NREL
Transforming ENERGY

Hydrogen Infrastructure and Storage Considerations for Iron/Steel

Steve Hammond, Elenya Grant, Jen King
and “green steel” team

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Outline

1 Iron / Steel 101

2 Hydrogen Production

3 Industry End Use

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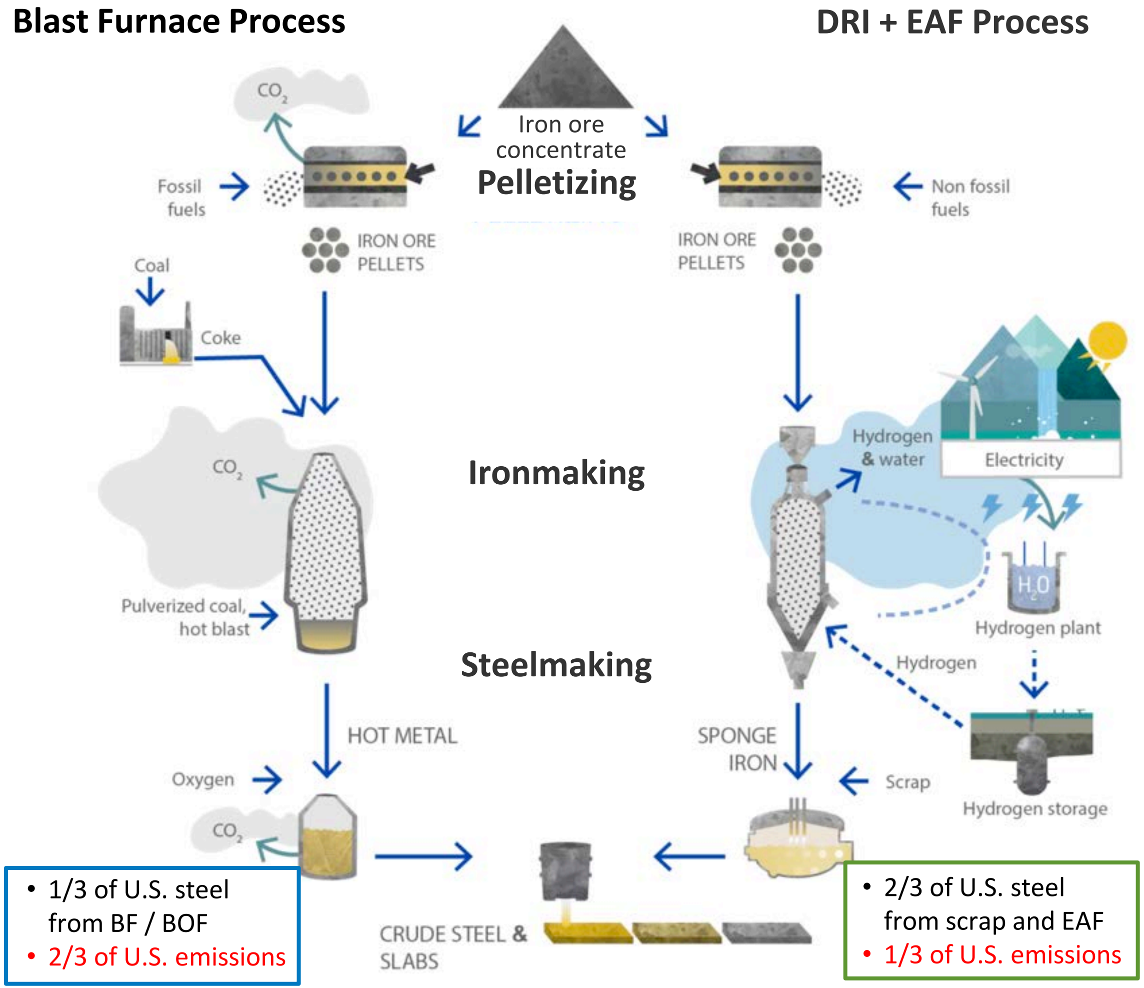
Iron and Steel 101

