Pacific Northwest
NATIONAL LABORATORY

HFTO Technology Portfolio through FY2025

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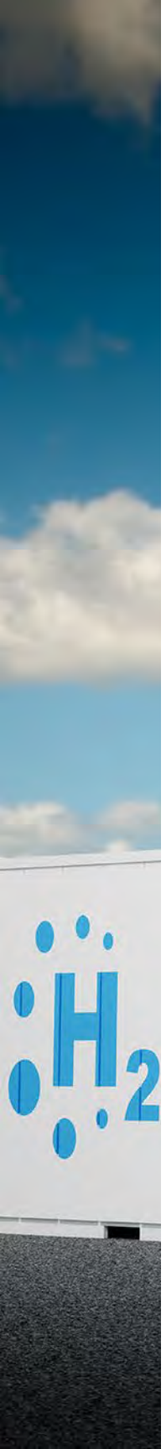
Pacific Northwest National Laboratory

PNNL - 38537

U.S. DEPARTMENT OF ENERGY BATTELLE

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Pacific Northwest NATIONAL LABORATORY

HFTO Technology Tracking Results Summary – FY2025

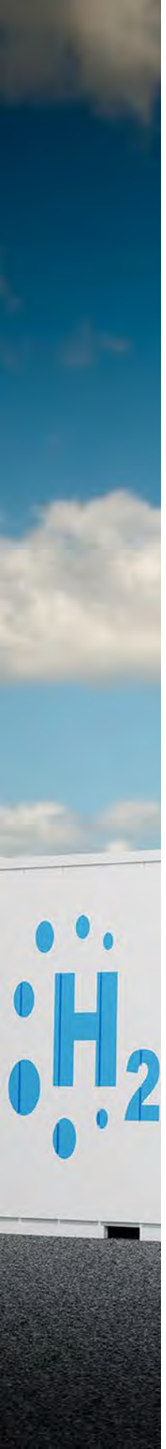
Numbers based on tracking from FY2008 – FY2025

- 534 technology projects resulting from HFTO R&D funding
- 318 projects currently actively developing technology
- 69 technologies achieved commercialization (4 new in FY25)
- 192 technologies near-market (within 5 years) (41 new in FY25)

- 22 commercial technologies no longer available
- 73 near market technologies with no further development

Technology Status (from 2008-2025)	Previous Status (Thru' FY24)	Count of projects at status level
Commercial	1	65
Emerging <3yrs	2	81
Potential 3-5 yrs	3	70
Stopped/No Go (3s & 9s)	4	119
Archive Commercial Tech	6	22
Archive Emerging Tech	7	73
Withdraw	8	2
New Project Added (TBD)	9	102
	Total Active	318
	Total Projects	534

Current Technology Status	Count of projects at status level
1	30
2	70
3	49
4	16
6	2
7	2
8	2
TBD	147
# Responses	171
Percentage of Responses	54%

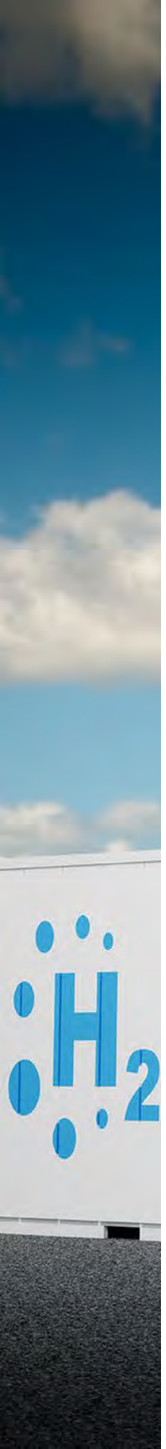


HFTO New Technology Tracking Results Summary – FY2025

- 4 new commercial technologies
- 24 new emerging technologies
- 17 new potential technologies
- 147 (46%) project/technologies with no updates

Abbreviation	Sub-Program
FC	Fuel Cell
PROD	Production
DLVY	Delivery
ST	Storage
INFRA	Infrastructure
SFTY	Safety

NEW Technologies FY2025	FC	PROD	DLVY	ST	INFRA	SFTY	Total
Commercial	2	0	1	1	0	0	4
Emerging	9	5	4	1	1	3	24
Potential	10	3	3	1	0	0	17
Total New Techs	**21**	**8**	**8**	**3**	**1**	**4**	**45**



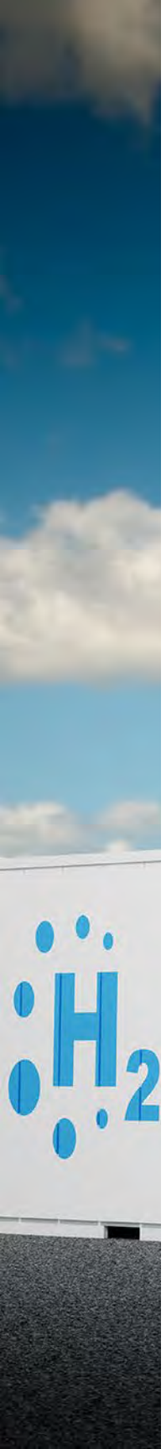
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Section Index

Click text to navigate

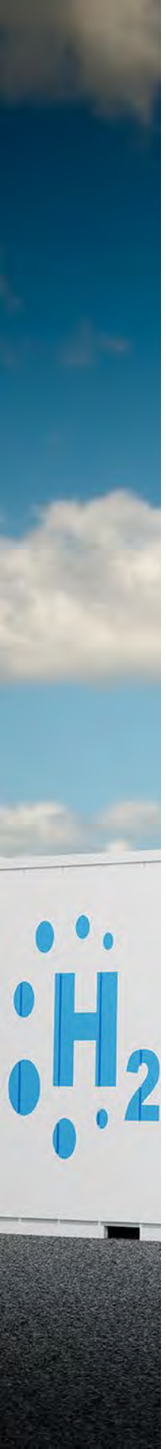
New FY2025 Technologies	Delivery
	Fuel Cell
	Production
	Safety
	Storage
Pre-FY2025 Technologies	Delivery
	Fuel Cell
	Production
	Safety
	Storage
Historical Technologies	Delivery
	Fuel Cell
	Production
	Safety
	Storage

Company Index



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New FY2025 Technologies



New Hydrogen Delivery Technologies for FY2025

Technology	Organization
Grid-Interactive Steelmaking with Hydrogen (GISH)	Missouri S&T
Hydrogen Blending Into Natural Gas Pipelines	Sandia National Laboratories
MC Formula Protocol for H35HF Fueling	National Laboratory of the Rockies
Port Demand Assessment: MARAD Co-Fund / Hydrogen for Maritime and Rail Fuel Cell Technologies	Sandia National Laboratories
Solid State Based Hydrogen Loss Recovery During LH2 Transfer	Colorado School of Mines

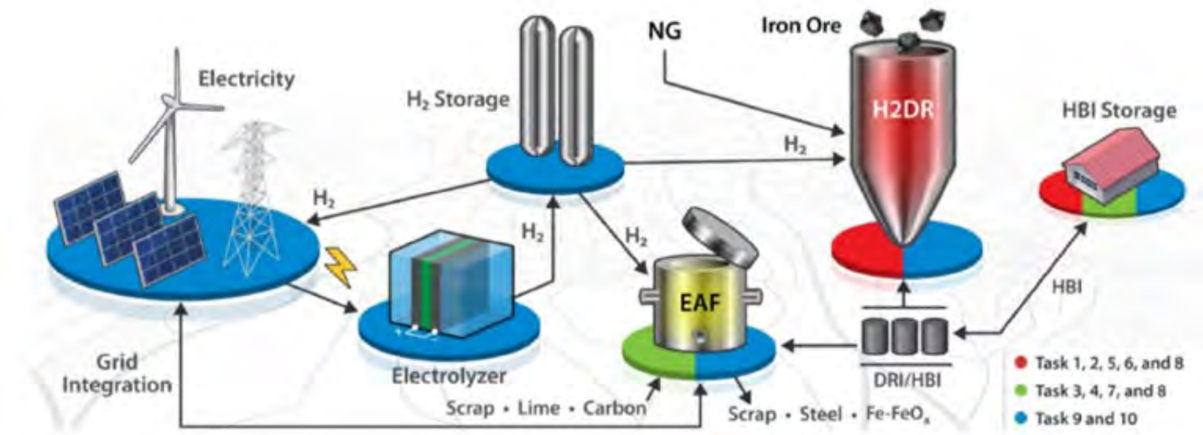
Note: Technology summary slides based on available information from PIs through the end of FY2025

Grid-Interactive Steelmaking with Hydrogen (GISH)

DLVY *Emerging*

Added FY2025

- Developed by Missouri University of Science and Technology in collaboration with numerous collaborators.
- Aimed to close critical knowledge gaps regarding hydrogen-based direct reduction of iron (H2DR) and steelmaking in electric arc furnaces (EAF).
- Conducted lab scale melting experiments, documenting the impacts of direct reduction iron (DRI) carbon content on melting rate.
- Operated a GISH pilot reactor for 3 one-week campaigns, facilitating H_2, natural gas, and mixed gas reduction while producing H2 DRI up to 94% metallization. Pilot reactor has provided guidance for adjusting reactor design and operating conditions.
- Modeled a scale-up of an innovative direct reduction (DR) pilot reactor that captures the characteristics of the materials flow and the thermal profile in a production-scale reactor.
- Evaluated the technoeconomic feasibility of GISH process including an economic penalty.
- Contract Number: DE-EE0009250 (2022)



Potential flexible iron production

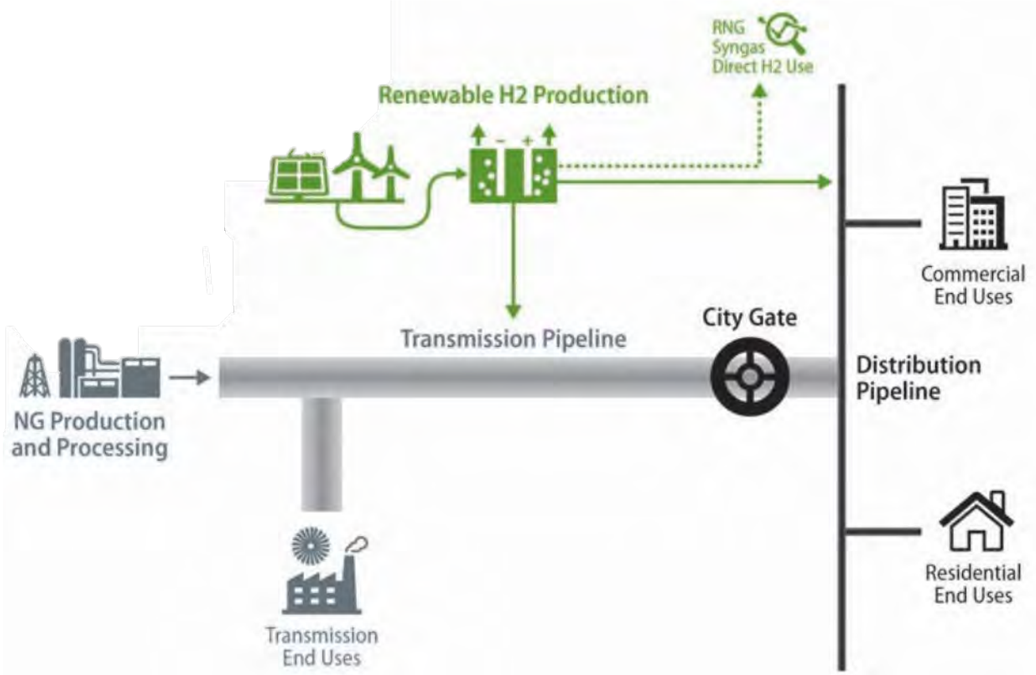
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Hydrogen Blending into Natural Gas Pipelines

DLVY Commercial

Added FY2025

- A collaborative effort between Sandia National Laboratories, Argonne National Laboratory, National Laboratory of the Rockies, and Pacific Northwest National Laboratory with industry support from Southern Company Services.
- Provide a high-level assessment of hydrogen blending in distribution gas networks by modeling the economic impact associated with blending.
- Assess hydrogen-induced degradation in distribution piping for service with hydrogen blends and address gaps in codes and standards.
- Conducted a technoeconomic analysis (TEA) and life cycle analysis (LCA) for injection into Atlantic Gas and Light Company (AGLC) network.
- Evaluated the fatigue and fracture properties of steel and polyethylene piping after exposure to gaseous hydrogen.
- Developed Hydrogen Extremely Low Probability of Rupture (HELPR) tool, an open-source software that assesses the structural integrity of natural gas infrastructure for transmission and distribution of hydrogen natural gas blends.
- Contract Number: DE-AC04-94AL85000 (2020)



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MC Formula Protocol for H35HF Fueling

DLVY *Emerging*

Added FY2025

- Effort lead by the National Laboratory of the Rockies (NLR) in collaboration with Frontier Energy Inc. and multiple industry partners including ElDorado National, Gas Technology Institute, Luxfer Gas Cylinders, New Flyer of America, South Coast Air Quality Management District, Sunline, SoCalGas, Shell, and First Element Fuel.
- Developing a fully tested and validated H35 high-flow (H35HF) MC Formula fueling protocol for medium-duty (MD) and heavy-duty (HD) buses and trucks in harmonization with SAE J2601 MD/HD fueling protocol.
- Providing design guidelines for H35HF stations and vehicles and enables equipment and vehicle OEMs to enter the hydrogen market.
- Upgrading NLR's hydrogen fueling model, H2FillS, for MC H35 MD and HD fueling.
- H2FillS modelling completed and testing of H35HF protocol using NLR's HD vehicle simulator is underway.
- H2FillS model is openly available to the public.
- H35HF fueling validation at commercial hydrogen station expected in 2025.
- Contract Number: DE-AC36-08GO28308 (2021)



NLR HD station



AZBT H35HFstation

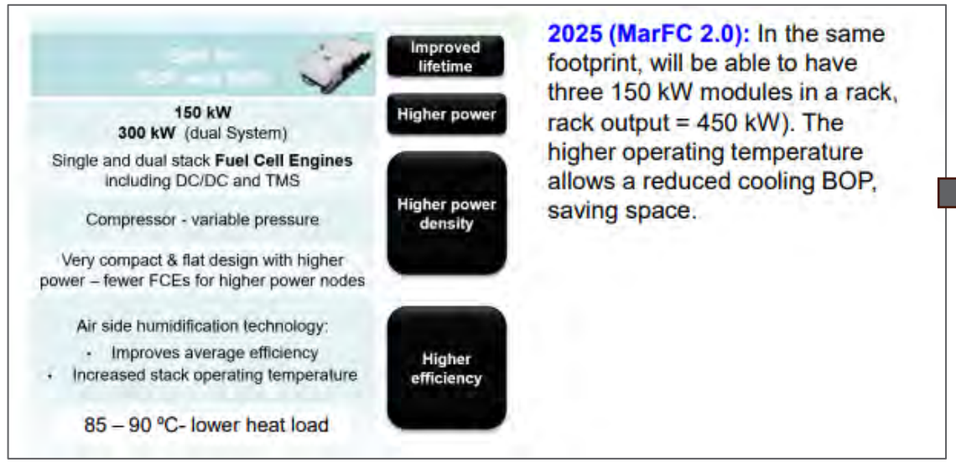
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Port Demand Assessment: MARAD Co-Fund / Hydrogen for Maritime and Rail Fuel Cell Technologies

DLVY *Emerging*

Added FY2025

- This is a follow-on project to a successful Maritime Fuel Cell (MarFC) Project which designed, built and deployed a 100 kW containerized hydrogen fuel cell generator for portable power on land and sea.
- In this phase, Sandia National Laboratory (SNL) with support from Accelera, will conduct a Port Power Demand Assessment to determine Port power needs and identify technical requirements that can be met by hydrogen fuel cell power solutions.
- The project will be co-funded by the U.S. Maritime Administration (MARAD) responsible for the execution of the mobile unit and the U.S. Department of Energy (DOE) will formulate a plan for a potential future stationary fuel cells and broader preparation for a stationary fuel cell market.
- Contract Number: DE-NA0003525 (2024)





20-foot iso Container
Length: ~ 20 feet
Width: ~ 8 feet
Height: ~ 8.5 feet
Weight: ~ 25,000 lbs

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Solid State Based Hydrogen Loss Recovery During LH2 Transfer

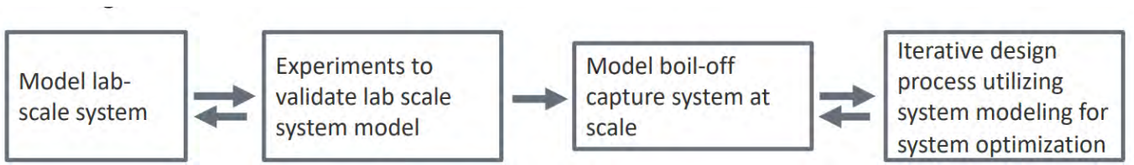
Pacific Northwest NATIONAL LABORATORY

DLVY *Emerging*

Added FY2025

- Design, engineer, construct, and demonstrate a materials-based solution for the capture of H2 from LH2 boil-off loss.
- Mitigating hydrogen (H2) losses throughout all stages of transfer operations is critical to enabling liquid hydrogen (LH2) as a high use and high-capacity energy storage reservoir, both in terms of cost and in limiting the environmental impact of H2 as an indirect greenhouse gas.
- Deliver a scalable prototype operating on-site to capture H2 losses from a LH2 transfer event and provide a detailed technoeconomic analysis (TEA) evaluating financial feasibility, which includes evaluation of end uses for the captured H2 such as reliquification and/or power generation as end uses for the captured H2.
- Contract Number DE-EE0011104 (2024)





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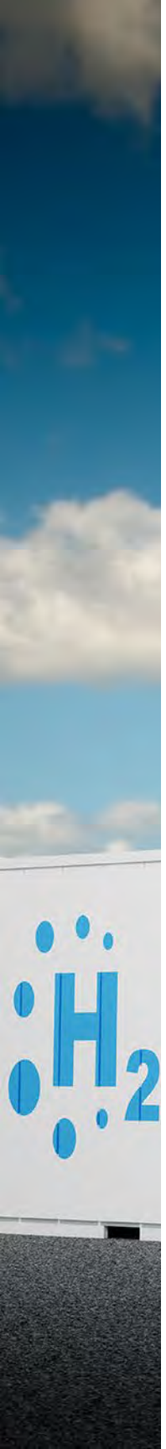
National Laboratory of the Rockies

Metropolitan State University of Denver

STOKE

AIRBUS

BERKELEY LAB



New Hydrogen Fuel Cell Technologies for FY2025

Technology	Organization
Advanced FC Vehicle DC-DC Converter Development	Oak Ridge National Laboratory
Bipolar Plate Manufacturing and Reconditioning Using Next-Generation IMPULSE HiPIMS Etching, Surface Preparation, and Pinhole-Free Deposition of Corrosion-Resistant, Low-ICR Coatings (SBIR)	Starfire Industries, LLC
Compact and Low-Cost Thermal Management for Heavy-Duty Vehicle Fuel Cells (SBIR)	Altex Technologies Corporation
Cross-Polarized Near-Ultraviolet/Visible (CPNUVV) Detector for In-Line Quality Control of Polymer Electrolyte Membrane Materials (SBIR)	Mainstream Engineering Corp.
Development and Manufacturing for Precious Metal Free Metal Bipolar Plate Coatings for PEM Fuel Cells	TreadStone Technologies, Inc.
Fuel Cell Integrated Power Electronics Module (FCIPEM) (SBIR)	RockeTruck, Inc.
High Performance Hydrocarbon Membrane Electrode Assembly	RTX Technology Research Center
L'Innovator Program – Next Generation HT PEM MEAs	Advent Technologies Holdings, Inc.
Low Cost Metal Bipolar Plate Carbon Coating Technology for Heavy Duty Fuel Cells (SBIR)	TreadStone Technologies, Inc.
Modification of Nafion® Thermoplastic Precursor to Enable Reprocessing of Fuel Cell Manufacturing Scraps (SBIR)	Rockytech Ltd.
Solution Based Nanostructured Carbon Coatings for Reusable, Corrosion Resistant, Stamped Metallic Bipolar Plates (SBIR)	Clenersys Inc.

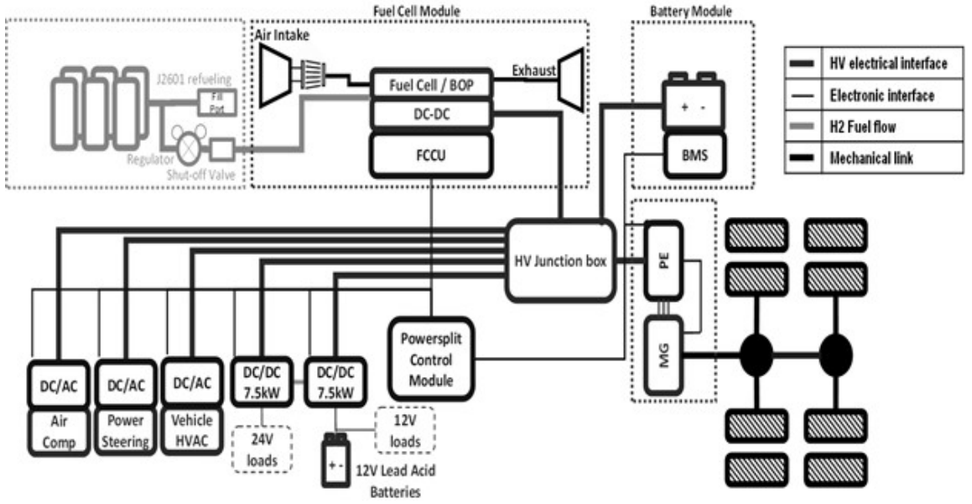
Note: Technology summary slides based on available information from PIs through the end of FY2025

Advanced FC Vehicle DC-DC Converter Development

FC
Emerging

Added FY2025

- Fuel cell electric vehicle (FCEV) system architecture value to end users strongly depends on overall cost and efficiency of the power train system.
- The fuel cell DC-DC converter plays a key role in overall system performance, efficiency and durability.
- The project identifies DC-DC converter architectures and isolation requirements for FCEV applications and is aligned to support DOE heavy duty truck targets.
- Alignment with the Million Mile Fuel Cell Truck (M2FCT) consortium stakeholders and identify industry partners; CMI (converters), Chemours (coolants), GE (components), and Volvo/Daimler (OEM)
- Contract Number : DE-AC05-00OR22725



Project targets

- Modular DC-DC converter development
- Efficiency ≥98%
- Vol. density ≥15 kW/L
- Grav. Density ≥ 15 kW/kg
- Scale: 250kW ➔ 400kW
- Isolation safety ≥ 500 Ω/V
- Critical systems analysis, design, and advanced concept validation

Potential impact

- Safety and durability: 1MM / 25k hours
- System efficiency
- Accelerate integrated power electronics development for fuel cells
- Reduce time to market for novel, low cost power electronics
- Understand current technology capabilities
- Develop future R&D requirements for performance, cost, and durability

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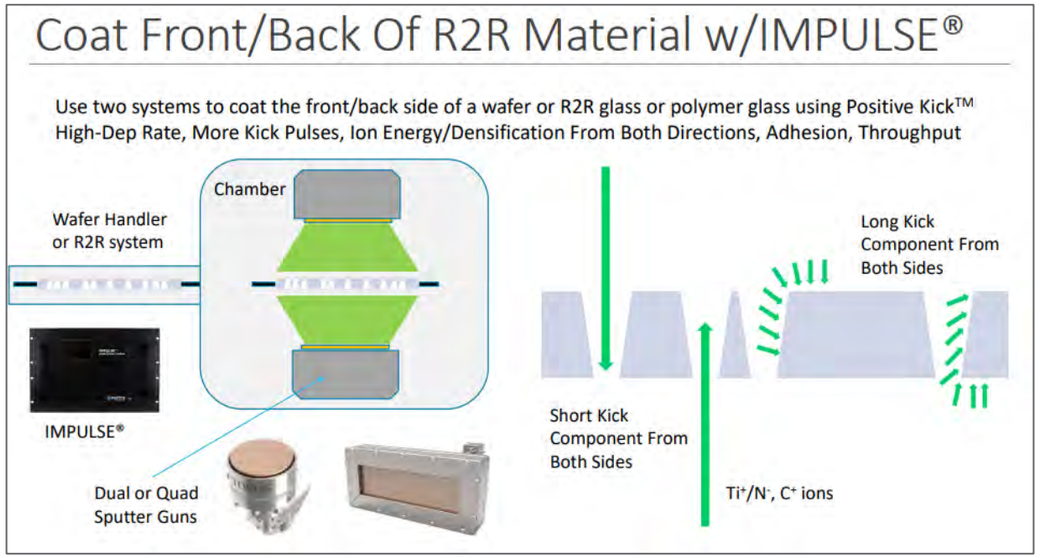
Bipolar Plate Manufacturing and Reconditioning Using Next-Generation IMPULSE HiPIMS Etching, Surface Preparation, and Pinhole-Free Deposition of Corrosion-Resistant, Low-ICR Coatings (SBIR)

FC
Emerging

uspto
2 patents

Added
FY2025

- Develop plasma processes utilizing Starfire Industries IMPULSE® HiPIMS power supply to deposit and etch conformal, high quality, corrosion resistant thin films on bipolar plates (BPPs) which are critical components in proton exchange membrane fuel cells (PEMFC)s.
- This plasma process will enable recycling of the BPP substrates to incrementally contribute to hitting the DOE HFTO manufacturing goal of $80/kW total cost of ownership.
- Contract Number: DE-SC0023992 (2023)



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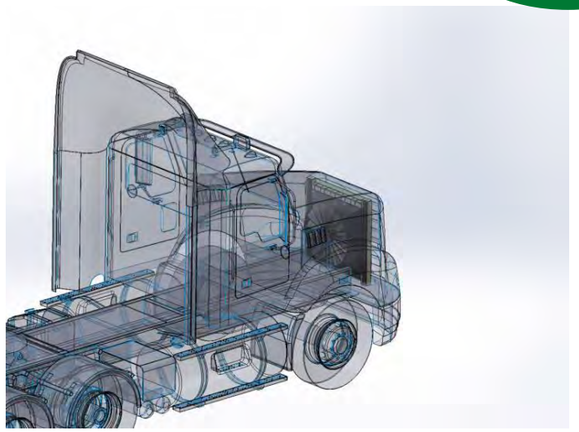
University of Illinois
Center for Plasma-Material Interactions (CMPI)·

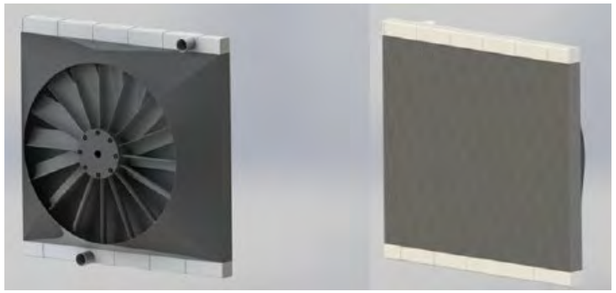
Compact and Low-Cost Thermal Management for Heavy-Duty Vehicle Fuel Cells (SBIR)

FC
Emerging

Added FY2025

- Developed by Altex Technologies Corporation, with support from industry partners and Darby Prototype LLC.
- Developed smart radiator and airflow design to address excessive radiator size and parasitic airflow pressure losses in heavy-duty FC truck applications and construction equipment.
- Utilizes smart design and design for manufacturing principles to improve radiator heat transfer and pressure drop performance, durability, reduce radiator size, and material and fabrication costs.
- Design meets over-the-road truck driving cycle requirements for vibration, engine load (hill climbing), endurance, radiator pressure drop and particulate deposit cleaning and salt fog pass/fail testing.
- Modelling and lab wind tunnel tests in agreement with overall 2X performance gain over conventional radiator design with 50% materials cost reductions.
- Scalable design 10 – 100kW (324kW/m^2 cooling power)
- Applications in transportation, stationary power, electronics and petroleum and chemicals processing
- Contract Number: DE-SC0023831 (2023)





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ALTEX TECHNOLOGIES CORPORATION

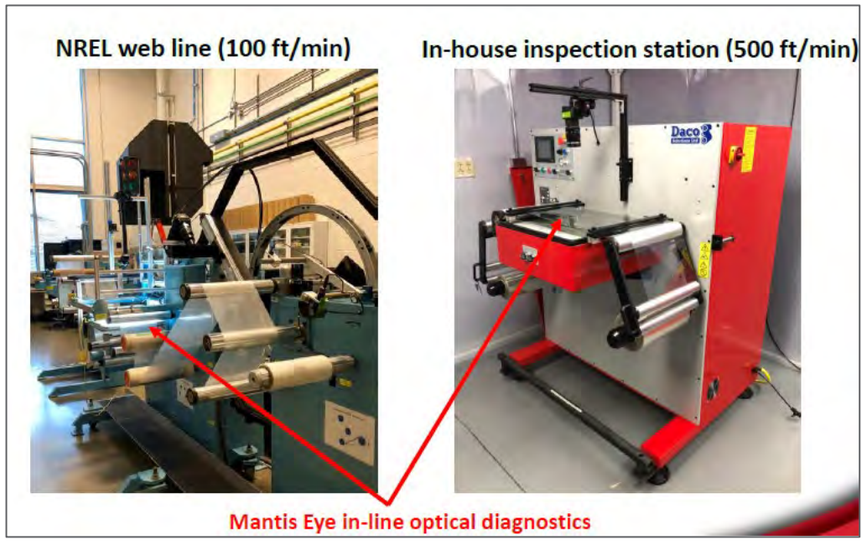
DARBYPROTOTYPE LLC

Cross-Polarized Near-Ultraviolet/Visible (CPNUVV) Detector for In-Line Quality Control of Polymer Electrolyte Membrane Materials (SBIR)

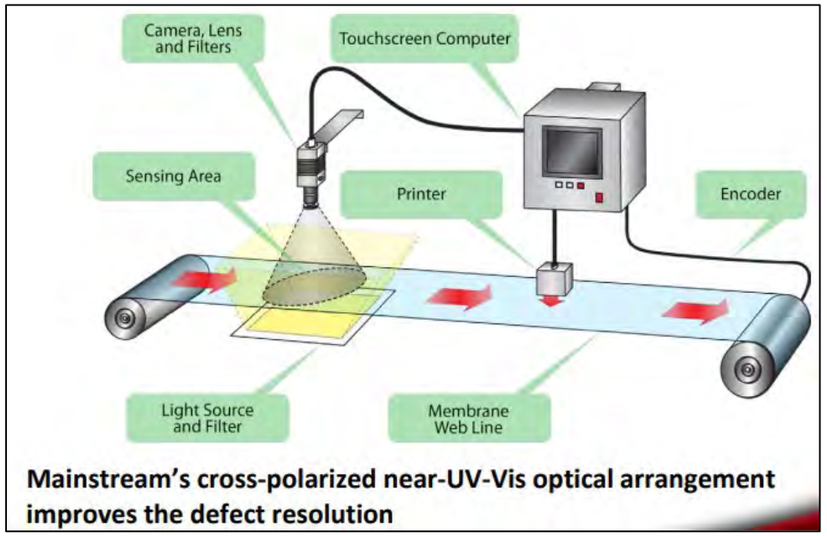
FC
Commercial

Added FY2025

- Developed a cross-polarized near-ultraviolet visible (near-UV/Vis) detector designed for in-line, real-time quality control of polymer electrolyte membrane (PEM) materials.
- The detector system measures membrane thickness and defects in real-time at roll-to-roll coating speeds, reducing costs, removing defective MEAs prior to coating (with expensive platinum catalyst) and assembly of stack materials.
- This quality control system will drive down costs and increase reliability of fuel cell membranes, making them more competitive with conventional power technologies.
- Contract Number DE-SC0013774 (2018)



Mantis Eye in-line **optical diagnostics**



Cross-polarized near-UV-Vis optical arrangement improves the defect resolution

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Development and Manufacturing for Precious Metal Free Metal Bipolar Plate Coatings for PEM Fuel Cells

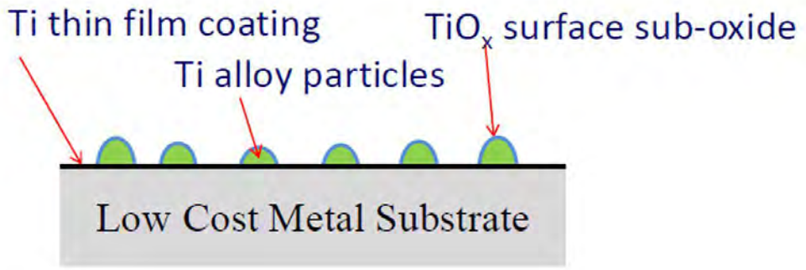
FC
Emerging

Added FY2025

- TreadStone Technologies, Inc., demonstrated that diffusion bonded titanium to aluminum was viable and that all 2020 DOE bipolar plate technical targets for light duty vehicles could be met with this solution.
- Demonstrated the feasibility of using a precious-metal-free Titanium Oxide (TiOx) coating to reduce the interface contact resistance (ICR) increasing the efficiency of a fuel cell.
- Demonstrated an alternative manufacturing process of the micro-textured TiOx coating.
- Demonstrated the coating process for low-cost metal substrates to pursue DOE's performance and cost target.
- Contract Number: DE-EE0009613 (2021)



Simultaneously formed and diffusion bonded titanium foil to aluminum bipolar plate



Schematic drawing of TiOx coating structure .

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Fuel Cell Integrated Power Electronics Module (FCIPEM) (SBIR)

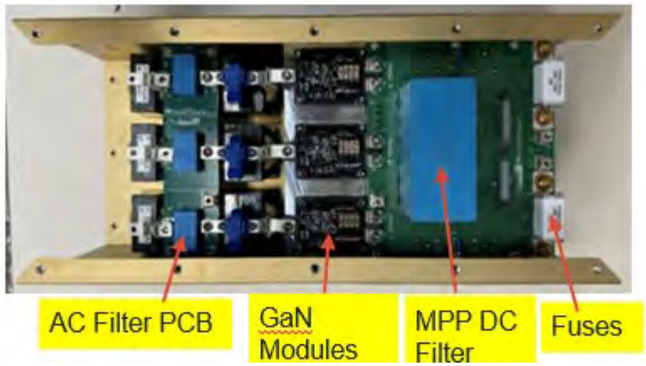
FC
Emerging

Added FY2025

- RockeTruck, Inc is developing an advanced power electronics module in partnership with Sandia National Laboratories, Infineon/GaN Systems, AVL Mobility Technologies, ARRS, Inc., and Southern California Gas.
- The module is being developed to eliminate the common drawbacks of relying on commercial off-the-shelf (COTS) inverters for fuel cell generator applications.
- Single-phase (28kW) or three-phase (42kW) Gallium Nitride (GaN) inverter utilizes higher switching frequency to reduce physical size (30lb, 10in wide rack mount), with a 330-440VDC input and capability for direct connection to Li-Ion batteries in parallel with FC modules.
- Inverter permits smooth transition between main power grid and backup power (islanded grid) and vice-versa.
- Provides dual CAN 2.0, RS-485 and ethernet data interface options.
- Applications include solar PV, fuel cell generators and battery storage applications.
- Contract Number: SBIR Phase I & II DE-SC0023825 (2023)



Rocke Truck's GaN Based Fuel Cell Integrated Power Electronics Module (FCIPEM)



Top view – control shelf and ends omitted

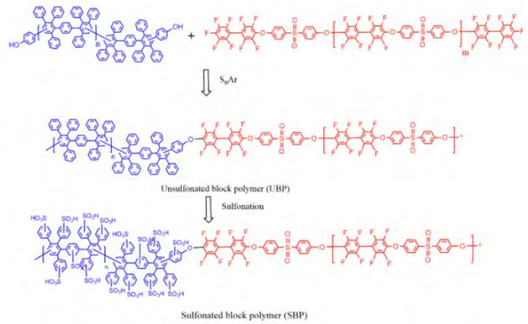
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High Performance Hydrocarbon Membrane Electrode Assembly

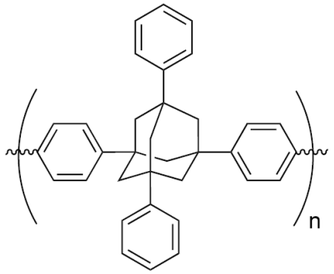
FC
Emerging

Added FY2025

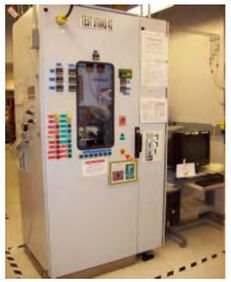
- Developed by RTX Technology Research Center (RTRC) in collaboration with Sandia National Laboratories (SNL), Michigan State University (MSU), Nimbus Power Systems (NPS) with assistance from M2FCT consortium.
- Develop alternative fuel cell membrane formulations that are free of per-and polyfluoroalkyl substances (PFAS) which pose a potential environmental liability – fluorine chemistry, regulatory risk to supply chains.
- Optimize and down select the best catalyst ink formation and new PFSA free ionomer materials since hydrocarbon ionomers performance currently lags PFSA-based ionomers.
- Contract Number: DE-EE0011107 (2024)



Scheme for baseline block polymer



O_2-permeable tetraphenyl adamantane







MEA Coating and Cell Testing

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L'Innovator Program – Next Generation HT PEM MEAs

FC Commercial

Added FY2025

- Developed by Advent Technologies, Inc., in collaboration with Los Alamos National Laboratory (LANL), Brookhaven National Laboratory (BNL), National Laboratory of the Rockies, Pajarito Powders LLC., TKK, Rensselaer Polytechnic Institute, and University of Stuttgart.
- Commercialized MEAs in 2025.
- HoneyBadger system development to improve current version of field charger units in field. Targets include smaller size, weight and power capacity (1.5X) using next generation MEA technology.
- Enables low-cost cooling subsystem, simplified power system architecture and provides rated peak power for heavy-duty applications.
- Applications in portable power, aerospace, heavy duty transportation, marine and armed forces applications.
- Contract Number: DE-AC52-06NA25396 (2021)



Honey Badger Unit (reformed MeOH) Field battery charger



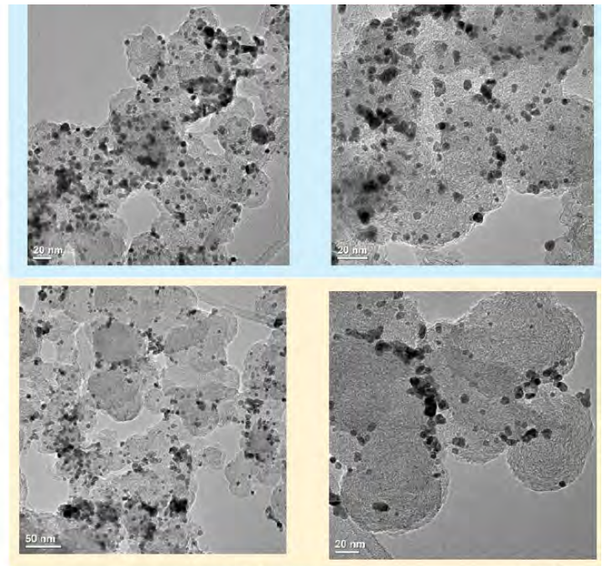
Honey Badger Stack

Core Shell PtNiN/C

Small particles in pores may stay at EOL

PtNi/C (standard)

Particle distribution at BOL is good, but is not good at EOL



BOL EOL

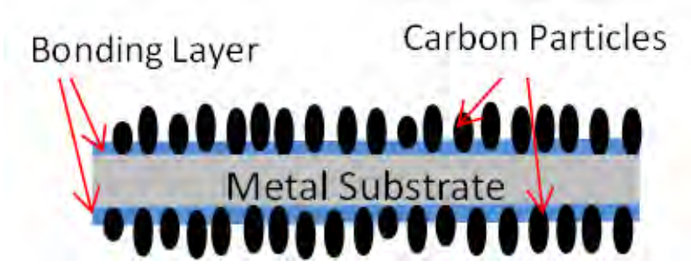
Contact Information:
Emory S. De Castro
Email: e@advent.energy
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Advent Technologies Holdings Inc.
500 Rutherford Avenue, Suite 102
Boston, MA, 02129
Website: www.advent.energy

Low Cost Metal Bipolar Plate Carbon Coating Technology for Heavy Duty Fuel Cells (SBIR)

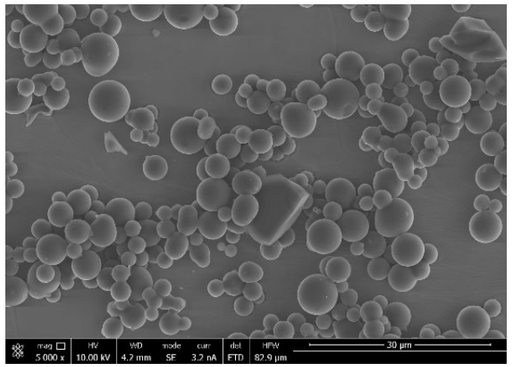
FC
Emerging

Added FY2025

- TreadStone Technologies, Inc., is working to reduce the cost of PEM fuel cell metal bipolar plates which are the second most expensive component in PEMFC stacks.
- Developed a coating technology that is suitable for roll to roll (R2R) manufacturing using low-cost carbon particle material to coat the metal plates.
- Demonstrated by ex-situ and in-situ testing that the coated metal plates can meet the performance and durability requirements for Heavy-Duty Vehicle (HDV) applications and meet DOE's performance and cost targets.
- Utilized a process to directly bond carbon particles on metal substrate surface to obtain the desired structure and properties.
- Contract Number: DE-SC0023921 (2023)



Schematic drawing of DuraC coating structure.



Manufacturing technology using a reliable bonding structure

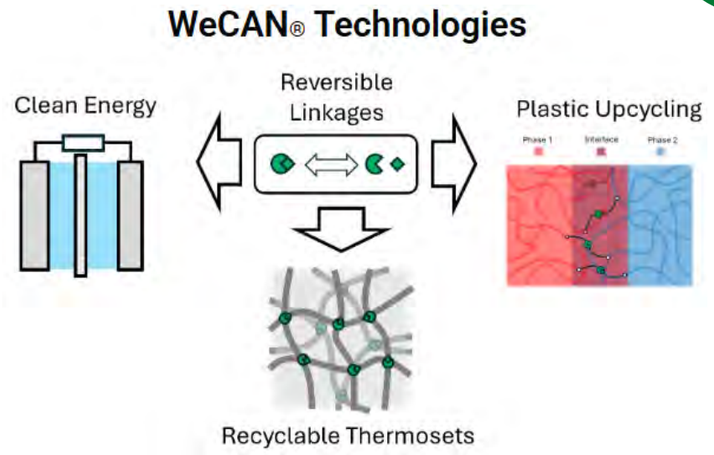
Contact Information:
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Modification of Nafion® Thermoplastic Precursor to Enable Reprocessing of Fuel Cell Manufacturing Scraps (SBIR)

FC *Emerging*

Added FY2025

- Developed by Rockytech Ltd in collaboration with the University of Colorado Boulder.
- Scalable process to modify Nafion-SO2F for manufacture of reprocessible and durable Nafion membranes and dispersions.
- Enables recycling of scrap and end-of-life membrane material and reduces fluorinated waste materials.
- Process is easily retrofitted into existing manufacturing process by adding a single reactor bath.
- Rapid click chemistry integrates crosslinkers and tethers into the Nafion-SO2F thermoplastic precursor enabling the preparation of modified a Nafion-SO3H ionomer.
- Crosslinked Nafion-SO3H can be reprocessed from powder to film - R2R feasible as the tethered material disperses in co-solvent of water and isopropyl alcohol.
- Modified Nafion-SO3H electrochemical properties meet or exceed new Nafion 115.
- Applications in fuel cells, flow batteries, and chloro-alkali electrolysis.
- Patent Applications: PCT/US25/12009, US 63/566,394
- Contract Number: DE-SC0023982 (2023)



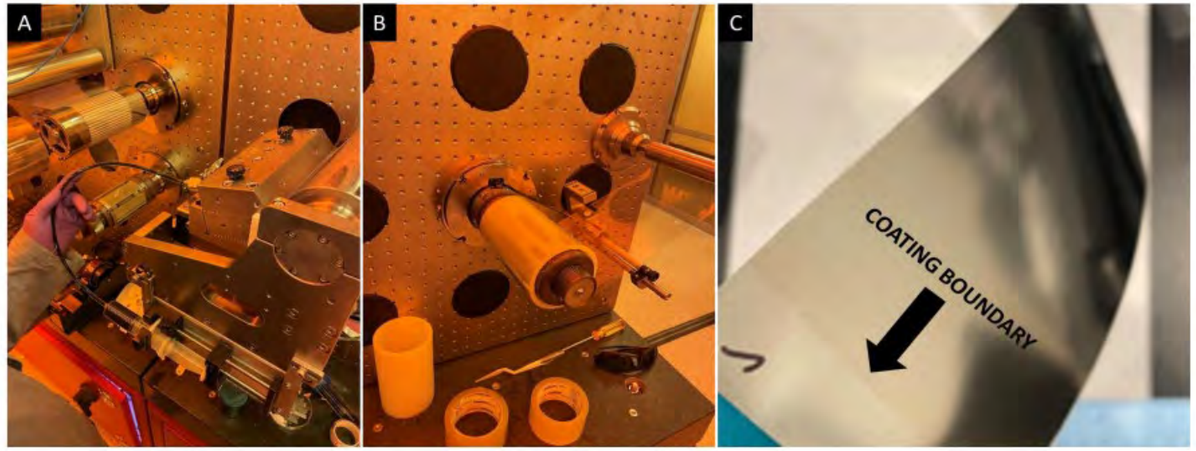
Contact Information:
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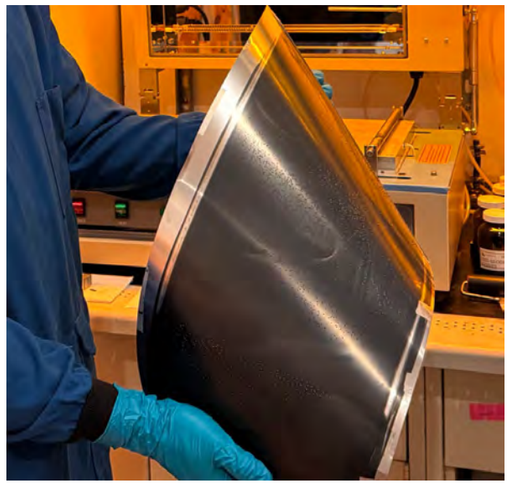
Solution Based Nanostructured Carbon Coatings for Reusable, Corrosion Resistant, Stamped Metallic Bipolar Plates (SBIR)

FC
Emerging

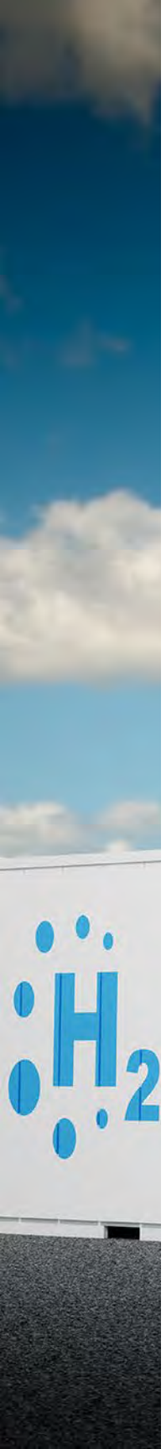
Added FY2025

- Developed by Clenersys Inc., (spinoff of Nano-C Inc) in collaboration with Northeastern University's Center for Renewable Energy Technology.
- Developing cost-effective, corrosion resistant, stamped metallic bipolar plates using an ink-based nanostructured carbon materials (NCM) coating, Clenersys' patented innovation CORE™.
- Tested and found that the electrochemical response of NCM coated stainless steel (SS316) is more like graphite than steel.
- Verified the electrochemical stability of NCM ink coatings using Raman spectroscopy and proved that NCM ink coatings can be stamped after deposition.
- Early trials show compatibility of NCM inks with R2R manufacturing, making the coatings scalable and cost-effective.
- Building a 1 kW demonstration fuel stack to demonstrate and validate NCM ink-based technology.
- Contract Number: DE-SC0023903 (2023)





Contact Information:
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New Hydrogen Production Technologies for FY2025

Technology	Organization
Development of Durable Materials for Cost Effective Advanced Water Splitting Utilizing All Ceramic Solid Oxide Electrolyzer Stack Technology	Saint-Gobain
Enabling Entrained-Flow Gasification of Blends of Coal, Biomass and Plastics	University of Utah
Performance Testing of a Moving-Bed Gasifier using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen	Electric Power Research Institute (EPRI)
Scalable and Highly Efficient Microbial Electrochemical Reactor for Hydrogen Generation from Lignocellulosic Biomass and Waste	Oregon State University
Scalable Halide Perovskite Photoelectrochemical Cell Modules with 20% Solar-to-Hydrogen Efficiency and 1,000 Hours of Diurnal Durability	Rice University

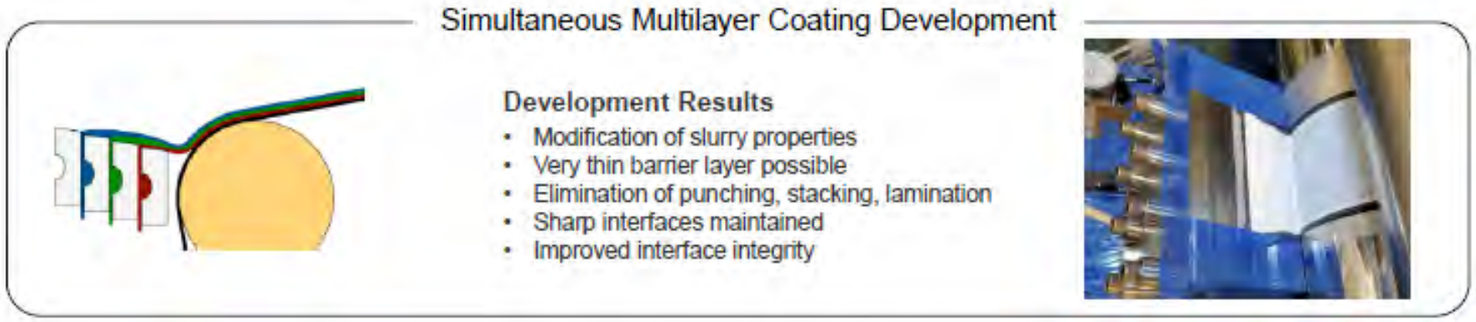
Note: Technology summary slides based on available information from PIs through the end of FY2025

Development of Durable Materials for Cost Effective Advanced Water Splitting Utilizing All Ceramic Solid Oxide Electrolyzer Stack Technology

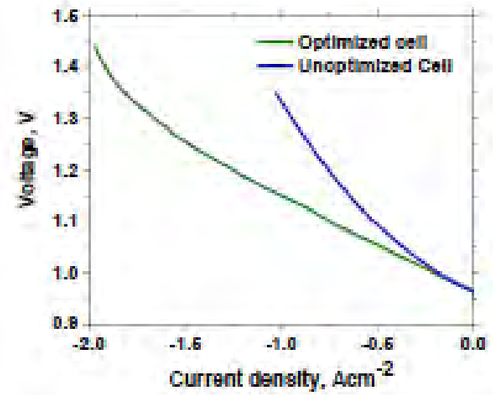
PROD
Emerging

Added FY2025

- Develop nickelate-based materials showing enhanced oxygen hyper-stoichiometry to solve the issue of air electrode delamination during SOEC operation
- Using materials that are compatible with the highly stable (0.2%/khr degradation rate) co-sintered SOFC stack architecture and result in a cost effective H2 production platform.
- Microstructure optimized for electrode supported button cells surpassing project targets, and optimal oxygen functional layer PSD has been identified to minimize polarization resistance, (Rp).
- Uniform 5 µm barrier layer production demonstrated to be reproducible and scalable.
- Sintering kinetics modified to produce dense barrier layer.
- No cracking due to thermal expansion mismatch has been found
- Contract Number: DE-EE0008377 (2018)



