Outlook for electrolytic hydrogen production - insights from systems modeling

CEEPR/EPRG/CERRE/RWE conference

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September 7th, 2023

Renewed interest in H_2 or H_2-derived carriers to enable decarbonization of end-uses where direct electricity use may be challenged

Global hydrogen use in the IEA Net Zero by 2050 emissions scenario

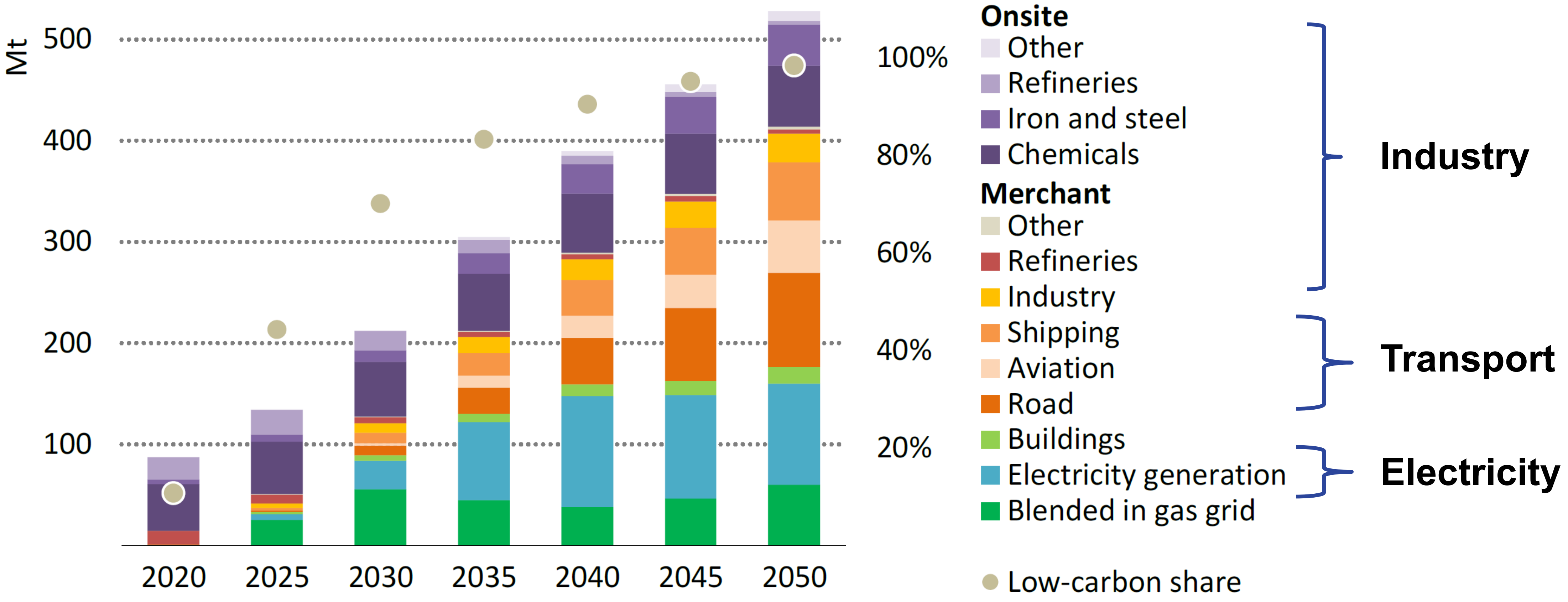
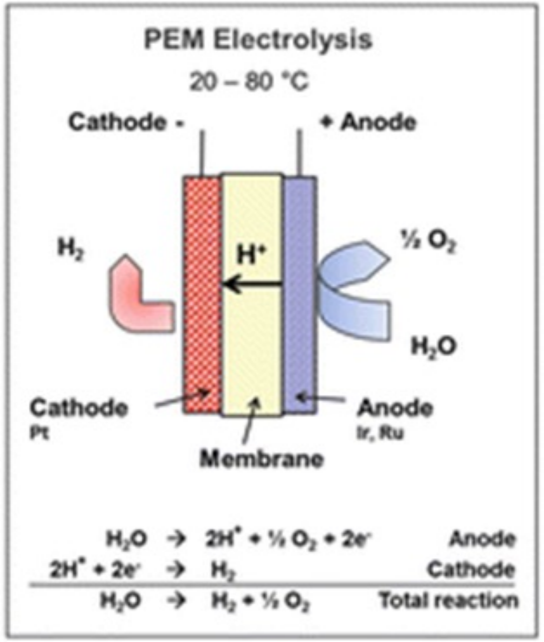


Figure source: Figure 2.19, International Energy Agency, Net Zero by 2050: A Roadmap for the Global Energy Sector, 2020

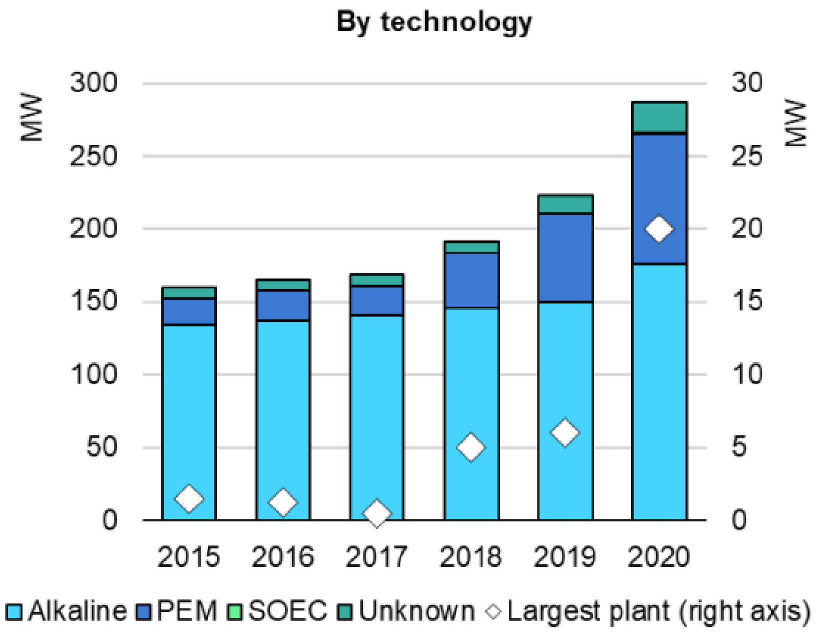
Growing interest in electrolytic H_2 production, with declining costs, policy support, and prospect of increasing renewables penetration in the electric grid

