H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications

Topic Area 1: H2@ARIES—Integrated Hydrogen Energy System Testing/Validation

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Brief Company Descriptions

NREL: Federal laboratory dedicated to research, development, commercialization, and deployment of renewable energy and energy efficiency technologies.

Blue Sky Maritime Coalition: was recently launched as a non-profit, strategic alliance formed to accelerate the transition of waterborne transportation in the United States and Canada toward net-zero greenhouse gas emissions.

MIT-Sea Grant: will provide expertise and knowledge in overall ship design, onboard hydrogen-based power system and storage.

Keuka Energy: Keuka Energy is a leading industry expert dedicated to providing the world with renewable stored energy on a global scale.

Baker-Hughes (Nexus Controls): Industrial Control Systems and Services Partner for Advanced Automation and Efficiency

Georgetown County (South Carolina): Georgetown County is a coastal community that encompasses Georgetown Port Authorities.

W. Leigh and Associates is a 'Woman Owned Small Business' and 'Multi State Disadvantaged Business Enterprise (DBE) Firm' that offers a full line of equipment, services and materials for the commercial marine contractor.

Crowley Maritime: Crowley, founded in 1892, is a privately held, U.S.-owned and operated logistics, government, marine and energy solutions company headquartered in Jacksonville, Florida. Services are provided worldwide by four primary business units – Crowley Logistics, Crowley (Government) Solutions, Crowley Shipping and Crowley Fuels.

Avangrid Inc: is a leading, sustainable energy company with $38 billion in assets and operations in 24 U.S. states. AVANGRID has two primary lines of business: Avangrid Networks and Avangrid Renewables. Avangrid Networks owns eight electric and natural gas utilities, serving 3.3 million customers in New York and New England. Avangrid Renewables owns and operates a portfolio of renewable energy generation facilities across the United States.

McAllister Towing and Transportation Inc.: McAllister Towing & Transportation is celebrating 150 years in marine transportation. We operate a fleet of more than 75 tugboats, crew boats and barges in 17 locations along the U.S. East Coast from Portland, ME to San Juan, PR.

Moran Towing: Starting off in 1860 as a tugboat company, we have grown from those roots to become a dominant provider of towing services, bulk marine transportation, LNG support operations, and environmental recovery services.

National Rural Electric Cooperative Association (NRECA): NRECA is the national service organization that represents America's electric cooperatives.

Non-Proprietary Summary: NREL, in partnership with MIT-Sea Grant, Keuka Energy, Baker-Hughes (Nexus Controls), Georgetown County, Avangrid, Crowley Maritime, McAllister Towing and Transportation, Moran Towing, NRECA, Georgetown Country, and Blue Sky Marine Coalition, and W. Leigh and Associates is proposing to develop and evaluate renewable-based hydrogen production for intracoastal marine applications. Intracoastal marine applications have relied on legacy fossil fuels and provide suitable candidates for decarbonization opportunities. Intracoastal ports in the Great Loop are diverse communities that have endured lower air and water quality due to emissions and lacked green job opportunities. The project will develop suitable controllers (aka H2Grid controllers) and onboard electrification designs to address the technology barriers for the intended marine applications.

1.0 Abstract

Global warming and air pollution from fossil fuel burning in power generation and transportation represent a threat for the living species and the sustainability of future generations**.** The negative impact of emissions from ships exhaust into the atmosphere requires immediate actions. The Marine Environment Protection Committee (MEPC) from International Maritime Organization (IMO) adopted a strategy setting out a goal of reduction in annual greenhouse emissions from ships by at least 50% by 2050 (goal set by Biden's administration). The strategy defines actions to be taken in the international shipping sector at different levels and timelines. Among these actions, besides regulation, uptake of alternative low-carbon and zero-carbon fuels, implementation of novel and innovative emission reduction mechanisms, and alternatives leading to further improvement of energy efficiency of existing ships are projected as fundamental and plausible paths forward to achieve the emission goals. The intracoastal waterways have been an avenue of large volumes of commerce and trade in the USA since the early nineteenth century. The "Great Loop" is formed by water bodies and large rivers that interconnect to provide a pathway for large cargo and marine vessels to navigate inland. However, these routes are used by ships using fossil fuels as primary energy sources, thereby contributing significantly to the greenhouse gas emissions that negatively impact the interiors as well as incongruous to the ambitious climate goals set forward by the US and other nations in the Paris Climate Accord of 2018.

In this project, we propose the development of **H2Grid** – a terrestrial grid for green hydrogen production and refueling infrastructure – by optimally utilizing nearby renewable energy for powering the intracoastal marine vessels. The H2Grid project goals are: (1) to perform feasibility analysis and hardware-based evaluation for establishing hydrogen infrastructure along the intracoastal *Great Loop;* (2) to test, develop, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of the marine transportation sector significantly, even though traditionally it is perceived to be difficult to de-carbonize. This collaborative project has a well-rounded team including renewable energy providers and developers, maritime infrastructure owner and operators, coalitions supporting electrification, naval architects, regional economic development offices, etc. We are proposing H2Grid in response to the Topic Area 1: H2@ARIES - Integrated Hydrogen Energy System Testing/Validation

2.0 Project Description

a. Introduction

Global warming and air pollution from fossil fuel burning in power generation and transportation represent a threat for the living species and the sustainability of future generations [1-3]. The negative impact of emissions from ships exhaust into the atmosphere requires immediate actions. The Marine Environment Protection Committee (MEPC) from International Maritime Organization (IMO) adopted a strategy setting out a goal of reduction in annual greenhouse emissions from ships by at least 50% by 2050 [4] (This goal was also goal set by Biden's administration). The strategy defines actions to be taken in the international shipping sector at

different levels and timelines. Among these actions, besides regulation, uptake of alternative low-carbon and zero-carbon fuels, implementation of novel and innovative emission reduction mechanisms, and alternatives leading to further improvement of energy efficiency of existing ships are projected as fundamental and plausible paths forward to achieve the emission goals [5].

Figure 1: Great Loop used for intracoastal cargo navigation [6]

The intracoastal waterways have been an avenue of large volumes of commerce and trade in the USA since the early nineteenth century. The "Great Loop" is formed by water bodies and large rivers that interconnect to provide a pathway for large cargo and marine vessels to navigate inland (see Figure 1 [6]). However, these routes are used by ships using fossil fuels as primary energy sources, thereby contributing significantly to the greenhouse gas emissions that negatively impact the interiors as well as incongruous to the ambitious climate goals set forward by the US and other nations in the Paris Climate Accord of 2018. Hydrogen technologies could be the key to reduce carbon emissions in this difficult-to-decarbonize energy sector [7]. Yet, a holistic system analysis is required to achieve a better understanding of the costs and benefits of deploying hydrogen technologies in the shipping sector.

In this project, we propose the development of **H2Grid** – a terrestrial grid for green hydrogen production and refueling infrastructure – by optimally utilizing nearby renewable energy for powering the intracoastal marine vessels. The H2Grid project goals are: (1) to perform feasibility analysis and hardware-based evaluation for establishing hydrogen infrastructure along the intracoastal *Great Loop;* (2) to test, develop, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of the marine transportation sector significantly, even though traditionally it is perceived to be difficult to de-carbonize.

b. Clean Hydrogen Production: State of the Art

There are several core industrial sectors – such as marine logistics, aviation, and steel production – which are vital to the US and global economies – however, are extremely challenging to decarbonize. Hydrogen (for marine applications – hydrogen infrastructure from renewables of intracoastal highways) as a fuel can offer a viable alternative clean energy solution for these industries. Though several pilot projects have demonstrated the success of hydrogen for use in energy systems in microgrids or all-electric ships – there remains a need for understanding the efficacy of using hydrogen-powered energy systems for diverse range of use-cases, testing at

scale, and system for developing intelligent control systems for the hydrogen-powered energy systems.

Until recently, hydrogen as a fuel source was not considered a form “clean energy” because traditional means of producing hydrogen generate large volumes of CO2. Such processes of producing hydrogen known as gray and blue hydrogen, also generates greenhouse gases (GHG) [8, 9]. The rapidly declining cost of renewables has provided a sustainable and cost-effective alternative for large-scale hydrogen generation using electrolysis. Innovation is required in integration of renewables such as wind, solar, and marine hydrokinetics with hydrogen infrastructure to accelerate adoption of hydrogen technologies for intracoastal marine applications. For instance, holistic model-based system analyses could help to assess the economics of integrating hydrogen technologies with wind, solar, and marine energy. Indeed, these types of analyses could be used to identify the costs, e.g., Capex, Opex, etc., and performance, e.g., efficiency, conditions under which a given hydrogen production cost target is achieved, e.g., the DOE HFTO targets of $1 per kg H2 in a decade [10].

The fact that renewable energy can be used to generate carbon-free hydrogen can be seen as a positive feedback loop: green-energy to green-hydrogen. This has reshaped the industrial and political outlook towards hydrogen and has thus been creating policies and platforms aimed at leveraging green hydrogen as a significant opportunity to boost economic growth and move away from fossil fuels. H2Grid focuses on the design of hydrogen grids uniquely optimize for hydrogen generation and distribution for marine intracoastal applications. H2Grid for hydrogen production using renewables are unique as they do not follow the traditional utility power system requirements that could hinder the production of hydrogen. To this end, the Revenue Operation and Device Optimization (RODeO) model will be used to evaluate the economics of the integrated hydrogen, wind, solar, and marine energy system in view of hydrogen use in the shipping sector. The RODeO model explores optimal system design and operation considering different levels of integration, equipment cost, operating limitations, financing, and credits and incentives. RODeO is an open-source price-taker model formulated as a mixed-integer linear programming (MILP) model in the GAMS modeling platform and publicly available via GitHub (https://github.com/NREL/RODeO). The objective function is to maximize the net present value of the revenue for a collection of equipment at a given site.

c. Project Overview

Considering the progress made in hydrogen energy systems, and the challenges facing the world today, it is important to focus on a long-term and large-scale viability of hydrogen as a transformative clean energy fuel. There are research gaps that need to be filled to develop technologies that will help the US reach the Biden administration’s ambitious decarbonization goals by 2050. As the most polluting sectors have large dependence on fossil fuels or gray hydrogen, it is necessary to develop power systems that can use green hydrogen as a fuel. Such systems must integrate with a wide variety of energy systems (ranging from standalone systems such as tugboats to utility microgrids), to deliver the decarbonization value of green hydrogen.

