U.S. NAVAL RESEARCH LABORATORY

OPERATIONAL ENERGY FROM SEAWATER

Materials Science & Technology Division

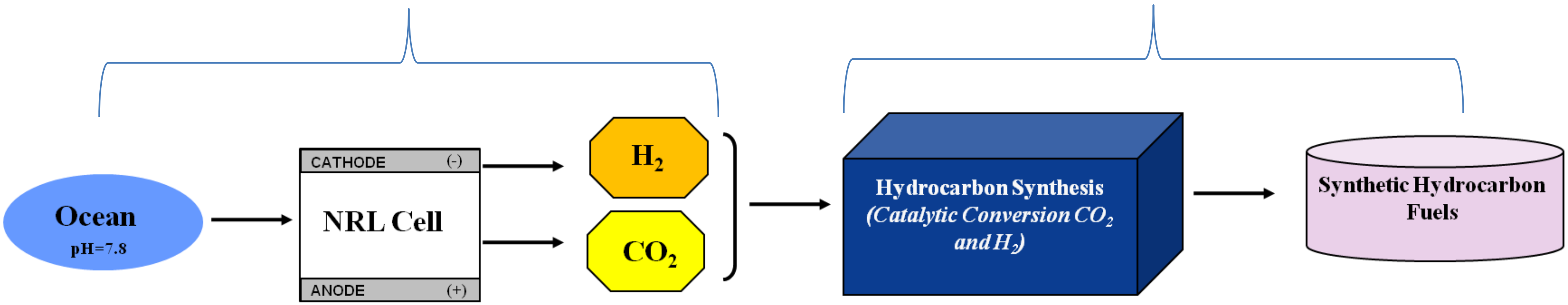
U.S. Naval Research Laboratory, Washington DC

May 2019

Principles of Operation

Step 1: CO_2 and H_2 Capture from Seawater

Step 2: Liquid Fuel Synthesis



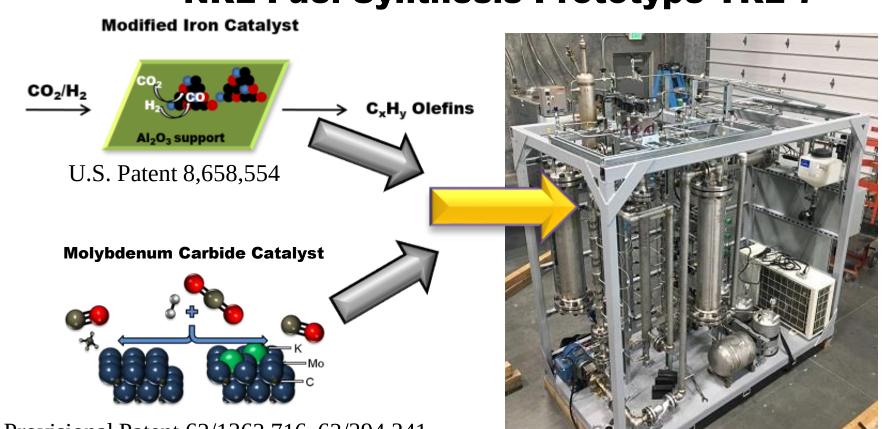
NRL Electrolytic Cation Exchange Module (E-CEM)