Proton exchange membrane (PEM) electrolyzers

- High current density range vs. alkaline
- Differential pressure operation –high Pressures H_2 product
- Greater operational flexibility
- High Iridium loadings (~1-2 mg/cm²)[2,3]

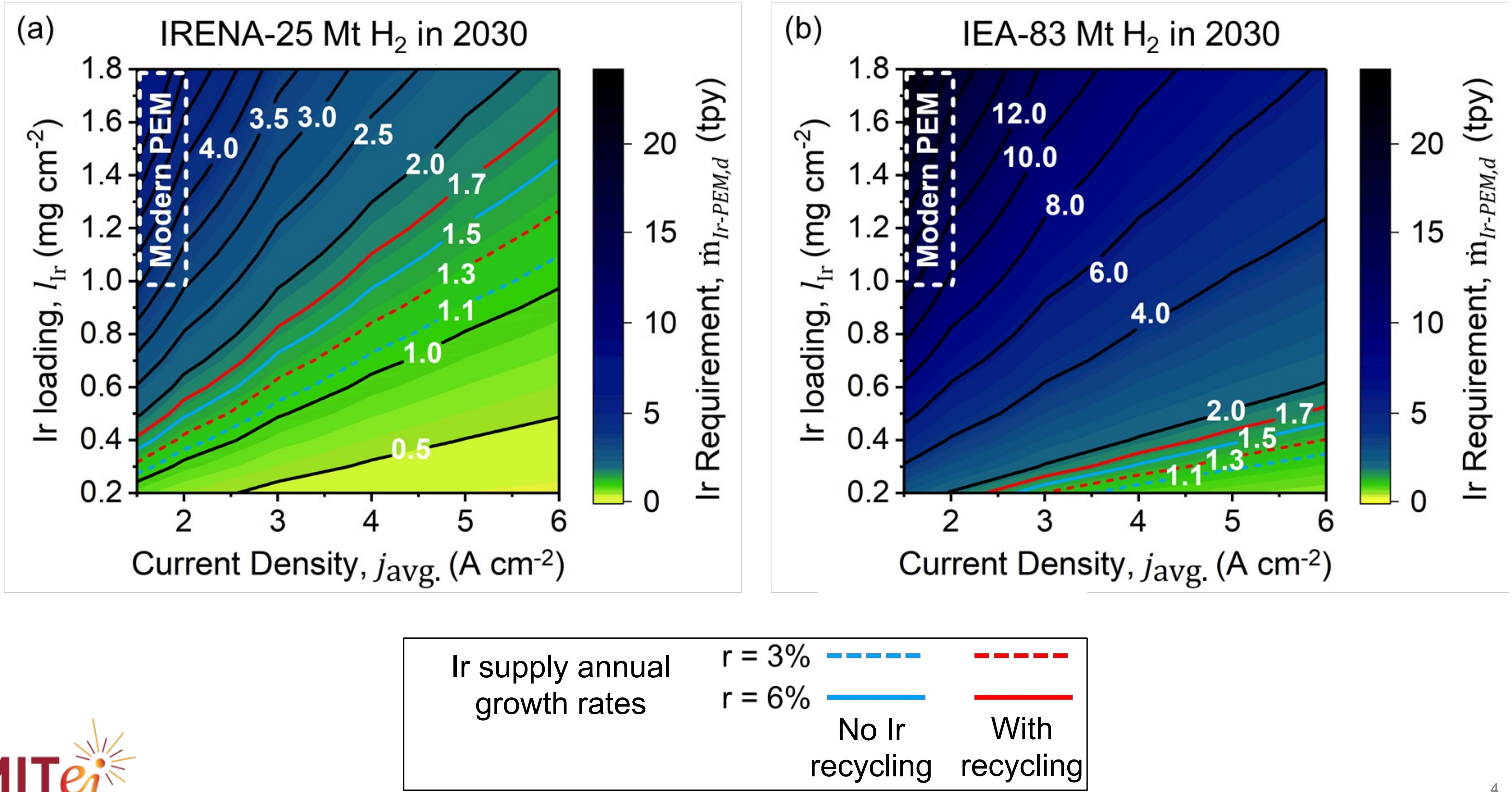


Global installed capacity by technology (2015-2020)[2]



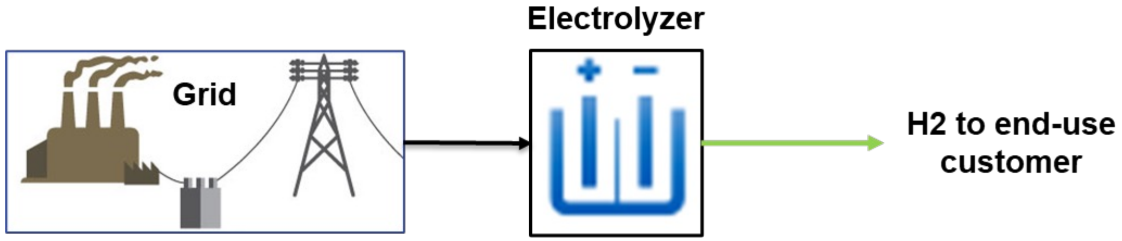
1. Buttler and Spliethoff, Renewable and Sustainable Energy Reviews, 82, 2440-2454, 2018; 2. IEA hydrogen review 2021, 3. Minke et al., International Journal of Hydrogen Energy, Vol 46, 23581-23590, 2021

Significant Technology Improvements Required for PEM electrolysis to meet 2030 H2 production targets



