FUEL FOR THOUGHTS:

HOW WE UTILIZE EARTH'S LARGEST CARBON SINK TO MAKE SUSTAINABLE FUELS

PRESENTED BY:
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03.04.2025 | 12 NOON
HALE IAKO OCEANVIEW CONFERENCE ROOM
HOST PARK, HI

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AGENDA

Defining Sustainable Fuel & The Sources	Discussion on how sustainable fuels are currently defined and the sources of the four main sustainable fuel categories: Green Hydrogen, Ammonia, Biofuels, and Synthetic Fuels.
The Market & The R&D	Global driving forces in the sustainable fuel market along with the current global relevant initiatives and R&D efforts.
The Ocean & The Opportunity	Look at how the ocean is the worlds largest carbon sink, but it is in trouble if it says on the current trajectory. However, this not all bad news. There is an opportunity to help stabilize the ocean's carbon uptake with synthetic fuels.
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WHAT IS A SUSTAINABLE FUEL? WHAT IS SAF?

- Defining Sustainable Fuel
  - Must reduce net greenhouse gas (GHG) emissions over its lifecycle
  - Fuel derived from renewable or captured carbon sources
  - Avoid negative environmental impacts (e.g., deforestation, excessive land use, water depletion)

Green Hydrogen	Ammonia	Biofuels	Synthetic Fuels (e-fuels)

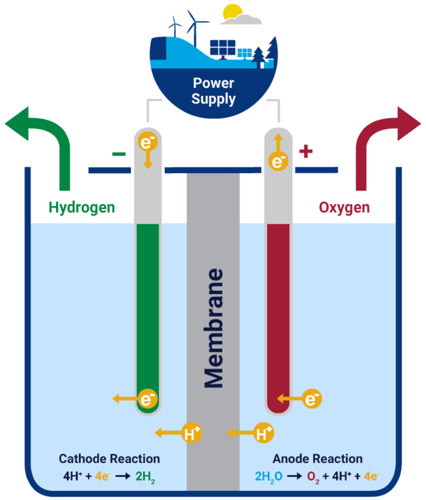
- SAF – Sustainable Aviation Fuel
  - Subcategory sustainable fuels (biofuels and synthetic fuels)
  - Must meet rigorous specifications
  - Must be blended with at least 50% conventional fossil-based jet fuel