Simultaneous Multilayer Coating Development



65% performance improvement over baseline cell performance

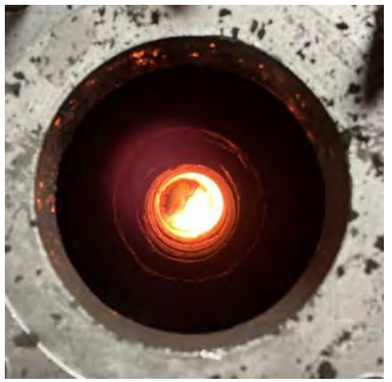
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Saint-Gobain
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Enabling Entrained-Flow Gasification of Blends of Coal, Biomass and Plastics

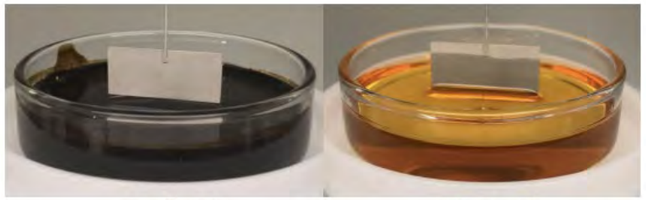
PROD
Emerging

Added FY2025

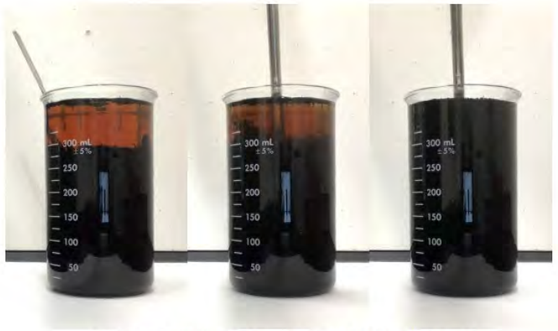
- Developed by the University of Utah in collaboration with Linde, Inc., Renewlogy Technologies, Eastman Chemical Co., and Ensyn Technologies.
- Demonstrating the technical feasibility of gasifying blends of coal, biomass, and mixed waste plastics in a pressurized entrained-flow gasifier for production of hydrogen.
- Entrained-flow gasification produces higher quality syngas when compared to other gasification technologies and enables heterogenous feedstocks to be processed using a slurry.
- Initial efforts determined mixed feedstock slurry properties including the slurry composition with the best properties for pumping (< 45 wt% coal. < 20 wt% plastic oil).
- Conducted initial gasification testing with “easy” feedstock (high bioliquid, low coal) at pressures up to 265 psi and temperatures up to 3000°F.
- Evaluating the feasibility of a 1 ton per day gasifier, with eventual scale up to a 20 ton per day pilot.
- Contract Number: DE-FE0032042 (2021)







Bio-liquid Plastic oil



10% coal, 75% bio-liquid, and 15% plastic oil before, during, after mixing

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Website: https://www.utah.edu/

Performance Testing of a Moving-Bed Gasifier using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen

PROD
Emerging

Added FY2025

- The Electric Power Research Institute (EPRI) tested feedstocks to provide data to advance the commercial-scale design of the moving-bed gasifier using coal, biomass and plastic waste blend feedstocks to produce hydrogen.
- Successfully produced tri-fuel pellets from selected feedstock powder river basin (PRB) coal, corn stover biomass and automotive shredder residue (ASR) waste plastic.
- Completed gasifier shake-down testing and initial PRB run.
- Provided nine barrels of pellets and one barrel of PRB to partner, Sotacarbo: Sotacarbo (Società Tecnologie Avanzate Low Carbon S.p.A.) to demonstrate their 12-inch pilot-scale updraft moving-bed gasifier installed at a facility in Italy.
- Collaborated with Hamilton Maurer International, Inc. (HMI) to leverage their expertise on gasifying a wide range of coal ranks, biomass (wood chips), and mixed plastic wastes.
- Contract award # DE-FE0032044 (2023)



Sotacarbo's lab-scale gasifier-feeder hopper



Corn Stover



PBR



ASR

Hamilton Maurer International, Inc. (HMI)

Contact Information:
George Booras: Contact has retired!
Electric Power Research Institute (EPRI):
3420 Hillview Ave
Palo Alto, CA 94304
Website: https://www.epri.com/

Scalable and Highly Efficient Microbial Electrochemical Reactor for Hydrogen Generation from Lignocellulosic Biomass and Waste

PROD
Emerging

Added FY2025

- Developed by Oregon State University in partnership with Texas A&M and other local brewery establishments.
- Original project: developed a microbial electrochemical system for H2 production from low-cost feedstock. New project focus: Developing a scalable hybrid microbial electrochemical reactor (combining fermentation and a microbial electrolysis cell (MEC) for hydrogen production from wastewater streams).
- Working to obtain a production cost close to or less than $2/kg H2 while achieving:
  - -Developing scalable and low-cost electrodes to reduce the capital cost of the reactor
  - -Developing a scalable reactor design to reduce the capital and operating costs
  - -Optimizing operating conditions using robust microbial communities to reduce the operating cost
- Contract Number: DE- EE0008844 (2019)



Schematic of the brewing process and wastewater (discarded sweet water) generation



Completed 10L MEC reactor with wiring system

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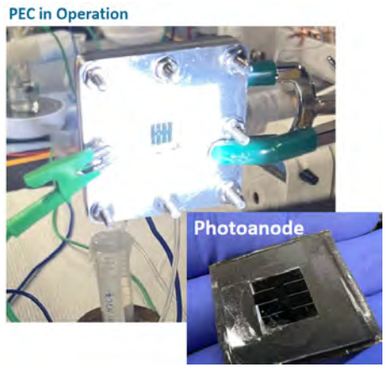
Scalable Halide Perovskite Photoelectrochemical Cell Modules with 20% Solar-to-Hydrogen Efficiency and 1,000 Hours of Diurnal Durability

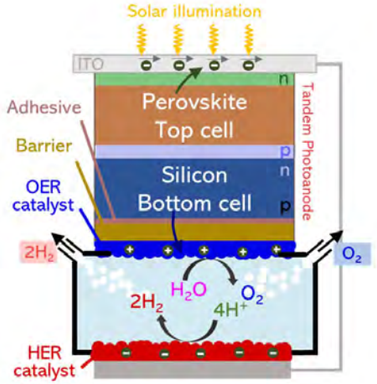
Pacific Northwest NATIONAL LABORATORY

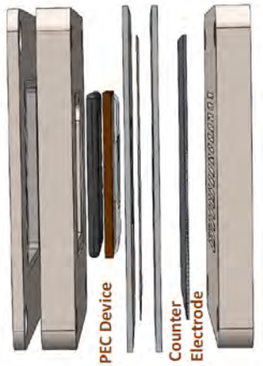
PROD *Emerging*

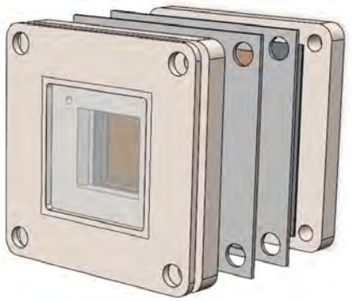
Added FY2025

- Developed by Rice University in collaboration with Lawrence Berkeley National Laboratory, and National Laboratory of the Rockies.
- Aimed to perform on-sun testing of photoelectrochemical cells (PECs) with 100-200 cm^2 Si/perovskite tandems with a diurnal stability of 1,000 hours with a rate of generation of 0.1g/hour.
- Validated a new reactor assembly that could achieve a bias-free water splitting at 21.7% Solar-to-Hydrogen (STH) efficiency.
- Demonstrated <50mV overpotential change over 500h in 2-electrode electrolyzer measurements validating voltage stability.
- Designed a Proton Exchange Membrane (PEM) with a PEC electrolyzer with <300mV overpotential indicating that the hybrid design is achieving high efficiency targets.
- DirectH2, Inc., a spin-off company, has exclusively licensed the intellectual property (IP) from that underpins this innovative technology. Hunt Energy (thru HL Energy Ventures) is funding the DirectH2 technology development.
- Contract Number: DE-EEDE-EE0010738 (2022)









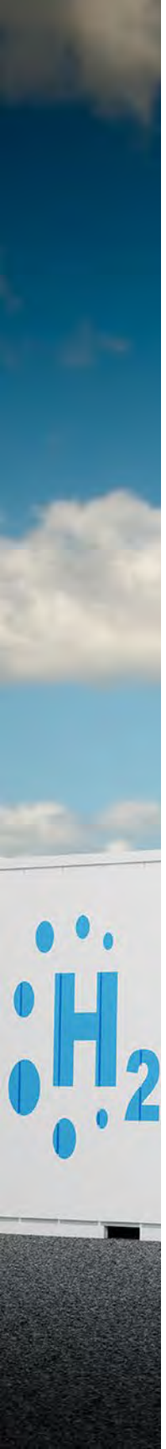
Low gap PEC cell architecture eliminates electrolyte resistance losses and catalyst delamination

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RICE UNIVERSITY

BERKELEY LAB

National Laboratory of the Rockies



New Hydrogen Safety Technologies for FY2025

Technology	Organization
DECIPHER: DEtection System Comprising Inexpensive Printed Sensor Arrays for Hydrogen Gas Emission Monitoring and Reporting	SRI International
Real-Time Ionic Liquid Electrochemical Sensor for Highly Sensitive and Selective Hydrogen Detection and Quantification	University of Missouri
The Electrical Hydrogen Sensor Technology with a Sub-minute Response Time and a Part-per-Billion Detection Limit for Hydrogen Environmental Monitoring	University of Georgia

Note: Technology summary slides based on available information from PIs through the end of FY2025

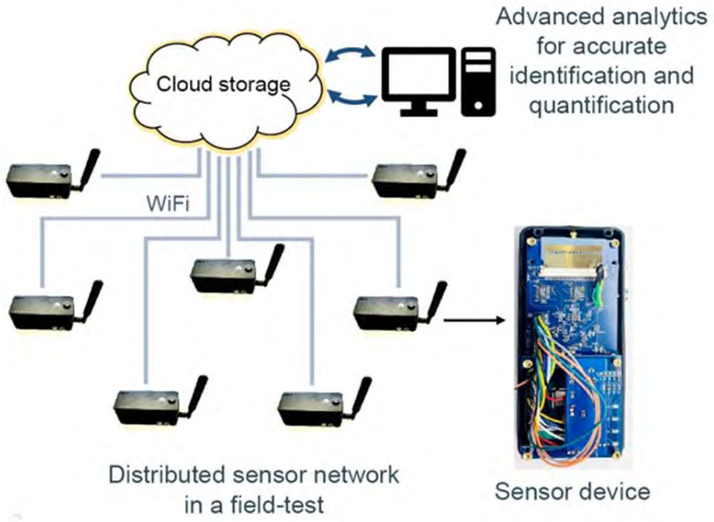
DECIPHER: DEtection System Comprising Inexpensive Printed Sensor Arrays for Hydrogen Gas Emission Monitoring and Reporting

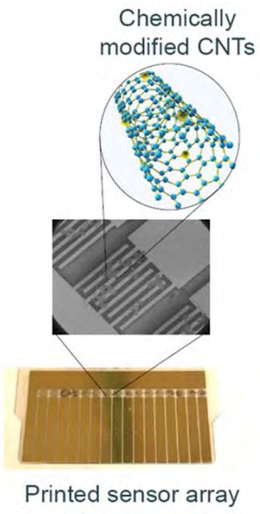
Pacific Northwest NATIONAL LABORATORY

SFTY *Emerging*

Added FY2025

- SRI International (formerly Palo Alto Research Center), in collaboration with Pacific Gas & Electric, is developing a printable, low-cost hydrogen sensor.
- New sensor will address low H2 sensitivity, selectivity, inaccurate H_2 concentration quantification and provide an economically viable measurement of ppb-level changes in ambient H2.
- Design encompasses optimized CNT-based transducer material chemistry and array design for maximum sensitivity.
- Current specification targets, H2 Sensitivity ppm → <10ppb, high selectivity, 10-year lifetime, minimal burn-in (pre-calibration) and operation is unaffected by changes in temperature and humidity. Installation and maintenance cost are also expected to be minimal.
- Multiple sensors can be deployed in a distributed network which uploads data to cloud storage where it can be analyzed using an ML-powered signal processing platform to provide highly accurate (>80%) H2 environment monitoring.
- Sensor network undergoing field testing at PG&E facility.
- Contract Number: ARPA-E DE-EE0010745 (2023)





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Pacific Gas and Electric Company

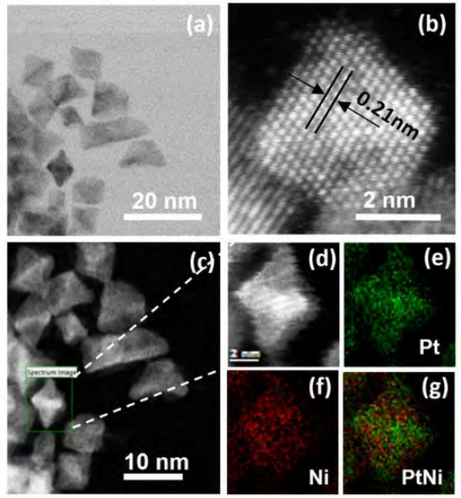
SRI

Real-Time Ionic Liquid Electrochemical Sensor for Highly Sensitive and Selective Hydrogen Detection and Quantification

SFTY
Emerging

Added FY2025

- Developed by the University of Missouri in collaboration with Michigan State University, Wayne State University, Oakland University, and the National Laboratory of the Rockies.
- Addresses shortcomings of available H2 sensors (e.g., degradation of sensing materials, poor selectivity, low sensitivity, slow response, size and limited lifetime).
- Metallic catalytic – ionic liquid-based sensor construction achieved <10 ppb in range 10ppb – 100ppm, < 1% drift over 90 days and less 30 second response time.
- Sensor operates continuously in real-time within a temperature range of -30 to 80 °C and relative humidity 10 – 98%.
- Other applications could include detection of other gases (GHG), explosive gases (mine safety), medical applications (COVID-19).
- Commercial prototype under development.
- Contract Number: DE-EE0010744 (2024)



(a) Representative TEM images of the PtNi bimetallic nanocrystal sample; (b) High-resolution lattice fingerprint image of the PtNi sample; (c) HAADF-STEM image of the PtNi nanocrystal sample; (d) HAADF-STEM image of an individual octahedral PtNi nanocrystal; (e-f) Element mapping images showing the distribution of Pt and Ni in the PtNi-nanocrystal sample.



Miniaturized H2 sensor device

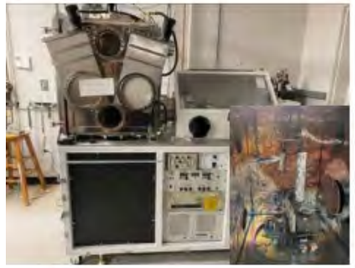
Contact Information:
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https://engineering.missouri.edu/faculty/xiangqun-zeng/

The Electrical Hydrogen Sensor Technology with a Sub-minute Response Time and a Part-per-Billion Detection Limit for Hydrogen Environmental Monitoring

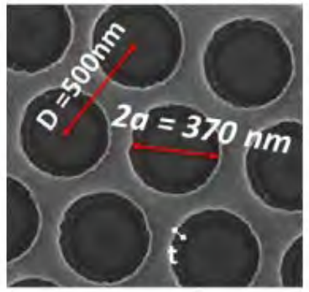
SFTY
Emerging

Added FY2025

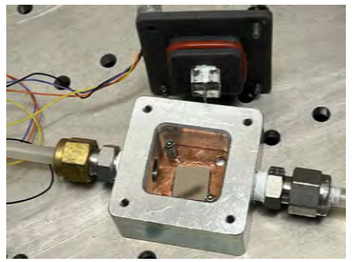
- Collaboration of sensor experts including the University of Georgia, Savannah River National Laboratory, National Laboratory of the Rockies, Southwest Research Institute, Pacific Gas and Electric Company, and Indrio Technologies.
- Developing a low-cost, high performance hydrogen sensor for hydrogen component leak rate quantification.
- Optimized the sensing materials, nanostructure design, and polymer coatings in a composite nano-hole arrays (CHA) sensor.
- Improved the surface-to-volume ratio (SVR) which resulted in a larger surface area to interact with hydrogen.
- Applied polymer/molecule coatings to a dual reference cell sensing apparatus to improve sensitivity, selectivity, response time, and extend sensor lifetime.
- Current sensor design has a parts-per-billion (ppb) sensitivity.
- Other potential applications in methane sensing, hydrogen transportation, the nuclear industry, and the medical field.
- Contract Number: DE-EE0010743 (2023)



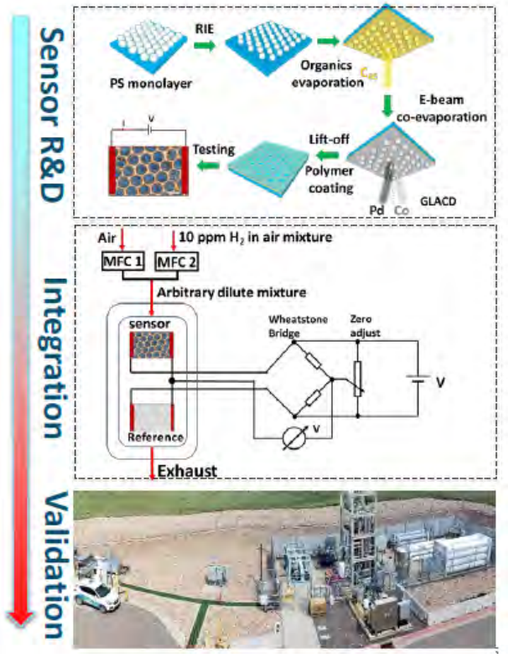
GLACD apparatus



SEM image of CHA sensor

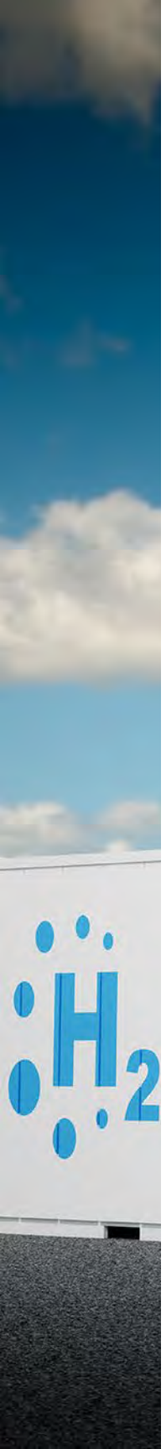


A sensing housing



The NLR Hydrogen Infrastructure Testing Research Facility (HITRF)

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New Hydrogen Storage Technologies for FY2025

Technology	Organization
High Efficacy Validation of Hydride Mega Tanks at the ARIES Lab (HEVHY METAL)	National Laboratory of the Rockies (NLR)
Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks	University of Kentucky CAER
System Demonstration for Supplying Clean, Reliable and Affordable Electric Power to Data Centers using Hydrogen Fuel	Caterpillar, Inc.

Note: Technology summary slides based on available information from PIs through the end of FY2025

High Efficacy Validation of Hydride Mega Tanks at the ARIES Lab (HEVHY METAL)

Pacific Northwest NATIONAL LABORATORY

ST Commercial

Added FY2025

- This project will advance materials- based hydrogen storage technologies by large-scale demonstration and identification of demand side techno-economics and deployment pathways.
- Demonstrate installation of two HY2MEGA subsystems with MW–scale green H2 infrastructure to validate performance: rates, capacity, and efficiency.
- Investigate benefits of new metal hydride technology such as storage vessel size, efficiency and safety.
- Apply best practices of hydrogen storage (materials) to validate charging/discharging rates and capacity.
- Examined positioning of GKN HY2MEGA tanks and thermal management system (TMS) at the Flatirons Campus.
- Established measurement and data collection needs, and data transfer and control strategies.
- Contract Number: DE-AC36-08GO28308 (2024)



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National Laboratory of the Rockies

GKN Hydrogen

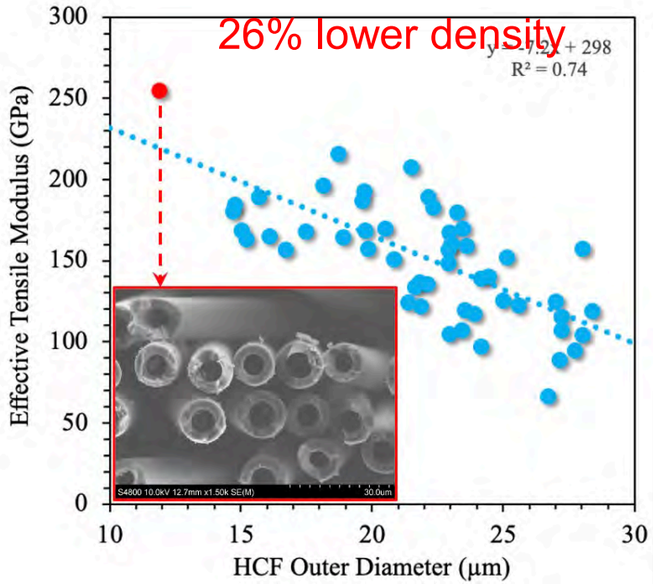
SoCalGas

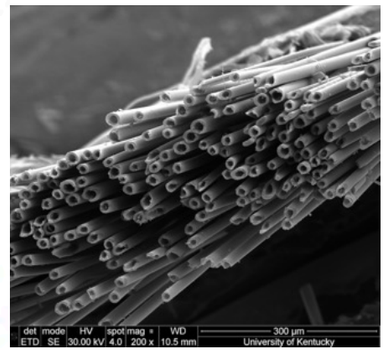
Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks

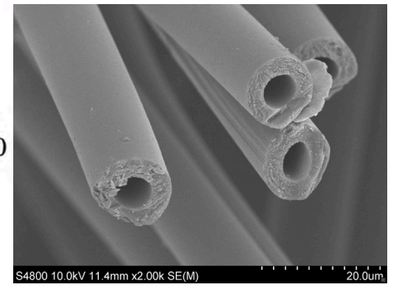
ST *Emerging*

Added FY2025

- Developed by the University of Kentucky in partnership with Solvay Composite Materials, Oak Ridge National Lab, Strategic Analysis Inc., Advanced Fiber Technologies, and Steelhead Composites.
- Developing hollow carbon fiber (HCF) that retains the mechanical properties of carbon fiber (CF) T700S, at a fraction of the density.
- Reduces CF cost (-12%), H_2 storage system cost (-30%) and increases H_2 tank storage kWh/kg (30%).
- HCF at 44% open area, while conserving T700S diameter and performance, targeted to meet metrics above.
- Extrusion process requires no fiber post processing (burning or etching) and retrofittable “drop-in” into existing carbon fiber manufacturing facilities.
- Applications include aerospace, wind, transportation, building materials, and domestic/retail items (e.g., sports equipment).
- Contract Number: DE-EE0009241 (2021)









Contact Information:

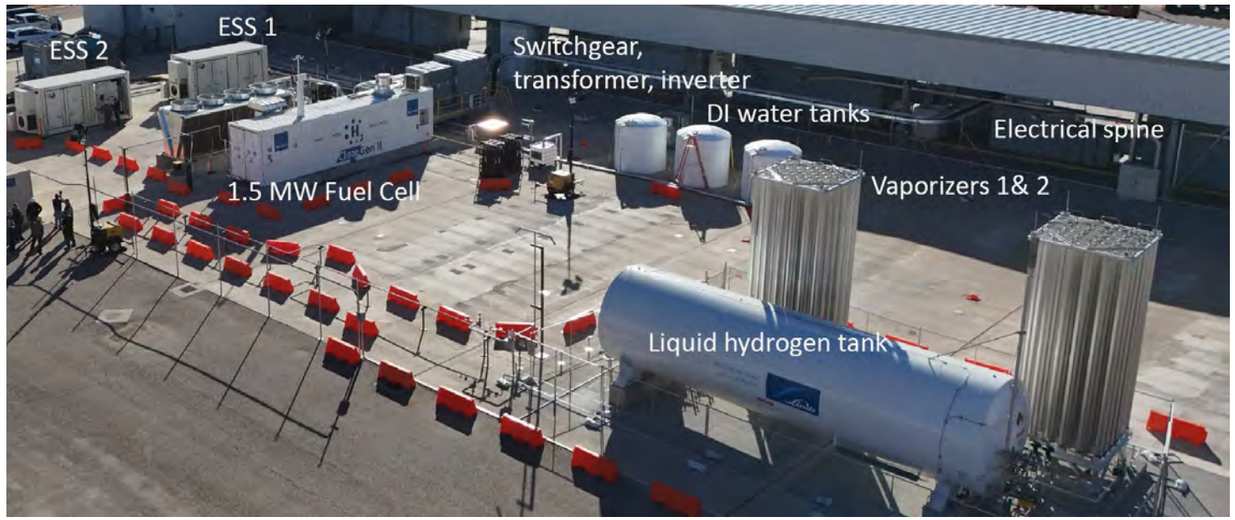
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System Demonstration for Supplying Clean, Reliable and Affordable Electric Power to Data Centers using Hydrogen Fuel

INFRA
Emerging

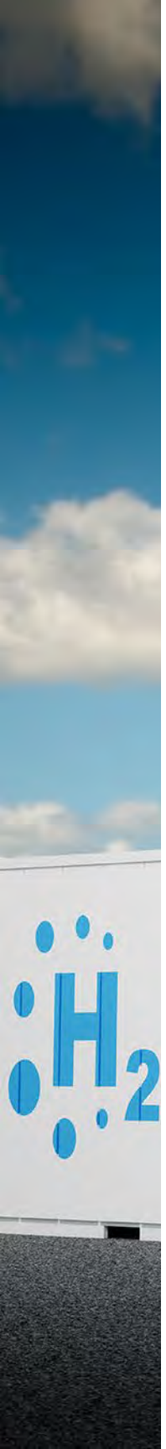
Added FY2025

- Developed by Caterpillar (2023) in collaboration with NLR, Microsoft and industry collaborators Ballard and Linde.
- Demonstrate a Megawatt scale stationary fuel cell (FC) to generate electric power and meet the stand-by requirements of a modern data center.
- First integrated MW scale H_2 fuel cell power generator with battery microgrid system that meets modern data-center stand-by requirements for operational resiliency.
- 1.5 MW full load rating and storage of 48 hours of fuel onsite (liquid H_2) for typical data center loads.
- Developed and approved safety plan, personnel training and work procedures.
- Over 150 hours of operation at altitude and in challenging weather conditions.
- Contract Number: DE-EE009252 (2021)



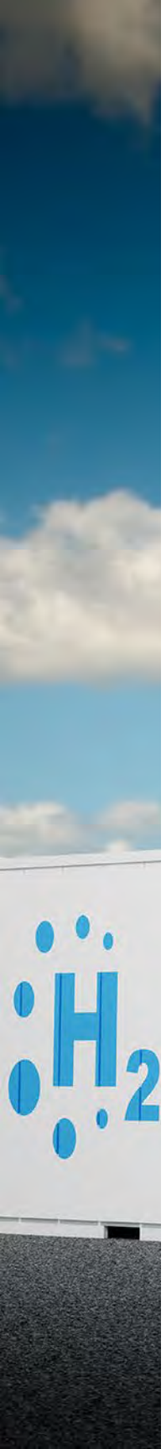
Caterpillar's 1.5MW Scale Data Center Back-Up Power Concept

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Pacific Northwest
NATIONAL LABORATORY

Pre-FY2025 Technologies



Pre-FY2025 Delivery Technologies

Technology	Organization
Advanced Barrier Coatings for Harsh Environments	GVD Corporation
Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks	Ivys Energy Solutions
ARIES / Flatirons Facility - Hydrogen System Capability Buildout	National Renewable Energy Laboratory
California Hydrogen Refueling Stations	Air Products and Chemicals, Inc.
Composite Pipeline Technology for Hydrogen Delivery	Oak Ridge National Laboratory
Flexhose: Cryogenically Flexible, Low Permeability Thoraeus Rubber Hydrogen Dispenser Hose (SBIR)	NanoSonic, Inc.
Fuel Cell Bus Evaluations	National Laboratory of the Rockies
High Pressure, High Flow Rate Dispenser and Nozzle Assembly for Heavy Duty Vehicles	Electricore, Inc.
High-Pressure, Low-Temperature Composite Nozzles for Long-Term Hydrogen Dispensing (SBIR)	NanoSonic, Inc.
Hydrogen Compression Application of the Linear Motor Reciprocating Compressor (LMRC)	Southwest Research Institute
Hydrogen Fuel Quality	Los Alamos National Laboratory
Innovating Hydrogen Station: Heavy-Duty Fueling	National Renewable Energy Laboratory
Innovative Advanced Hydrogen Mobile Fueler	Electricore, Inc.
Performance Evaluation of Delivered Hydrogen Fueling Stations	Gas Technology Institute
Station Operational Status System (SOSS) 3.0 and Station Map Upgrade Project	California Fuel Cell Partnership
Sustainable Hydrogen Fueling Station - Performance Evaluation and Optimization	California State University LA
TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery	Hexagon Lincoln (Formerly Lincoln Composites, Inc.)

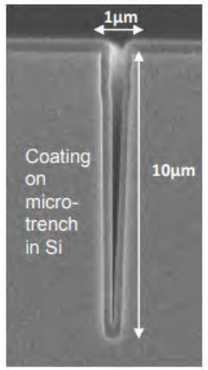
Advanced Barrier Coatings for Harsh Environments

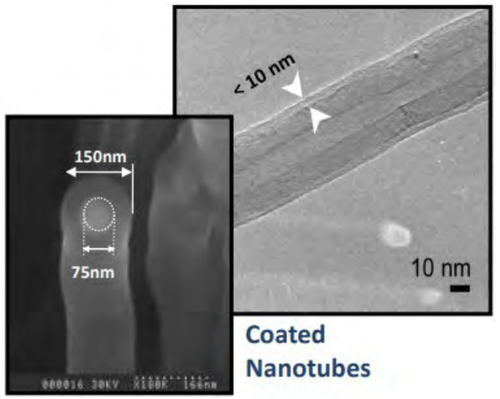
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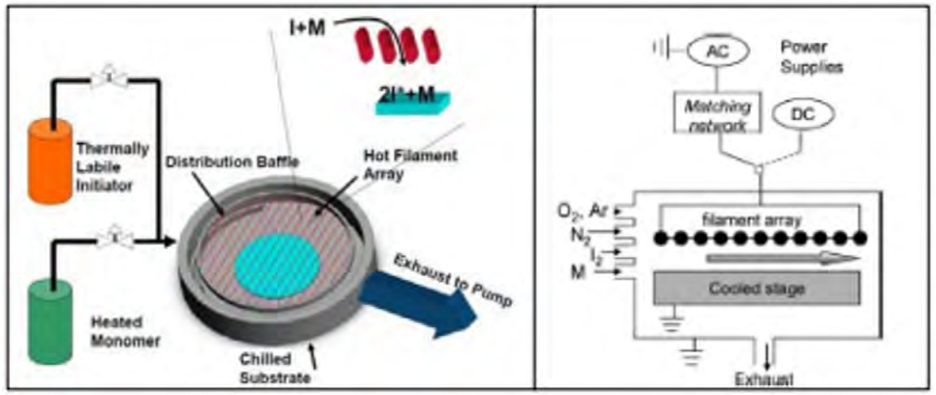
DLVY Emerging

- Developed by GVD Corporation in partnership with Greene, Tweed & Co., Oak Ridge National Laboratory, HydroPac.inc., Linde (formerly Praxiar), and PowerTech.
- Can be used as a barrier coating for o-rings and other high-pressure hydrogen seals to mitigate hydrogen permeability and reduce seal wear due to friction.
- Improves Hydrogen CSD seal life from <1,500 hours to >8,000 hours.
- Reduces the relative permeability of helium by 35%.
- Decreases hydrogen CSD cost.
- Improves lifetime of seals by 5 times.
- Contract Number: DE-SC0011339 (2015)









GVD's Modified Standard Deposition Hardware to Allow Single Chamber Hot Filament CVD (left) and plasma-enhanced CVD (right)

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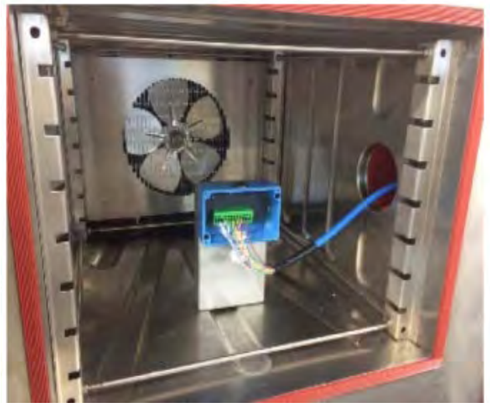
GVD · Oak Ridge National Laboratory · Hp · Powertech · Linde

Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks

- Developed by Ivys, Inc., in collaboration with Aire Liquide Advanced Technologies, National Laboratory of the Rockies, and Rheonik.
- First commercial deployments in Japan (2018) and Australia (2021) and planned domestic installations in the U.S.
- A hydrogen dispensing system that uses modern communication standards and data-driven integrated system controls.
- Can be used to easily and quickly dispense hydrogen for hydrogen vehicles such as cars, buses, forklifts, etc.
- “Mono-block” design tube reduces impacts of temperature changes and decreases flow turbulence.
- Two temperature measurements added to optimize software temperature compensation.
- Contract Number: DE-EE0007273 (2016)



Dispenser and Hydrogen cooling system installed at NLR’s Hydrogen Infrastructure Testing and Research Facility (HITRF)

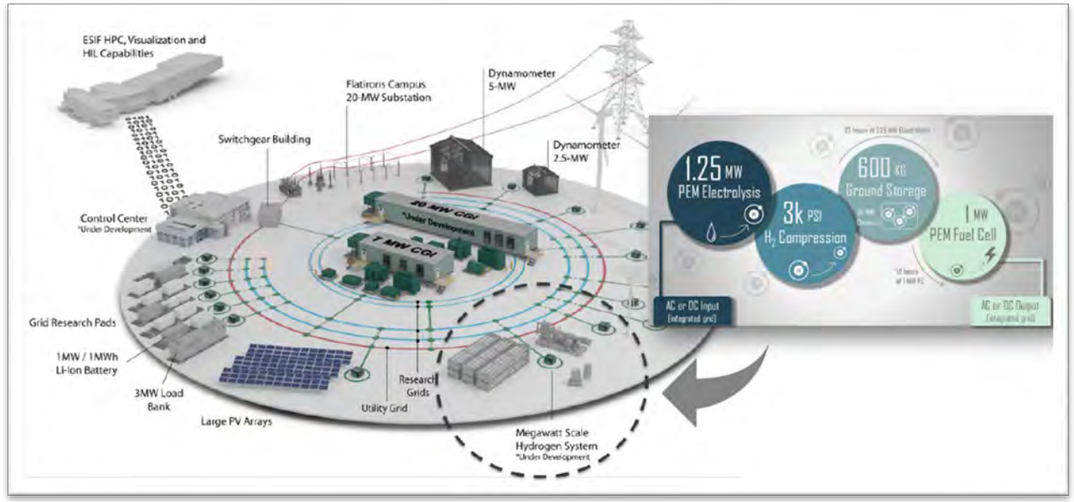


Climate chamber test apparatus for meter development work

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ARIES / Flatirons Facility - Hydrogen System Capability Buildout

- Developed by the National Laboratory of the Rockies (NLR) in collaboration with Nel and Toyota.
- Integrated fuel cell generator, electrolyzer, storage tank and gas management panel, compressor system and fuel cell system.
- The infrastructure will support future research projects under the ARIES umbrella, specifically in the areas of energy storage, direct hydrogen production coupling with renewables, grid stabilization, electrons to molecules, heavy duty transportation, and other innovative end uses
- Multiple funded projects are currently leveraging this capability.
- All day runs with “sweep” (10-100%) of constant power levels, and calculated efficiencies for major equipment.
- Contract Number: AC36-08GO28308





National Laboratory of the Rockies

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TOYOTA

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California Hydrogen Refueling Stations

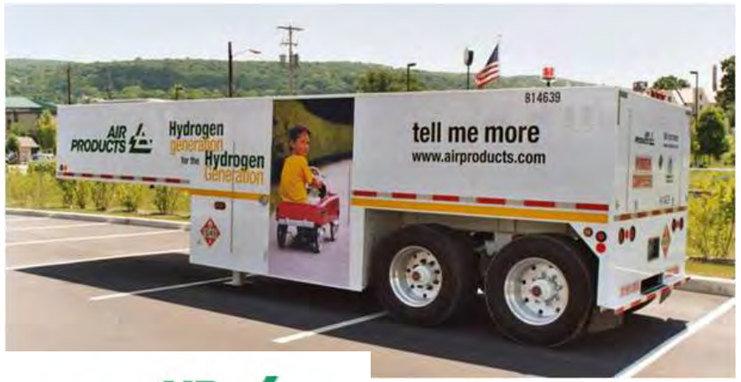
Pacific Northwest NATIONAL LABORATORY

DLVY Commercial

uspto 1 patent

- Developed by Air Products and Chemicals Inc. as part of California Infrastructure Project. Commercial production and delivery under contract began in 2013.
- Delivers hydrogen and hydrogen fueling service as dictated by location and demand.
- Can be used in polymer electrolyte membrane fuel cell stacks intended for both stationary and automotive applications.
- Permanent or temporary options at 300 or 700 bar and up to 100 kg per day.
- Uses a variety of hydrogen delivery, storage, and refueling services to reduce infrastructure installation costs.
- Contract Number: DE-FC36-05GO85026 (2005) and DE-FC36-01GO11087 (2001)





AIR PRODUCTS



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Composite Pipeline Technology for Hydrogen Delivery

Pacific Northwest NATIONAL LABORATORY

DLVY *Emerging*

uspto 1 patent

- Commercially available technology being evaluated by ORNL for hydrogen delivery.
- Can be used for delivery of hydrogen fuel for zero-emission fuel-cell-powered vehicles.
- Partners and collaborators include Fiberspar LinePipe, LLC,. (now National Oilwell Varco/NOV), Polyflow Inc., SRNL, and University of Tennesee.
- Materials provided by Fiberspar, Lincoln Composites, Ticona (Celanese), Arkema.
- Achieves 2020 DOE hydrogen pipeline leakage target of <780 kg/mi/y.
- Reduces pipeline installation costs by eliminating pipeline welding.
- Eliminates the need for anodic protection against corrosion.
- Contract Number: DE-AC05-00OR22725 (2005)



Emplacement of FRP Pipeline (left) and Pipeline Testing at ORNL (right)

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OAK RIDGE National Laboratory · PolyFlo INCORPORATED · Savannah River National Laboratory · NOV · The University of Tennessee Knoxville

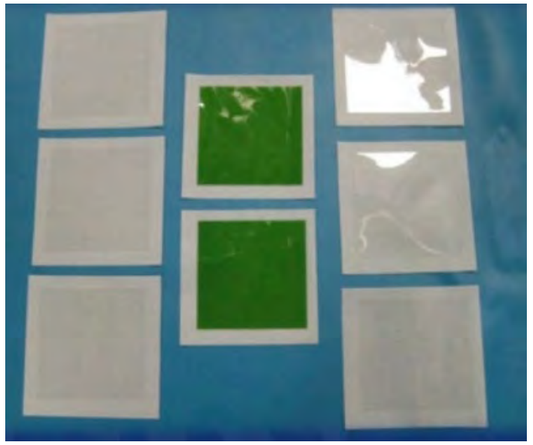
Flexhose: Cryogenically Flexible Low Permeability Thoraeus Rubber Hydrogen Dispenser Hose (SBIR)

DLVY Commercial

- Developed by NanoSonic, Inc., and with support from CSA Group, NLR, Fittings Partner, WEH USA, and Giles County Government.
- Components of the system have been transitioned to commercial sales.
- Currently testing hose capabilities and specifications.
- Can be used in cryogenic hydrogen fueling stations to dispense fuel.
- Provides hose flexibility at cryogenic temperatures.
- Achieves high-pressure hydrogen fueling requirements at 875 Bar.
- Provides 25,550 annual refueling cycles.
- Electrically nonconducting.
- Reduces hydrogen losses to evaporation during fueling using a low hydrogen permeability resin layer within the hose.
- Contract Number: DE-SC0010162 (2017)



NanoSonic's Flexhose



Low T_g Polymer Matrix Resins and Films for Cryogenic Flex Testing

Corn Stover
Corn Stover

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Fuel Cell Bus Evaluations

- Assessment led by National Laboratory of the Rockies (NLR) with support from transit agencies, manufacturers (New Flyer, Ballard), fuel providers, and other organizations (California Air Resources Board, Center for Transportation and Environment, CALSTART).
- Provides a non-biased evaluation of fuel cell electric bus (FCEB) performance and cost.
- Utilizes existing data from transit agencies (AC Transit, SunLine, OCTA, etc.) to assess the progress of FCEB technology towards DOE/DOT technical targets and commercialization.
- Documents progress on implementing FCEBs in transit operations, shares early adopter lessons and addresses barriers to market acceptance.
- Publishes reports to aid transit agencies considering FCEBs.
- Compares FCEBs to conventional technologies in similar service, collecting data on three baseline technologies: CNG, diesel and diesel hybrid.
- Contract Number: DE-AC36-08GO28308 (2001)



Sunbus, Sunline



SunLine, New Flyer



OCTA, New Flyer



AC Transit, New Flyer



AC Transit, New Flyer



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High Pressure, High Flow Rate Dispenser and Nozzle Assembly for Heavy Duty Vehicles

DLVY Commercial

- Developed by Electricore, Inc. in collaboration with WEH Technologies, Inc., Bennett Pump Company, Quong & Associates, Inc., and NLR.
- Dispenser has been installed on the NLR HD Pad at HITRF and in use since December of 2022. Nozzle and breakaway are still under development.
- Hydrogen trucks that will benefit from the production of the HDND have the potential to reduce emissions throughout communities.
- A heavy-duty dispenser and nozzle assembly will accelerate the development and adoption of sustainable transportation technologies.
- Contract Number: DE-EE0008817 (2019)





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High-Pressure, Low-Temperature Composite Nozzles for Long-Term Hydrogen Dispensing (SBIR)

Pacific Northwest NATIONAL LABORATORY

DLVY Commercial

- Developed by NanoSonic, Inc., with support from Air Liquide, First Element/True Zero, Nikola, and WEH.
- Components of materials technology have been transitioned to commercial sales.
- H2 fueling nozzle (H30 or H70).
- Rugged, safe and reliable (-50 ^{o}C, 70 fills per day, lifetime > 2 years).
- Customized (nanocoated) OEM nozzle disconnect/connect cycle testing (22,000 cycles freeze test -30^{o}C to +85^{o}C – improved operability).
- 20,000 cycle pressurized (700 bar) and freeze endurance tests in progress.
- Enables DOE cost target for H2 refueling hose and nozzle.
- Contract Number: DE-SC0019824 (2020)







H2 fueling nozzle testing and component concept

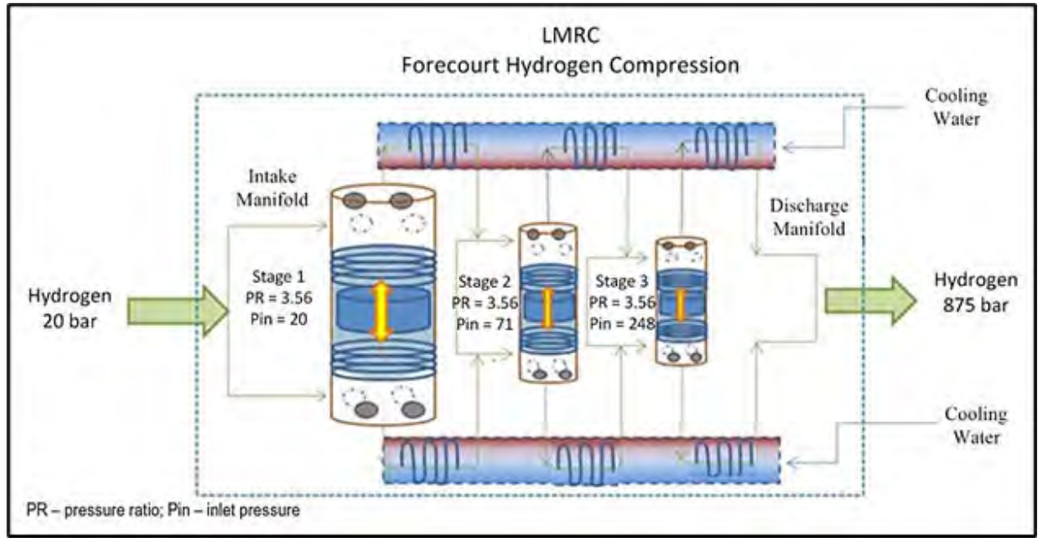
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NanoSonic Putting nanotechnology to work | WEH | Air Liquide | FIRST ELEMENT FUEL

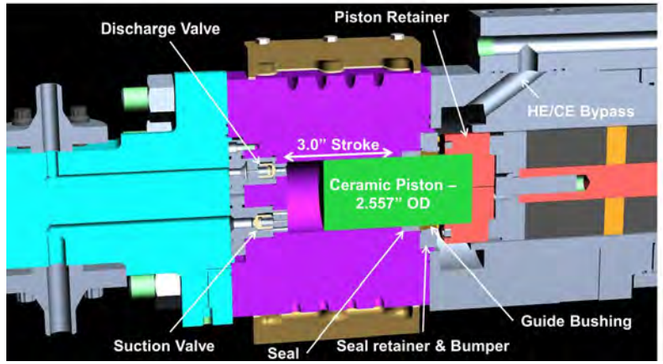
Hydrogen Compression Application of the Linear Motor Reciprocating Compressor (LMRC)

DLVY Emerging

- Being developed by Southwest Research Institute (SwRI) in partnership with ACI Services, Inc.
- Currently transitioning from completed design to assembling/testing of the LMRC.
- Can be used to provide low-cost, high-efficiency compression of hydrogen at forecourt fueling stations.
- Achieves a compressor specific energy of ~1.53 kWh/kg H2 compressed from 100 bar to 950 bar (2020 DOE target 1.6 kWh/kg).
- Maintains ceramic seal life for up to 48 months (assuming an operation time of approximately 6 hours per day).
- Reduces capital costs compared with conventional reciprocating compressors by minimizing part count.
- Reduces wear-related maintenance compared with conventional reciprocating compressors by reducing friction and reducing the number of wear components.
- Contract Number: DE-EE0006666 (2014)



SwRI's Three-Stage LMRC System



Piston Close-up

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Hydrogen Fuel Quality

DLVY Emerging

uspto 1 patent

- Being developed by LANL, in partnership with Japan Automobile Research Institute, European Union, WG-11, National Hydrogen, and Fuel Cell Codes and Standards Coordinating Committee, SAE International, Smart Chemistry, CEA France, VTT Finland, Joint Research Centre, Greece, ASTM International, Air Liquide, California Fuel Cell Partnership, CDFA, CONSCI, H2 Frontier, NLR, VI Controls, ONEH2, FORD, HNEI, UConn, and SKYRE.
- Can be used to detect low levels of impurities present in gaseous hydrogen fuel.
- Can detect the presence of CO in quantities at or below 200 ppb in less than 5 minutes.
- Developing hydrogen contaminant detector that can operate in dry hydrogen at higher pressures without the need for a humidification system.
- Developing PEMFC testing and characterization methods of chemicals that can be applied uniformly across the hydrogen industry.
- Investigating detection of other contaminants present at hydrogen refueling stations in operation and maintenance stages, such as refrigerants, lubricants, and solvent-based cleaning solutions.
- Contract Number: DE-AC52-06NA25396 (2006)



LANL's hydrogen contamination detection system.