As of today, prototypes of such microgrids have been tested, but not at scale, and not with the intent of rapidly deploying such energy systems, or for prototyping of controllers required for operating such energy systems. In this project, we focus on conducting feasibility analysis and hardware-based evaluation of hydrogen-based terrestrial power system to produce green hydrogen. The project team will leverage the expertise of tugboat operators such as Crowley Maritime, McAllister Towing and Transportation, Moran Towing, Blue Sky Marine Coalition, and W. Leigh and Associates, renewable deployment of marine applications such as Keuka Energy and Avangrid, and industrial control design leaders such as Baker-Hughes (Nexus Controls). These will complement NREL's expertise in at-scale evaluation of renewable and hydrogen-based power systems [11-13].

d. H2Grid Concept

H2Grid is a terrestrial grid for green hydrogen production and refueling infrastructure by optimally utilizing nearby renewable energy for powering the intracoastal marine vessels. H2Grid operates in a standalone mode of operation and uses a digital control system to optimize green hydrogen production based on fuel demand and the variability of renewable energy resources (shown in Fig. 2). H2Grid can incorporate other energy storage technologies with renewable energy resources and hydrogen electrolyzer for green hydrogen production. H2Grid can also operate in grid-connected mode with the area electric power system, based on prevailing operating conditions, for higher reliability, high availability, and improved resilience of hydrogen supply infrastructure.

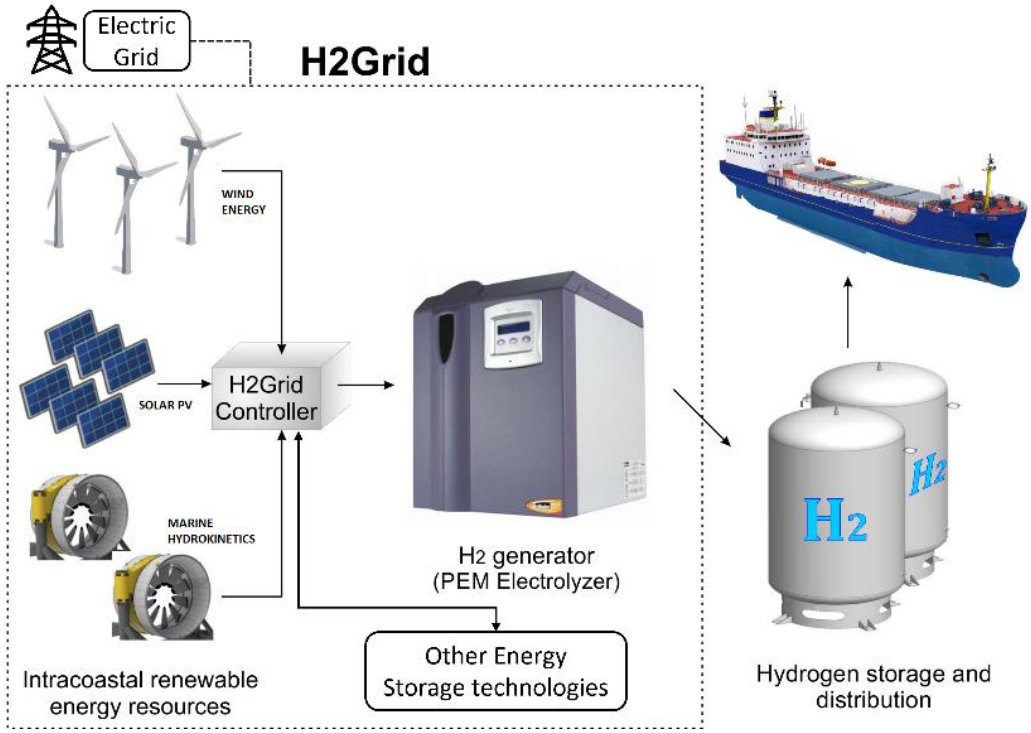

Figure 2 Overview of renewable-focused H2Grid Concept

The **H2Grid project goals** are:

1. To perform feasibility analysis and hardware-based evaluation for establishing hydrogen infrastructure along the intracoastal *Great Loop,*
2. To test, develop, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of the marine transportation sector significantly, even though traditionally it is perceived to be difficult to de-carbonize.

H2Grid will greatly help the sectors that are hard to decarbonize due to legacy energy systems that depend on fossil fuels:

1. Marine industries, freight and logistics operators, tugboat owners can electrify their energy demands using H2GRID, leading to reduction in intracoastal greenhouse gas emission because of operating these ships.
2. Disadvantaged communities are more likely to be impacted more heavily by negative consequences of climate change. H2GRID can rapidly decarbonize energy systems, bringing more energy equity and environmental justice to communities that bear the brunt of carbon pollution in the USA and across the world.
3. Since hydrogen can be stored or long periods, without degradation, H2GRID can harness variable renewable energy for marine applications.

e. Project Objectives

- Evaluation the renewable availability of intracoastal waterways and propose optimal locations based on availability of renewables and fueling needs of intracoastal marine traffic.
- Assessment of reduction in greenhouse gas emissions for ship transportation with integrating green H2-based propulsion technologies.
- Design hydrogen shipboard applications to address the unique power system design requirements and naval architecture. Work with naval architects, shipboard power systems to design hydrogen driven power systems for shipboard electrical ships.
- Develop non-linear scaling for H2Grid for design analysis based on renewable availability and hydrogen demand.
- Integration into the marine transportation applications, including refueling, and onboard power system working closely with MIT-Sea Grant's naval architects.
- Establish a pilot at-scale H2Grid at NREL's ARIES facility to design and optimize hydrogen generation from renewables.
- Technoeconomic analysis of hydrogen production from renewable energy and hydrogen distribution infrastructure at different intracoastal waterway locations.

3. Potential Technology Advancement

There are several challenges associated with using clean or green hydrogen as an energy resource, not only to naval and maritime applications, but also in general. This can be attributed

to the fact that in global markets, hydrogen commodity trade is not well formed, but systems and controllers are not typically designed for using hydrogen at scale as a primary fuel. However, by creating testbeds for testing and validation energy systems that are based on hydrogen can enable this market to mature and accelerate the decarbonization of critical, global commerce and trade industries.

Green hydrogen is currently more expensive than traditional production processes, roughly twice as much as gray hydrogen. According to a 2020 Global Energy Outlook report, the demand for green hydrogen will exceed 160 million metric tons by 2050 – causing the economies of scale to drastically reduce the cost (Fig. 3). Also, the fact the hydrogen storage units are bulkier and have higher safety requirements are some infrastructure bottlenecks that are challenging the development of this industry. It is also non-trivial to design and analyze infrastructure for multiple size capacities due to non-linear scaling behavior and complex interaction of various subsystems. Based on ongoing discussions with MIT Sea-Grant, a member Blue Sky Marine Coalition, different size and capacities based on renewable availability and hydrogen demand along intracoastal waterways pose challenges for analysis of scaling behavior.

The other challenge is to address the design and retrofit requirements for hydrogen-based marine power systems and hydrogen refueling infrastructure. This is addressed by incorporating inputs from tugboat operators and marine designers early in the design process to better understand the needs and challenges.

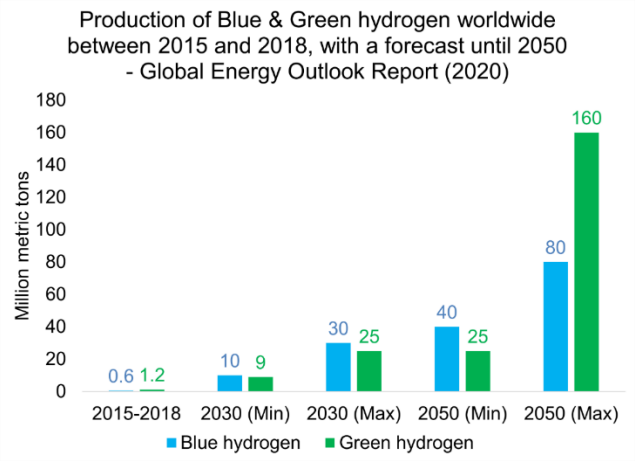

Figure 3 Production of Blue and Green Hydrogen worldwide (Reference: Global Energy Outlook Report, 2020)

There are several advantages and tailwinds associated with overcoming the challenges associated with overcoming the challenges related to hydrogen integration as an energy resource for intracoastal applications. Overcoming these challenges are critical and require technical support through testing and validation across other energy systems to make sure that all developments are targeted towards market and industrial demands. At-scale evaluation can

reveal the efficiency of green hydrogen an energy carrier or as feedstock – thereby creating more commercial interest in using the hydrogen fuel.

The greatest value of green hydrogen is its ability to be stored for long periods without degradation, and portability of stored energy. It can be used to store seasonal renewable electricity. Green hydrogen can not only help reduce the dependence of the steel sector on fossil fuels, but it can also serve as green fuel for heavy-duty marine transportation. To achieve this, the hydrogen production must be cost-effective, and this can be done by using renewable energy. According to The Dawn of Green Energy survey by Price Waterhouse and Coopers & Lybrand (PwC) in 2020 [14], the minimum cost to produce green hydrogen in rapidly declining across all economies around the world (Fig. 4). It is estimated that it would cost less than $1 to produce a kilogram of hydrogen in the US by 2050, lower than the equal cost of energy produced using fossil fuels today. This is in line with DOE's targets of hydrogen production of $1 per kg of H2 in one decade [10].

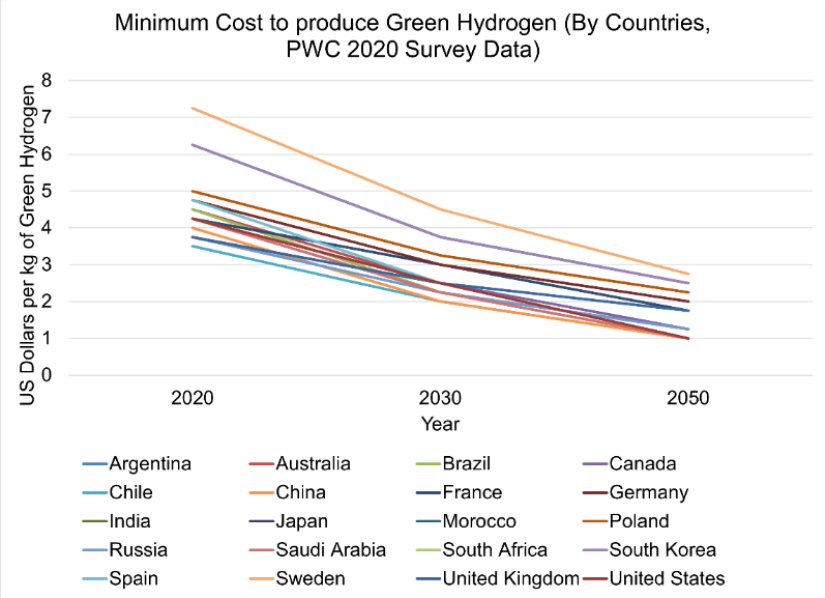

Figure 4 Minimum cost to produce Green Hydrogen is projected to go down by 2050 [14]

Recently, there have been several demonstrations of hydrogen powered energy systems serving local loads. In the United States, Southern California Gas have installed Bloom Energy's fuel cell based "energy servers" which functionally work as always-on microgrids in several operating sites for their business. In Hamburg, Germany, a 1 MW hydrogen powered microgrid was commissioned in 2019. In the same year, a 600-acre botanical garden facility in Pattaya, Thailand, adopted green-hydrogen powered energy systems from Enapter to power their infrastructure. Both companies, Enapter and Bloom Energy have seen year-on-year growth in their revenues and industrial adoption – heralding a new era of integrating hydrogen powered energy systems into mainstream applications. A similar approach can be

adopted for use of hydrogen as a fuel for marine transportation in United States along the Great Loop intracoastal waterways.