Virgin Atlantic

1st Transatlantic Flight on 100% SAF

November, 28, 2023

SOURCES OF SUSTAINABLE FUELS

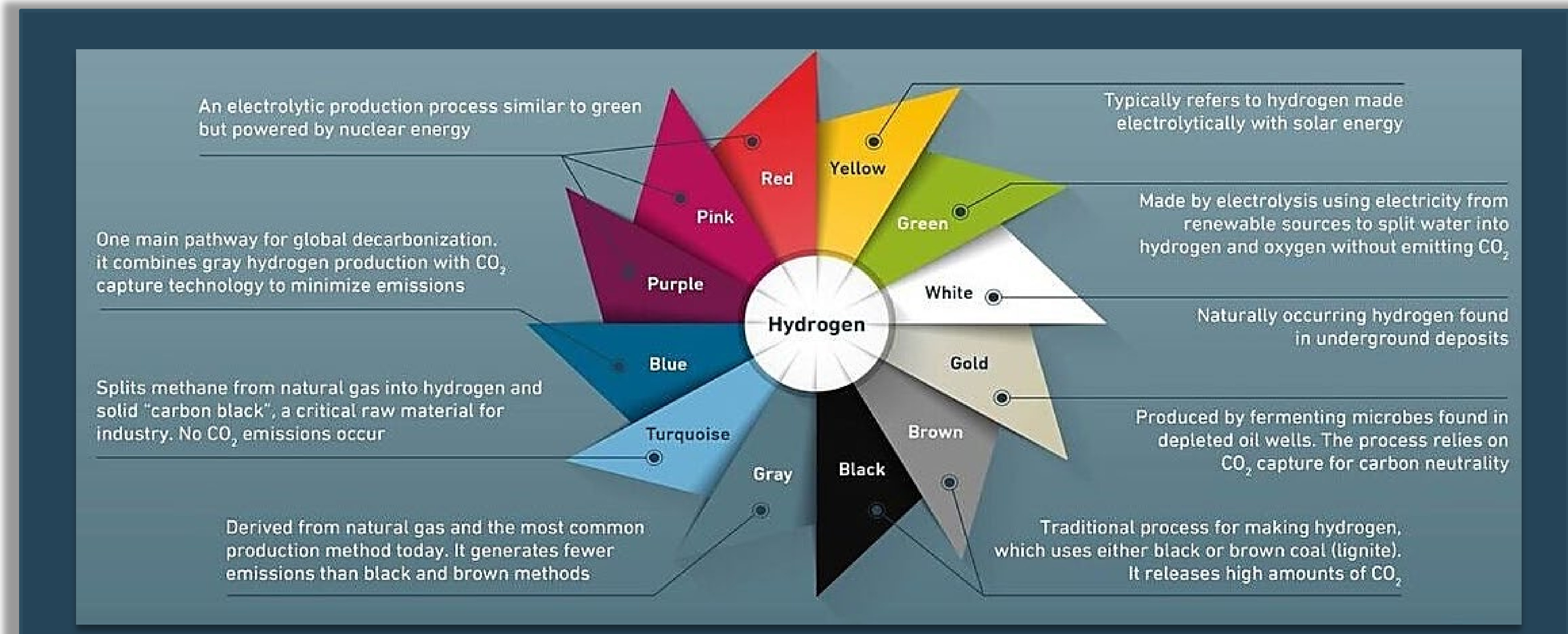


Source: aleasoft.com/green-hydrogen-fuel-future/

Green Hydrogen

- Hydrogen is classified based on how it is produced
- Green Hydrogen is based on electrolysis from renewable sources
- Three primary uses

1. Fuel Cells for Hydrogen-to-Electricity
2. Sustainable Fuels for Hydrogen-to-Liquid Fuels
3. Hydrogen Combustion for Direct use in Engines & Turbines



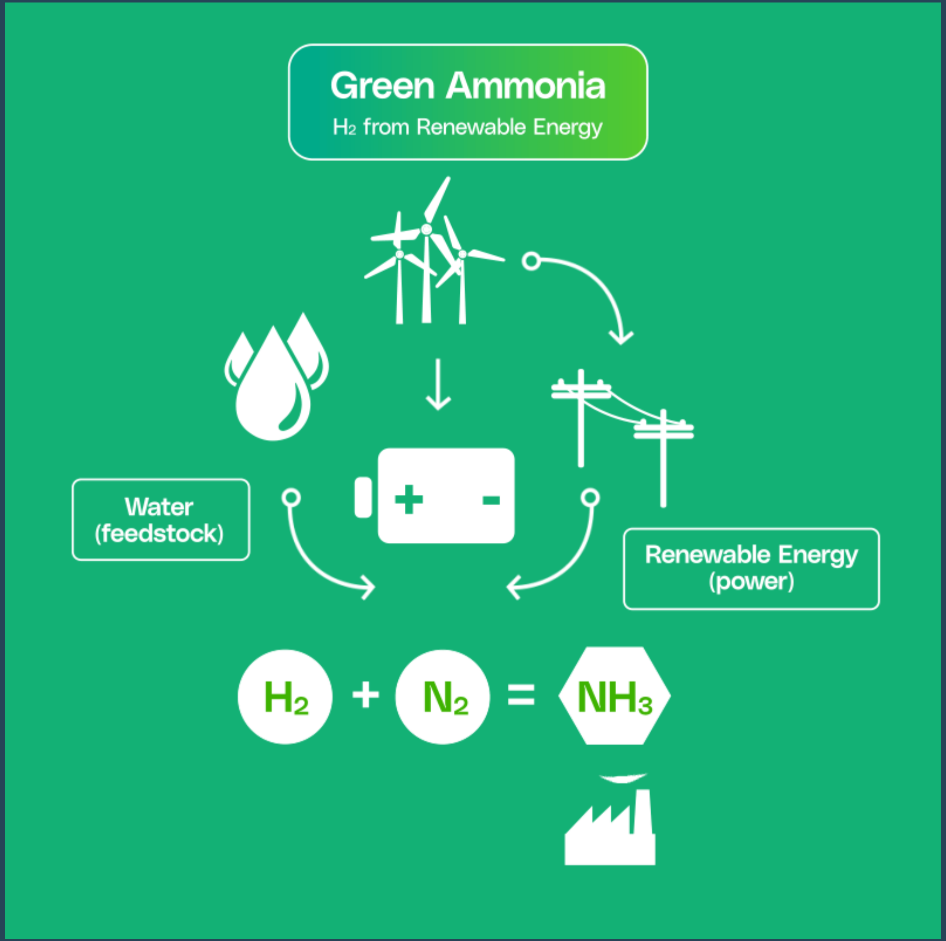
Source: spectra.mhi.com/the-colors-of-hydrogen-expanding-ways-of-decarbonization