Today: 2 Routes for U.S. Steel Production:

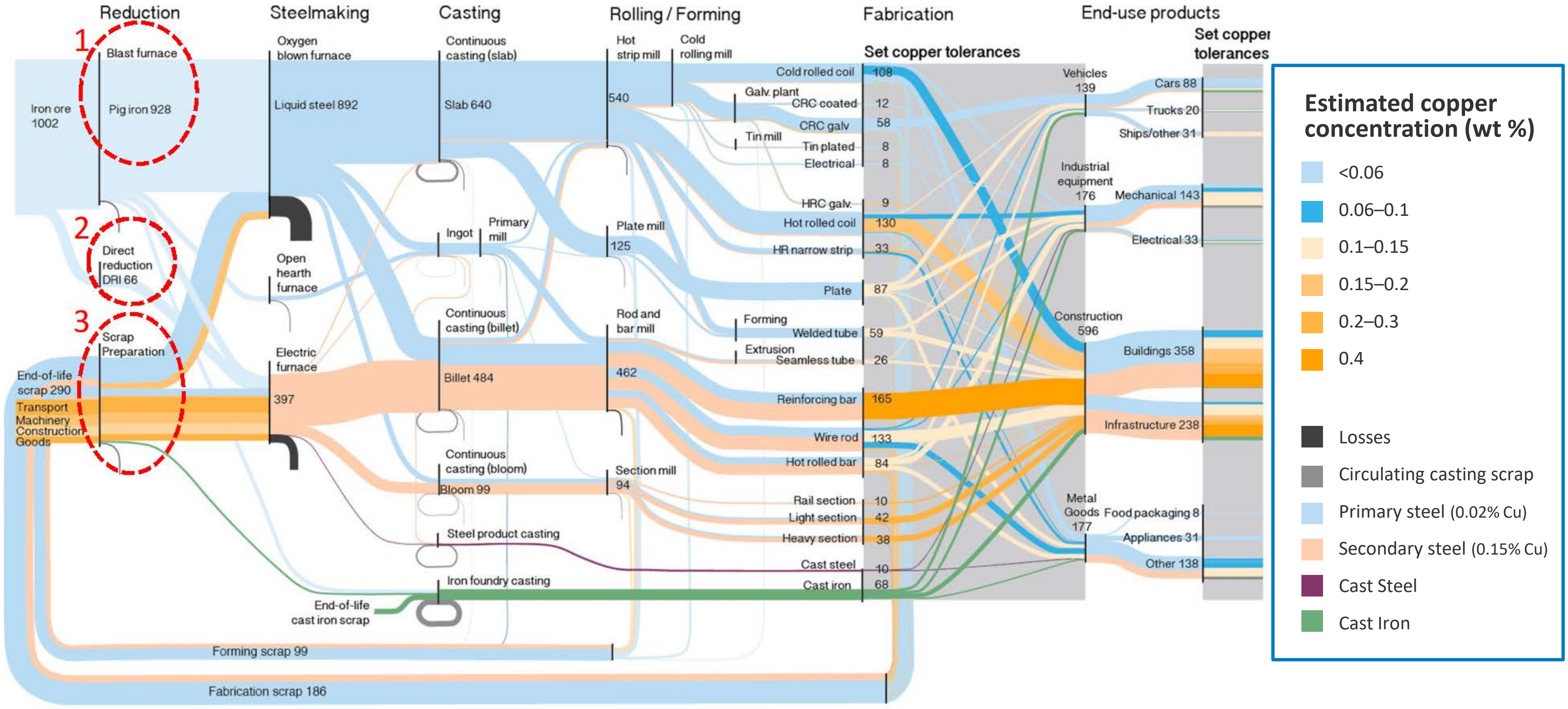
- Blast Furnace (BF) and
- Electric Arc Furnace (EAF)

Challenge: Develop cost competitive, zero emission technologies and infrastructure appropriate for U.S. feedstocks and full spectrum of steel end use products.