NREL ARIES offers a high-fidelity, real-time, configurable emulation environment where existing and future energy systems and controller technologies for integrating novel systems can be prototyped, developed, and de-risked. Such an approach has been used previously for design and validation of shipboard power systems by researchers from NREL and MIT-Sea Grant in this project team [11-12]. The project will leverage this previous development experience and learnings at NREL and using its large constellation of digital real-time simulators, digital twins of large power systems, hardware-in-loop capabilities to test actual devices, and hardware controllers. The integration of renewable-powered H2Grid with the evolving infrastructure of future shipboard power systems can be emulated and analyzed at-scale of up to 20 MW for multi-physics analysis of system interactions such as mechanical to electrical, electrical to molecule (hydrogen, liquid air, ammonia) as shown in Fig. 5. Using a digital multiplier at the digital real-time simulation facility at ARIES, the analytics can be scaled twenty times (20x) of the base capacity while taking the physics and all systemic non-linearities into account. This non-linear behavior based on at-scale validation will address the pressing challenge based on ongoing discussions with MIT Sea-Grant, a member Blue Sky Marine Coalition. The high-level design as an outcome of this project will provide an insight into the requirements for hydrogen infrastructure and help de-risk upgrades and adoption of green hydrogen in the all-electric ship infrastructure.

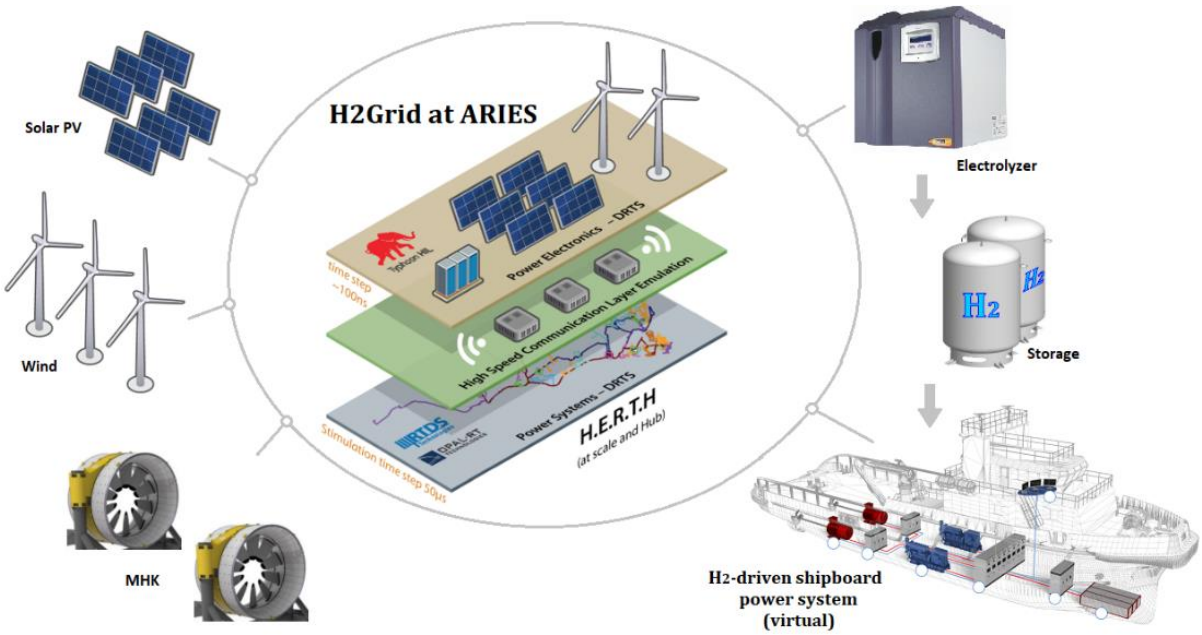

Figure 5 Emulation of H2 fueling infrastructure for intracoastal marine applications utilizing ARIES' actual PV, Wind, and Electrolyzer as hardware-in-the-loop.

4. Expected Benefits

The successful completion of the project will provide direct benefit to marine, hydrogen, renewable energy industry stakeholders through insights for the green hydrogen infrastructure. The major anticipated benefits are listed below.

Emission and fossil fuel use reduction

- Pathways to harness renewable energy potential near intracoastal waterways for green hydrogen production to help achieve DOE's goal of $1 per kg in one decade.
- Design of the zero-emission intracoastal refueling stations for developing the next generation of inland marine transportation network for N. America.
- Help companies achieve net carbon reduction goals.

Economic and industrial technology maturity

- Provide insight into hydrogen fueling needs and refueling infrastructure design for intracoastal marine applications.
- Marine industry participation to provide end-use & application-specific inputs for design and operation of H2-based power system.
- Design and validation of hydrogen production microgrid (H2Grid), which is different from traditional microgrids.
- Next generation hydrogen-driven all-electric ship architecture for marine applications.
- Ability of industry to participate in the clean port of the future.

5. Required Resources

a. Summary of Evaluation at NREL ARIES

In support of H2@Scale objectives, the following research will be conducted at ARIES.

- Assessment of renewable across intracoastal waterways for green hydrogen generation will be done through actual electrolyzer hardware operated through renewable wind output, solar PV output, and for MHK as representative profiles through digital real-time simulation (DRTS). Controllable Grid Interface (CGI) at ARIES will be used to emulate multi-MW level (up to 20 MVA) renewable variability and use actual 1.25 MW electrolyzer operation (balance of plant, hydrogen storage tanks) to evaluate performance and use it in design of **H2Grid** for hydrogen production.
- Development of H2Grid will utilized the hardware electrolyzer at ARIES for maximizing hydrogen production based on marine traffic itineraries (O&M schedules, fuel availability), hydrogen fuel requirements for shipboard power system, variability of intracoastal renewables, grid interchange schedules, etc. H2Grid hardware controllers will be evaluated as multiple CHIL to validate the real-time control interaction and operational performance of hydrogen production.
- At-scale evaluation of electrification of shipboard applications using hydrogen as a fuel will be tested as CHIL and PHIL of electrolyzer using CGI (up to 20 MVA) at ARIES. The onboard power system will consist of propulsion system, hydrogen turbine generation

system, hydro-state model, onboard electric distribution system and will be evaluated using DRTS, CHIL, and PHIL-based emulation.

- Techno-economic analysis of hydrogen-specific H2Grid for marine fuel will include performance evaluation based on actual hardware at ARIES to validate and iteratively inform economic (production cost) modeling and analysis to further refine assumptions on techno-economic analysis.

b. Project Tasks and Deliverables

Task-1 Establish a technical advisory board consisting of experts from industry will be created at the start of the project. The technical advisory board will consist of tugboat operators, naval architects, hydrogen generation and refueling operations.

Task-2 Renewable energy assessment across intracoastal waterways with focus on the Great Loop and utilizing the renewable resource data and profiles, marine traffic profiles, and marine infrastructure for feasibility analysis.

Task-3 Hydrogen infrastructure design and renewable integration will be done in close coordination with the project team with inputs from marine architecture, tugboat operators, electrolyzer designers and power system design experts.

Task-4 Onboard architecture design for hydrogen-based power system will leverage naval architects at MIT-Sea Grant with inputs from marine industry partners for design and operation.

Task-5 Hydrogen-based electrification for marine applications will leverage ARIES assets for renewable, hydrogen and controller development for H2Grid.

Task-6 At-scale evaluation and validation of H2Grid at NREL ARIES will use MW-scale hardware for hydrogen electrolyzer and multi-MW renewables for design, and validation as shown in Fig. 6.

Task-7 Techno-economic analysis of H2Grid and hydrogen production cost analysis will include quantification of economic benefits and emission reduction by adoption of clean hydrogen.

Final Deliverable: A technical report on the project that summarizes all the findings will be created and published.

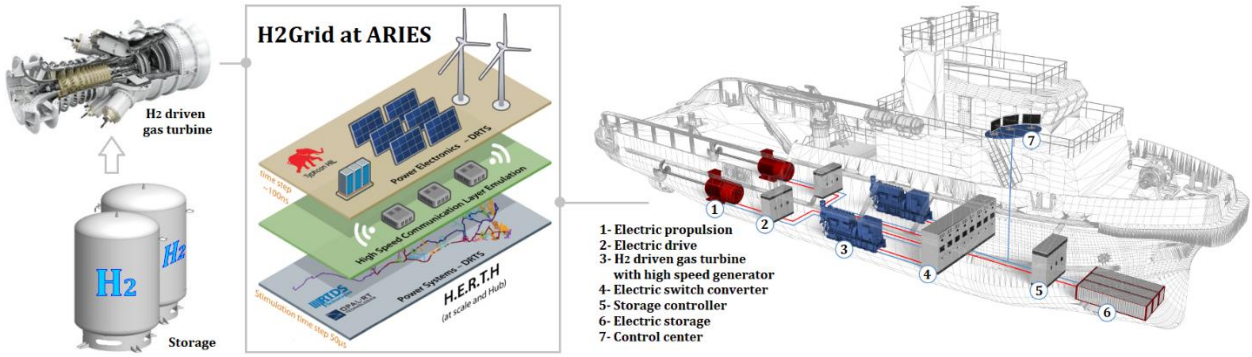

Figure 6 Hydrogen driven all electrical shipboard power system setup at NREL ARIES. The infrastructure included as a part of the H2 All-electric ship is illustrative only – the equipment is flexible and can be optimally located to maximize the ship's real-estate

6. Budget/Cost-Sharing

a. Budget

Task Description	Federal Share
Task-1: Formation of a technical advisory committee	$50,000
Task-2: RE assessment across intracoastal waterways	$150,000
Task-3: Hydrogen infrastructure design and RE integration	$150,000
Task-4: Onboard architecture design for hydrogen-based power system	$150,000
Task-5: Hydrogen-based electrification for marine applications	$200,000
Task-6: At-scale evaluation and validation of H2Grid at NREL ARIES	$350,000
Task-7: Techno-economic analysis of H2Grid and H2 production cost analysis	$200,000
Federal Share Total	**$1,250,000**

b. Cost Sharing: In-kind and cash/funds-in

Federal Share	Funds-In	In-Kind	Total cost-share	Project Total
$1,250,000	$178,571	$357,143	$535,714	$1,785,714

7. References

[1] Clean Shipping Coalition. Air pollution from ships, 2011. https://www.cleanshipping.org/download/111128_Air%20pollution%20from%20ships_New_Nov-11(3).pdf. Accessed 08/05/2019.