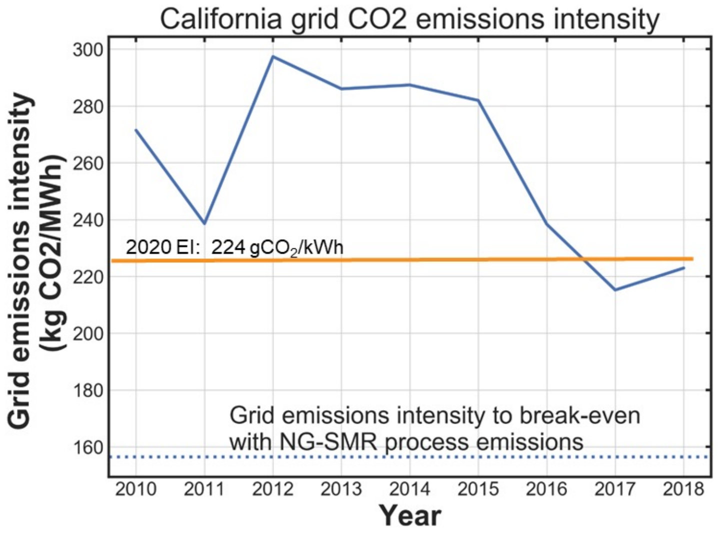
Riedmayer et al, PEM Electrolysis Performance targets for achieving 2050 expansion goals constrained by iridium supply, *Energy Fuels* 2023, 37, 12, 8614–8623

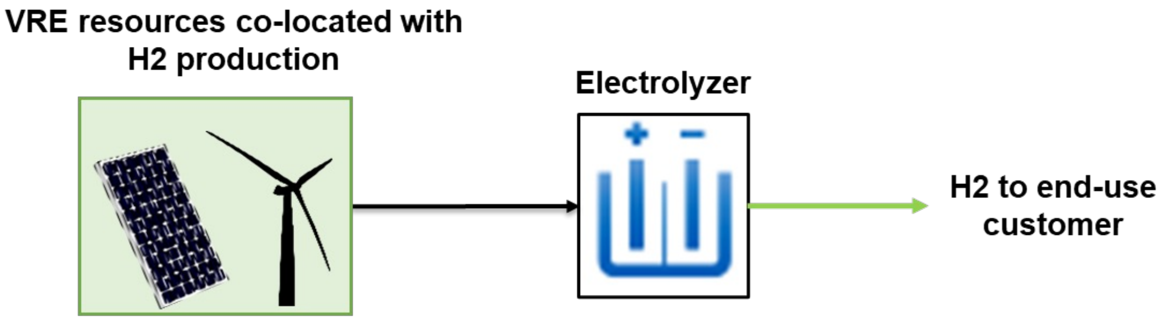
Two bookends for electricity sourcing for electrolytic H_2 production



- More emissions intensive than NG based H_2
- Ineligible for H2 tax credit in U.S

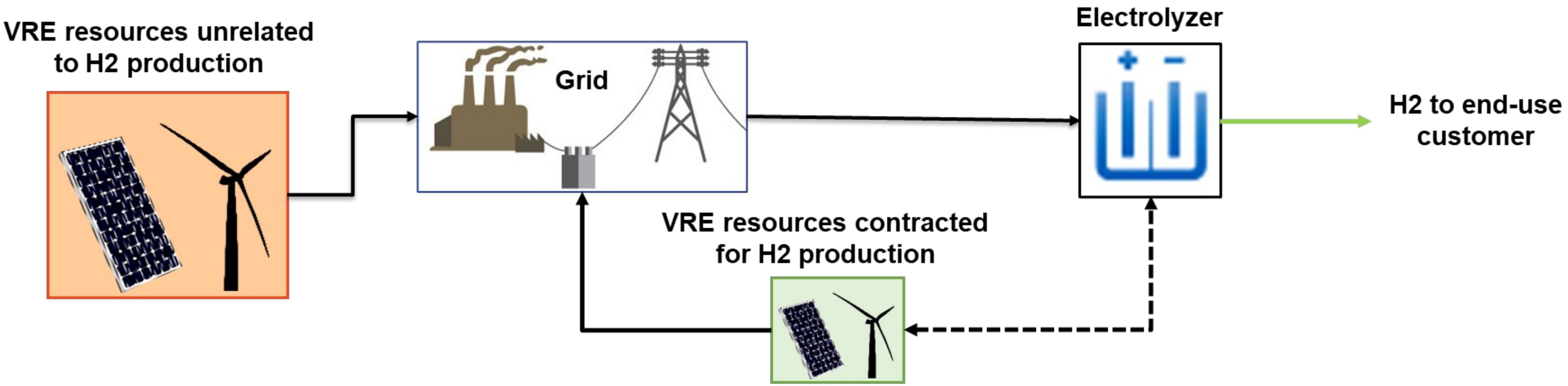
Emissions outlook





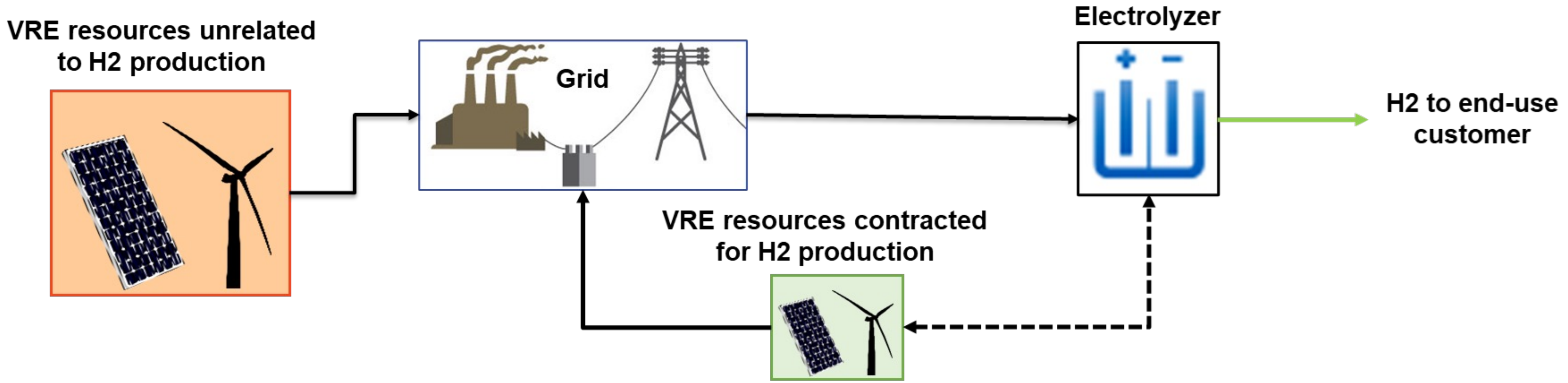
- Trivially qualifies for PTC but may not be practical or cost-effective in many regions

Grid-connected processes that contract low-carbon electricity supply are likely to be the norm – why?