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Innovating Hydrogen Station: Heavy-Duty Fueling

DLVY
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Currently being developed by the National Laboratory of the Rockies (NLR) in partnership with Air Liquide, Honda, Shell, and Toyota.
- Addressing technological gaps for medium and/or heavy-duty fuel cell electric truck storage systems in terms of high flow rate fueling data, high flow rate system models, and light duty station/component reliability.
- Upgrading NLR's legacy station to achieve HD fast fills at mass flow rates of 10 kg/min average at 70 MPa at -40ºC.
- Developing high flow rate fueling models utilizing NLR's high-performance computing capabilities (CFD modeling).
- All systems are installed, and operating, and station commissioning underway with preliminary testing.
- Contract Number: DE-AC36-08GO28308 (2019)





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National Laboratory of the Rockies
Air Liquide
HONDA
TOYOTA

Innovative Advanced Hydrogen Mobile Fueler

DLVY Emerging

Pacific Northwest NATIONAL LABORATORY

- Currently being developed by Electricore, Inc., in partnership with Air Liquide, HTEC, Quong & Associates, Inc., and Manta Consulting.
- Uses Air Liquide's C100 station design as the base design for the project, which utilizes several components from the C100, with appropriate modifications to accommodate AHMF specifications and mobile approach.
- On-board 480 VAC, low-noise, low-emissions diesel generator for power, with options of using external power.
- Up to 170 kg H2 at 45 MPa with the ability to connect to external storage.
- The AHMF is the first mobile fueler capable of filling vehicles to 95-100% in 3-5 minutes, 3-5 cars in the first hour, and 20-40 cars daily.
- Electricore has collaborated with Air Liquide in getting an operational advanced hydrogen mobile fueler in Pomona, California. Fuel dispensed by this fueler comes from a production plant which came online May of 2022.
- Contract Number: DE-EE0007275 (2016)



Air Liquide AHMF fueling station developed in collaboration with Electricore



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Performance Evaluation of Delivered Hydrogen Fueling Stations

DLVY *Emerging*

Pacific Northwest NATIONAL LABORATORY

- Developed by Gas Technology Institute (GTI) in partnership with Linde Gas, LLC.
- Design and deployment of a custom data acquisition system in five hydrogen fueling stations in California.
- Collects, organizes, and reports on operational, transactional, safety, and reliability data for the five fueling stations.
- The GTI data acquisition system has been installed and commissioned at the San Ramon station, which will open for public use in the very near future.
- Codes and standards development support.
- Contract Number: DE-EE0005886 (2013)



Figure 2: GTI data acquisition panel installed at San Juan Capistrano

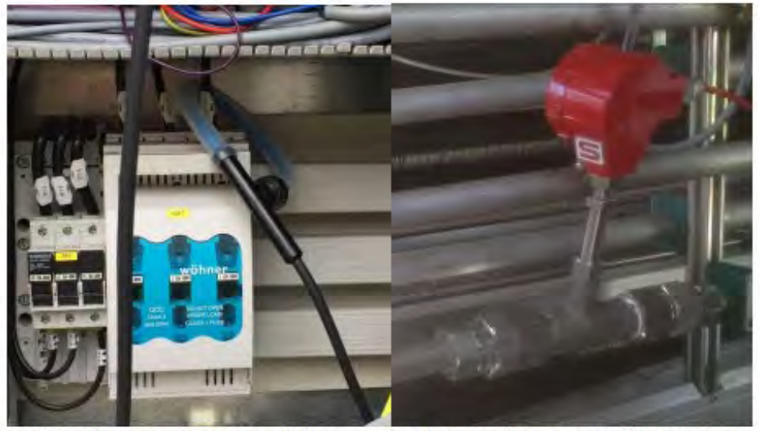


Figure 3: Rogowski coil current sensor (left) and hot-wire hydrogen flow meter (right) installed in Linde compressor enclosure

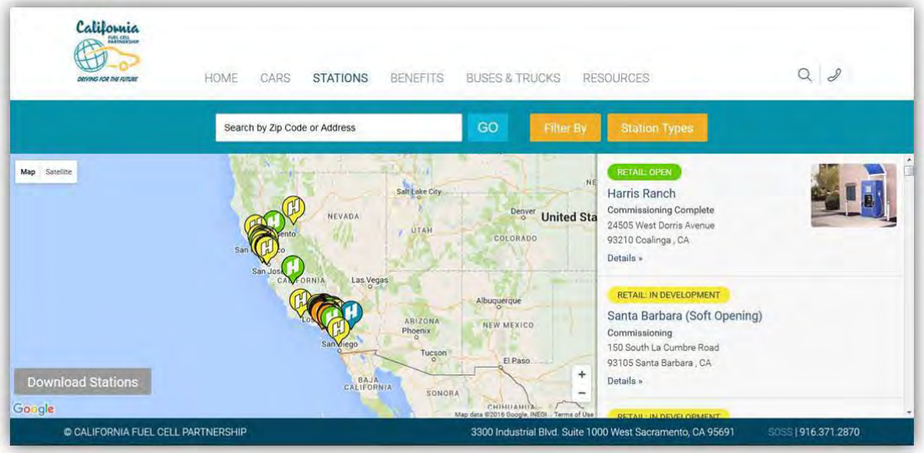
GTI ENERGY *solutions that transform*

Linde

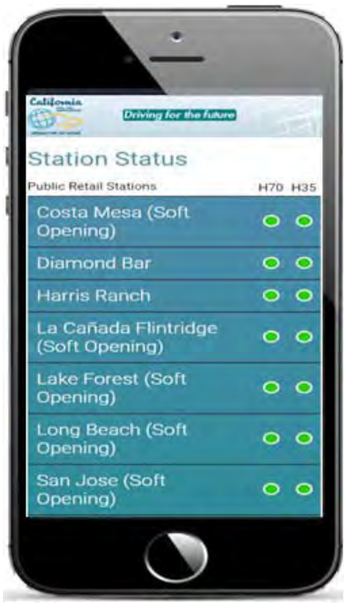
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Station Operational Status System (SOSS) 3.0 and Station Map Upgrade Project

- Developed by California Fuel Cell Partnership (CaFCP) in partnership with Argonne National Laboratory and DOE.
- SOSS is a mobile web application that provides status information about each of the available hydrogen stations in California to fuel cell electric vehicle (FCEV) customers to increase customer satisfaction and station demand.
- Twenty-seven hydrogen stations in California are participating on SOSS (as of 7/22/2016).
- DOE: CaFCP 2014

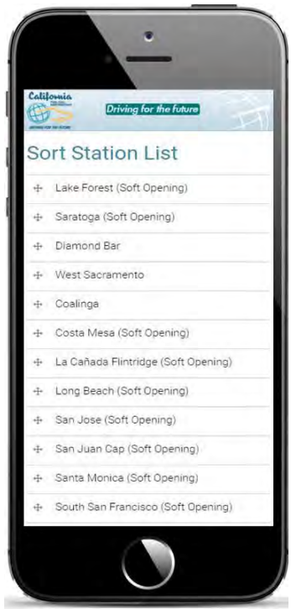


Station Map



SOSS home page



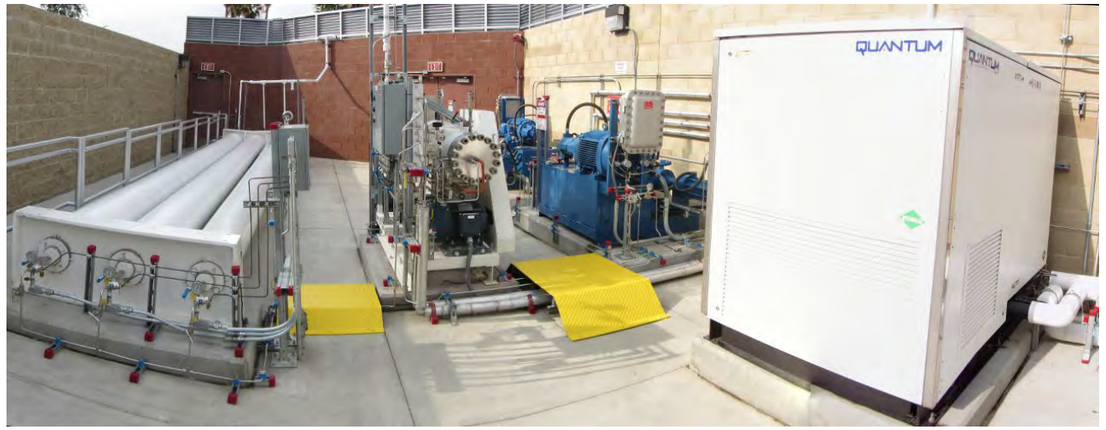


SOSS capacity view (left) SOSS sort view (right)

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Website: https://cafcp.org

Sustainable Hydrogen Fueling Station - Performance Evaluation and Optimization

- California State University, Los Angeles is the lead on the project with partner Hydrogenics Corp. (acquired by Cummins operated by Accelera).
- The objective of the project is to test, collect data, and validate hydrogen refueling architecture deployed at CSULA and its individual components in a real-world operating environment. The evaluation data will be provided to the Hydrogen Secure Data Center (HSDC) at the National Laboratory of the Rockies (NLR).
- Developed and implemented fueling station system performance optimization and a data acquisition (DAQ) system to track station performance.
- Conducted outreach and training activities for international visitors, first responders, scholars, students and local government.
- Contract Number: DE-EE0005890 (2012)



Production: 60 kg/day Storage: 60 kg Pressure: 5,000 and 10,000 psi
Capacity: 15-20 fuel cell vehicles per day



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TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery

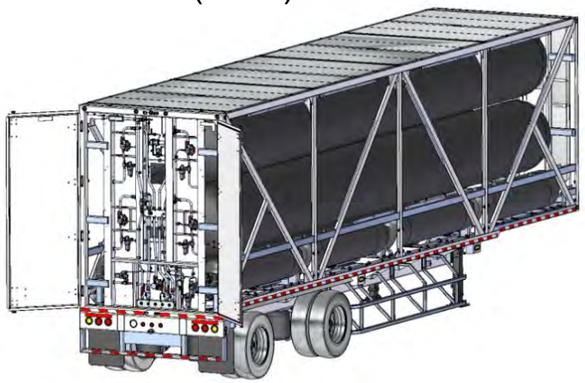
DLVY Commercial

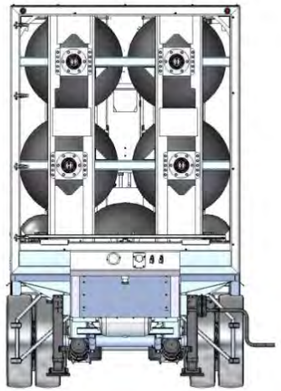
Pacific Northwest NATIONAL LABORATORY

- Developed by Lincoln Composites, Inc., and commercialized in 2012.
- Stores 1600 lb. of compressed hydrogen (400 lb. per tank) at 3,600 psi (250 bar).
- Achieves a performance of 0.018 kg of hydrogen per liter of tank volume and 0.06 kg of hydrogen per kg of tank weight.
- Developing systems to increase capacity and optimize gross vehicle weight and 5,000 psi system design.
- Meets strength (burst and pressure cycling), environmental (corrosive fluids, extreme temperatures), and durability (flaw tolerance, penetration) targets.
- Contract Number: DE-FG36-08GO18062 (2008)



Assembled TITAN™ ISO Container (without outer panels) on Standard ISO Trailer

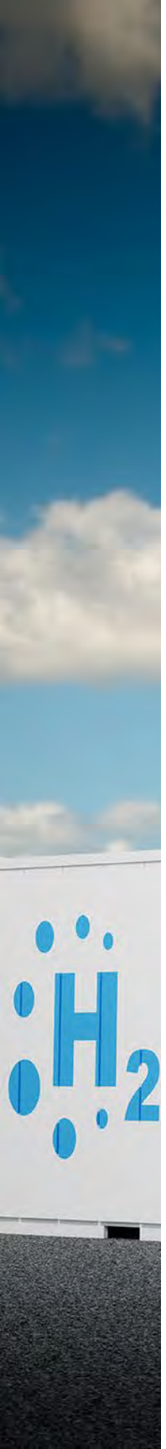






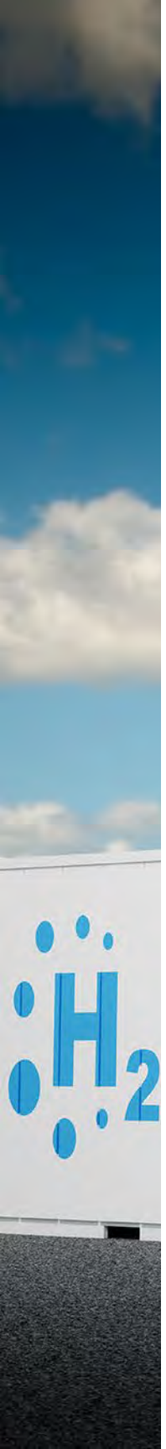
LINCOLN COMPOSITE MATERIALS

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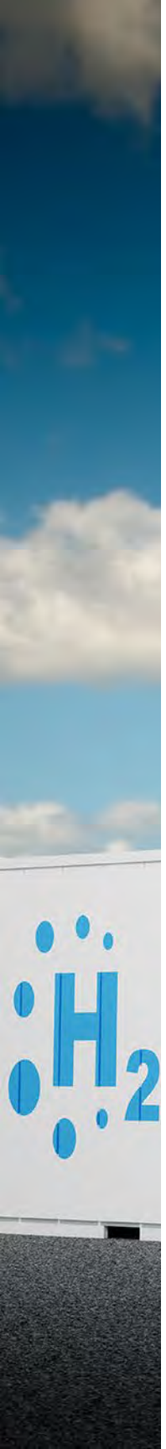
Pre-FY2025 Fuel Cell Technologies

Technology	Organization
Active and Durable Platinum-Group-Metal-Free Cathodic Electrocatalysts for Fuel Cell Application	Pajarito Powder, LLC
Affordable, High Performance, Intermediate Temperature Solid Oxide Fuel Cells	Redox Power Systems
Bio-Fueled Solid Oxide Fuel Cells (SBIR)	SulfaTrap, Inc.
Bipolar Membranes with an Electrospun 3D Junction	Vanderbilt University
Channeling Engineering of Hydroxide Ion Exchange Polymers and Reinforced Membranes	Rensselaer Polytechnic Institute
Coatings for Compressor Seals	GVD Corporation
Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System	Technology Management, Inc.
Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR)	Dynalene, Inc.
Conductive Compound for Molding Fuel Cell Bipolar Plates	Los Alamos National Laboratory w\Lyondellbasell Industries Holdings B.V. (Formerly Bulk Molding Compounds, Inc.)
Corrosion Test Cell for PEM Bipolar Plate Materials	Los Alamos National Laboratory w/Fuel Cell Technologies, Inc.
Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM)	Nuvera Fuel Cells, Inc. (Acquired by Hyster-Yale)
Development of Durable Active Supports for Low Platinum Group Metal Catalysts (SBIR)	Pajarito Powder, LLC
Development of Low Cost, Thin Flexible Graphite Bipolar Plates for Heavy Duty Fuel Cell Applications	NeoGraf Solutions, LLC
Development of Novel Non-PGM Electrocatalysts for Proton Exchange Membrane Fuel Cell Applications	Northeastern University
Development of PGM-free Catalysts for Hydrogen Oxidation Reaction in Alkaline Media	University of New Mexico (UNM)



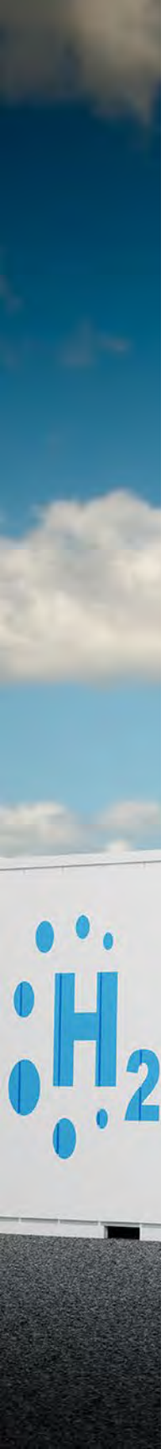
Pre-FY2025 Fuel Cell Technologies (continued 2/5)

Technology	Organization
Direct Methanol Fuel Cell (DMFC) for Handheld Electronics Applications	MeOH Power (Formerly MTI Micro Fuel Cells, Inc.)
Domestically Manufactured Fuel Cells for Heavy-Duty Applications	Plug Power, Inc.
Durable and Efficient Centrifugal Compressor-Based Filtered Air Management System and Optimized BOP	Mahle Powertrain, LLC
Durable High Power Density Fuel Cell Cathodes for Heavy-Duty Vehicles	E.I. du Pont de Nemours and Company w/Canegie Mellon University
Durable High-Power Membrane Electrode Assemblies with Low Pt Loading	General Motors Company (GM)
ElectroCat: Durable Mn-Based Platinum-Group-Metal-Free Catalysts for Polymer Electrolyte Membrane Fuel Cells	Giner, Inc.
FARADAYIC® ElectroEtching of Stainless Steel Bipolar Plates (SBIR)	Faraday Technology, Inc.
Foil Bearing Supported Compressor-Expander	R&D Dynamics Corporation
Fuel Cell Membrane Electrode Assemblies with Ultra-Low-Platinum Nanofiber Electrodes	Vanderbilt University
Fuel Cell Membrane Electrode Assembly Manufacturing R&D	National Renewable Energy Laboratory
Fuel Cell Membrane Measurement System for Manufacturing (SBIR)	Scribner Associates, Inc.
Fuel Cell Turbocompressor	Honeywell International, Inc.
Fuel-Cell-Based Mobile Lighting	Sandia National Laboratories w/Stray Light Optical Technologies
Fuel-Cell-Powered Airport Ground Support Equipment Deployment	Plug Power, Inc.
GenDrive™: Fuel Cell Power System (ARRA)	Plug Power, Inc.
High Efficiency Reversible Solid Oxide System	FuelCell Energy, Inc.



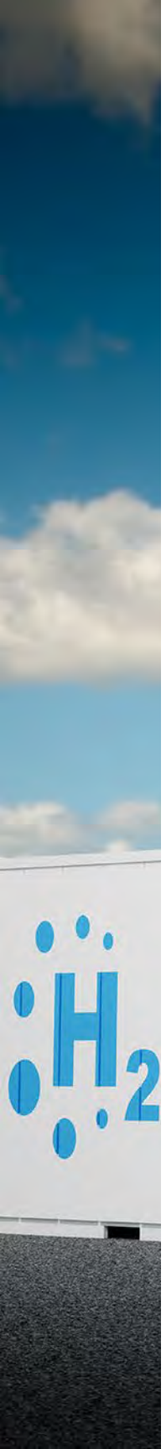
Pre-FY2025 Fuel Cell Technologies (continued 3/5)

Technology	Organization
High Performance, Durable, Low-Cost Membrane Electrode Assemblies for Transportation Applications	3M Company
Highly Active, Durable, and Ultra-low PGM NSTF Thin Film ORR Catalysts and Supports	3M Company
Highly Robust Low PGM MEAs Based upon Composite Supports	Forge Nano
Highly-Accessible Catalysts for Durable High-Power Performance	General Motors Company (GM)
High-Performance AEM LTE with Advanced Membranes, Ionomers and PGM-Free Electrodes	Georgia Institute of Technology
High-Performance Water Vapor Membranes to Improve Fuel Cell Balance of Plant Efficiency and Lower Costs (SBIR)	Tetramer Technologies, LLC
HydroGEN Seedling: High-Efficiency Proton Exchange Membrane Water Electrolysis Enabled by Advanced Catalysts, Membranes, and Processes	Nel Hydrogen (Formerly Proton Onsite)
Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods (SBIR)	NuVant Systems Inc.
In-Line Membrane Thickness Mapping with Real-Time Data Processing	National Renewable Energy Laboratory
Laser 3-D Printing of Highly Compacted Protonic Ceramic Electrolyzer Stack	Clemson University
Low Platinum Loading Fuel Cell Electrocatalysts	Brookhaven National Laboratory
Low-Cost 3-10 kW Tubular SOFC Power System	Special Power Sources, LLC (Formerly Atrex Energy, Inc.)
Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells (SBIR)	Nanotek Instruments, Inc.
Low-Cost PEM Fuel Cell Metal Bipolar Plates	TreadStone Technologies, Inc.
Low-Cost, High-Performance Catalyst Coated Membranes for Proton Exchange Membrane Water Electrolyzers	3M Company
Manufacture of Durable Seals for PEM Fuel Cells	Freudenberg-NOK General Partnership



Pre-FY2025 Fuel Cell Technologies (continued 4/5)

Technology	Organization
Maritime Fuel Cell Generator (MarFC) Project	Sandia National Laboratories
Mobile Fuel Cell Generator (STTR)	RockeTruck, Inc.
Multi-Functional Catalyst Support (SBIR)	pH Matter, LLC
Nanoscale Water Gas Shift Catalysts	Nexceris LLC (formerly NexTech Materials, Ltd.)
Northeast Demonstration and Deployment of FCRx200	US Hybrid Corporation
Novel Manufacturing Process for PEM Fuel Cell Stacks	Protonex Technology Corporation (Acquired by Ballard Power Systems)
Novel Structured Metal Bipolar Plates for Low-Cost Manufacturing (SBIR)	TreadStone Technologies, Inc.
Nuvera® Fuel Cell System (ARRA)	Nuvera Fuel Cells, Inc. (Acquired by Hyster-Yale)
Orion™: Fuel Cell Technology for Hybrid Power Applications	Nuvera Fuel Cells, Inc. (Acquired by Hyster-Yale)
Platinum and Fluoropolymer Recovery from PEM Fuel Cells	Ion Power, Inc.
Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports	Brookhaven National Laboratory
Polymerized Ionic Liquid Block Copolymer/Ionic Liquid Composite Ionomers for High Current Density Performance	Drexel University
Portable Reformed Methanol Fuel Cells	Lawrence Livermore National Laboratory w/UltraCell Corporation (Acquired by Advent Technologies, LLC)
Reduction in Fabrication Costs of Gas Diffusion Layers	AvCarb, LLC (Formerly Ballard Material Products, Inc.)
Regenerative Fuel Cell System (SBIR)	pH Matter, LLC
Smart Matrix Development for Direct Carbonate Fuel Cell	FuelCell Energy, Inc.
Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells	University of South Carolina



Pre-FY2025 Fuel Cell Technologies (continued 5/5)

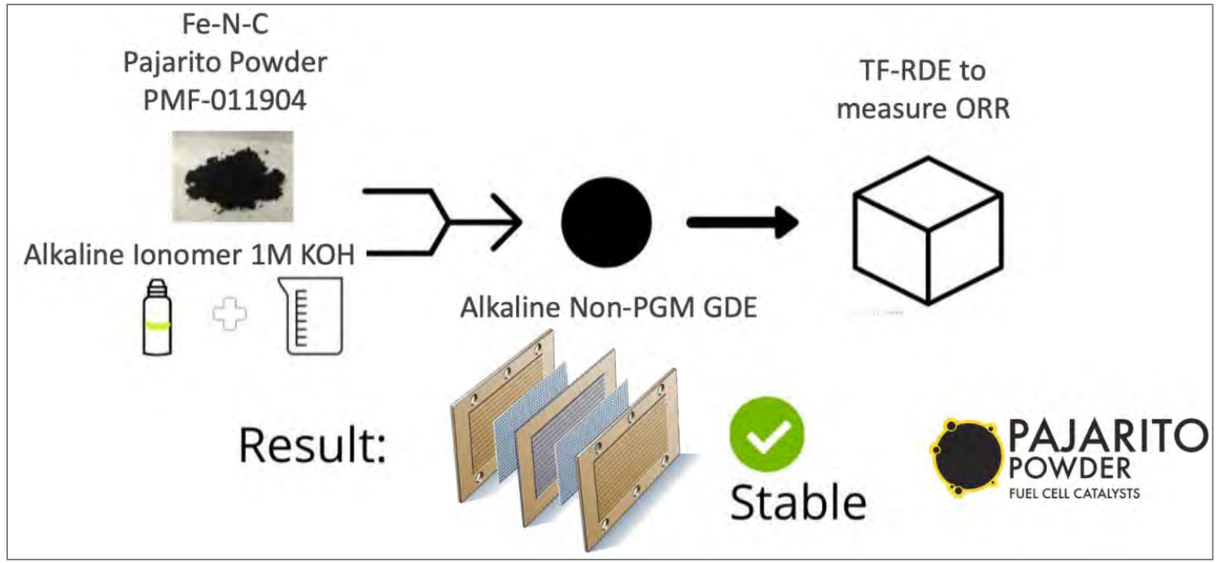
Technology	Organization
Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids	National Renewable Energy Laboratory

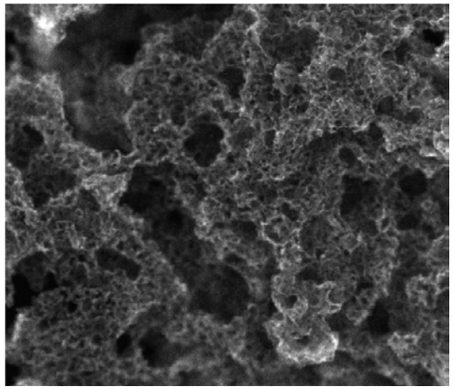
Active and Durable Platinum-Group-Metal-Free Cathodic Electrocatalysts for Fuel Cell Application

FC Commercial

Pacific Northwest NATIONAL LABORATORY

- Developed by Pajarito Powder, LLC in conjunction with researchers led by Hawaii Natural Energy Institute and IRD Fuel Cells.
- New PGM-free catalyst product commercialized in 2021.
- Use of the precious metal platinum in fuel cell studies and technology increases high costs and limits the marketing of Pt-based devices and vehicles.
- VariPore™ manufacturing process allows for PMF catalysts to achieve high activity, stability, and reasonable durability under real-world operating conditions, with production costs lower than platinum-based catalysts.
- Pajarito Powder's commercial precious-metal-free catalysts provide a low-cost solution for low and moderate power density applications such as stationary or back-up power, CHP and waste-water treatment.
- Contract Number: DE-EE0008419 (2019)





PAJARITO POWDER FUEL CELL CATALYSTS · HISERF · IRD

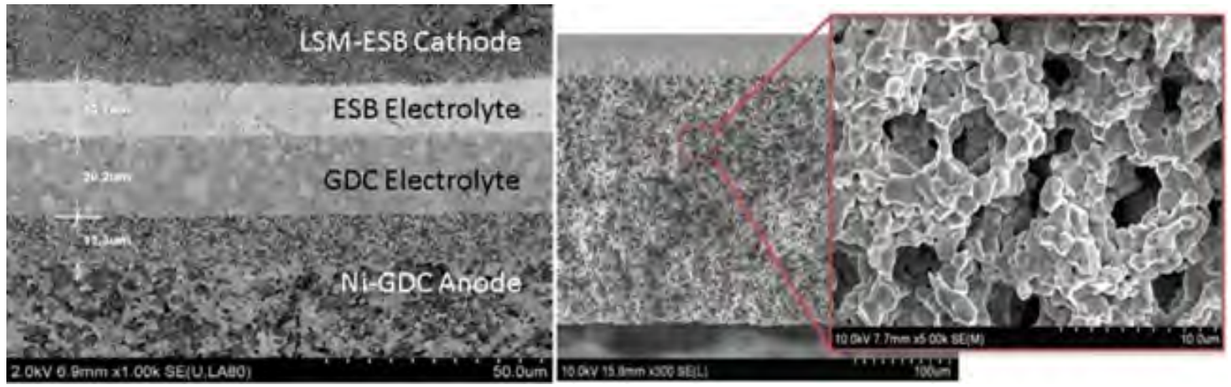
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Affordable, High Performance, Intermediate Temperature Solid Oxide Fuel Cells

FC
Commercial

uspto
3 patents

- Developed by Redox Power Systems, with University of Maryland and Trans-Tech Inc. as collaborators.
- The Redox Cube SOFC stationary power system entered the market in 2016.
- This intermediate temperature solid oxide fuel cell design includes an optimized bilayer electrolyte mechanism.
- Can be used to improve performance, durability, and cost compared to other solid oxide fuel cell technologies.
- Provides > 1.25 W/cm^2 of power at 600 degrees Celsius for button cells with catalysts in the cathode and/or anode.
- Improved electrical conversion efficiency with the GDC/ESB bilayer electrolyte.
- Reduces overall fuel cell stack cost by allowing the use of simpler materials due to lower intermediate temperature operation (~600 degrees Celsius).
- Contract Number: DE-EE0006735 (2014)



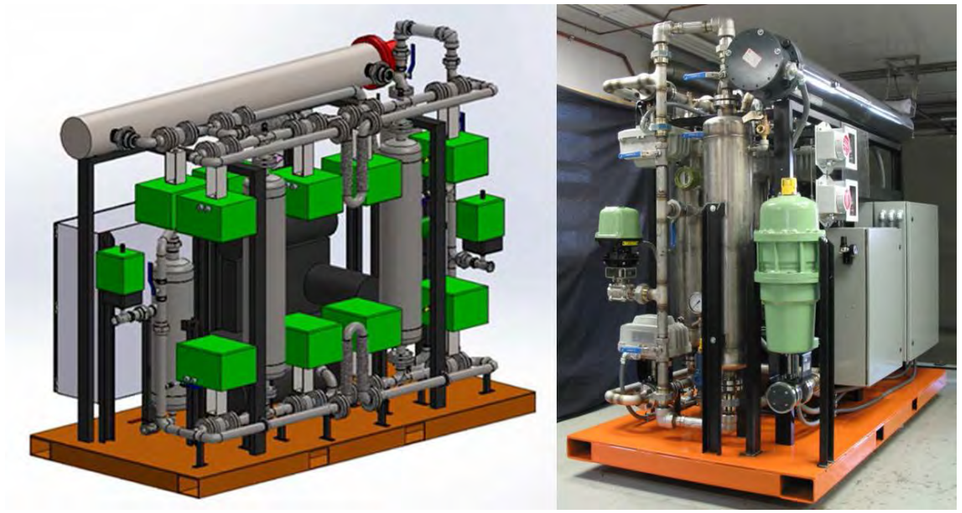
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Bio-Fueled Solid Oxide Fuel Cells (SBIR)

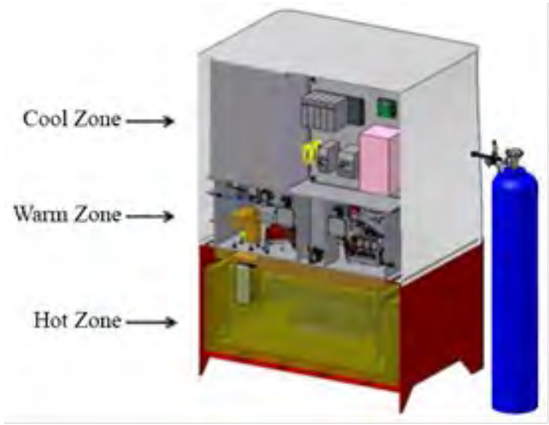
FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by TDA Research Inc. and available from SulfaTrap LLC. Commercialized in 2011.
- Sorbent and Catalyst Materials Produce Clean Bio-Gas for Integrated SOFC Based Power System.
- Used for producing ultraclean biogas (Sulphur removal) in CHP and SOFC applications using opportunity fuels such as anaerobic digester gas.
- CHP and SOFC operation in waste-to-energy applications.
- Provides regenerability, small form-factor, and reduced replacement frequency.
- Contract Number: DE-EE0004537 (2010)



TDA's Skid-Mounted Field-Deployable Prototype Biogas Clean-Up System



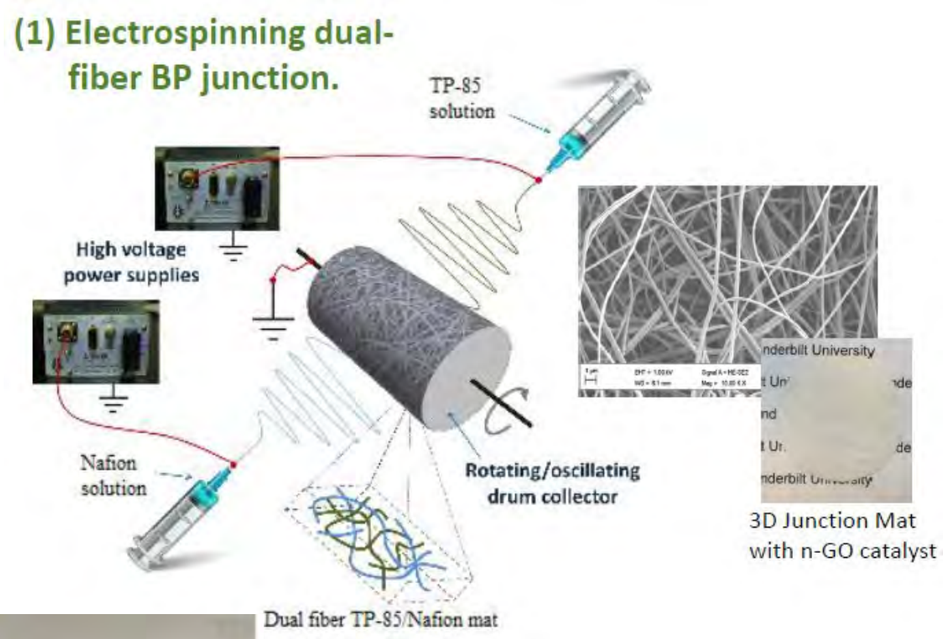
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Phone: (303) 940-2349
SulfaTrap, Inc.
5130 Ward Rd
Arvada, CO 80002
Website: https://sulfatrap.com

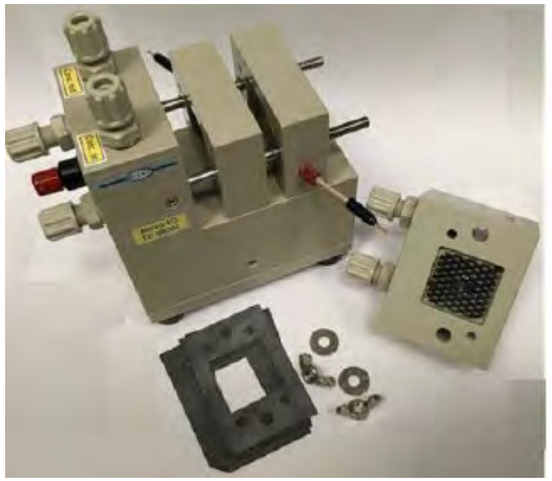
Bipolar Membranes with an Electrospun 3D Junction

FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by Vanderbilt University.
- Goals to design and fabricate a new type of robust bipolar membrane (BPM), with 3D water splitting junction for high performance electrolyzers and fuel cells, using electrospinning.
- Reduced costs and higher performance of new BPMs will make water reuse and industrial separations more economical.
- Use of BPMs in a high power, self-hydrating fuel cell MEA that does not require a Pt-based cathode will make hydrogen fuel cells commercially attractive.
- The membranes will allow for higher current density operation as compared to conventional BPMs while maintaining a low operating voltage, long-term durability, and high separation efficiency.
- Contract Number: DE-AR0001035 (2019)





VANDERBILT UNIVERSITY

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Channeling Engineering of Hydroxide Ion Exchange Polymers and Reinforced Membranes

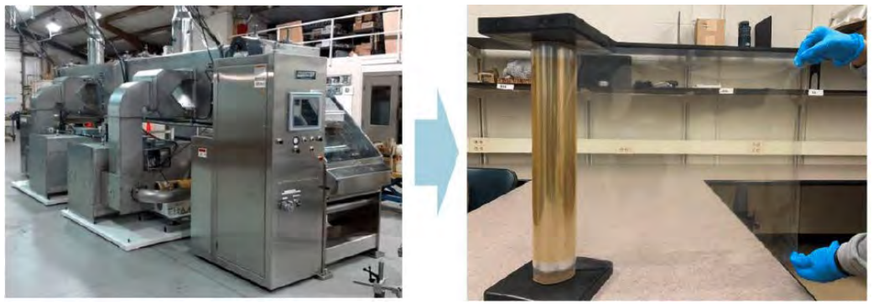
FC Commercial

uspto 10 patents

- Developed by Rensselaer Polytechnic Institute in partnership with Georgia Institute of Technology, Xergy, and Nel Hydrogen (Proton Onsite). Commercialized since 2022.
- Manufactured in the US through startup company Orion Polymer Corp under the product name Orion CMX.
- Proven high temperature stability for electrochemical devices, 80 degrees C.
- No platinum or titanium needed for low-cost housings and inexpensive metal cathodes.
- CMX can withstand high temperatures while maintaining conductivity and ion exchange capacity. Additionally, CMX can take high pressure differentials and repeated cycling to zero and back.
- No corrosive environment enables alkaline fuel cells, hydrogen electrolyzers for a zero-emission future.
- Contract Number: DE-AR0000769 (2017)



Orion CMX Self-Supporting AEM Membranes



Roll-to-Roll Slot-Die Line and Polymer C Roll-to-Roll Membrane

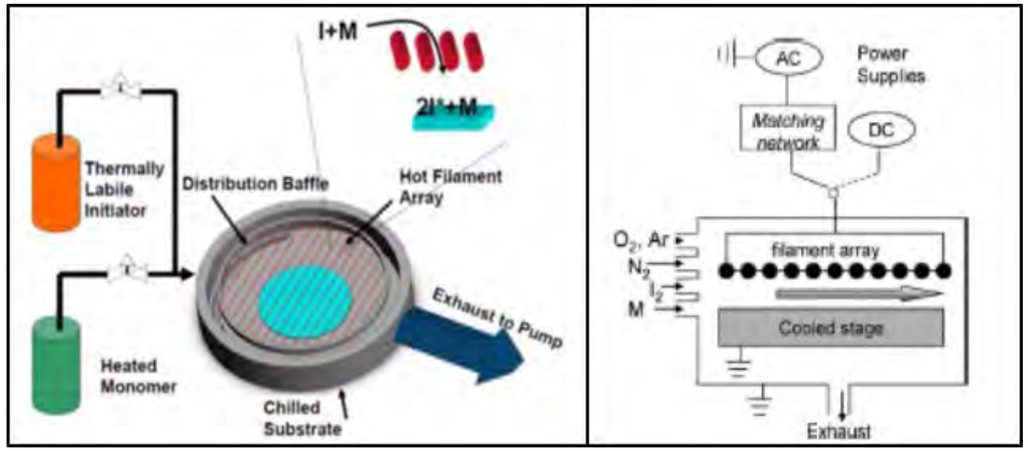
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Coatings for Compressor Seals

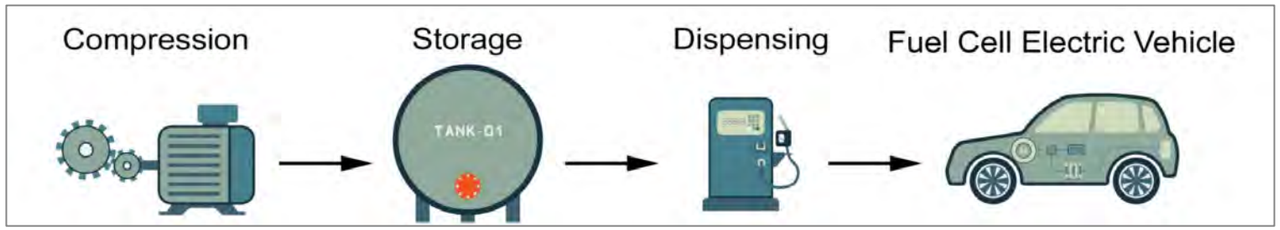
FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by GVD Corporation in partnership with Greene, Tweed & Co.
- Finished initial testing of the barrier coatings.
- Can be used as a barrier coating for o-rings and other high-pressure hydrogen seals to mitigate hydrogen permeability and reduce seal wear due to friction.
- Using polymer vapor deposition (PVD), GVD Corporation is able to produce thin polymer coatings on almost any material.
- Improves Hydrogen CSD seal life from <1,500 hours to >8,000 hours.
- Reduces the relative permeability of helium by 35%.
- Contract Number: DE-SC0011339 (2015)



GVD's modified standard deposition hardware to allow single chamber: hot filament CVD (left) and plasma-enhanced CVD (right)



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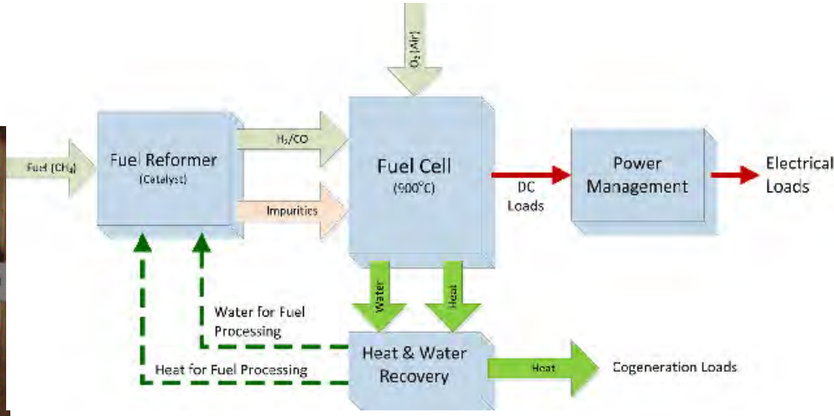
Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System

FC Commercial

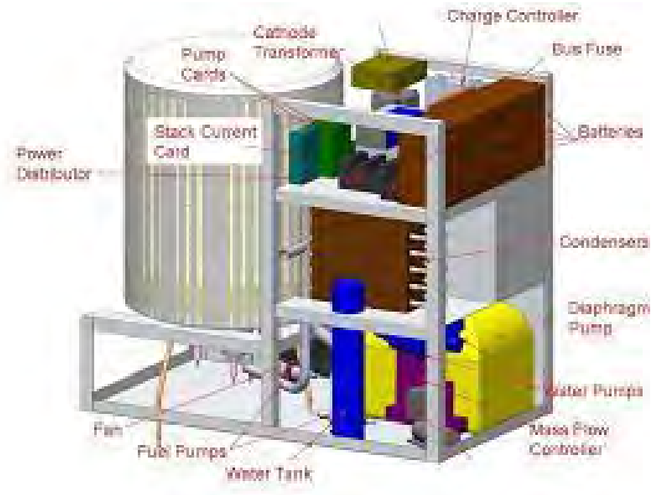
Pacific Northwest NATIONAL LABORATORY

- This SOFC, originally developed by Standard Oil of Ohio and BP, was acquired by TMI from BP.
- Commercialized in 2011.
- Used as a primary or back-up source of clean, quiet, continuous power in remote locations with no or unreliable power.
- Fuel interchangeable operation in residential-scale and mobile applications with fuel supply limitations, e.g., military JP-8 fuel, diesel, digester biogas, hand-pressed vegetable oils, propane, and heating oil.
- Operates interchangeably between fossil and renewable biofuels without shutdown.
- Can be used for both stationary residential-scale and mobile applications.
- Contract Number: DE-FC36-04GO14215 (2004)









ANYWHERENERGY a TMI company

Technology Management, Inc.

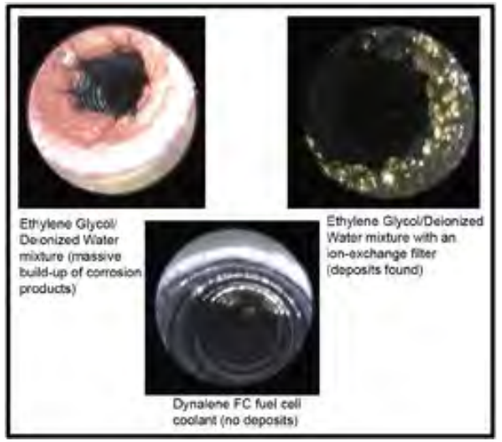
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Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR)

FC
Commercial

uspto
2 patents

- Developed by Dynalene Inc., and commercialized in 2009.
- Developed an advanced complex coolant fluid (CCF) (Dynalene FC) to maintain acceptably low levels of electric conductivity while addressing issues with water/glycol coolants.
- Dynalene FC maintains acceptably low corrosion rates on stainless steel and aluminum heat exchangers as well as yellow metals like copper and brass.
- Coolant stabilizes particles preventing flocculation and deposition on flow channels
- Eliminates the need for deionizing filters in fuel cells, reducing the overall cost of ownership and maintenance.
- Largest customer is fuel cell forklift developer, but other applications include EV chargers, semiconductor manufacturing, medical field, and data centers.
- Working towards passing Automotive Tier 1 supplier certifications for new automotive applications.
- Contract Numbers: DE-FG02-04ER83884 (2005) and DE-EE0000278 (2009)



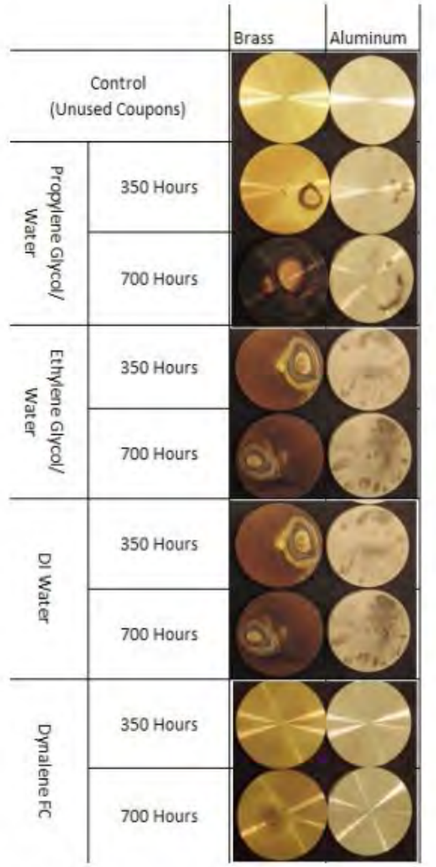
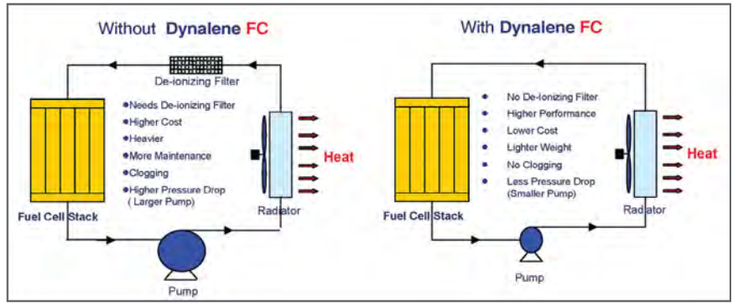


FIGURE 2. Aluminum and Brass Corrosion Testing in Various Coolant Fluids



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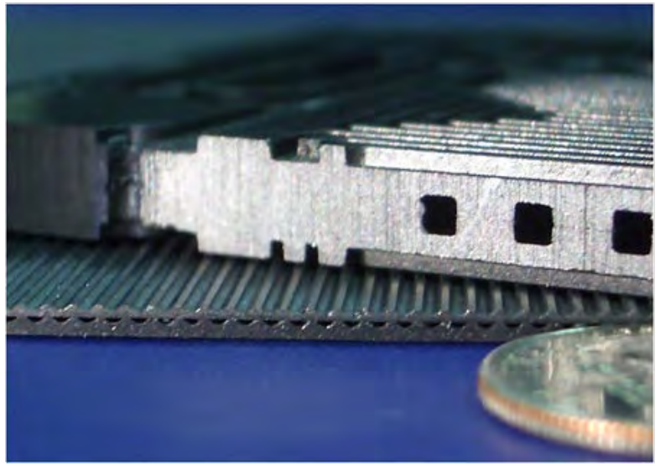
DYNALENE
Tomorrow's Solutions Flow Through Us

Conductive Compound for Molding Fuel Cell Bipolar Plates

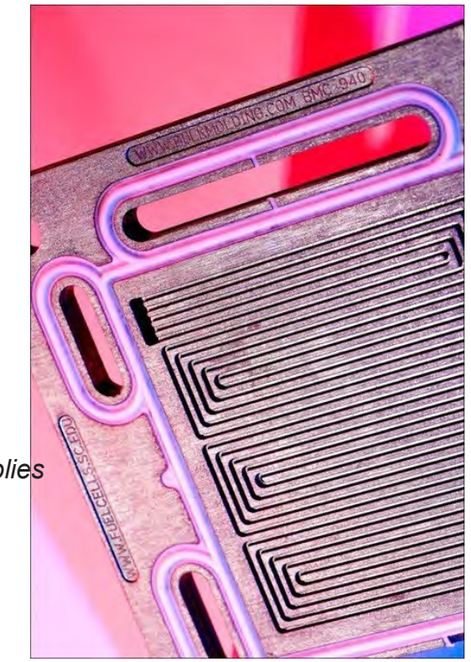
FC
Commercial

uspto
3 patents

- Developed and marketed by Bulk Molding Compounds, Inc., (BMCI) (later acquired by Citadel Plastics Holdings Inc.) using patented Los Alamos National Laboratory Technology. Commercialized in 2000.
- Allows the thickness of bipolar plate assemblies to be reduced from 7 mm to less than 2 mm, which reduces material costs and provides chemical resistance in a PEM fuel cell environment, avoiding the need for expensive corrosion-resistant coatings.
- Uses a conductive vinyl-ester adhesive to minimize contact resistance and enhance conductivity in making bipolar plate assemblies.
- Allows for large-volume commercial production because flow and cooling channels are directly molded into the part.
- Reduces process cycle times while maintaining critical properties.
- Can be used where bipolar plate assemblies are needed for PEM cells in stationary, automotive, and portable power.
- Contract Number: W-7405-ENG-36 (1995)



Decrease in Plate Thickness in Bonded Bipolar Assemblies



Bulk Molding Compounds, Inc. (BMCI), has developed and commercialized a graphitized thermoset vinyl-ester compound for molding bipolar plates.

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Bulk Molding Compounds, Inc.
1600 Powis Court
West Chicago, IL 6185
Website: http://www.bulkmolding.com

Corrosion Test Cell for PEM Bipolar Plate Materials

FC
Commercial

uspto
1 patent

- Developed by Los Alamos National Laboratory and licensed to Fuel Cell Technologies, Inc. Commercialized in 2008.
- Provides a long-term measurement of electrical resistance of the anode and cathode BPP interfaces.
- Allows soluble BPP dissolution products to be monitored in the electrolytes.
- Reduces costs by using corrosion cells and accessory equipment rather than the traditional fuel cell test stands.
- Allows materials to be screened without fabrication of BPPs and multiple cells to screen multiple materials at the same time, simultaneously reducing development time.
- Contract Number: W-7405-ENG-36 (1999)

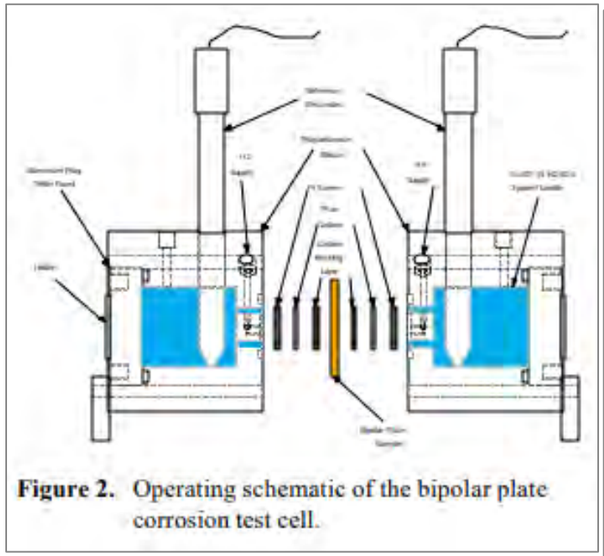


Figure 2. Operating schematic of the bipolar plate corrosion test cell.

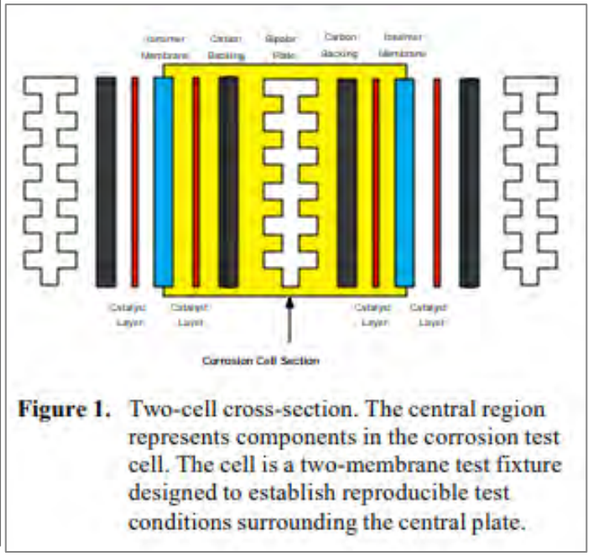


Figure 1. Two-cell cross-section. The central region represents components in the corrosion test cell. The cell is a two-membrane test fixture designed to establish reproducible test conditions surrounding the central plate.













