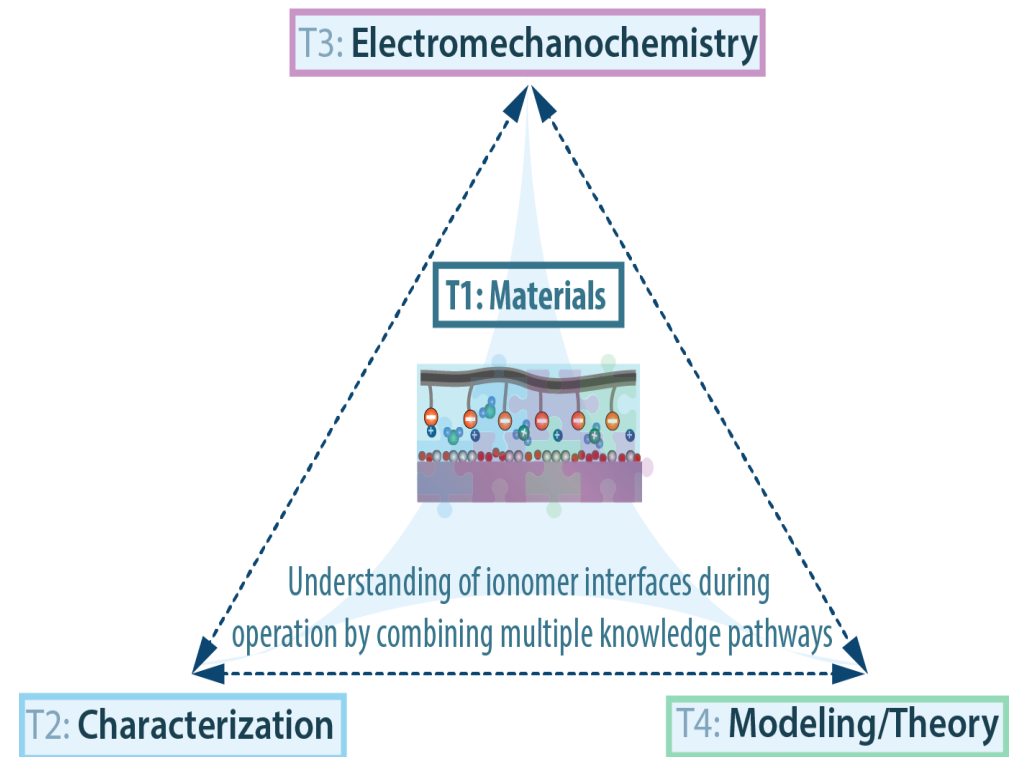
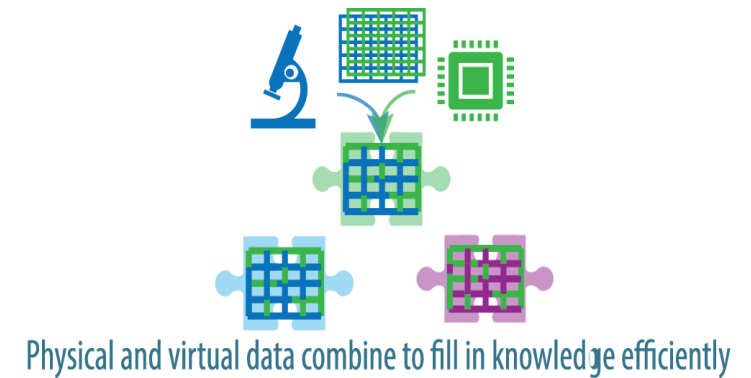
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# Center for Ionomer-based Water Electrolysis

- **Focus on interface discovery and understanding**
  - ↳ Material is the crosscut and focuses more on known materials
  - ↳ Build interface complexity over time
- **Use Digital-Twin paradigm**
  - ↳ Physical and virtual worlds are brought together in a unity of theory and experiments to interrogate and interpret simultaneously
    - Overcome “small data” problem
- ***In-Machina* experiments**
  - ↳ Representative *operando* studies
- **Robust PIER plan**
  - ↳ Focus on developing workforce of the future
- **Robust Data Management plan**
  - ↳ Ensure (meta)data coherence

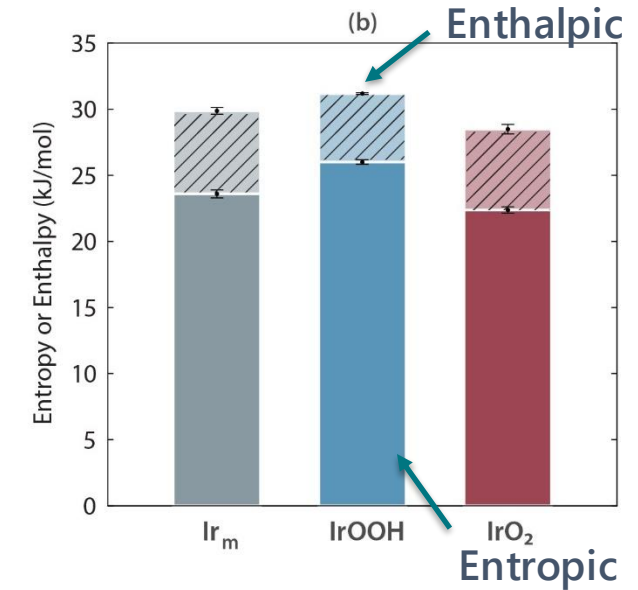
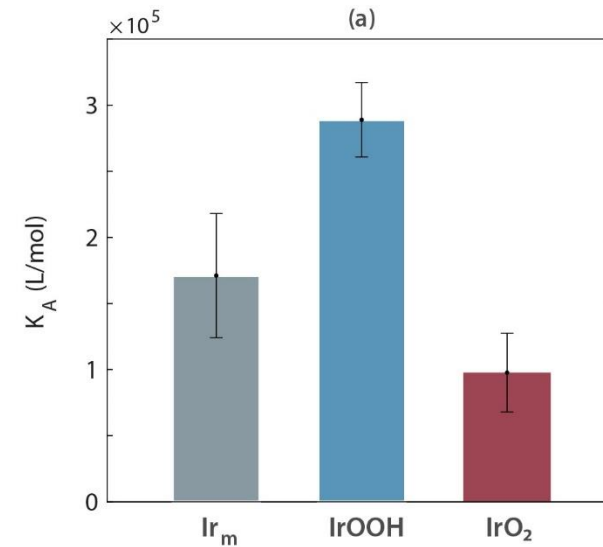


# Center for Ionomer-based Water Electrolysis

## Ionomer-catalyst interactions

- **Three different Ir oxide formulations**

- ↳ Charging and bonding interactions (association constant  $K_A$ ) result in different ink structures
  - Impacts Nafion thin-film swelling and structure
- ↳ Correlated to overall cell performance



# Center for Ionomer-based Water Electrolysis

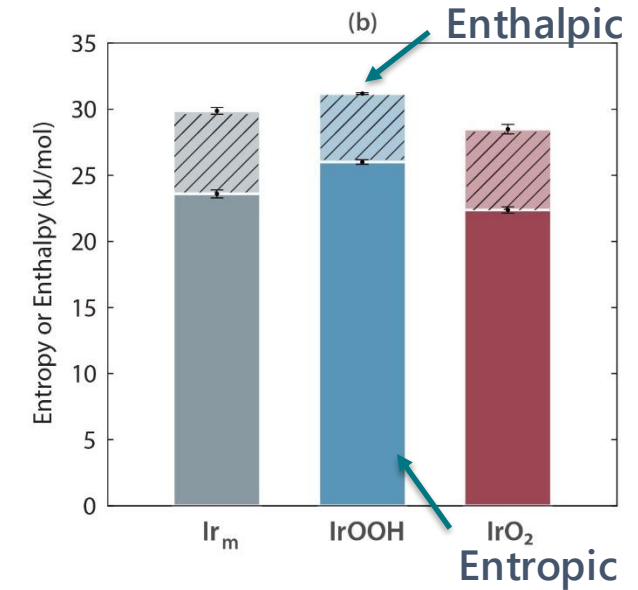
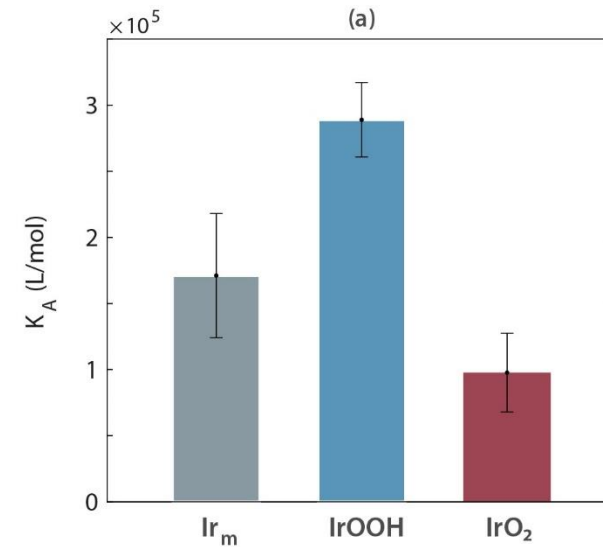
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Ir <sub>m</sub> - bare metal	Ir(OOH) - hydroxide layer	Ir(O <sub>2</sub> ) - thermally grown
Conformation of ionomer chains on metallic surface with mixed oxide coverage	Stronger binding of ionomer on (OOH) functionalized surface disrupting ionomer structure	Weaker catalyst-ionomer binding modulated by complete oxide coverage
Ionomer film swells more with nano-phase separation	Ionomer film swells less with reduced phase-separation	Ionomer swells more with stronger anisotropy

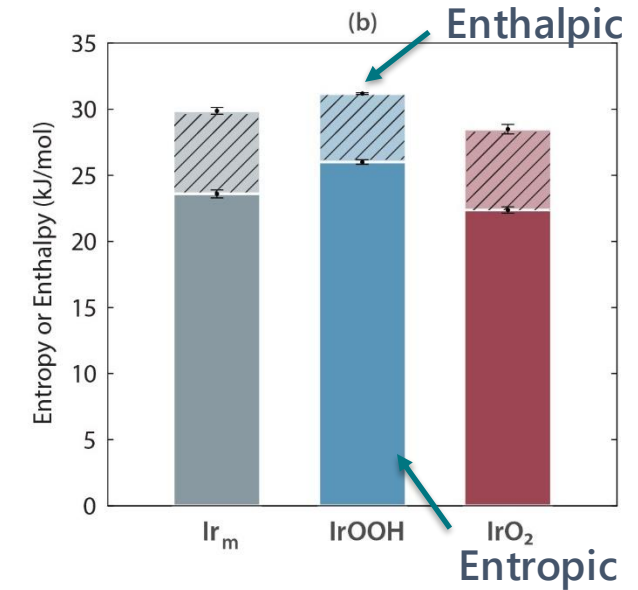
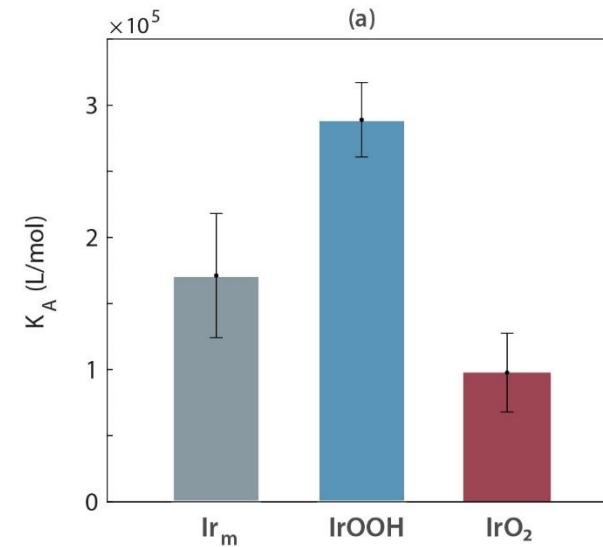