Favorable aspects:
- Locational flexibility for chemical plant and VRE resource
- Improved utilization of contracted renewable asset
- Allow electrolyzer to participate in electricity market

What are the cost and emissions impact of this approach?



System-level factors

- Grid-centric policies
- Electricity demand growth
- Technological evolution

Contract structure

- Additionality definition
- Temporal matching
- Spatial matching

Technological factors

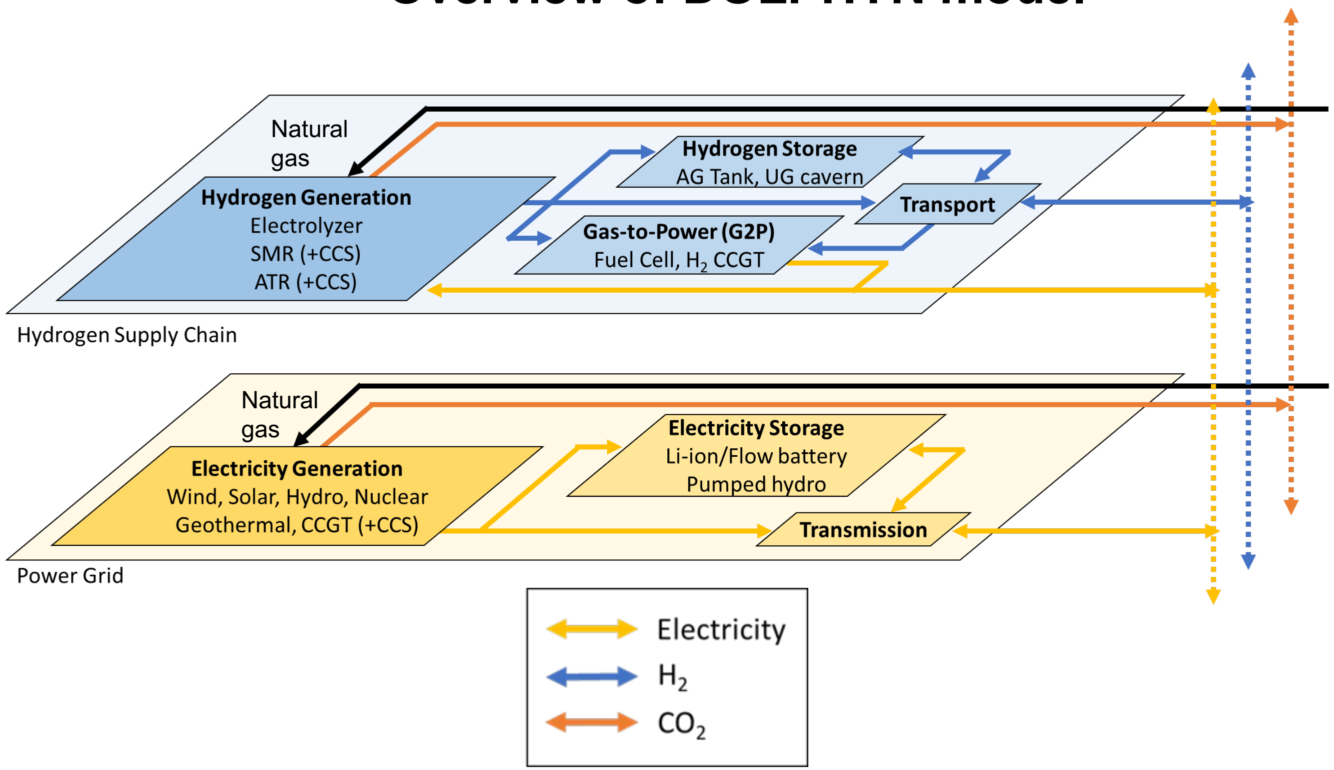
- Process energy use and flexibility characteristics
- Renewables intermittency

Integrated energy systems analysis can inform the emissions and cost of grid-connected electrolyzers under different system, contractual and technology scenarios

DOLPHYN

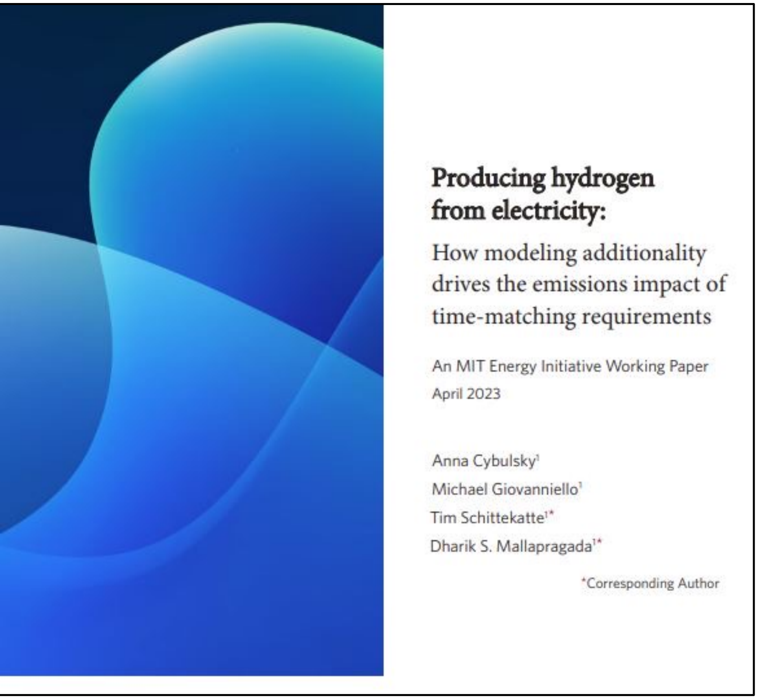
- An Electricity-Hydrogen infrastructure capacity expansion model[1]
- Allows modelling of operational decisions and the portfolio of generation, storage and transmission for electricity and H_2 to meet demand at lowest cost.
- Model can consider operational constraints, resource availability limits, and other environmental, market design, and policy constraints.