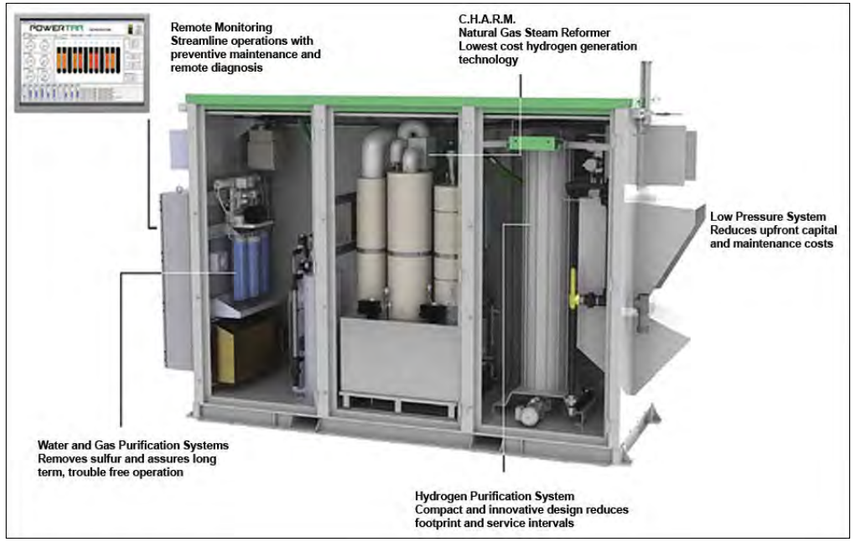
Contact Information:
Chuck Derouin
Email: chuck@fuelcelltechnologies.com
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Fuel Cell Technologies, Inc.
5620 Venice Ave, NE, Suite F
Albuquerque, NM 87113
Website: http://www.fuelcelltechnologies.com

Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM)

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Nuvera Fuel Cells, Inc.
- Commercialized in 2009 as part of Nuvera®'s hydrogen fueling technology, an integrated hydrogen generation, and refueling system.
- Can be used for on-site hydrogen generation from natural gas and water to enable the adoption of fuel-cell-powered industrial and on-road vehicles. This includes forklift trucks, port equipment, cars, and buses.
- On-site hydrogen generation eliminates transportation charges and emissions associated with delivering hydrogen via bottles/tube trailers.
- Reduces the effects of thermal cycling and supports long product life through its system design.
- Can generate pure (>99.995%) hydrogen up to 56 kg/day.
- Contract Number: DE-FC36-02AL67618 (2002)





The Nuvera® Hydrogen Generation and Refueling System

NUVERA®

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Nuvera Fuel Cells, LLC
129 Concord Rd, Building 1
Billerica, MA 01821
Website: http://www.nuvera.com

Development of Durable Active Supports for Low Platinum Group Metal Catalysts (SBIR)

FC Commercial

Pacific Northwest NATIONAL LABORATORY

- Developed by Pajarito Powder, LLC in partnership with Advent Technologies. Commercialized by 2023.
- Active carbon support with controlled morphology and chemical speciation.
- Reducing platinum content reduces material costs and increases the longevity of the fuel cell stack.
- Allows platinum to be dispensed inside of a three-dimensional matrix.
- Increases graphitization of the engineered carbon support (ECS) to improve the durability of Pt/ECS. ECS is composed of inexpensive, widely available materials, manufactured economically at scale using the patented VariPore™ process.
- Uses proprietary methods and materials which improve fuel cell performance, extend working life, and reduce cost of fuel cells for demanding applications such as heavy-duty fuel cell vehicle applications.
- Contract Number: DE-SC0017250 (2017)

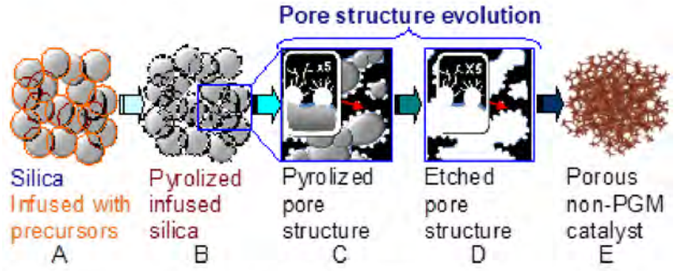
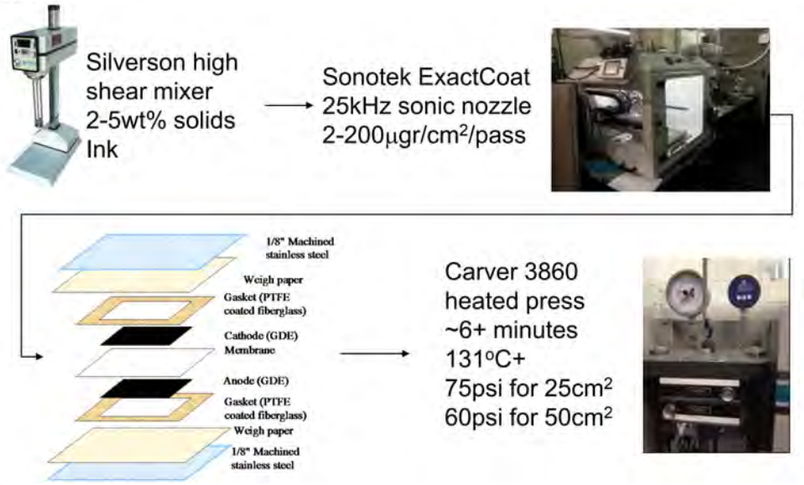
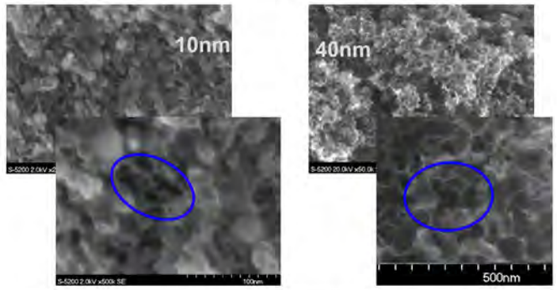


FIGURE 2. The approach on making durable active support





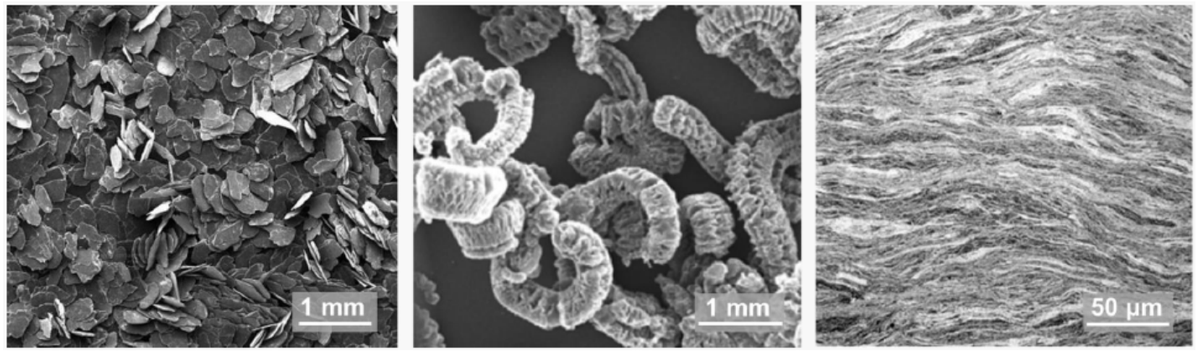
Design of DACS by VariPore® approach allows control support morphology

Contact Information:
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Phone: (505) 293-5367
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3600 Osuna Rd NE Ste 309
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Website: https://pajaritopowder.com

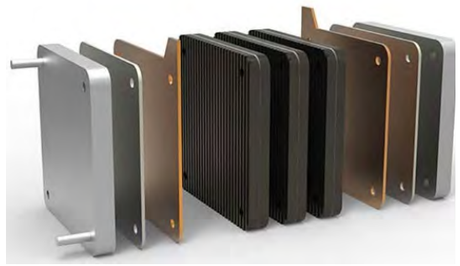
Development of Low Cost, Thin Flexible Graphite Bipolar Plates for Heavy Duty Fuel Cell Applications

FC
Emerging

- Currently being developed by NeoGraf Solutions, LLC, in partnership with Ballard Power Systems, Strategic Analysis, Inc., and Norley Carbon & Graphite Consultants, LLC.
- Flexible graphite bipolar plate assembly (BPA) meets current requirements for heavy-duty fuel cell applications, such as durability and corrosion resistance.
- Through the development of thin and durable flexible graphite, BPA graphite costs for next-generation heavy-duty fuel cell applications have the potential to be reduced by approximately 90%.
- This technology will be a critical advancement towards meeting 2030 system-level heavy-duty truck targets of $80/kW system cost and 25,000-hour durability.
- Contract Number: DE-EE0009615 (2022)



Natural graphite flake (left) is treated with a combination of chemicals, exfoliated in a high temperature furnace to produce vermicular expanded graphite or “worms” (middle), and densified to produce flexible graphite sheet (right)



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Development of Novel Non-PGM Electrocatalysts for Proton Exchange Membrane Fuel Cell Applications

Pacific Northwest NATIONAL LABORATORY

FC *Emerging*

uspto 3 patents

- Being developed by Northeastern University in partnership with University of New Mexico, Michigan State University, Pajarito Powders, and Nissan Technical Center North America.
- New classes of non-PGM electrocatalysts would meet or exceed 2015 project targets for activity and durability.
- Independence from Platinum (Pt) and other precious metals' global availability.
- Lower MEA costs to less than or equal to $ 3/KW.
- Greater tolerance to poisons that typically affect Pt and Pt alloys (i.e., sulfur, CO, etc.).
- Contract Number: DE-EE0000459 (2010)

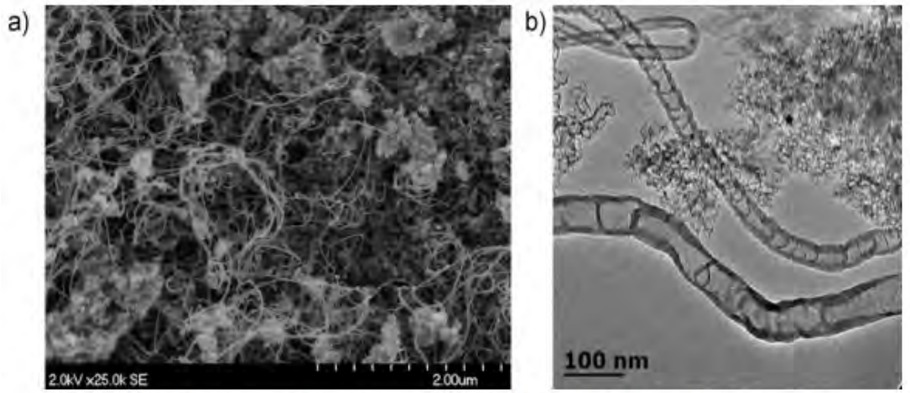


Figure 1.11. SEM (a) and TEM (b) images of Fe-AAPyr hybrid with CNTs catalyst.

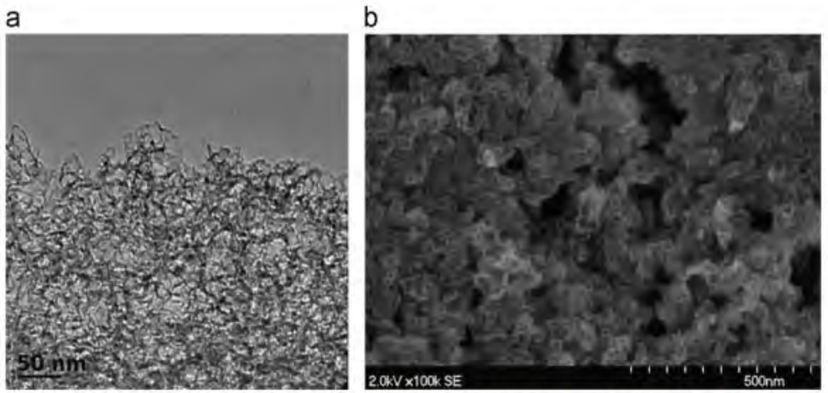


Figure 1.12. TEM (a) and SEM (b) images for the Fe-CTS catalyst synthesized at T=900 °C in N_2 for X minutes with Fe:CTS ratio1:8, second heat treatment at T=950 °C for 30 min in NH_3.

Northeastern University

PAJARITO POWDER

NISSAN

MICHIGAN STATE UNIVERSITY

THE UNIVERSITY OF NEW MEXICO

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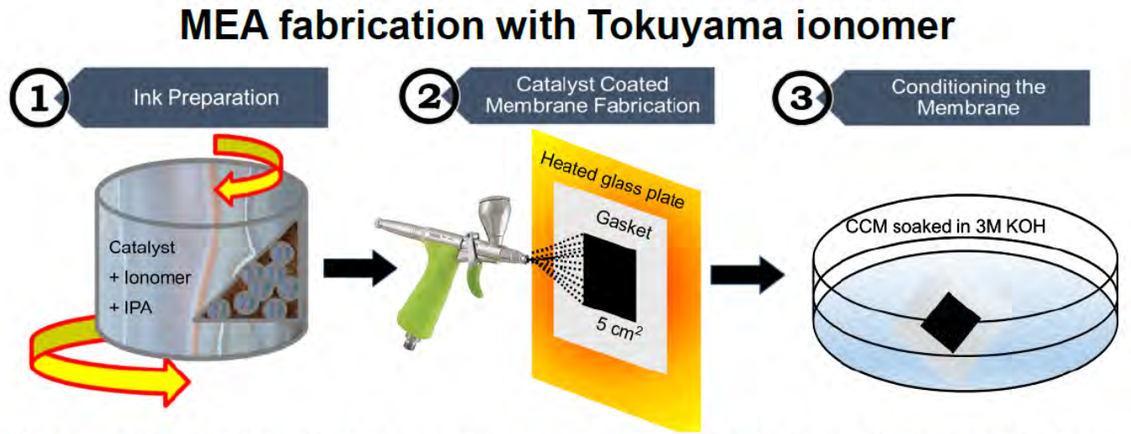
Development of PGM-free Catalysts for Hydrogen Oxidation Reaction in Alkaline Media

Pacific Northwest NATIONAL LABORATORY

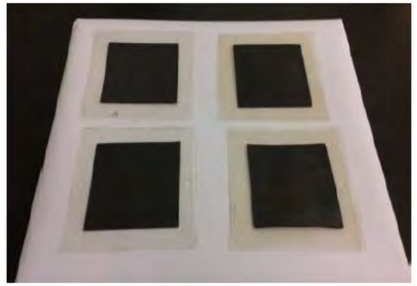
FC *Emerging*

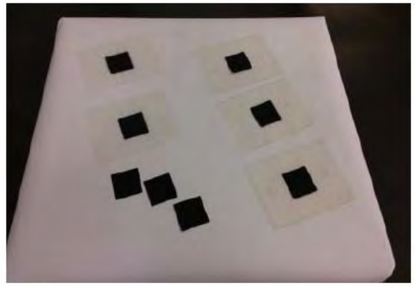
uspto 5 patents

- Currently being developed by the University of New Mexico in collaboration with Los Alamos National Laboratory, Pajarito Powders LLC., and EWII Fuel Cells LLC, (a U.S. subsidiary of the Danish energy company EWII Group) registered as IRD Fuel Cells LLC.
- Complimentary research has begun at Georgia Institute of Technology (DE-EE0008833).
- Alkaline membrane fuel cells (AMFCs) operate using PGM-free ORR catalysts, which are earth-abundant, instead of precious metal catalysts.
- Successful developments of anion exchange ionomers are greatly improved over PEMFC ionomers.
- Enabled catalyst and ionomer developers to collaborate for industrial scale-up and MEA fabrication.
- Contract Number: DE-EE0006962 (2015)



Mixture of catalysts, Tokuyama ionomer and alcohols were dispersed by ball-milling: 450RPM, t=20 min.
CCM sprayed. Converted to OH^- form by soaking in 3M KOH





THE UNIVERSITY OF NEW MEXICO

IRD POWERING PEOPLE ANYWHERE

PAJARITO POWDER

Los Alamos NATIONAL LABORATORY

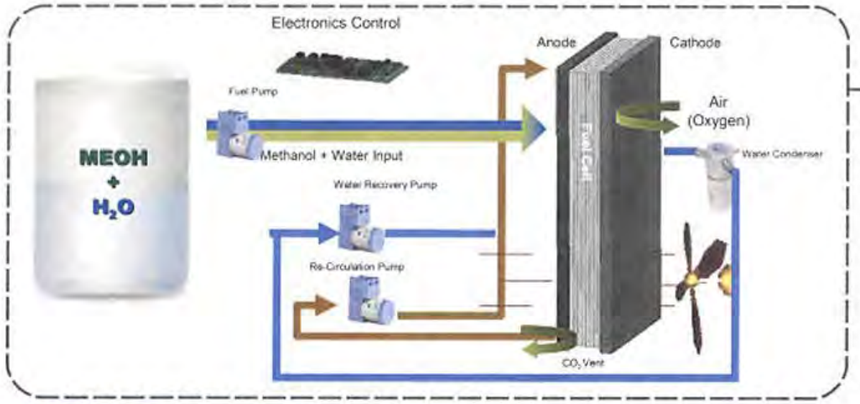
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Direct Methanol Fuel Cell (DMFC) for Handheld Electronics Applications

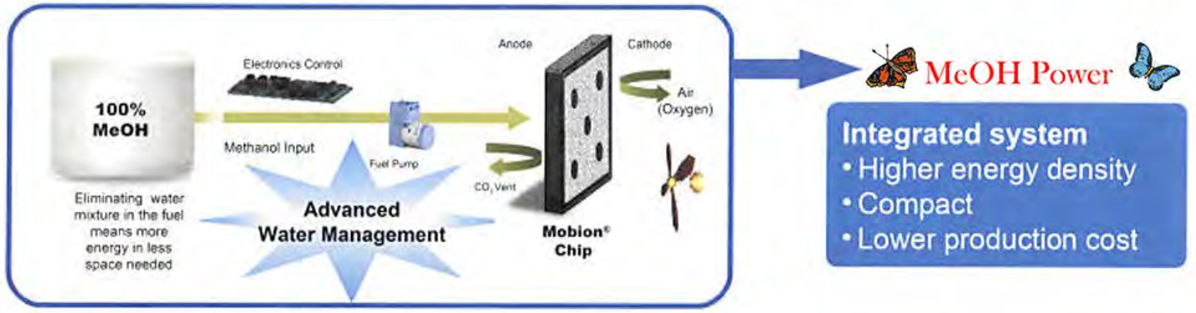
FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by MeOH Power, formerly MTI Micro Fuel Cells.
- Continued improvements are being made to the unit based on field tests results.
- Can be used as a complement for current handheld electronic devices to keep their batteries in a charged state.
- Eliminates the need for a wall outlet to keep devices charged for true mobile power.
- Operates over a wide temperature range (-40ºC to 40ºC) and at any humidity level.
- Fuel is safer than hydrogen or natural gas.
- Can be stored indefinitely and still is quick to start up.
- Contract Number: DE-FC36-04GO14301 (2004)



Other Active DMFC Large and complicated system that produces low energy density





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MeOH Power

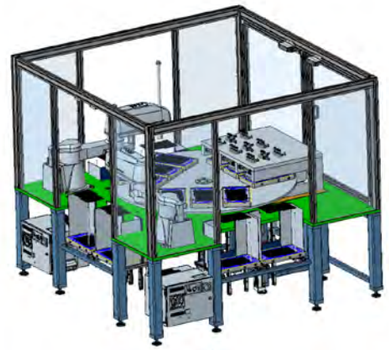
Domestically Manufactured Fuel Cells for Heavy-Duty Applications

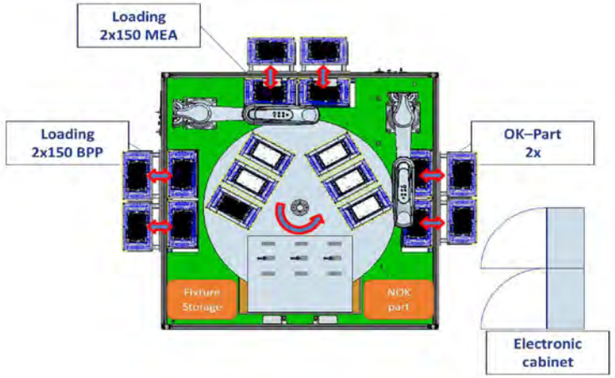
FC
Emerging

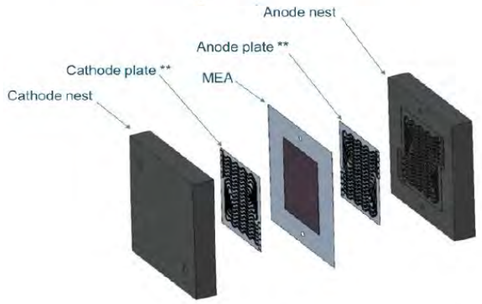
Pacific Northwest
NATIONAL LABORATORY

- Developed by Plug Power, Inc.
- Creating high performance, robust fuel cell stacks that can be manufactured in high volumes in the United States and meet DOE goals for heavy duty applications.
- Researching manufacturing methods and operational conditions for improved fuel cell durability and endurance.
- Investigated new material compatible with automated sealing, outperformed existing material in stack designs, achieving power density of 840 mW cm^{-2} at 0.769V.
- Demonstrated robotics for automated stacking.
- Domestically manufactured fuel cells provide a path to lower costs and higher efficiency fuel cells for applications including Class 8 and heavy-duty vehicles (trucks) and data centers.
- Contract Number: DE-EE0009248 (2021)

Automated Stack Assembly Equipment







Single Fuel Cell



Seal Dispense

PLUG POWER

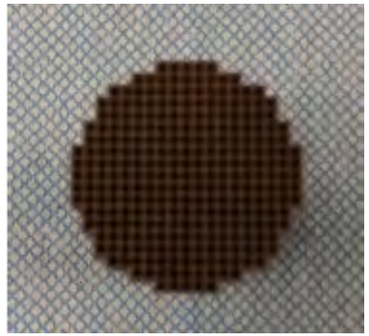
Contact Information:
Dr. Cynthia Rice
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Plug Power, Inc
125 Vista Boulevard
Singlerlands, NY 12159
Website: https://www.plugpower.com

Durable and Efficient Centrifugal Compressor-Based Filtered Air Management System and Optimized BOP

FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by Dumarey USA, LLC. (formerly MAHLE Powertrain) in partnership with BMTS Technology, MAHLE Filter Systems, Oakridge National Laboratory, and GM Global Propulsion Systems.
- Developing low cost ($12/kW), high reliability (25k hr.) air management system components that promote fuel cell stack health to minimize heavy duty (HD) fuel cell (FC) vehicle operator costs.
- Designing a redundant filtration system that will target high efficacy over a wide operating range to promote the durability of the FC stack, in addition to considering the longevity of the air compressor.
- Striving to enable widespread adoption of HD FC vehicles by promoting more favorable total cost of ownership.
- Aiming to achieve system efficiency improvements through a modeling-based holistic design approach, intelligent controls, and to incorporate innovative components.
- Contract Number: DE-EE0009619 (2022)



Core sample of a ceramic monolith coated with a catalyst for air filtering



E-Turbo from BMTS Portfolio



Air filter housing

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Dumarey USA, LLC.
(formerly MAHLE Powertrain, LLC)
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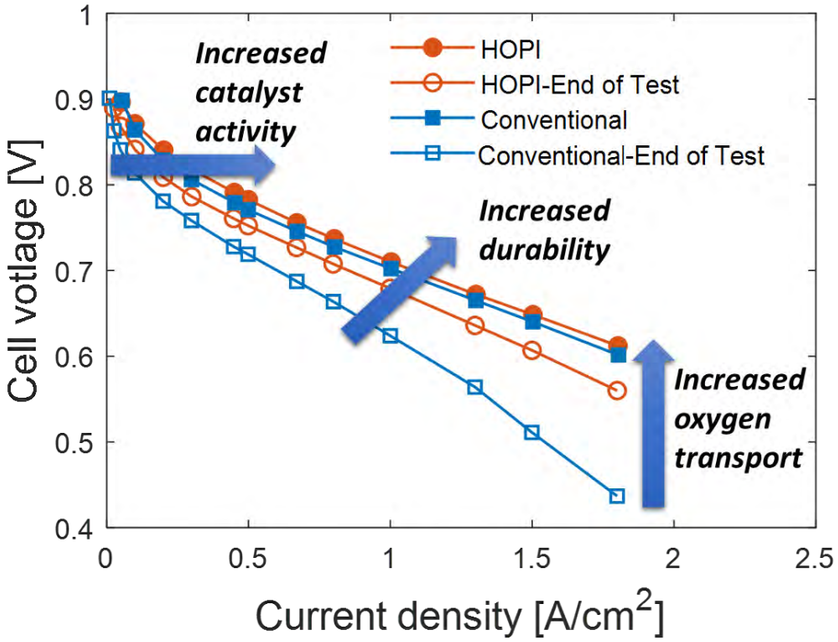
DUMAREY MAHLE Powertrain BMTS TECHNOLOGY OAK RIDGE National Laboratory GENERAL MOTORS GLOBAL PROPULSION SYSTEMS

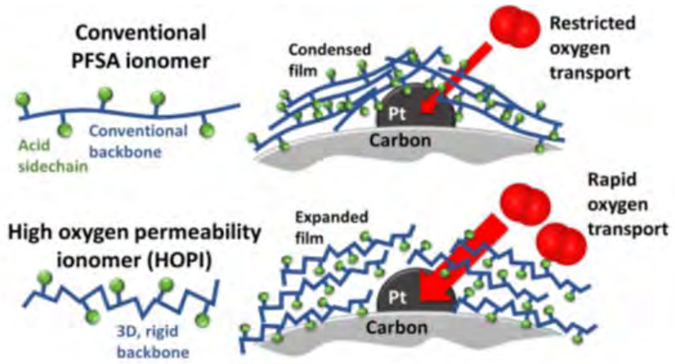
Durable High Power Density Fuel Cell Cathodes for Heavy-Duty Vehicles

FC *Emerging*

uspto 1 patent

- Developed by Carnegie Mellon, Ballard Power Systems, Chemours Company (commercializing partner), and collaboration with the fcPAD and M2FCT initiatives.
- FC MEAs with low Pt-loading (≤0.2 mg/cm^2), enhanced ionic activity (O_2 transport) performance (67% cf. baseline) and durability (70% less degradation) for heavy-duty applications.
- High Oxygen Permeable Ionomer (HOPI) designed specifically to meet electrode demand and maintain FC efficiency and power output.
- Material (catalyst ink) coating developed from lab scale to manufacturing scale (R2R – Ballard) for full FC stack integration.
- FC stack accelerated stress test >4X improvement with HOPI versus traditional ionomer baseline)
- Contract Number: DE-EE0008822 (2019)





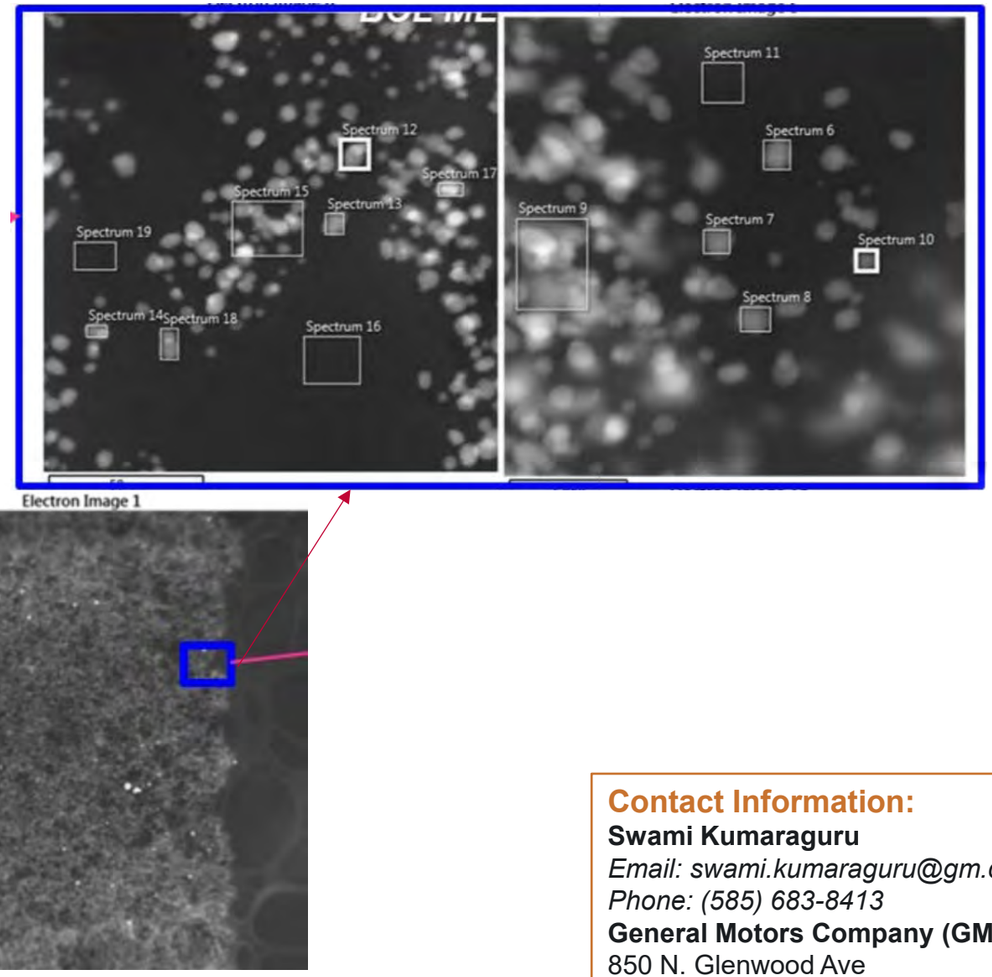
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Shawn Litster
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Website: https://www.cmu.edu/me/tpes/index.html

Durable High-Power Membrane Electrode Assemblies with Low Pt Loading

FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Being developed by GM in partnership with University of Texas, Austin, and Giner, Inc.
- Can be used to predict and address degradation phenomena in membrane electrode assemblies with low-Pt loading cathodes for proton exchange membrane fuel cells.
- Determined an optimized membrane electrode assembly that exhibits > 1000 mW/cm^2 through a systematic selection of catalyst, ionomers, and membrane.
- Developed a combined chemical/mechanical highly accelerated stress test (HAST) and a method developed to generate and quantify local resistance of membrane shorts.
- Fundamental studies will continue and are designed to isolate the impact of stress factors (mechanical stress, membrane thickness, and gas crossover) on membrane degradation.
- Contract Number: DE-EE0007651 (2017)



gm
TEXAS
The University of Texas at Austin
GINERLABS

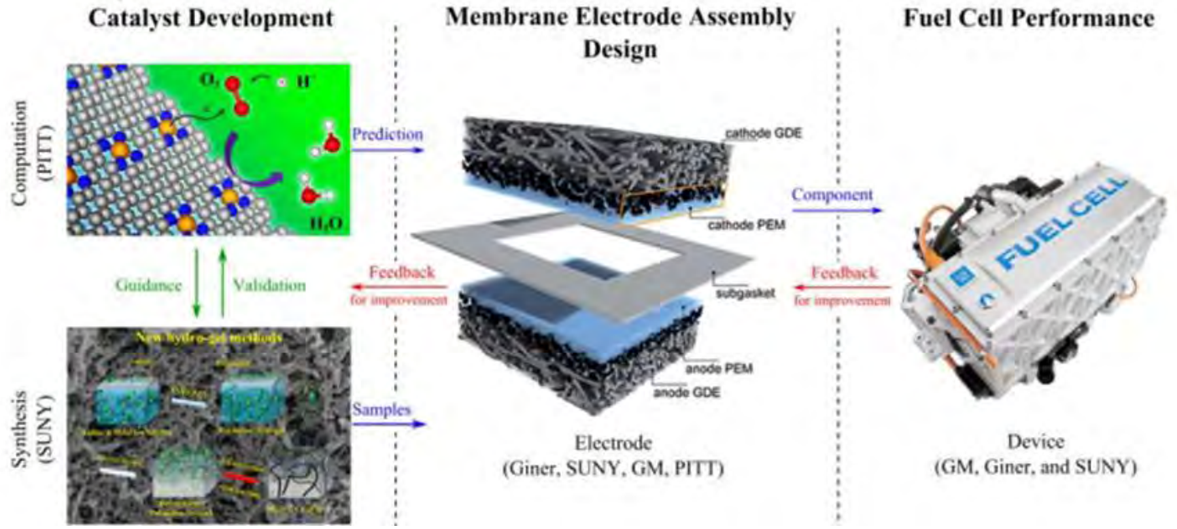
Contact Information:
Swami Kumaraguru
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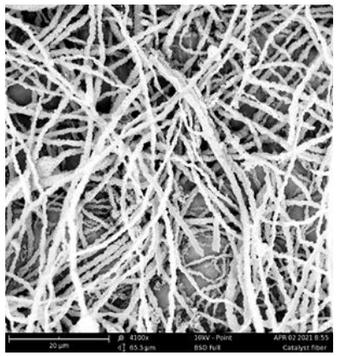
ElectroCat: Durable Mn-Based Platinum-Group-Metal-Free Catalysts for Polymer Electrolyte Membrane Fuel Cells

FC Emerging

Pacific Northwest NATIONAL LABORATORY

- Currently being developed by Giner, Inc. in collaboration with the University at Buffalo, University of Pittsburgh, and GM.
- Developing Mn-based catalysts that are sufficiently active and stable in acidic media.
- Will demonstrate fuel cell membrane electrode assemblies (MEAs) utilizing DOE testing metrics.
- Have developed various catalyst synthesis strategies which ensure better performance and durability.
- Performance and durability have also been improved by optimizing electrode design.
- Contract Number: DE-EE0008075 (2017)





Electrospun Nanofibers

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GINER LABS · University at Buffalo · University of Pittsburgh · gm

FARADAYIC ElectroEtching of Stainless-Steel Bipolar Plates (SBIR)

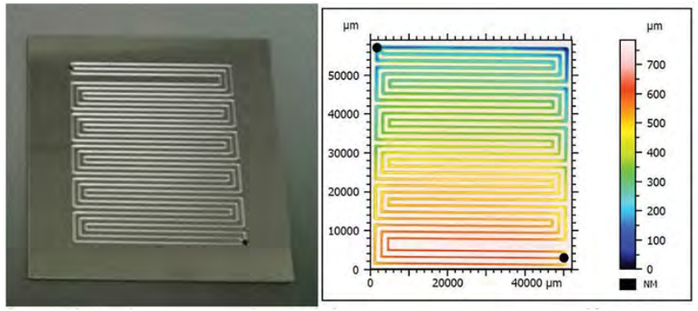
FC
Commercial

uspto
2 patents

- Developed by Faraday Technology, Inc., a subsidiary of Physical Sciences Inc., in collaboration with the University of South Carolina's IUCRC Fuel Cell Center. Commercialized in 2012.
- Can be used in PEM fuel cells and electrolyzers, solid oxide fuel cells and electrolyzers, and flow batteries for both stationary and automotive applications.
- Creates gas flow channels on substrate plates using electrochemical etching of a patterned photoresist on metal substrates.
- Adaptable to many metal substrates, including steels, stainless steels, nickel alloys, titanium alloys, and pure titanium.
- Channel formation is a non-contact process, allowing the plate to maintain flatness and parallelism.
- Enables inexpensive manufacturing of both simple and complicated channel flow designs through using a high-volume batch process with low capital equipment and tooling costs.
- Contract Number: DE-FG02-08ER85112 (2008)



FARADAYIC®ElectroCell Etching Process Technology For Low-Rate Manufacturing



Sample 430 Stainless Steel Bipolar Plate with Gas Flow Fields Formed Using The FARADAYIC® ElectroEtching Process (left) and color map obtained from non-contact optical profilometer illustrating the decreasing depth of the flow field channels from inlet to outlet (right).

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Website: http://www.faradaytechnology.com

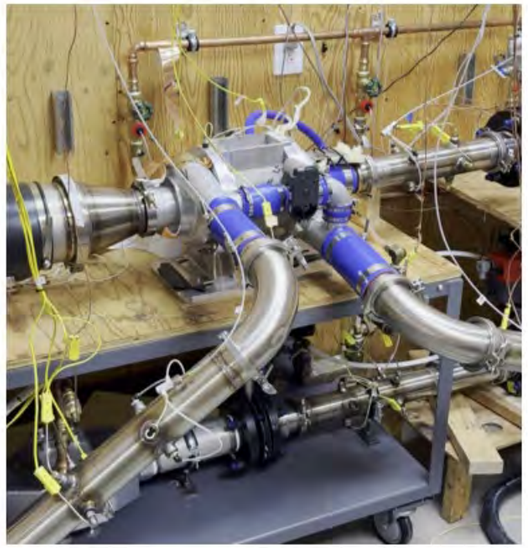
Foil Bearing Supported Compressor-Expander

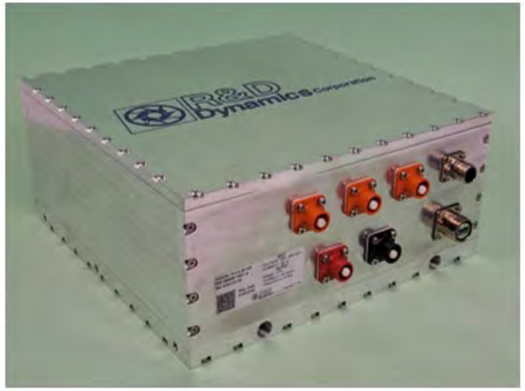
FC
Emerging

uspto
2 patents

- Developed by R&D Dynamics Corporation (RDD).
- Developing a fuel cell system compressor-expander for heavy-duty vehicle applications that is highly reliable, versatile, has a long service life, and can be mass-produced at a lower cost.
- Design comprises of a high-speed centrifugal compressor/expander, oil-free foil air/gas bearings, a permanent magnet motor (DCPM), and an inverter with silicon carbide (SiC) switches.
- Advantages of this design include high efficiency, smaller size and weight, increased reliability, and no risk of oil contamination.
- Potential applications include long haul semi-trucks, mining and construction equipment, power generation, data centers, marine applications, and other heavy machinery.
- Ready to ship evaluation units and develop manufacturing capability.
- Contract Number: DE-EE0009617 (2021)







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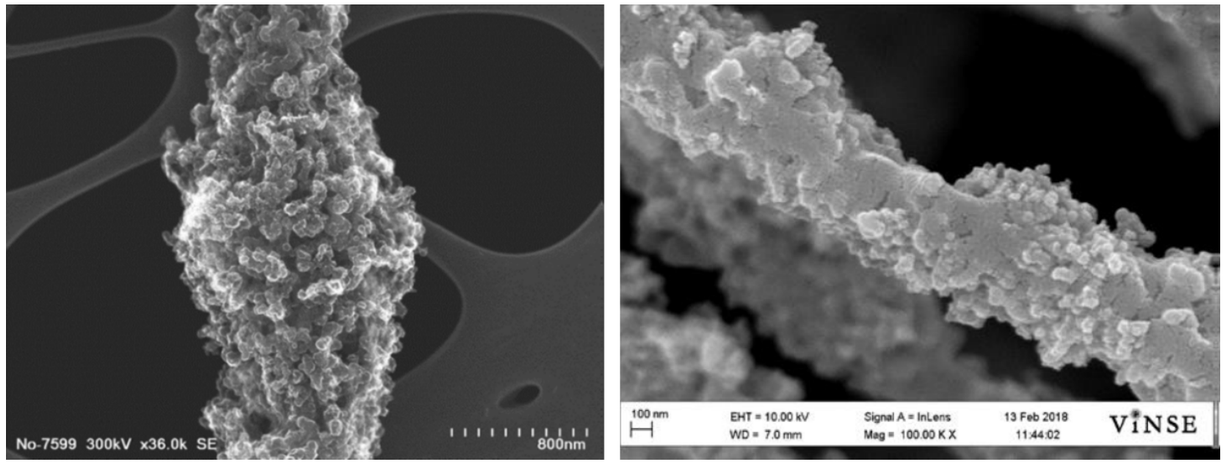
Fuel Cell Membrane Electrode Assemblies with Ultra-Low-Platinum Nanofiber Electrodes

Pacific Northwest NATIONAL LABORATORY

FC *Emerging*

uspto 1 patent

- Being developed by Vanderbilt University in partnership with Nissan Technical Center North America, Georgia Institute of Technology, eSpin Technologies, Inc., FC-PAD Consortium Labs (LANL, ORNL, LBNL, and ANL), and 3M Company.
- Can be used to fabricate membrane electrode assemblies (MEAs) with electrospun nanofiber electrodes with highly active oxygen reduction reaction catalysts for hydrogen/air fuel cells for automotive applications.
- Nanofiber MEAs can maintain power output in relative humidity conditions as low as 40%.
- Nanofiber MEAs can be fabricated at power levels greater than 300 mA/cm^2 at 0.8V and can operate at a rated power greater than 900 mW/cm^2.
- Received a total of 18 patent awards on technology developed from this research dealing with membranes and electrodes, industrial separations, energy conversion, storage applications, and more.
- A start-up company, eFiber Innovations, LLC, has been created by the PI to commercialize technology (Target late 2022).
- Contract Number: DE-EE0007653 (2017)



Electrospun Pt/C Gen-1 Fibers (Left) and PtCo/C Gen-2 Fibers (Right)

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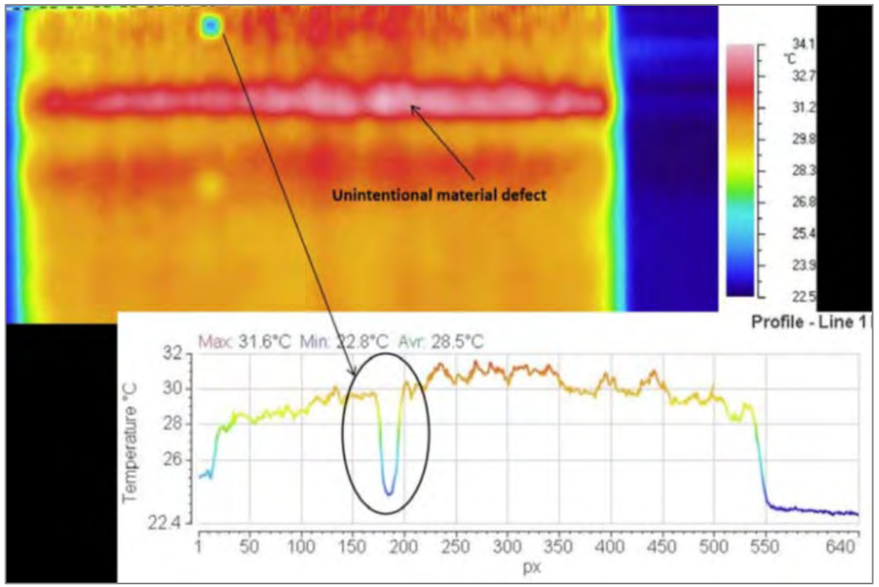
Fuel Cell Membrane Electrode Assembly Manufacturing R&D

Pacific Northwest NATIONAL LABORATORY

FC Commercial

uspto 2 patents

- Developed by NLR in collaboration with LBNL, Colorado School of Mines, New Jersey Institute of Technology, Automotive Fuel Cell Cooperation, General Motors, Ion Power, and W.L. Gore and Associates.
- Implemented IR/DC technique on industry partner Ion Power's production electrode coating line and demonstrated successful detection of intentionally created defects and process variability at their process conditions.
- Can be used to evaluate, develop, and validate inline diagnostics that can determine the effects of defects in MEA components to make improvements to the design of MEAs for hydrogen and fuel cell technologies.
- Can detect membrane pinholes at least as small as 150 µm diameter in MEAs and membrane-containing subassemblies using through-plane reactive excitation (TPRE).
- Have developed an apparatus and methods for creating pinholes at least as small as 50 µm in diameter in membranes and membrane-containing subassemblies with high repeatability.
- Contract Number: DE-AC36-08GO28308 (2007)



Infrared/reactive impinging flow (IR/RIF) data from a web-line demonstration, showing a detection of a 0.25 cm^2 defect having a 100% reduction in the nominal electrode thickness (a bare spot), at a web speed of 30 fpm. (top) The line graph of cross-web temperature (bottom) shows the thermal response of this defect.

BERKELEY LAB · GORE · Ion Power

National Laboratory of the Rockies · NJIT New Jersey Institute of Technology · AUTOMOTIVE FUEL CELL COOPERATION · COLORADO SCHOOL OF MINES · gm

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Fuel Cell Membrane Measurement System for Manufacturing (SBIR)

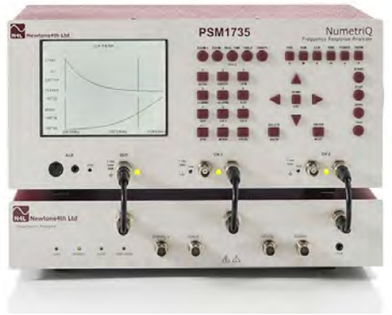
Pacific Northwest NATIONAL LABORATORY

FC *Commercial*

uspto 1 patent

- Developed by Scribner Associates, Inc.
- RAMMS – Rapid Membrane Measurement System - can be used to rapidly measure the through-thickness ionic resistance of bare, as-manufactured fuel cell membranes under controlled environmental conditions.
- Scribner Associates has been issued a U.S. patent (USPTO 7,652,479) based on this work, specifically for a novel electrode design and measurement apparatus that is compatible with bare membrane and MEA samples.
- Achieves consistent results and lowers manufacturing costs by reducing waste.
- Improves fuel cell membrane manufacturing efficiency by using high throughput testing.
- Technology was market-ready in 2012 and has been used in academic research since 2015.
- Contract Number: DE-FG02-06ER84574 (2006)







Scribner's 740 Membrane Test System

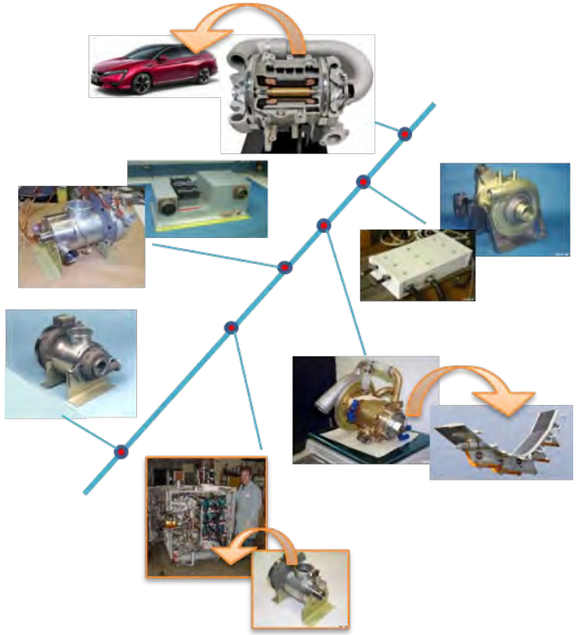
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Fuel Cell Turbocompressor

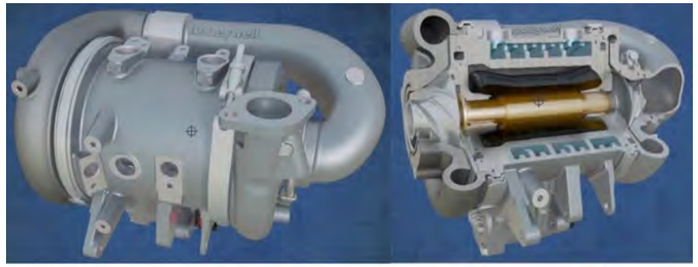
FC
Commercial

uspto
2 patents

- Developed by Honeywell International, Inc.
- Commercialized in 2016.
- Fuel cell air pressurization for industrial and transportation.
- Provides a contamination-free, pressurized airflow to the fuel cell stack and recovers fuel cell stack exhaust.
- Achieves reduced mechanical losses, zero maintenance, and low noise operation using internally cooled foil air bearings to eliminate fuel cell poisoning with contaminants.
- Has cost savings by producing a lightweight, compact, efficient, and reliable unit.
- Contract Number: DE-FC36-02AL67624 (2002)



Timeline of Honeywell's Turbocompressor Development for Automotive Applications 1995 – 2016





Honeywell's Fuel Cell Turbocompressor for Transportation Applications

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Website: http://www.honeywell.com

Fuel-Cell-Based Mobile Lighting

FC
Commercial

uspto
3 patents

- Developed by Sandia National Laboratories, with partnerships that include new technology holders, mass manufacturing and end users.
- Fuel-cell powered mobile lighting tower was planned to be commercialized by Multiquip in 2014, but product release was delayed and ultimately cancelled due to high costs. However, a fuel cell mobile light was developed and commercialized in 2020 by the IGX Group, the hydrogen provider for the development of the fuel cell mobile lights. IGX Group was then acquired by BayoTech in 2021.
- Provides efficient plasma or SSL lighting powered by a PEM fuel cell that can be used for numerous off-grid indoor or outdoor lighting applications, e.g., road construction, aviation ground support, entertainment lighting, and other temporary lighting applications.
- Uses a 1 kW fuel cell to provide 17.5 kW of equivalent power capacity with zero emissions at point of use and reduced noise compared to traditional light towers.
- Fueled with six hydrogen gas cylinders that can be swapped out for refueling.
- Contract Number: DE-AC04-94AL85000 (2010)



Fuel cell powered mobile light tower deployments



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Fuel-Cell-Powered Airport Ground Support Equipment Deployment

FC Commercial

- Developed by Plug Power, Inc., in collaboration with FedEx Express and Charlatte.
- Used in port fleets around the world, including airport baggage tractor tuggers, belt loaders, and deck loaders.
- Fuel cell-powered and produces zero emissions, which improves sustainability.
- Wear and tear on the vehicles are lower, reducing maintenance demands such as lubricants, brakes, and starter replacements. This results in reduced operational costs while increasing productivity.
- An easily scalable hydrogen storage system that requires less space than electric charging stations.
- Contract Number: DE-EE0006093 (2013)



FedEx Express has deployed a fleet of hydrogen fuel cell cargo tractors at Memphis SuperHub..