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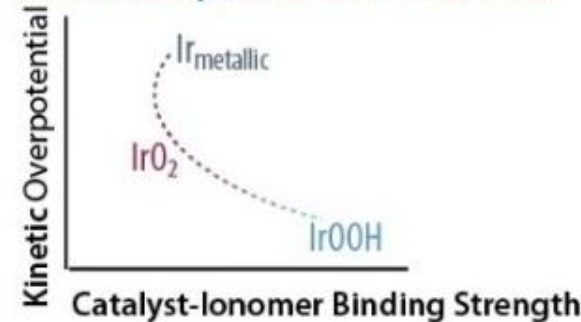
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**Ir(O<sub>2</sub>) - thermally grown**

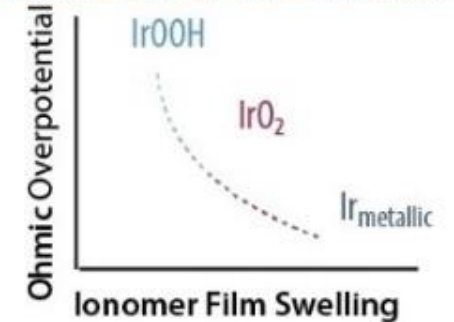
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Ionomer swells more with stronger anisotropy

kinetics ↔ catalyst-ionomer interaction

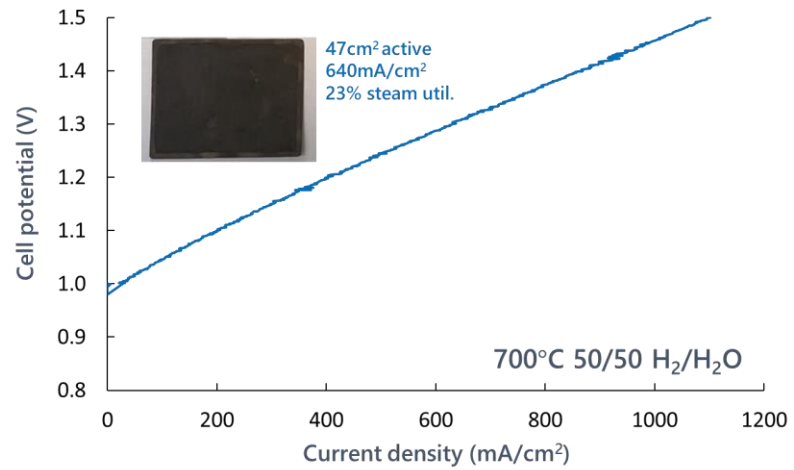
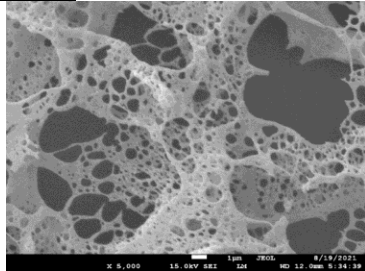
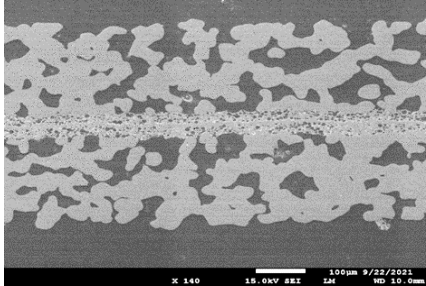


Ohmic resistance ↔ ionomer swelling



# HydroGEN

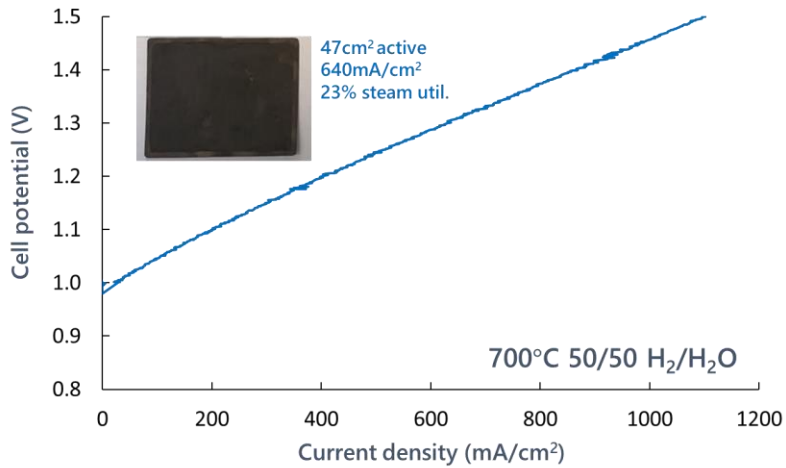
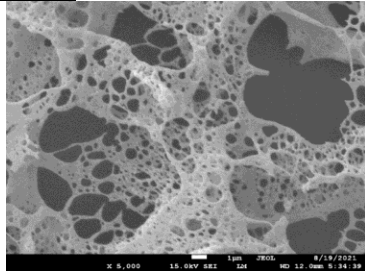
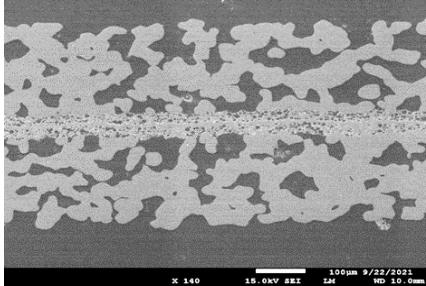
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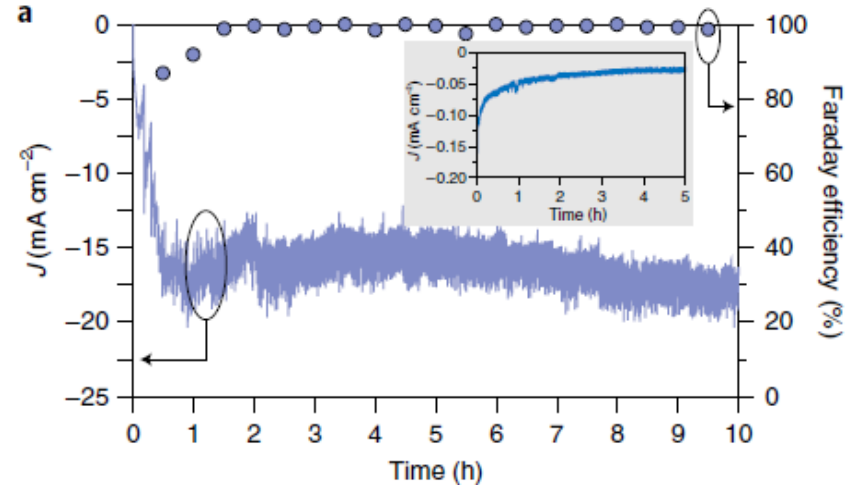


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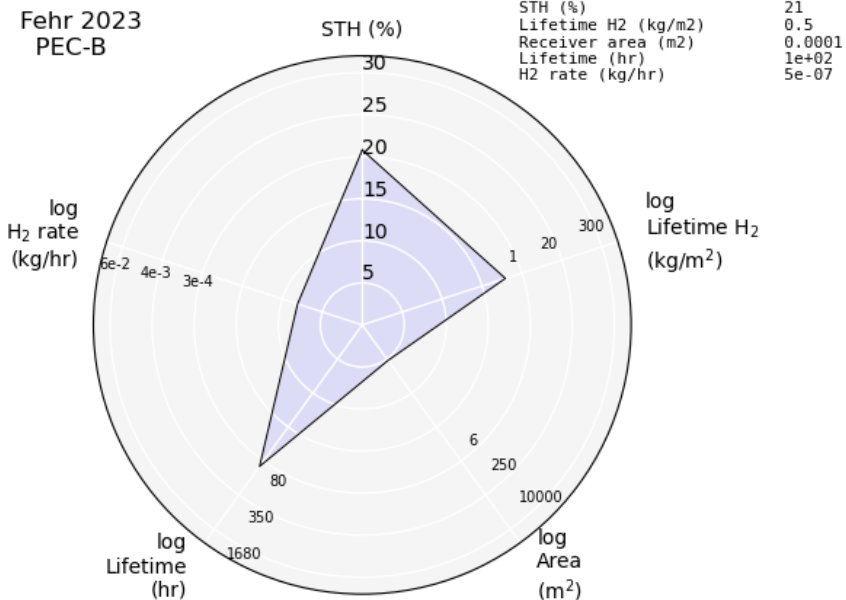
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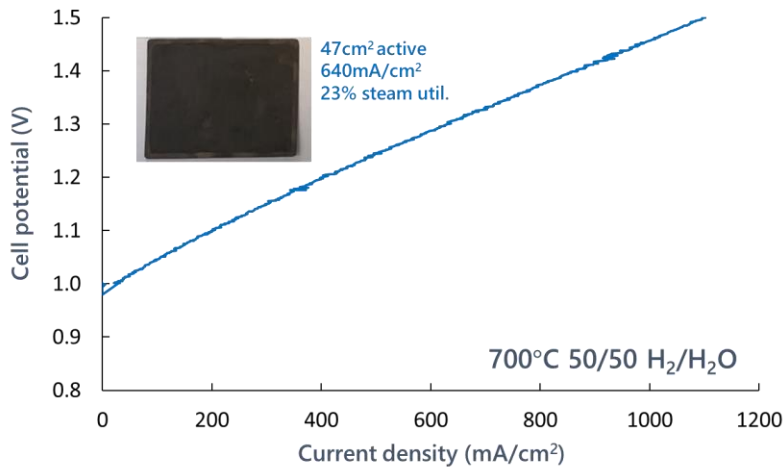
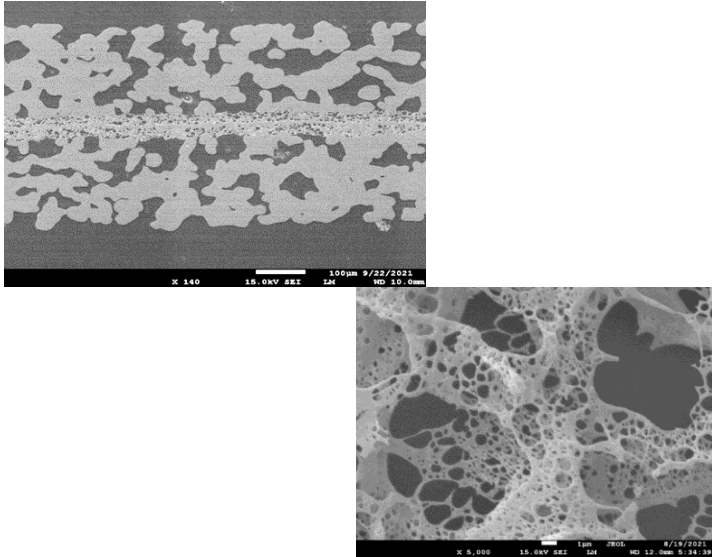


Tobias A. Kistler, et al., *Adv. Energy Mat.*, 10, 2002706 (2020)