SOURCES OF SUSTAINABLE FUELS

Ammonia

- Green Ammonia is an effective hydrogen carrier
- Three Primary Fuel or Power Uses

1. Marine Fuel Direct Use
2. Hydrogen source for biofuels and synthetic fuels (eFuels)
3. Power Generation in Gas Turbines and Fuel Cells

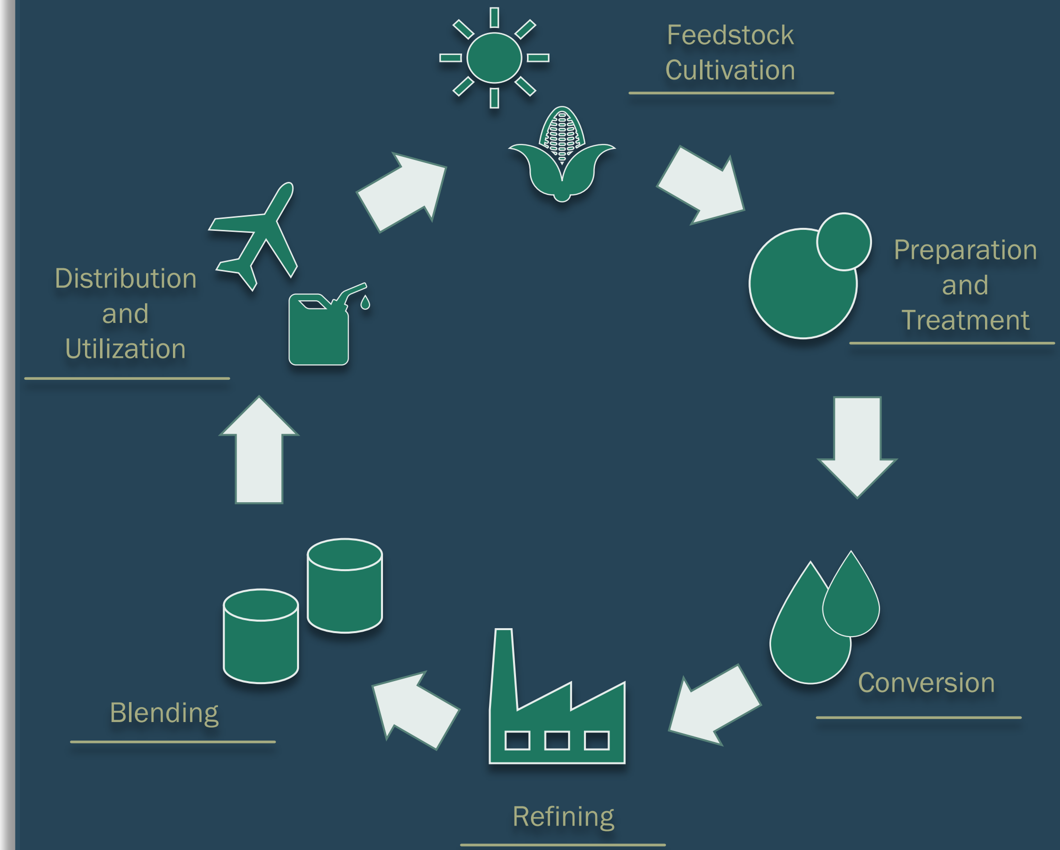


Source: .stamicarbon.com/our-business/stami-green-ammonia

SOURCES OF SUSTAINABLE FUELS

Biofuels

- HEFA (Hydroprocessed Esters and Fatty Acids)
  - The most popular SAF (90% commercial SAF)
  - Derived from biomass, specifically lipid-based feedstocks such as: Used cooking oil (UCO), Animal fats (tallow, lard), Vegetable oils (soybean, canola, palm, etc.), Algae-derived oils
- Alcohol to Jet (AJT)
  - Derived from sugar, cellulose, biogas
- Catalytic Hydrothermolysis (CH)
  - Derived from fats, oils, greases
- Fischer-Tropsch (non-synthetic PtF)
  - Derived from biomass trash, biogas