Power: Fuel Cell/ Li Battery, Energy Storage: H2 Tank, and Tractor Traction: Ballast

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GenDrive™: Fuel Cell Power System (ARRA)

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed and commercialized in 2010 by Plug Power Inc.
- Provides 1.5 - 14 kW of continuous power (depending on model).
- GenDrive™ fuel cells always maintain constant power, keeping the vehicle running at the required speed throughout the entire shift, unlike battery-powered lift trucks.
- No ventilation or personal protective equipment (PPE) needed for employees, providing a safer work environment.
- Produces zero emissions and eliminates handling of toxic materials found in battery operations.
- Companies using this technology include Sysco Corporation, FedEx Freight, Wegmans Food Markets, Inc., Whole Foods Market, Inc., Kimberly-Clark Corporation, and Coca-Cola Consolidated, Inc.
- Contract Number: DE-EE000-0482, -0483, -0485 & -6093



PLUG POWER

Contact Information:

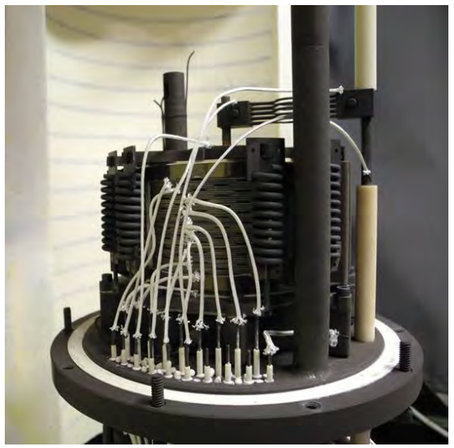
Email: gendrive@plugpower.com
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Plug Power, Inc.
968 Albany Shaker Rd
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Website: http://www.plugpower.com

High Efficiency Reversible Solid Oxide System

FC
Emerging

- Currently being developed by FuelCell Energy, Inc., in partnership with Versa Power Systems, which is now part of WLF Energy.
- Developing an energy storage technology based on a Reversible Solid Oxide Fuel Cell (RSOFC) system.
- This technology has the potential to have round-trip efficiency (RTE) of 70%, and a projected energy cost of less than $100/kWh.
- A 50-cell stack has been fabricated for this project, which has achieved a peak stack RTE of 80%.
- Currently identifying operating conditions that maximize the potential of the RSOFC stack.
- Contract Number: DE-FE0031974 (2019)





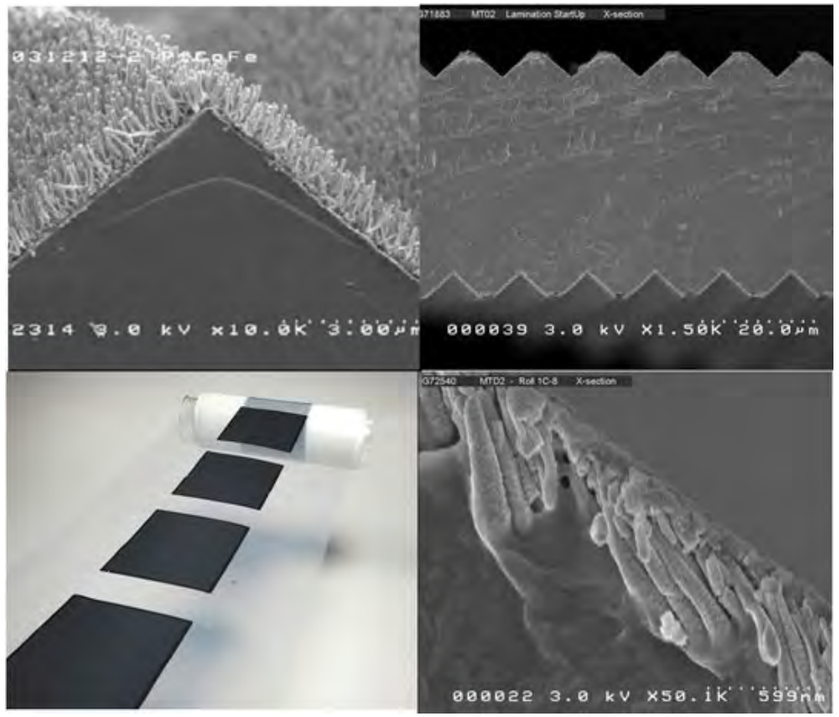


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High Performance, Durable, Low-Cost Membrane Electrode Assemblies for Transportation Applications

FC
Emerging

- Being developed by 3M Company.
- Continuing materials development, performance improvement, and fuel cell stack performance testing.
- Can be used in hydrogen fuel cells for portable, stationary, and on-vehicle applications.
- Reduces catalyst PGM loading to 0.131mg/cm^2 (DOE target is ≤ 0.125 mg/cm^2), including cathode interlayer for improved operational robustness.
- Reduces MEA cost by using less PGM and processes that are scalable to high-volume manufacturing.
- MEA passes the catalyst support cycle and MEA chemical tests and achieves 2 out of 3 electrocatalyst cycle milestones.
- Contract Number: DE-EE0005667 (2012)



P3M's MEA using NSTF Catalyst

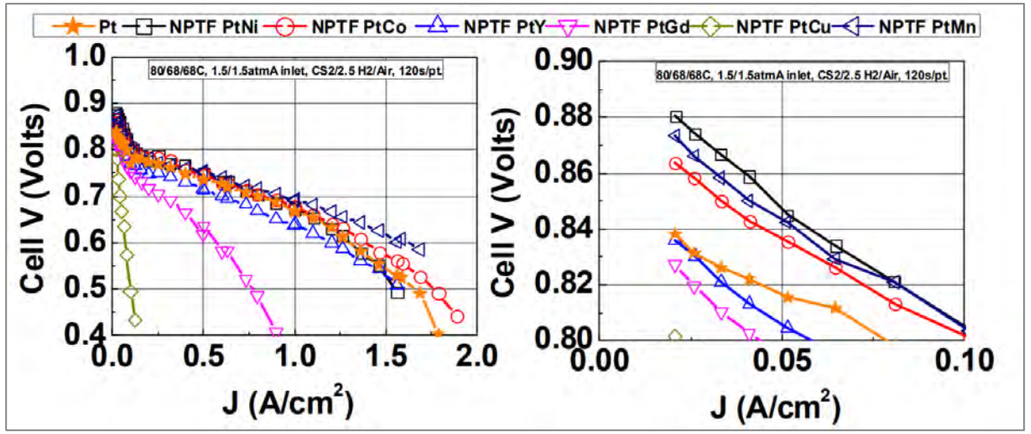
Contact Information:
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3M Center, Building 0201-01-N-19
St. Paul, MN 55144-1000
Website: http://www.3m.com

Highly Active, Durable, and Ultra-low PGM NSTF Thin Film ORR Catalysts and Supports

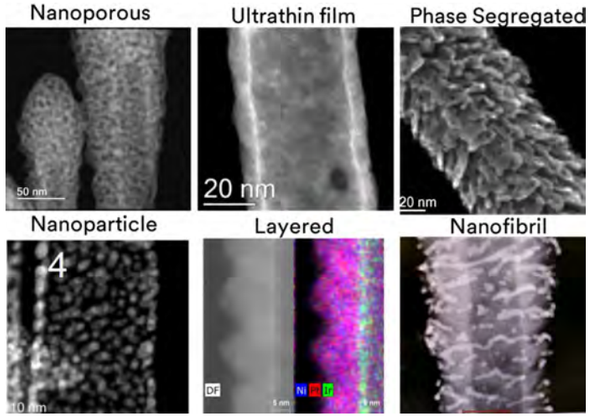
FC
Emerging

uspto
2 patents

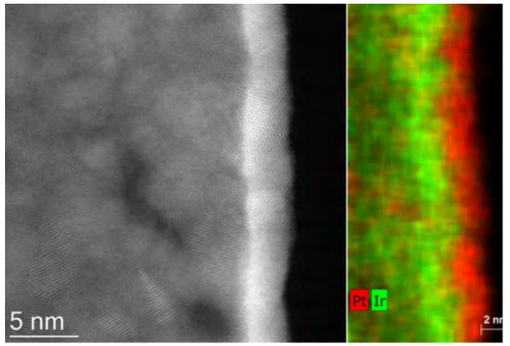
- Being developed by 3M company in partnership with Johns Hopkins University, Purdue University, Oak Ridge National Laboratory, and Argonne National Laboratory.
- Provided key insights into observed experimental activity and durability trends.
- These trends were utilized to assess new electrocatalyst concepts prior to or coincident with physical catalyst development.
- Provided several electrocatalyst candidates with activity and durability which approach or exceed DOE targets (one class of catalysts met or exceeded 6 of the 6 DOE targets the project addressed).
- Contract Number: DE-EE0007270 (2016)



Summary of peak HCT H2/Air performance for each alloying element.



Electrocatalyst morphologies assessed during project



3M 10Pt/12Ir Catalyst.

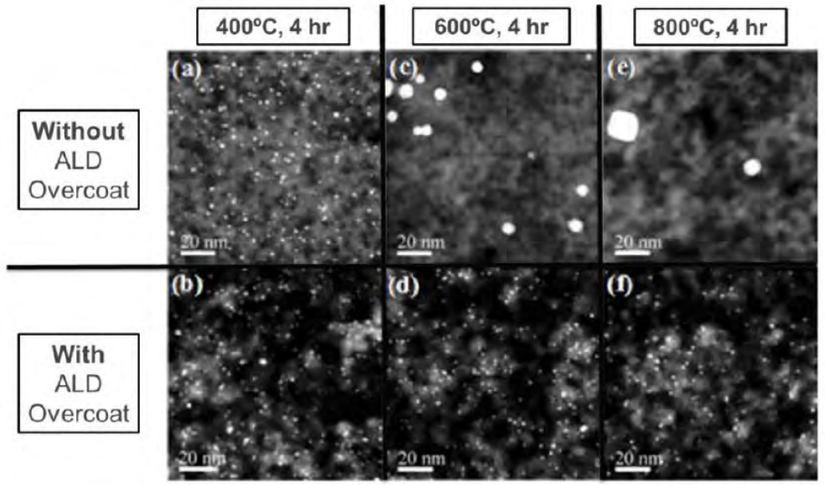
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Highly Robust Low PGM MEAs Based upon Composite Supports

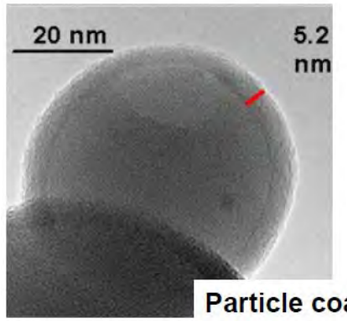
FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

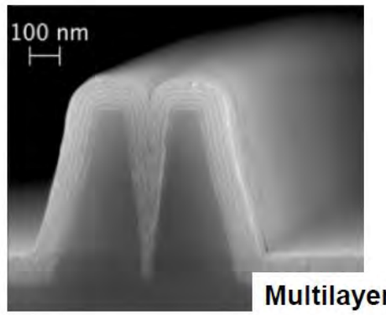
- Developed by Forge Nano (merged with ALD NanoSolutions, Inc. in 2020) in collaboration with Ugur Pasaogullari Research Group at the University of Connecticut.
- Entered the market in 2018.
- Performance of fuel cells is limited as the surface area for electrochemical reactions decreases.
- Currently developing strategies to stabilize the electroactive catalyst, and the carbon support, with atomic layer deposited (ALD) thin films.
- Coating optimization includes ALD film growth process, film conductivity, film porosity, and post process annealing.
- Contract Number: DE-SC0017191 (2017)



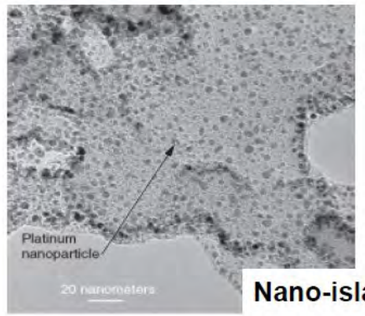
Al_2O_3 ALD overcoating on ALD-derived Pt nanoparticles, showing effective elimination of sintering/ripening at high temperatures.



Particle coatings



Multilayers



Nano-islands

FORGE NANO

UCONN

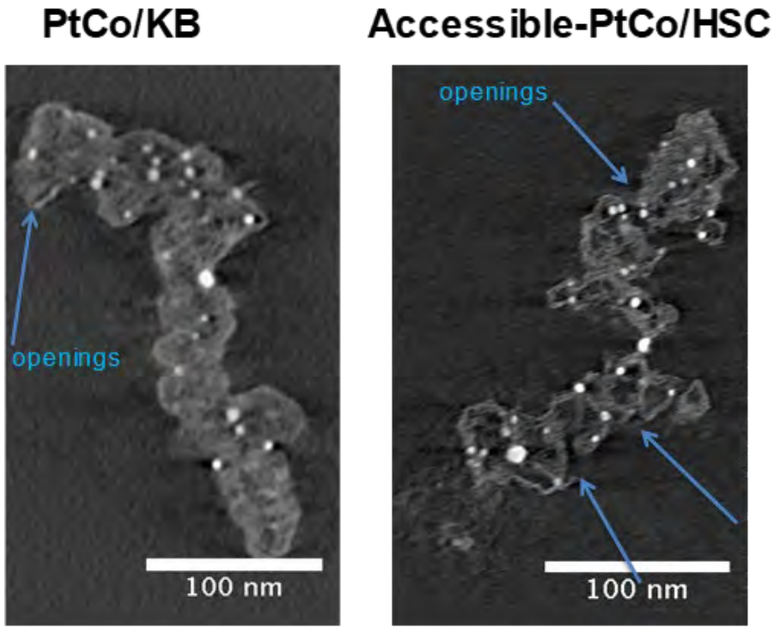
Contact Information:
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Highly-Accessible Catalysts for Durable High-Power Performance

FC Emerging

uspto 1 patent

- Developed by General Motors (GM), in partnership with 3M Company, Carnegie Mellon University, Cornell University, Drexel University, and National Laboratory of the Rockies (NLR) .
- Goals are to develop a process in order to add ionic liquid in MEA and study the effect, optimize PtCo on accessible carbon with emphasis on stability, validate cation performance model with in-situ visualization, and more.
- Selected ionomer and ionic liquid has been implemented with selected catalysts.
- Validation tests at NLR have confirmed improved HCD performance with catalysts with accessible carbon.
- Advanced PGM utilization status by 15% by reducing Pt in both anode and cathode.
- Intermetallic ordering was effective for improving durability of accessible-PtCo with minimal performance penalty.
- Contract Number: DE-EE0007271 (2016)



Sliced images of PtCo/KB and PtCo/HSC-f catalysts showing the openings of the carbon internal pores. Sliced image analysis was reconstructed from scanning transmission electron microscopic tomography

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High-Performance AEM LTE with Advanced Membranes, Ionomers and PGM-Free Electrodes

FC Commercial

Added FY2025

- Developed by the Georgia Institute of Technology in collaboration with University of South Carolina and industry partners Pajarito Powder and Nel Hydrogen.
- State-of-art alkaline polymer membrane and electrodes for low temperature electrolyzers (LTEs).
- Highest conductivity in a hydroxide membrane for electrochemical devices.
- Developed leading electrode and MEA fabrication process methods for PGM/PGM-free catalysts on ionomers (R2R).
- Technologies licensed exclusively in 2021 and commercially available as Pention™ and PNB™.
- Applications in fuel cells, electrolyzers, gas separation, and electrochemical synthesis.
- Contract Number: DE-EE0009241 (2020)



Pention™ Ionomer



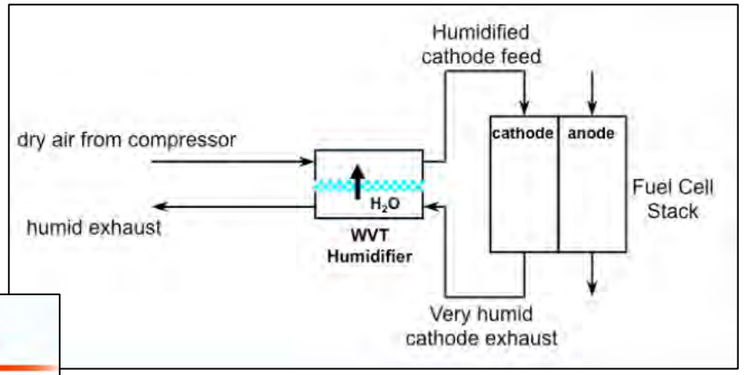
PNB™ Membrane

Contact Information:
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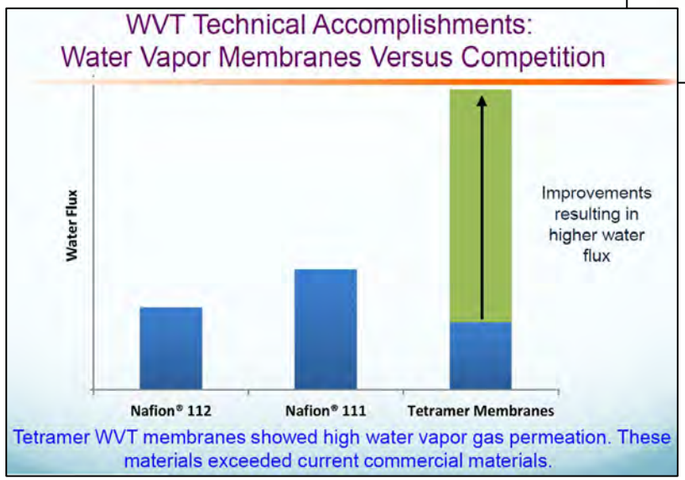
High-Performance Water Vapor Membranes to Improve Fuel Cell Balance of Plant Efficiency and Lower Costs (SBIR)

FC Emerging

- Tetramer developed proprietary polymer architectures which provided multiple water transport paths while mitigating or eliminating degradation pathways.
- Monomers and polymers were successfully synthesized which have shown improved water vapor transport and represent a best-in-class performance at temperatures above 120℃.
- Industrial partners, Dana Holding Corporation, General Motors and Membrane Technology and Research, Inc. (MTR) provided testing and qualifying membrane materials according to automotive specifications.
- Contract Number: DE-SC0006172 (2015)



Water Vapor Transport (WVT) unit transfers moisture that is formed from fuel cell reactions within the stack from cathode exhaust to the feed; improves performance and lowers balance of plant costs.

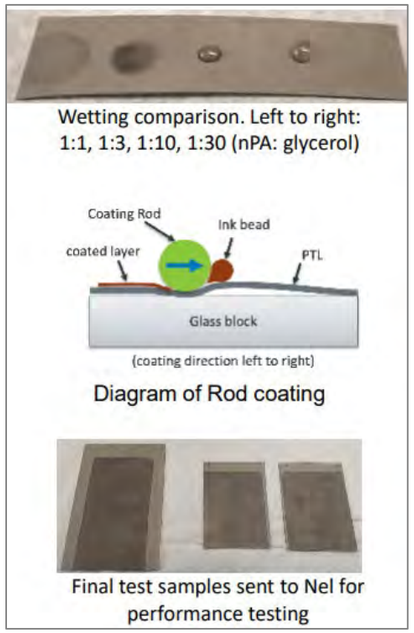


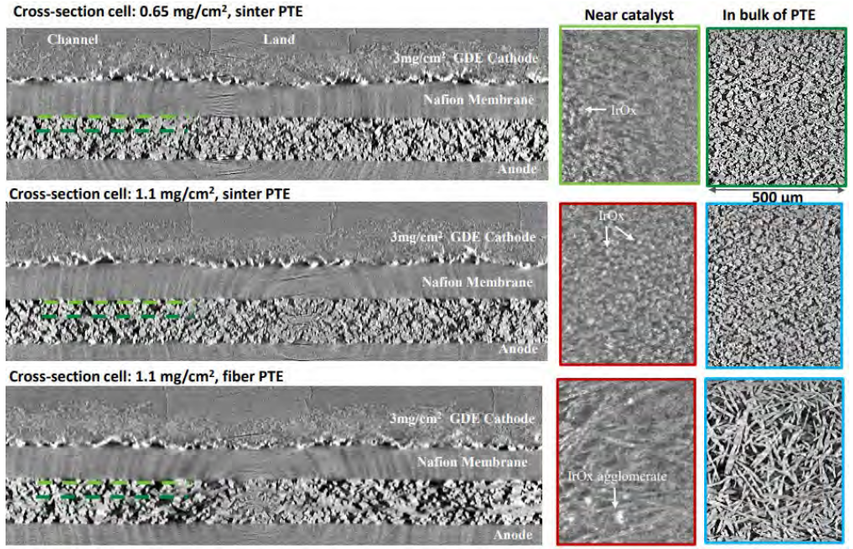
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Chris Topping
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Website: https://tetramer.com/

HydroGEN Seedling: High-Efficiency Proton Exchange Membrane Water Electrolysis Enabled by Advanced Catalysts, Membranes, and Processes

FC
Emerging

- Being developed by ProtonOnsite, in partnership with University of California, Irvine, and Oak Ridge National Laboratory.
- Project objective is to develop an advanced proton exchange membrane electrode assembly (MEA) that meets or exceeds the Energy Materials Network (EMN) targets by addressing membrane, catalyst, catalyst layers, and their interfaces.
- Targeting production of hydrogen at 43 kWh/kg.
- Aiming to show decay rates of less than 4 mV/1,000 h.
- Goal to achieve costs of $2/kg hydrogen based on $0.02/kWh renewable energy input as estimated by the H2A (Hydrogen Analysis).
- Demonstrate 1.8A/cm^2 at 1.7 V for advanced MEA model.
- Contract Number: DE-EE0008081 (2017)





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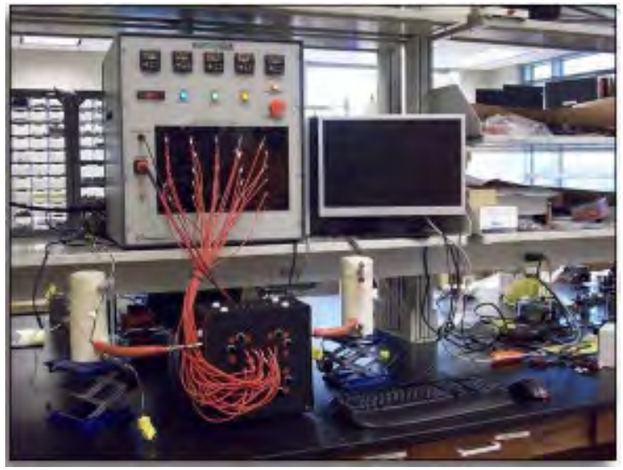
Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods (SBIR)

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by NuVant Systems, Inc. (SBIR grant).
- Sold the first commercial Arraystat in 2006 and sold the first commercial parallel array fuel cell in 2007.
- Used to test MEAs using different combinations of catalysts as well as flow-field design, MEA degradation, parallel battery charge-discharge characteristics, and optimized plating conditions.
- Eliminates random error introduced by multiple test standards because of a single common counter electrode.
- Allows maximum flexibility by having user-defined measurement discs.
- Reduces costs associated with testing MEAs because of the high throughput and a single test station.
- Over 160 units in the field.
- Follow-on development of additional multichannel electrochemical methods, and high throughput nickel metal hydride battery reconditioning.
- NuVant was acquired by A3 Global in 2022.
- Contract Number: DE-FG02-03ER83734 (2004)





NuVant Systems Inc.
Pioneering Electrochemical Technologies
An A3 Global Company

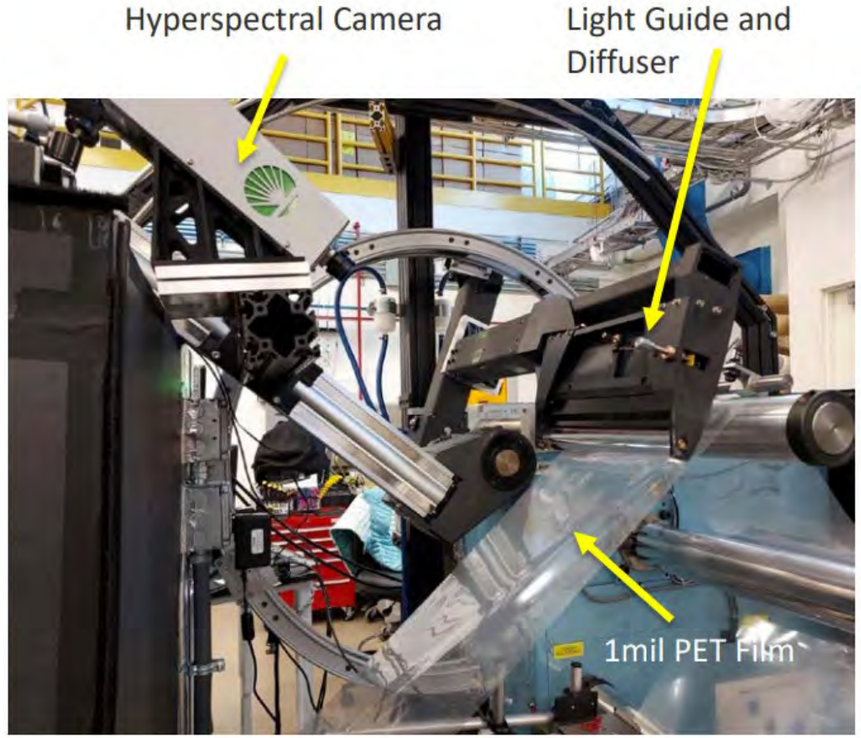
Contact Information:
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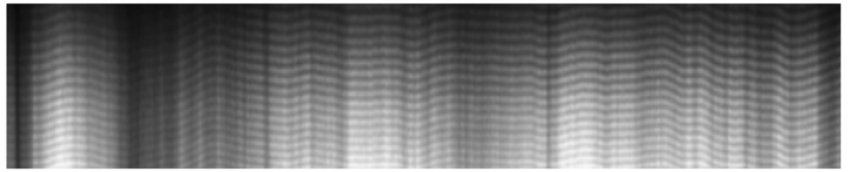
In-Line Membrane Thickness Mapping with Real-Time Data Processing

FC
Emerging

uspto
1 patents

- Developed by National Laboratory of the Rockies (NLR) in collaboration with Middleton Spectral Vision (MSV), Cummins, Oxyion, and Plug Power.
- Testing materials can reduce waste of expensive materials.
- In-line quality control tools will enable high-volume, low-cost, low-risk fabrication of the fuel cell and electrolyzer components.
- Demonstration of the first real-time, high-resolution membrane thickness mapping system was successfully performed on rolls with total length of 65m.
- The system can run at more than 100Hz frame rate yielding maps with the special physical resolution of ~200 μm.
- Large area thickness variations as well as sub-mm thickness defects can now be detected in in-line fashion for rolls of membrane goods moving through a roll-to-roll system.
- NLR's patent and software records are available for licensing. They also provide testing as a service.
- Contract Number: DE-AC36-08GO28308 (2020)





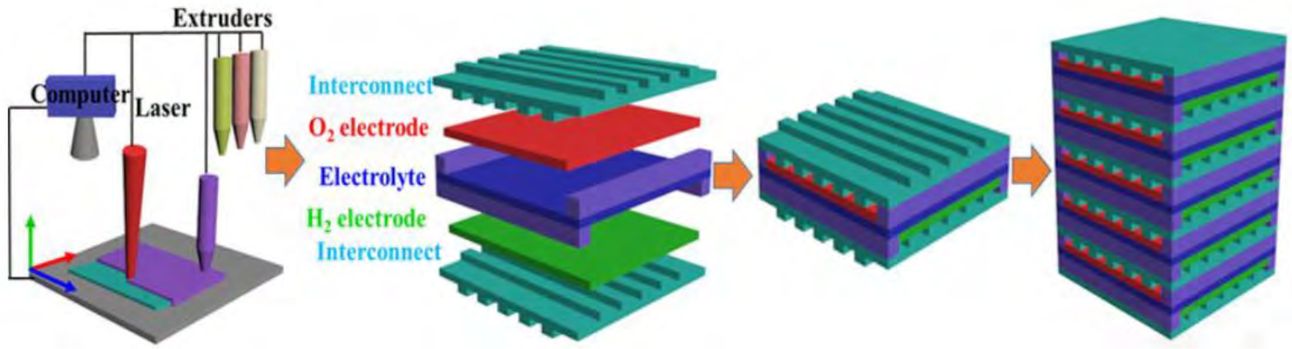
Imaging from 1mil PET Film

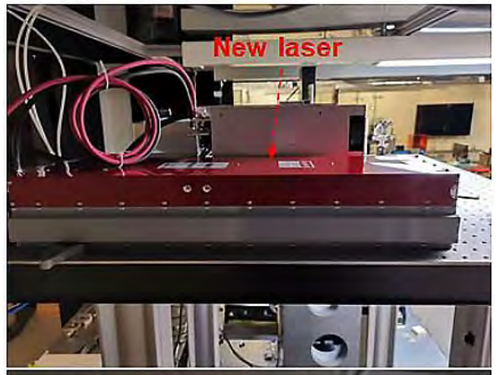
Contact Information:
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National Laboratory of the Rockies
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Laser 3-D Printing of Highly Compacted Protonic Ceramic Electrolyzer Stack

FC
Emerging

- Currently being developed by Clemson University.
- Designing and developing a laser 3D printing (L3DP) technology for cost-effective, rapid, and flexible manufacturing of high-performance intermediate-temperature protonic ceramic electrolier stacks (PCESs) for H2 production at various scales.
- Has the potential to significantly decrease manufacturing costs.
- Single cells can be fabricated in a 3D printer with a layer of ceramic and a laser can sinter it at the same time, eliminating the need for a furnace, which significantly decreases manufacturing energy consumption and time.
- Currently attempting to scale up; the stack is at 100W/hr. and need to prove out a 200W/hr. stack.
- Looking to collaborate to get to the next level and increase power output to 5kW/hr. for niche markets.
- Contract Number: DE-EE0008428 (2018)







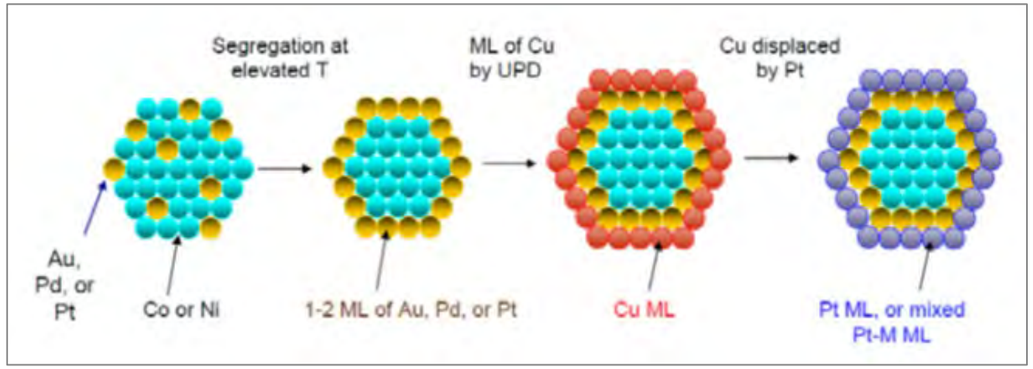
Contact Information:
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Low Platinum Loading Fuel Cell Electrocatalysts

FC
Emerging

uspto
13 patents

- Being developed by BNL in collaboration with Los Alamos National Laboratory, Battelle Memorial Institute, 3M Company, Power Plug, Inc., and General Motors Company.
- Can be used in fuel cells to enhance their performance by eliminating CO poisoning.
- Survives in a CO environment without degradation.
- Allows the use of less platinum while maintaining performance.
- Reduces costs due to lower content of noble metal.
- Contract Number: DE-AC02-98CH10886 (2002)



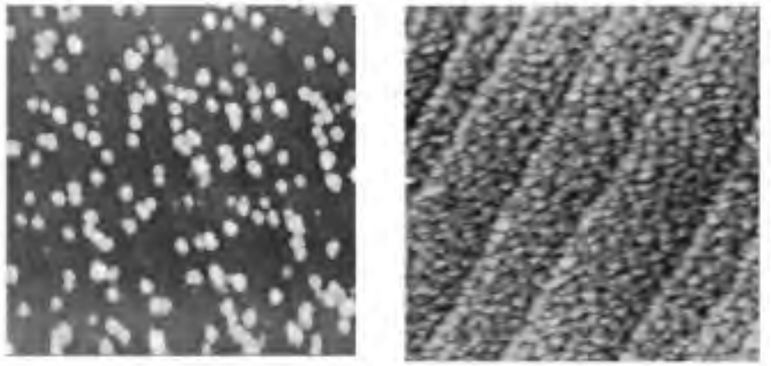


Figure 1. STM images (200 × 200 nm, left, and 100 × 100 nm, right) of spontaneously deposited Pt on Ru(0001) from solutions containing 0.1 and 10 mM H_2PtCl_6 in 0.1 M H_2SO_4, respectively. Images recorded at open circuit potentials with Z ranges of 5 (left) and 2 nm (right).

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Low-Cost 3-10 kW Tubular SOFC Power System

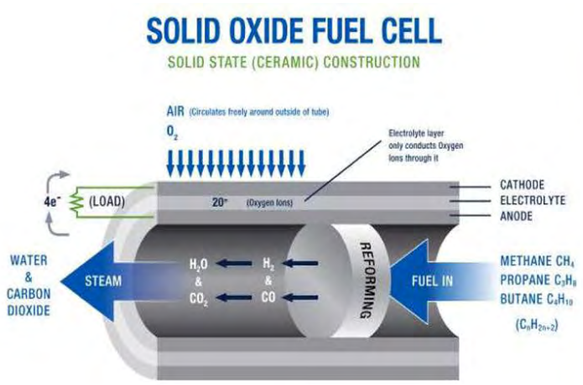
FC
Commercial

uspto
3 patents

Pacific Northwest
NATIONAL LABORATORY

- Developed by Atrex Energy, Inc. (formerly Acumentrics Corporation), acquired by Special Power Sources, LLC in 2019.
- Commercialized in 2016.
- Can be used for off-grid electricity generation or to provide electricity and hot water in residential applications.
- Demonstrated electrical efficiencies of 35-40% and a CHP efficiency of 85%.
- Can operate for more than 5,000 hours with a degradation rate of less than 1% per 1000 hours.
- Reduces costs by using an isopressing process for tube manufacturing, which enables high-volume throughput and reduced material waste.
- Handles fuels such as natural gas and propane without requiring an external reformer to produce hydrogen.
- Contract Number: DE-FC36-03NT41838 (2008)







Field installation of Atrex Energy's Tubular SOFC Power System (Top)
Atrex Energy's SOFC Tubes (Bottom)

ALTEX TECHNOLOGIES CORPORATION

SPS Special Power Sources
SUPPLYING YOUR REMOTE POWER NEEDS

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Website: https://www.spsources.com

Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells (SBIR)

FC
Emerging

uspto
14 patents

- Developed by Nanotek Instruments Group LLC. (dba Global Graphene Group) in collaboration with the National Composite Center.
- Developing lost-cost sheet molding compound (SMC) bipolar plates and large-scale manufacturing processes.
- SMC bipolar plates consists of a thin nanocomposite core layer sandwiched between two flexible graphite (FG) sheets.
- Nanocomposite core lowers material costs and improves electrical, mechanical, and gas permeation properties.
- FG-SMC bipolar plates meet or exceed DOE targets for conductivity, cost per kW, weight, gas permeation rate, corrosion, strength, and flexibility.
- Demonstrated roll-to-roll SMC fabrication process, where the sheets can then be die-cut, molded into the desired shape, and fully cured.
- Contract Number: DE-FG02-06ER84558 (2007)



Nanotek's Roll-to-Roll System for Producing Multiple-Layer Bipolar Plates

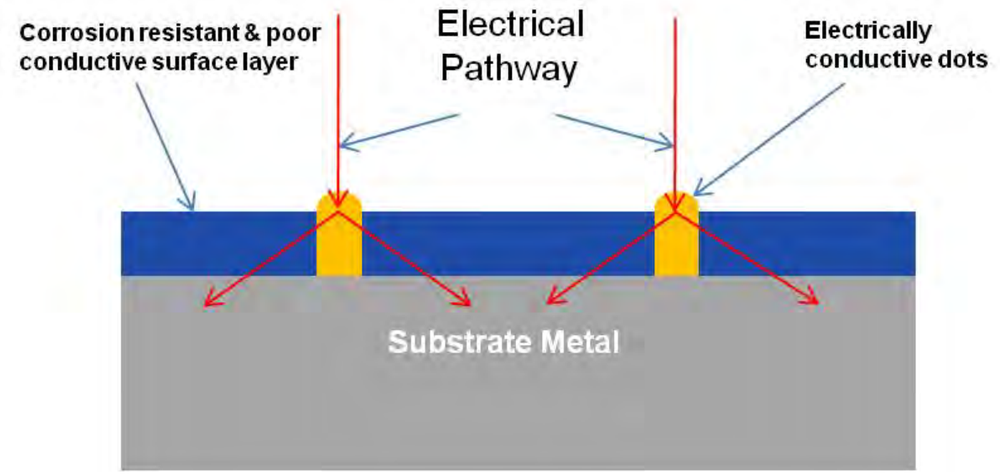
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Low-Cost PEM Fuel Cell Metal Bipolar Plates

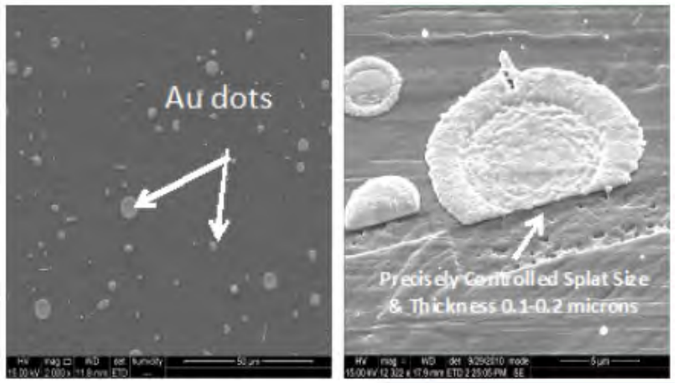
FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by TreadStone, Inc., and commercialized in 2011.
- TreadStone's plate coating process manages to reduce the cost of fuel cell metal plate coatings to as low as $0.30/plate.
- The DOTS technology reduces electrical contact resistance by selective material deposition of aluminum plates followed by application of gold dots (or other materials for AEM fuel cell applications).
- Produces corrosion-resistant, cost-effective metallic bi-polar plates for fuel cell and other electrochemical applications.
- Optimizes the fabrication process for large-scale manufacturing.
- Applications for fuel cells and electrolyzers
- Contract Number: DE-EE0000463 (2009)







TreadStone Technologies, Inc.

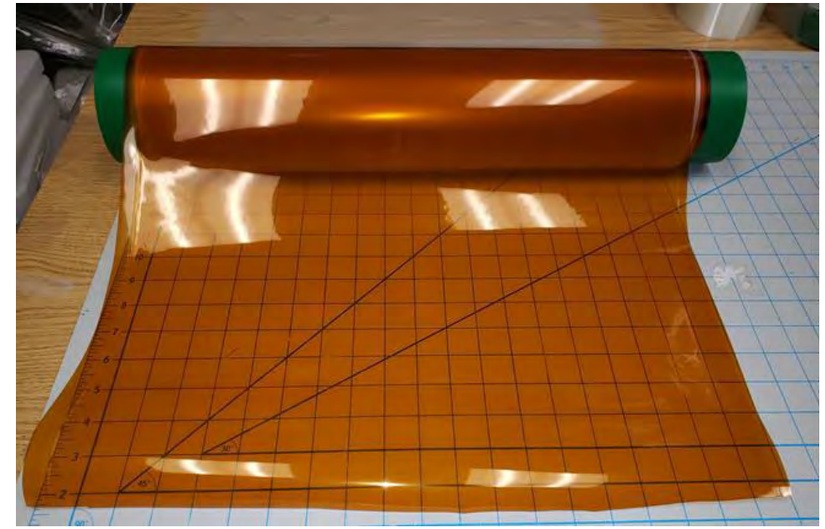
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TreadStone Technologies, Inc.
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Low-Cost, High-Performance Catalyst Coated Membranes for Proton Exchange Membrane Water Electrolyzers

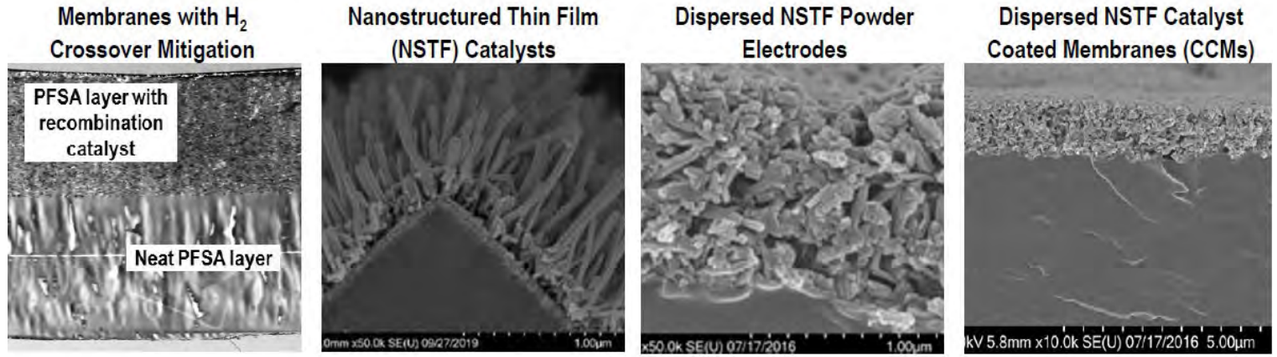
FC
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Currently being developed by the 3M Company in collaboration with National Laboratory of the Rockies (NLR) and Giner, Inc.
- Developing reduced-cost, roll-to-roll manufacturing processes for high-performance membranes, catalysts, electrodes, and catalyst-coated membranes for PEM water electrolyzers.
- Electrolyzer capital costs can be reduced by utilizing roll-to-roll continuous manufacturing.
- Lowers material and manufacturing costs.
- Contract Number: DE-EE0008425 (2018)



0.48m Wide, 825EW 100µm Membrane Produced with Advanced Process at 20.6x Areal Rate



National Laboratory of the Rockies

GINERLABS

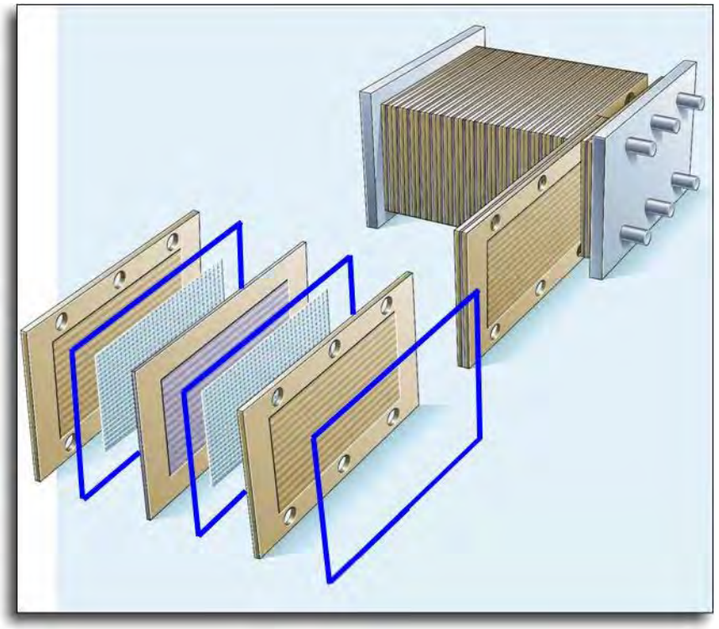
Contact Information:
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Manufacture of Durable Seals for PEM Fuel Cells

FC
Commercial

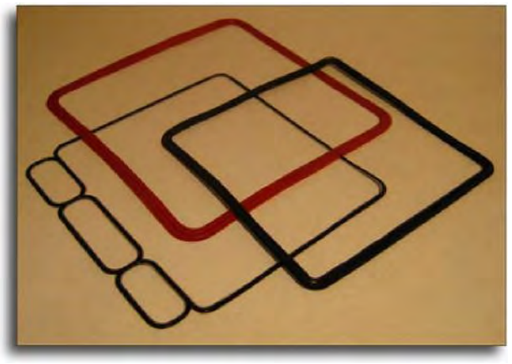
Pacific Northwest
NATIONAL LABORATORY

- Developed by Freudenberg-NOK Sealing Technologies (FNST) in partnership with UTC Power, commercialized in 2009. UTC power was part of United Technologies Corporation and was acquired by ClearEdge Power in 2013.
- FNST uses a custom elastomer material that exhibits improved chemical and mechanical properties compared with conventional silicones.
- Used in PEM fuel cell stacks to improve plant efficiency and durability for bus/transportation applications and stationary power sources.
- Allows the seals to survive the electrochemical environment while reducing catalyst poisoning concerns in the fuel cell.
- Displays low levels of ionic contaminants.
- Contract Number: DE-FG36-07GO17005 (2007)



FREUDENBERG
SEALING TECHNOLOGIES

ClearEdge | POWER®
Delivering Smart Energy Today™



FNST Durable Seal for PEM Fuel Cells

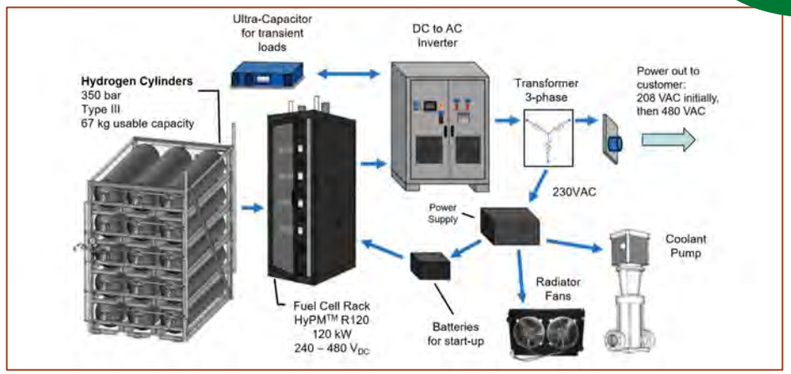
Contact Information:
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Phone: (734) 354-5309
Freudenberg-NOK Sealing Technologies
47690 East Anchor Court
Plymouth, MI 48170-2455
Website: https://www.fst.com/

Maritime Fuel Cell Generator (MarFC) Project

FC *Emerging*

Added FY2025

- Developed by Sandia National Laboratories and Cummins (formerly Hydrogenics) as a commercial project.
- Completed on-site deployment at the Young Brothers wharf in Honolulu Harbor, Honolulu, HI powering refrigerated containers (reefers) (2014 – 2017).
- Completed on-site deployment with the Scripps Institution of Oceanography in La Jolla, CA providing shore power for the *Robert Gordon Sproul* research vessel (2018 – 2022).
- Can be used as a low-emission alternative to diesel generators for powering refrigerated containers and other auxiliary equipment used in maritime material handling applications, shore power for marine vessels, and grid-independent port.
- Produces 100 kW of electrical power and stores 75 kg of compressed hydrogen (67 kg usable).
- Contract Number: DE-NA0003525 (2013)



Essential Components of the Maritime Fuel Cell (MarFC) Generator



20-foot iso Container
Length: ~ 20 feet
Width: ~ 8 feet
Height: ~ 8.5 feet
Weight: ~ 25,000 lbs

H_2 storage | Fuel Cell Power



Portable MarFC can be moved by crane or forklift.



MarFC Deployment with Young Brothers powering Reefers.



