Louisiana's Hydrogen Economy: From Pipe Dreams to Pipelines

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Pipe Dream

THE PRIMARY TECHNICAL INCENTIVE BEHIND THE DEVELOPING HYDROGEN (H2) ECONOMY

No Carbon In---No Carbon Out

$$2H_2 \text{ (gas)} + O_2 \text{ (gas)} \rightarrow 2H_2O \text{ (gas)} + \text{energy}$$

CURRENT H2 PRODUCTION AMOUNTS

LIKELY WILL NEED ~500 MMT GLOBALLY BY 2050 – AND MAKE THAT BLUE OR GREEN

UNITED STATES

10 MmT ANNUALLY

PRODUCTION METHOD

95% Steam Methane Reforming (SMR)
4% COAL GASIFICATION
1% ELECTROLYZER

GLOBAL

80 MmT ANNUALLY

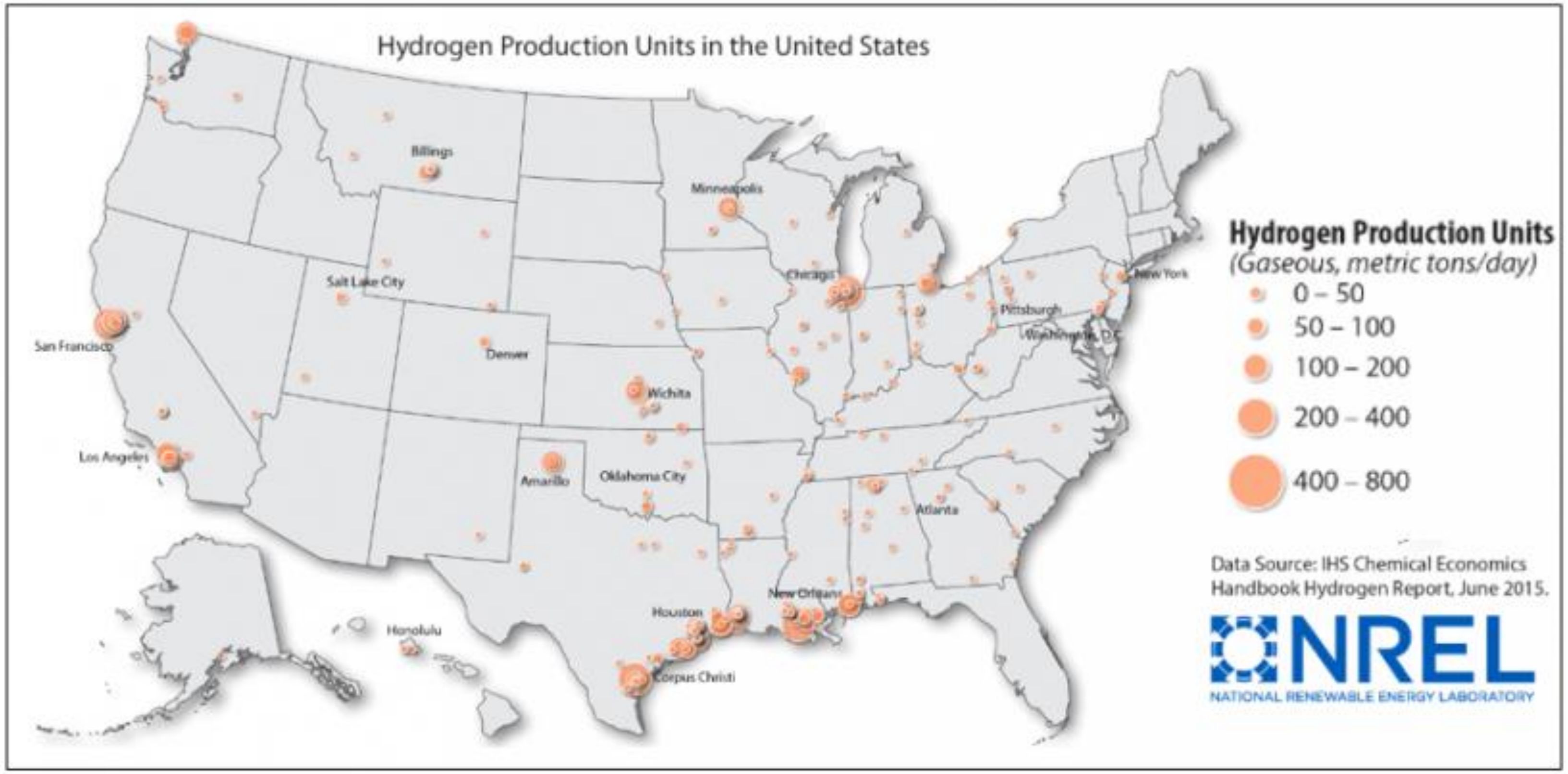
PRODUCTION METHOD

76% SMR
22% COAL GASIFICATION
2% ELECTROLYZER

CH_4 or COAL or OIL

H2

SMR = STEAM METHANE REFORMING PROCESS



Hydrogen Production Units in the United States

Data Source: IHS Chemical Economics Handbook Hydrogen Report, June 2015.

U.S. annual hydrogen production

10 million metric tons

Largest Users in the U.S.

Petroleum Processing	**68%**	**Fertilizer Production**	**21%**

The major hydrogen-producing US states are (mainly as SMR-H2):

✓ California

✓ Louisiana

✓ Texas

CURRENT HYDROGEN USES IN THE LOUISIANA (USA):

- ☐ **Refining Petroleum** - Huge activity in Louisiana
- ☐ **Producing Fertilizer** – Significant activity in Louisiana
- ☐ **Processing Foods** – Moderate H2 activity in Louisiana
- ☐ **Treating Metals** – Small activity in Louisiana

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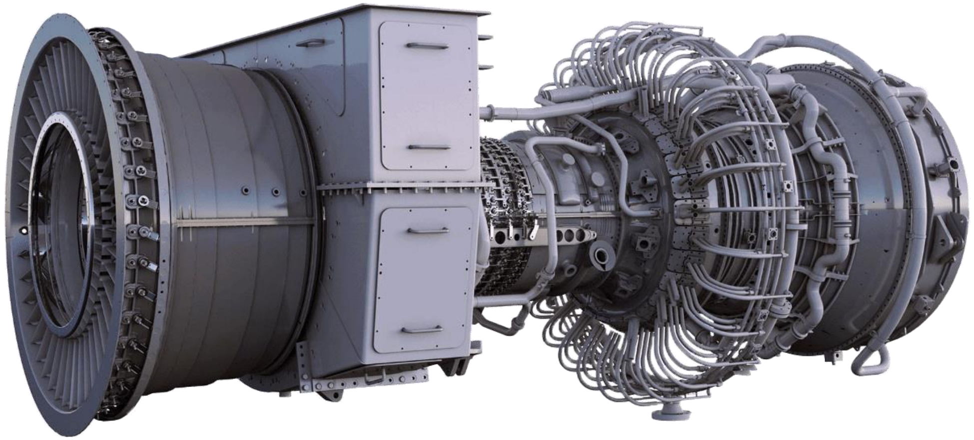
POTENTIAL H2 USE EXAMPLE GROWTH AREAS

HYDROGEN BURING POWER PLANT



HYDROGEN BURING POWER TURBINE

Power Generation

FUTURE USES OF HYDROGEN

Transportation

FLEET SERVICE - FUEL CELL BUS

FLEET SERVICE - FUEL CELL TRUCK

H_2

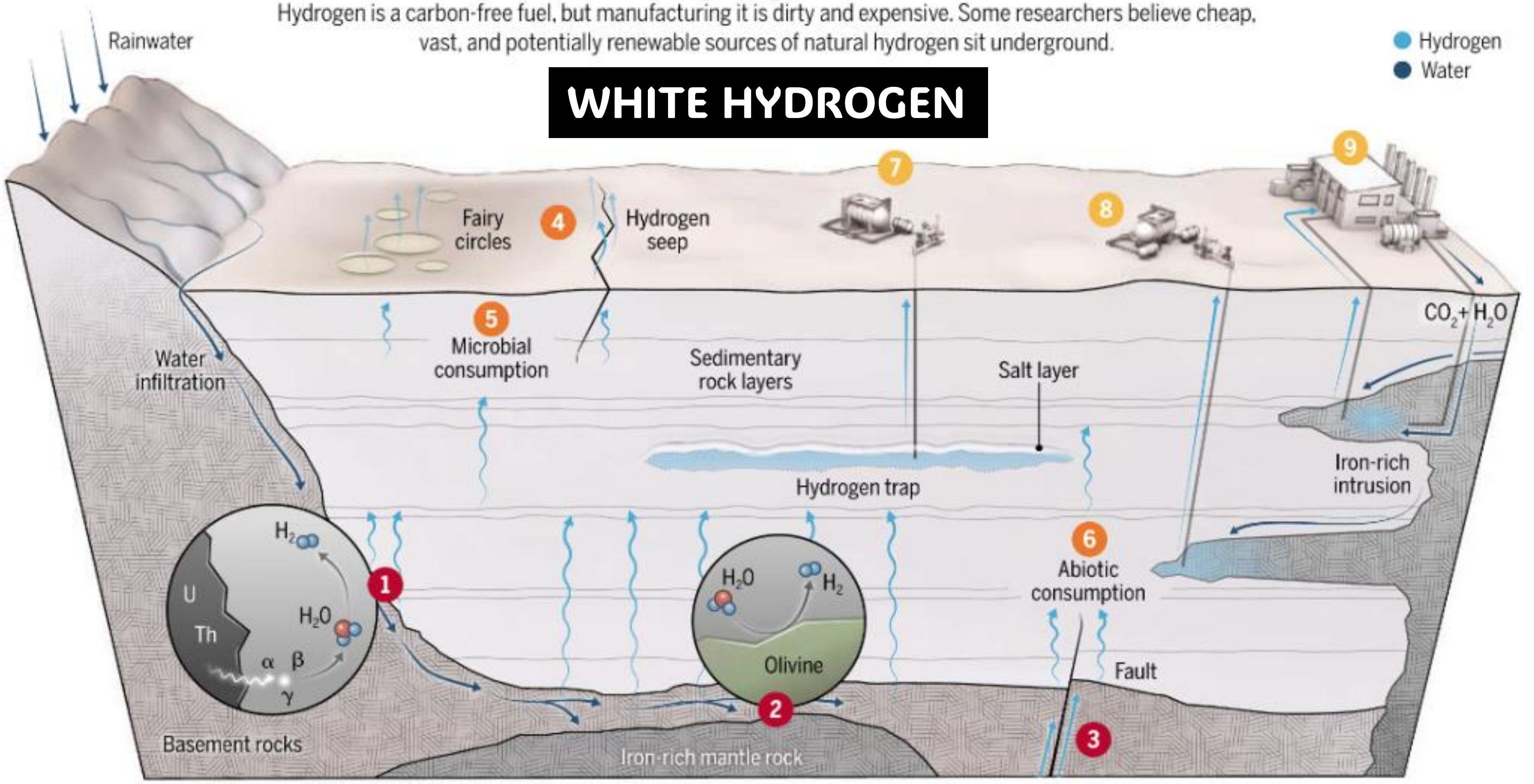
MAKING H2

BLACK		PRODUCED FROM BLACK COAL VIA GASIFICATION
BROWN		PRODUCED FROM BROWN COAL VIA GASIFICATION
GREY	MOST POPULAR	PRODUCED FROM NATURAL GAS STEAM REFORMING
PINK		PRODUCED FROM HYDROLYSIS POWERED BY NUCLEAR
YELLOW		PRODUCED FROM HYDROLYSIS POWERED BY GRID
BLUE	TARGETED	PRODUCED FROM NATURAL GAS WITH CCS
TURQUOISE		PRODUCED FROM THERMAL SPLITTING OF NATURAL GAS
GREEN	TARGETED	PRODUCED FROM TOTALLY CARBON-NEUTRAL SOURCES

Earth's hydrogen factories

Hydrogen is a carbon-free fuel, but manufacturing it is dirty and expensive. Some researchers believe cheap, vast, and potentially renewable sources of natural hydrogen sit underground.