SOURCES OF SUSTAINABLE FUELS

Synthetic Fuels (e-fuels)

- Carbon-neutral synthetic hydrocarbons (e-fuels)
  - Power-to-Fuels (PtF)

Source	CO_2 Concentration	Multiplier vs. Air
Direct Air Capture (Most common)	~0.6 mg/L	1x (Baseline)
Fresh Water (not a current pathway)	0.1 - 10 mg/L	~0.2x - 17x
Seawater (Sea Dragon)	~90-100 mg/L	~140x

  - Methanol-to-Fuels (MtF)

Source	Status
Methanol to Gas (MtG)	Proven commercial technology, limited scalability
Methanol to Jet (MtJ)	Not commercialized, R&D
Methanol to Diesel (MtD)	Early commercialization, still advancing

What about non-carbon-neutral synthetic hydrocarbons?

There are carbon rich sources that may not qualify for SAF due to their origination, however there is opportunity and value to using available and alternative feed sources to produce fuels in a way that does help the overall carbon footprint

- Industrial emissions (grey area)
- Natural gas processing plants
- Stranded natural gas

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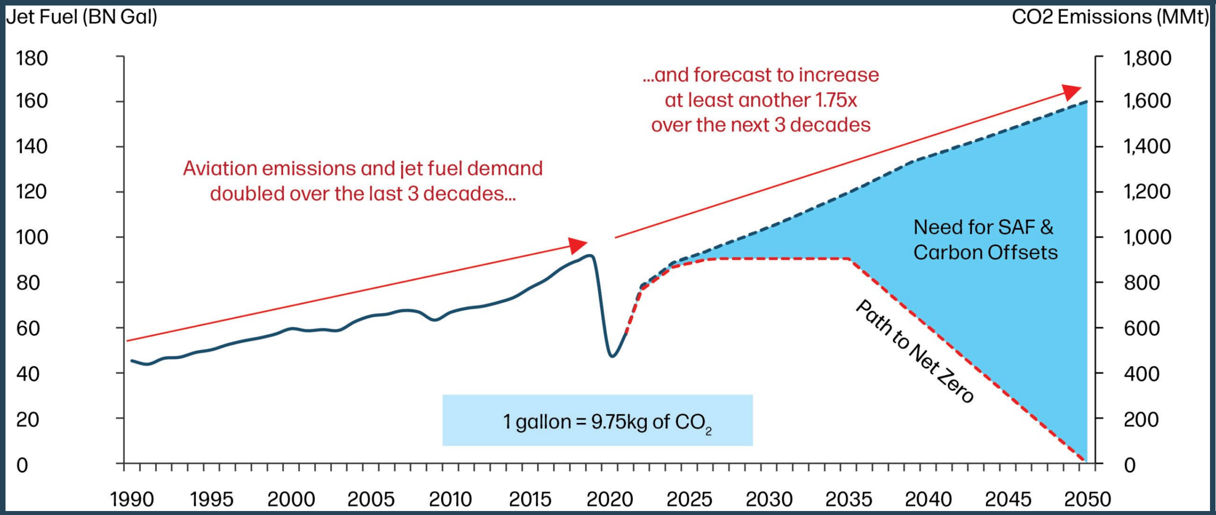
SUSTAINABLE FUEL MANDATES AND MARKET GROWTH

- **Global Market Growth:** The e-fuel market is experiencing rapid expansion. Valued at $8.8 billion in 2024, it's projected to reach $48.5 billion by 2030, growing at a CAGR of 34.3%.
- EU RefuelEU mandate requires 5% of PtF fuels in aviation by 2030 (2% 2025, 1% 2020)
- France, Norway, and Sweden also have similar Mandates to the EU. Germany, Spain, and the UL have proposed Mandates, and Finland and the Netherlands have aggressive targets of 30%-100%
- US SAF Target of 3 billion gallons by 2030 and 35 billion gallons of 100% SAF by 2050
- U.S. Inflation Reduction Act (IRA) and Renewable Fuels Act offers tax credits for e-fuels to allow them to be sold at a competitive price.