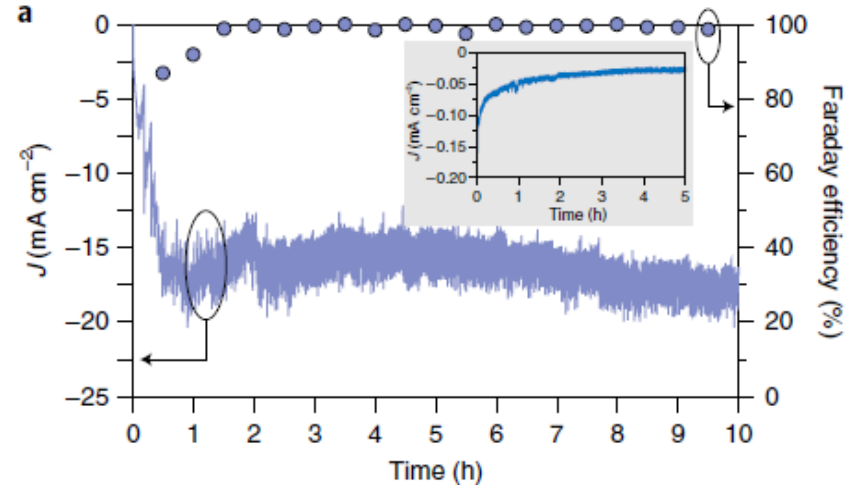


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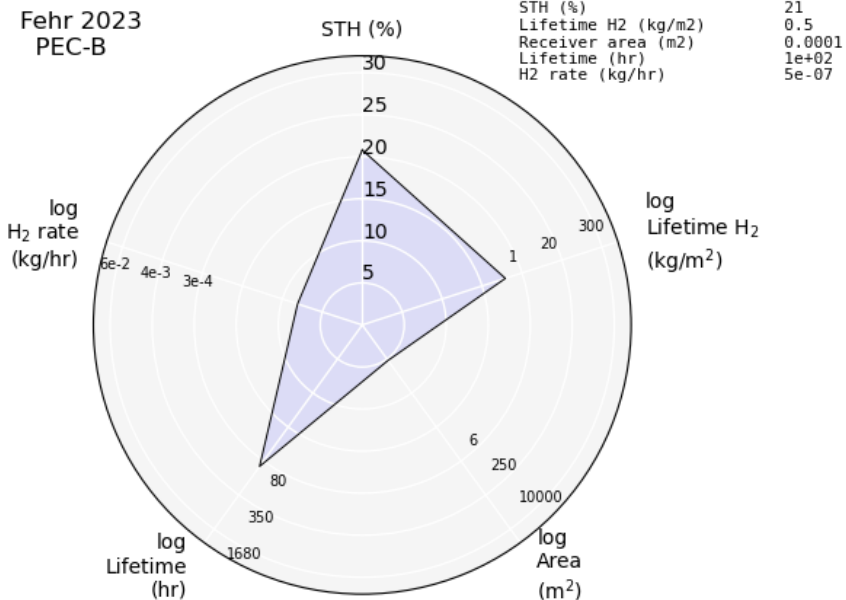
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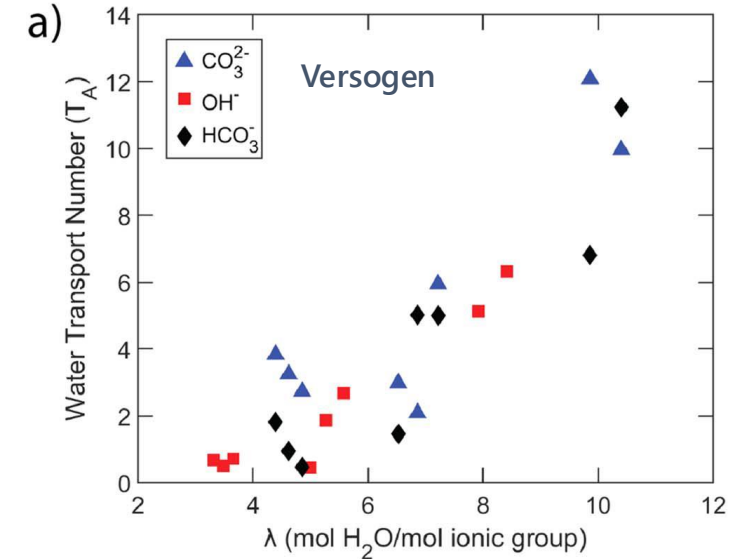
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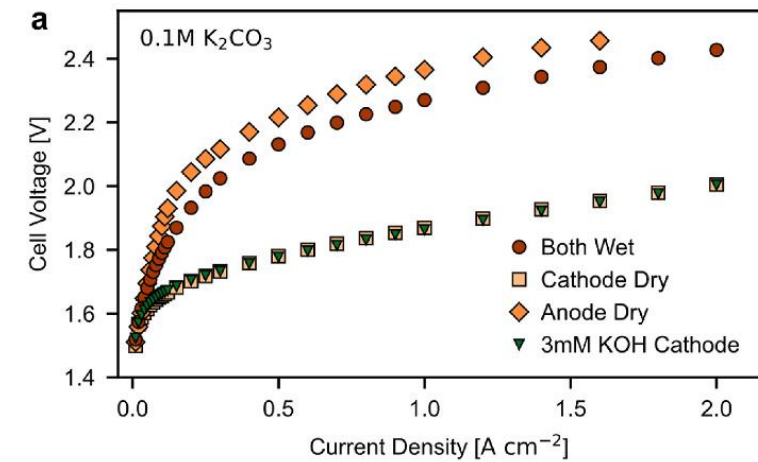
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AEMWE



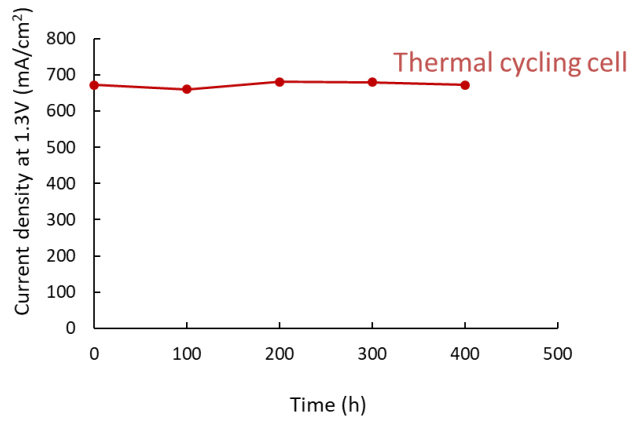
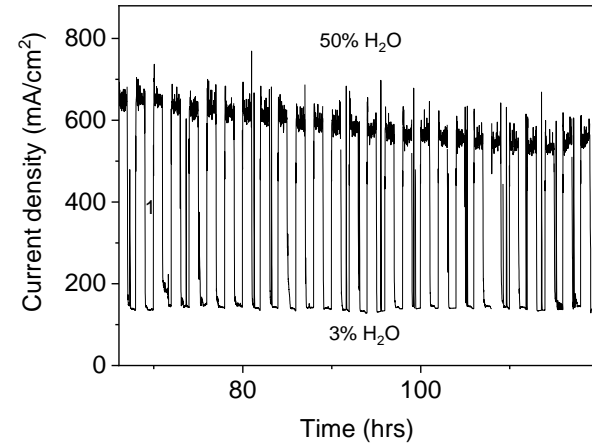
J. Petrovick, et al., *JES*, 170, 114519 (2023)



*Adv. Energy Mater.* 2023, 2303629

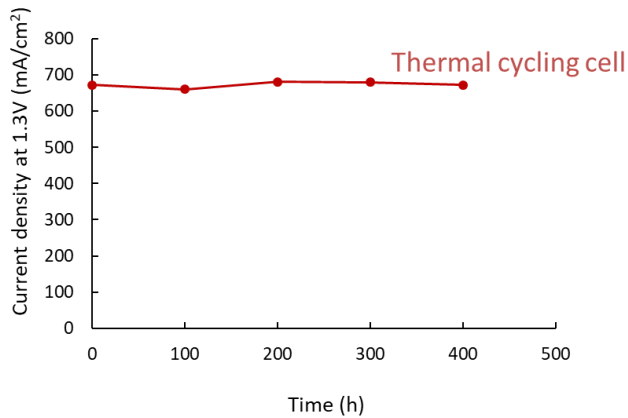
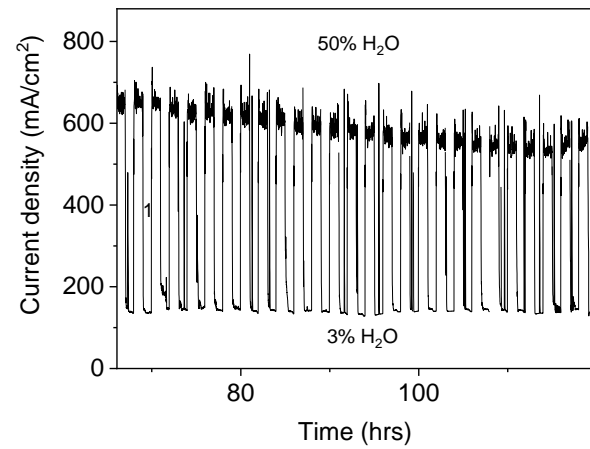
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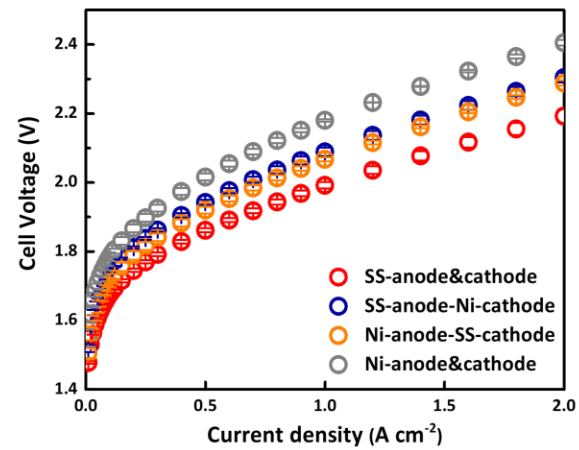
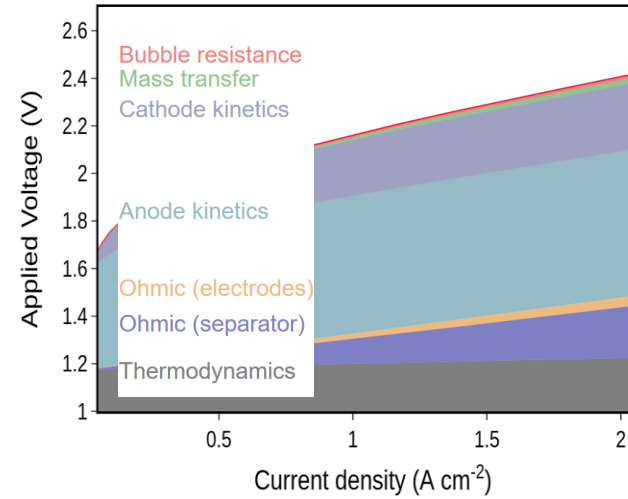