- 1/3 of U.S. steel from BF / BOF
- 2/3 of U.S. emissions

- 2/3 of U.S. steel from scrap and EAF
- 1/3 of U.S. emissions



High-Level View of Iron/Steel

1. Develop alternatives to the ~30 U.S. Blast Furnaces
2. Scale up the use of Direct Reduction, using H2 rather than methane.
3. Improve approach to scrap preparation to remove impurities (mostly copper).

Big Picture: Water, Electricity, H2, and Iron

- It takes about **9L of DI water** and **55kWh of electricity** to produce **1 kg of H2 in a PEM electrolyzer**.
- It takes about **80-120kg of H2** to produce **1 tonne of metallic iron** from iron ore.

To replace one blast furnace that produces 1M Tonne metallic iron per year, it takes:

- About 80,000 – 120,000 tonnes of H2 per year,
- 4,400,000,000 to 6,600,000,000 kWh electricity (about 1 GW), and
- 720,000,000L to 1,080,000,000L DI water (about 2,000 acre-feet)

*Iron/Steel production is a "**steady-state**" industrial process, 7x24x365.*

Pipelines and storage provide **essential infrastructure** to get H2 to where it is used and buffer between variable generation and steady state end use.

* Note that the numbers here are not exact, +/- 10%, meant to give a sense of scale

H2 and Iron

The DOE Industrial Decarbonization Roadmap discusses the important role H2 plays in decarbonizing iron and steel.

The Roadmap is largely silent on the critical role that H2 storage plays.

Using H2 for iron ore reduction, economic viability is reached at an H2 procurement cost of $1.70 per kg, while achieving a CO2 emission reduction of 76% at the plant site*.

To account for lower quality U.S. iron ores, increased energy for beneficiation, and reduced EAF yields, getting the LCOH *delivered* closer to $1/kg will be needed to spur industry change and rapid adoption of low/no carbon processes using clean H2.

* Rosner, Papadias, Brooks, Yoro, Ahluwalia, Autrey, and Breunig, "Green steel: design and cost analysis of hydrogen-based direct iron reduction" ChemRxiv, March 2023.