[2] International Maritime Organization, http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx. Accessed 07/05/2021.

[3] J. Houghton. Global Warming: The Complete Briefing, Cambridge University Press; 5 edition 2015.

[4] Blue Sky Marine Coalition, 2021. https://www.bluesky-maritime.org/. Accessed 06/28/2021.

[5] Specialized agency of the United Nations responsible for regulating shipping International Maritime Organization.

[6] International Maritime Organization (IMO). Adoption of The Initial IMO Strategy on Reduction of GHG Emissions from Ships and Existing IMO Activity Related to Reducing GHG Emissions in the Shipping Sector.

[7] S. J. Davis et al., "Net-zero emissions energy systems," Science, vol. 360, no. 6396, Jun. 2018, doi: 10.1126/science.aas9793.

[8] NOAA Article, "What is the Great Loop?," Available online: https://oceanservice.noaa.gov/facts/great-loop.html, Accessed: 06/27/2021.

[9] Microgrid Knowledge, "Hydrogen Becomes More Viable as a Microgrid Fuel" https://microgridknowledge.com/hydrogen-microgrid-fuel/ Accessed: 06/28/2021

[10] 2021 AMR Plenary Session, Dr. Sunita Satyapal, Director, U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office, June 7, 2021.

[11] H. Ali, R. Dougal, A. Ouroua, R. Hebner, M. Steurer, M. Andrus, J. Langston, K. Schoder, and R. Hovsapian, "Cross-platform validation of notional baseline architecture models of naval electric ship power systems," IEEE Electric Ship Technologies Symposium (ESTS 2011), Alexandria, Virginia, USA, April 10-13, 2011, pp. 78-83.

[12] F. G. Dias, J. A. Souza, J. C. Ordonez, J. V. C. Vargas, R. Hovsapian and J. V. Amy, "Notional all-electric ship thermal simulation and visualization," 2009 IEEE Electric Ship Technologies Symposium, 2009, pp. 539-546, doi: 10.1109/ESTS.2009.4906564.

[13] NREL ARIES: Advanced Research on Integrated Energy Systems, Available, online: https://www.nrel.gov/aries/, Accessed: 07/19/2021.

[14] "The Dawn of Green Energy survey by Price Waterhouse and Coopers & Lybrand," PwC report, Available, Online: https://www.strategyand.pwc.com/m1/en/reports/2020/the-dawn-of-green-hydrogen/the-dawn-of-green-hydrogen.pdf, Accessed: 07/19/2021.

8. Team

Rob Hovsapian, Ph.D.
National Renewable Energy Laboratory

Education:
Ph.D., Mechanical Engineering, Energy Systems - Florida State University
M.S., Mechanical Engineering, Control Systems - Florida State University
B.S., Mechanical Engineering - University of Alabama

Employment History

3/2019 - Present	Research Advisor, **National Renewable Energy Laboratory**
2011 – 3/2019	Department Manager, Power and Energy Systems, **INL, Idaho Falls, ID**
2010- Present	Affiliated faculty Department of Mechanical Engineering, **FAMU/FSU College of Engineering, Tallahassee, FL**
2017- 2020	Affiliated faculty Department of Electrical and Computer Engineering, **Colorado State University, Fort Collins, CO**
2003-2012	Assoc. Scholar Scientist / *Program Manager of the Center for Advanced Power Systems*, **Florida State University, Tallahassee, FL**
1994-2003	*Program Manager*, **Northrop-Grumman Mission Systems / Northrop-Grumman Space**
1989-1994	*Computer Integrated Manufacturing Manager,* **General Dynamics**

Relevant Publications:
On Google Scholar:
https://scholar.google.com/scholar?hl=en&as_sdt=0%2C6&q=Rob+Hovsapian&btnG=&oq=Rob+

1. "Grid-Scale Ternary-Pumped Thermal Electricity Storage for Flexible Operation of Nuclear Power Generation under High Penetration of Renewable Energy Sources" Rob Hovsapian, Julian D. Osorio, Mayank Panwar, Chryssostomos Chryssostomidis and Juan C. Ordonez, Journal - Energies 2021, 14(13), 3858; https://doi.org/10.3390/en14133858
2. "Leveraging National Laboratory Assets to Address Stability Challenges due to Declining Grid Inertia Using Geographically Distributed Electrical-Thermal Co-Emulation" R. Hovsapian, M. Panwar, J. D. Osorio, M. Mohanpurkar, D. Maloney, Paper 97 – Clean Energy Conference 2019
3. "Real-time Modeling and Testing of Microgrid Management System for the Blue Lake Rancheria - Performance Assurance Report," Manish Mohanpurkar; Yusheng Luo; Rob Hovsapian; Anudeep Medam, INL/EXT-17-44130, March 2018.
4. " Modeling, Simulation and Optimization of a Solar System for Water Heating and Absorption Cooling" J.C.Vargas, J.C. Ordonez, R. Hovsapian, F. G. Dias, Energy Sustainability 2008 , Jacksonville, FL 2008
5. "Thermodynamic Optimization of a Solar System for Cogeneration of Heat and Cold" R. Hovsapian ,J.C.Vargas, et al. Journal - International Journal of Energy Research, v. 32, p. 1210-122, 2008
6. "Modeling and Simulation of the Thermal and Psychrometric Transient Response of All Electric Ships, Internal Compartments and Cabinets," J.C.Vargas, J.C. Ordonez, and R. Hovsapian, Summer Computer Simulation Conference - SCSC2007, July 15-18, 2007, San Diego CA

Patents:

- Vargas, Jose Viriato Coelho, Gardolinski, Jose Eduardo Ferreira da Costa, Ordonez, Juan Carlos, Hovsapian, ZohRob, 2014, "Alkaline Membrane Fuel Cell," Pub. No. US 2014/0087275 A1, March 27, 2014.
- Vargas, Jose Viriato Coelho Vargas, Balmont, Wellington, Stall, Alexandre Stall, Miaiano, Andre Bellin, Ordonez, Juan Carlos, Hovsapian, ZohRob, Dilay, Emerson, 2012, "Photobioreactor system," Pub. No. US 2012/0088296 A1, April 12, 2012.

Digital Profiles:
LinkedIn

Resume

Mayank Panwar

phone: +1 970-286-9740
email: mayank.panwar@nrel.gov, mpanwar@ieee.org

Research Focus Areas

Power and energy systems modeling, real-time simulation, hardware-in the-loop experiments, electric microgrid operations, electrical-thermal co-simulation, advanced computing for grid operation, wide-area protection and control.

Education

Colorado State University, Fort Collins, CO

Doctor of Philosophy, Electrical and Computer Engineering	01/2013 – 05/2017
Master of Science, Electrical and Computer Engineering	08/2011 – 12/2012

Dr. A. P. J. Abdul Kalam Technical University, India

Bachelor of Technology, Electronics and Instrumentation Engineering	08/2003 – 05/2007

Employment History

Researcher-III, National Renewable Energy Laboratory, Golden, CO	01/2020 – present
Research Scientist, Idaho National Laboratory, Idaho Falls, ID	11/2017 – 01/2020
Postdoctoral Research Associate, Idaho National Laboratory, Idaho Falls, ID	02/2017 – 11/2017
Summer Intern, Idaho National Laboratory, Idaho Falls, ID	05/2014 – 08/2014
Graduate Student Researcher, National Renewable Energy Laboratory, Golden, CO	05/2013 – 05/2014
Graduate Research Assistant, Colorado State University, Fort Collins, CO	09/2011 – 12/2016
Engineer (O&M), NTPC Limited, Ramagundam, India	08/2007 – 08/2011

Selected Publications

- M. Sinha, R. Kadavil, **M. Panwar**, T. Hussain, S. Suryanarayanan, SMS Alam, M. Papic, "An Integrated High-performance Computing and Digital Real-time Simulation Testbed to Benchmark Closed-loop Load Shedding Algorithms in Power Systems,2020 52nd North American Power Symposium (NAPS), 2021.
- R. Hovsapian, J. D. Osorio, **M. Panwar**, C. Chryssostomidis, J. C. Ordonez, "Grid-Scale Ternary-Pumped Thermal Electricity Storage for Flexible Operation of Nuclear Power Generation under High Penetration of Renewable Energy Sources, Energies, Multidisciplinary Digital Publishing Institute, 2021.
- J. D. Osorio, **M. Panwar**, C. Chryssostomidis, R. Hovsapian, A. Rivera-Alvarez, M. Mohanpurkar, S. Chanda, H. Williams, 'Harnessing offshore renewable energy sources via energy carriers for waste heat recovery and thermal efficiency improvement,' Applied Energy Symposium: MIT A+B, May 22-24, 2019, Boston, USA.
- **M. Panwar**, S. Suryanarayanan, R. Roche and R. Hovsapian, "A Performance Metric for Co-Optimization of Day-Ahead Dispatch and Reserves in Electric Microgrids," in 13th IEEE PowerTech, June 23-27, 2019, Milan, Italy.
- **M. Panwar**, S. Chanda, M. Mohanpurkar, Y. Luo, F. Dias, R. Hovsapian, A. K. Srivastava, "Integration of flow battery for resilience enhancement of advanced distribution grids," International Journal of Electrical Power & Energy Systems, Volume 109, 2019, Pages 314-324, ISSN 0142-0615.
- **M. Panwar**, S. Suryanarayanan, and R. Hovsapian, "A multi-criteria decision analysis-based approach for dispatch of electric microgrids," in Intl. J. of Electrical Power and Energy Systems, vol. 88, pp. 99–107, Jun. 2017.
- **M. Panwar**, B. Lundstrom, J. Langston, S. Suryanarayanan, and S. Chakraborty, "An overview of real time hardware-in-the-loop capabilities in digital simulation for electric microgrids," in North American Power Symposium (NAPS), 2013, 2013, pp. 1–6.
- O. Nayak, A. Thant, **M. Panwar**, "PHIL Testing of Integrated Supercapacitor Energy Storage System for Providing Blackstart and Wide-Area Stability Services through DER Plants," RTDS Applications and Technology Conference, Denver, CO, May 14-16, 2019.
- M. Mohanpurkar, R. Krishan, **M. Panwar**, S. Vyas, L. Slezak, N. Rodrigues, A. Datta, A. Meintz, R. Hovsapian, "Enabling Seamless Integration of EV Charging Infrastructure with Weak Electric Grids," in IEEE Transportation Electrification Conference (ITEC-India), 2019.
- M. Mohanpurkar, M. Panwar, S. Chanda, M. Stevic, R. Hovsapian, V. Gevorgian, S. Suryanarayanan, A. Monti, "Distributed real-time simulations for electric power engineering," Cyber-physical social systems and constructs in electric power engineering, 451-486,2016.