MarFC Deployment with Scripps Institution of Oceanography providing shore power for the *Robert Gordon Sproul. .*

Sandia National Laboratories

Cummins

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Mobile Fuel Cell Generator (STTR)

FC
Emerging

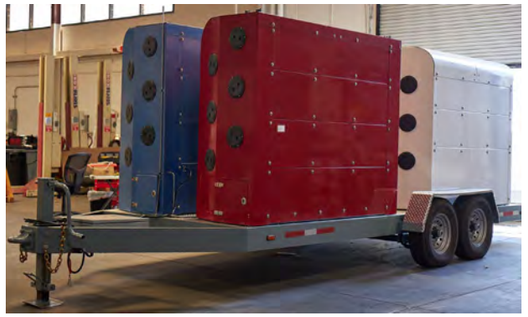
Pacific Northwest
NATIONAL LABORATORY

- Developed by RockeTruck, Inc. in partnership with California State University Los Angeles, American Honda Motors, AVL Mobility Technologies, S/W & Controls, San Diego Gas & Electric Company, and Southern California Gas Company.
- Demonstrates a portable, hydrogen-fueled electric generator that provides a clean, economically viable alternative to diesel generators.
- Completed Mobile Fuel Cell Generator (MFCG) Ultra (2023) which stores 100-150 kg of H_2 and can meet 35 kW/48-hour specifications.
- MFCG Ultra can provide power for 24 hours at full power (80 kW) and for several days at lower power demand (10s of kW).
- Built the MFCG Mini which is similar in size and weight to a diesel generator, with a power output of 80 kW and a large battery pack (70 kWh) that increases peak power output.
- External fueling trailer stores ~130 kg H2, supports the requirement to deliver an average of 35 kW over a 48-hour period, and can be towed by the same pickup truck transporting the MFCG Mini.
- Technology possesses safety systems to stop fuel cell shut down (preventing self-inflicted damage).
- Contract Number: DE-SC0022776 (2022)

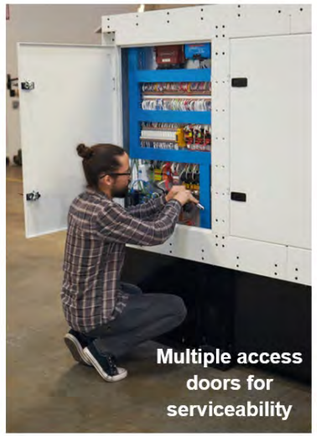


MFCG Mini (2024-2026)





External Fueling Trailer



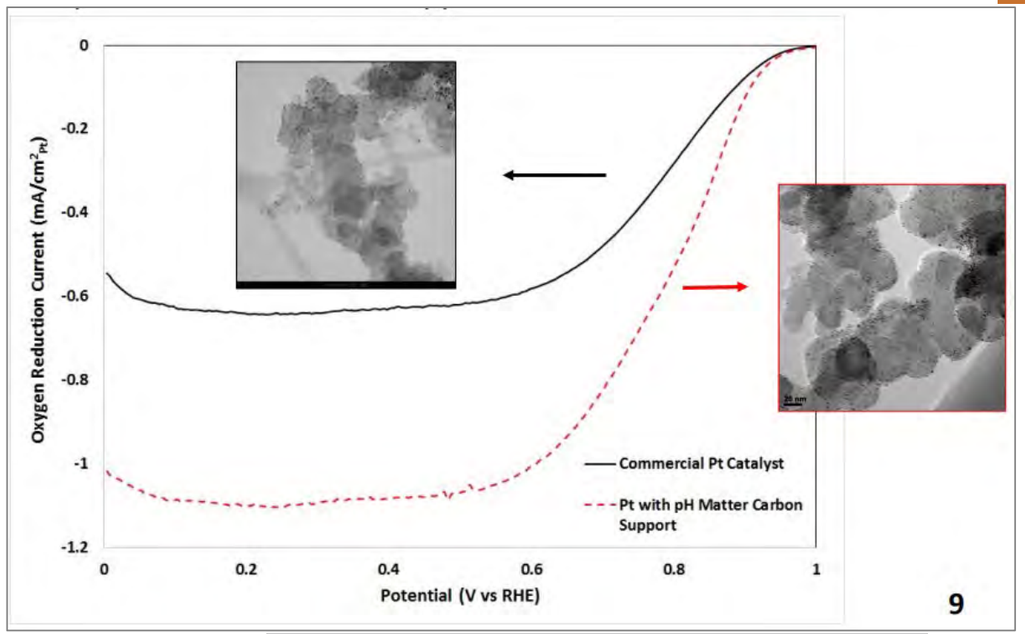
Contact Information:
Paul Scott
Email: paul@rocketruck.com
Phone: (626) 644-4171
RockeTruck, Inc
2415 Auto Park Way
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Multi-Functional Catalyst Support (SBIR)

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by pH Matter, LLC in partnership with Giner Labs and NLR, commercialized in 2022. Later worked with Hyzon Motors to enhance fabrication techniques.
- Next generation fuel cell electrode catalysts with materials that will out-perform current precious metal catalysts in terms of cost, efficiency, and stability during voltage cycling.
- The unique properties of these materials will allow them to be chemically resistant to degradation mechanisms suffered by traditional catalysts.
- Can be used in a range of applications such as automotive, materials handling (forklifts), fleet vehicles, and stationary back-up power.
- Lower costs than electrodes currently used in hydrogen fuel cells.
- Better durability in start/stop applications.
- Contract Number: DE-SC0017144 (2018)

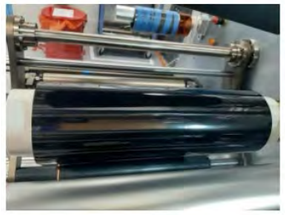


Demonstrated improved performance with tuned hydrophobicity GDEs using a patent-pending treatment process:

Contact angle measurements

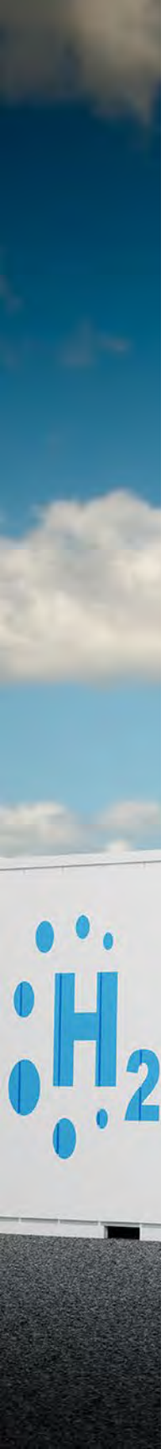






Hyzon-fabricated MEA using roll-to-roll equipment integrating pH Matter catalyst

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pH Matter, LLC
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Website: https://www.phmatter.com

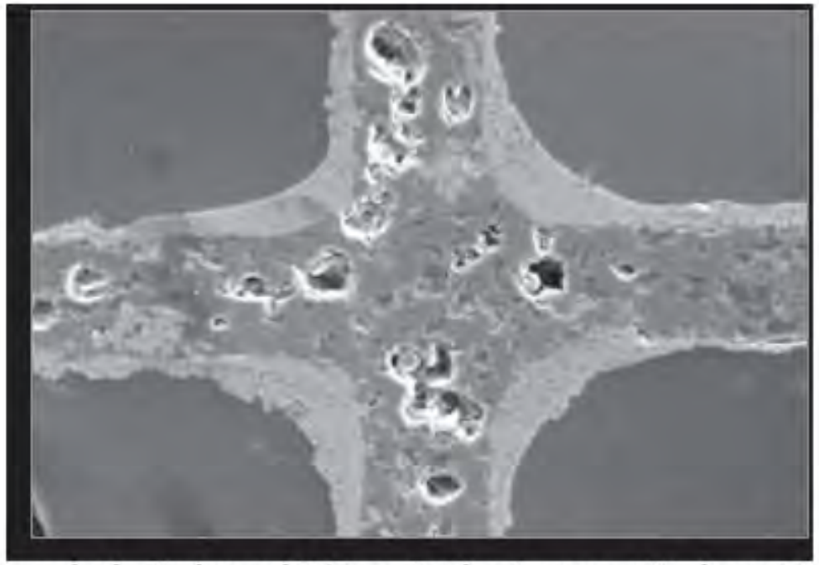


Nanoscale Water Gas Shift Catalysts

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Nexceris, LLC, and commercialized in 2005.
- Can be used in fuel processing systems for proton exchange membrane fuel cells, reforming reactors for solid oxide fuel cells, and hydrogen production systems.
- Has a high activity for water-gas-shift reaction at temperatures above 250 degrees C.
- Does not require complex pre-reduction processes.
- Allows the design and construction of compact, high-performance, and thermally integrated water-gas-shift reactors.
- Available in multiple forms and can be tailored for specific reactions, conditions, & temperatures, depending on customer requirements.
- Contract Number: DE-FC02-98EE50529 (1999)



Micrograph of a Washcoated Pt/Ceria Catalyst Layer on a Cordierite Monolith

NEXCERIS
where energy meets environment

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Lewis Center, OH 43035
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Northeast Demonstration and Deployment of FCRx200

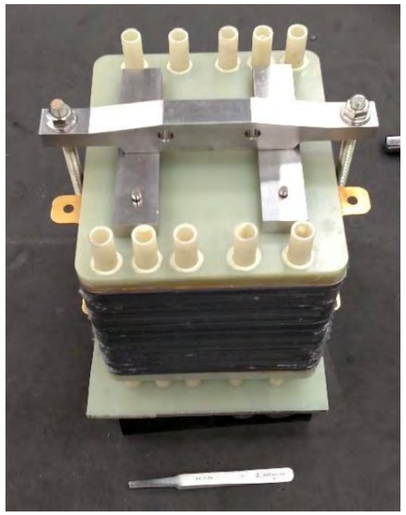
FC Emerging

Pacific Northwest NATIONAL LABORATORY

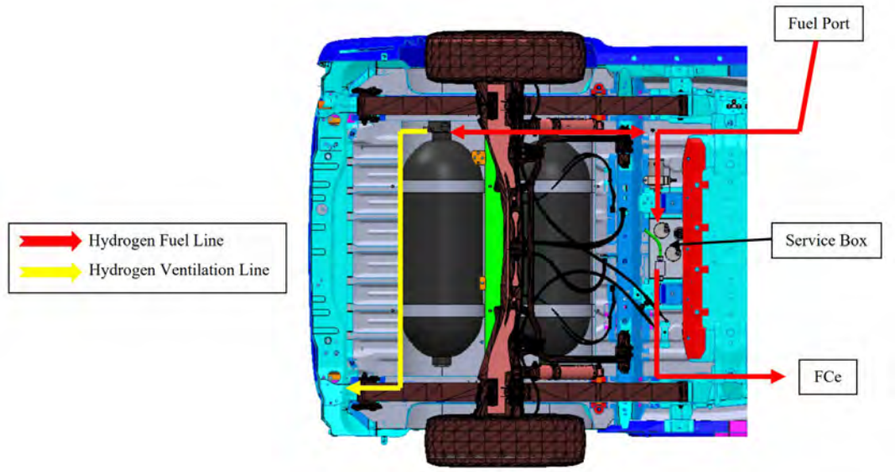
- Being developed by US Hybrid Corporation in collaboration with Argonne National Laboratory, Nissan North America, and National Grid.
- Designed, developed, tested, and demonstrated one fuel cell range-extended plug-in hybrid utility vehicle (FCRx200) at the operator's site.
- Performed accelerated stack-level testing and engine-level vehicle integration testing.
- FC engine performance evaluated to meet or exceed the target kWh/kg of H2, fuel efficiency, and FC engine, tanks and fill ports were integrated with the OEM control, command and diagnostics.
- Hydrogen fueling and charging demonstrated on a vehicle.
- Contract Number: DE-EE0007276



Initial short stack CSA installed for test stand validation run and system sign-off



First prototype CSA for initial testing



US HYBRID

NISSAN

Argonne NATIONAL LABORATORY

nationalgrid

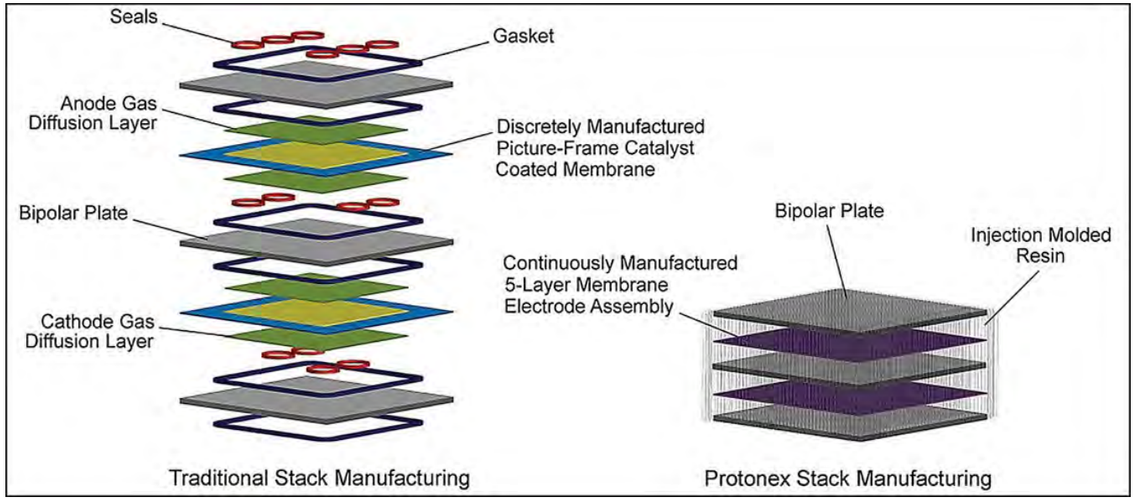
Contact Information:
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Website: https://ushybrid.com

Novel Manufacturing Process for PEM Fuel Cell Stacks

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Protonex Technology Corporation (acquired by Galvion) and commercialized in 2008.
- One-step molding process reduces manufacturing costs and improves fuel cell stack and system durability.
- Demonstrates that high-performance PEM stacks can be produced with a high degree of manufacturability.
- Lowers costs by using lower tolerance and fewer components.
- Uses adhesive-based seals to improve stack reliability and robustness over traditional compression-based seals.
- Developing systems for unmanned aircraft applications.
- Contract Number: DE-FC36-04GO14217 (2004)





GALVION

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Phone: (508) 490-9960
Protonex Technology Corporation
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Southborough, MA 01772
Website: http://www.protonex.com

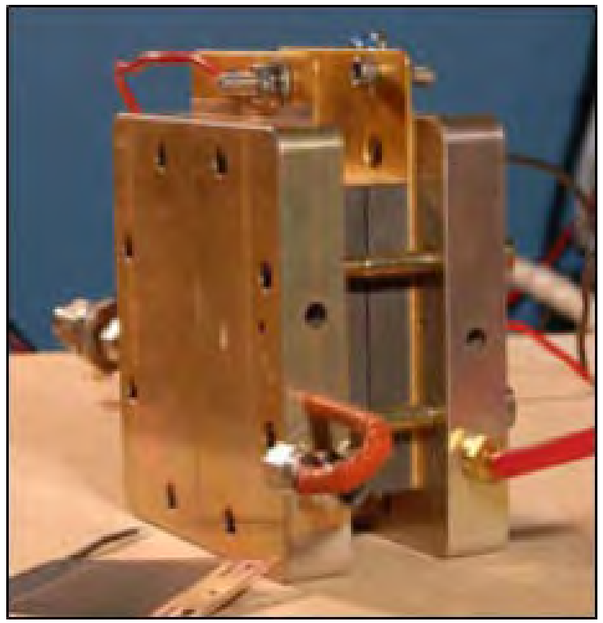
Novel Structured Metal Bipolar Plates for Low-Cost Manufacturing (SBIR)

Pacific Northwest NATIONAL LABORATORY

FC Emerging

uspto 2 patents

- Developed by TreadStone Technologies, Inc., in partnership with University of Hawaii - Hawaii Natural Energy Institute, and ORNL.
- Can be used in PEM fuel cell applications.
- Uses a method of coating stainless steel bipolar plates that are used in hydrogen fuel cell stacks first with a thin layer of Ti-Nb or Ti-Ta alloy, followed by growing doped titanium oxide (TiO_x) on the Ti alloy layer.
- Meets the 2020 corrosion resistance target of less than 1 $\mu A/cm^2$.
- Achieves low electrical contact resistance of less than 4 $m\Omega.cm^2$.
- Ex-situ tests show that a fuel cell with coated plates can operate for 1,100 hours without performance degradation.
- Developed a low-cost manufacturing method that can still achieve desired properties of corrosion resistance and electrical contact resistance.
- Contract Number: DE-FG023-13ER90469 (2013), DE-SC0009215 (2014) and DE-EE0007732 (2017)



Single-Cell Test with TreadStone's Nb-TiO_x-coated Stainless Steel Bipolar Plates.

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TreadStone Technologies, Inc.

University of Hawai'i

Oak Ridge National Laboratory

Nuvera® Fuel Cell System (ARRA)

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Nuvera Fuel Cells, LLC and commercialized in 2016.
- A fast-fueled power option that replaces batteries for Class I, II, and III electric lift trucks.
- Fills up to 350 bar in less than three minutes at standard operating conditions (20 degrees Celsius and 100 kPa).
- Provides constant voltage output with no performance degradation.
- Reduces carbon dioxide emissions attributable to forklift operation by approximately one-third compared with batteries charged with grid-generated electricity.
- Contract Number: DE-EE0000489 (2009)



NUVERA
FUEL CELLS



Nuvera® Fuel Cell Systems for Class I, II, and III forklifts (shown from left to right).

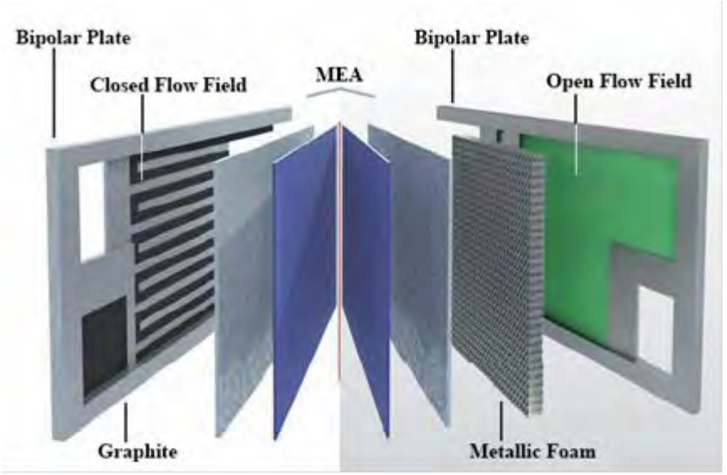
Contact Information:
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Email: gblock@nuvera.com
Phone: (617) 245-7553
Nuvera Fuel Cells, LLC
129 Concord Rd, Building 1
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Website: https://www.nuvera.com

Orion™: Fuel Cell Technology for Hybrid Power Applications

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Nuvera Fuel Cells, Inc. and commercialized in 2013.
- Platform for DOE programs: Cirrus, Aurora, Spire.
- Improves fuel cell performance in applications involving subfreezing conditions, such as automobiles, forklifts, and auxiliary power units.
- Reduces system costs by increasing fuel cell stack power density and improving water purging procedure prior to cold shutdown.
- Achieves rapid start up at -20°C (28s), 50% of rated power.
- Uses less than 3.0 MJ for a complete startup and shutdown cycle.
- Contract Number: DE-FG36-07GO17014 & DE-PS36-06GO9601 (2007)



Nuvera's ORION Fuel Cell (R)Compared to Conventional Fuel Cell Technology

ORION® Gen1





NUVERA
FUEL CELLS

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Phone: (617) 245-7553
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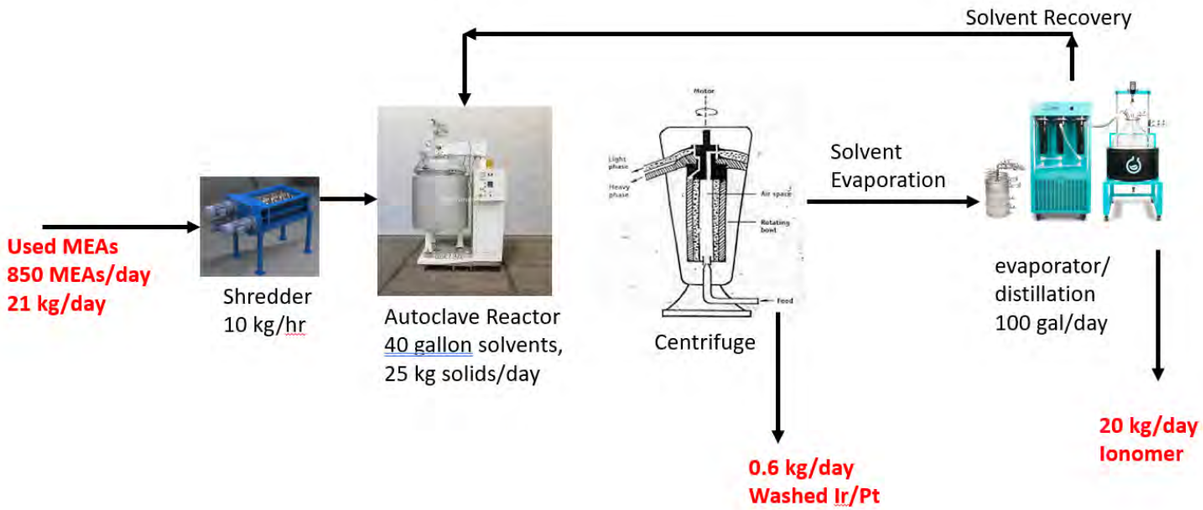
Platinum and Fluoropolymer Recovery from PEM Fuel Cells

Pacific Northwest NATIONAL LABORATORY

FC Commercial

uspto 1 patent

- Developed by Ion Power, Inc., in collaboration with DuPont Fuel Cells and Delaware State University. Commercialized in 2022.
- Process allows remanufacturing of new Membrane Electrode Assemblies (MEAs) made from used Catalytic Coated Membranes (CCMs) extracted from failed and/or end of life fuel cell stacks.
- Process is solvent-based dissolution of ionomers to separate catalysts, recovering ionomer and PGM value. Prevents dangerous hydrofluoric acid fumes during recycling and reduces environmental impact from recycling process.
- Properties of Ion Power's remanufactured membranes are comparable to membranes made with a fresh ionomer.
- Part of a circular economy, with opportunities to bring cost savings and reduce environmental impacts associated with resource collection. An opportunity exists to introduce remanufactured products into commerce.
- Products resulting from research include NAFION™, and AMAZion™ recycled MEAs.
- Contract Number: DE-FC36-03GO13105 (2003)





Ion Power Process for 1 GW Output Potential to Re-Manufacture 222,000 MEAs/year

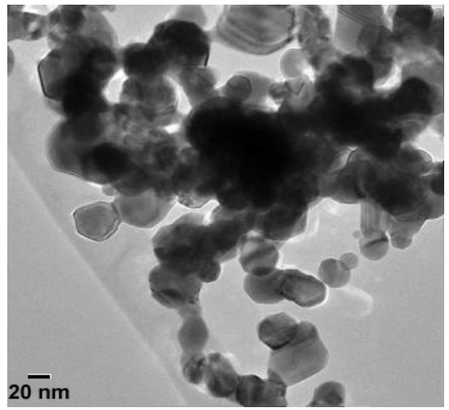
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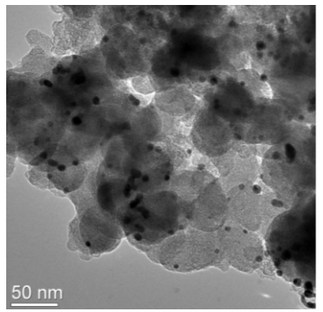
Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports

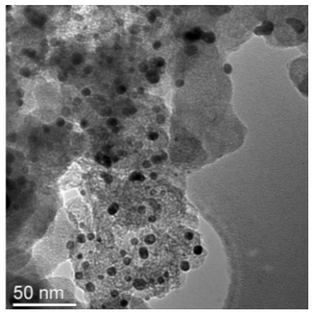
FC
Emerging

uspto
5 patents

- Developed by Brookhaven National Laboratory.
- Continuing testing of prototype electrocatalysts in membrane electrode assemblies and fuel cells.
- Can be used for oxygen reduction, such as in fuel cells and as a heterogeneous catalyst.
- Achieves high activity for the oxygen reduction reaction in fuel cells.
- Reduces Pt loading and resists Pt dissolution under cycling conditions.
- Contract Number: DE-SC0012704 (2015)

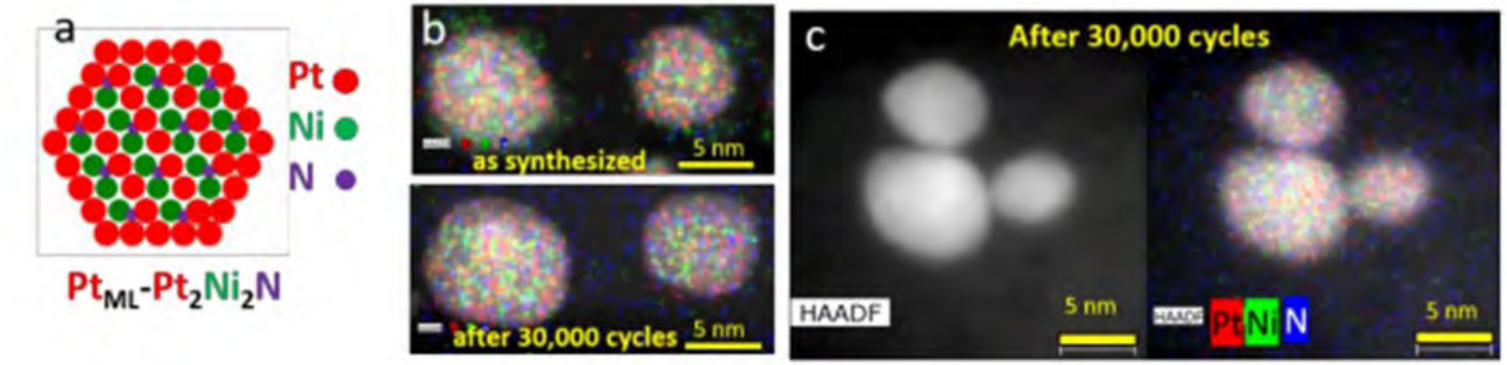






TEM Images of catalyst after 10.000 cycles

BNL's Pt-Coated Palladium Nanostructures



a) 2D schematic model of a Pt monolayer on Ni-enriched bimetallic nitride core;

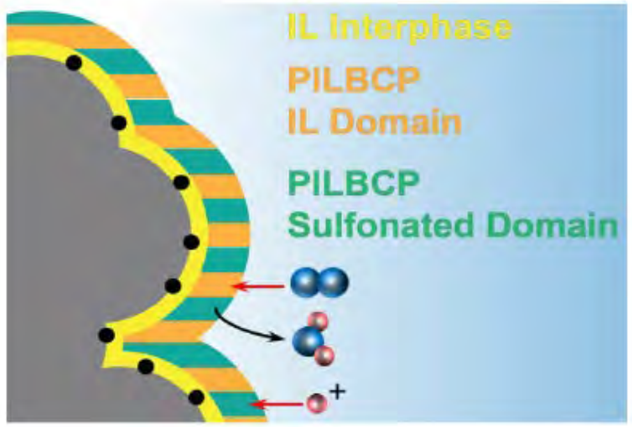
b),c) HAADF and EDS mapping of PtML-Pt2Ni2N particles on VC

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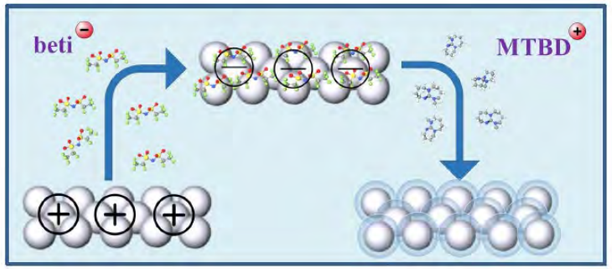
Polymerized Ionic Liquid Block Copolymer/Ionic Liquid Composite Ionomers for High Current Density Performance

FC
Emerging

- Currently being developed by Drexel University in collaboration with Texas A&M University, General Motors, and National Laboratory of the Rockies (NLR).
- Developing a polymerized ionic liquid block co-polymer/ionic liquid (PILBCP/IL) composite ionomer to replace traditional PFSA-based ionomers.
- The PILBCP/IL would facilitate the development of a cathode that meets DOE targets for low and high current density.
- The PILBCP composite ionomer has the potential to be beneficial in many ways, including improved ORR, low humidity proton conduction, limited specific adsorption, kinetic enhancement, and enhancement of HCD performance.
- Contract Number: DE-EE0008434 (2018)



Schematic of the interface between catalyst, IL interphase, and PILBCP ionomer. The PILBCP is composed of an IL domain that optimizes the interaction with the IL interphase and a sulfonated domain that provides fast proton transport and water management.



Alternating potential and electrolyte composition sequentially attracts and condenses ionic liquid (IL) thin films on conductive electrodes.

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Portable Reformed Methanol Fuel Cells

Pacific Northwest NATIONAL LABORATORY

FC *Commercial*

uspto 1 patent

- Developed by Ultracell-LLC, a subsidiary of Bren-Tronics, and commercialized in 2007.
- Has passed military standard testing (MIL-STD-810F Environmental Testing) for extreme conditions.
- The XX55 weighs three kilograms, can be used with different size fuel cartridges or an external fuel source, and offers various voltages (12 to 30 volts).
- Won “Best Soldier System Innovation & Technology” at the Soldier Technology USA 2008 Conference.
- Used for portable power for laptops, communication devices, off-grid battery charging, etc.
- Supplies up to 25 or 50 watts of continuous power with hot swapping of methanol fuel cartridges.
- Can be hybridized with external batteries for high power peaks and with up to 5-gallon fuel tanks for long run time.
- Contract Number: DE-FC36-04GO14215 (2007)



Bren-Tronics
an EnerSys company



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Reduction in Fabrication Costs of Gas Diffusion Layers

FC
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Ballard, owned and operated by AvCarb, LLC, and in use since 2011.
- Improves GDL uniformity and production quality.
- Reduces the fabrication costs and provides a path to reach the 2015 DOE cost target of $5/kW.
- Achieves production of 800-mm-wide, 800-m-long continuous rolls of GDL material.
- Can be used in a variety of fuel cell applications, e.g., materials handling, backup power, and transportation.
- Significantly reduces the fabrication costs and provides a path to reach the 2015 DOE cost target of $5/kW.
- Contract Number: DE-FG36-08GO18051 (2008)





AvCarb®

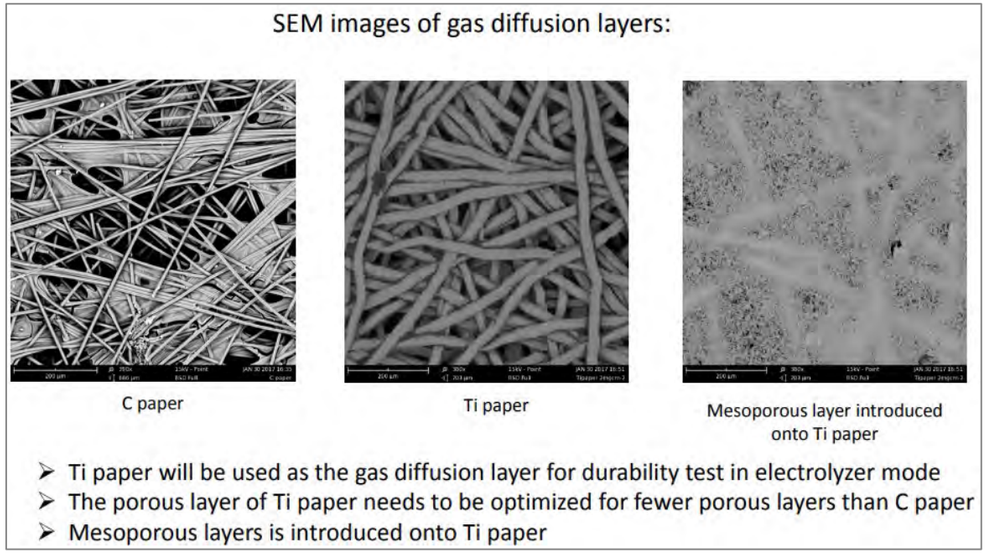
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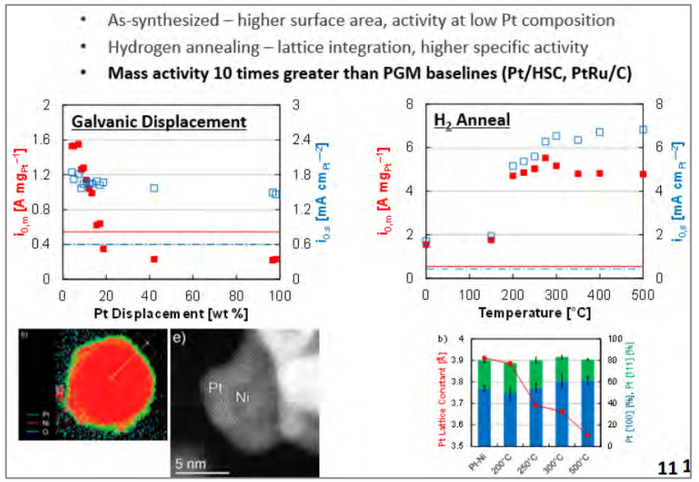
Regenerative Fuel Cell System (SBIR)

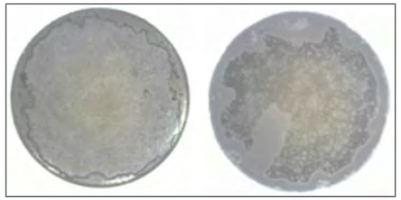
FC
Emerging

uspto 2 patents

- Being developed by pH Matter, LLC, in partnership with Giner, Inc. and National Laboratory of the Rockies (NLR).
- Development of new catalyst materials and membrane electrode assemblies for a regenerative alkaline fuel cell stack.
- Technical targets for energy storage applications include: 1,000 cycles at target current density and above the efficiency targets, as well as 42% efficiency; >250 mA/cm^2 power generation; >50 mA/cm^2 energy storage.
- At the commercial scale, these materials will be an order of magnitude less expensive than electrodes currently used and will not be sensitive to market fluctuations.
- Applications for the technology will include stationary power generation and energy storage.
- Contract Number: DE-SC0013111 (2016)







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Smart Matrix Development for Direct Carbonate Fuel Cell

FC Commercial

uspto 4 patents

- Developed by FuelCell Energy, Inc. (FCE), in partnership with the University of Connecticut and the Illinois Institute of Technology. Commercialized since 2018.
- Developed an innovative electrolyte matrix (dubbed smart matrix) which promise higher power output, longer service life, and cost reduction gains.
- A porous microstructure layered between two electrodes, consisting mainly of ultra-fine sub-micron α-LiAlO2 powders incorporating innovative ceramic additives.
- Enabled increased porosity, improved fine-pore structure, and increased mechanical strength for improved durability and performance.
- Used in FCE commercial MW-scale clean power generation products, including a 2.3 MW Tri-gen production system at the Port of Long Beach, which produces renewable electricity, renewable hydrogen. and usable water.
- Material is also retrofittable into existing FCE field units and increases stack lifetime from 5 years to 7 years.
- Increased market penetration for stationary fuel cell, hydrogen infrastructure and CO_2 capture.
- Contract Number: DE-EE0006606 (2014)



2.3 MW Carbon-Neutral Tri-gen Fuel Cell Plant



2.8 MW Carbonate Fuel Cell Power Plant

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Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells

Pacific Northwest NATIONAL LABORATORY

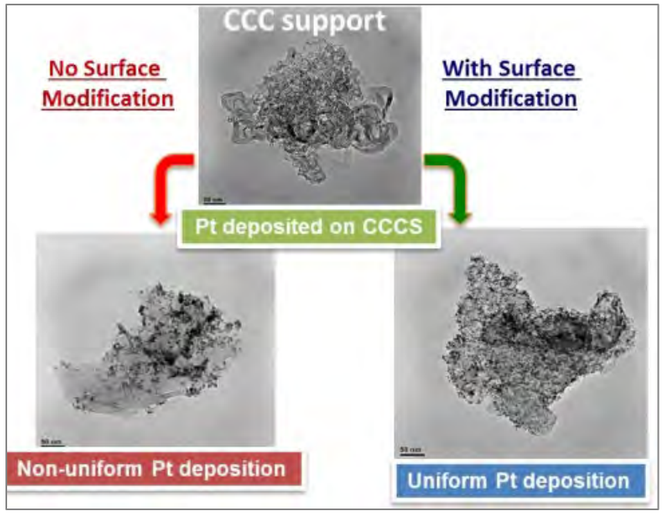
FC Emerging

uspto 2 patents

- Developed by University of South Carolina in collaboration with Yonsei University and Hyundai Motor Company.
- Can be used to reduce fuel cell costs and maintaining or exceeding current fuel cell durability and performance specifications.
- Achieves 11.25 – 1.4 A cm^{-2} current densities under H_2-air operating conditions (80°C, 40% RH, 150 kPabs outlet pressure.)
- Reduces precious metal content.
- Catalyst synthesis process is scalable from laboratory scale to high-volume production.
- Contract Number: DE-FC36-03GO13108 (2003) and DE-EE0000460 (2010)



USC's MEAs in a Prototype Test Fuel Cell Stack (left)
Durability & Performance Evaluation Testing Equipment (right)



UNIVERSITY OF South Carolina

HYUNDAI

YONSEI UNIVERSITY 1885

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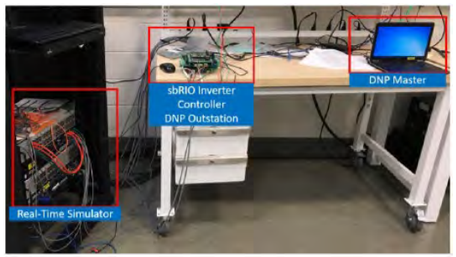
Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids

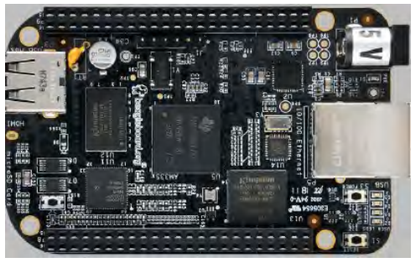
FC
Emerging

- Developed by National Laboratory of the Rockies (NLR) in partnership with SoCalGas and University of California - Irvine.
- Aiming to standardize the sensing, operation, and control of grid-forming fuel cell inverters.
- Successful update to the standards would reduce the cost of installation, operation, and control of grid-forming fuel cell inverters and enable them to functionally replace traditional generation, thus creating a greater market for potential and installation at scale.
- This work aims to reduce the costs for integrating hydrogen assets into the grid.
- Completed alpha version of interoperability codes and power hardware-in-the-loop experiments with grid-forming inverter.
- Contract Number: DE-AC36-08GO28308 (2022)



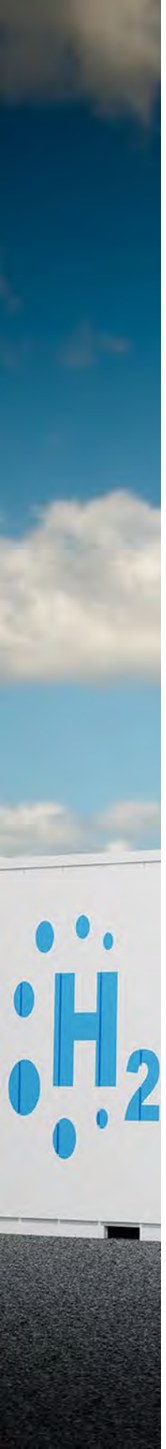
Fuel Cell Inverter (Left) and Fuel Cell Stack Setup (Right)





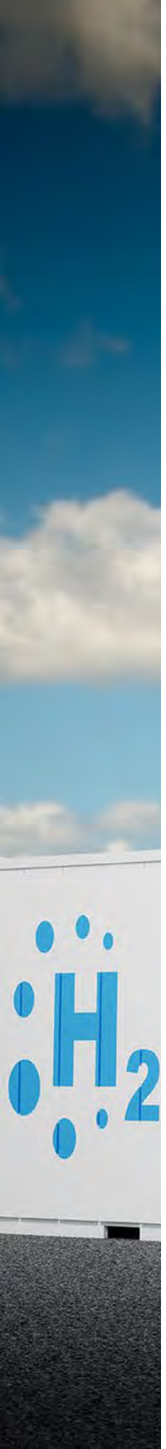
Opal-rt FPGA (Left) and Beaglebone Board (Right) (Controller Hardware Equipment)

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Pre-FY2025 Production Technologies

Technology	Organization
Accelerated Deployment of Fully Integrated Wind-H2 Systems	WETO/NREL
Active Magnetic Regenerative Liquefier	Emerald Energy NW, LLC (Acquired technology from Prometheus Energy Group, Inc.) & Pacific Northwest National Laboratory
Advanced Coatings to Enhance the Durability of SOEC Stacks	Nexceris, LLC
Advanced Manufacturing Processes for Gigawatt Scale Proton Exchange Membrane Water Electrolyzer Oxygen Evolution Reaction Catalysts and Electrodes	3M Company
Composite Membrane for High Temperature Hydrogen Separation (SBIR)	Bettergy Corporation
Demonstration and Framework for H2@Scale in Texas and Beyond	Frontier Energy Inc.
Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply	Constellation Energy Corp. (formerly Exelon Corporation)
Economical Production of Hydrogen Through Development of Novel, High Efficiency Electrocatalysts for Alkaline Membrane Electrolysis (SBIR)	Nel Hydrogen (Formerly Proton Onsite)
Enabling Low Cost PEM Electrolysis at Scale Through Optimization of Transport Components and Electrode Interfaces	Nel Hydrogen
Extremely Durable Concrete Using Methane Decarbonization Nanofiber Co-Products with Hydrogen	University of Colorado-Boulder
High Performance, Low-Cost Hydrogen Generation from Renewable Energy (SBIR)	Nel Hydrogen (Formerly Proton Onsite)
HRS-100™: Hydrogen Recycling System (SBIR)	Skyre, Inc. (formerly Sustainable Innovations, LLC)
Hydrogen Contamination Detection (SBIR)	Skyre, Inc. (formerly Sustainable Innovations, LLC)
Hydrogen Distributed Production System	Air Liquide Process and Construction, Inc.
Hydrogen Energy Systems as a Grid Management Tool	University of Hawaii at Manoa - Hawaii Natural Energy Institute



Pre-FY2025 Production Technologies (continued 2/2)

Technology	Organization
Hydrogen Generation from PEM Electrolysis	Nel Hydrogen (Formerly Proton Onsite)
Hydrogen Production for Refineries (SBIR)	TDA Research, Inc.
Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor	Media and Process Technology, Inc.
Integrated Membrane Anode Assembly & Scale-Up	Plug Power, Inc.
Low-Cost Alloys for Magnetocaloric Refrigeration (SBIR)	General Engineering & Research, LLC
Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage (SBIR)	Nel Hydrogen (Formerly Proton Onsite)
MagnetoCaloric Hydrogen Liquefaction	Pacific Northwest National Laboratory
ME100 Methanol Reforming Hydrogen Generator (SBIR)	REB Research & Consulting
Modular Solid Oxide Electrolysis Cell System for Efficient Hydrogen Production at High Current Density	FuelCell Energy, Inc.
Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass	Oregon State University
Novel Microbial Electrolysis System for Conversion of Biowastes into Low-Cost Renewable Hydrogen	Southern Company Services, Inc.
PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane (SBIR)	Giner, Inc.
Performance and Durability Investigation of Thin, Low Crossover Proton Exchange Membranes for Water Electrolyzers	The Chemours Company FC, LLC
Pure Hydrogen Production through Precious-Metal-Free Membrane Electrolysis of Dirty Water	University of Oregon
Reformer-Electrolyzer-Purifier (REP) for Production of Hydrogen [CO2 Pump]	FuelCell Energy, Inc.
Solid Oxide Electrolysis System Demonstration	FuelCell Energy, Inc.
Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production	Catacel Corporation (Acquired by Johnson Matthey Plc)
Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi (SBIR)	Giner, Inc.
Waterfront Maritime Hydrogen Demonstration Project	Pacific Hydrogen (formerly Hornblowe Energy, LLC)

Accelerated Deployment of Fully Integrated Wind-H2 Systems

PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Collaborative effort between EERE Wind Energy Technologies Office (now Integrated Energy Systems Office (IESO , in DOE's Critical Minerals and Energy Innovation (CMEI). and the National Laboratory of the Rockies (NLR).
- Produces "green" hydrogen by co-locating wind and H2 generation installations to enable 2035 decarbonization goals.
- Leverage offshore, land-based, distributed wind systems in conjunction with systems integration, data modelling and analysis.
- Wind-H2 interconnectivity through modelling (H2OPP tool), analysis (using offshore wind and electrolysis), integrated controls (FlexPower project), and demonstration validation (ARIES electrolyzer).
- Goal is to enable lower electricity, capital, and manufacturing costs at MW-scale.
- 10GW wind generation = 5M Kg/year H2 = 5% U.S. market.
- DE-FOA-0002828 (2022)





National Laboratory of the Rockies

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Active Magnetic Regenerative Liquefier

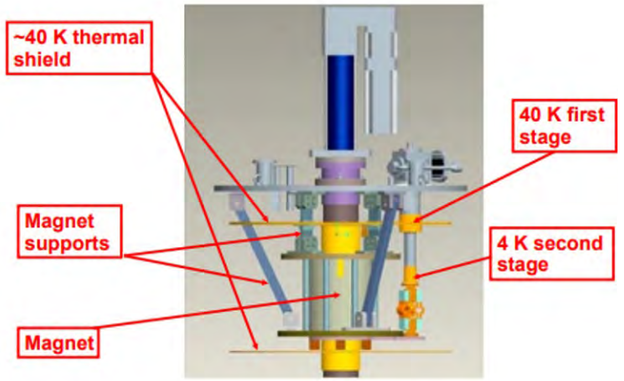
PROD
Emerging

uspto
5 patents

- Developed by Prometheus Energy. In 2011, a new company, Emerald Energy NW, LLC, was formed out of Prometheus Energy and acquired ownership of the technology and IP.
- Can be used to produce liquefied hydrogen (LH_2) for storage, transport, and delivery to multiple end-users among different energy sectors.
- Produces LH_2 with a projected figure of merit of ~0.5.
- Can produce ~25 kg of LH_2 per day at ~101 kPA.
- Starting in 2016, Emerald Energy NW has been working with PNNL to develop a second generation of the device and work towards commercialization.
- Laboratory tests of the second-generation device have been able to liquefy propane and plan to soon be capable of liquefying methane as well.
- Contract Number: DE-FG36-08GO18064.A000 (2008)



Emerald Energy NW's Active Magnetic Regenerative Liquefier



Mechanical Design of the 290 K to 120 K AMRL Prototype as Built

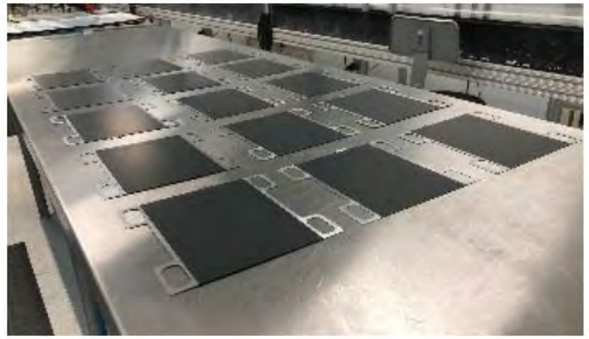
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Advanced Coatings to Enhance the Durability of SOEC Stacks

PROD
Emerging

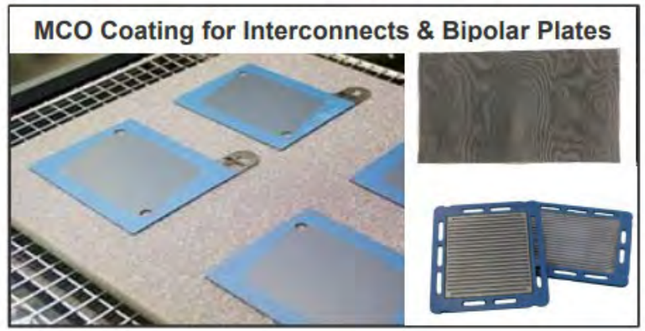
Pacific Northwest
NATIONAL LABORATORY

- Developed by Nexercis in partnership with University of Connecticut, Lawrence Berkeley National Laboratory, and Idaho National Laboratory.
- Develop a comprehensive coating strategy that addresses critical SOEC degradation mechanisms of metal corrosion and chromium evolution.
- Spray-coated 50 interconnects (250 cm^2 active area) with ChromLok™ with less than 10% variation in coating thickness and an overall production yield of 94%.
- Demonstrated stable operation of high temperature electrolysis stack by integrating chromium protective coatings (ChromLok™).
- Initial modeling indicates that interconnects could be coated with ChromLok™ at a cost of less than $3 per kW (or $1 per part) for a plant that produces 6 million coated interconnects per year.
- Contract Number: DE-EE0008834 (2020)









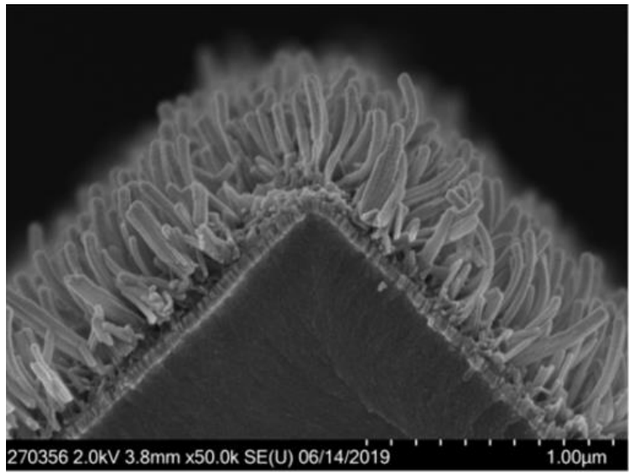
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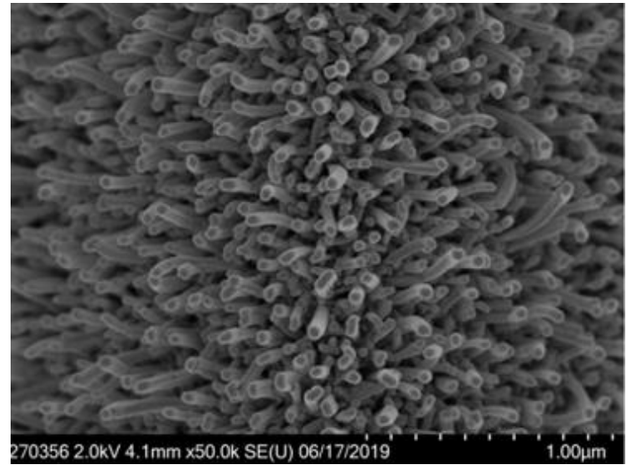
NEXCERIS where energy meets environment
UCONN
BERKELEY LAB Bringing Science Solutions to the World
INL Idaho National Laboratory

Advanced Manufacturing Processes for Gigawatt Scale Proton Exchange Membrane Water Electrolyzer Oxygen Evolution Reaction Catalysts and Electrodes

PROD
Emerging

- Currently being developed by the 3M Company in collaboration with Giner, Plug Power, National Laboratory of the Rockies, and Oak Ridge National Laboratory.
- Developing manufacturing processes for PEM water electrolysis OER catalyst, electrode, and thrifted catalyst coated membranes suitable for GW/year scale.
- New manufacturing processes have the potential for high uniformity, reliability, reproducibility, and quality.
- Enables lower manufacturing costs as well as high-volume capacity.
- Advanced components will meet efficiency, durability, and power requirements set by the DOE.
- Contract Number: DE-EE0009237 (2021)







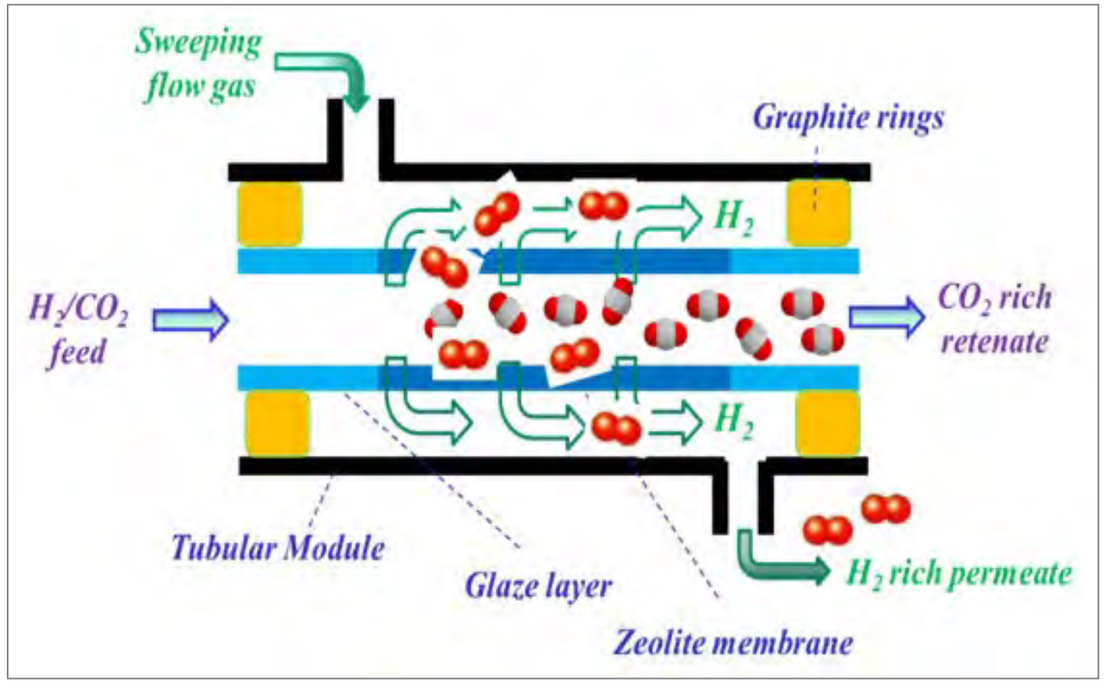
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Composite Membrane for High Temperature Hydrogen Separation (SBIR)

PROD
Emerging

uspto
1 patent

- Developed by Bettergy Corp. with the assistance of the University of Cincinnati.
- Can be used to produce hydrogen when high selectivity and stability are needed.
- Offers high hydrogen separation selectivity (70) at operating temperatures of up to 550 degrees C.
- Can be used as membrane reactor for water-gas-shift reaction and methane reforming reaction.
- Achieves high hydrothermal stability, chemical stability, and durability.
- Provides highly energy efficient separation.
- Lowers upfront cost of hydrogen separation and recovery by replacing PSA and cryogenic systems with a low-cost composite membrane.
- Contract Number: DE-FG02-11ER90172 (2011)



Bettergy's Composite Separation Membrane

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Demonstration and Framework for H2@Scale in Texas and Beyond

PROD
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Frontier Energy Inc., in collaboration with Gas Technology Institute, The University of Texas Austin, and industry partners.
- Demonstration activities began in 2021.
- Achieved minimized hydrogen production costs by using multi-generation sources with a baseload stationary power generation application co-located with hydrogen vehicle fueling.
- Enabling deployment of stationary fuel cell power and hydrogen-fueled vehicles in the Port of Houston/Gulf Coast region.
- Will demonstrate multiple RH2 generation options to enable cost-effective H2 energy solutions at UT Austin.
- Currently developing framework for actionable H2@Scale pilot plans in Texas, Port of Houston, and Gulf Coast region.
- Contract Number: DE-EE0008850 (2019)





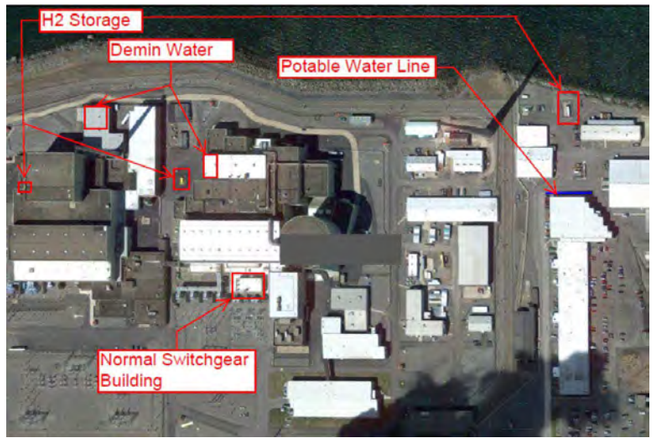
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Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply

PROD
Commercial

- Currently being developed by Constellation Energy Corporation (separated from Exelon Corp. Q1 2022) in collaboration with Idaho National Laboratory, National Laboratory of the Rockies (NLR), and Nel Hydrogen.
- The value of nuclear power plants can be enhanced by utilizing hydrogen production.
- Large-capacity PEM electrolysis systems can act as controllable loads to provide grid support.
- Installing a 1MW Polymer Electrolyte Membrane (PEM) electrolyzer and supporting infrastructure at a Constellation nuclear power plant.
- Established a communication link between the front-end controller (FEC) and NLR's electrolyzer testbed with a 750-kW stack.
- Contract Number: DE-EE0008849 (2019)





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Economical Production of Hydrogen Through Development of Novel, High Efficiency Electrocatalysts for Alkaline Membrane Electrolysis (SBIR)

PROD
Emerging

- Developed by ProtonOnsite (acquired by Nel Hydrogen), with assistance from multiple universities.
- Can be used to reduce the cost of hydrogen production for a variety of end-use applications (e.g., high-purity gas for laboratory instruments or as a storage medium for renewable energy).
- Achieves a levelized hydrogen production cost of $3.46/kg (DOE 2015 target: $3.90/kg; DOE 2020 target: $2.30/kg).
- Achieves an electrolyzer stack energy efficiency of 67% (DOE 2015 target: 76%; DOE 2020 target: 77%).
- Reduces electrolyzer stack costs by using non-noble metal catalysts and stainless-steel flow field plates.
- Enables full utilization of renewable energy sources during off-peak hours (e.g., nighttime wind energy) by storing energy in the form of hydrogen.
- Contract Number: DE-SC0007574 (2012)