Overview of DOLPHYN model



[1] https://github.com/macroenergy/DOLPHYN

The two additionality frameworks: same non-H2 baseline but different H2 counterfactual



Producing hydrogen from electricity:

How modeling additionality drives the emissions impact of time-matching requirements

An MIT Energy Initiative Working Paper
April 2023

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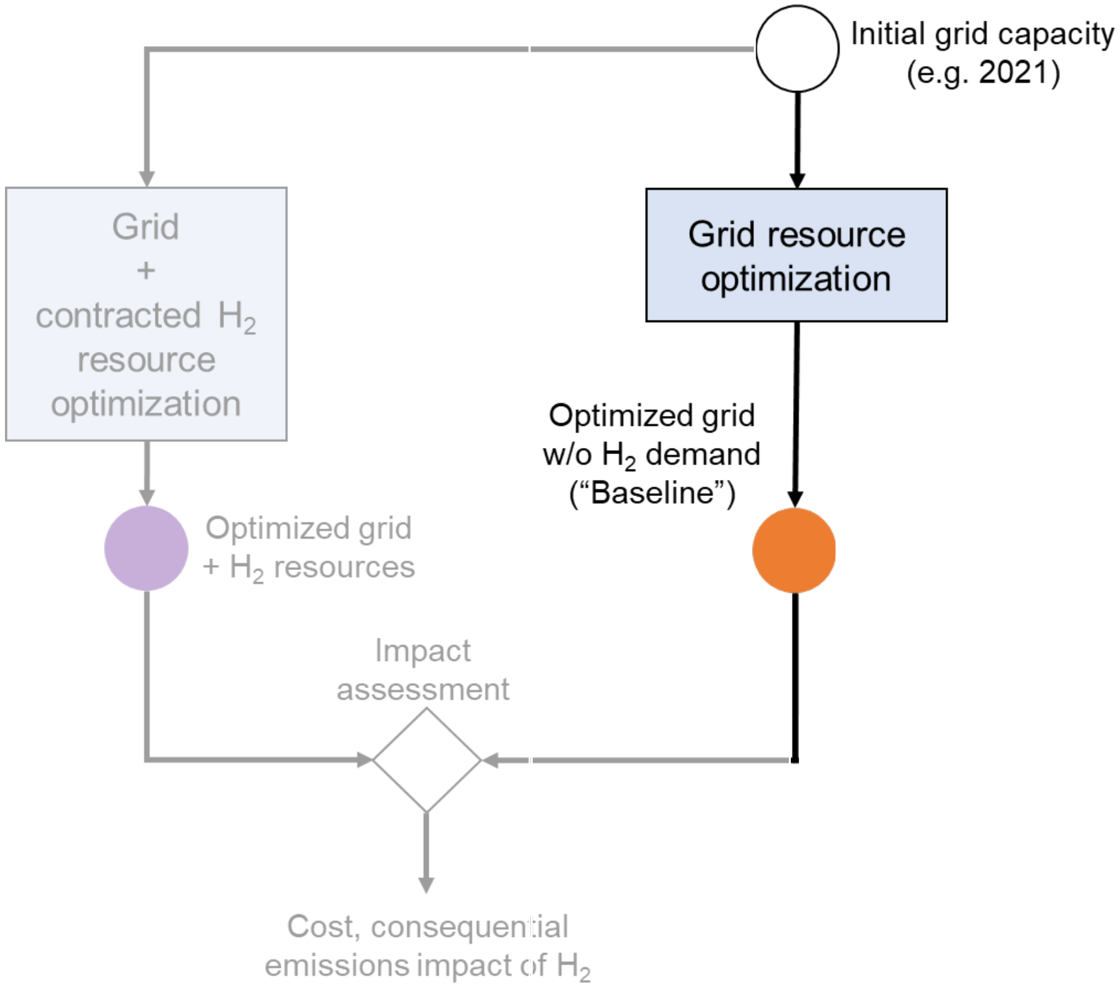
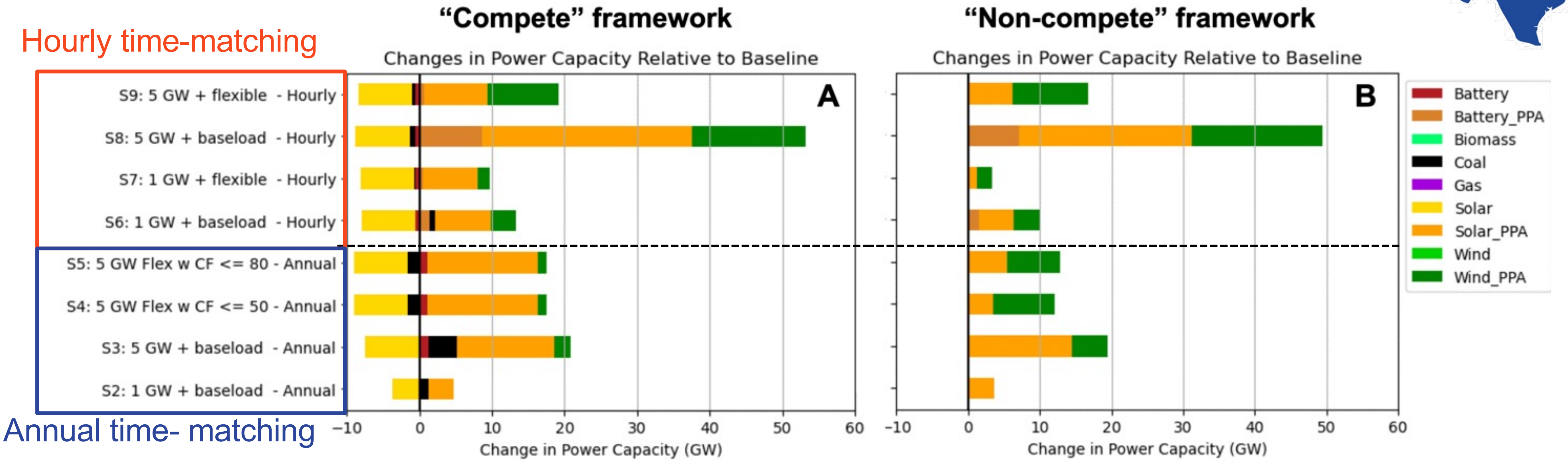
"Compete" additionality definition