SAYONSOM CHANDA
National Renewable Energy Laboratory | Simulations Engineer
Phone: (509) 432 9525 | sayonsom.chanda@nrel.gov

EDUCATION

Ph.D., Electrical Engineering, Washington State University, 2018
MS, Electrical Engineering, Washington State University, 2015

PROFESSIONAL EXPERIENCE

National Renewable Energy Laboratory
Simulations Engineer | 2021 – Present
Developing a large-scale real-time simulation cluster to study the evolution of the power grid infrastructure after the integration of novel, clean energy technology and diverse distributed energy resources

Sync Energy AI
Chief Technology Officer | 2020 – 2021
Developed a satellite-imagery based smart vegetation tracking system to reduce vegetation related power outages, upto 96% accuracy in outage forecasts, improved resilience of clients by several units of SAIDI.

National Grid
Senior Data Scientist | 2018 – 2020
Electric load forecasting (short term and long term) for diverse business use-cases for New York and Massachusetts

Idaho National Laboratory
Research Engineer | 2015-2016
Development of microgrid models for testing and validating microgrid controllers

SELECTED PUBLICATIONS

1. S. Chanda and A. K. Srivastava, "Defining and Enabling Resiliency of Electric Distribution Systems With Multiple Microgrids," in IEEE Transactions on Smart Grid, vol. 7, no. 6, pp. 2859- 2868, Nov. 2016.

2. S. Chanda, F. Shariatzadeh, A. Srivastava, E. Lee, W. Stone, J. Ham, Implementation of nonintrusiveenergy saving estimation for Volt/VAr control of smart distribution system, in Electric Power Systems Research, Volume 120, 2015, Pages 39-46

3. P. Bajpai, S. Chanda and A. K. Srivastava, "A Novel Metric to Quantify and Enable Resilient Distribution System using Graph Theory and Choquet Integral," in IEEE Transactions on Smart Grid, 2017.

PATENTS

1. US63/041,800: System And Method for Computing Probabilistic Correlations Between Events And Component Failures In Complex Infrastructure Assets

2. US63/041,126 System and method for modeling, simulating, and querying complex systemsusing conversational artificial intelligence

Michael Cosgrove Peters

Centennial, CO -- (303) 524-0864 -- Michael.Peters@nrel.gov

PROFESSIONAL BACKGROUND

National Renewable Energy Laboratory (NREL) - Golden, CO — June 2010 to Present

Hydrogen Infrastructure Engineer — (January 2013 to Present)

- Lead on DOE's HyBlend initiative which addresses pipeline material compatibility, life-cycle assessment, and technoeconomic analysis as it relates to blending hydrogen in the natural gas infrastructure.
  - Project team comprises of 6 national laboratories and over 20 industry partners
- Principal investigator on NREL's fast filling hydrogen station data collection and modeling project focused on the medium- and heavy-duty fuel cell electric vehicle market
  - Project aims for a hydrogen transfer from station to vehicle of 60 kg in less than 6 minutes
  - Fast fill data supports thermodynamic modeling that explores temperature and pressure profiles in the FCEV storage system
- Project lead for the Dispenser Reliability project which performs accelerated life testing of hydrogen components that are typically found in a light-duty hydrogen dispenser
- Principal investigator for light-duty hydrogen fueling model that looks at the pressure and temperature profiles of the hydrogen fueling process from the high-pressure storage to the fuel cell electric vehicle
- Lead on applied research team focused on the integration of renewable electricity to produce hydrogen via PEM and alkaline electrolysis for use in hydrogen stations or energy storage.
- Participated in design, installation and commissioning of Colorado's first high-pressure, light-duty hydrogen refueling station capable of fueling fuel cell vehicles to 700 bar.
- Developed NREL's electrolyzer stack test bed with a small team of NREL engineers. The test bed enables PEM electrolyzer stack testing up to 500 kW by providing variable electrolyzer balance of plant systems to accommodate different size PEM stacks.
- Contributed to the design, fabrication, testing, analysis, and programming on a device that is used to determine accuracy of commercial hydrogen dispenser flow meters for the sale of hydrogen in the state of California.

Engineering Intern — June 2010 to January 2013

- Provided daily operational support and troubleshooting of electrolyzers, compressors, storage, 350 bar dispensing, and balance-of-plant systems.

ACADEMIC BACKGROUND

University of Colorado at Boulder — December 2012
Bachelor of Science in Mechanical Engineering
Lockheed Martin Engineering Management Program, Undergraduate Certificate

PUBLICATIONS & PRESENTATIONS

- Peters, Michael. "Renewable Hydrogen Production for Use in Hydrogen Fuel Cell Vehicles," Presentation at the ACT Expo, Dallas, TX, May 2015
- Eichman, J.; Harrison, K.; Peters, M. (2014). Novel Electrolyzer Applications: Providing More than Just Hydrogen. 35 pp.; NREL Report No. TP-5400-61758.
- Peters, M.; Harrison, K (2014). Innovative Drying Technique for Wind and Solar Powered Electrolysis. ASME 2014 12th Fuel Cell Science, Engineering & Technology Conference. Boston, MA. June 2014

Sam J Sprik
Team Lead and Principal Investigator

Education and Training

M.S., Mechanical Engineering, University of Michigan, Ann Arbor, MI 1998
B.S., Mechanical Engineering, Calvin College, Grand Rapids, MI 1995

Professional Experience

2017 – Present Team Lead and Principal Investigator, Center for Integrated Mobility Sciences, NREL, Golden, CO

- Integration & Safety team lead in the Hydrogen Production, Power and Storage group, focusing on project management and strategic direction, assessment of current hydrogen infrastructure and vehicle applications.
- Recent projects involve demonstrating electrolyzer operation for multiple objectives including grid stabilization and connection to renewables.

1998-2017 Research Engineer, Transportation and Hydrogen, NREL, Golden, CO

- Principal Investigator for projects within the National Fuel Cell Technology Evaluation Center including Next Generation Hydrogen Stations. Outputs: aggregation of real-world data across multiple projects.
- Developed software to compare H2 fueling data with standards.
- Managed project to update a vehicle framework Simulink model for analyzing advanced hydrogen storage concepts in vehicles.
- Collected and analyzed vehicle data (CAN) and custom-built MATLAB software to view signals, calculate key performance parameters, and patch missing data.

1995-1998 Research and Teaching Assistant, University of Michigan, Ann Arbor, MI

- Included work in manufacturing quality at Chrysler Technology Center in Auburn Hills, MI.

1992-1995 Technical Engineer, Herman Miller Inc, Custom Choices, Zeeland, MI

- Created and modified designs and bill of materials for non-standard office furniture.

Publications

- Multiple data analysis publications at www.nrel.gov/hydrogen/technology-validation.html
- S Sprik, J Kurtz, C Ainscough, G Saur, M Peters, "Next Generation Hydrogen Station Composite Data Products: Retail Stations, Data through Quarter 2 of 2017", National Renewable Energy Laboratory, Golden, CO, November 2017
- K Wipke, S Sprik, J Kurtz, T Ramsden, C Ainscough, G Saur, "National fuel cell electric vehicle learning demonstration final report", National Renewable Energy Laboratory (NREL), Golden, CO, 2012

15013 Denver W Pkwy MS ESIFA238-02 Golden, CO 80401
Email: OmarJose.GuerraFernandez@nrel.gov. Mobile: (765) 3372047

OMAR JOSÉ GUERRA FERNÁNDEZ

EDUCATION

- **Ph.D. Chemical Engineering** 2013 – 2017, Purdue University (Advisor: Professor Gintaras Reklaitis), GPA 3.91/4.0, West Lafayette, Indiana, United State. Thesis: "*Management of Energy Supply Chains under Uncertainty*".

- **M.Sc. Chemical Engineering**, 2008-2009, University of São Paulo (USP), São Paulo, Brazil. Thesis: "*Formulation of Process Models for Production Planning in Oil Refineries*".

- **B.Sc. Chemical Engineering**, 1999-2005, Industrial University of Santander (UIS), Bucaramanga, Colombia. Thesis: "*Parameter Estimation of a 5-lump Kinetic Model for Fluidized Catalytic Cracking (FCC) Based on Data from a Riser Pilot Plant*".

EMPLOYMENT HISTORY

- **Research Engineer** 2020 - Present
  National Renewable Energy Laboratory (NREL), Power System Design and Planning (PSDP) Group, Golden (CO), United States.
  - Techno-economic assessment of integrated solar PV and hydrogen production systems.
  - Techno-economic assessment of electrolysis-based hydrogen.
  - Techno-economic assessment of hydrogen and natural gas blending.
  - Modeling and optimization of grid energy storage and Power-to-X technologies (Electroreduction of carbon dioxide (CO_2)).
- **Postdoctoral Researcher** 2017 - 2020
  National Renewable Energy Laboratory (NREL), Power System Design and Studies (PSDS) Group, Golden (CO), United States.
  - Analysis of industrial and commercial electric utility rates.
  - Techno-economic assessment of electrolysis-based hydrogen.
  - Techno-economic assessment of integrated solar PV and hydrogen production systems.
  - Market-based coordination of electricity and natural gas networks.

AWARDS & AFFILIATIONS

- College of Engineering Outstanding Research Award, Purdue University, 2017.
- CAST Director's Student Presentation Award Finalist (invited oral presentation), 2016.
- Eastman Graduate Travel Award, 2014.
- NSF Travel Grant for the Shale Gas Monetization Workshop, 2014.
- PhD fellowship (2013-2018), COLCIENCIAS (Purdue-Colciencias scholarships).
- Master fellowship (2008-2009), CNPq, Ministry of Science and Technology, Brazil.
- Top 10 (694 students) in the Superior Education State Exams (ECAES), 2004.
- Distinguished student, second academic period of 2002.