Proton's Prototype AEM Electrolysis System

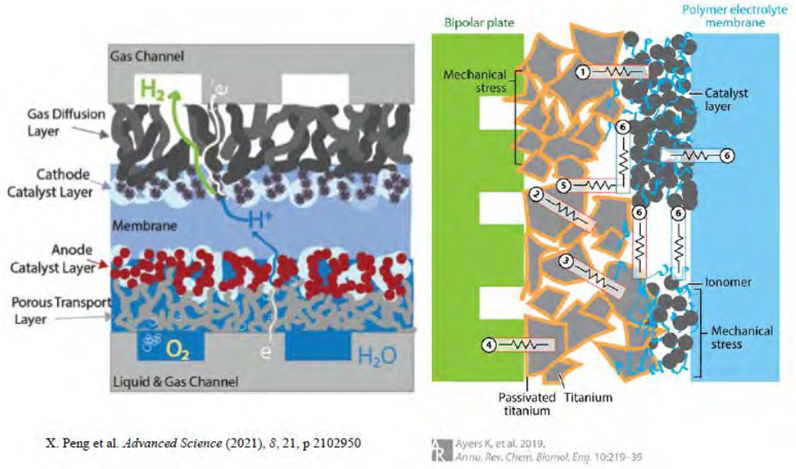
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Enabling Low Cost PEM Electrolysis at Scale Through Optimization of Transport Components and Electrode Interfaces

PROD Emerging

Pacific Northwest NATIONAL LABORATORY

- NEL led collaborators, Oak Ridge National Laboratory (ORNL),the University of California, Irvine (UCI), De Nora and the National Laboratory of the Rockies (NLR), with a goal to optimize the porous transport layer (PTL) designed for an electrolyzer system using minimal precious metal coating and upscaling to a manufacturing level.
- This PTL will enable integration of advanced membrane electrode assemblies with lower cost and higher efficiency, in order to advance PEM electrolyzers towards the DOE cost goals of $2/kg, as compared to the Nel commercial baseline costs.
- ORNL manufactured and characterized titanium wafers and determined focus offset (FO), current and overlap parameters..
- UCI developed and benchmarked a 2D cross-section model and performed overpotential analysis on modeling data to investigate PEMWE losses.
- NLR developed a robust technique to measure Pt thickness using a benchtop XRF apparatus.
- NEL developed testing methods and determined the deposition of surface layers and the impact on conductivity. The data was also used to establish correlation to in-cell testing which will aide in the development of final inspection criteria, and predictive testing to reduce operational testing.
- Contract Number: DE-EE0009238 (2020)

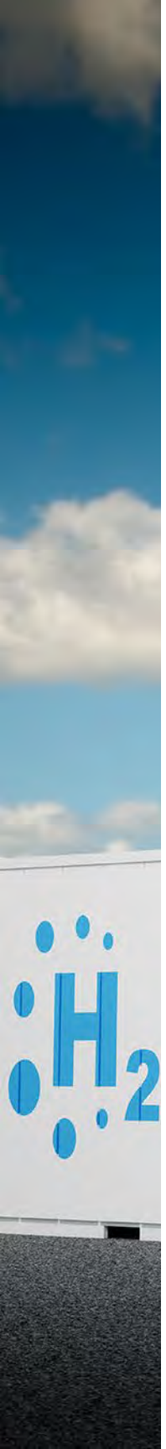


X. Peng et al. *Advanced Science* (2021), *8*, 21, p 2102950

Ayers K, et al. 2019. *Annu. Rev. Chem. Biomol. Eng.* 10:219–39

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nel · DE NORA · UCI University of California, Irvine · National Laboratory of the Rockies · OAK RIDGE National Laboratory

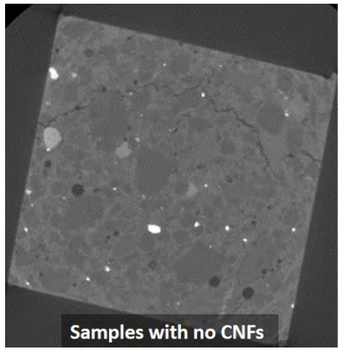


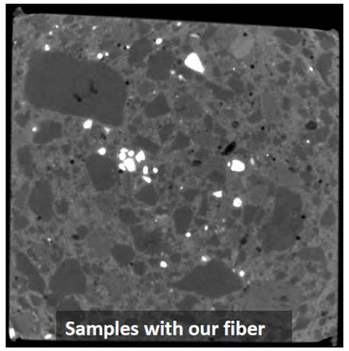
Pacific Northwest NATIONAL LABORATORY

Extremely Durable Concrete Using Methane Decarbonization Nanofiber Co-Products with Hydrogen

PROD *Commercial*

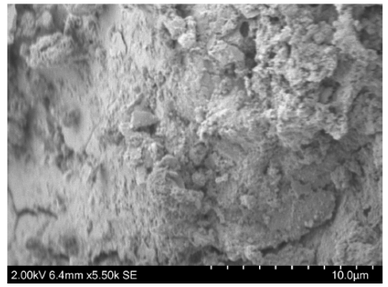
- Developed by University of Colorado-Boulder in collaboration with ForgeNano and the National Ready Mixed Concrete Association.
- This technology has the potential to displace U.S. H2 production by steam methane reforming (SMR) with a low-cost and scalable chemical vapor deposition (CVD) process.
- No CO2 is produced directly from CVD of CH4.
- There is also potential to increase the service life of concrete structures using optimized mixtures.
- Developed extremely durable high-performance concrete by adding the co-product carbon nanofibers (CNFs). Durability should be improved by at least 25% compared with mixtures that contain no CNFs, and chloride permeability should be 25% lower.
- Contract Number: DE-EE0008846 (2020)





Maximum crack sizes ≤100 µm under drying conditions





Well-dispersed CNFs with sacrificial metal catalyst

University of Colorado Boulder

FORGE NANO

NRMCA NATIONAL READY MIXED CONCRETE ASSOCIATION

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High Performance, Low-Cost Hydrogen Generation from Renewable Energy (SBIR)

PROD
Commercial

uspto
1 patent

- Developed by ProtonOnsite (acquired by Nel Hydrogen) and commercialized in 2017.
- Can be used to improve cost and efficiency in hydrogen production applications.
- Reduces fuel cell stack cost by >40% and overall electrolyzer system cost by >20%.
- Reduces catalyst precious metal content by >50%.
- Achieves an H2A model production cost of $3.64/kg at an electricity cost of $0.05/kWh.
- Offers compatibility with high-volume manufacturing by consolidating components and simplifying assembly.
- Contract Number: DE-EE000276 (2009)

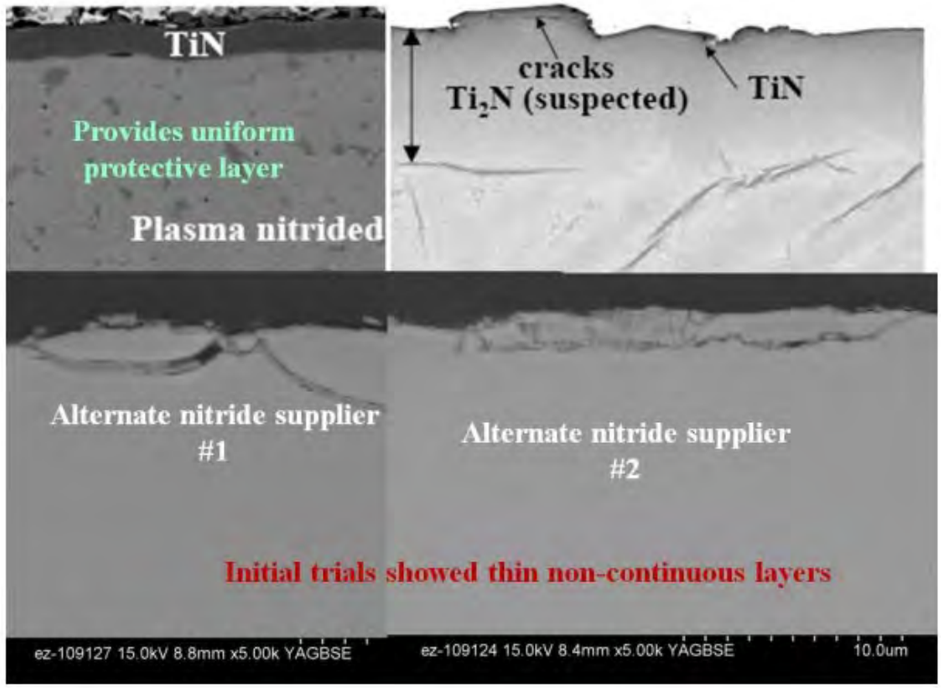
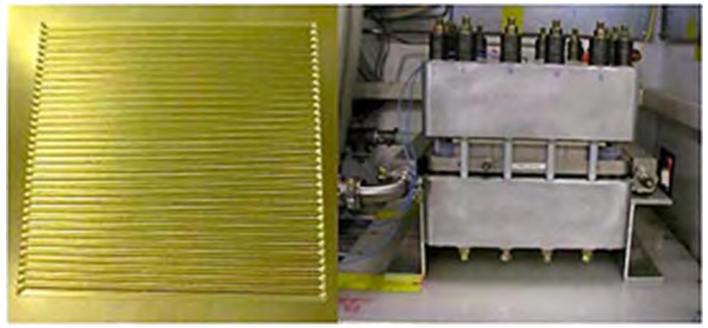


Image of Nitrided Part and Analysis of Composition vs. Layer Depth and Operation



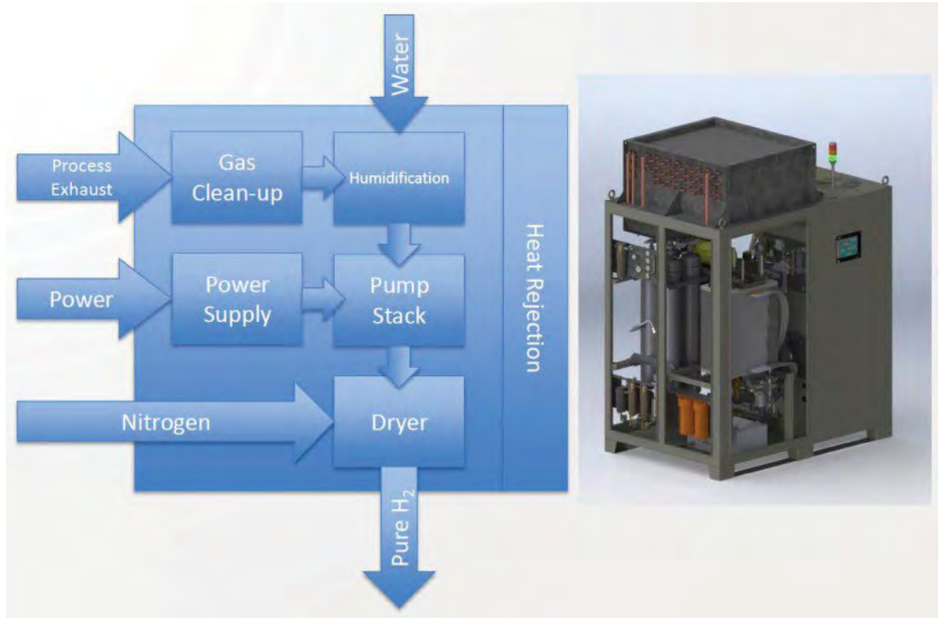
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HRS-100™: Hydrogen Recycling System (SBIR)

PROD
Commercial

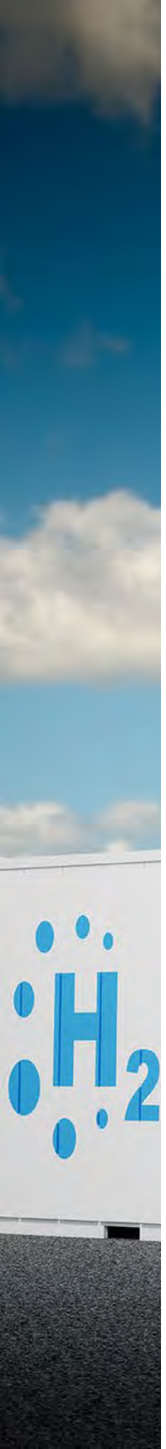
uspto
2 patents

- Developed by H2Pump, LLC, (acquired by Sustainable Innovations, LLC and in 2018 rebranded as Skyre, Inc.), with support from NYSERDA, and commercialized in 2014.
- Used to recover byproduct or unconsumed hydrogen from process exhaust and recycle purified, pressurized hydrogen back to the process feed stream.
- Recycles up to 100 kg H2 per day and can recover up to 90% of the hydrogen present in the exhaust stream.
- Purifies hydrogen to >99.999% (purity depends on exhaust gas stream composition).
- Contract Number: DE-EE0006091 (2013)





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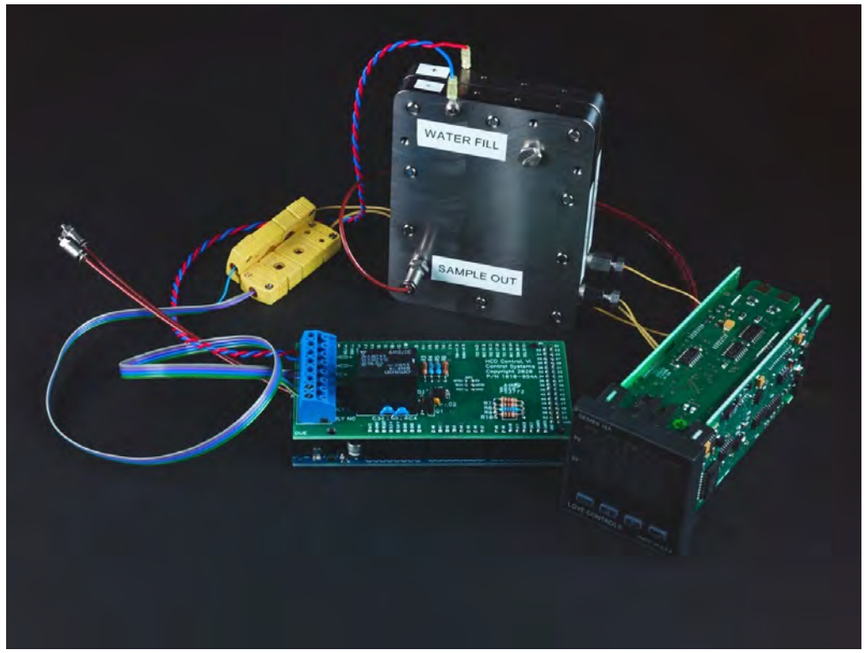


Hydrogen Contamination Detection (SBIR)

PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Being developed by SKYRE, Inc., formerly Sustainable Innovations, LLC, in partnership with LANL and the University of Connecticut.
- Can analyze hydrogen gas samples for contamination on-site, instead of having to take a sample and send them to a laboratory for analysis.
- Can prevent poisoning of fuel cells through quick identification of contaminated hydrogen supply at refueling stations.
- The hydrogen contamination detector's sensor can readily be regenerated after detecting impurities through electrochemical methods.
- Can detect the presence of CO in quantities at or below 200 ppb in less than 5 minutes.
- Contract Number: DE-SC0013228 (2015)



Skyre, Inc.'s and LANL's second generation model of their electrochemical Hydrogen Contamination Detection system.

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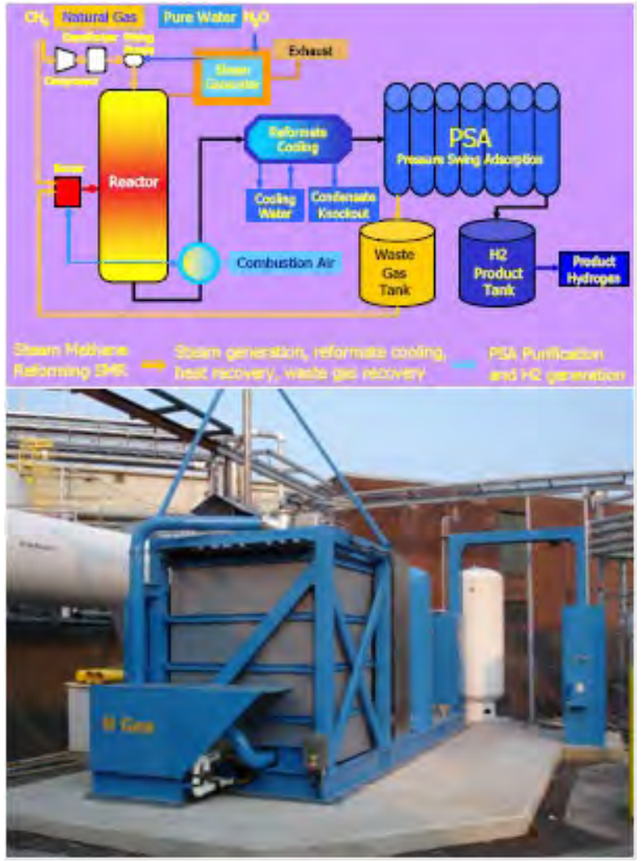
SKYRE Los Alamos NATIONAL LABORATORY UCONN

Hydrogen Distributed Production System

PROD
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed and launched in 2008 by H2Gen Innovations Inc. (acquired by Air Liquide in December of 2009),in partnership with Sud Chemie, Inc.(acquired by Clariant in 2011).
- Available as part of Air Liquide's FLOXAL™ hydrogen gas supply system (HYOS™-R).
- Can be used where high-purity hydrogen is required, including industrial gas, chemical processing, pharmaceuticals, electronics, hydrogen energy, and automotive systems.
- Achieves fuel efficiency of up to 73% high heating value and provides up to 99.999% pure hydrogen.
- Cuts the cost of producing high-purity hydrogen by up to 50% compared with trucking in either liquid or compressed hydrogen.
- Produces 200 or 300 psig hydrogen products and allows remote monitoring without the need for staffing.
- Contract Number: DE-FG36-05GO15026 (2005)



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Hydrogen Energy Systems as a Grid Management Tool

PROD
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by University of Hawaii at Manoa - Hawaii Natural Energy Institute, in partnership with Oak Ridge National Laboratory, Natural Energy Laboratory of Hawaii Authority, and other industry partners.
- Electrolyzers can be utilized to reduce/increase a variable load to maintain total load balance and frequency stability.
- Currently demonstrating and validating the performance, durability, and cost benefits of integrating hydrogen systems with electric power grids.
- Converted buses to FCEV Hybrid Shuttle Buses for demonstrating the advantages of fuel cell vehicles (currently in public service).
- Aiming to supply hydrogen to shuttle buses operated by County of Hawaii Mass Transit Agency (MTA) and Hawaii Volcanoes National Park (HAVO).
- Contract Number: DE-EE0002811 (2010)





Hawaii MTA Fuel Cell Electric Hybrid Shuttle Bus

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

OAK RIDGE
National Laboratory

NELHA

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Hydrogen Generation from PEM Electrolysis

PROD
Commercial

uspto
3 patents

- Developed and marketed by ProtonOnsite (acquired by Nel Hydrogen in Q2 2017).
- First commercialized HOGEN in 1999 (S series) with later series models released in 2004 (H), 2011 (C), 2015 (M), and 2021 (A).
- Over 3,000 HOGEN units have shipped worldwide.
- Responds to demand signals in less than one millisecond and can achieve 100% turndown.
- Generates fuel cell grade hydrogen with no additional clean-up required and no caustic electrolytes to manage or to be disposed.
- Contract Number: DE-FC36-04GO14237 and DE-FC36-04GO13030 (2004)





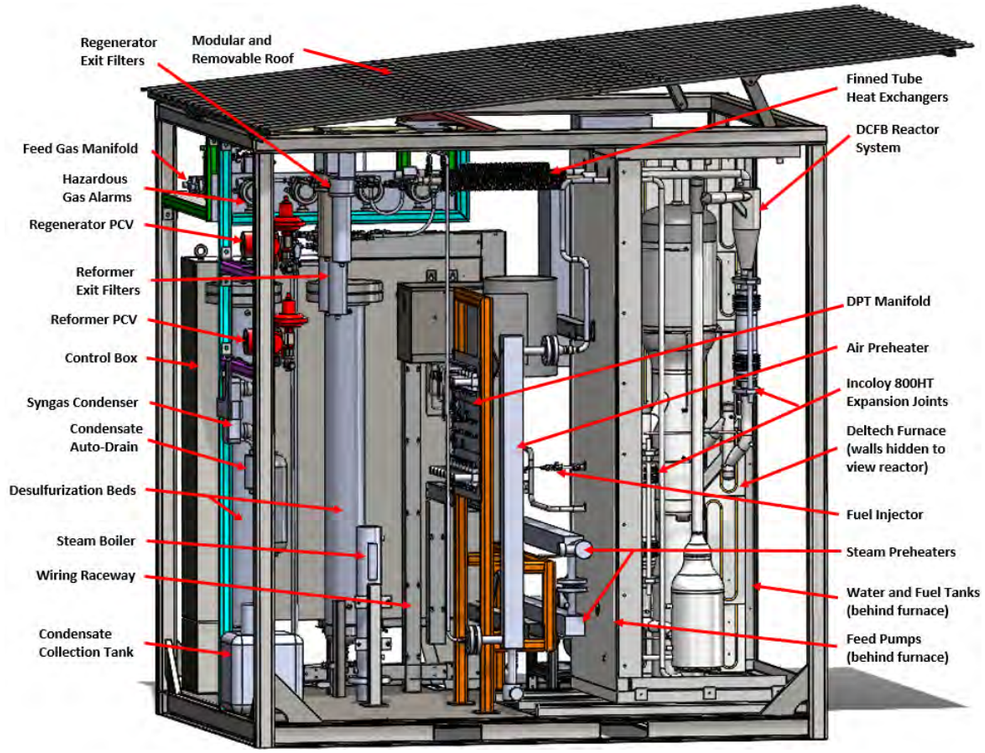
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Hydrogen Production for Refineries (SBIR)

PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Being developed by TDA Research, Inc.
- Successfully tested on a pilot-scale set-up.
- Working with a multinational chemical company to design a process to convert waste oil into H_2.
- Can be used to produce H_2 from heavy feedstocks in refineries as well as oil sands bitumen.
- Enables steam reforming of heavy feedstocks without catalyst deactivation.
- Allows use of proven nickel-based steam reforming catalysts which can be periodically regenerated to burn off any coke/carbonaceous deposits.
- Converts heavy oil, residuum, and bitumen to an H_2-rich syngas.
- Process operates at lower temperatures than steam methane reforming and gasifiers.
- Contract Number: DE-FG02-08ER85135 (2009)





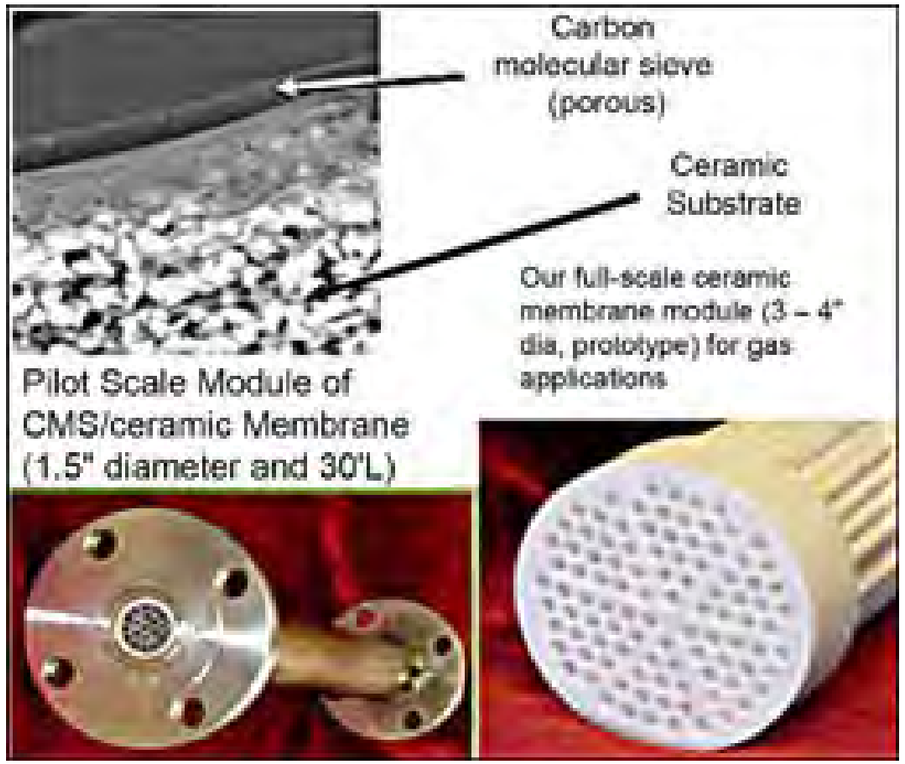
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Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor

PROD
Emerging

uspto
1 patent

- Being developed by Media and Process Technology, Inc., with support from Johnson Matthey, Inc., the University of Southern California, and Chevron Energy Technology Company.
- Can be deployed to produce hydrogen using syngas from coal and hydrogen recovery from sulfur and heavy hydrocarbon containing streams.
- Uses coal syngas and hydrocarbon waste streams to generate hydrogen.
- Achieves production and separation of hydrogen in one step.
- Produces hydrogen from syngas from coal and recovers hydrogen from sulfur and heavy hydrocarbon-containing streams.
- Contract Number: DE-FC26-03NT41852 (2003)



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MEDIA AND PROCESS TECHNOLOGY INC

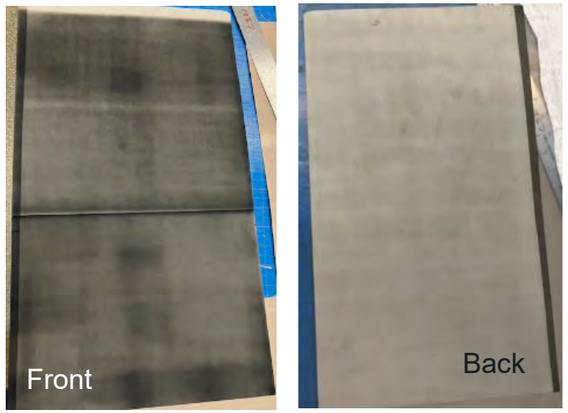
Integrated Membrane Anode Assembly & Scale-Up

PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by Plug Power, Inc., in partnership with the University of Tennessee, Colorado School of Mines, Oak Ridge National Laboratory, and National Laboratory of the Rockies.
- Creating and scaling a manufacturing process to fabricate single-piece anode support structure (SPASS) using conventional materials.
- Developing catalytic and ionomeric coatings applied directly to the surface of the SPASS to form the Integrated Membrane Anode Assembly (IMAA).
- Exploring alternate coating methods to overcome difficulties related to non-uniform wettability and surface roughness, air brush and ultrasonic spray processes demonstrated promise for uniform catalyst coatings with minimal bleed-through.
- Reducing the cost and manufacturing time of two of the most expensive components of a PEM electrolyzer stack: the membrane electrode assembly and the anode support structure.
- Contract Number: DE-EE0009236 (2020)





Example of MW-size IMAA

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Low-Cost Alloys for Magnetocaloric Refrigeration (SBIR)

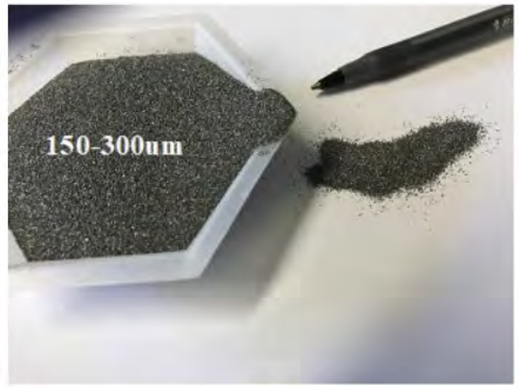
PROD
Commercial

uspto
1 patent

- Developed by General Engineering & Research, LLC (GE&R) in collaboration with the University of California, San Diego, and with additional development funding from the California Energy Commission.
- Initial development started in 2016 and the first small-scale line of commercialized products launched in 2018.
- Developing low cost, high performance magnetocaloric (MCE) alloys for energy efficient magnetic refrigeration technology in hydrogen liquefaction applications.
- MCE material is stable in air and available in various forms (bulk ingot pieces, thin plates, and powder form).
- Peak performance materials can be synthesized for any temperature between 10K and 330K.
- Behaves like elemental Gd – no cracking or hysteresis.
- Reduces MCE material costs by greater than 95%.
- Contract Number: DE-SC0015932 (2016)



Ingot Pieces



150-300um Magnetocaloric Powder

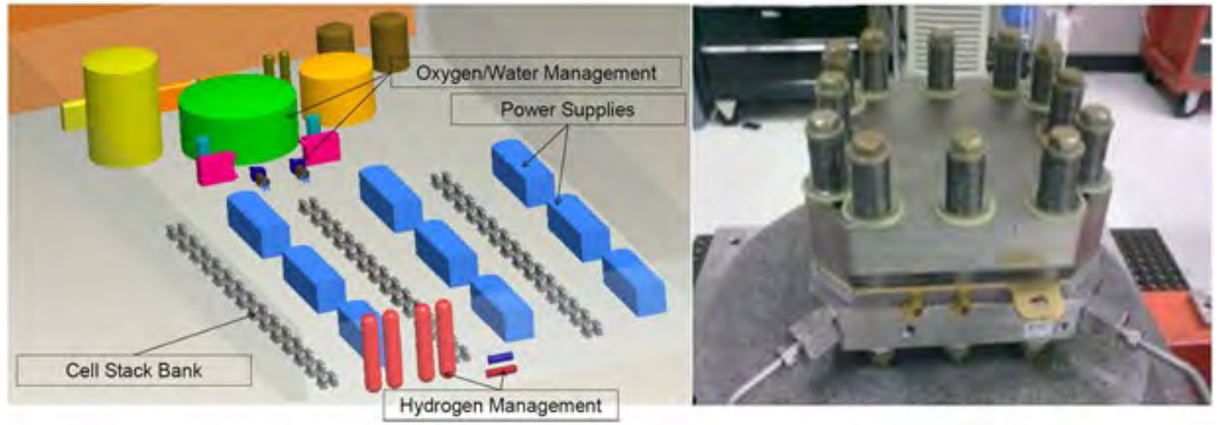
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Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage (SBIR)

PROD
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by ProtonOnsite (acquired by Nel Hydrogen). Commercialized PEM water electrolysis for distributed production of hydrogen in 2017.
- Technology transfer to manufacturing is nearing completion and final design testing is under way.
- Can be used to improve cost and efficiency in hydrogen production applications.
- Reduces catalyst precious metal loading by 50%.
- Reduces ionic resistance by >50% and increases catalyst activity by a factor of 10.
- Achieves a capital cost of $0.49/kg hydrogen in a 50,000 kg/day Greenfield facility.
- Contract Number: DE-SC0001338 (2010)



Proton's 50,000 Kg/day Concept (left) and Advanced Fuel Stack (right)

nel

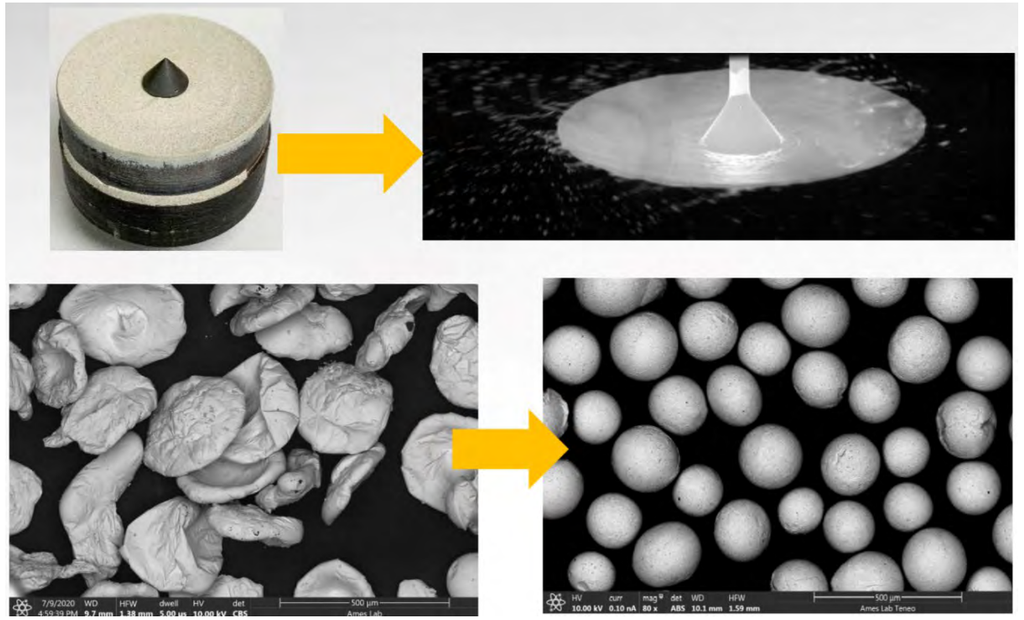
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MagnetoCaloric Hydrogen Liquefaction

PROD
Emerging

uspto
4 patents

- Being developed by Pacific Northwest National Laboratory in collaboration with Raytheon Technologies Research Center, Nikola Corporation, Broadwind Corporation, and Confidential Energy infrastructure company.
- Overall project objective is to develop active magnetic regenerative liquefiers (AMRLs), which are ~50% more efficient than and ~20% less expensive than state-of-the-art liquefiers.
- Improved rotating disk atomizer (RDA) to make reactive powders for sieving and regenerator fabrication.
- Developed innovatively-shaped and positioned high-permeability materials for opposing identical multilayer regenerators. This eliminates magnetic force imbalance in reciprocating MCHL designs.
- Contract Number: DE-AC05-76RL01830 (2015)



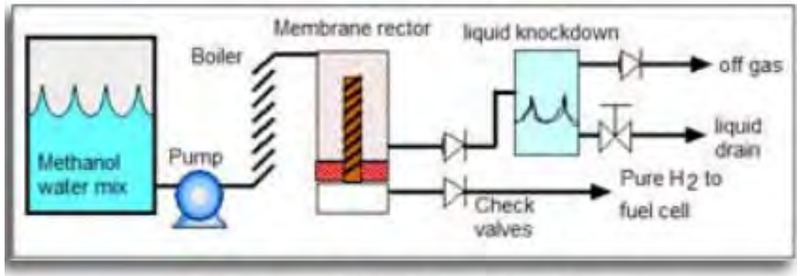
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ME100 Methanol Reforming Hydrogen Generator (SBIR)

PROD
Commercial

- Developed and marketed by REB Research & Consulting to provide improved delivery of high-purity hydrogen. Commercialized in 2002.
- Over 500 hydrogen membrane reactors and various sizes of ME100 hydrogen generator systems installed since 2002.
- Used to make ultrapure hydrogen (99.99995%) from methanol reforming at a cost far lower than bottled gas.
- Delivers continuous hydrogen output at a variable rate of up to 10 kg per day and at pressures up to 40 psig.
- Provides quiet, reliable hydrogen generation that can be developed in remote and mobile applications where size and weight are a premium.
- Contract Number: DE-FG02-97ER82467 (1997)





Schematic of ME100 Reactor and Flows

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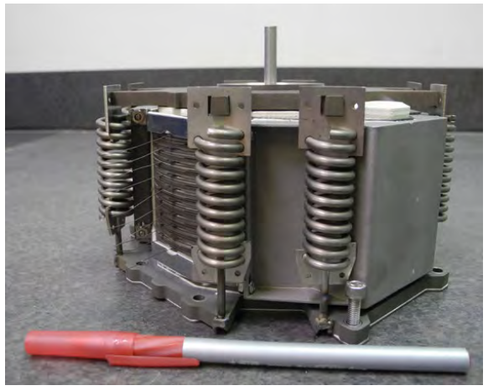
Modular Solid Oxide Electrolysis Cell System for Efficient Hydrogen Production at High Current Density

PROD
Emerging

- Currently being developed by FuelCell Energy, Inc., in collaboration with Versa Power Systems acquired by FuelCell Energy, DOE/FE, and the National Technology Laboratory.
- Demonstrating the potential of Solid Oxide Electrolysis Cell (SOEC) systems to produce hydrogen at a cost of <$2/kg H_2, disregarding delivery, compression, storage, and dispensing.
- Aiming to reduce the cost of electricity usage for electrolysis by improving SOEC performance to achieve >95% stack electrical efficiency based on lower heating value (LHV) of H_2 (>90% system electrical efficiency).
- Developing SOEC system design configuration to reach >75% overall efficiency.
- Contract Number: DE-EE0007646 (2016)





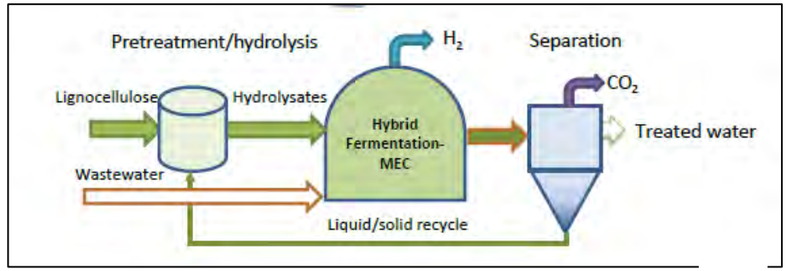


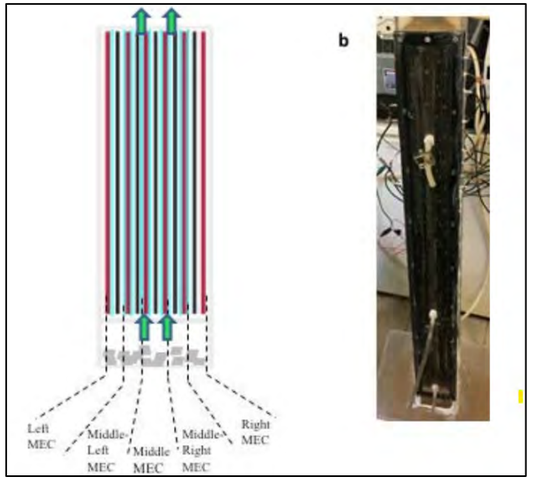
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Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass

PROD
Emerging

- Oregon State University working with partners Pacific Northwest National Laboratory (PNNL) and Oregon Nanoscience and Microtechnologies Institute (ONAMI) to develop a hybrid fermentation and microbial electrolysis cell (F-MEC) system that can be integrated with lignocellulose pretreatment/hydrolysis or wastewater treatment processes for H2 production that is green and has the potential to cost less than $2/kg.
- Identified microbial communities that are capable of utilizing all major components in lignocellulosic biomass hydrolysates and food/beverage wastewater and their fermentative products for H2 production
- Developed an immobilization method that can increase the fermentative bacteria density in reactors with stable H2 production
- Discovered a low-cost chemical that can effectively inhibit methanogens and reduce the H2 uptake in MECs.
- Synthesized MoP HER catalysts with high activity (comparable to Pt) and high durability.
- Contract Number: DE-EE0007269 (2016)





Left: Diagram of reactor electrode configurations with recirculation inlets and outlets—green arrows; anode set—red; cathode—black; separator—blue; and fermentative beads in bottom—gray.
Right: Photo of the F-MEC reactor.

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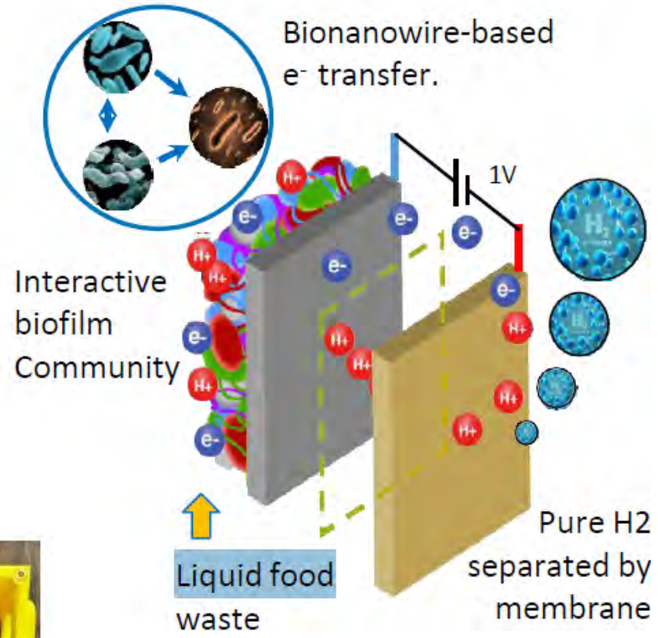
Novel Microbial Electrolysis System for Conversion of Biowastes into Low-Cost Renewable Hydrogen

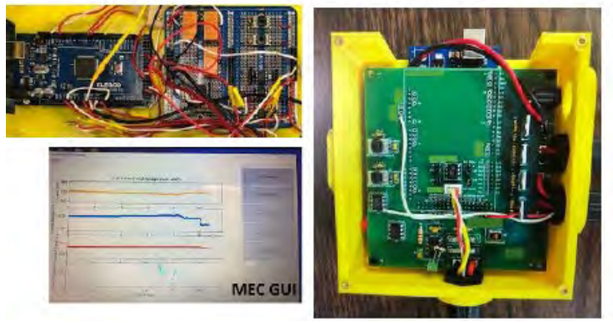
PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by Southern Company Services, Inc., in partnership with Electro-Active Technologies, Inc., and T2M Global.
- Identify the critical scale-up parameters of microbial electrolysis (MEC) stack and demonstrate the stability and durability of MEC technology.
- Deploy pilot system with industrial partners to demonstrate two-pronged operational benefits of abating waste management costs while producing renewable hydrogen onsite for use in fuel cells.
- Developed conditions to transition and maintain high hydrogen production after reaching target growth.
- Demonstrated that hydrogen production and performance metrics (bioprocess stability) are stable over 10+ weeks.
- Plan to develop a system prototype for demonstration purposes in the next 6-12 months.
- Contract Number: DE-EE0009624 (2022)







EAT Process Control System

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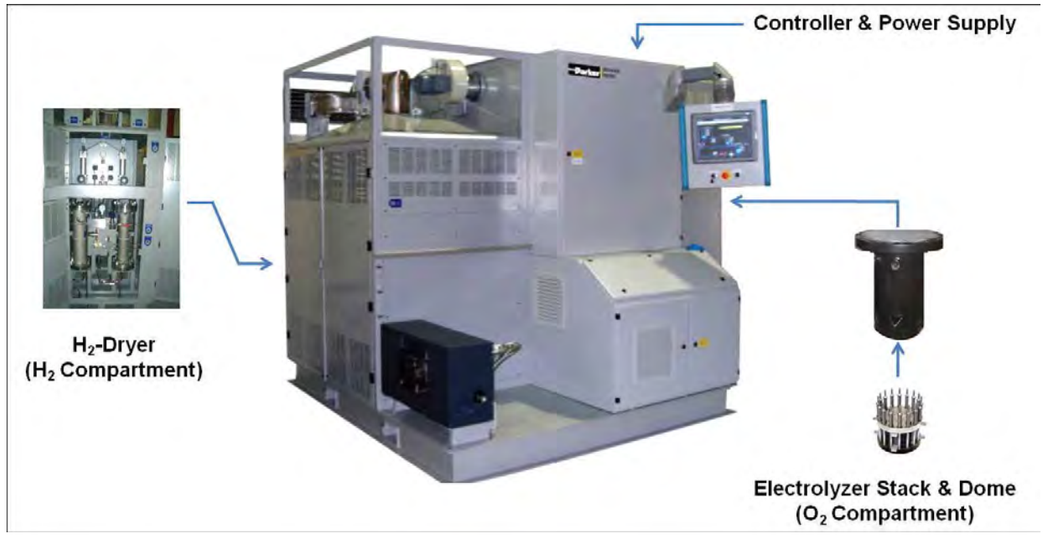
Southern Company electro-active technologies T2M Global

PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane (SBIR)

PROD
Commercial

Pacific Northwest
NATIONAL LABORATORY

- The electrolyzer was developed by Giner Electrochemical Systems, (GES) LLC., which was a subsidiary of Giner Inc., and in 2005 GES was acquired by Ener1).
- The product was commercialized in 2011.
- Electrolyzer stacks and full electrolyzer systems sold domestically.
- Produces 0.5 (or 8.0?) kg-H2/hr. at an operating pressure of 350 psig.
- Reduces electrolyzer stack capital cost by using low-cost materials.
- Uses components with long operating lifetimes (estimated at 55,000 hours for the DSM and >60,000 hours for the carbon/titanium cell separators).
- Contract Number: DE-FG36-08GO18065 (2008)





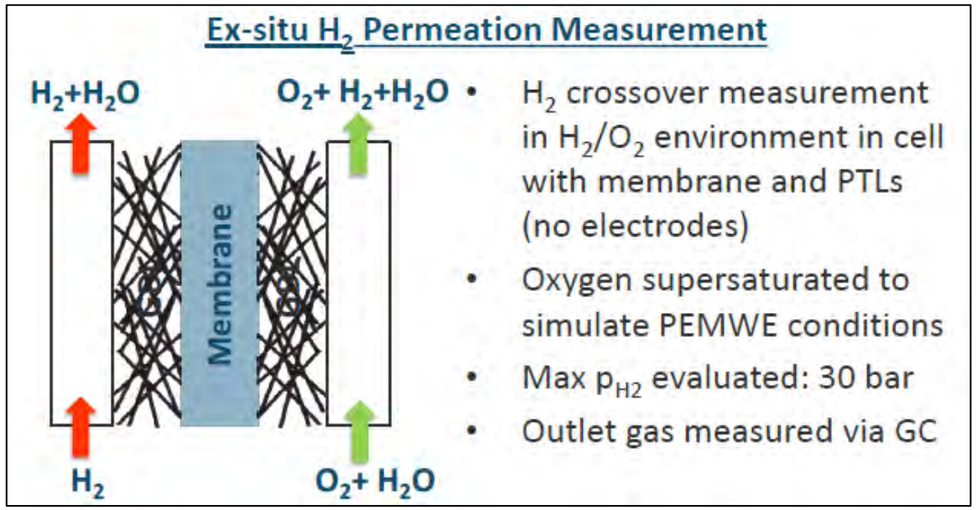
GINERLABS

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Giner Electrochemical Systems, LLC.
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Website: http://www.ginerinc.com

Performance and Durability Investigation of Thin, Low Crossover Proton Exchange Membranes for Water Electrolyzers

PROD Emerging

- Chemours has produced thin, reinforced membranes incorporating gas recombination catalysts (GRC) and radical scavenger additives using roll-to-roll equipment at a pilot scale to enhance the durability of Proton Exchange Membrane Water Electrolyzer (PEMWE) systems.
- PEMWE technology is essential for achieving the Hydrogen Shot initiative's target of hydrogen production costs at or below $1 per kilogram.
- These membranes were provided to project collaborators, including Los Alamos National Laboratory (LANL), National Laboratory of the Rockies (NLR), and Lawrence Berkeley National Laboratory (LBNL), for testing and modeling purposes.
- LANL has developed new capabilities for testing, NLR has leveraged the in-operando gas crossover testing platform (0-30 bar) to differentiate GRC candidates and understand durability effects and LBNL's modeling has established a platform to assist with design of prototype membranes.
- Contract Number: DE-EE0008836 (2019



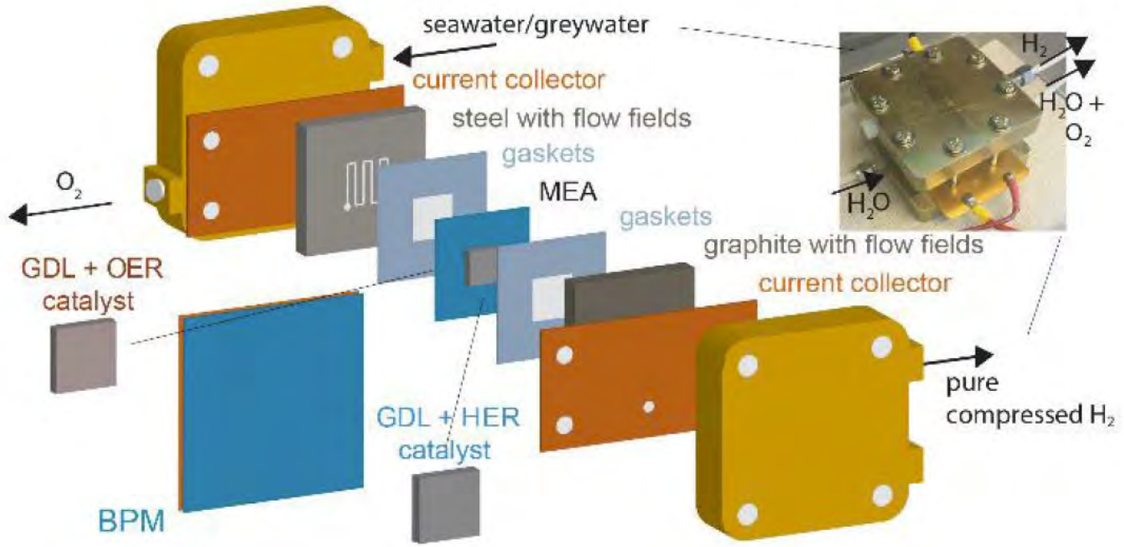
Ex-situ crossover experiment successfully adapted to 30 bar differential pressure and observed a modest reduction in hydrogen permeation.