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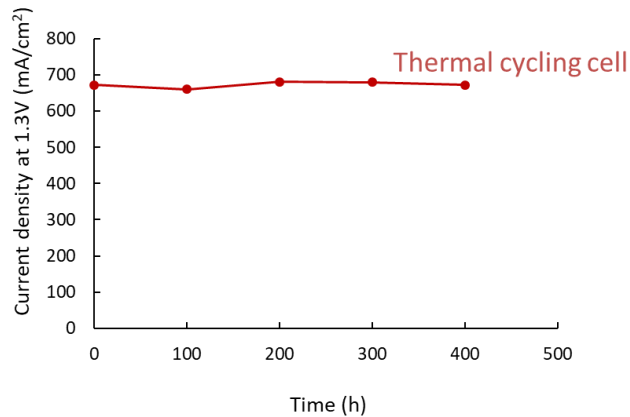
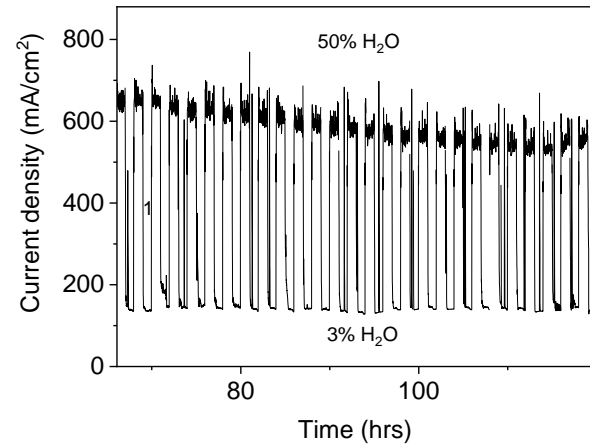
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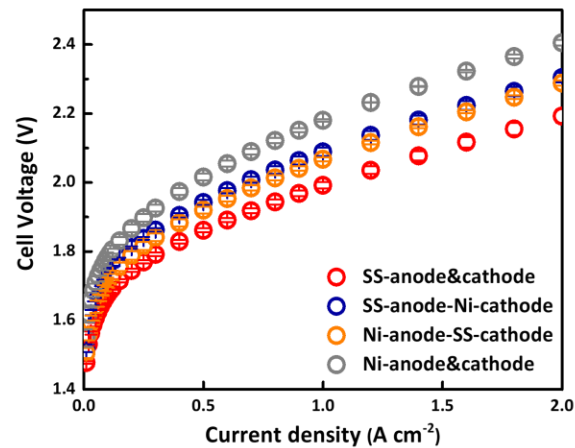
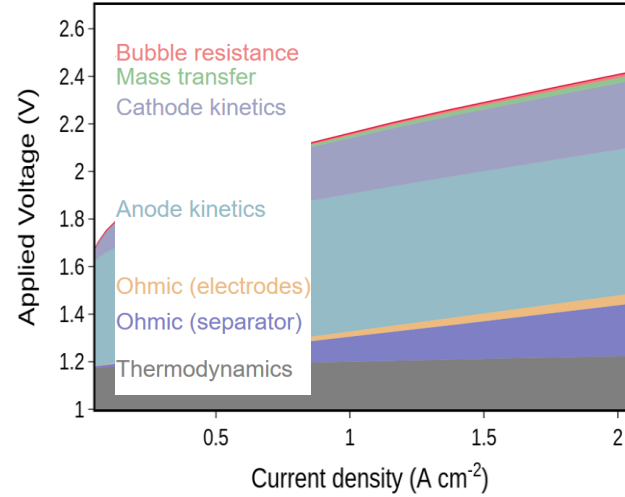
*J. Electrochem. Soc.* DOI: 10.1149/1945-7111/ad4fe6

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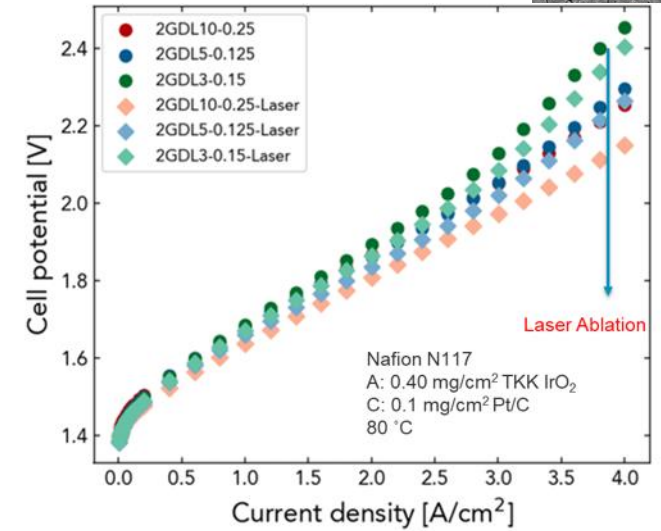


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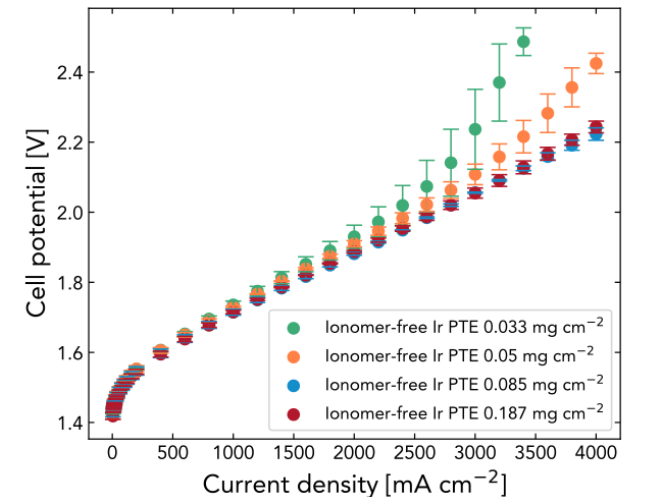


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## PEMWE



Lee et al. *Applied Energy* 336 (2023) 120853



JK, Lee and X, Peng\* *et al. Nature Communication*





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





# Regional Clean Hydrogen Hubs

**Build regional clean H2Hubs across the country to create networks of clean hydrogen producers, consumers, and local connective infrastructure to accelerate use of clean hydrogen.**

### ***H2Hubs Demand-Side Support Initiative***

- Sept 2023: Announced RFP. Responses were due on November 2, 2023.
- Jan 2024: H2DI was selected as the independent entity.
- Learn more about the initiative here:  
[https://www.youtube.com/watch?v=QgOL\\_Xg7K1Q](https://www.youtube.com/watch?v=QgOL_Xg7K1Q)

### ***H2Hubs Current Status***

- **October 2023: DOE announced 7 projects selected for award negotiations.**

# Selected Regional Clean Hydrogen Hubs





# California's Clean Energy Commitments



## Clean Energy

SB 100 (100% clean energy)  
SB 423 (firm zero carbon resources)  
SB 1020 (interim clean energy targets)



## Clean Transportation

Exec. Order 79-20 (ZEVs)  
ZEV Regulations  
Advanced Clean Fleets  
Low Carbon Fuel Standard



## Climate Change

AB 32  
SB 32 (2030 target)  
AB 1279 (carbon neutrality )  
Governor/Scoping Plan goals (sustainable aviation fuel, carbon removal, etc..)



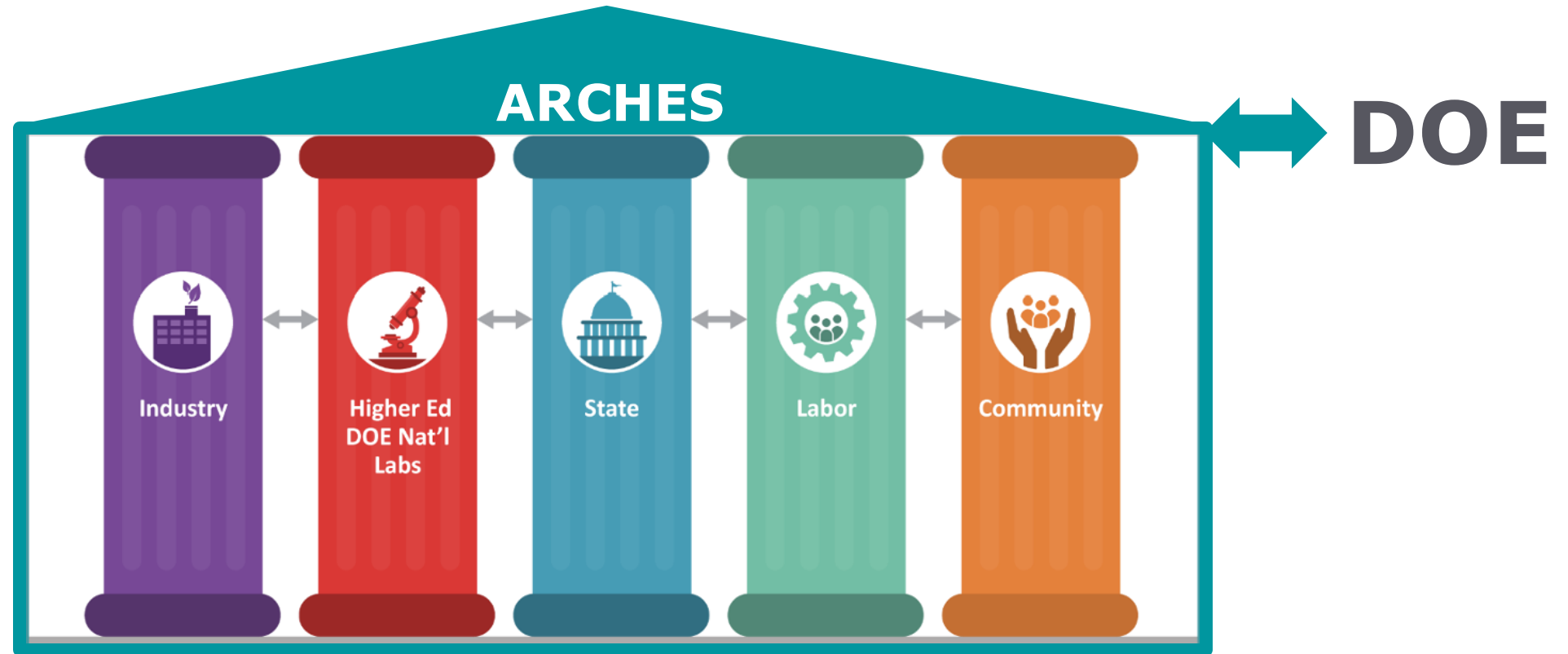
## Market Transitions

Cap-and-Trade  
Governor's infrastructure package and Executive Order  
ARCHES/Hydrogen Hub application



# Who is ARCHES

**Alliance for  
Renewable  
Clean  
Hydrogen  
Energy  
Systems**





# ARCHES Principles

## ✓ **Statewide**

Leveraging California's size and diverse geography and economy to produce, transport, store, and use H<sub>2</sub> at scale with multiple clusters of each, provides an ideal H<sub>2</sub> test-bed for the nation

## ✓ **Green**

California has long led the nation and the world in environmental innovation and policy and will do so again with clean H<sub>2</sub>.

## ✓ **Stakeholder and Community Engaged**

Built-in and ensured at all stages of the process

## ✓ **Equity and Justice Centered**

Prioritized in all decisions with a focus on California's impacted, disadvantaged, low-income, and tribal communities.

## ✓ **Aligned with State Interests**

To move California toward a robust H<sub>2</sub> economy and marketplace, and a cleaner, greener future.

## ✓ **Solution-Oriented**

Focused on implementation with targeted research and innovation to achieve the DOE's \$2/kg 5-year goal and the administrations \$1/kg 10-year goal.

## ✓ **Objective and Unbiased**

Representing and ensuring the interests of all parties

## ✓ **Multi-dimensional**

Considering all aspects of a successful H<sub>2</sub> economy.

## ✓ **Connected**

Within California and other H<sub>2</sub> hubs.