Ricks et al. (2023)

Capacity changes due to H2 production - ERCOT case study



- PPA VRE displaces non-PPA VRE in "compete" framework
- More PPA VRE capacity for hourly vs. annual
- Flexibility reduces VRE deployment

Further details in: Cybulsky, Giovanniello, Schittekatte, Mallapragada, Producing hydrogen from electricity: How modeling additionality drives the emissions impact of time-matching requirements , MITEI Working Paper, 2023

Generation impacts of H_2 production under time-matching and additionality requirements

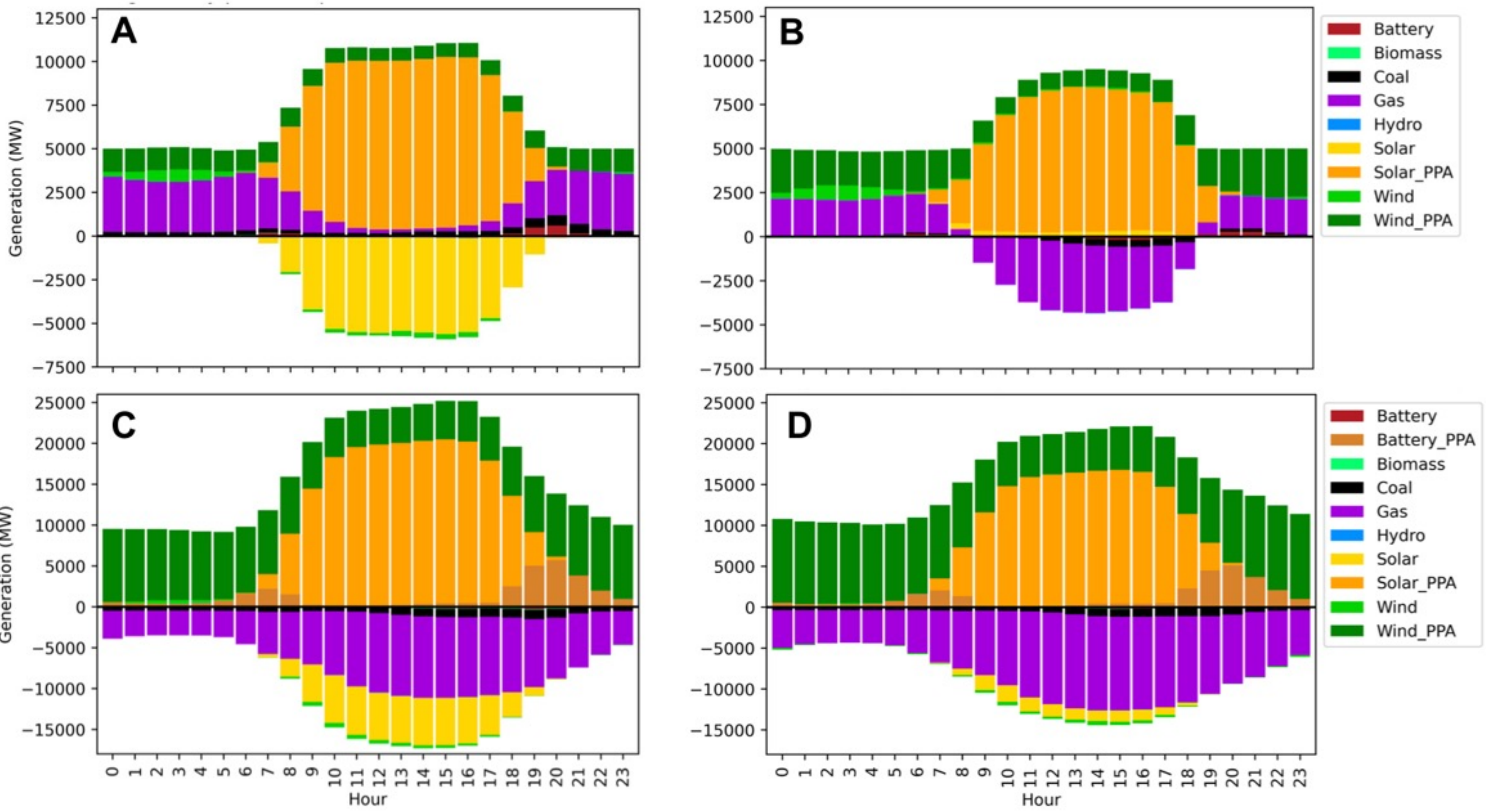
Difference in average hourly dispatch with and without electrolytic H_2 production

Texas grid case study (2030)

"Compete" **"Non-Compete"**

Annual - 5 GW baseload

Hourly - 5GW baseload

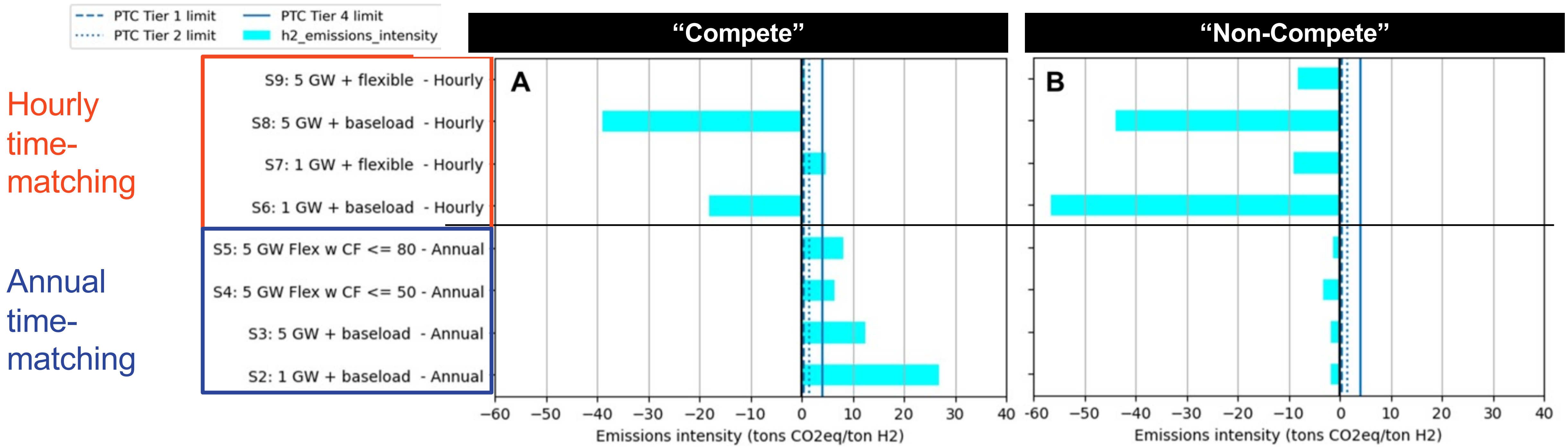


- Additionality definition primarily impacts annual time-matching cases
- "Compete" + annual: net increases in fossil fuel generation
- "Non-compete" + annual: little change in net fossil generation
- Hourly time-matching: PPA VRE generation producing excess electricity at certain times that can earn additional revenues by selling to grid