WHITE HYDROGEN



Generation

1 Radiolysis
Trace radioactive elements in rocks emit radiation that can split water. The process is slow, so ancient rocks are most likely to generate hydrogen.

2 Serpentinization
At high temperatures, water reacts with iron-rich rocks to make hydrogen. The fast and renewable reactions, called serpentinization, may drive most production.

3 Deep-seated
Streams of hydrogen from Earth's core or mantle may rise along tectonic plate boundaries and faults. But the theory of these vast, deep stores is controversial.

Loss mechanisms

4 Seeps
Hydrogen travels quickly through faults and fractures. It can also diffuse through rocks. Weak seeps might explain shallow depressions sometimes called fairy circles.

5 Microbes
In shallower layers of soil and rock, microbes consume hydrogen for energy, often producing methane.

6 Abiotic reactions
At deeper levels, hydrogen reacts with rocks and gases to form water, methane, and mineral compounds.

Extraction

7 Traps
Hydrogen might be tapped like oil and gas—by drilling into reservoirs trapped in porous rocks below salt deposits or other impermeable rock layers.

8 Direct
It might also be possible to tap the iron-rich source rocks directly, if they're shallow and fractured enough to allow hydrogen to be collected.

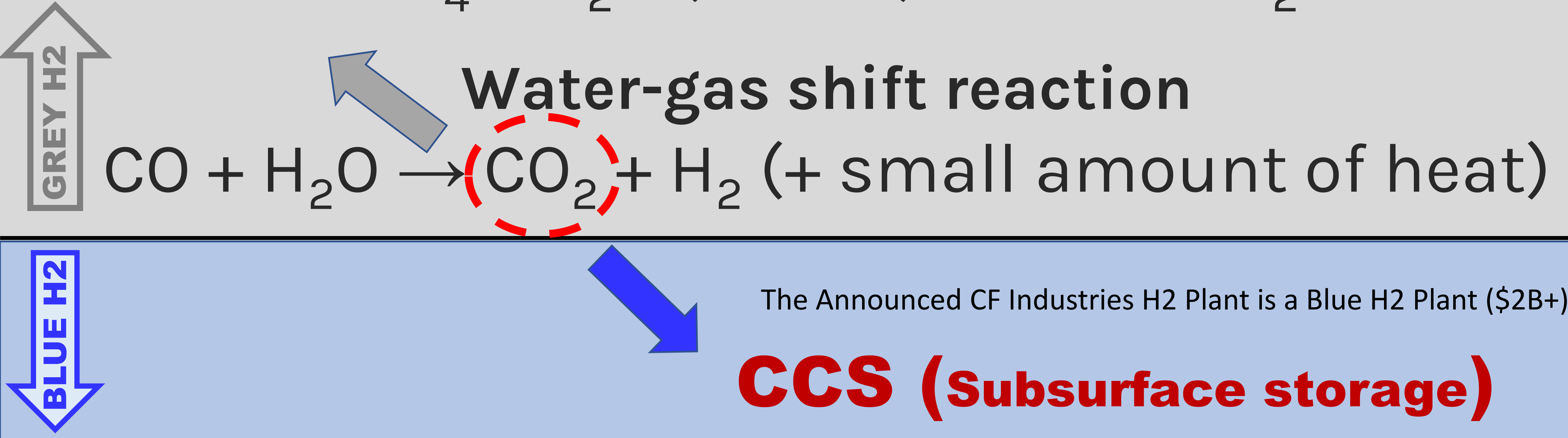
9 Enhanced
Hydrogen production might be stimulated by pumping water into iron-rich rocks. Adding carbon dioxide would sequester it from the atmosphere, slowing climate change.

GREY & BLUE HYDROGEN PRODUCTION

STEAM-METHANE (NATURAL GAS) REFORMING (AKA: SMR)

Steam-methane (Natural Gas) reforming reaction

$$CH_4 + H_2O \text{ (+ heat)} \rightarrow CO + 3H_2$$



GREY H2

Water-gas shift reaction

$$CO + H_2O \rightarrow CO_2 + H_2 \text{ (+ small amount of heat)}$$

BLUE H2

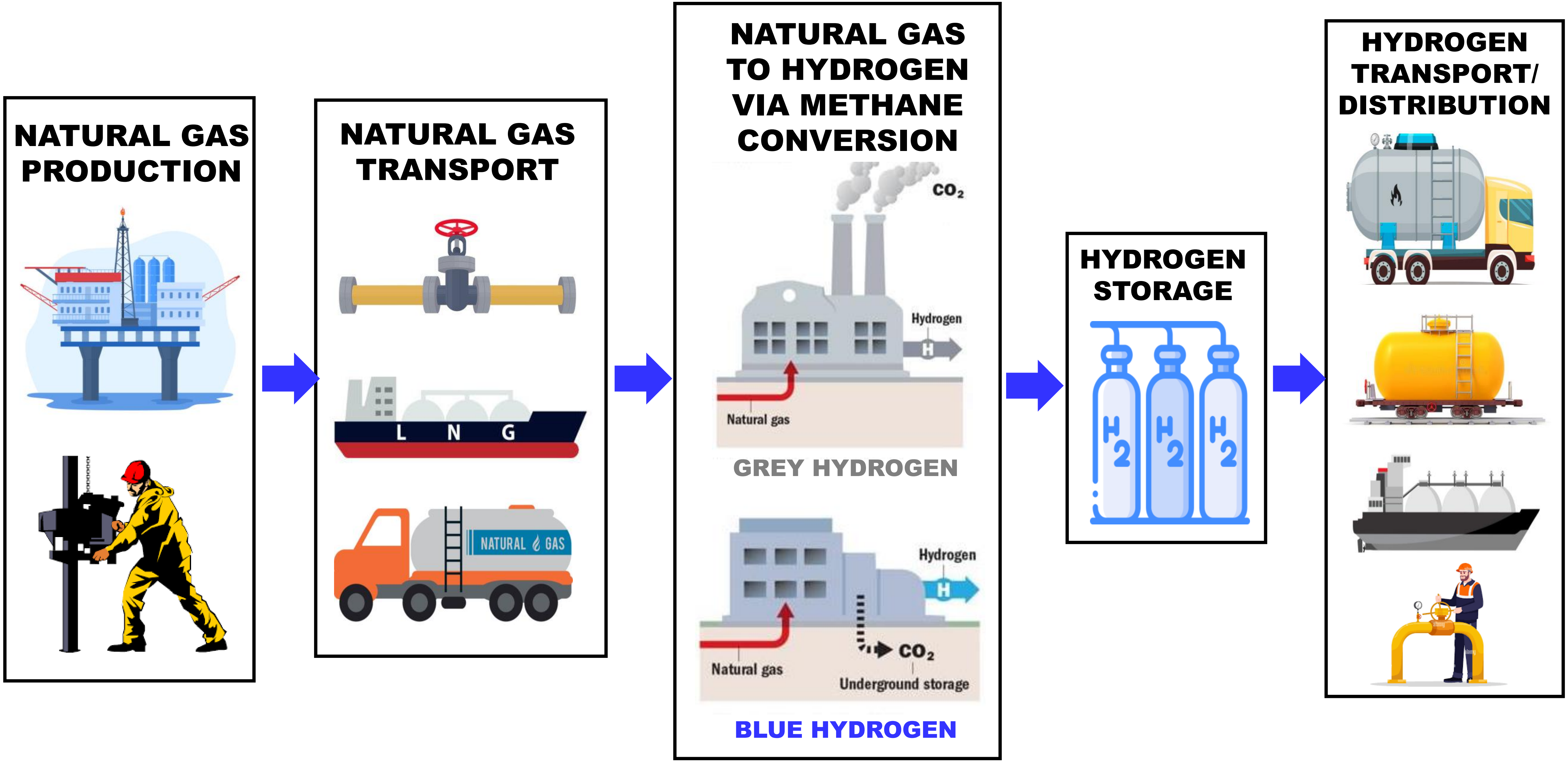
The Announced CF Industries H2 Plant is a Blue H2 Plant ($2B+)

CCS (Subsurface storage)

A Third Reaction for H2 from CH4 may be Considered: Direct Methane Reforming or DMR

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

THE CURRENT GREY AND BLUE HYDROGEN PRODUCTION SUPPLY LINE



NATURAL GAS PRODUCTION

NATURAL GAS TRANSPORT

NATURAL GAS TO HYDROGEN VIA METHANE CONVERSION

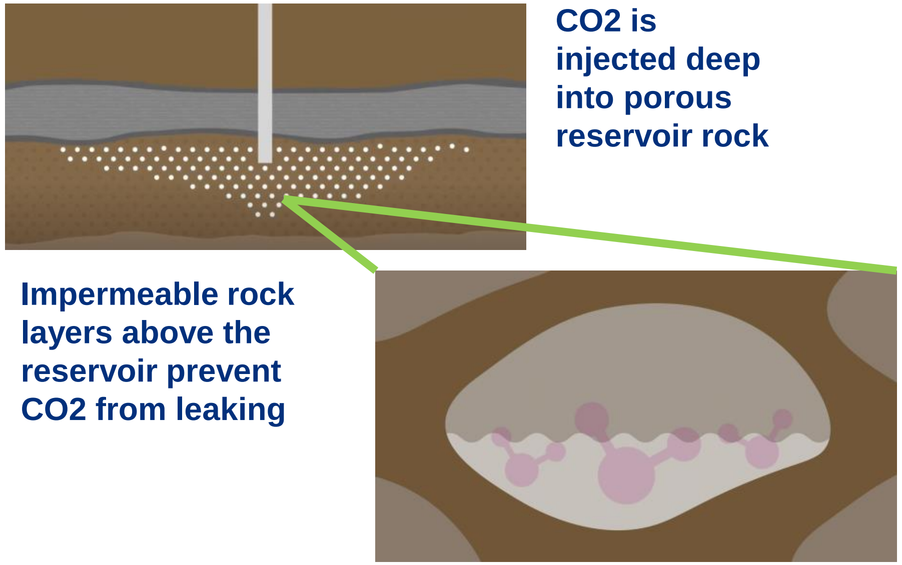
HYDROGEN STORAGE

HYDROGEN TRANSPORT/ DISTRIBUTION

SCHEMATIC OF CARBON, CAPTURE, AND STORAGE (CCS)