Manish Mohanpurkar, Ph.D.
National Renewable Energy Laboratory

Education:

Ph.D., Electrical Engineering, Power Systems - Colorado State University
M.S., Electrical Engineering, Power Systems – Oklahoma State University
B.E., Electrical Electronics, and Power – Government College of Engineering, Aurangabad, India

Employment History

7/2021 - Present	Senior Researcher, Integrated Devices & Systems, **National Renewable Energy Laboratory**
10/2018 – 7/2021	Technology Advisor, Vehicle Technologies Office, Department of Energy, **Washington DC**
03/2017 – 09/2018	Group Lead, Energy Systems, **Idaho National Laboratory, Idaho Falls, ID**
02/2015 – 03/2017	Scientist, Energy Systems, **Idaho National Laboratory, Idaho Falls, ID**
01/2014 – 02/2015	Postdoctoral Research Associate, Energy Systems, **Idaho National Laboratory, Idaho Falls, ID**

Selected Relevant Publications:

Google Scholar: https://scholar.google.com/citations?user=8X87GdMAAAAJ&hl=en

1. "Leveraging National Laboratory Assets to Address Stability Challenges due to Declining Grid Inertia Using Geographically Distributed Electrical-Thermal Co-Emulation" R. Hovsapian, M. Panwar, J. D. Osorio, **M. Mohanpurkar**, D. Maloney, Paper 97 – Clean Energy Conference 2019
2. "Real-time Modeling and Testing of Microgrid Management System for the Blue Lake Rancheria - Performance Assurance Report," **M. Mohanpurkar**, Yusheng Luo, Rob Hovsapian, Anudeep Medam, INL/EXT-17-44130, March 2018.
3. "Electrolyzers Enhancing Grid Flexibility," **M. Mohanpurkar**, Y. Luo, D. Terlip, F. Dias, K. Harrison, J. Eichman, R. Hovsapian, J. Kurtz, Energies, November 2017, Volume 10, Issue 11, pp 1-17.
4. "Integration of flow battery for resilience enhancement of advanceddistribution grids," M. Panwar, S. Chanda, **M. Mohanpurkar**, Y. Luo, F. Dias, R. Hovsapian, A.Srivastava, International Journal of Electrical Power and Energy Sys-tems, Volume 109, January 2019, pp. 314 - 324
5. "Big Data Analytics in Smart Grids: State-of-the-Art, Challenges, Opportunities, and Future Directions," Bhattarai, S. Paudyal, Y. Luo, **M. Mohanpurkar**, K. Cheung, R. Tonkoski,R. Hovsapian, K. Myers, R. Zhang, P. Zhao, M. Manic, S. Zhang, X. Zhang, IET Smart Grid, 05 February 2019, pp. 15.

Relevant Past Projects:

1. 'Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation' funded by the Fuel Cell Technologies Office, DOE.
2. 'Integration and impact analysis of eXtreme Fast Charging with the electric grid,' funded by the Vehicle Technologies Office, DOE.
3. 'Integrated Hydropower and Storage Systems Operation for Enhanced Grid Operations' funded by the Water Power Technologies Office, DOE.
4. 'Dynamic Simulations for Large Scale Electric Power Networks Using Multiple RTDS' funded by the Laboratory Directed Research and Development, Idaho National Laboratory.
5. 'H2@Scale Experimental and Core Capability' funded by the Fuel Cell Technologies Office, DOE.
6. 'Demonstrating a Secure, Reliable, Low Carbon Community Microgrid at the Blue Lake Rancheria,' funded by the California Energy Commission.

Chryssostomos Chryssostomidis Resume

Professor Chryssostomidis was educated at King's College, University of Durham, UK, and the Massachusetts Institute of Technology (MIT) Cambridge, MA, USA. He joined the MIT faculty in 1970 and retired in 2017. During his 47 years at MIT he served in various positions including Head of the Department of Ocean Engineering and Director of the MIT Sea Grant College Program. He was also the founding director of three Sea Grant laboratories including the Autonomous Underwater Vehicles (AUV) Laboratory. Out of this lab, Bluefin (a commercial company) was spun-off to commercialize *Odyssey* the AUV created by the MIT Sea Grant AUV lab. His work was recognized by MIT by awarding him two career chairs, the NAVSEA Research Professor from the department of Ocean Engineering, and the chair of Teaching Innovation from the School of Engineering. In addition, in 1991 he was awarded the Henry L. and Grace Doherty Professor of Ocean Science and Engineering, a lifetime MIT chair.

In order to gain a broader professional experience Professor Chryssostomidis utilized his summers at the early part of his career working for industry or government organizations. This included design offices specializing in ship design and the Gulf Research and Development Company to gain an understanding of offshore design. Similarly, the location of where to spend his sabbaticals and leaves of absence were carefully selected to enhance and broaden his professional experience. For example, in order to gain an understanding of how research is funded by the US Government he applied and secured an IPA appointment at the Office of Naval Research, London, UK

Professor Chryssostomids has mentored at least 150 graduate students and 40 postdoctoral fellows. He is the author of over 150 technical publications and the holder of three patents. He was awarded the Captain Joseph H Linard Prize for his paper submission to the Transactions of the Society of Naval Architects and Marine Engineers.

Professor Chryssostomidis is an active member of the professional community and has served in a number of capacities including the National Academy of Engineering and the National Research Council committee for the Analysis of Causes of the Deepwater Horizon Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future (interim report *http://www.nap.edu/catalog.php?record_id=13047,* 2010). More recently he became a founding member of the Blue Sky Maritime Coalition, a nonprofit corporation committed to accelerating the transition of waterborne transportation in the United States and Canada towards net zero greenhouse gas emissions.

Since his retirement Professor Chryssostomidis has stopped teaching but continues to be active in research and thesis supervision. Currently he is actively involved in the supervision of six Master of Science theses and is the Principal Investigator of three research projects. The first is The All -Electric Ship, an ONR-funded research project started in 2001 and funded to 2026. The second is industry funded research on the Decarbonization of the Cargo Shipping Fleet, terminating in 8/2021. The third is funded by NREL and is a seed project on Physics Informed Machine Learning terminating in 9/2021.

HENNA TREWN

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https://www.linkedin.com/in/htrewn

EXPERIENCE

AVANGRID — Boston, MA
Lead Innovation Analyst | CEO Office — 2021 – Present
- Manage portfolio of strategic projects and partnerships across the business, including green hydrogen demonstrations

CANDELA RENEWABLES — Remote
Project Development & Origination Summer Associate — Summer/Fall 2020
- Coordinated and drafted responses to requests for proposals for solar and storage projects; evaluated contract and pricing risks
- Developed storage dispatch modeling tool; reviewed utility resource plans to demonstrate business case for new market entry

ENGIE U.S. SERVICES — Remote
Business Development & Strategy MBA Intern — Summer 2020
- Presented $100M business case for integrated fleet electrification services to chief strategy officer; interviewed vendors/financiers to evaluate partnership opportunities; quantified market size, policy drivers, and value proposition

CITY OF HOUSTON, OFFICE OF SUSTAINABILITY — Houston, TX
Environmental Defense Fund Climate Corps Fellow | EVolve Houston Electrification Coalition — Summer 2019
- Created an implementation plan for 13 electric bus deployments estimated to generate $1.7M in lifetime savings for the City
- Authored the City's first Volkswagen settlement grant application for $85K; identified $2M in additional funding

THE BRATTLE GROUP — San Francisco, CA
Senior Research Analyst | Regulation & Energy Markets Practice (Promoted from Research Analyst in 2017) — 2015 – 2018

Project Management and Leadership
- Oversaw a team of three analysts to produce significant portions of a report that informed utility client's ratemaking strategy
- Managed rebuttal case for international arbitration focused on three wind farms; supervised junior analyst on financial modeling; coordinated with client and experts to draft report, hearing presentation, and cross-examination questions
- Streamlined valuation model used by at least 13 clients; served as model expert and trained 30 consultants across six offices
- Mentored and monitored development of incoming analysts on modeling, writing, and auditing over six-month training period

Data Analysis and Research
- Modeled project valuation for seven renewable plants under multiple regulatory scenarios in support of initial testimony in international arbitrations; estimated $220M in financial damages to advise arbiter's determination of investor awards
- Developed five models illustrating a gas pipeline's business risks; analysis accepted as key evidence in rate case settlement
- Advised wind company's market entry decision by building power plant supply/demand model to forecast capacity prices
- Wrote case studies on market power mitigation to assist development of new electricity market in Asia-Pacific region

CALIFORNIA DEPARTMENT OF FINANCE — Sacramento, CA
Executive Fellow | Capital Fellows Program — 2014 – 2015
- Negotiated sensitive budget decisions on $1M in cap-and-trade funding projects as liaison to other state agencies

EDUCATION

MIT SLOAN SCHOOL OF MANAGEMENT — Cambridge, MA
Master in Business Administration — June 2021
- Selected for AVANGRID Innovation Challenge; assessed viability of firm (24/7) clean energy product using hybrid portfolio
- Quidnet Energy, Consultant; presented utility procurement model and ways to improve storage tech competitiveness to CEO

HARVARD KENNEDY SCHOOL OF GOVERNMENT — Cambridge, MA
Master in Public Policy — May 2021
- Completed thesis analyzing policies and utility programs to accelerate heat electrification in National Grid's service territories
- Selected for Climate Leaders Program and Climate Solutions Lab Course; analyzed feasibility of novel district heating system
- Evaluated distributed energy resource deployment and economic value using New York utility data for course term paper

UNIVERSITY OF CALIFORNIA, BERKELEY — Berkeley, CA
Bachelor of Arts in Political Economy (Highest Distinction in General Scholarship) — May 2014

Herbert Williams

hwilliams@keukaenergy.com
Keuka Energy - 171 Comfort Road, Palatka, FL 32177
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386.328.2470

Career Highlights

- Youngest licensed United States Coast Guard Captain in Alaska (1969).
- Designed and built the first U.S. flagged twin hull fuel tanker-Tanzy lea (1970)
- Designed the first vacuum system for offloading shrimp at Kodiak Alaska (1968)
- Inventor, *Open center turbine technology* (1973)
- Inventor, *Wave Piercing-Lady Jessica* (1976)
- Founded and patented the *RimDrive*™ technology (2005).
- Founder and CEO, *OpenHydro-US*, later sold and renamed *OpenHydro* (2005).

Work Experience

Commercial Fisherman, Alaska, USA ***1967 – 1987***

- Captain, USCG, Alaska – captained king crab boats for 9 years while fishing for halibut, shrimp, salmon, and herring during the off seasons.
- Chartered his boat for oil and gas industry to do seafloor imaging in vicinity of oil platforms in Cook Inlet, AK.

Independent Researcher and Contractor, Florida, USA ***1985 – 1992***

- Explored options for using the ocean's waves and currents as a source of energy and focused primarily on the Gulf Stream current off the coast of Florida.
- Built a research and development facility in Palatka, Florida on the St. Johns River in 1992, funded from his marine construction business.
- Worked with engineers who were furnished by NASA on a program to study the Gulf Stream current in and around Florida and the Gulf of Mexico.
- Worked with the University of Florida on improving the design of an electrolyzer to produce hydrogen.

Independent Researcher, Florida, USA ***1993 – 2004***

- Entered a six-year CRADA with U.S. Naval Surface Warfare (Carderock, Division). ***2001 – 2006***
- Six open-center turbine prototypes were constructed and tested in tidal currents.
- Has 16 patents.
- Founded and patented the *RimDrive*™ technology that takes power from the tip of propeller blades instead of their central shafts.
- Founded and has patent pending on the method of liquifying gases using mechanical torque and rpm of a wind machine.