Further details in: Cybulsky, Giovanniello, Schittekatte, Mallapragada, Producing hydrogen from electricity: How modeling additionality drives the emissions impact of time-matching requirements , MITEI Working Paper, 2023

Additionality framework can alter the emissions impact of H_2 production

Grid-level emissions impacts of H2 production, ton CO_2e / ton H_2 -Texas grid case study (2030)



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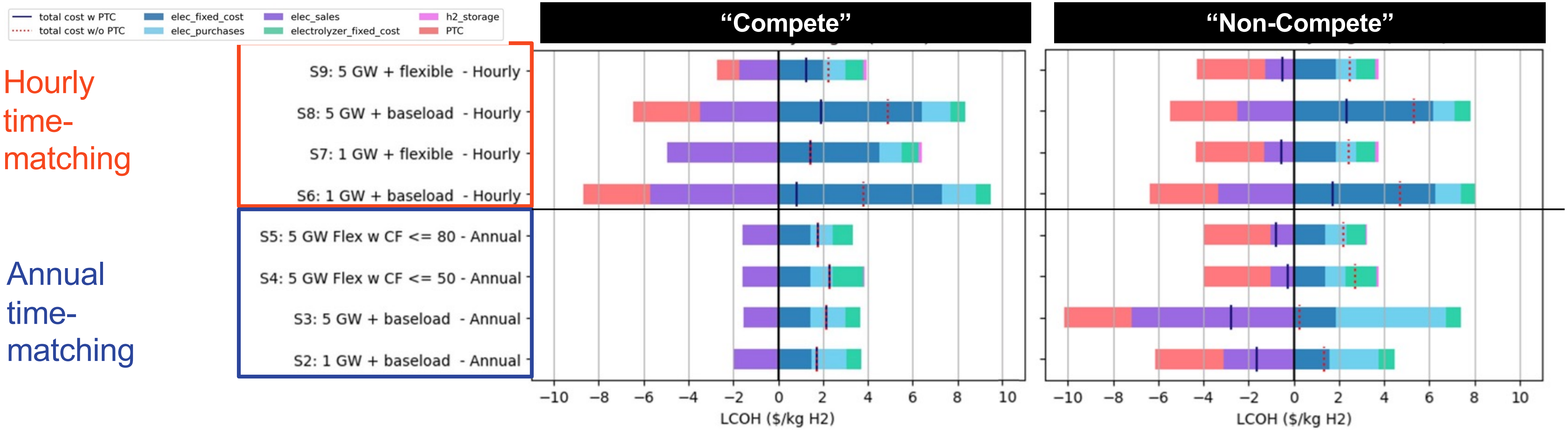
Impact of additionality framework on levelized cost of H_2 (LCOH) production

H_2 costs under different additionality and temporal matching scenarios , *LCOH in \$ / kg H_2*



- LCOH (excluding PTC) typically lower under annual matching;
- LCOH (excluding PTC) generally lower in the "compete" vs the "non-compete" framework
- Flexible electrolyzer operation reduces LCOH

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Further details in: Cybulsky, Giovanniello, Schittekatte, Mallapragada, Producing hydrogen from electricity: How modeling additionality drives the emissions impact of time-matching requirements , MITEI Working Paper, 2023

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How might system-level factors impact these results? Consider the example of VRE capacity deployment limits

What happens if we assume total new renewables capacity is constrained?