REALISTICALLY SPEAKING TODAY: WITHOUT CCS, THERE IS NOT A VIABLE BLUE H2 INDUSTRY

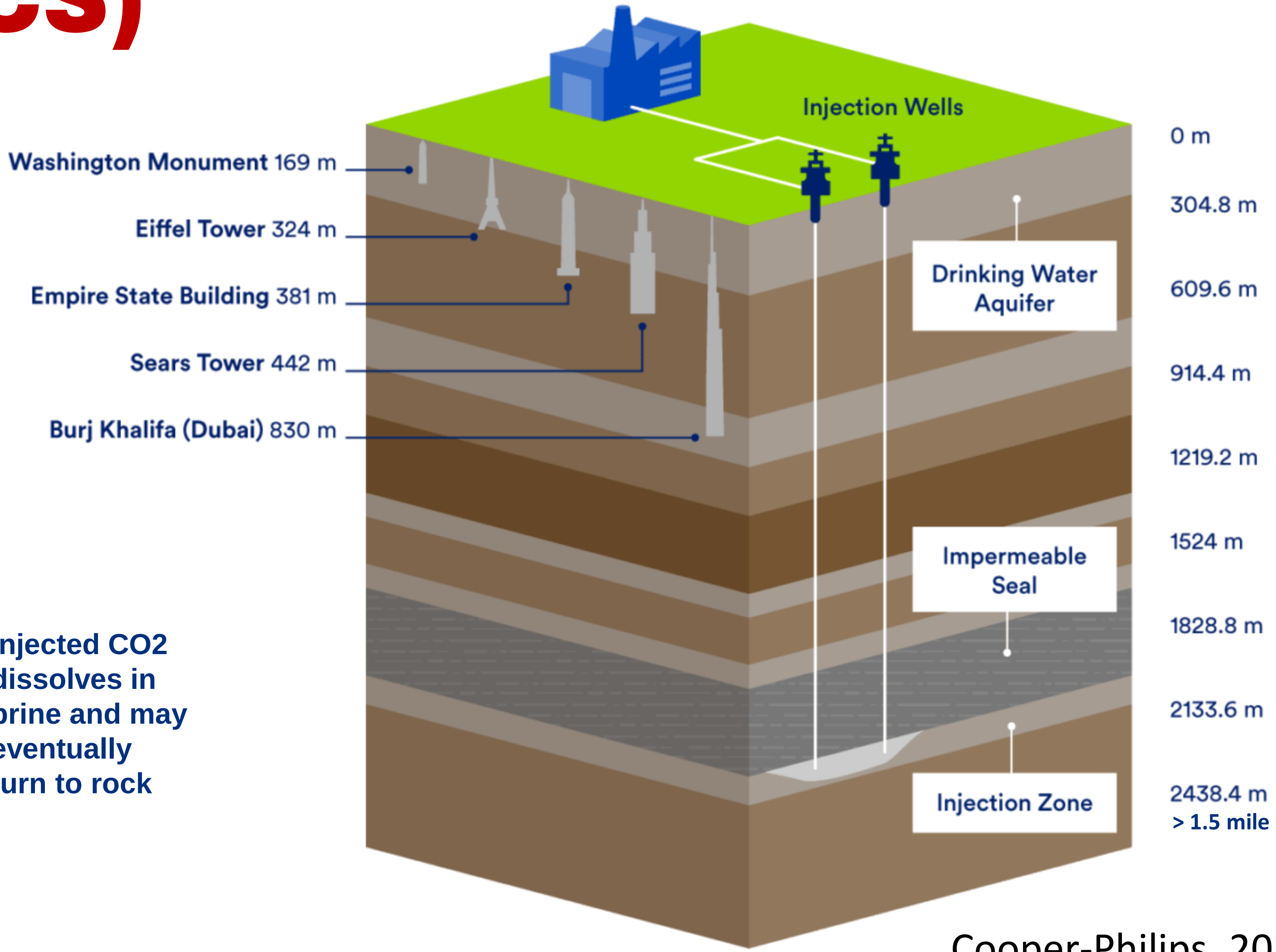
CCU MAY MATURE TO WHERE THE ABOVE STATE IS NO LONGER CORRECT



CO2 is injected deep into porous reservoir rock

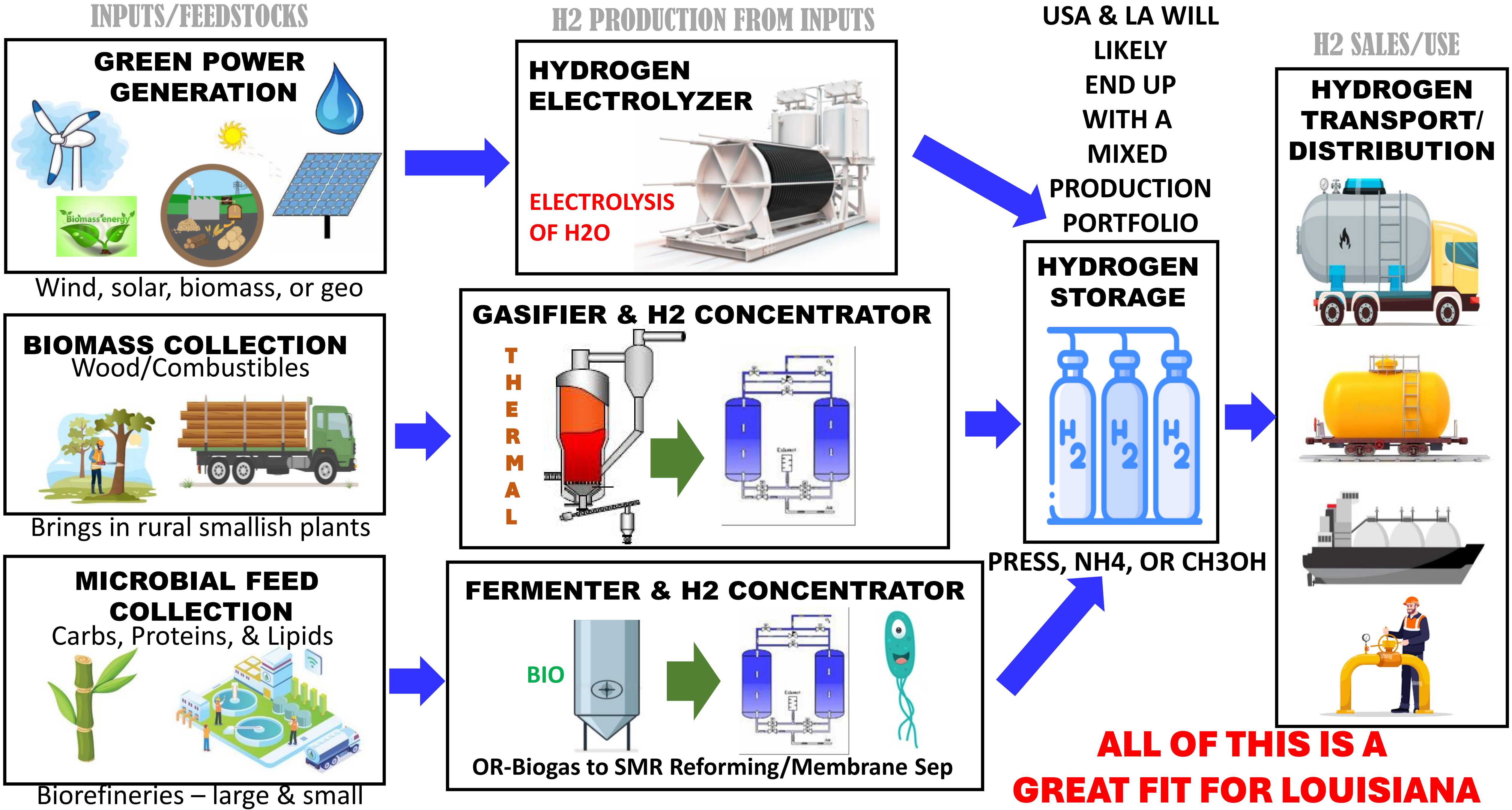
Impermeable rock layers above the reservoir prevent CO2 from leaking

Injected CO2 dissolves in brine and may eventually turn to rock



Cooper-Philips, 2024

THE ENVISIONED GREEN HYDROGEN SUPPLY LINE



INPUTS/FEEDSTOCKS

GREEN POWER GENERATION

Wind, solar, biomass, or geo

BIOMASS COLLECTION
Wood/Combustibles

Brings in rural smallish plants

MICROBIAL FEED COLLECTION
Carbs, Proteins, & Lipids

Biorefineries – large & small

H2 PRODUCTION FROM INPUTS

HYDROGEN ELECTROLYZER

ELECTROLYSIS OF H2O

GASIFIER & H2 CONCENTRATOR

THERMAL

FERMENTER & H2 CONCENTRATOR

BIO

OR-Biogas to SMR Reforming/Membrane Sep

USA & LA WILL LIKELY END UP WITH A MIXED PRODUCTION PORTFOLIO

HYDROGEN STORAGE

PRESS, NH4, OR CH3OH

H2 SALES/USE

HYDROGEN TRANSPORT/ DISTRIBUTION

ALL OF THIS IS A GREAT FIT FOR LOUISIANA

A KEY INTEREST AREA FOR LOUISIANA

THERMAL BIOMASS-BASED (AG) PRODUCTION OF GREEN HYDROGEN

Biomass
Feed

Thermally Convert
into Synthesis Gas
within the Gasifier

Syngas Gas:
(H2, CO, &CO2)