# Project Selection

**Enables Sustainable H<sub>2</sub> Economy  
and the ARCHES Ecosystem**

**Realizes Co-Funding and  
Market Viability**

**Provides Realizable and  
Ready Actualization**

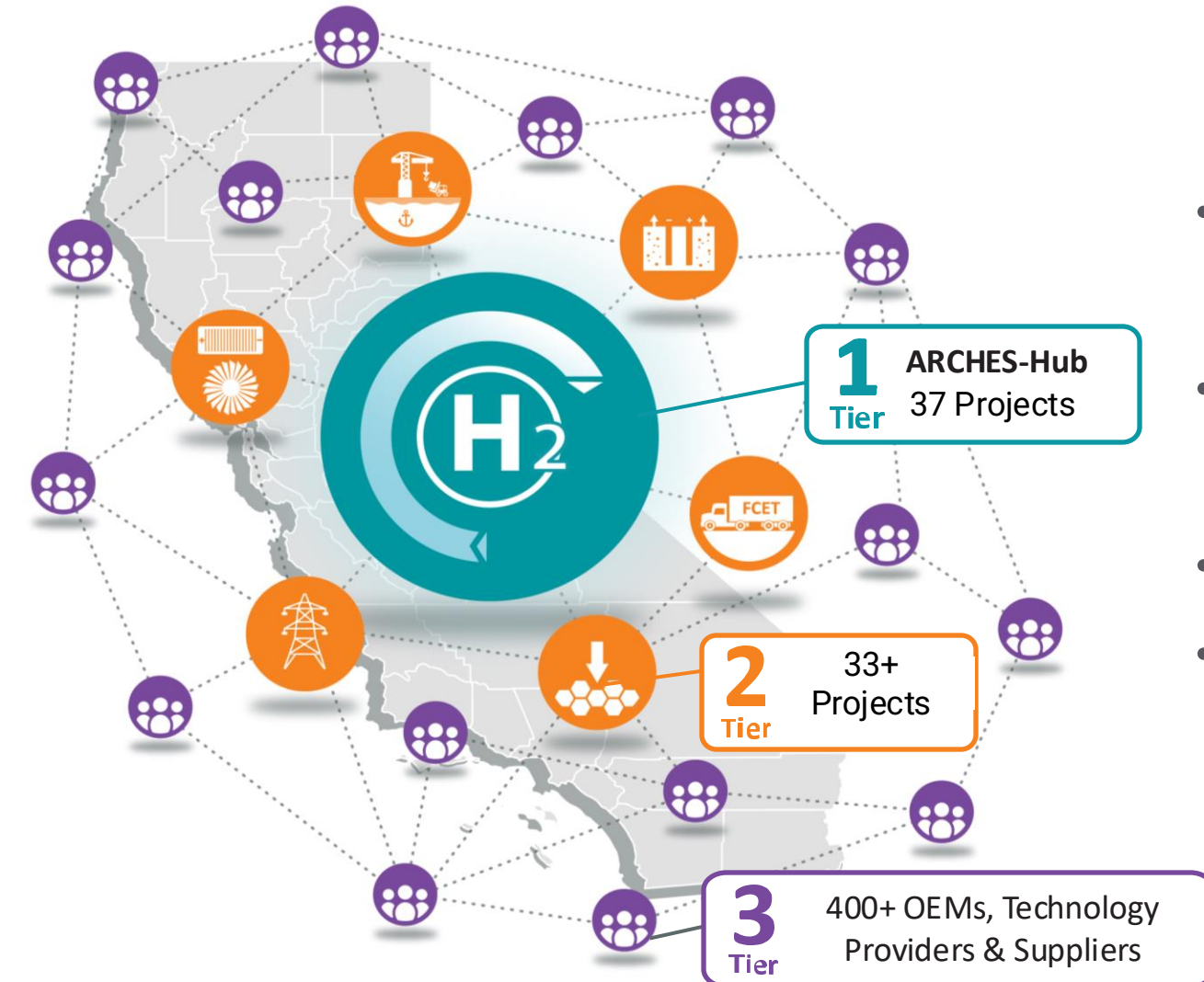
**Provides Strong  
Community Benefits**

- ❑ Chosen from an open RFP followed by in-depth negotiations that went into adoption scenarios and systems analysis
  - Value proposition
  - Market acceptance
  - Resource maturity
  - Community acceptance
  - Project integration





# The Resilient H<sub>2</sub> Ecosystem for California



- **ARCHES DOE H2Hub = Tier 1** = DOE funding through H2Hub Program
- **Tier 2** = viable project but no DOE funding through the DOE H2Hub Program
- **ARCHES Ecosystem = Tier 1 + Tier 2**
- **Tier 2 is growing** through our open rolling RFP process

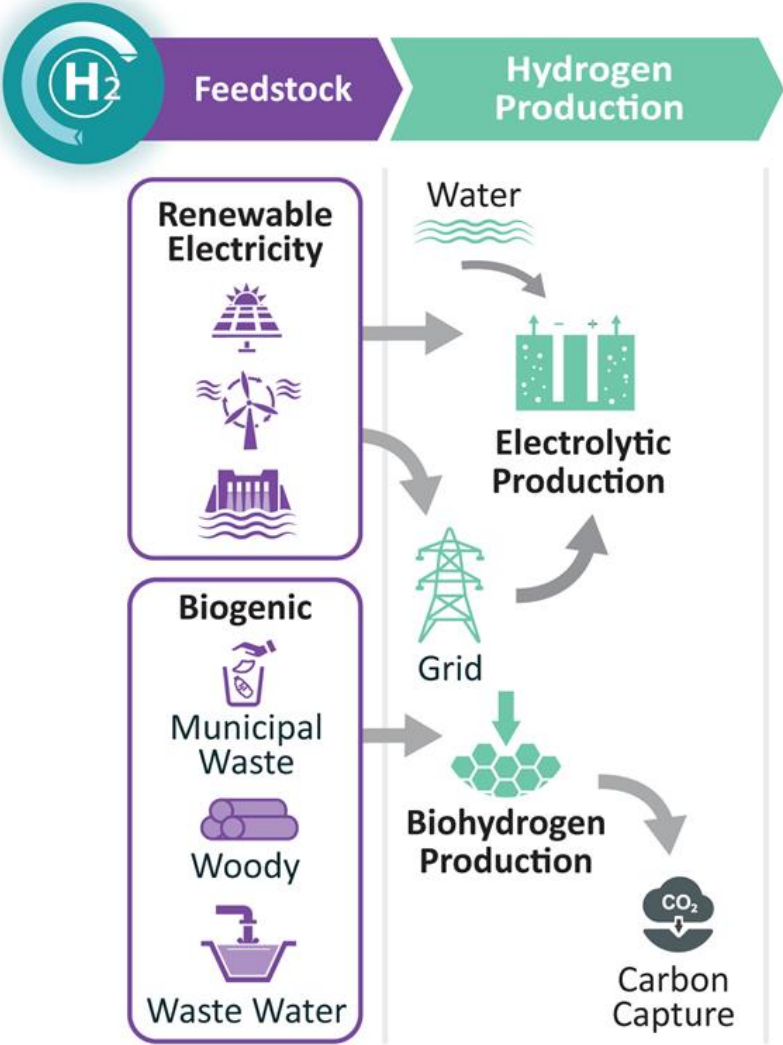


# ARCHES Hydrogen Flow



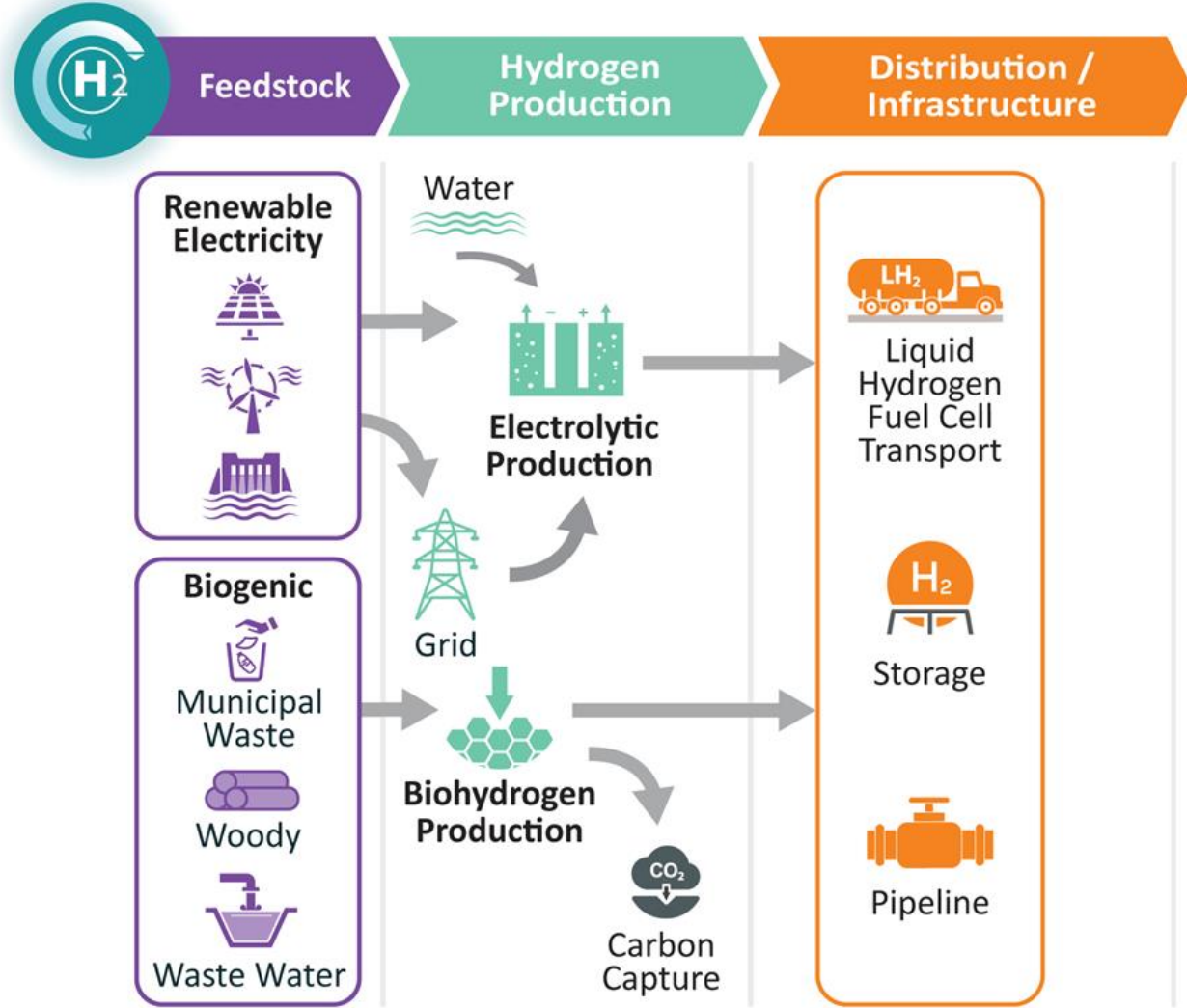


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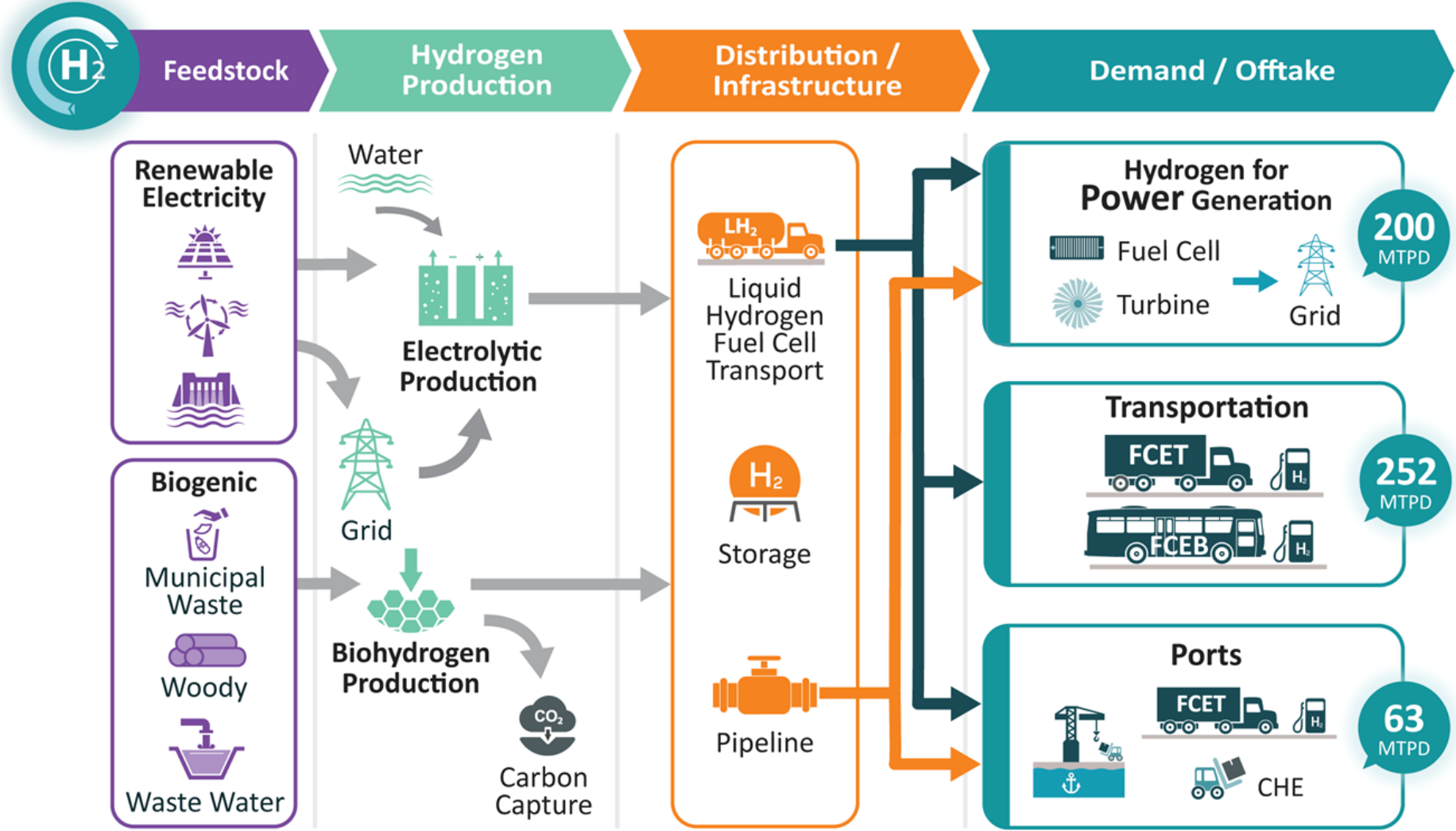