Founder and CEO, OpenHydro-US, Palatka, Florida, USA ***2005***

Founder and CEO, Keuka Energy (keukaenergy.com), Palatka, Florida, USA ***2006***

- One of the Keuka group of companies to research how and if the *RimDrive*™ could play a role in reducing the cost of stored energy with hopes of cutting the planets dependency on fossil fuel.
- Installed an open-center turbine at Orkney Island, Scotland being the first grid connected tidal turbine. (2006)
- Designed a wind turbine for land Under a new development agreement with Florida State University (FSU) – Center for Advanced Power Systems. (2009)
- Contracted with the Florida State University – Center for Advanced Power Systems to map the power curve of the RimDrive turbine against nominal three blade designs. The test occurred in Lubbock, Texas at Texas Tech University. (2011 – 2012)
- Pursuing using offshore wind to produce liquid air and hydrogen as stored energy. (***2015 – present***)

Personal Details

- Born: 1943 in Pahokee, Florida, USA.

Emma Stewart | Chief Scientist
National Rural Electric Cooperative Association Research (NRECAR)
Phone: 571-327-4272 | E-mail: emma.stewart@nreca.coop

RESEARCH AND PROFESSIONAL EXPERIENCE:

National Rural Electric Cooperative Association (NRECA)
Chief Scientist | Feb 2021 - Present
Leading the NRECA Research team, with expertise in distribution integration

Lawrence Livermore National Laboratory
Associate Program Leader | 2017 - 2021
Led over $15M in DOE, DOD funded grid integration projects, on resilience, cyber interconnection and distributed resource integration, include novel restoration and black start processes

Lawrence Berkeley National Laboratory
Deputy Grid Integration Group Leader, Research Scientist | 2013 - 2021
Led projects and team in advanced sensing and analytics, funded by DOE & the California Energy Commission

DNV-GL (Formerly BEW Engineering)
Senior Engineer | 2009 - 2013
Led the distribution modeling and analysis team and high renewable penetration studies for large utility customers including HECO and SMUD.

PUBLICATIONS:

Roberts, C., Scaglione, A., Jamei, M., Gentz, R., Peisert, P., Stewart E.M., "Learning Behavior of Distribution System Discrete Control Devices for Cyber-Physical Security" in IEEE Transactions on Smart Grid, vol. 11, no. 1, pp. 749-761, Jan. 2020.

Morales-Rodriguez, M.E., E. Stewart and P. L. Fuhr, "Multiparameter Outstation Agents for Cyber-Physical Electrical Grid Security and Restoration" 2018 IEEE International Symposium on Technologies for Homeland Security (HST), Woburn, MA, USA, pp. 1-7.

A. von Meier, E. Stewart, A. McEachern, M. Andersen and L. Mehrmanesh, "Precision Micro-Synchrophasors for Distribution Systems: A Summary of Applications," in *IEEE Transactions on Smart Grid*, vol. 8, no. 6, pp. 2926-2936, Nov. 2017

PATENTS, COPYRIGHTS, AND SOFTWARE SYSTEMS:

Stewart, Kara, Roberts et al, "Contextually Supervised Generation State Estimation (CSGSE)" U.S. Patent 62/311,319, March 21, 2016.

EDUCATION AND TRAINING

2009, PhD, Electrical Engineering, University of Strathclyde, Glasgow, UK
2004, MEng, Electrical and Mechanical Engineering, University of Strathclyde, Glasgow,UK

9. Commitment Letters

MIT SEA GRANT COLLEGE PROGRAM

Chryssostomos Chryssostomidis
Professor of Mechanical and Ocean Engineering Department of Mechanical Engineering Massachusetts Institute of Technology

July 19, 2021

Dr Rob Hovsapian
15013 National Renewable Energy Laboratory
Denver West Parkway, Golden, Colorado 80401

Dear Dr. Hovsapian and Team,

Re: Letter of Support for proposal titled **"H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications"**

Massachusetts Institute of Technology (MIT) Sea Grant College Program is pleased to extend support of the proposal "H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications" for the H2@Scale July 2021 GRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).

This proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and the next generation of the "Clean Port of the Future" using renewable energy. This will optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also

- Develop, test, de-risk and deploy hydrogen powered resilient shipboard power systems that can be used to significantly reduce the emissions of this marine transportation sector, and
- Establish H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which in turn will reduce overall cost of clean hydrogen production to meet DOE's goal of 1 dollar per kg in one decade.

Our R&D team at MIT Sea Grant will provide expertise and knowledge in overall ship design, onboard hydrogen-based power system and storage. MIT Sea Grant, as a member of the Blue Sky Maritime Coalition, will coordinate with other members of the Blue Sky Coalition for inputs on marine infrastructure and architecture and potential participation in the CRADA agreement.

Upon award selection and successful negotiation of the CRADA agreement, MIT will be supporting this research with contributions and involvement as R&D partners over the three-year period of the project. We anticipate a collaborative relationship with this project team with exchange of information and R&D results to mutually inform programs.

We look forward to the collaboration with NREL and team to address this topic.

Sincerely,

C. Chrysostomidis

Dr. Chryssostomos Chryssostomidis
Professor of Mechanical and Ocean Engineering
Doherty Professor in Ocean Science and Engineering (Emeritus)

MIT Sea Grant College Program | 12 Emily Street NW98 | Cambridge, MA 02139 P: 617-253-7131 | Email: chrys@mit.edu | C: 617-852-3127

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

July 19, 2021

Re: Letter of Support for proposal titled **"H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications"**, a multi-industry R&D proposal led by NREL.

Dear Dr. Hovsapian and Team,

On behalf of the Georgetown County Economic Development, South Carolina, I am pleased to submit this letter in support of the proposal titled 'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).

Georgetown County isn't your typical coastal County. Our commerce history reads more like an industrialized port city; rather than just a coastal resort. And we have a great coastline too! As the best kept secret in the Southeast, we have a port, land to build, industrial parks and sites ready for industry. Additionally, our community understands and supports heavy industry. The Port of Georgetown, located in our county, is situated approximately 60 miles north of Charleston.

According the US Census of 2019, Georgetown boasts diversity (>46%) of more than twice as compared to national average of 23%.

Given the diverse community of our county, we have two primary goals for getting involved in this project:

- **Environmental Justice:** understanding and assessing the potential impact of technologies such as green hydrogen can have on our community and reduce emissions
- **Green Jobs Creation:** create jobs in our community by potentially bringing green hydrogen technologies for shipping applications

The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. We would like to work with the project team to assess the potential green hydrogen production for our port operations and marine applications. The H2Grid project will also perform evaluation activities:

- Assess hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

Upon award selection and successful negotiation of the CRADA agreement, Georgetown County will be supporting this research over the three-year period of the project. The exact form of participation will be decided during the CRADA agreement negotiation.

Georgetown County looks forward to the collaboration with NREL and team.

Sincerely,

Brian Tucker
Director of Economic Development

Moran Towing and Transportation
50 Locust Avenue
New Canaan, CT 06840-4737

Edward J. Tregurtha
President and CEO
Office: (203) 442-2896
Mobile: (203) 442-2809
tedt@morantug.com

July 16, 2021

VIA E-MAIL

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

Re: Letter of Support for proposal titled **"H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications"**, a multi-industry R&D proposal led by NREL.

Dear Dr. Hovsapian and Team,

We at, Moran Tug, are pleased to submit this letter in support of the proposal titled **'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).** One of the oldest companies in America, Moran has survived and prospered by continuously reinventing itself for over 160 years. Starting off in 1860 as a tugboat company, we have grown from those roots to become a dominant provider of towing services, bulk marine transportation, LNG support operations, and environmental recovery services.

The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.

We, at Moran, would like to provide technical expertise and know how on the energy requirements of tug boat operations and associated fueling requirements. This will serve as key inputs to the design evaluation of H2Grid at NREL ARIES in collaboration with marine industry, naval architects, Blue Sky Marine coalition as partners on this project to better inform development, at-scale testing, and validation for accelerated progress towards DOE's clean hydrogen cost reduction goals. There are strong synergistic activities between this proposal and Moran's current interest in renewable energy infrastructure for marine applications at NREL's ARIES facility.

Upon award selection and successful negotiation of the CRADA agreement, Moran Tug will be supporting this research with up to $10K per year funds-in cost share contribution over the three-year period of the project . The exact cost share contribution will be decided during the CRADA agreement negotiation.

We look forward to the collaboration with NREL and team to address this topic.

Sincerely,

Edward J. Tregurtha
President & CEO
Moran Towing and Transportation

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

July 16, 2021

Re: Letter of Support for proposal titled "H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications", a multi-industry R&D proposal led by NREL.

Dear Dr. Hovsapian and Team,
We at, Keuka Energy, are pleased to submit this letter in support of the proposal titled 'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES). Keuka Energy is a leading industry expert dedicated to providing the world with renewable stored energy on a global scale. Keuka Energy has an expertise in the fields of coastal renewable energy, marine hydrokinetic design/deployment , floating wind turbine design/deployment, and tug operations. The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.
We, at Keuka Energy, would like to provide controls design and integration expertise for marine hydrokinetic and floating wind turbines for hydrogen generation in a marine enviroment. There are strong synergistic activities between this proposal and Keuka's current interest in the controls design, integration and validation of floating wind turbines, marine hydrokinetic and renewable energy infrastructure for marine applications.
Upon award selection and successful negotiation of the CRADA agreement, Keuka Energy will be supporting this research with up to $282,000 USD in-kind cost share contribution and $115,000 funds-in cost share contribution over the three-year period of the project. The exact cost share contribution to be decided during the CRADA agreement negotiation with NREL.

We look forward to a successful collaboration with NREL ARIES team to address this topic. Feel free to reach out to me for any additional information.

Sincerely,

Herbert Williams
CEO Keuka Energy LLC

*Corporate Office: 171 Comfort Road * Palatka, FL 32177 Phone: (386) 328-2470 Fax: (386) 326- 1155*
*Manufacturing Facility: 561 Keuka Road * Interlachen, FL 32148*

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

July 19, 2021

Re: Letter of Support for proposal titled **"H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications"**, a multi-industry R&D proposal led by NREL.

Dear Dr. Hovsapian and Team,
We at, W. Leigh Associates, are pleased to submit this letter in support of the proposal titled 'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES). W. Leigh & Assoc., Inc. offers a full line of equipment, services and materials for the commercial marine contractor. We are a 'Woman Owned Small Business and Multi-State Disadvantaged Business Enterprise with wide varying offerings in the marine cargo space.
The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.
We, at W. Leigh Associates, would like to provide expertise and experience regarding maritime fueling requirements for tug boats and potential conversion towards hydrogen-based fueling. The design evaluation of H2Grid at NREL ARIES in collaboration with marine industry, naval architects, Blue Sky Marine coalition as partners on this project to better inform development, at-scale testing, and validation for accelerated progress towards DOE's clean hydrogen cost reduction goals. There are strong synergistic activities between this proposal and W. Leigh Associates current interest in the controls design, integration and validation of renewable energy infrastructure for marine applications.
Upon award selection and successful negotiation of the CRADA agreement, W. Leigh Associates will be supporting this research with up to $72,000 USD in-kind cost share contribution and $36,000 funds-in cost share contribution over the three-year period of the project. The exact cost share contribution will be decided during the CRADA agreement negotiation.