H2 Separation

C-Negative

W/CCS

GEO
CO2

H2

-OR-

NO CCS

ATMOS
CO2

H2

C-Neutral

THE BIOMASS FED GASIFIER PROCESS

Note: More H2 can be produced via the CO water-gas shift reaction

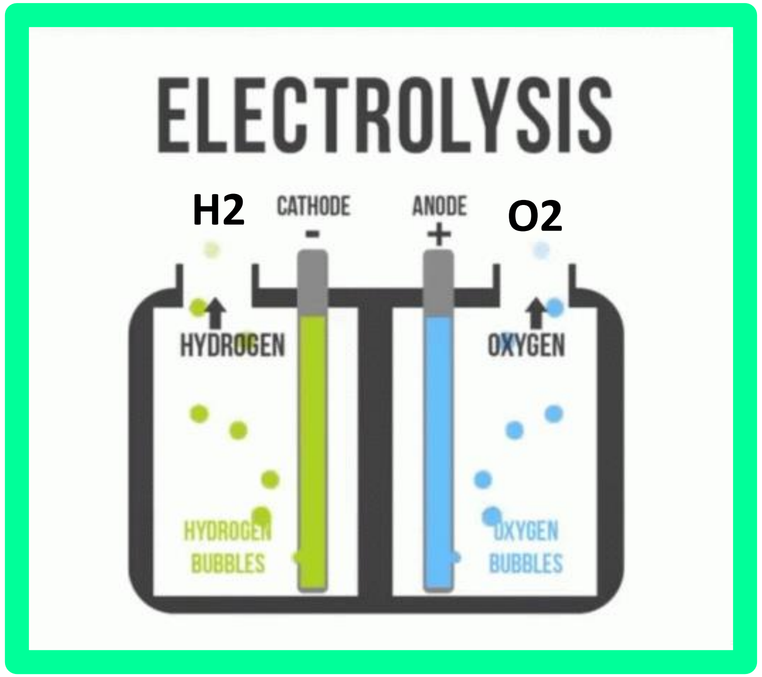
INPUTS AND OUTPUTS FOR ELECTROLYTIC HYDROGEN PRODUCTION

PRACTICAL: ~50 kWh/kg-H2
THEORETICAL: 39.4 kWh/kg-H2

POWER
(See Below)

WATER

9 Kg (2.4 gal)



HYDROGEN ELECTROLYSER

1 Kg HYDROGEN GAS

8 Kg OXYGEN GAS

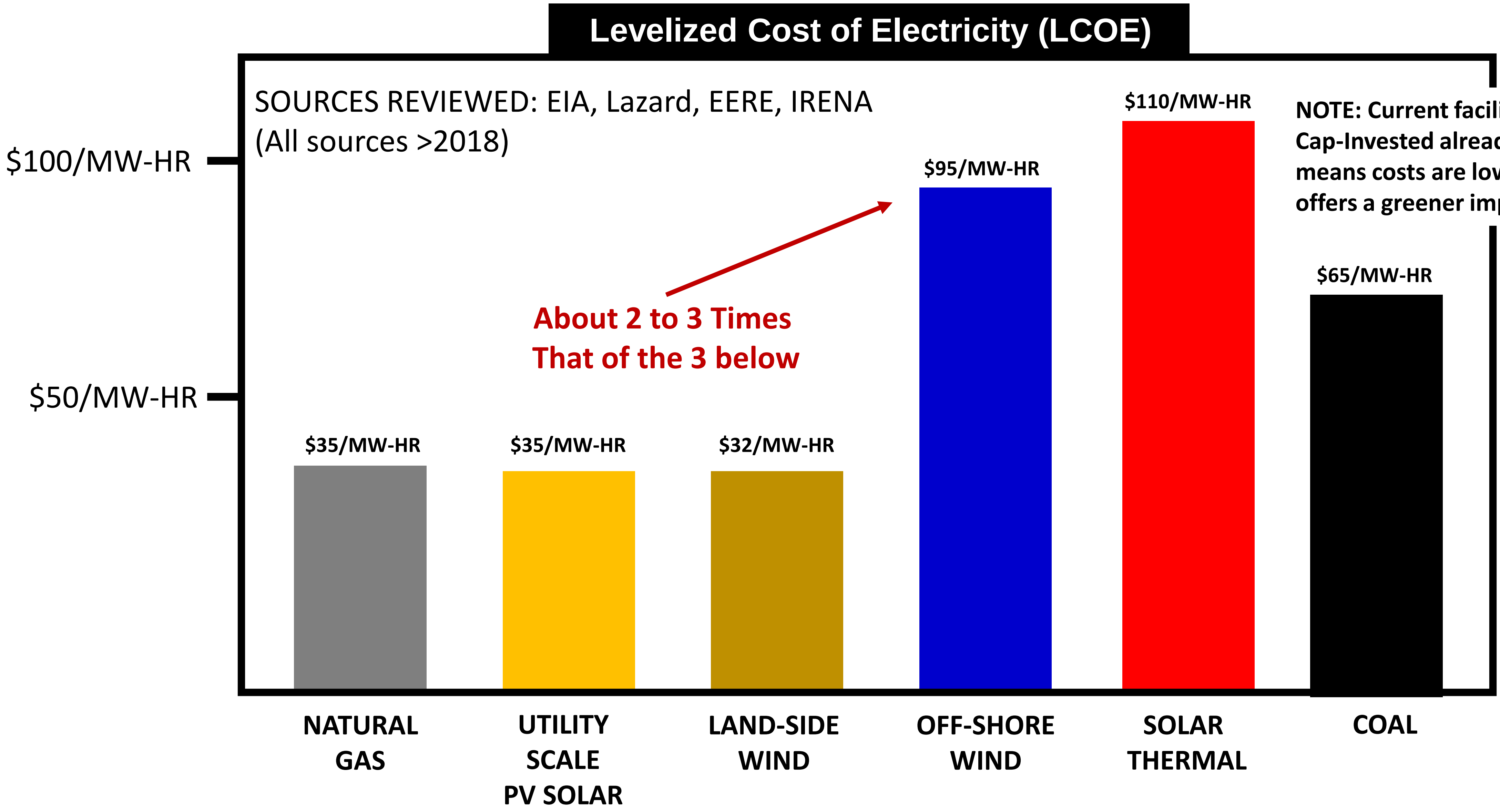
POWER SOURCE OPTIONS: (1) From Nuke – Pink H2; (2) From Fossil Fuel Grid – Yellow H2; (3) From Renewables – Green H2

COMMERCIAL ELECTROLYZERS

20 MW electrolyzer can produce ~400 kg H2

ZAPPI RELATIVE ASSESSMENT OF GENERALIZED LCOE POWER COSTS

POWER COSTS WILL GREATLY IMPACT H2 PRODUCTION COSTS



SOURCES REVIEWED: EIA, Lazard, EERE, IRENA
(All sources >2018)

About 2 to 3 Times That of the 3 below

NOTE: Current facilities are Cap-Invested already which means costs are lower (biocoal offers a greener impact)

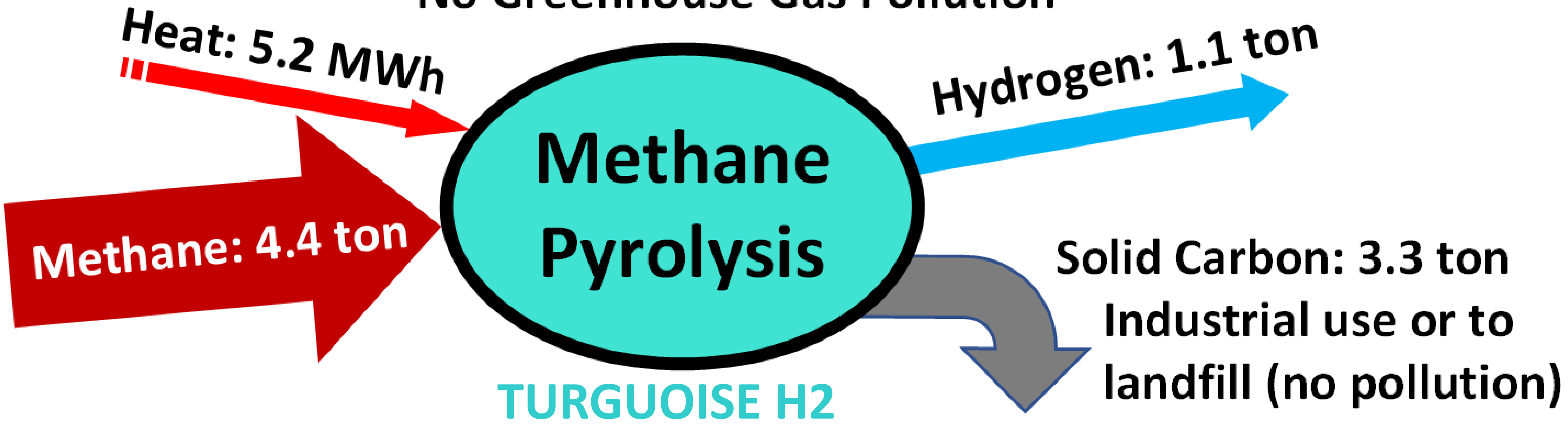
…emerging…

METHANE PYROLYSIS

Can use Either Biogas and/or Natural Gas as Feeds

Newer Hydrogen Production Method

No Greenhouse Gas Pollution



Heat: 5.2 MWh

Methane: 4.4 ton

Methane Pyrolysis

Hydrogen: 1.1 ton

Solid Carbon: 3.3 ton
Industrial use or to
landfill (no pollution)

TURGUOISE H2

Costs: ~$3.50/Kg H2 Produced

H_2 INFORMATION AND COMMENTS

Parameter	Implication
MW = 2 g/mole (CH4 is 16 g/mole)	Very small molecule that can leak (and often will)
BTUs/pound = 51,623 (CH4 is 21,510)	High energy content per pound (but not a dense gas)
BTUs/cubic feet = 266 (CH4 is 881)	Need ~3X more volumetric flow for the same energy as natural gas at the same flowrate
Adiabatic Flame Temperature (Burn Temp) ^{o}F = 4,000 (CH4 is 3,365)	Make sure your equipment can handle the higher burn temps

NOTE: Natural Gas is about 95% CH4

H_2 INFORMATION AND COMMENTS

Parameter	Implication
Flame Speed = 200 to 300 cm/sec (CH4 is 30 to 40)	Quick ignition & back-burning
Lower Explosion Limit (LEL)/ Higher Explosion Limit (HEL) For H2 = 4% & 75% in air [v/v] (CH4 is 7%/20%)	More explosive/dangerous than NG
Reacts with metals	Metals embrittlement