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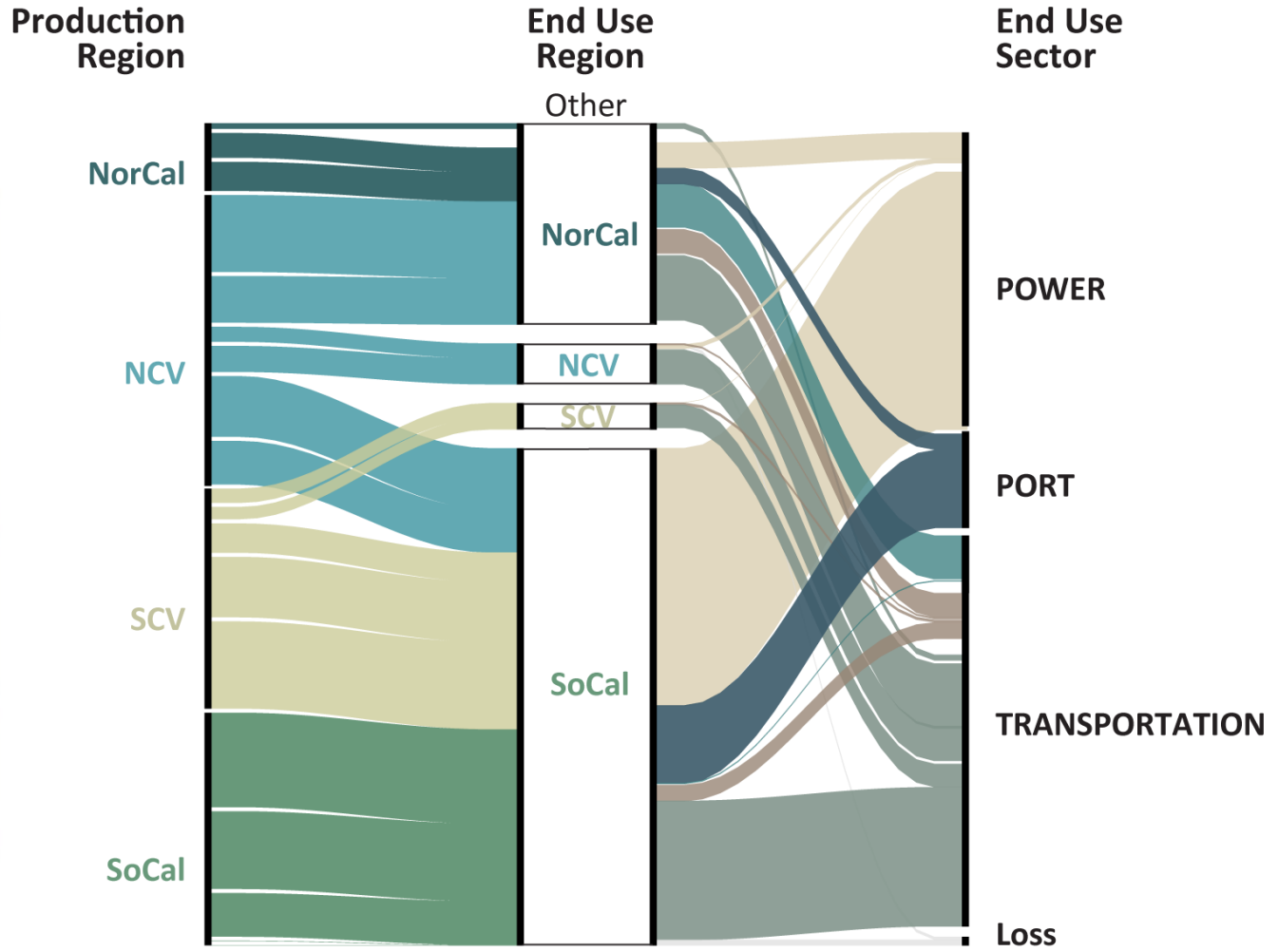
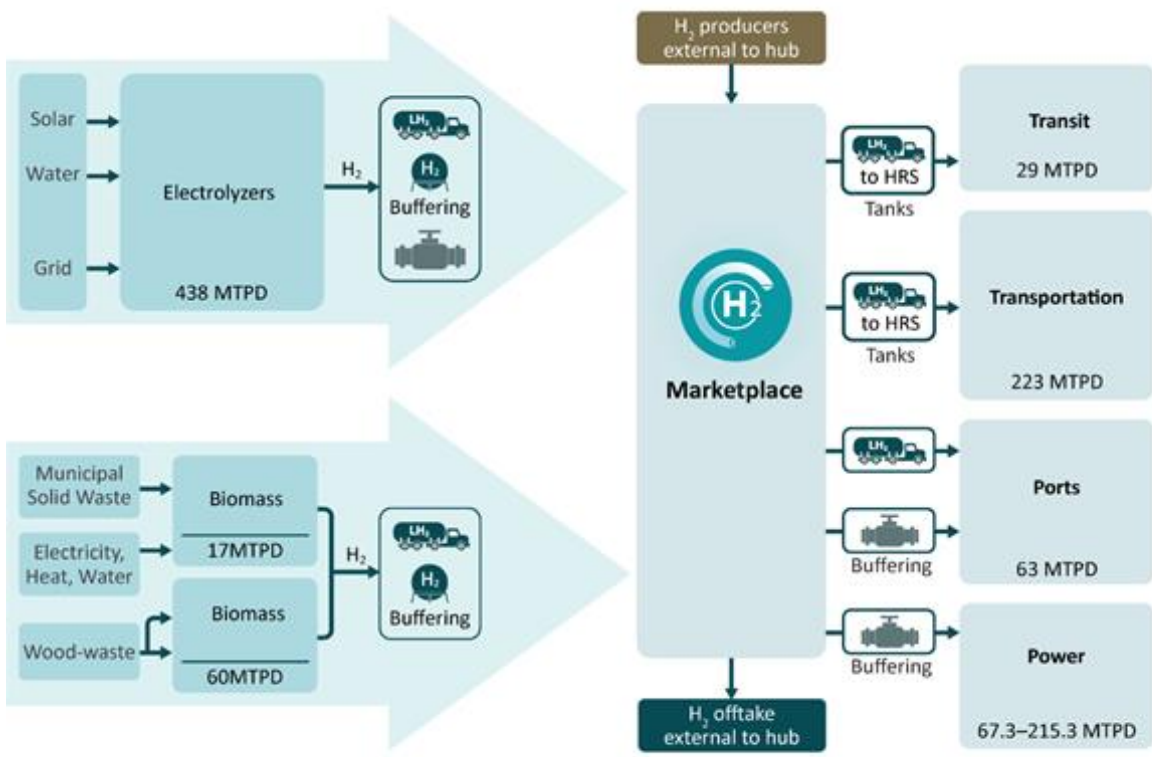


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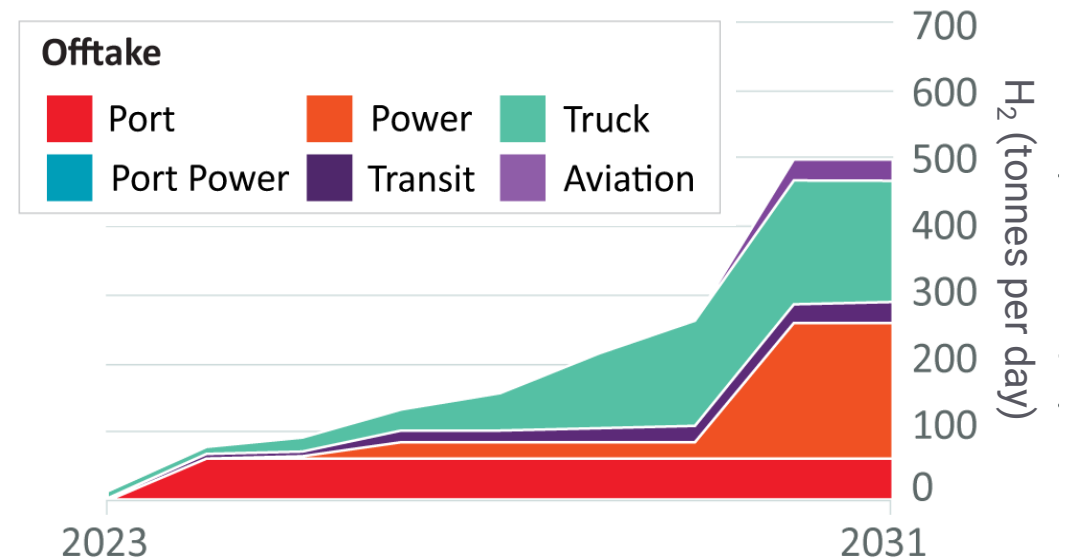
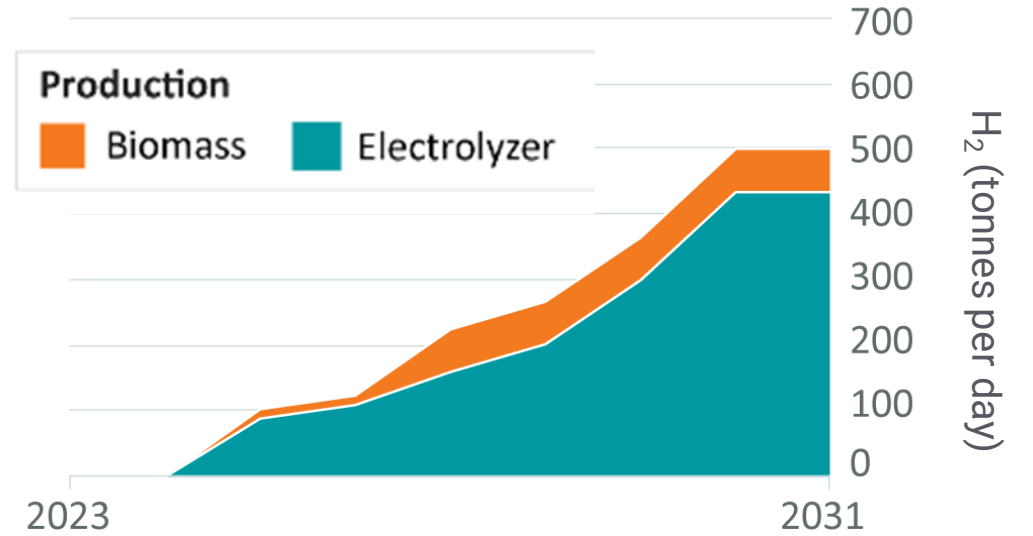
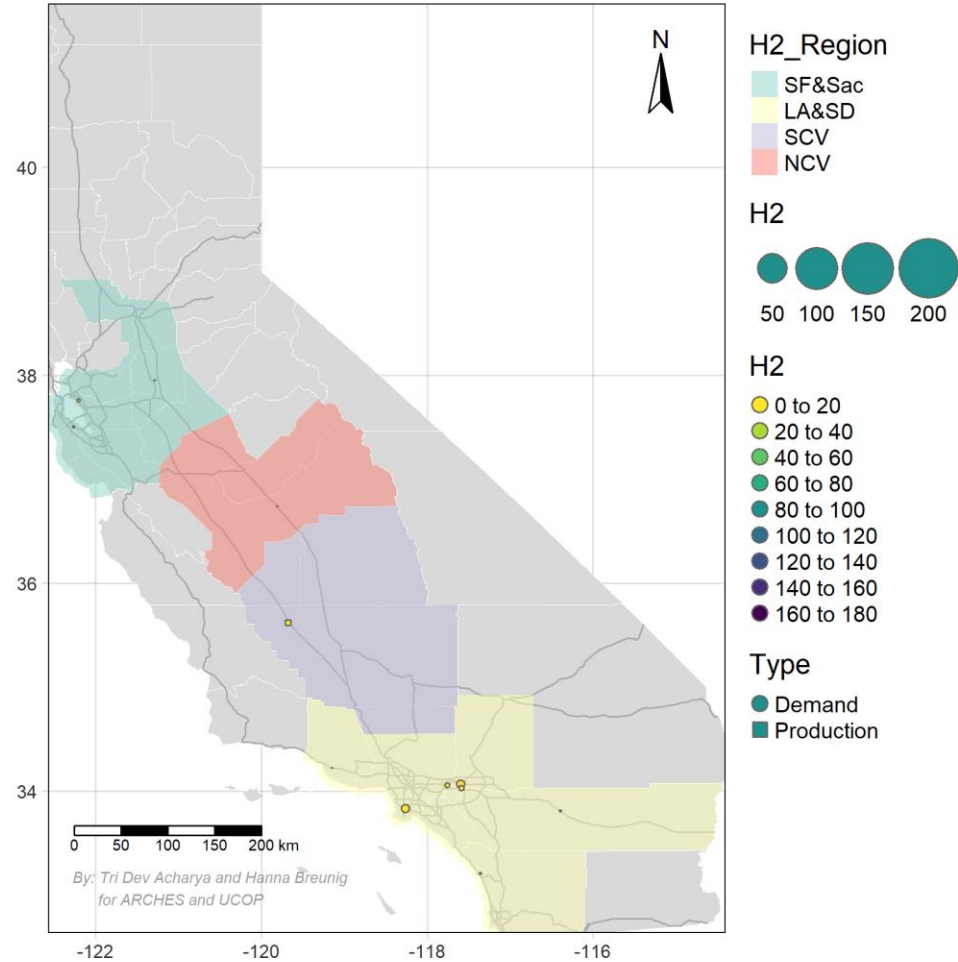