Catalytic Conversion of CO_2 and H_2 to Naval Platform Fuels

NRL E-CEM Prototype TRL 7

U.S. Patents 9,303,323 U.S. Patent 9,719,178

NRL Fuel Synthesis Prototype TRL 7



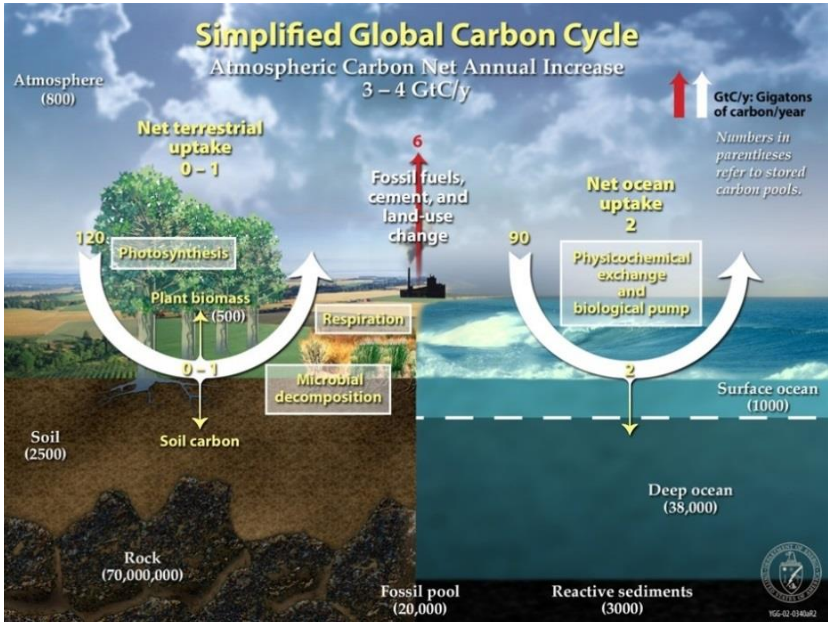
U.S. Patent 8,658,554

U.S. Provisional Patent 62/1362,716, 62/394,341

Step 1: Carbon Capture

Why capture CO_2 from Seawater?

- Renewable supply of CO_2 and H_2 feedstocks in Navy marine and littoral environments ~72% of the globe.
- CO_2 is 140 times more concentrated in seawater than air on a (w/v) basis (100 mg/L seawater vs 0.77 mg/L air).
- CO_2 from seawater is 1/3 (100 mg/L) the concentration of CO_2 found in stack gas from coal fire power plants (296 mg/L).
- Additional electrolysis equipment for production of H_2 is required if CO_2 is capture from air.

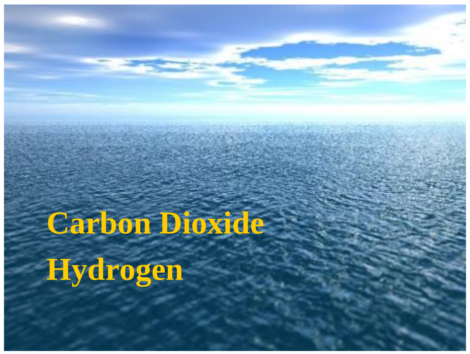


Genomics: GTL Roadmap, U.S. Department of Energy Office of Science, August 2005

Step 1: NRL Carbon Capture Approach

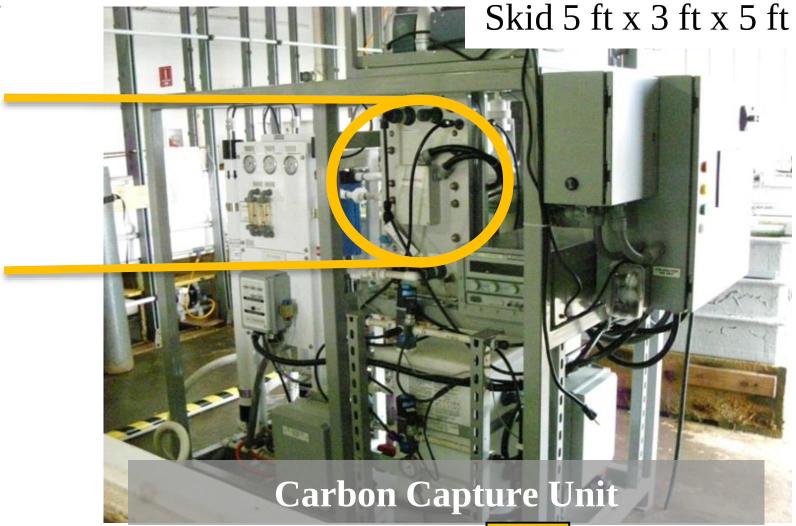
Capturing CO_2 and H_2 from Seawater

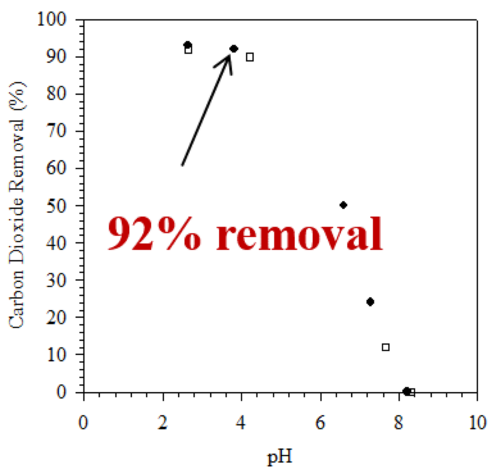
H_2O
(oceans or rivers)