H_2 INFORMATION AND COMMENTS

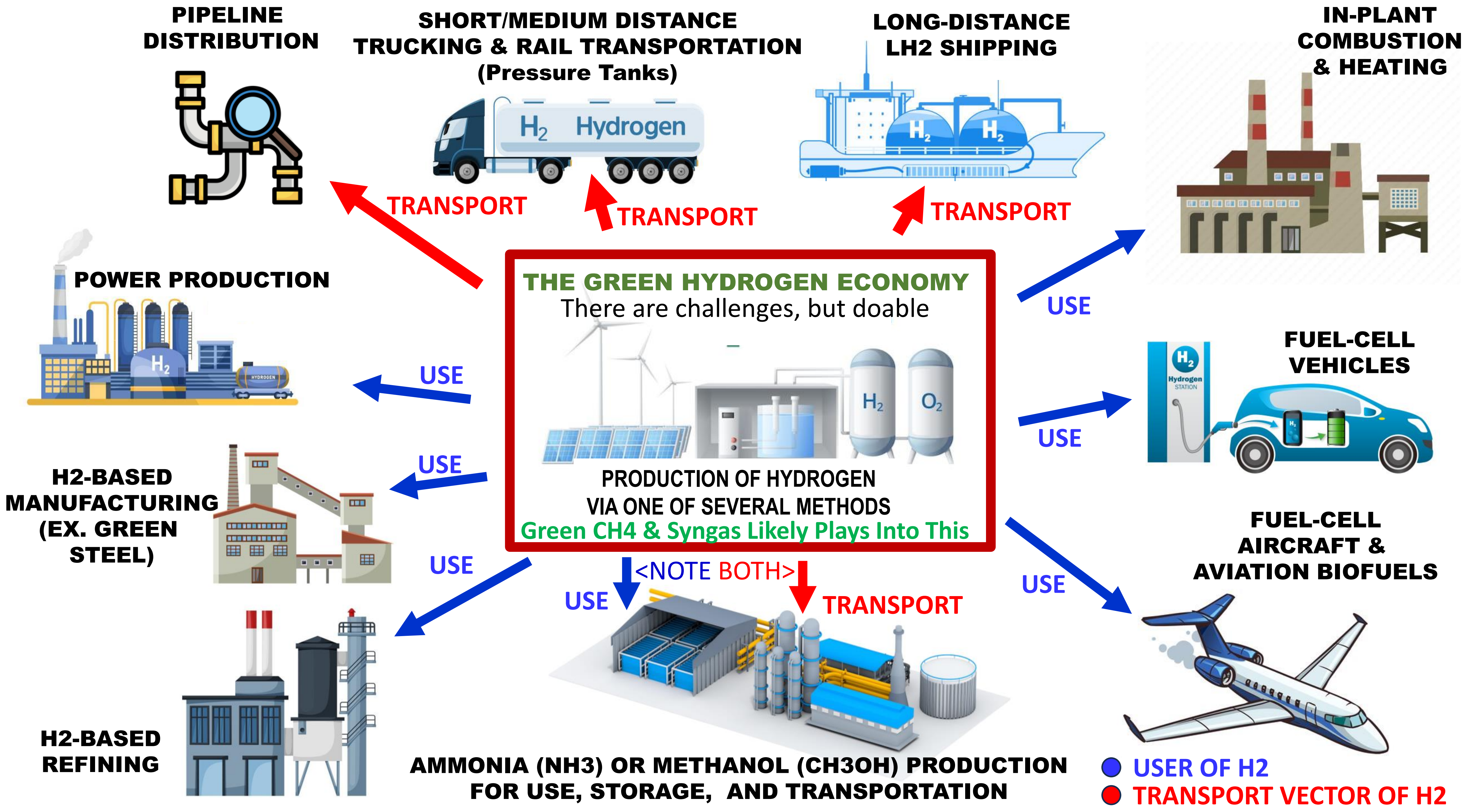
- To hit the Paris Agreement goals, Blue/Green H2 would have to represent ~15% of global energy usage

- Blending H2 with NG (mainly CH4) to hit a resulting 50% reduction in CO2 emissions would require ~75% H2 to 25% CH4 volumetric blend (v/v) for the same BTU production

- >$7 TRILLION USD is expected to be spent globally on Blue/Green H2 conversion by 2050

VISION FROM KEY EXPERTS FOR THE H2 FUTURE
-2050 View-

iea International Energy Agency	**Fossil fuels will still be the dominant H2 source, but coupled with CCS (US [75%], Europe [65%], & Japan [85%])**
DNV	**Green H2 will represent about 5% of the total global energy mix by 2050**
Wood Mackenzie	**Hydrogen could make up around one-third of global seaborne energy trade by 2050**
Forbes	**Hydrogen could become a $130 Billion U.S. industry**



THE GREEN HYDROGEN ECONOMY

There are challenges, but doable

PRODUCTION OF HYDROGEN
VIA ONE OF SEVERAL METHODS

Green CH4 & Syngas Likely Plays Into This

TRANSPORT

PIPELINE DISTRIBUTION

TRANSPORT

SHORT/MEDIUM DISTANCE TRUCKING & RAIL TRANSPORTATION (Pressure Tanks)

TRANSPORT

LONG-DISTANCE LH2 SHIPPING

USE

IN-PLANT COMBUSTION & HEATING

USE

FUEL-CELL VEHICLES

USE

FUEL-CELL AIRCRAFT & AVIATION BIOFUELS

USE

POWER PRODUCTION

USE

H2-BASED MANUFACTURING (EX. GREEN STEEL)

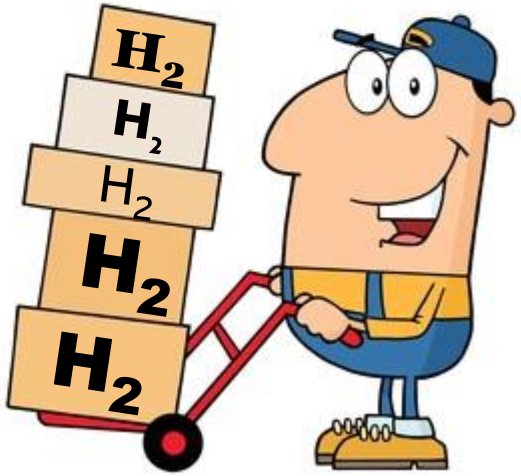
USE

H2-BASED REFINING

USE <NOTE BOTH> TRANSPORT

AMMONIA (NH3) OR METHANOL (CH3OH) PRODUCTION FOR USE, STORAGE, AND TRANSPORTATION

● USER OF H2
● TRANSPORT VECTOR OF H2



MOVING PRODUCT FROM PRODUCTION TO USERS

LIKELY TRANSPORTATION VECTORS

WITHIN REGION/CONTINENT

PIPELINES

TRUCKED/RAILED AMMONIA OR METHANOL OR COMPRESSED H2

BETWEEN CONTINENTS

SHIPPED LH2

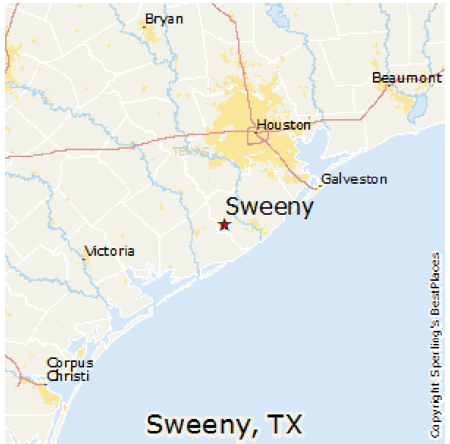
OR SHIPPED AMMONIA

HYDROGEN
BLE GAS
LIQUIFIED HYDROGEN
FLAMMABLE GAS

GEO-STORAGE OF HYDROGEN

CHEVRON PHILLIPS CLEMENS TERMINAL
(One of three UHS systems currently active in the US)

- **The Chevron Phillips Clemens Terminal in Texas stores hydrogen in a solution-mined salt cavern (salt dome) - Sweeny, TX.**
- **Located about 2,800 feet (850 m) underground.**
- **The cavern is a cylinder with a diameter of 160 feet (49 m), a height of 1,000 feet (300 m)**
- **Usable hydrogen capacity of 1,066 million cubic feet (30.2×10^6 m^3), or 2,520 metric tons**



H_2 LIQUEFACTION OF HYDROGEN LH2

- Liquefaction of hydrogen is doable as LH2
- Been around for many years – i.e., NASA shuttle program
- A typical LNG plant design is inadequate to meet the demands of LH2
- Power requirements: LH2 needs about 2.5 times that of LNG (T's: −253°C or −423°F for H2 versus –162°C or –260°F for natural gas)
- For roughly the same boil-off rate as NG in the LNG process, the insulation of a LH2 storage tank must be about 10 times more efficient than an LNG tank (means - needs a lot of insulation)

December 24, 2021

Japanese shipbuilder Kawasaki Heavy Industries (KHI) said the world's first liquefied hydrogen (LH2) carrier Suiso Frontier left Japan to pick up its first cargo in Australia.

SHIPPING USING H2-POWERED AMMONIA TANKERS

How is hydrogen stored?