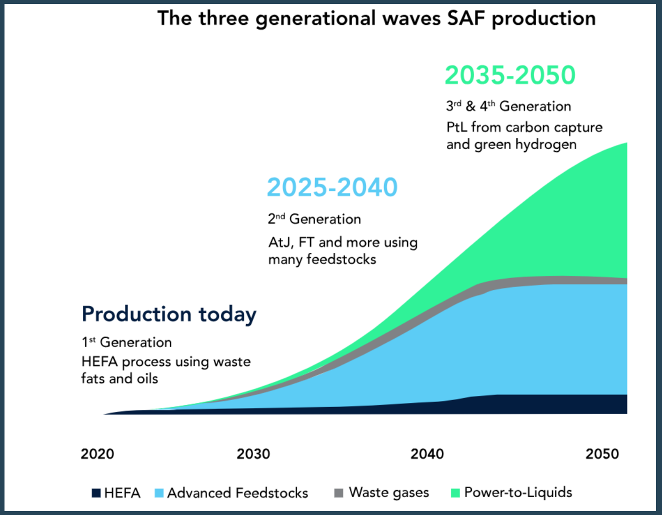
Sector-Specific Demand:

Aviation: The aviation industry is a significant driver, with sustainable aviation fuels (SAFs) expected to contribute approximately 65% of the emission reductions needed to achieve the aviation industry's net-zero carbon emissions by 2050.

Shipping: Projections indicate a substantial increase in e-fuel usage within maritime transport, aligning with global decarbonization goals.



https://asaenergy.com/carbon-emissions/



https://www.icf.com/insights/aviation/requirements-sustainable-aviation-fuel-financing

KEY R&D INITIATIVES AND PROJECTS IN POWER-TO-FUEL

Decarbonization is a global effort

*Not an exhaustive list of projects

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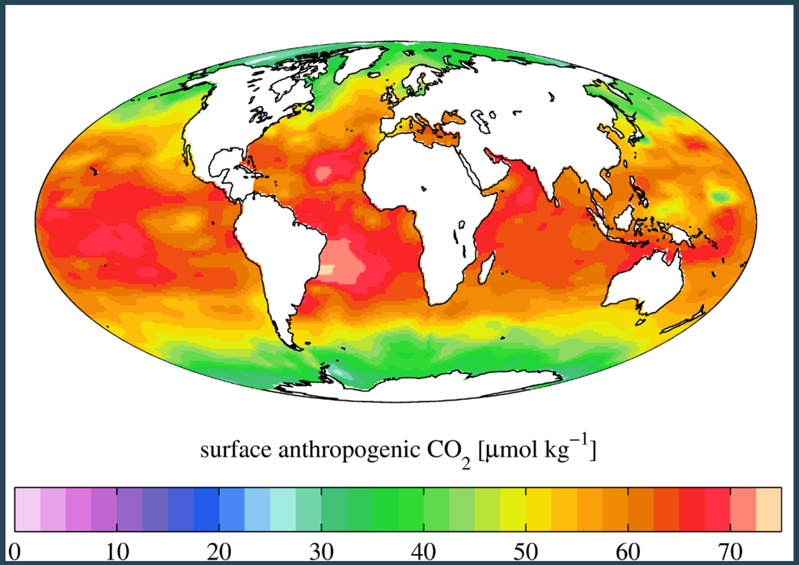
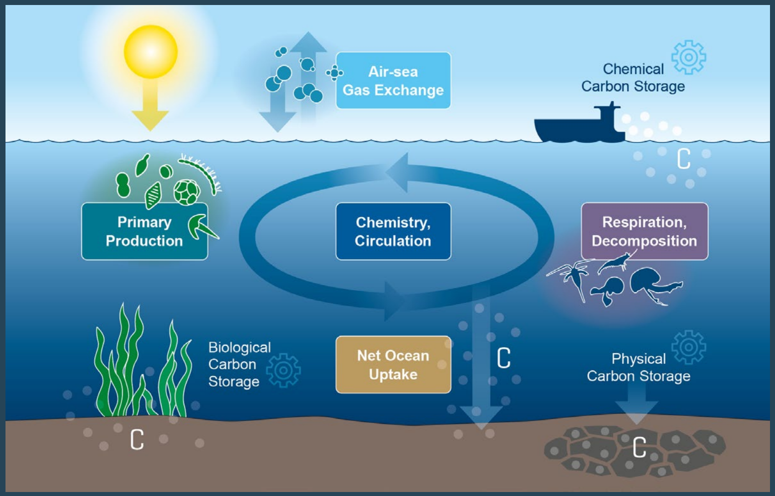
THE OCEAN IS THE LARGEST NATURAL CARBON SINK