Electrolytic Cation Exchange
Module E-CEM 4

Skid 5 ft x 3 ft x 5 ft





Carbon dioxide recovery from Seawater as a function of pH

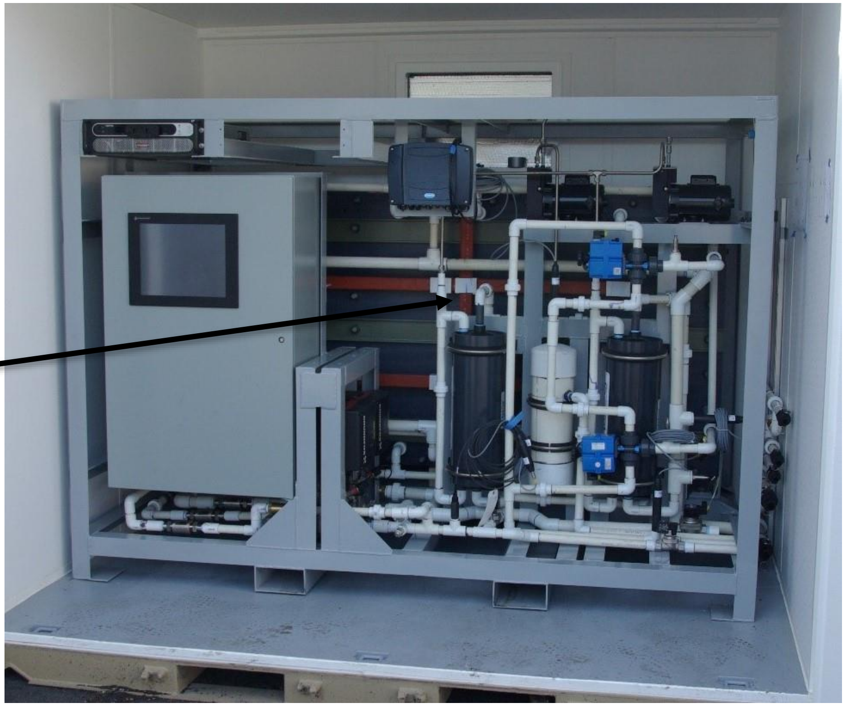
- 92% recovery of H_2 and CO_2 from seawater in a 3:1 ratio H_2 to CO_2
- A single E-CEM processes 7,200 gallons seawater/day
- Three E-CEM units to make 1 gallon fuel/day
- Power consumption to produce both H_2 and CO_2 is 14 kWhr/m^3
- Target power consumption 4.3 kWhr/m^3

Capturing CO_2 and H_2 from Seawater

Next Steps

(TRL 7)

U.S. Patents 9,303,323 U.S. Patent 9,719,178



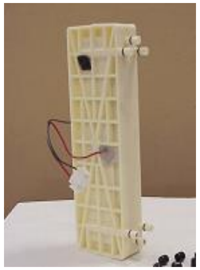
- A 50 x scale-up in electrolytic cation exchange module (E-CEM-5) for extracting carbon dioxide (CO_2) and producing hydrogen (H_2) from seawater.
- E-CEM-5 processes more than enough seawater (36,000 gal/day) to obtain feedstock (CO_2 and H_2) for up to 1 gallon/day of fuel.
- E-CEM 5 has been designed and built as a prototype system that will be the basis for future commercial applications
- Critical operational parameters determined in E-CEM 5 will establish the number, size, weight, and configuration of modules needed for a given fuel process.

U.S. NAVAL RESEARCH LABORATORY

NRL Technology Development

NRL Technologies Developed In Parallel

Electrolytic cation exchange module (E-CEM), 110 mL seawater (TRL 3)



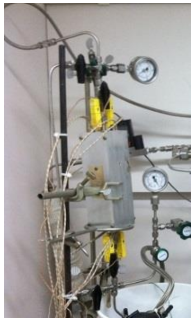
Scaling and integrating E-CEM to process 0.5 gpm seawater

E-CEM 4, 0.5 gpm seawater

Scaling E-CEM, 25 gpm (TRL 7)

CO_2 and H_2 Capture Process **2009 to 2019**

Laboratory scale production of hydrocarbons (TRL 3)



Flight using fuel from CO_2 and H_2

https://www.youtube.com/watch?v=lavz7AnKI8I

Commercial scale testing of NRL catalyst systems (TRL 6)