Physical-based

- **Compressed Gas**

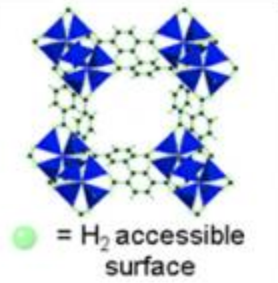
- **Cold/Cryo Compressed**

- **Liquid H_2**

Material-based

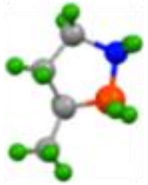
- **Adsorbent**

Ex. MOF-5



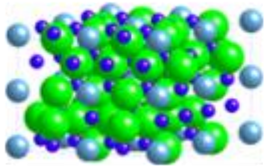
- **Liquid organic**

Ex. BN-methyl cyclopentane



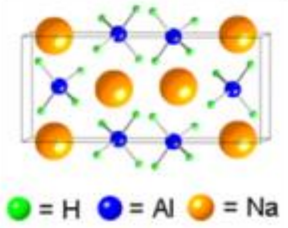
- **Interstitial hydride**

Ex. $LaNi_5H_6$



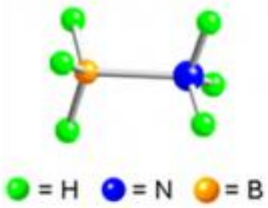
- **Complex hydride**

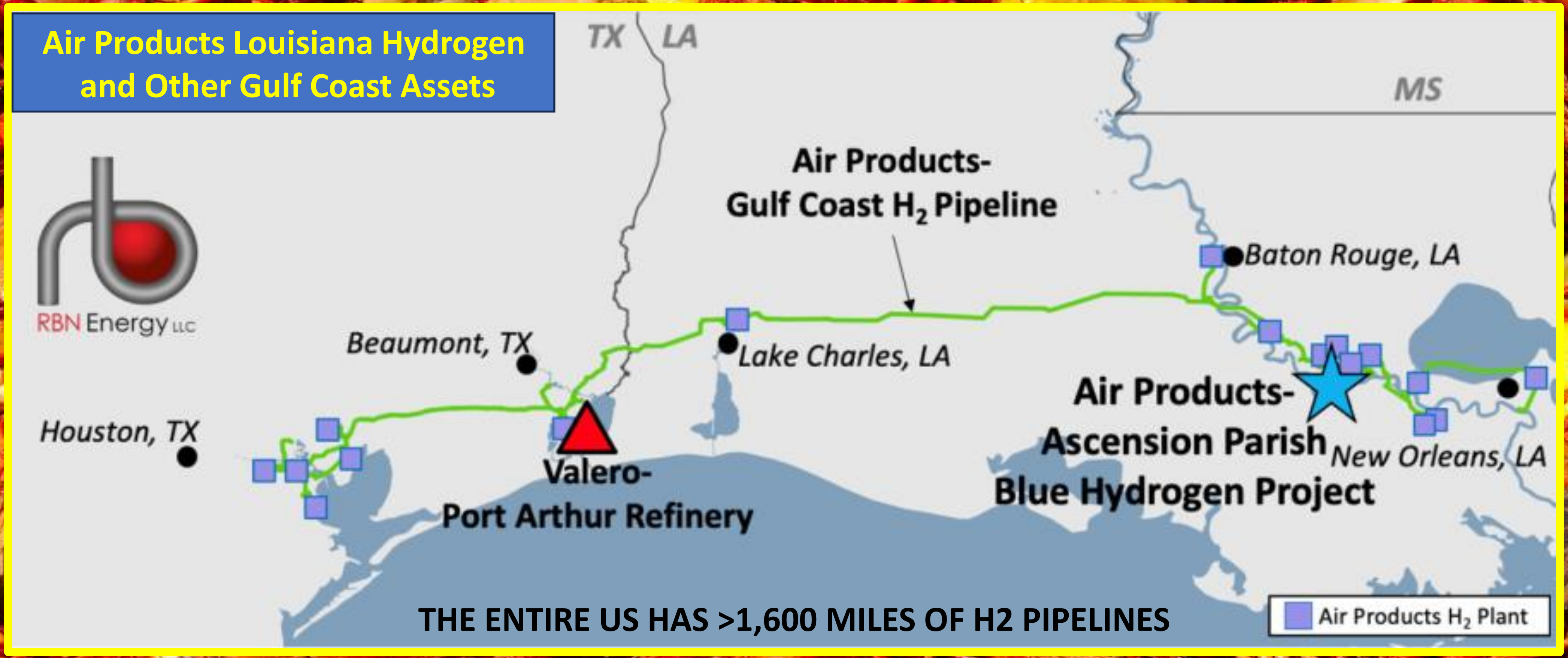
Ex. $NaAlH_4$



- **Chemical hydrogen**

Ex. NH_3BH_3





Air Products Louisiana Hydrogen and Other Gulf Coast Assets

THE ENTIRE US HAS >1,600 MILES OF H2 PIPELINES

LA HAS CURRENT AND EXPANDING H2 INFRASTRUCTURE

DOE HYDROGEN SHOT

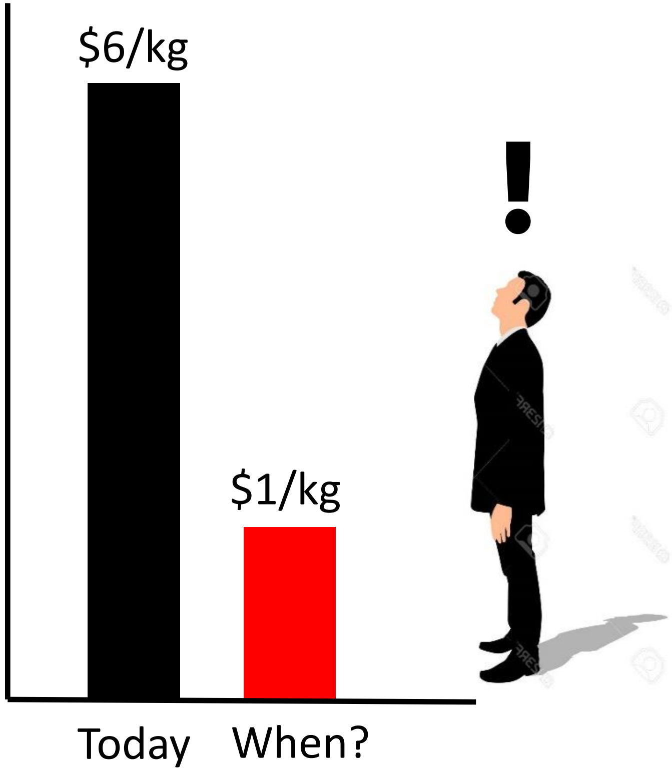
(Green H2)

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

1 Dollar

1 Kilogram

1 Decade

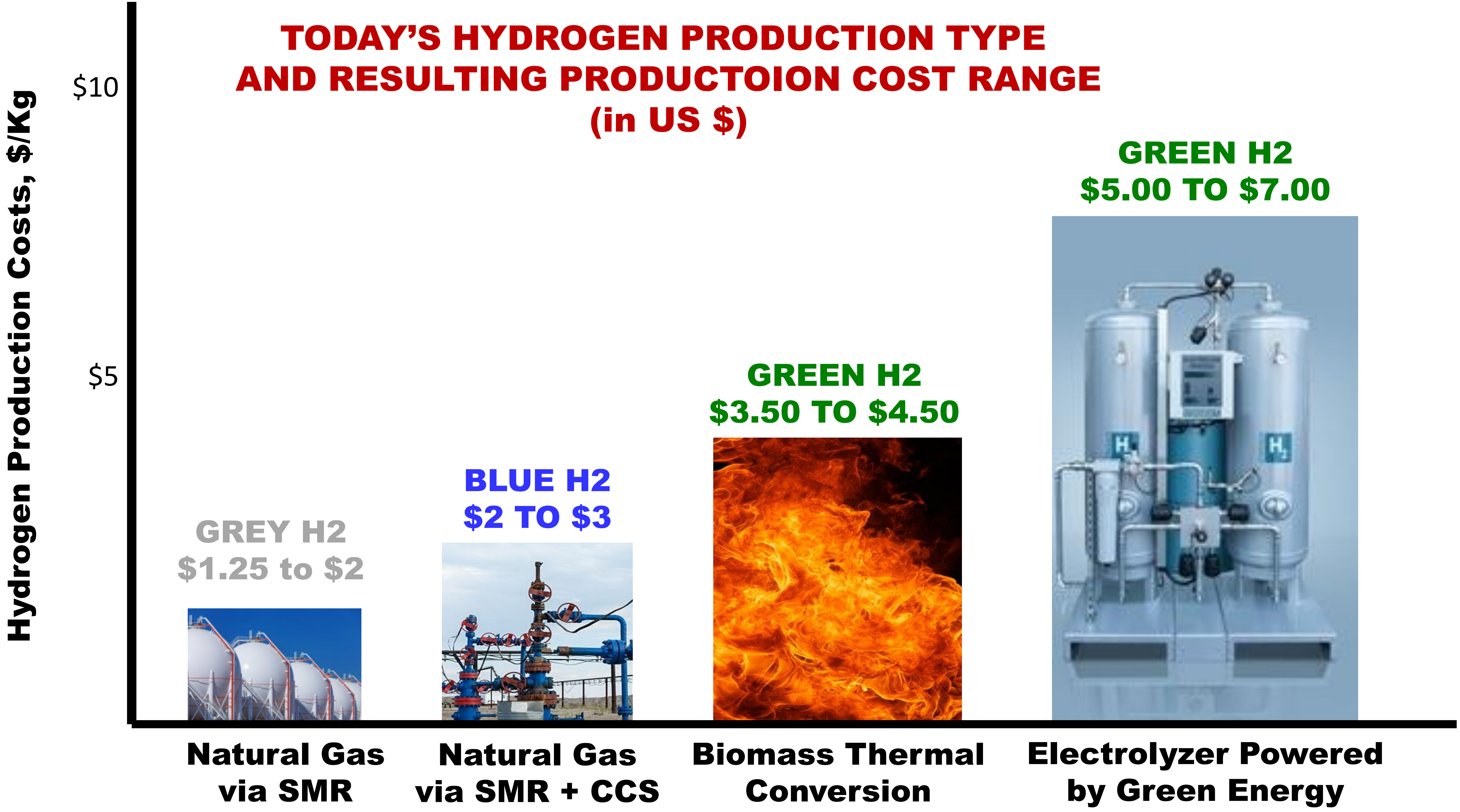


Hydrogen Shot has a goal of reducing the cost of green hydrogen to $1 per 1 kilogram in 1 decade ("1 1 1")

Green Hydrogen price today is about $4-$6.50/kg

TODAY'S HYDROGEN PRODUCTION TYPE AND RESULTING PRODUCTOION COST RANGE

(in US $)