We look forward to the collaboration with NREL and team to address this topic.

Sincerely,

From: "gene wleigh.com" <gene@wleigh.com>
Date: Monday, July 19, 2021 at 07:51
To: "Hovsapian, Rob" <Rob.Hovsapian@nrel.gov>
Subject: RE: DOE NREL - H2Grid Proposal

CAUTION: This email originated from outside of NREL. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Rob,

I am in agreement, subject to acceptable final negotiations, after award. I am not in a location where I can print and sign this today so I hope this email will be sufficient.

Best regards,

K. Gene Gotcher
(904) 449-1187 Cell
(386) 312-0433 Office
gene@wleigh.com

Nexus Controls
a Baker Hughes business

1800 Nelson Road
Longmont, CO 80501
303-678-2611

To: Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

From: M. Stefan Maier
Director of Product Management

Re: Letter of Support for proposal titled "**H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications**", a multi-industry R&D proposal led by NREL.

July 16, 2021

Dear Dr. Rob Hovsapian,

We at, Nexus Controls, a Baker Hughes business, are pleased to submit this letter in support of the proposal titled '**H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications**' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).

The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.

We, at Nexus Controls, a Baker Hughes business, would like to provide digital solutions in support of energy management, as well as Vessel, H2 Generator (PEM Electrolyzer), and offloading control solutions for production and onboard marine applications. The design evaluation of H2Grid at NREL ARIES in collaboration with marine industry, naval architects, Blue Sky Marine coalition as partners on this project to better inform development, at-scale testing, and validation for accelerated progress towards DOE's clean hydrogen cost reduction goals. There are strong synergistic activities between this proposal and Baker Hughes' current interest in the controls design, integration, and validation of hydrogen infrastructure for marine applications at NREL's ARIES facility.

Nexus Controls
a Baker Hughes business

1800 Nelson Road
Longmont, CO 80501
303-678-2611

Upon award selection and successful negotiation of the CRADA agreement, Nexus Controls – a Baker Hughes will be supporting this research with up to $75,000 USD in-kind cost share contribution and $36,000USD funds-in cost share contribution over the three-year period of the project. The exact cost share contribution will be decided during the CRADA agreement negotiation.

We look forward to the collaboration with NREL and team to address this topic.

Sincerely,

M. Stefan Maier

CROWLEY®
People Who Know®

16 July 2021

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado 80401

Re: Letter of Support for proposal titled **"H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications",** a multi-industry R&D proposal led by NREL

Dear Dr. Hovsapian and Team,

We at Crowley Maritime Corporation are pleased to submit this letter in support of the proposal titled 'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).

The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly
- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.

Crowley Maritime Corporation is willing to provide technical expertise and knowledge on the energy requirements of intracoastal vessel operations and fueling requirements as requested. This knowledge will serve as key inputs to the design evaluation of H2Grid at NREL ARIES in collaboration with marine industry, naval architects, and Blue Sky Marine coalition as partners on this project to better inform development, at-scale testing, and validation for accelerated progress towards DOE's clean hydrogen cost reduction goals.

We look forward to the collaboration with NREL and team to address this topic.

Yours respectfully,

CROWLEY MARITIME CORPORATION

Paul Manzi

Vice President, Crowley Shipping Marine Assets

crowley.com/social

9487 Regency Square Boulevard
Jacksonville, Florida 32225
crowley.com

BLUE SKY
MARITIME COALITION

Dr. Rob Hovsapian
National Renewable Energy Laboratory
15301 Denver West Parkway
Golden, Colorado

July 19, 2021

Re: Letter of Support for proposal titled "**H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications**", a multi-industry R&D proposal led by NREL

Dear Dr. Hovsapian and Team,

Blue Sky Maritime Coalition is pleased to submit this letter in support of the H2GRID proposal for the H2@Scale July 2021 CRADA Call. The proposal is to develop H2Grid, which will effectively design hydrogen based microgrid for intracoastal marine applications optimizing the use of renewable energy by converting green energy into green hydrogen. This R&D is needed to provide a comprehensive understanding of green hydrogen production from renewables. H2Grid will optimized for hydrogen generation and distribution for marine intracoastal applications which is critical to successfully scaling green hydrogen as a clean energy solution for marine vessels in the United States intracoastal waters.

We, at Blue Sky Maritime Coalition (the Coalition), are excited to collaborate with NREL and your team as a research partner on the H2Grid proposal for the Department of Energy- Hydrogen and Fuel Cell Technologies Office (HFTO) – H2@Scale CRADA Call. There are strong synergistic activities between the H2Grid proposal and the Coalition's current interest in the hydrogen infrastructure R&D. Specifically, the Blue Sky Maritime Coalition recently launched as a non-profit, strategic alliance formed to accelerate the transition of waterborne transportation in the United States and Canada toward net-zero greenhouse gas emissions. The Coalition brings together industry, community, government, academia and other stakeholders across the waterborne transportation value chain to pursue projects that remove barriers to accelerating development, encourage innovation, and promote policies in support of zero emissions.

The Coalition was conceived and designed to bring together all parties that directly or indirectly play a part in the North American waterborne value chain, from cradle to grave, and to collaboratively develop a roadmap to net zero greenhouse gas emissions by 2050 by identifying barriers to decarbonization and then executing demonstration projects and other initiatives that help to remove those barriers. The Coalition membership welcomes all companies and organizations that are directly or indirectly involved in maritime activities in the U.S. and Canada. The Coalition acts to connect various cluster organizations and maritime industry participants in order to leverage learnings and solutions across all of North America, enabling our vision to think big, start small and scale fast.

Upon award selection and successful negotiation of the CRADA agreement, the Coalition is committed to supporting this research with a combination of monies and in-kind support to cover the required cost share contribution over the three-year period of the project. In-kind contributions in the form of technical support from member companies such as Crowley Maritime Corporation and several other industry leaders will be forthcoming, describing the expertise and knowledge that our industry members can provide in support of the H2GRID (see the attached support letter from Crowley Maritime Corporation as an example).

The proposed collaboration between Blue Sky Maritime Coalition and NREL and its outcomes would be critical to perform future evaluation and help reduce the technological barriers in the adoption of a hydrogen infrastructure for marine intracoastal applications. We look forward to this much needed collaboration.

Sincerely,

David H. Cummins
President & CEO
M: (832) 374-4700
E: President@Bluesky-Maritime.org
BLUE SKY MARITIME COALITION www.Bluesky-Maritime.org

Attachment: Crowley Maritime Corporation support Letter

AVANGRID

July 19, 2021

Dr. Rob Hovsapian

National Renewable Energy Laboratory
15301 Denver West Parkway, Golden, Colorado

Re: Letter of Support for proposal titled "H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications", a multi-industry R&D proposal led by NREL.

Dear Dr. Hovsapian,

AVANGRID Inc. is pleased to submit this letter in support of the proposal titled 'H2GRID: Hydrogen-based Green Infrastructure for Decarbonization of Marine Intracoastal Applications' for the H2@Scale July 2021 CRADA Call Supporting Advanced Research on Integrated Energy Systems (ARIES).

AVANGRID, Inc. is a leading, sustainable energy company with $38 billion in assets and operations in 24 U.S. states. AVANGRID has two primary lines of business: Avangrid Networks and Avangrid Renewables. Avangrid Networks owns eight electric and natural gas utilities, serving 3.3 million customers in New York and New England. Avangrid Renewables owns and operates a portfolio of renewable energy generation facilities across the United States. AVANGRID supports the U.N.'s Sustainable Development Goals and was awarded Compliance Leader Verification by Ethisphere, a prestigious third-party verification of its ethics and compliance program.

The proposal is to develop infrastructure for green hydrogen production and distribution for intracoastal marine applications and next generation 'Clean Port of the Future' using renewable energy. This will effectively optimize the use of renewable energy for powering the intracoastal marine vessels by converting green energy into green hydrogen. The H2Grid project will also perform evaluation activities:

- Establishing H2 refueling infrastructure along the intracoastal Great Loop using nearby renewables.
- Develop, test, de-risk and deploy hydrogen powered, resilient shipboard power systems that can be used to reduce the emissions of this marine transportation sector significantly

This will effectively reduce integration and maintenance cost for hydrogen generation which will reduce overall cost of clean hydrogen production to meet DOE's goal of 1$ per kg in one decade.

We, at AVANGRID Inc., would like to support H2Grid proposal through renewable energy integration to H2Grid and support evaluation by providing renewable energy modeling for

AVANGRID, Inc.
180 Marsh Hill Road, Orange, CT 06477
Telephone 203.231.2390
james.rincon@avangrid.com
www.avangrid.com,

10. Diversity, Equity, and Inclusion Plan

The project will directly study the 'Great Loop' for the intracoastal navigation and assess the techno-economic potential for green hydrogen to be a fueling source for electrified barge, work floats, and tug boats. There are several towns across the Loop with that have significant economic impact due to the port activities. One such cities is Georgetown, South Carolina. Few other areas in America contain more history or charm than Georgetown, South Carolina. From its earliest beginnings as the probable site of the first European settlement in North America in 1526, to its present status as a vibrant and gracious city Georgetown has long been known for its warm hospitality and Southern charm. One of our project partners is the 'Georgetown Economic Development' who is extremely interested in clean energy, clean fuels, and job creation through port activities. Please see the attached support letter with the proposal for details. This town boasts some of the highest diversity with regards to residents with approximately 46.5% Black or African Americans and 5.7% of two or more races[1]. If compared to the national US average, which is ~23% residents who can be termed as 'people of color'. Based on sheer diversity, this town is and has been historically very diverse. Creation of *green jobs* and ensuring *environmental justice* for such a town would be very meaningful and justified. This project is expected to benefit several other towns which may have similar diverse populations that need cleaner air, water, and green jobs. The team comprises of a potential partner as W. Leigh Associates that has committed to be a part of the overall effort. W. Leigh & Assoc., Inc. offers a full line of equipment, services and materials for the commercial marine contractor. A support letter is attached with this proposal. W. Leigh Associates is a 'Woman Owned Small Business' and 'Multi-State Disadvantaged Business Enterprise (DBE) Firm'. They and similar companies that are minority-, woman-, and veteran-owned business that are in the marine shipping for intra-coastal cargo. The NREL PI is an affiliate faculty at the FAMU/FSU College of Engineering, Florida Agriculture & Mechanical University (FAMU) - Florida State University (FSU). FAMU is a Historically Black University (HBCU) and the project will create a pipeline for graduate students, interns, staff, and PhD R&D activities for FAMU students. Additionally, this project R&D team itself is quite diverse with prominent roles as scientists and key contributors from underrepresented communities such as Latin and Asian origin.

[1] https://www.census.gov/quickfacts/fact/table/georgetowncitysouthcarolina/PST045219