NRL Fuel Synthesis Skid (TRL 7)

Fuel Synthesis Process **2011 to 2019**

NRL Test and Evaluation Capabilities

“Proof of Concept” NRL Technology Capable of Producing Up To 1 Gallon of Fuel Per Day By Integrating Module Skid Platforms

NRL E-CEM Integrated Into Skid

- Independent mobile skid
- Contains control logic platform
- E-CEM processes 25 gallons/min seawater
- 21,000 L/day hydrogen (H_2)
- 7,000 L/day of carbon dioxide (CO_2)
- E-CEM dimensions 8ft x 4ft x 0.33ft
- Skid dimensions 8.7ft x 6.2ft x 4.7ft
- Conex container dimensions 9.8ft x 8.5ft x 8ft
- 480 VAC, 3 phase, 60 Hz and 100 Amps

NRL Gas Collection/Storage Skid

- Independent mobile skid
- Contains control logic platform
- Dries, compresses, and stores H_2 and CO_2 gases from E-CEM
- Skid dimensions 7.6ft x 7ft x 4ft
- 240 VAC, single phase, 50 Amp breaker

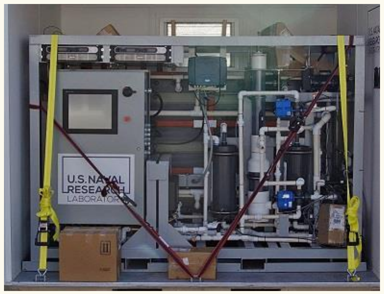
NRL Fuel Synthesis Skid

- Independent mobile skid
- Contains control logic platform
- Converts H_2 and CO_2 gases into up to 1 gpd liquid fuel
- Skid dimensions 8.8ft x 8.8ft x 3.9ft
- 208 VAC, 3 phase

NRL Plans

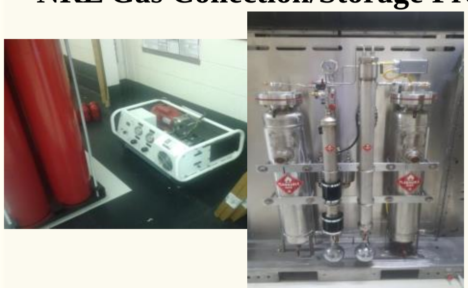
NRL Technologies

NRL E-CEM Prototype in Skid TRL7



- Single module processes 25 gallons/min seawater
- Produces up to 21,000 L/day hydrogen (H_2) and 7,000 L/day of carbon dioxide (CO_2) gas.

NRL Gas Collection/Storage Prototype Skid TRL7



- Dries, compresses, and stores H_2 and CO_2 gases from E-CEM

NRL Hydrocarbon Synthesis Prototype Skid TRL7

- NRL fixed-bed reactor skid prototype built for NRL that processes H_2 and CO_2 at 3:1 ratio to produce liquid hydrocarbons C_9-C_{16})

FY19 Plans

Test Evaluate E-CEM in Littoral Environment

- Process efficiencies at 50 X scale-up
- Electrical efficiencies
- Membrane efficiencies
- Polarity reversal on mineral deposition
- Power requirements
- H_2 and CO_2 production efficiencies
- Proof of design and scale-up

Design and Build Integrateable NRL-Gas Collection/Prototype Skid

- Test and evaluate system
- Determine efficiency of CO_2 and H_2 recovery and purity

Test Evaluate NRL Catalyst System

- Test and evaluate catalyst at higher flowrates and temperatures
- Down select catalyst system for liquid hydrocarbon demonstration
- Proof of design and scale-up

FY20 Plans

Demonstration/ Transitions

- Integrate individual technologies together for production of up to 1 gallon of liquid hydrocarbon per day from CO_2 and H_2 in seawater.
- Find transition partners and transition programs of record (FNC, INP, etc)

NRL Key West Facility

U.S. NAVAL RESEARCH LABORATORY

Conceptual Scaling of Fuel Producing Process

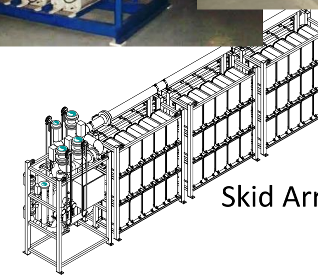
- Scaling carbon capture

A single E-CEM unit will process up to 36,000 gpd seawater

Ease of scaling by addition of modules

- "Proof of Concept" E-CEM designed to produce enough feedstock (H_2 and CO_2) to make 1.5 gpd of fuel
- Evaluation will lead to future small, lighter, more energy efficient E-CEM design