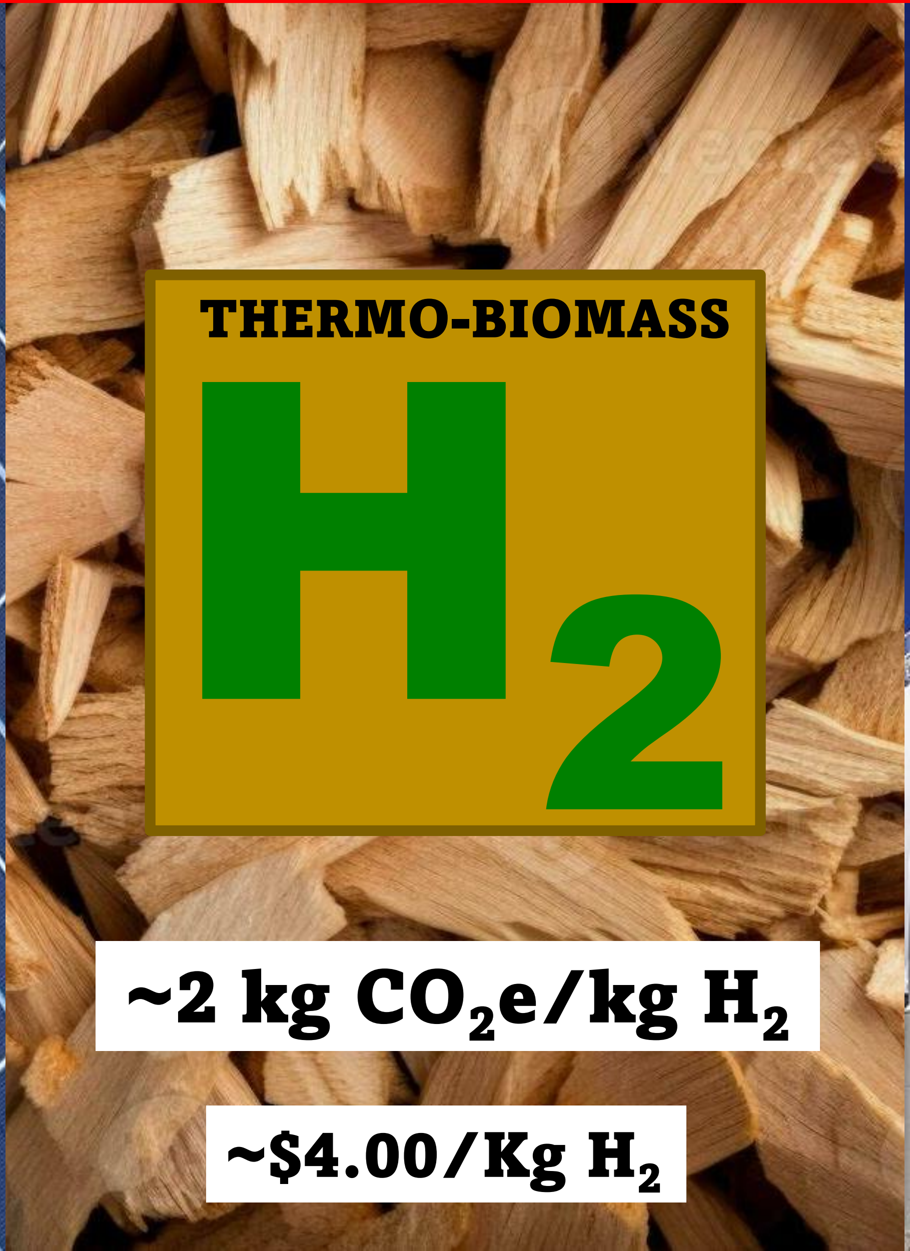
COMPARING GREEN H2 VS. GREY H2

ELECTROLYZER

H_2

~1 kg CO_2e/kg H_2

~\$6.50/Kg H_2

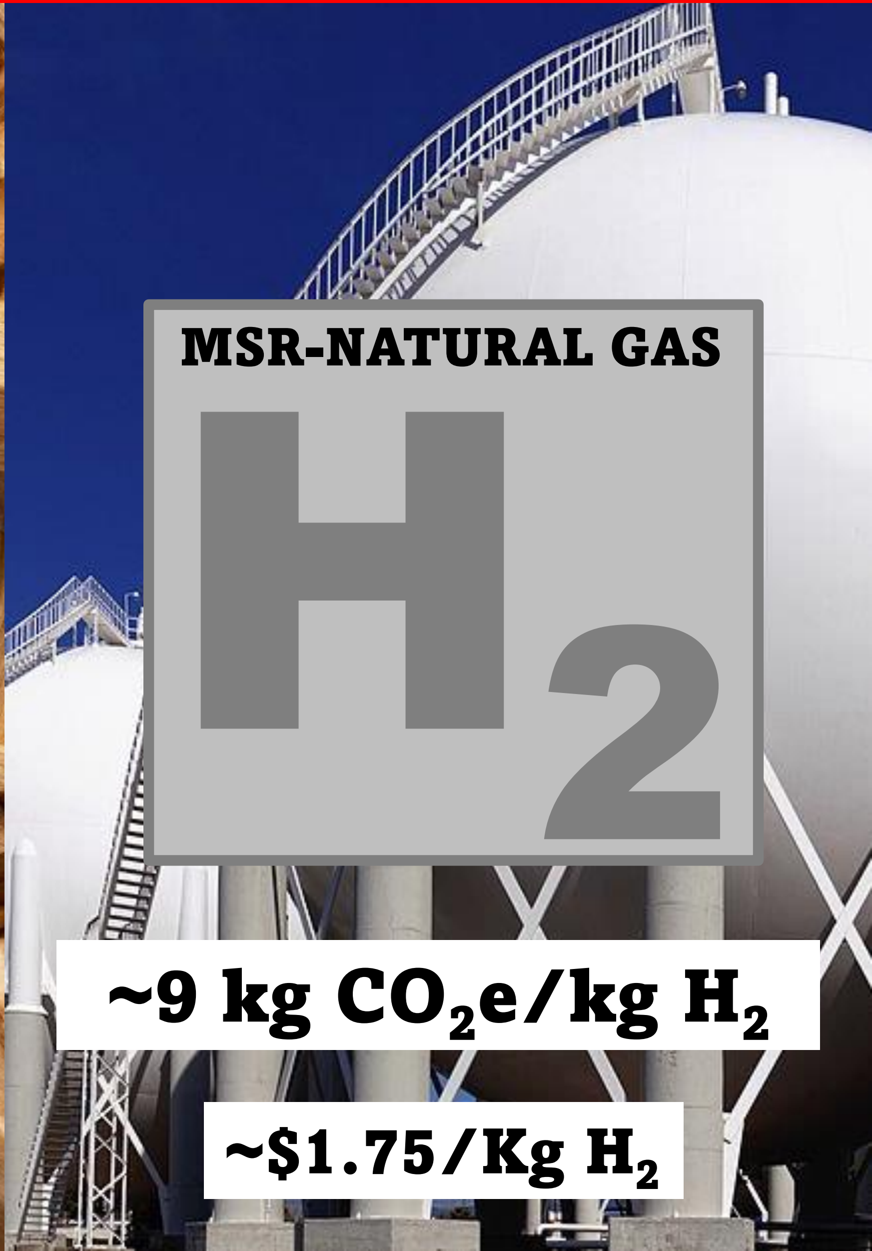


THERMO-BIOMASS

H_2

~2 kg CO_2e/kg H_2

~\$4.00/Kg H_2



MSR-NATURAL GAS

H_2

~9 kg CO_2e/kg H_2

~\$1.75/Kg H_2

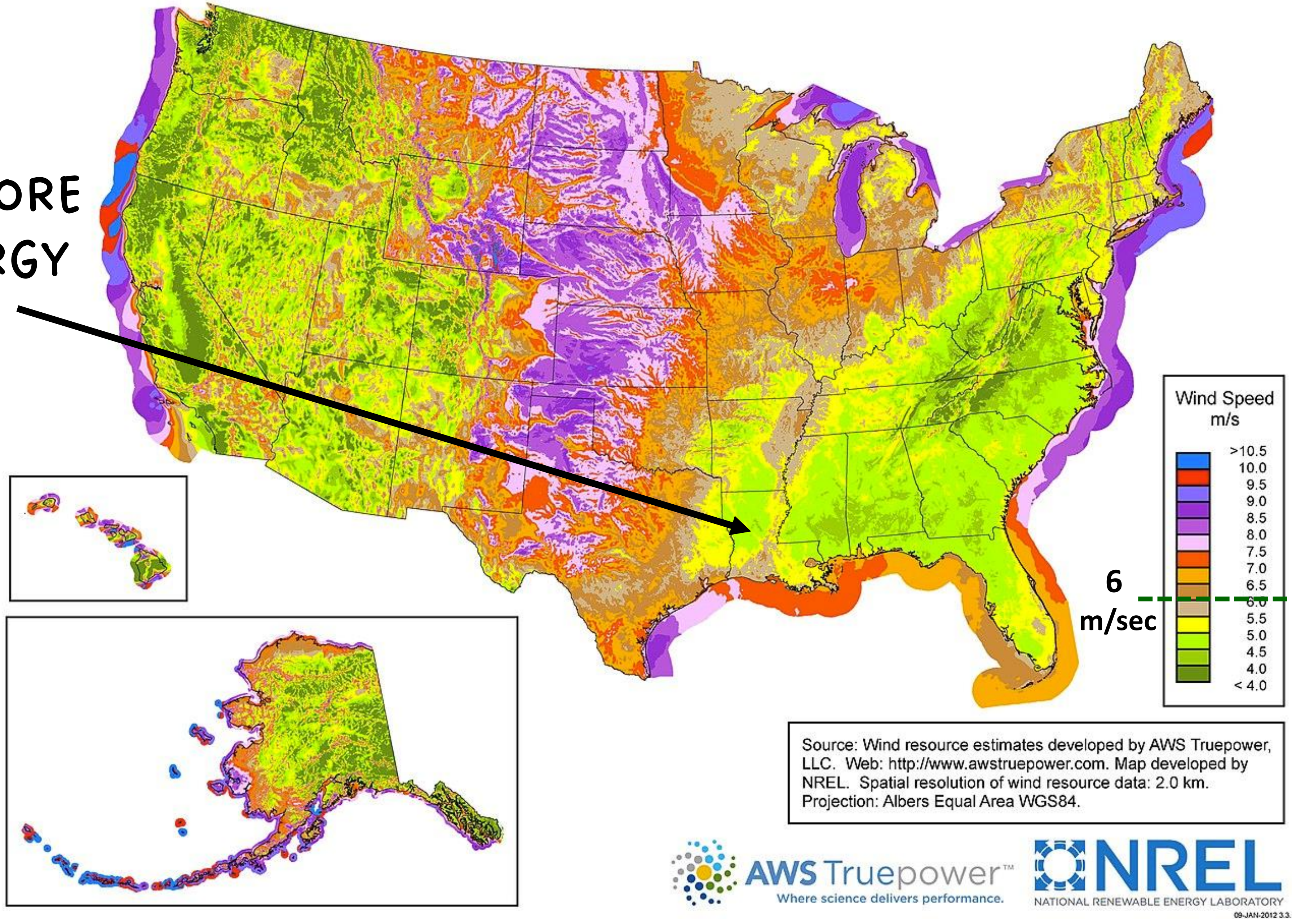
45V Clean Hydrogen Production Tax Credit

FINAL RULE IS NOT OUT YET - But, under the IRA of 2022 Provides up to $3/Kg of H2 based on Life Cycle Greenhouse Gases (mainly CO2) generated during production

- **Represents a 10-year tax credit incentive that is GHG production staggered via the following four ranges (10-year term of production service for facilities constructed after January 2024):**
  - ❖ **<0.45 Kg CO2$_{eq}$ – per Kg H2 Produced - $3/kg (highest)**
  - ❖ **0.45 to <1.5 Kg CO2$_{eq}$ – per Kg H2 Produced**
  - ❖ **>1.5 to <2.5 Kg CO2$_{eq}$ – per Kg H2 Produced**
  - ❖ **>2.5 to <4 Kg CO2$_{eq}$ – per Kg H2 Produced - $0.60/kg (lowest)**
- **Tax Credit has a GHG ceiling of eligibility that must be less than 4 Kg CO2$_{eq}$ per Kg H2 produced –**
- **LCA used is the Argonne National Laboratory Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model - more specifically, the 45VH2-GREET model component**
- **Awaiting the US Treasury's final rule announcement based on an early-2024 public comment period (GNO Inc. and UL both provided comments based on concerns with the proposed rule)**

LOUISIANA
IS REALLY
AN OFF-SHORE
WIND ENERGY
STATE

United States - Land-Based and Offshore Annual Average Wind Speed at 80 m



6 m/sec

Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

AWS Truepower™ Where science delivers performance.