"Green Steel" Project Overview

Funded by HFTO/WETO
NREL (lead) + ANL, LBNL, ORNL, & SNL

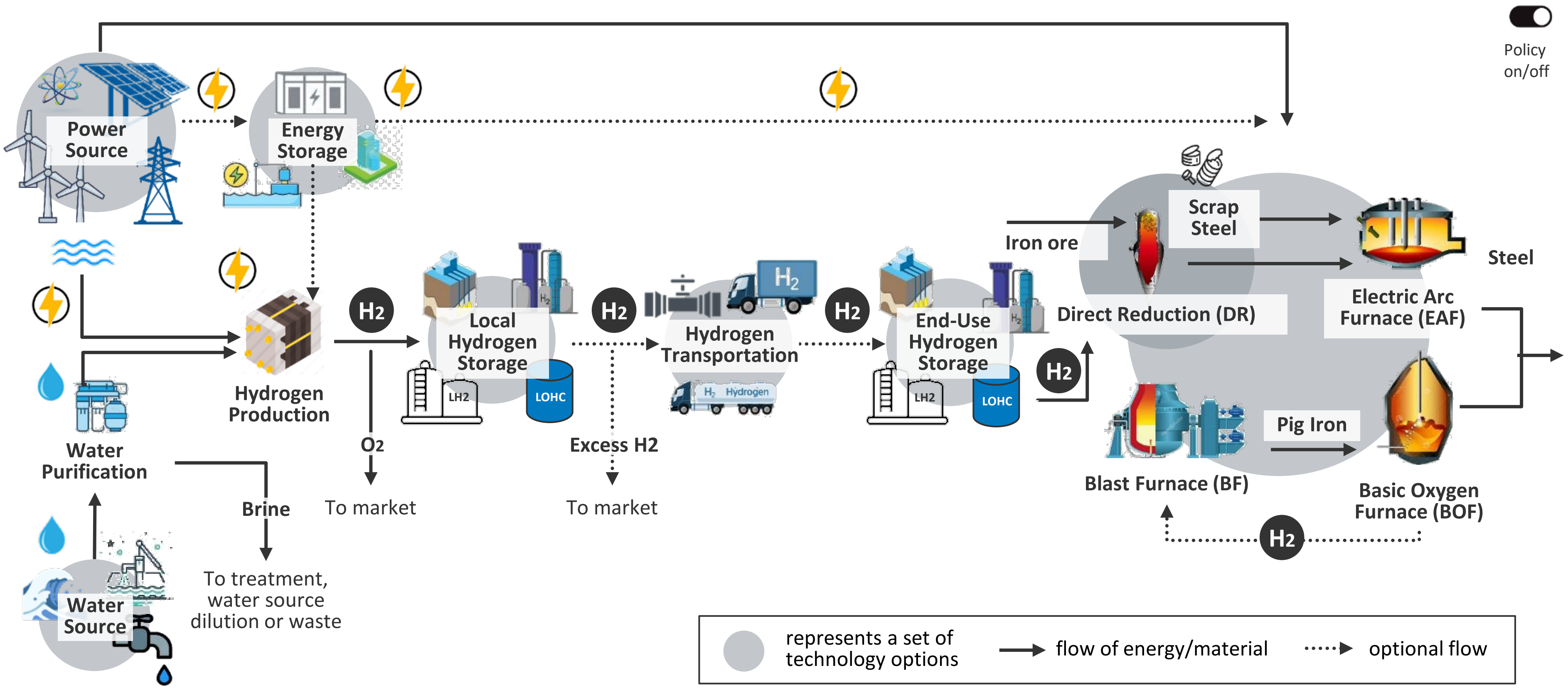
Vision:

Develop a national roadmap and reference designs for purpose-built, <u>off-grid</u>, **GW-scale** hybrid energy system, tightly-coupled w/ green H_2 production, co-located with industry end uses, that can accelerate the path to decarbonization.

Novelty and Advantages:

- Optimized LCOH delivered for the specific end use,
- Holistic approach, increased efficiency, & reduced capital costs,
- Independence from natural gas price volatility, grid connection permits and new large-scale transmission build outs.

Off-grid hybrid energy system H2 production is important as it will take full advantage of IRA 45V $3/kg Clean Hydrogen Production Tax Credit.