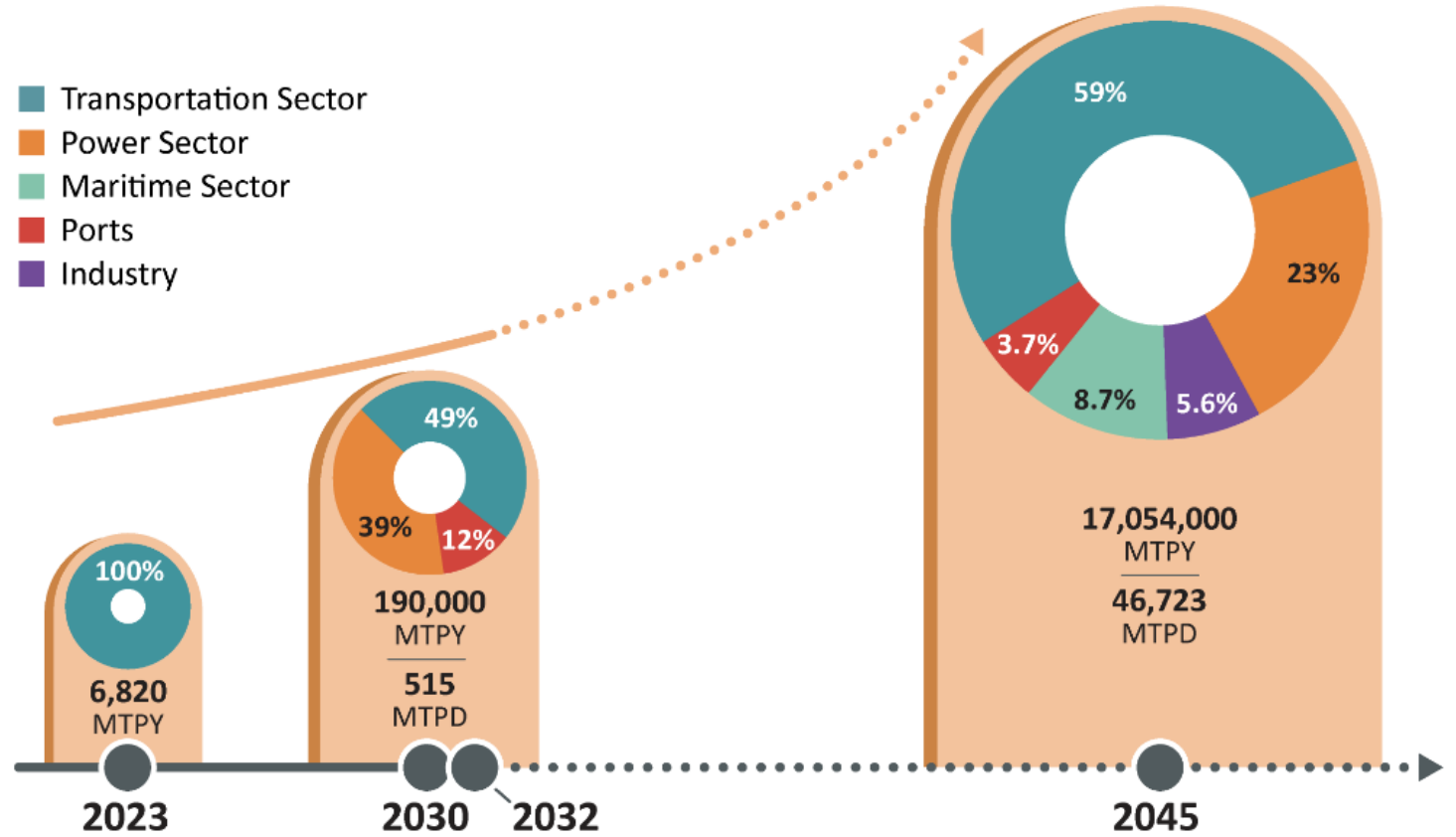
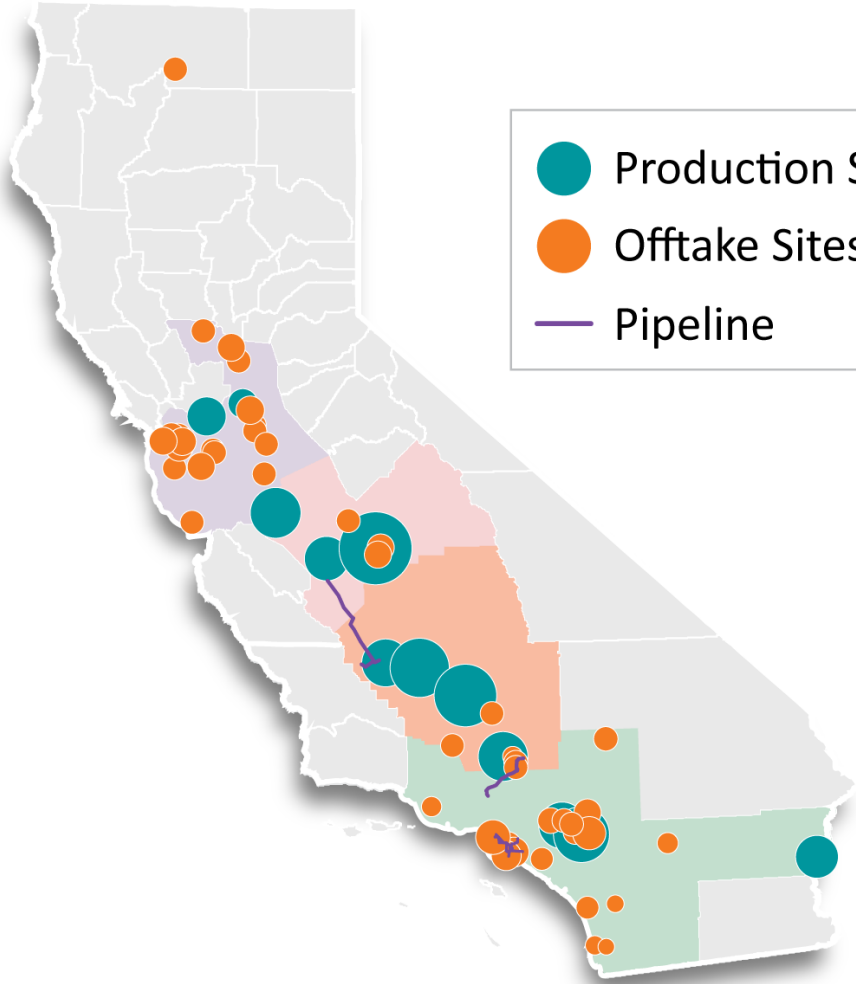
# ARCHES Systems Approach Balances Production and Offtake Over Time

Year 2023 (tpd)





# ARCHES Systems Approach Initiates Large Future Growth





# Life Cycle Assessment

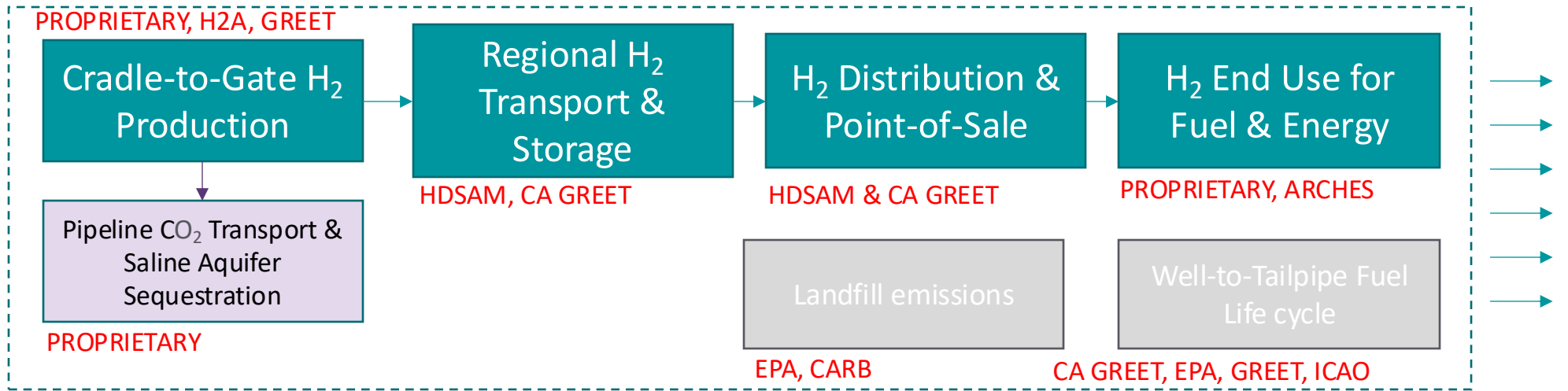
Carbon Intensity & Human Health Impacts were modelled at the individual project level, the regional level, and at the hub level