- The ocean is the largest natural carbon sink, absorbing about 25-30% of human-made CO_2 emissions (~10 gigatons/yr)
- It plays a crucial role in regulating Earth's climate by removing CO_2 from the atmosphere and storing it in surface waters, deep ocean currents, and marine ecosystems.
- How the Ocean Absorbs CO_2
  - Physical (Solubility) Pump – CO_2 dissolves into seawater at the surface, particularly in cold waters where solubility is higher.
  - Biological Pump – Phytoplankton absorb CO_2 through photosynthesis, transferring carbon to the deep ocean when they die and sink.
  - Carbonate Pump (Shell Formation) – Marine organisms convert CO_2 into calcium carbonate ($CaCO_3$) for shells, locking away carbon.
- Challenges to the Ocean's Carbon Sink Capacity
  - Ocean Acidification – More CO_2 in seawater forms carbonic acid (H_2CO_3), lowering pH levels and harming coral reefs, shellfish, and marine life.
  - Warming Waters Reduce CO_2 Absorption – Warmer oceans hold less CO_2, weakening the ocean's role as a carbon sink.
  - Disruptions to Ocean Circulation – Changes in currents and stratification slow the mixing of surface and deep water, limiting CO_2 storage.

Dissolved inorganic carbon concentration (2018)



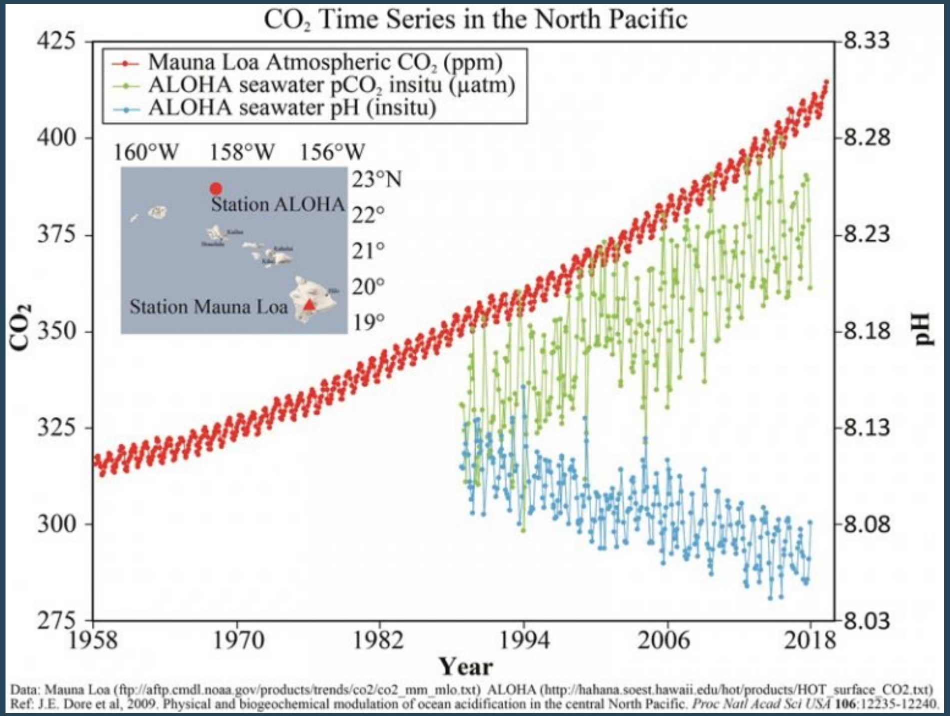
Source: geomar.de/en/research/irf/marine-carbon-sinks



Source: geomar.de/en/research/irf/marine-carbon-sinks

WHY SEAWATER IS A GAME CHANGER

- The Opportunity in Seawater
  - Provides Both CO_2 & H_2 for E-Fuels – Seawater electrolysis can extract CO_2 for fuel synthesis and hydrogen (H_2) through water splitting, eliminating the need for separate feedstocks.
  - Higher CO_2 Concentration than Air – Seawater contains ~100-140 times more CO_2 than air, making extraction more efficient than Direct Air Capture (DAC).
  - Readily Available & Renewable – The ocean is an unlimited CO_2 and H_2 reservoir, enabling large-scale, continuous fuel production.
  - Supports Carbon-Neutral E-Fuel Production – Extracting CO_2 from seawater and combining it with green hydrogen allows for net-zero synthetic fuels for aviation, shipping, and defense.
  - Strategic & Energy-Secure Source – On-site production for island nations, offshore platforms, and naval bases and reduces fuel transportation costs and enhances energy security.
  - Less Land Use vs. Biomass-Based CO_2 – Unlike biofuels, seawater CO_2 & H_2 extraction does not compete with agriculture or forests for resources.