Concept Multiple E-CEM Skid



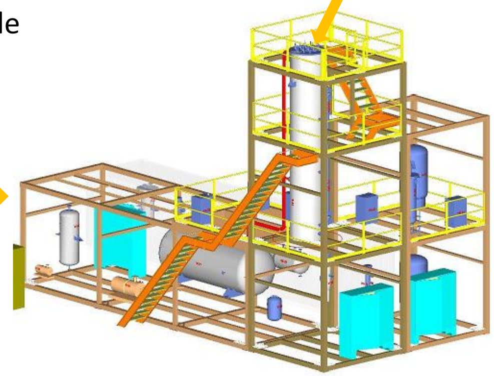
Skid Arrangement

- Scaling synthesis

OxEon Energy single 4" diameter reactor module (~ 2 gallon/day)

Ease of scaling by addition of reactor modules larger in diameter

7 single 4" diameter by 12' long reactors in module set (~2 barrel/day fuel)



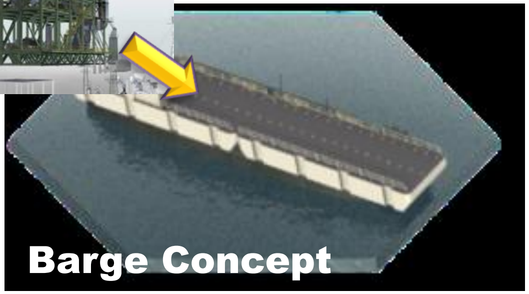
- Synthesis reactors are modular in design to optimize performance; reactor module are added to increase fuel production
- Fuel synthesis module for 2 barrel/day production is constructed and process in place at OxEon Energy (see pic)

- The key to scaling up to and beyond 2 barrel/day process is modularity of the E-CEM skid and fuel synthesis reactors
- Integrating, testing, evaluating, and modeling at "Proof of Concept" scale will result in the **optimal size and number of modules** needed for H_2 and CO_2 capture and fuel production up to and beyond 1000 gpd.
- The modular nature and design of the technology will support efficient manufacturing production, lowest cost of construction, ease of scaling, and insertion/arrangement on a sea-based platform

Operational Energy Scenarios

- Huntington Ingalls Newport News Shipbuilding (NNS) fuel ship concept based on NRL technologies could produce 350,000 gpd of fuel.
- The fuel cost ~ $2.00/gallon including $0.16/gal additive packages for drop-in JP5 and/or F76 diesel.
- A 1,600 ft ship could produce 600,000 gpd.

    - NNS Mobile Landing Platform (MLP) fuel producing concept based on NRL technologies could produce 30,000 gpd of fuel.



- Fuel producing plant concept pictured as a modular skid would be mounted on deck.
- Remaining front deck area open for air cushion vehicles to ferry fuel/cargo or other equipment ashore.
- Fuel producing plant transferable between platforms so can be mounted on a barge for added operational flexibility.

- Fuel producing plant on remote islands using pictured energy sources
- Fuel producing plant on lily pads or submersible platforms.

U.S. NAVAL RESEARCH LABORATORY

Operational Energy From Seawater Team

Dr. H. Willauer
6360.2 NRL

Dr. J. Baldwin
7316 NRL

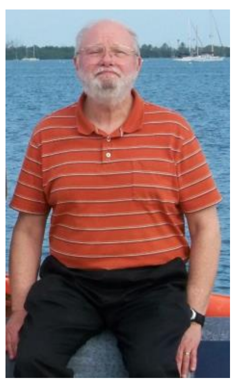
CDR/Dr. F. DiMascio
ONR S&T 112

Dr. J. Morse
6360.2 NRL

HES

University of Pittsburgh

Dr. R. Ananth
6185 NRL



Dr. D. Hardy
NOVA Research Inc.

Office of Naval Research Science & Technology ONR Reserve Component

As needed reserve member support with exceptional degree of operational/technical expertise and an advocate for the technological needs of the warfighter

evoqua WATER TECHNOLOGIES

OxEon energy

University of Rochester

Newport News Shipbuilding
A Division of Huntington Ingalls Industries