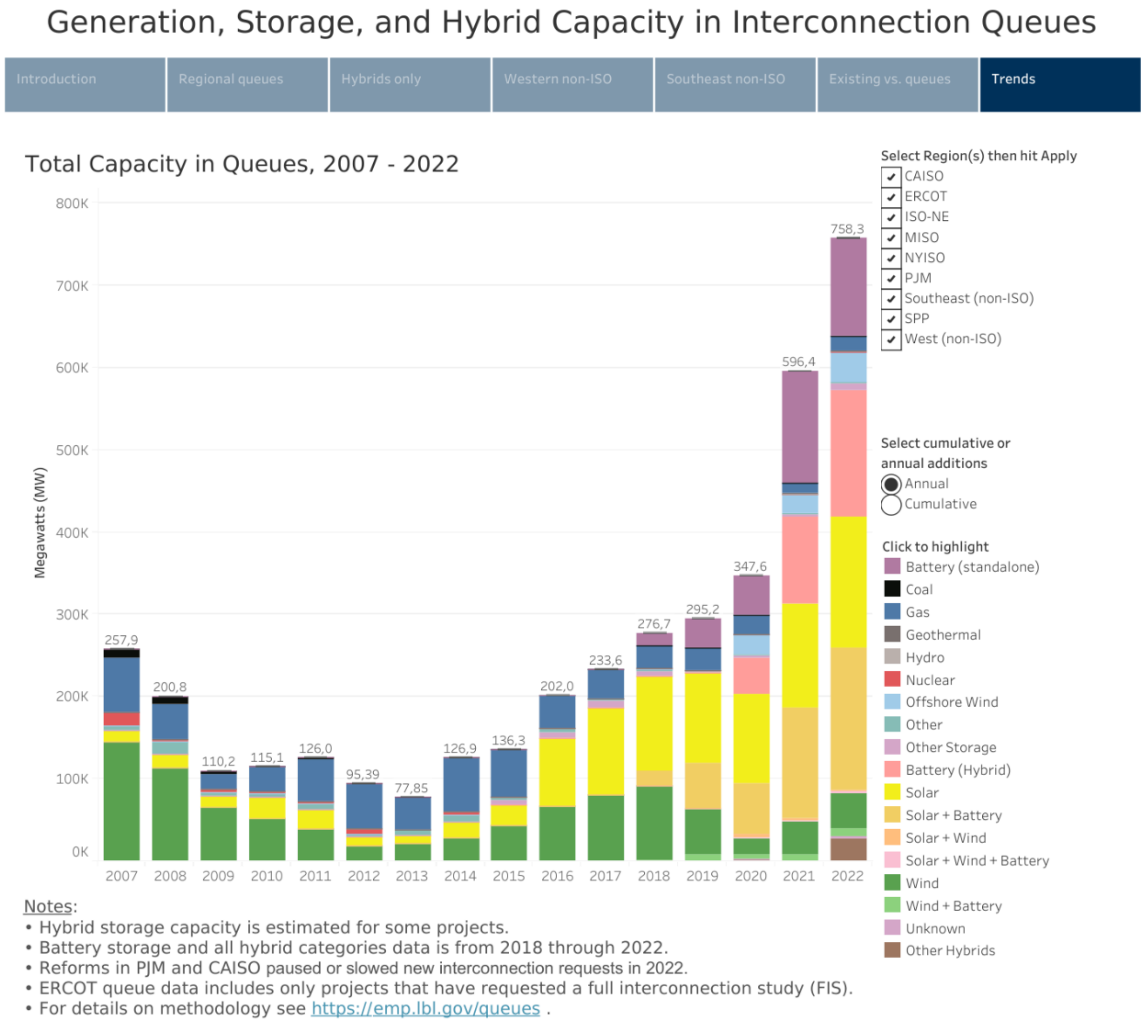
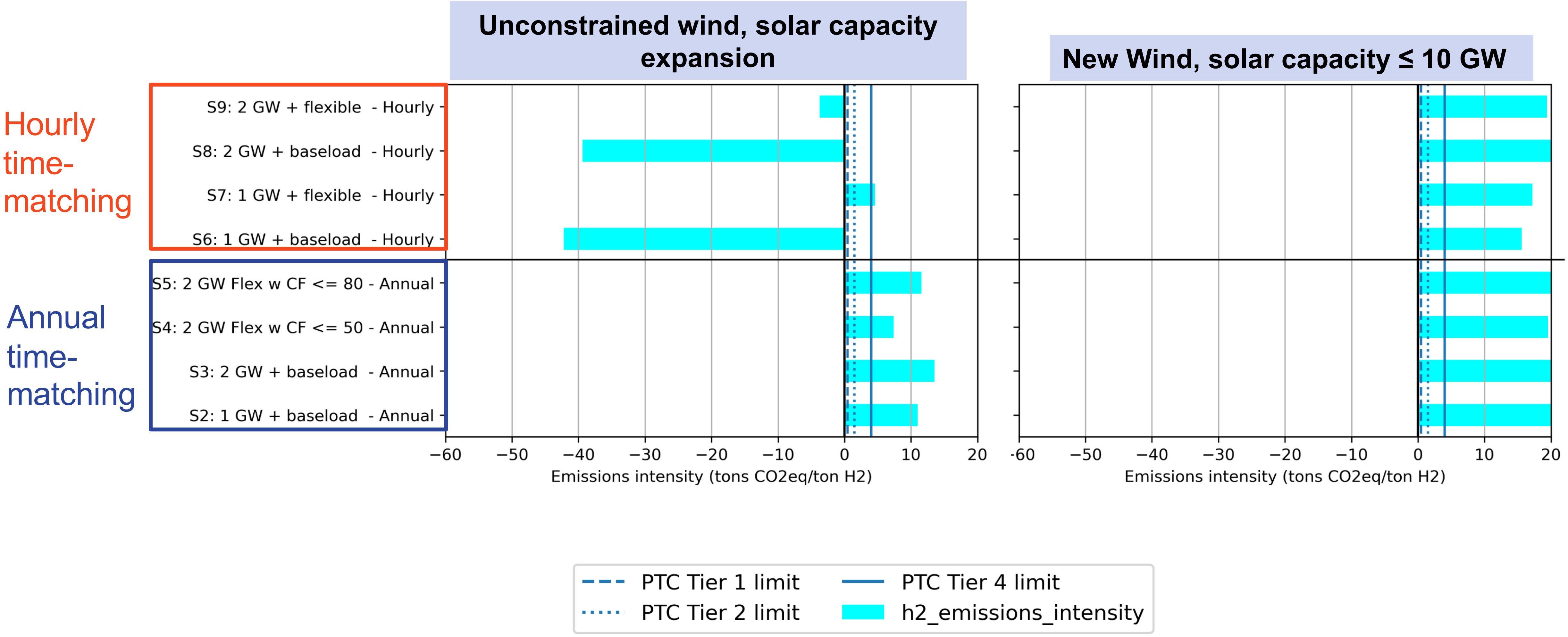


Figure source: Queued up, report, LBNL, 2022

Hourly matching results in positive consequential emissions when renewables deployment is constrained (“Compete” framework)



Preliminary results, do not cite or distribute

How do various policies impact emissions and costs of grid-connected electrolyzers? View from the “Compete” world

	Time-matching requirement	Emissions impact	LCOH impact
Limiting annual electrolyzer capacity factor	Annual matching	↓	↑
Minimum annual renewable generation requirement		↓	↑

Preliminary results, do not cite, quote or distribute

Summary and recommendations

Emissions from producing electrolytic H_2 under annual time-matching are conditional upon how additionality requirement is modeled AND also affected by other system and technology specific policy factors

- ΔVRE for H2 production << ΔVRE for grid decarbonization → "Non-compete" world
- Post-2030 volumes of electrolytic H2 are expected to boom and we might enter a "compete" world
- Pragmatic to allow a phased approach,
  - **Short-term:** Start with annual time-matching requirements to qualify as "clean hydrogen"
  - **Medium term:** Shift to more stringent time matching (e.g. hourly) in 2030s as volume of electrolytic H2 is expected to boom and grid is still fossil fuel dominant
  - **Long term:** As grid substantially decarbonizes, stringent time-matching requirements (e.g. hourly) may not be necessary

Questions?