Source: seagrant.soest.hawaii.edu/2021/05/19/changing-ocean-chemistry/

SAF from CO2 in seawater can help stabilize the curves

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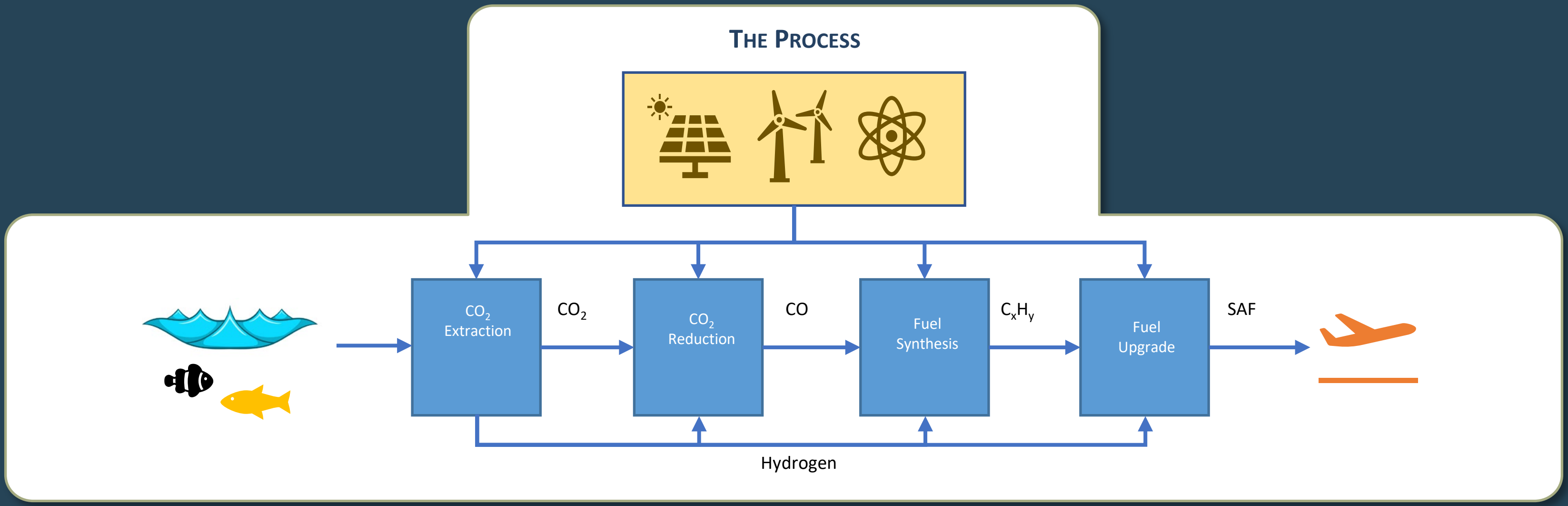
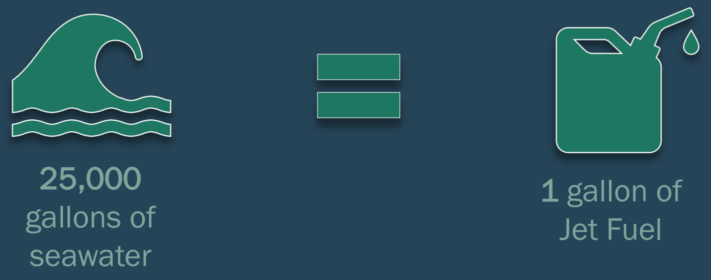
HOW THE SEA DRAGON PROCESS WORKS

- How the Seawater-to-Jet-Fuel (SJF) Process Works
  - A stream of seawater is brought into the system where it is acidified so that it releases the CO2
  - A second stream of seawater is brought into the system where it is electrolyzed to produce hydrogen
  - CO2 is reduced to CO
  - CO and Hydrogen are catalytically converted via Fischer Tropsch to hydrocarbons
  - The hydrocarbons are then upgraded using heat and pressure to produce SAF