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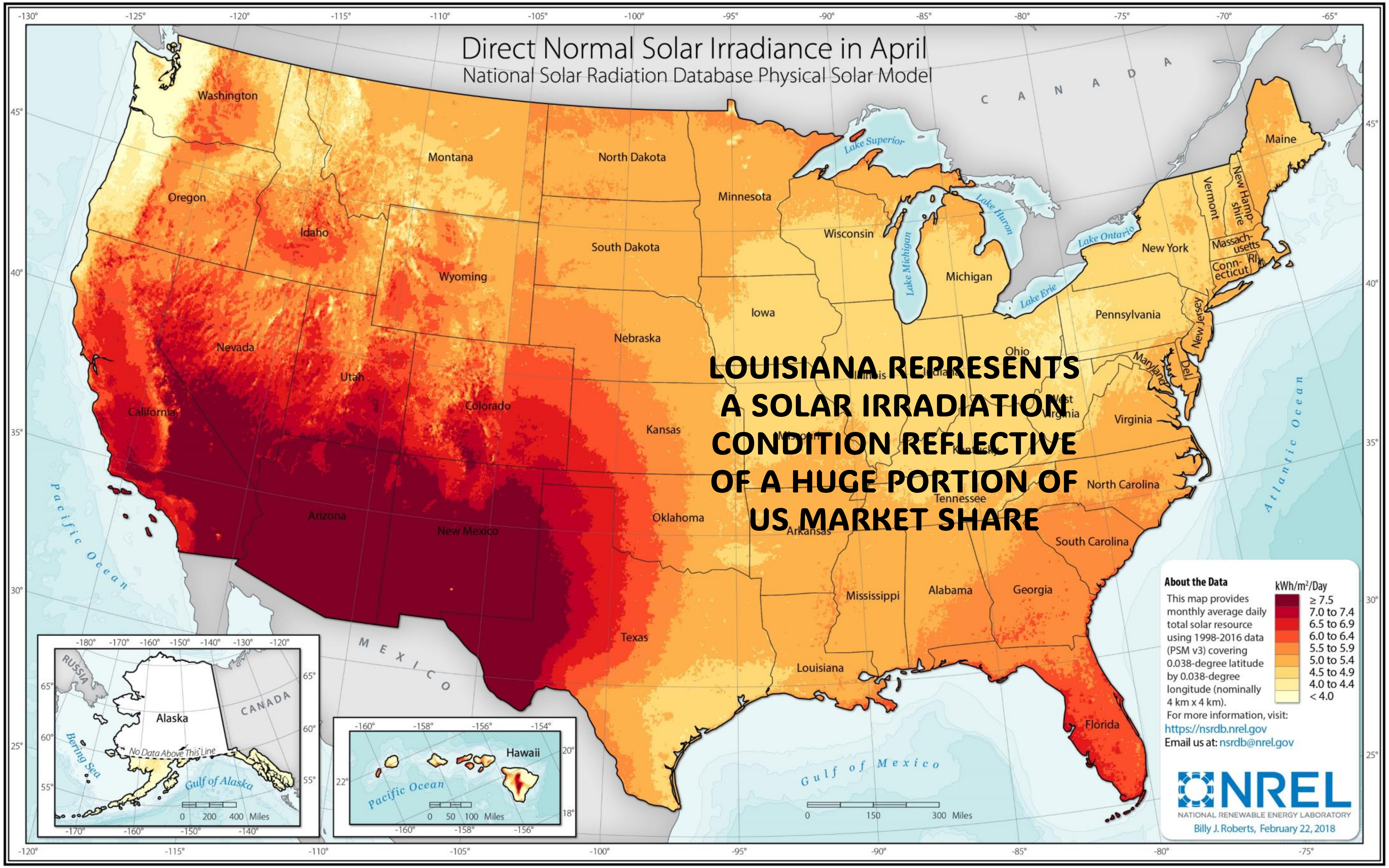

About the Data

This map provides monthly average daily total solar resource using 1998-2016 data (PSM v3) covering 0.038-degree latitude by 0.038-degree longitude (nominally 4 km x 4 km).

For more information, visit: https://nsrdb.nrel.gov

Email us at: nsrdb@nrel.gov

LOUISIANA REPRESENTS A SOLAR IRRADIATION CONDITION REFLECTIVE OF A HUGE PORTION OF US MARKET SHARE

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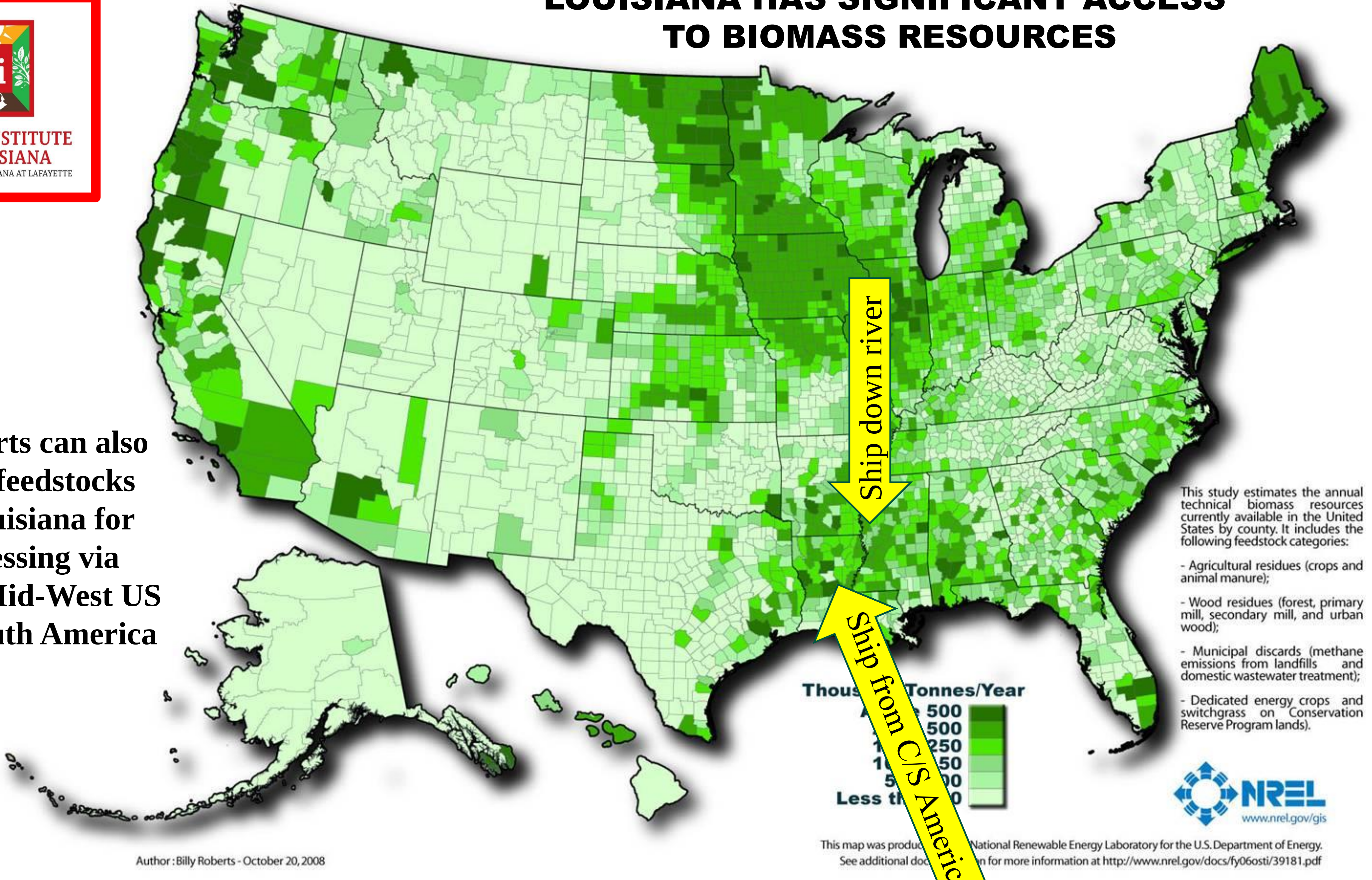
LOUISIANA HAS SIGNIFICANT ACCESS TO BIOMASS RESOURCES

Our ports can also
Bring feedstocks
To Louisiana for
Processing via
Upper Mid-West US
And South America



This study estimates the annual technical biomass resources currently available in the United States by county. It includes the following feedstock categories:

- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops and switchgrass on Conservation Reserve Program lands).

This map was produc National Renewable Energy Laboratory for the U.S. Department of Energy.
See additional doc n for more information at http://www.nrel.gov/docs/fy06osti/39181.pdf

Author: Billy Roberts - October 20, 2008

Ship down river

Ship from C/S America

POTENTIAL CHALLENGES TOWARD A WIDESPREAD HYDROGEN ECONOMY IN LA/USA

- **Medium, distributed H2 off-takers (buyers)**
- **Widespread product transport**
- **CAPEX of process equipment conversion**
- **Perceived stability of markets**
- **Government policies and potential shifting**
- **Storage at all industrial scales**
- **Bias toward power sources and processes**
- **Price stability**

THE LOW-HANGING FRUIT IN THE EVOLVING HYDROGEN ECONOMY IS PRODUCING GREEN OR BLUE HYDROGEN ADJACENT TO HIGH-VOLUME AND/OR CONSISTENT HYDROGEN USERS.

- Refineries
- Fertilizer Plants

Very-High Volume Usage

- Food processing

AND THAT LOW-HANGING FRUIT IS FOUND THROUGHOUT MUCH OF SOUTH LOUISIANA.

OTHER FACTORS FOR A LOUISIANA H2 ECONOMY

HIGHLY TRAINED CHEMICAL PROCESS ORIENTED WORKFORCE:

- Refineries
- Chemical Production Industries
- Pipeline and Pressure Vessels/Unit Ops

SUBSTANTIAL HYDROGEN PIPELINE SYSTEM:

- Cuts across Southern Louisiana and More Coming

NUMEROUS ESTABLISHED H2 OFF-TAKE CUSTOMERS:

- Fertilizer, Refinery, Power, and Chemical Systems

HIGH VOLUMES OF WATER

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THE H2 TRANSITION IS REALLY TWO TRANSITIONS

FUEL TRANSITION

EQUIPMENT TRANSITION

Likely Scenario is a Stepped Transition

PRODUCERS AND USERS

USERS – SWITCH AND/OR MODIFY EQUIPMENT

BUILD BACK BETTER REGIONAL CHALLENGE
E·D·A
WINNER

H_2theFUTURE
ENERGY TRANSFORMATION IN SOUTH LOUISIANA

- **A $75M+ WIN FOR LOUISIANA**
- **FUNDED BY THE EDA-BBB PROGRAM**
- **LED BY GREATER NEW ORLEANS INC.**
  Regional Economic Development
- **SUPPORTS THREE TECH HUBS:**
  UNO – GOM Wind Power
  LSU – CCUS
  UL – Green H2

GREATER NEW ORLEANS
INC
REGIONAL ECONOMIC DEVELOPMENT

Baton Rouge Area Chamber®

ONEACADIANA™

SLEC
South Louisiana Economic Council
Assumption · Lafourche · St. Mary · Terrebonne

SWLA ECONOMIC DEVELOPMENT
ALLIANCE

Led by LSU with 26 academic partners and numerous economic development and industry collaborators

Funded by a groundbreaking $160 million award from the National Science Foundation, FUEL partners will work together to advance the nation's capacity for energy innovation through use-inspired research and development

QUESTIONS?
COMMENTS?

Ei

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