## System Boundary

### Cradle-to-Gate

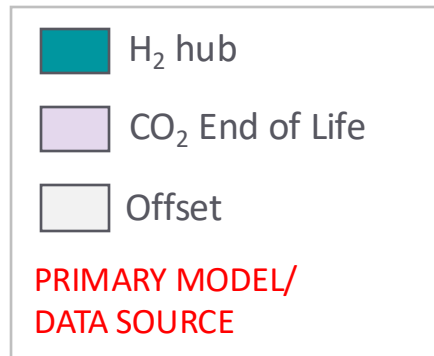
#### Inputs

- Electricity →
- Natural gas →
- Water →
- Biomass →
- Cooling fluids →
- Other feedstocks →
- Fuels →



GREET, UTILITIES, EIA, eGRID

BenMAP, ARCHES



### Life Cycle Inventory

- GHG
- NOx
- SO<sub>2</sub>
- DPM
- PM<sub>10</sub>
- PM<sub>2.5</sub>

### Mercury

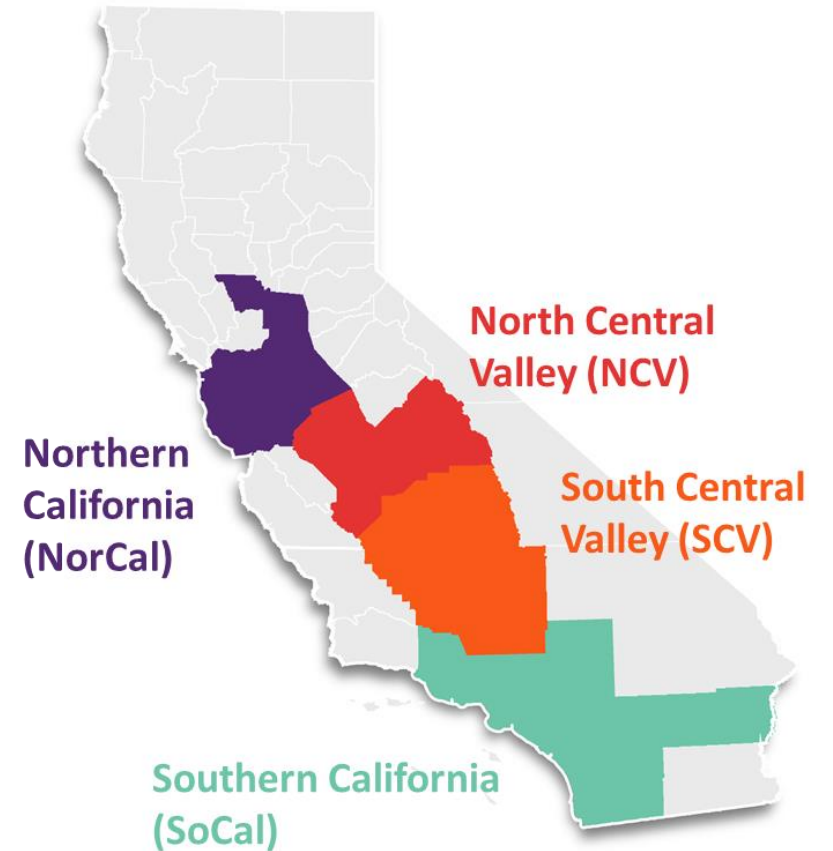
- H<sub>2</sub> emissions
- Water Consumption
- Water Withdrawal
- Fuel Consumption



# Life Cycle Assessment: Production

Carbon Intensities of Produced Hydrogen by Region










Region	Carbon Intensity	Quantity
	kgCO <sub>2</sub> eq/kgH <sub>2</sub>	MTPD
Northern CA	-1.13	41
Northern CA Valleys	2.15	185
Southern CA Valleys	-6.03	140
Southern CA	2.89	149
<b>Weighted Average</b>	<b>-0.15</b>	<b>515</b>





# ARCHES Community Benefits

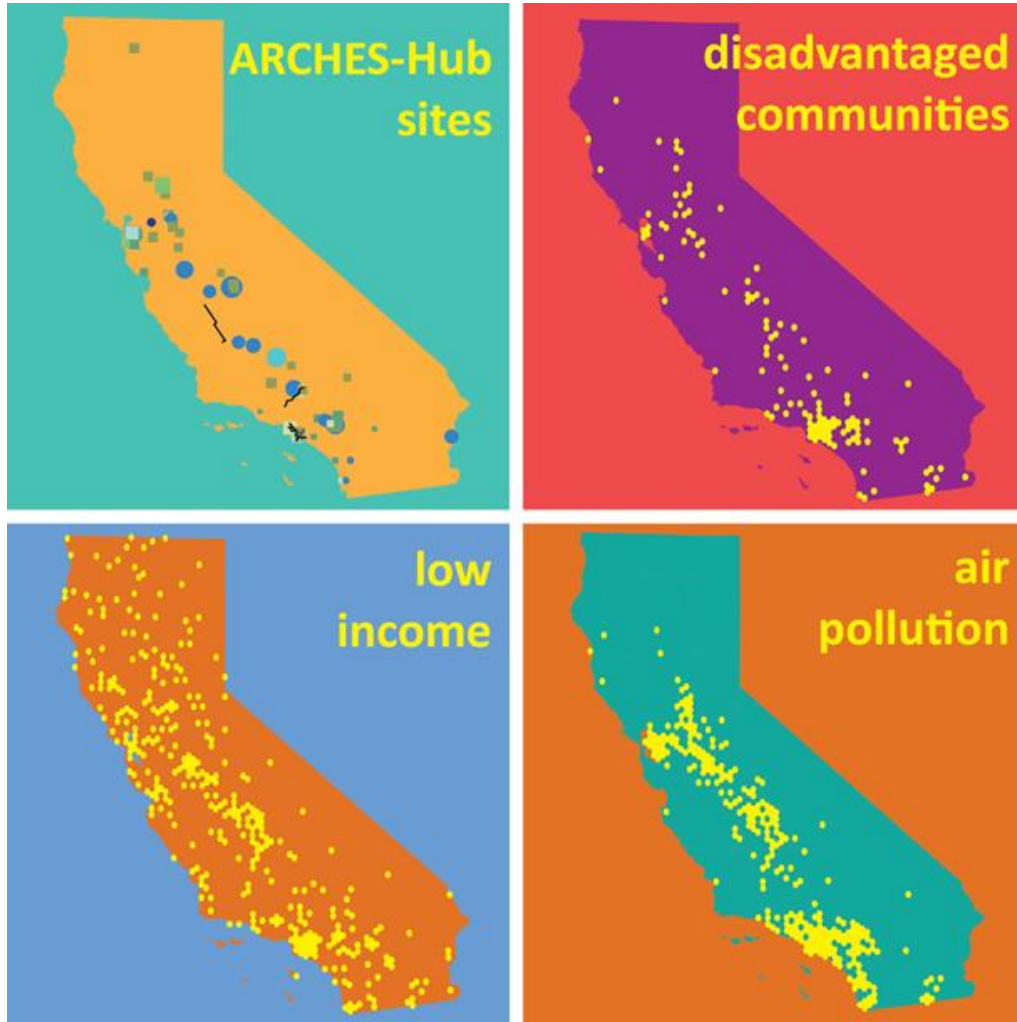


- ▲ **\$2.95 billion**  Economic Value of increased health and associated health costs savings per year\*
- ▲ **222,400**  Number of jobs created
- ▼ **2,097**  Fewer hospitalizations for respiratory & cardiac illness per year
- ▼ **13,292**  Fewer work loss days per year
- ▼ **6,900**  Nitrogen oxide net emissions avoided (MTPY)
- ▼ **239**  Sulfur dioxide net emissions avoided (MTPY)
- ▼ **326**  Particulate matter net emissions avoided (MTPY)
- ▼ **48**  Fewer premature deaths per year
- ▲ **\$380 million**  Invested in community benefits & workforce development

\*Reduced premature death, asthma, cancer, missed work days



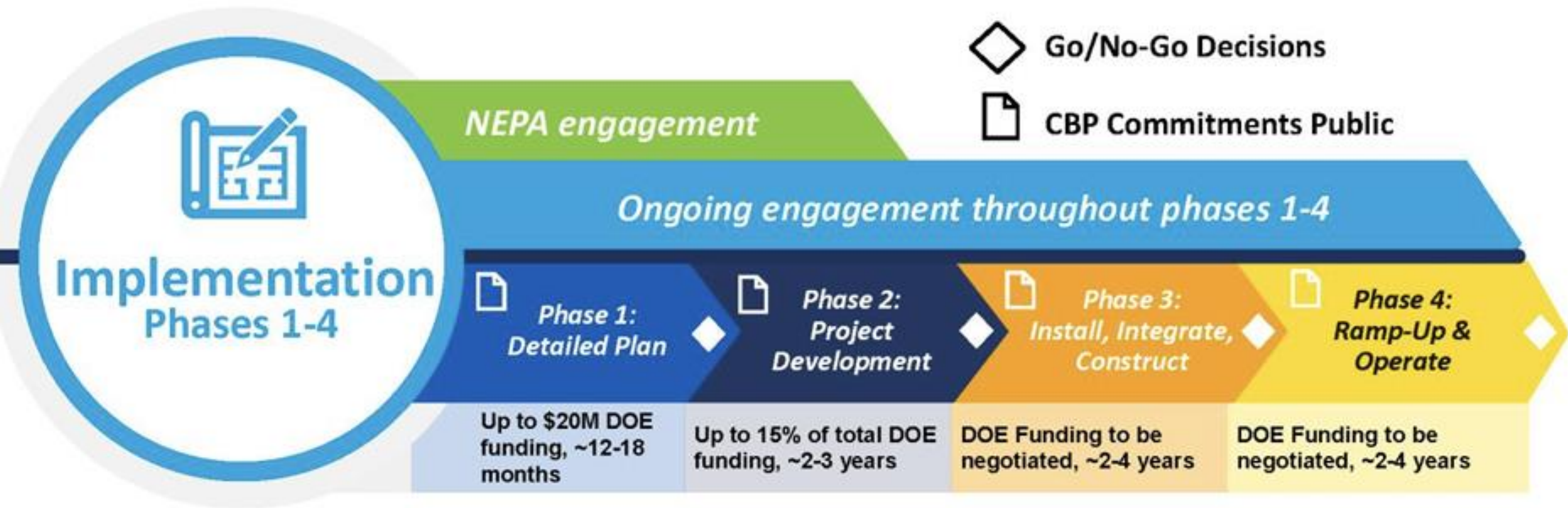
# Community Benefits Pathways Highlights



- **Focus on the most impacted communities**
  - Many touchpoints and opportunities for engagement
- **Chief Community Officer** leading ARCHES CB efforts
  - Hub-level community benefits team with on-the-ground engagement and partnership
- **Community Benefits Auditing Team** for accountability
- **Labor and Workforce**
  - \$229M in workforce development
  - PLAs for all projects
  - Broad educational collaboration: UCs, CSUs, California Community Colleges, and labor training institutes
- **Community Engagement and Support**
  - \$150M in direct community benefits
  - Local CB teams for local engagement and influence



# Project Timeline





# ARCHES Summary

- **ARCHES** is a **public-private partnership** to create a **sustainable renewable, clean hydrogen (H<sub>2</sub>) market and ecosystem** in California and beyond by 2030
  
- **ARCHES** goals encompass
  - Kickstart **commercial viability of H<sub>2</sub>**
    - ❑ Focus on hard-to-decarbonize sectors: **Ports, Power, HD Transportation**
    - ❑ Initiate expansion to: **Heavy Industry, Aviation, Maritime, Agriculture, and others**
  - Ramp production/offtake of renewable, clean H<sub>2</sub> from **30 tonnes per day (TPD)** to **500+ TPD**
  - Produce **measurable benefits** for California communities, with **robust monitoring**, and **strong accountability**
  - Develop a **H<sub>2</sub> workforce** for California, and a **H<sub>2</sub> workforce development model** for the nation
  - **Meet CA and National carbon neutrality goals**