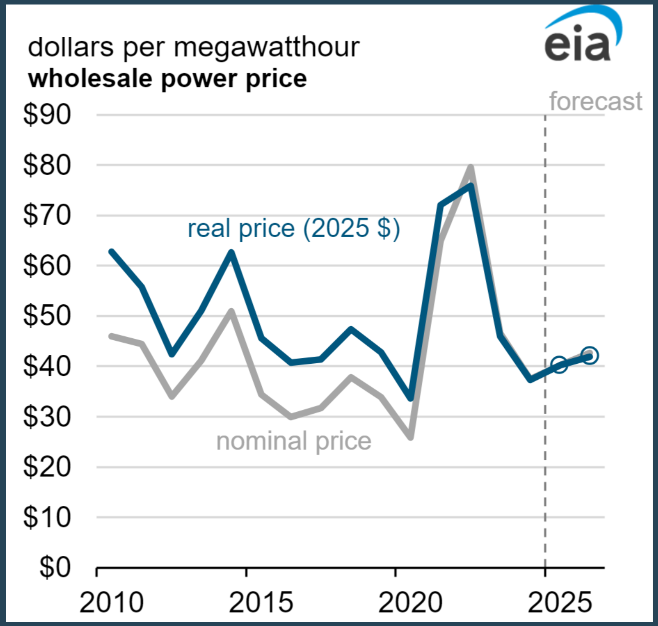


CHALLENGES TO SCALING SEAWATER SAF PRODUCTION

- Scaling Technology
  - Increasing the efficiency of electrolysis
  - Increasing the efficiency of CO2 extraction
  - Processes for cost-effective CO2 conversion
  - Powering processes with renewables to avoid indirect emissions
- Cost Considerations
  - Electricity costs dominate synthetic fuel production
  - Need for economies of scale and process optimization
  - Policy incentives and carbon pricing to make it competitive
- Infrastructure and Logistics
  - Integration with existing fuel supply networks
  - Storage and transportation of synthetic fuels
  - Regulatory hurdles and safety considerations



Average US Energy Cost



Source: eia.gov/todayinenergy/detail.php?id=64384

SEA DRAGON'S PROJECT AT NELHA

- Sea Dragon's Role at NELHA
  - Developing a pilot system to extract CO2 and H2 from seawater
  - Demonstrating sustainable hydrocarbon production
  - Testing feasibility for future scale-up
- Why This is an Important First Step
  - Validates the core seawater-to-fuel process
  - Provides real-world operational data
  - Attracts investment and government collaboration

Source: .aiche.org/resources/publications/cep/2018/april/best-practices-pilot-plant-layout

SEA DRAGON'S PROJECT AT NELHA

- Technological Leadership:
  - Investing in innovative fuel technologies positions the U.S. at the forefront of sustainable energy solutions.
- Hard-to-Decarbonize Sectors
  - Aviation, shipping, and heavy industry rely on energy-dense liquid fuels
  - Seawater-based hydrocarbons can replace fossil fuels without major infrastructure changes
- Supporting Island States Like Hawaii
  - Reducing import dependency on petroleum
  - Enhancing grid stability with local fuel production
  - Building a model for other island nations

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ACTION

- The Path Forward to Sustainable Fuel
  - Continued R&D and technology validation
  - Scaling production through public-private partnerships
  - Policy support for synthetic fuel adoption
- How You Can Get Involved
  - Collaboration and partnership opportunities
  - Advocacy for policy incentives

CLOSING

- Summary of key takeaways
  - Sustainable fuels must reduce net GHG emissions and use renewable carbon sources.
  - Global SAF mandates & U.S. incentives are driving market growth, with SAF set to play a major role in achieving net-zero aviation and HEFA as the dominant commercial pathway today.
  - Power-to-Fuels (PtF) is the next generation technology because it offers scalable synthetic fuel pathways for aviation, shipping, and heavy industry.
  - Seawater is an ideal feedstock for PtF—it contains 100-140x more CO_2 than air and provides both CO_2 & H_2 for e-fuel production
  - Challenges remain in scaling technology, reducing electricity costs, and blending regulations.
  - Sea Dragon Energy's project at NELHA is pioneering seawater-to-fuel technology, proving feasibility for future larger-scale deployment.
  - This is a strategic opportunity for Hawaii to lead in next-generation fuels, reduce import reliance, and serve as a model for island nations.

MAHALO

QUESTIONS?

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