GreenHEART models full Integrated System

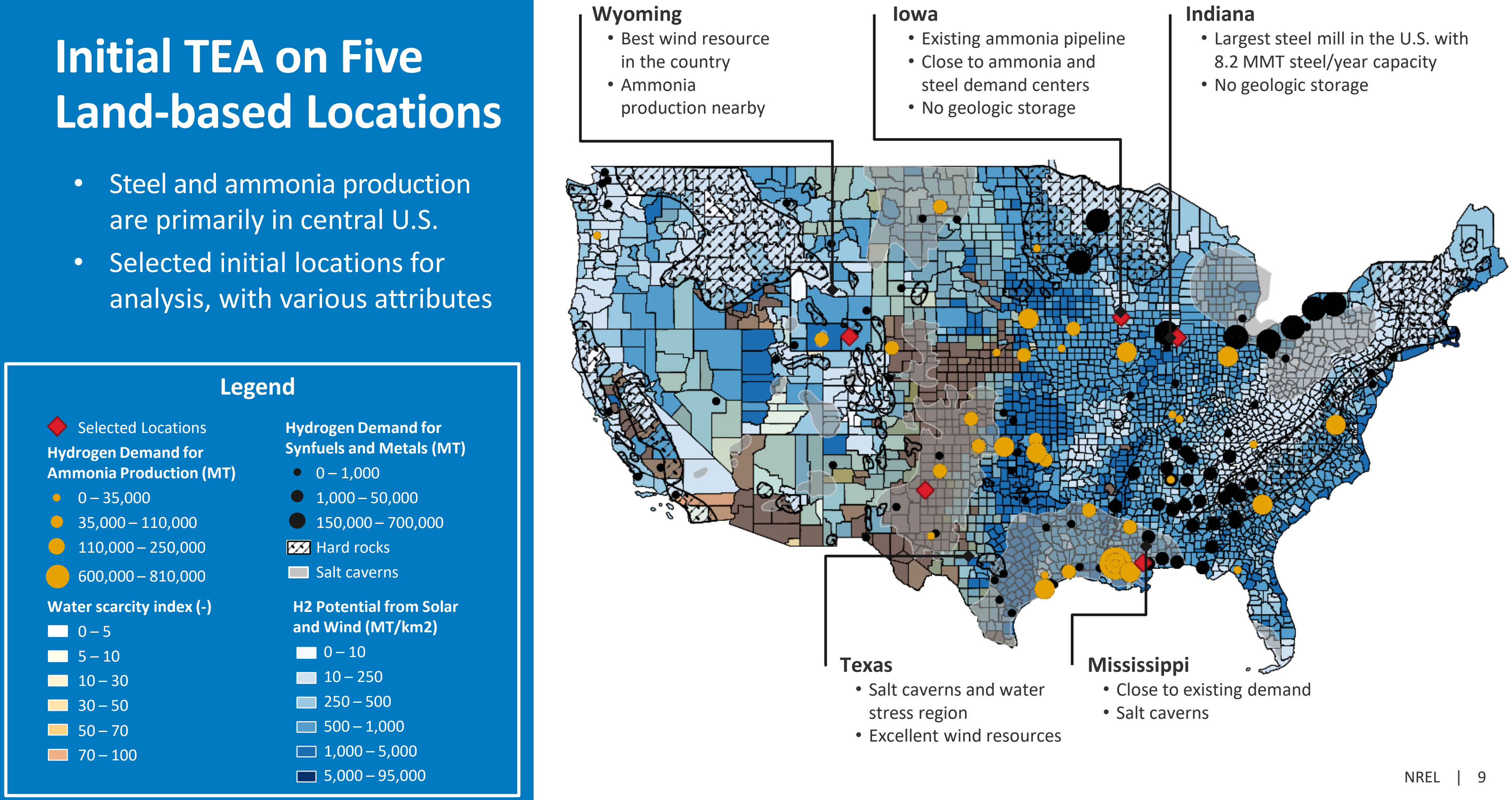
Renewables to H2 to Storage to Steel

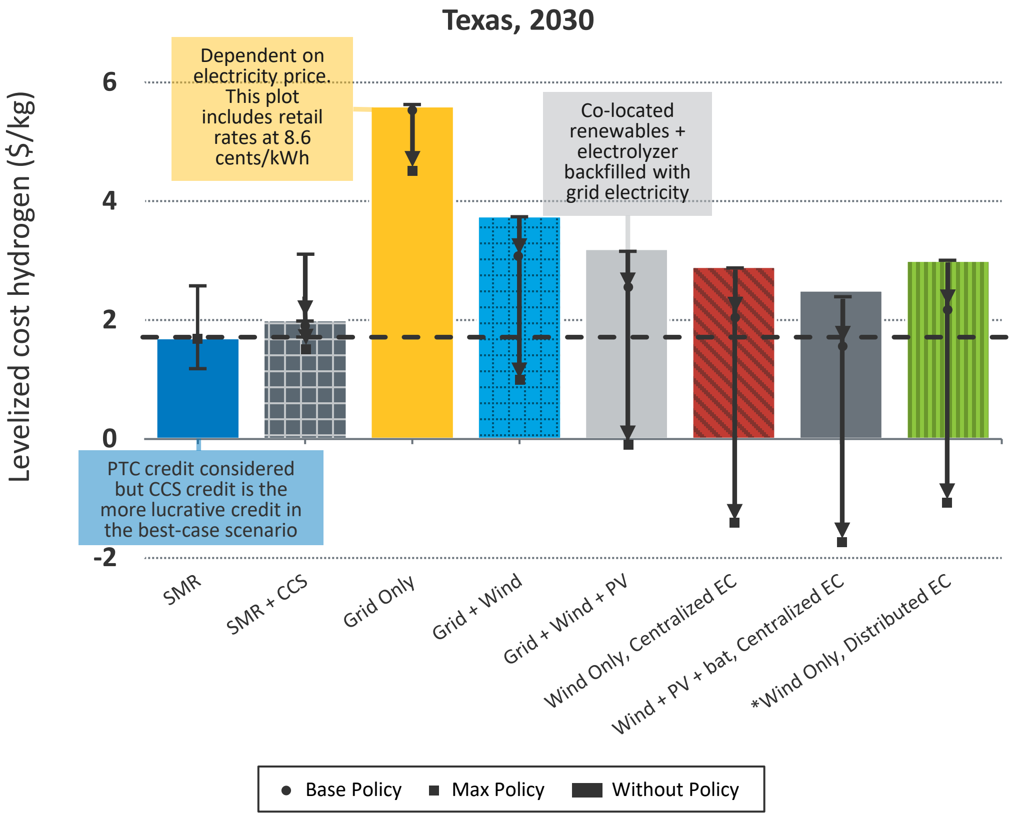
END-USE:

- Ancillary equipment not depicted
- One icon on the diagram does not reflect the number of technologies which are required for the actual process flowsheet

Initial TEA on Five Land-based Locations

- Steel and ammonia production are primarily in central U.S.
- Selected initial locations for analysis, with various attributes





Off-grid costs less than on-grid:

- Reduced electricity costs (retail vs. dedicated PPA results in decrease)
- Dynamic operation of H2 allowed (and accounted for in increased replacement costs)
- Low-cost hydrogen storage (salt caverns)

*Made conservative assumptions.

*Distributed includes electrical efficiency gains ~4%

*Potential conversion efficiencies are not included

Key Insight: With max policy, all locations compete with SMR

Notes:

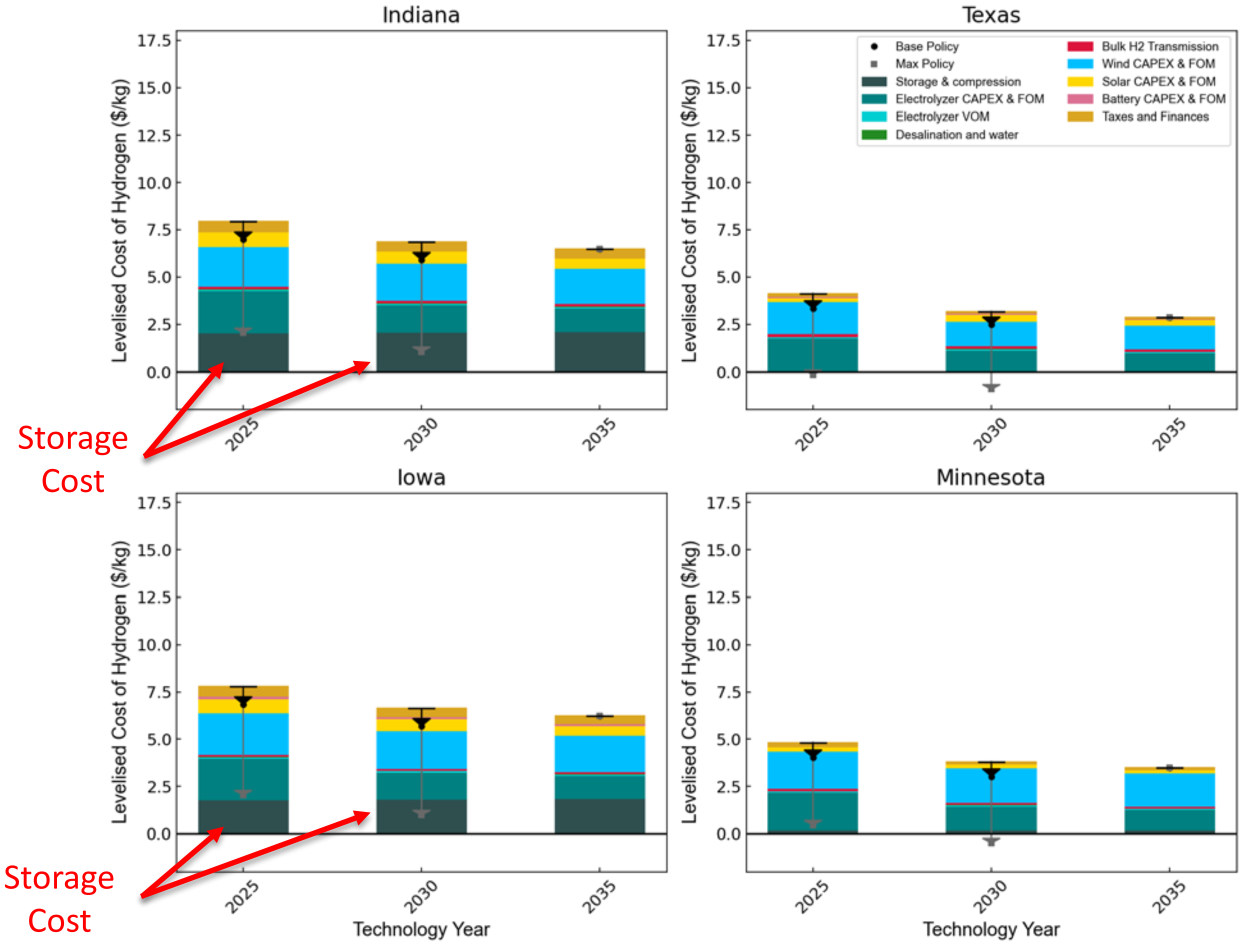
- Technology year (TY) 2030 corresponds to operational year 2035
- CCS credit considered for over 12 years
- H2/wind PTC applied over 10 years
- Model does not account for RECs

LCOE for TX 2030

- Off-grid: 1.3 cents/kWh with PTC
- On-grid: 8.6 cents/kWh (retail rates), 4.1 cents/kWh (wholesale rates)

Delivered LCOH in Best Location Analyzed: Texas, TY 2030

Delivered LCOH, Four Locations (wind+PV+battery)



Notes:

- Off-grid Hybrid Energy System – Wind+PV+battery
- Technology year (TY) 2030 corresponds to operational year 2035
- Built in 50Km Bulk Transmission
- IN and IA, use buried pipe.
- MN, rock formation.
- TX, salt cavern.

Key Insights

IRA policy is a game changer for H2 production.

- Behind the meter, integrated H2 systems qualify for the full clean 45V H_2 \$3/kg credit.
- H2 storage cost is the linchpin to industrial decarbonization of iron/steel.

H2 storage plays the key role to buffer between low-cost, clean H2 production from renewables and steady state industrial end uses (iron/steel, e-fuels, etc.)

Renewable resource and industry end use drive required H_2 storage capacity.

Current bulk H2 storage costs range between ~\$0.02/kg (salt caverns in TX) and ~\$2.93/kg (PVS in IA).

Low-cost, bulk H2 storage technologies that are ~4x salt caverns is needed for regions of the U.S. that don't have access to geological storage.

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Open Discussion

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