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Pure Hydrogen Production through Precious-Metal-Free Membrane Electrolysis of Dirty Water

PROD
Emerging

- Developed by University of Oregon in partnership with National Laboratory of the Rockies, Lawerence Berkeley National Laboratory, and Sandia National Laboratory and in collaboration with industry and academic collaborators.
- Develop a technical understanding of alkaline and bipolar membrane electrolyzers' performance degradation in pure and dirty water.
- Engineer impurity tolerant systems as to increase system longevity and allow less-stringent input water purity, leading to lower system costs.
- Demonstrated tap-water-fed AEM electrolyzer performance with 1 A cm^{-2} at applied voltages of < 2.05 V and with a start-to-end degradation of ~2 mV/hr.
- Revealed ionomer oxidation as the largest limiting degradation mechanism for pure water AEM electrolyzers.
- Contract Number: DE-EE0008841 (2014)



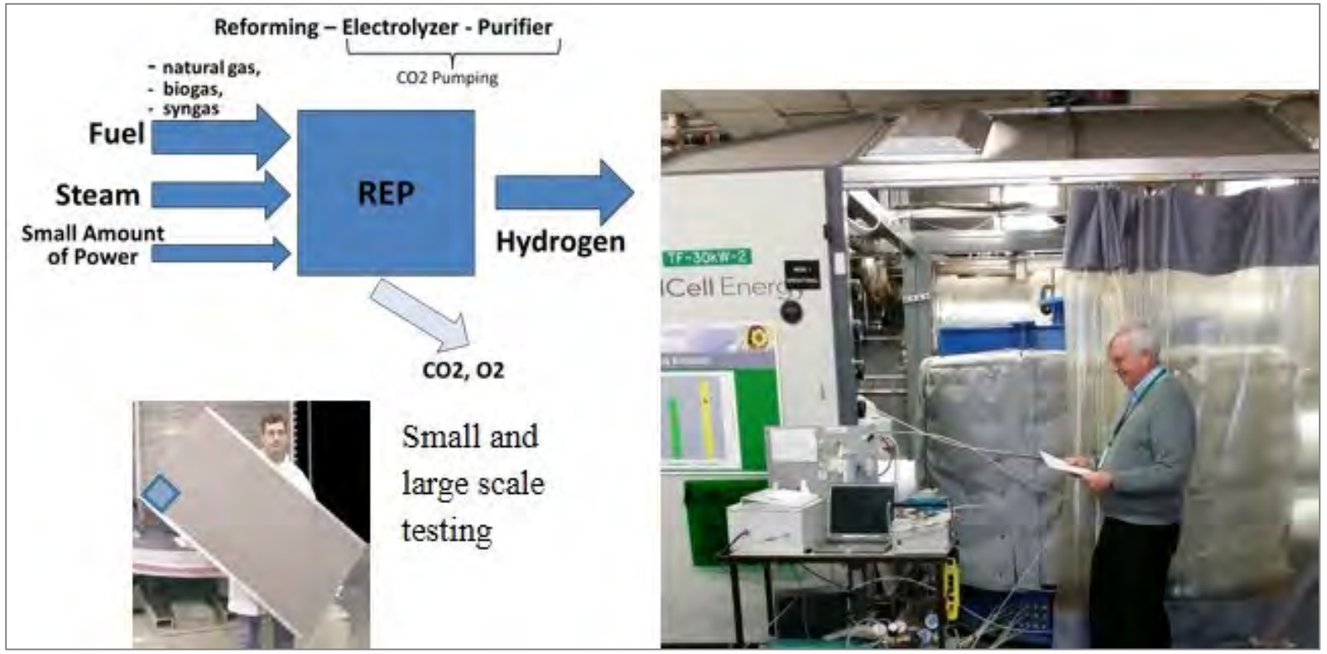
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Reformer-Electrolyzer-Purifier (REP) for Production of Hydrogen [CO2 Pump]

PROD
Emerging

uspto
10 patents

- Being developed by FuelCell Energy, Inc.
- Can be used to produce hydrogen from various feedstocks, including natural gas, methane, and biogas.
- Provides durable stack life with a range of 3 – 5 years.
- Achieves hydrogen production cost aligned with HFTO long-term cost targets.
- Provides small footprint on-site H_2 generation.
- Reduces H_2 delivery cost by lowering system cost for on-site distributed hydrogen production and by using heat, if available, to increase operating efficiency.
- Reduces CO2 emissions up to 50% lower than a typical SMR using low-power, high-temperature electrolysis combined with near 100% conversion of methane and CO to hydrogen.
- Contract Number: DE-EE0006669 (2014)



FuelCell Energy's Large Scale REP Test
System produced over 100 kg/d using DFC® cell components

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Solid Oxide Electrolysis System Demonstration

PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Currently being developed by FuelCell Energy, Inc., in partnership with Versa Power Systems (acquired by WLF Energy GmbH in 2026) and Idaho National Laboratory.
- Demonstrating the benefits of integration of solid oxide steam electrolysis with nuclear plants.
- Benefits of this technology include a high-efficiency and low-cost alternative for production of hydrogen utilizing electricity and waste heat.
- Developing system operational and control strategies specific to the nuclear industry.
- Contract Number: DE-EE0009290 (2020)







FuelCell Energy

WLF energy

INL Idaho National Laboratory

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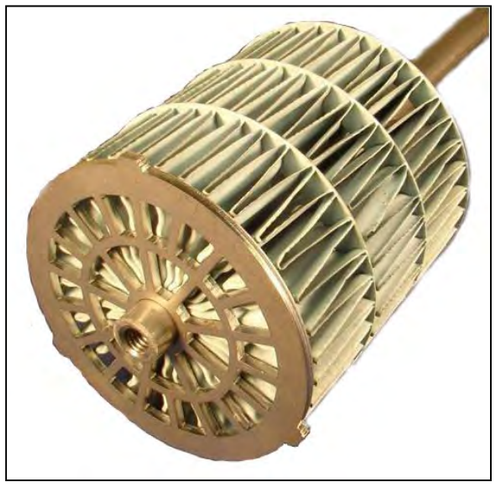
Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production

PROD
Commercial

uspto
9 patents

- Developed and Commercialized by Catacel Corporation (acquired by Johnson Matthey).
- Replaces the loose ceramic catalyst media that is currently used in steam-methane reformers.
- Improves heat transfer and durability compared with conventional ceramic media.
- Eliminates periodic replacement of deteriorated ceramic shapes.
- Retrofits into existing plant equipment without modification.
- Contract Number: DE-FC36-04GO14215 (2004)





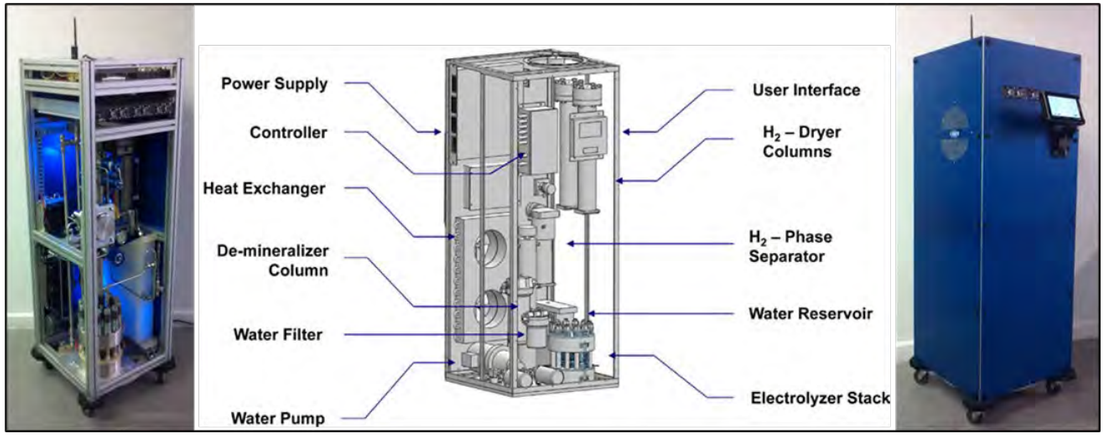
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Utilized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi (SBIR)

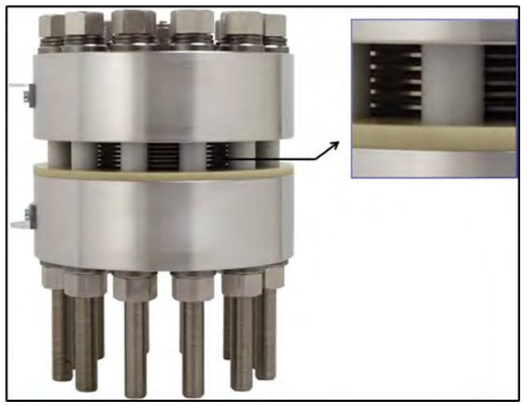
PROD
Commercial

uspto
1 patent

- Developed by Giner, Inc. and commercialized in 2015.
- Developed a low-cost electrolyzer stack and balance of plant (BOP) components.
- Can be used as a hydrogen refueling device for residential and a wide range of other applications that require pressurized hydrogen
- Produces hydrogen at pressures of up to 6,000 psi.
- Provides remote system monitoring and operation via Bluetooth™ connection up to 30 feet away.
- Provides hydrogen at a cost per kilogram that is approaching DOE program 2020 targets of less than $4.00/kg.
- Contract Number: DE-FG02-06ER84537 (2006 Phase I),
  DE-FG02-09ER85404 (2009 Phase I & II) and
  DE-SC0001486 (2010)



Giner's Prototype Electrolyzer (Home Refueling Appliance) System



Giner's High-Pressure Electrolyzer Stack with Reinforced Cell Frames

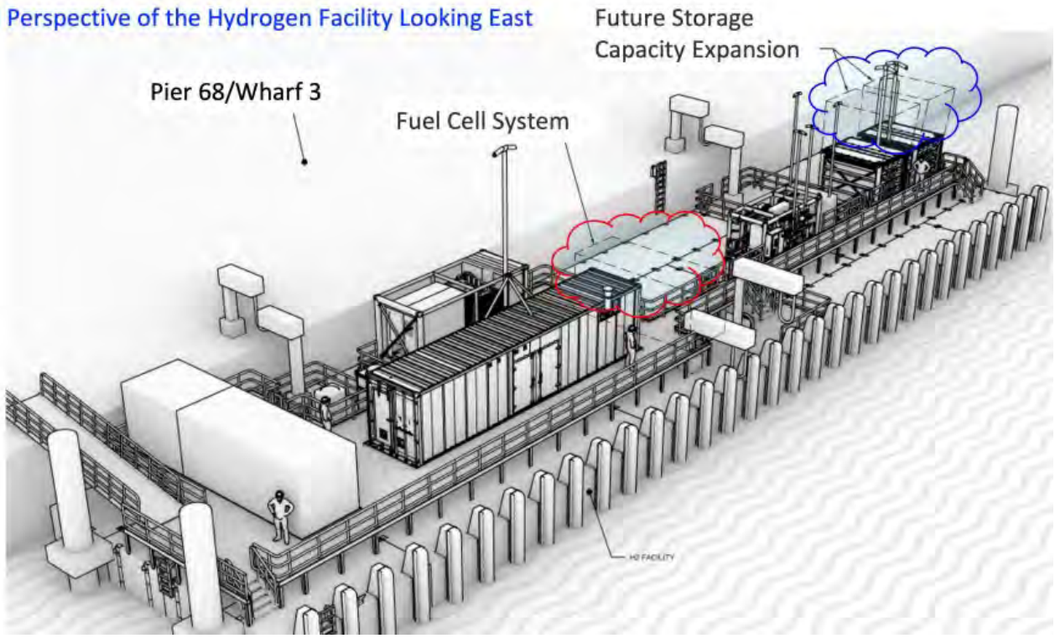
Contact Information:
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Waterfront Maritime Hydrogen Demonstration Project

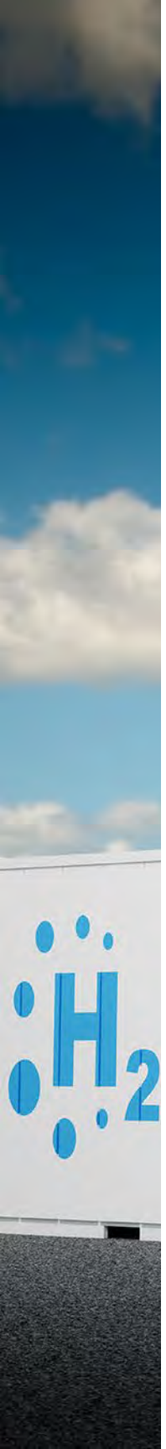
PROD
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by Pacific Hydrogen, LLC. (formerly Hornblower Energy, LLC.), in collaboration with Air Liquide, Sandia National Laboratories, BayoTech Inc., Nel Hydrogen US, Glosten, Moffatt & Nichol, and the Port of San Francisco.
- Demonstrate bunkering of fuel-cell vessels with hydrogen produced in a maritime context, establishing a solid technical foundation for maritime H_2 production, compression, storage, and over-the-water fueling.
- Develop procedures and safety codes & standards for safe over-the-water transportation of hydrogen to vessels and landside trailers.
- Establish a refueller and H_2 generating system that produces 500 kg of H_2 per day.
- Design and work concept has been proved out, permitting has been completed, and coastguard approval has been granted.
- Seeking further funding opportunities and partners.
- Contract Number: DE-EE0009251 (2021)



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Pre-FY2025 Safety Technologies

Technology	Organization
DetecTape™: Early Warning Visual Hydrogen Leak Detector	Element One, Inc. w/National Renewable Energy Laboratory
Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors (SBIR)	InnoSense, LLC
Enabling Hydrogen Infrastructure Through Science-Based Codes and Standards	Sandia National Laboratories
Fuel Cell & Hydrogen Energy Association Codes and Standards Support	Fuel Cell & Hydrogen Energy Association (FCHEA)
Hydrogen Gas Sensing System	Intelligent Optical Systems, Inc.
Hydrogen Safety Outreach to Expedite H2 Fueling and Energy Project Deployment and Promote Public Acceptance for Zero Emission Vehicles and Reliable Distributed Power Generation	Pacific Northwest National Laboratory
Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources	Pacific Northwest National Laboratory
Hydrogen Safety Sensor for Advanced Energy Applications	Nexceris LLC (Formerly NexTech Materials, Ltd.)
Hydrogen Station Equipment Performance (HyStEP) Device	Sandia National Laboratories
Intellipigment™: Visible Hydrogen Gas Leak Detection Material	HySense Technology LLC (UCFL Start Up)
Low-Cost Hydrogen Sensor for Transportation Safety	Makel Engineering, Inc.
MEMS Hydrogen Sensor for Leak Detection	Oak Ridge National Laboratory
R&D for Safety, Codes and Standards: Materials and Components Compatibility	Sandia National Laboratories
Robust and Reliable Hydrogen Leak Detection and Warning Systems (SBIR)	SPEC Sensors, LLC

DetecTape™: Early Warning Visual Hydrogen Leak Detector

Pacific Northwest NATIONAL LABORATORY

SFTY Commercial

uspto 10 patents

- Developed by Element One in collaboration with NLR and commercialized in 2015 through Midsun Specialty Products, Inc.
- Can detect hydrogen gas leaks in fuel cell, transmission, storage, and generation facilities.
- Indicating pigments rely on the catalyzed reaction between a thin film or nano-particles of a transition metal oxide and hydrogen; the joint technology is patent pending.
- Provides passive, visual location detection of hydrogen leaks as low as 400 ppm.
- Provides quick response to the presence of hydrogen gas, changing color in less than 20 seconds at 100% gaseous H_2.
- Provides 1 year shelf-life and a service life of several years.
- Prevents plant closures and shutdowns by enabling quick and safe detection and identification of hydrogen gas leaks.
- Contract Number: DE-AC36-08GO28308 (2004)



Element One's DetecTape™ Chemo-chromic Hydrogen Leak Detector Product (Left)
DetecTape™ Color Change Before and After Exposure to Hydrogen Leak (Right)

MSP MIDSUN SPECIALTY PRODUCTS

ELEMENT ONE

National Laboratory of the Rockies

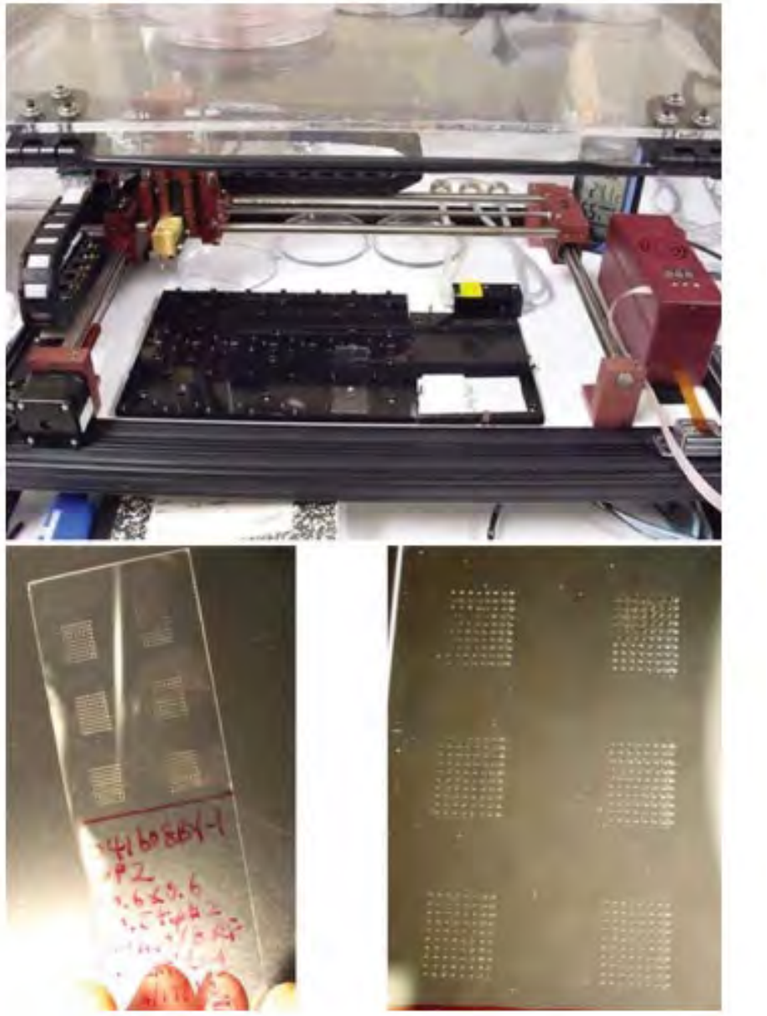
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Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors (SBIR)

SFTY
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Being developed by InnoSense, LLC, with DOE funding in the form of SBIR grants.
- Can be used to produce inexpensive hydrogen sensors for hydrogen storage facilities and other applications using hydrogen.
- Produces hydrogen sensors with improved consistency batch to batch.
- Reduces manual assembly costs by using pin-printing technology.
- Allows sensors to be mass-produced by using a high-volume fabrication process.
- Contract Number: DE-FG02-06ER84541 (2006)



InnoSense's Sensor Fabrication Process Using Pin-Printing Techniques

InnoSense
Technologies for Tomorrow

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Enabling Hydrogen Infrastructure Through Science-Based Codes and Standards

SFTY
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Sandia National Laboratory in collaboration with FirstElement Fuel, Inc., Linde, and HySafe.
- International collaboration developing harmonized standards e.g., opensource HyRAM tool, numerous organizations adopting FPA2 code (2023 edition).
- Fundamental science and engineering are utilized to assess risks associated with the growth of hydrogen infrastructure, as well as improve the basics of codes and standards.
- ALDEA, a calculation approach to evaluating risk, addresses functional limitations of HyRAM, a different method of risk assessment.
- Has better informed future hazard and risk assessments for hydrogen/natural gas blends.
- Contract Number: AC04-94AL85000 (2003)



Figure 2-13. Jet Flame in Test Images- Test 1 (22% hydrogen/natural gas blend) on Left, Test 2 (natural gas only) on Right (from [17])

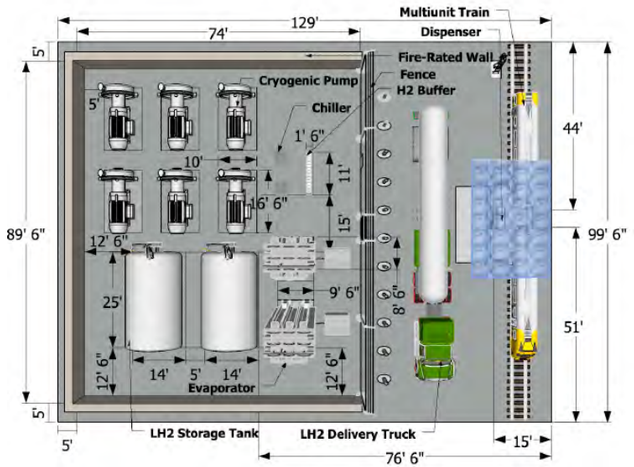


Figure 2-7 Multiple Unit Train Refueling Facility Direct-Fill Cryopump 15-Minute Fill Time Design Layout

Sandia National Laboratories

TRUE ZERO
A FirstElement Fuel brand

Linde

HySafe

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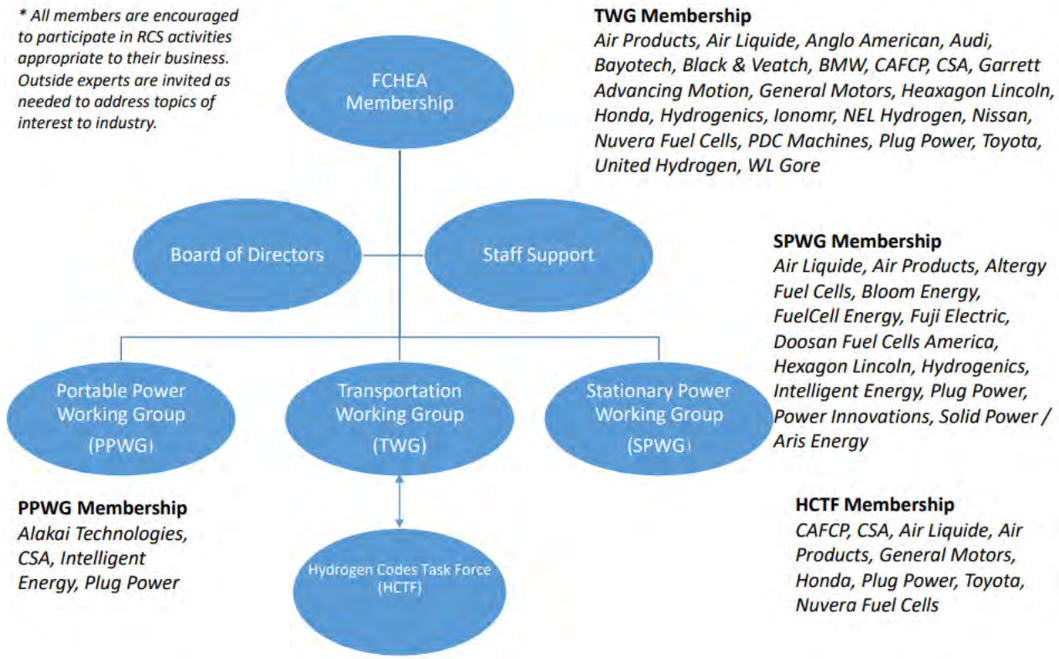
Fuel Cell & Hydrogen Energy Association Codes and Standards Support

SFTY
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by the Fuel Cell & Hydrogen Energy Association (FCHEA).
- Develops and enables widespread sharing of safety-related information resources and lessons learned with first responders and other key stakeholders.
- Harmonized codes, standards, and regulations, as well as removal of regulatory and policy barriers.
- Participation in FCHEA RCS Working Groups allows businesses (particularly small ones) opportunities to be briefed on RCS efforts of interest and weigh in on current issues.
- As of 2020, there are various types of FCHEA member organizations including 3M, Air Liquide, Audi, Bloom Energy, CSA Group, Hydrogenics, Plug Power, Toyota Motor North America, and many more.
- Project ID Number: DE-AC05-00OR22725 (2011) and SCS022 (2019)

FCHEA RCS Activities Flow



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FCHEA

Hydrogen Gas Sensing System

SFTY
Emerging

uspto
1 patent

- Developed by Intelligent Optical Systems, Inc., in partnership with National Lab of the Rockies (NLR).
- Can be used to detect hydrogen leaks in a variety of operating environments, including garages, passenger compartments, production facilities, and refueling stations.
- Detects hydrogen at concentrations from 10% to 100% of the lower flammability limit of hydrogen-in-air with a response time of less than 5 seconds and can detect hydrogen at concentrations as low as 100 ppm in air.
- Can operate at temperatures between 10°C-55°C and at relative humidity between 0% - 90%.
- Integrated optic sensors and optrodes are ideal for single-point or multiple-point detection.
- Can be handheld, wall-mounted, or deployed for remote monitoring of multiple locations where a potential hydrogen leak is expected.
- Contract Number: DE-FG36-06GO86057 (2006) and DE-FG36-08GO88098 (2008)



Intelligent Optical Systems's H_2-dTECT™ Compact Hydrogen Safety Sensor Unit

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Hydrogen Safety Outreach to Expedite H2 Fueling and Energy Project Deployment and Promote Public Acceptance for Zero Emission Vehicles and Reliable Distributed Power Generation

SFTY
Commercial

- Developed by Pacific Northwest National Laboratory (PNNL) in collaboration with the California Energy Commission.
- Formed a Hydrogen Safety Panel (HSP) that can share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen.
- PNNL HSP promotes the safety of hydrogen infrastructure in California, and other parts of the United States.
- Enables identification of safety-related gaps, best practices, and lessons learned.
- Potentially reduce costs by eliminating over-engineering that results from unnecessary features.
- Contract Number: DE-AC05-76RL01830 (2019)



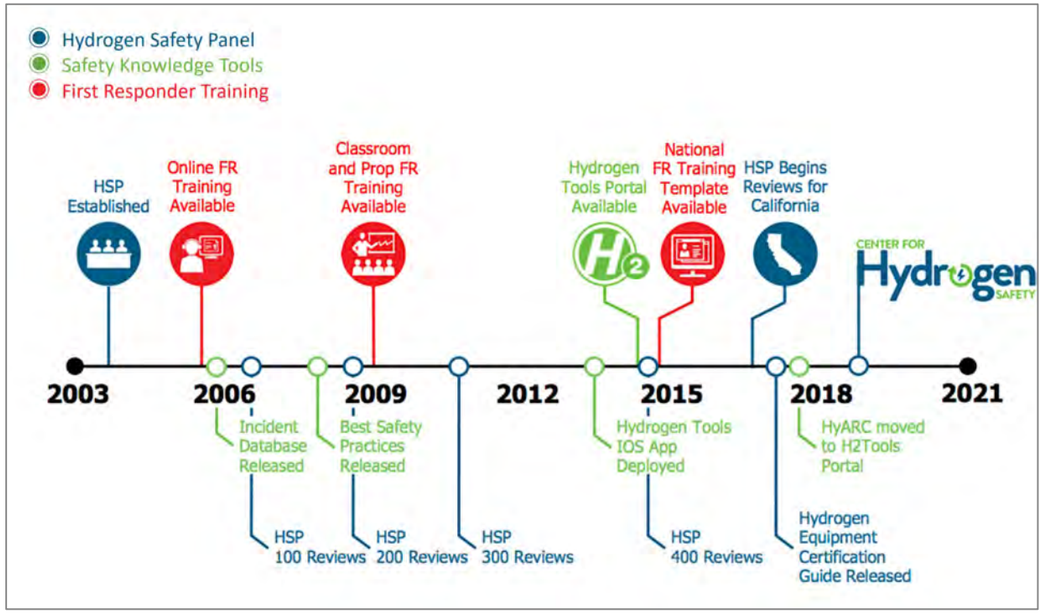


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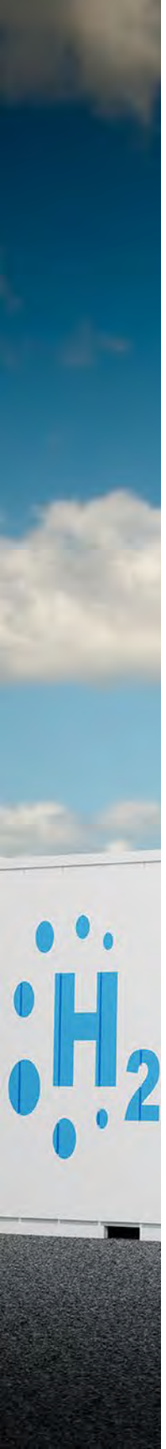
Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources

SFTY
Commercial

- Developed by Pacific Northwest National Laboratory in partnership with AIChE and numerous other subcontractors to establish the CHS, thus enabling long-term sustainability and broader impact of the Hydrogen Safety Panel (HSP), first responder training, and safety knowledge resources.
- Providing expertise and recommendations to DOE to help identify safety-related technical data gaps, best practices, and lessons learned.
- Helping DOE integrate safety planning into funded projects to ensure that all projects address and incorporate hydrogen and related safety practices.
- Supporting implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders.
- Contract Number: DE-AC05-76RL01830 (2004)



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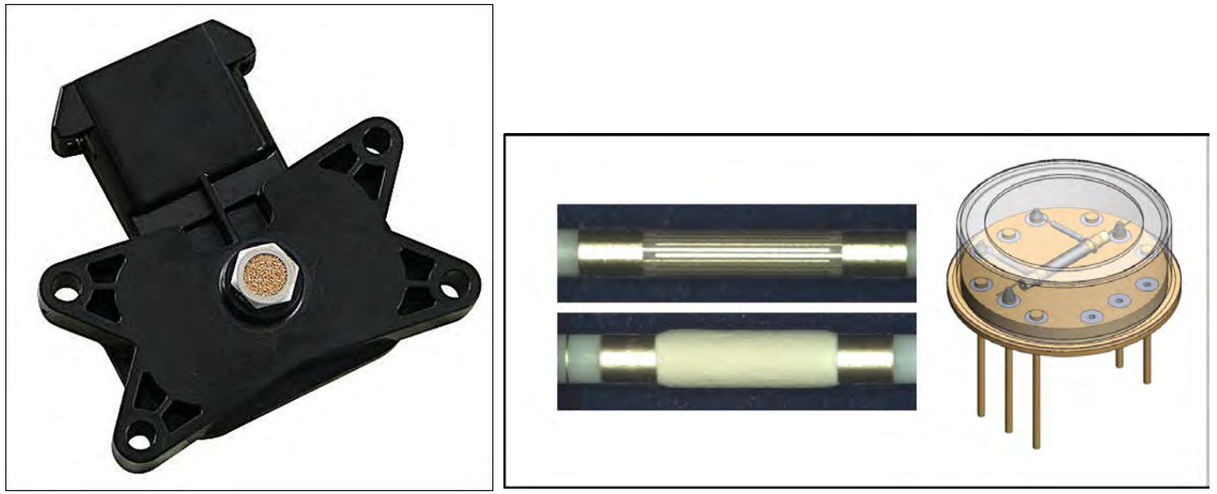
Pacific Northwest NATIONAL LABORATORY

Hydrogen Safety Sensor for Advanced Energy Applications

SFTY
Commercial

uspto
1 patent

- Developed by Nexceris LLC, formerly NexTech Materials, Ltd., and commercialized in 2010 by NTM Sensors, a division of Nexceris, LLC.
- Can be used to detect hydrogen in fuel cells, electrolysis systems, hydrogen distribution points, battery monitoring, semiconductor manufacturing, and laboratory safety monitoring.
- Uses a chemi-resistive ceramic sensor element, electronic controls, and an electronic signal output that is calibrated to measure hydrogen content in air corresponding to 0 to 100% of the lower flammability limit.
- Can accurately detect the presence of hydrogen in air concentrations from 0.25 to 4 percent H2, even under varying temperature and humidity conditions.
- Selectively measures hydrogen in the presence of carbon monoxide, methane, and volatile organic compounds.
- Contract Number: DE-FC36-04GO14215 (2004)



Nexceris's NTM SenseH_2 Hydrogen Sensor (Left) and Ceramic Sensor Element used in the NTM Sense H_2 (Right)

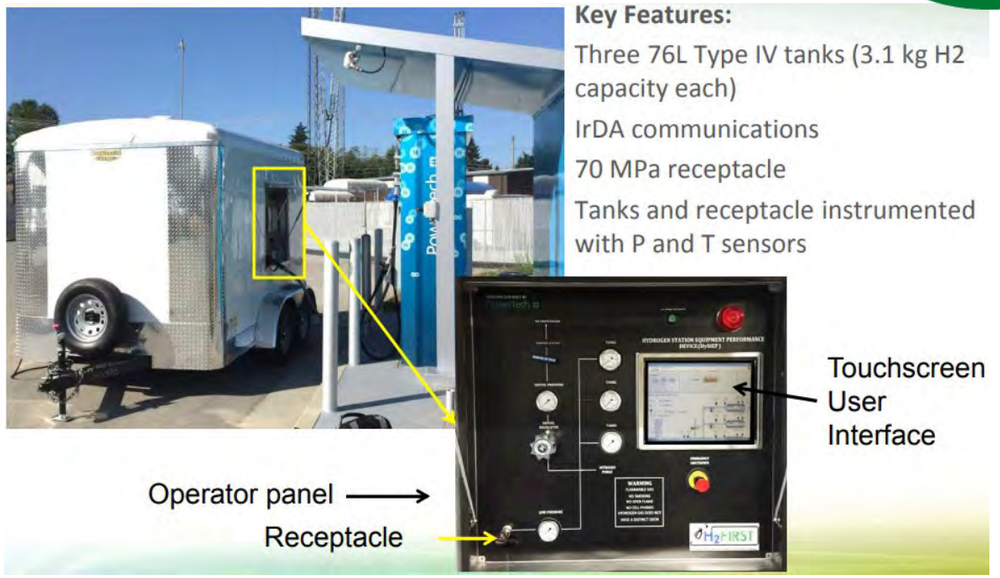
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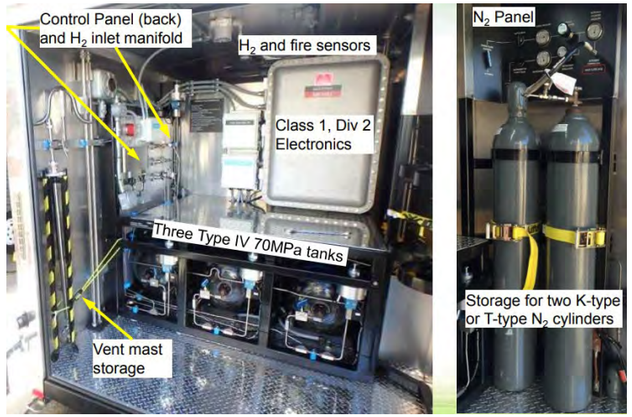
Hydrogen Station Equipment Performance (HyStEP) Device

SFTY
Commercial

Added FY2025

- Developed by Sandia National Laboratories with assistance from multiple project partners.
- Significantly accelerating station commissioning from months to about one week.
- Performs all tests defined in CSA HGV 4.3 within the limitation of the station being tested.
- Validates hydrogen fueling stations more efficiently using a standardized process, compared to current methods.
- Uses trailer-mounted platform, enabling movement of the device to the most convenient location for station validation; Compatible with most trailer mounts.
- 2016 recipients of a Federal Laboratory Consortium (FLC) Far West Region Award for their outstanding partnership in designing, building, and deploying the Hydrogen Station Equipment Performance (HyStEP) Device.
- The California Air Resources Board (CARB) tested new and existing stations with HyStEP to verify and ensure the proper functioning and safety of hydrogen refueling stations.
- Contract Number: DE-NA0003525 (2014)





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Intellipigment™: Visible Hydrogen Gas Leak Detection Material

Pacific Northwest NATIONAL LABORATORY

SFTY Commercial

uspto 8 patents

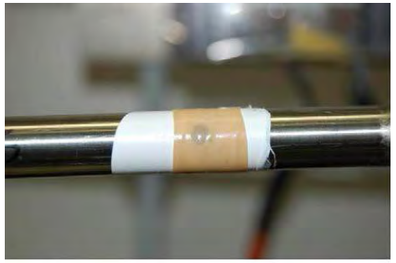
- Developed by the University of Central Florida as part of Florida Hydrogen Initiative. Commercialized by HySense Technology, LLC in 2013.
- Exclusive licensed to Nitto Denko Corporation.
- Useful for any facility engaged in the handling and use of hydrogen, such as aerospace, research laboratories, refineries, transportation, storage, and power generation market segments.
- Safe, color changing indicator for locating hydrogen and other hydrocarbon gas leaks.
- Easy to apply to suspected leak areas, e.g., around pipes, flanges, fittings, and valves.
- Available as a finished tape whose length and width can be customized for specific applications.
- Contract Number: DE-FC36-04GO14225 (2004)

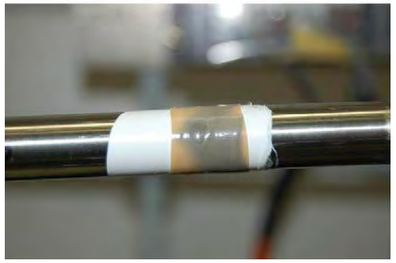
HySense TECHNOLOGY

R&D 100 2014 Awarded Technology









UCF

HySense TECHNOLOGY



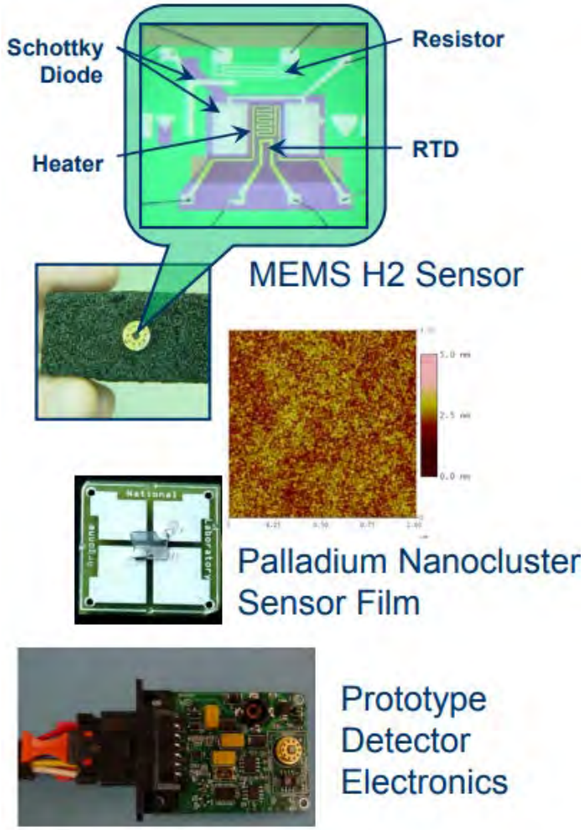
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Low-Cost Hydrogen Sensor for Transportation Safety

SFTY
Emerging

Pacific Northwest
NATIONAL LABORATORY

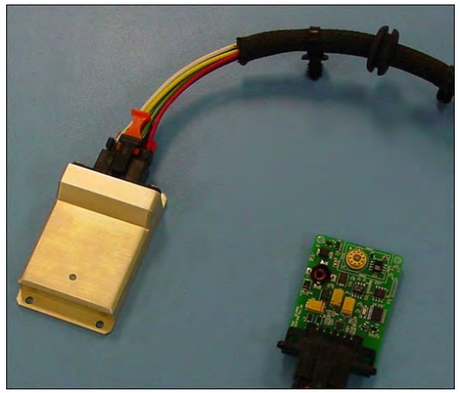
- Developed by Makel Engineering, Inc., in collaboration with Argonne National Laboratory and Case Western Reserve University.
- Funding and commercial partnership opportunities are actively being sought out.
- Can be used anywhere hydrogen gas leakage is a concern, such as fuel cell-powered automobiles and stationary power systems.
- Reduces sensor costs due to mass-production manufacturing.
- Detects hydrogen from 50 ppm up to 100% in oxygen and inert backgrounds.
- Contract Number: DE-FC36-04GO14215 (2004)



MAKEL ENGINEERING

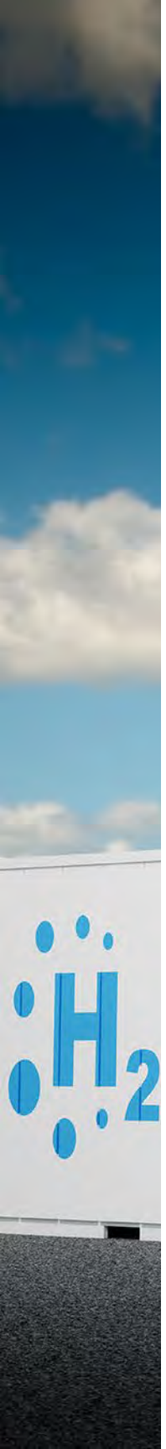
Argonne NATIONAL LABORATORY

CASE WESTERN RESERVE UNIVERSITY



Makel's Low-Cost Hydrogen Sensor for Transportation Safety

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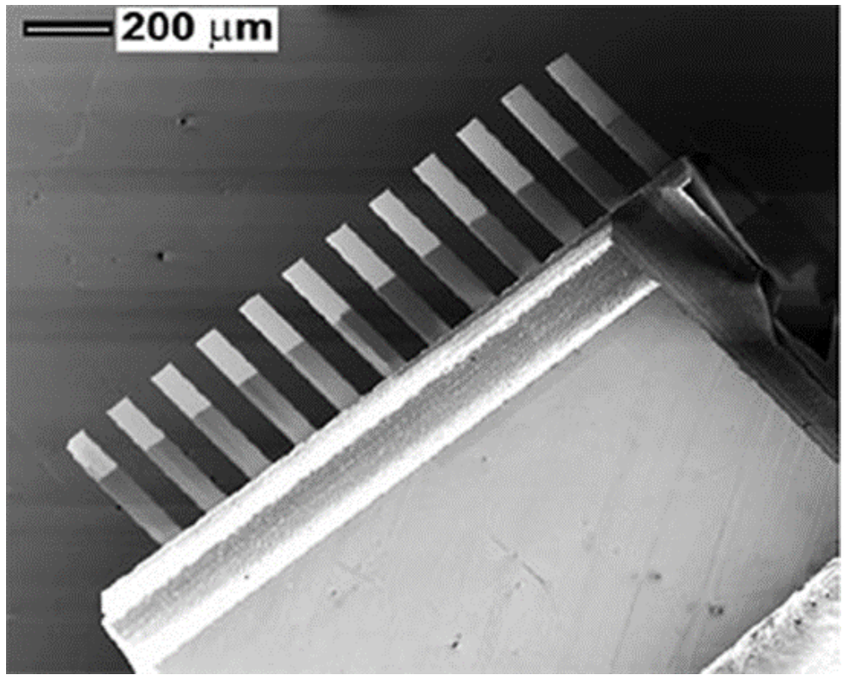
MEMS Hydrogen Sensor for Leak Detection

Pacific Northwest NATIONAL LABORATORY

SFTY *Emerging*

uspto 3 patents

- Developed by ORNL in partnership with the University of Tennessee-Knoxville.
- Developing prototypes for third-party evaluation and exploring technology licensing and commercialization opportunities.
- Can be used for hazardous condition detection in H2 fuel-powered applications.
- Achieves DOE response and recovery time targets of less than 10s-.
- Operates in ambient atmospheric conditions and is immune to interferents (e.g., H2O, CO2, CH4, H2S, and CO).
- Provides a measurement range of 0.1%-10% H2 over a wide temperature range (-22°F to 176°F).
- Provides H2 gas detection in air at concentrations significantly below the flammability threshold.
- Contract Number: DE-AC05-00OR22725 (2007)



OAK RIDGE National Laboratory

THE UNIVERSITY OF TENNESSEE KNOXVILLE

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R&D for Safety, Codes and Standards: Materials and Components Compatibility

SFTY
Commercial

Pacific Northwest
NATIONAL LABORATORY

- Developed by Sandia National Laboratories in partnership with standards development organizations and industry.
- Enables technology deployment by performing and applying foundational research toward the development of science-based codes and standards.
- Demonstrated fatigue and fracture in thick-walled pressure vessels can be independent of orientation and location.
- Design curves were approved and accepted for pipeline steels in ASME B31 Code Case 220.
- Revision to ASME CC2938 for pressure vessels steels to include pressure dependent design curves.
- Fostered international partnerships to support the harmonization of standards for qualifying materials and components for high-pressure hydrogen service engaging with AIST (Japan), Kyushu Univ. (Japan), KRISS (Korea), and MPA Stuttgart (Germany).
- Contract Number: DE-AC04-94AL85000 (2003)

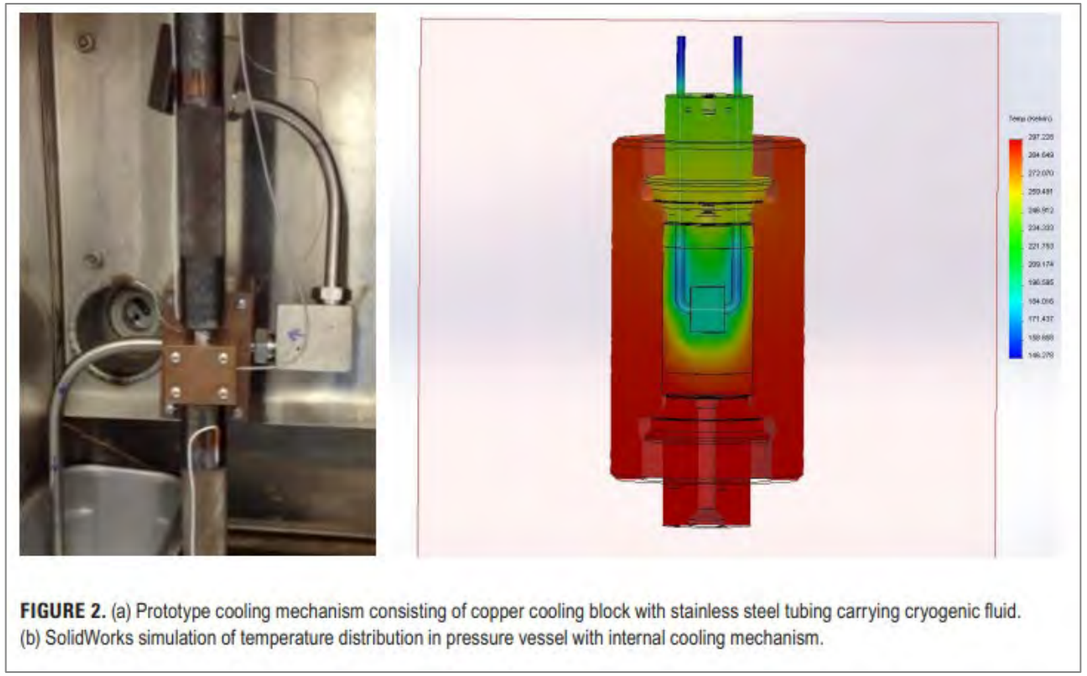


FIGURE 2. (a) Prototype cooling mechanism consisting of copper cooling block with stainless steel tubing carrying cryogenic fluid. (b) SolidWorks simulation of temperature distribution in pressure vessel with internal cooling mechanism.

Sandia National Laboratories · CSA GROUP · ASME SETTING THE STANDARD · SAE INTERNATIONAL · ISO · FIBA QUALITY PRODUCTS-SERVICE · TenarisDalmine

NASA White Sands Test Facility · HEXAGON DIGITAL WAVE · JSW · Swagelok · LUNA · AIR PRODUCTS

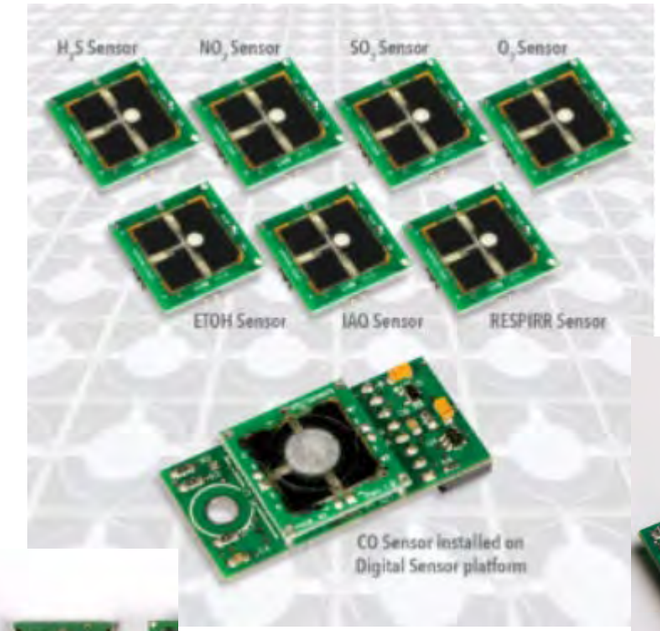
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Robust and Reliable Hydrogen Leak Detection and Warning Systems (SBIR)

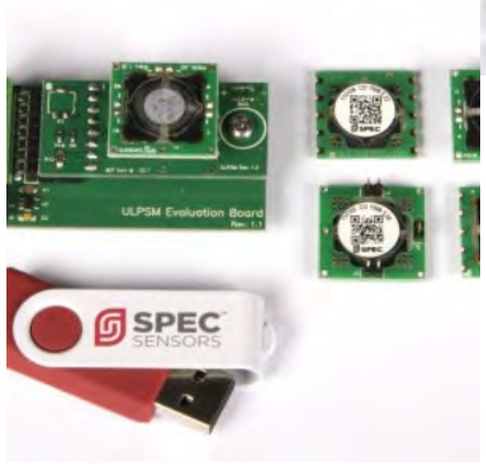
SFTY
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by SPEC Sensors, LLC in collaboration with KWJ Engineering; Los Alamos National Labs, Materials Synthesis and Integrated Devices Group; TechOpp Consulting, Inc.
- Project will develop a wireless mesh network, consisting of individually networked hydrogen sensor nodes, that will provide redundancy and reliability for quickly identifying and locating leaks and other types of facility failures.
- Initial application was for hydrogen detection at refueling facility; new application for air quality monitoring.
- Improved the safety of proposed hydrogen refueling stations.
- Developed wireless hydrogen sensing technology.
- Contract Number: DE-SC0019838 (2019)







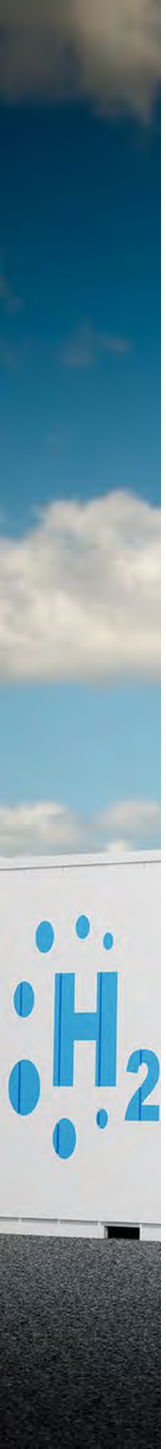
SPEC SENSORS
A division of Interlink Electronics, Inc.

KWJ ENGINEERING

Los Alamos
NATIONAL LABORATORY

TechOpp Inc.
Technology Meets Opportunity™

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Pre-FY2025 Storage Technologies

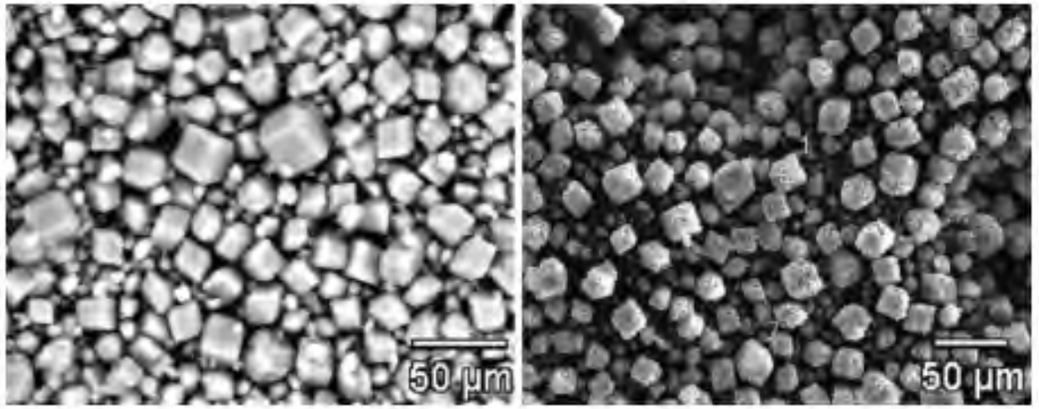
Technology	Organization
Electrochemical Reversible Formation of Alane	Savannah River National Laboratory
Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks	Pacific Northwest National Laboratory
First Demonstration of a Commercial Scale LH2 Storage Tank Design for International Trade Applications	Shell
Low-Cost Hydrogen Storage at 875 Bar Using Steel Liner and Steel Wire Wrap	Wiretough Cylinders, LLC
Low-Cost, Efficient, Metal Hydride Hydrogen Storage System for Forklift Applications (SBIR)	Hawaii Hydrogen Carriers, LLC
Low-Cost, High Strength Commercial Textile Precursor (PAN-MA)	Oak Ridge National Laboratory
NDE Techniques for Pressure Vessels: Detection of Micron-Scale Flaws through Nonlinear Wave Mixing (SBIR)	Luna Innovations
Onboard Monitoring Method for Detection of Damage to Carbon Fiber Composite Overwrap on Hydrogen Fuel Tanks (SBIR)	TDA Research, Inc.
Optimizing the Heisenberg Vortex Tube for Hydrogen Cooling	Washington State University
Vessel Design and Fabrication Technology for Stationary High-Pressure Hydrogen Storage	Oak Ridge National Laboratory

Electrochemical Reversible Formation of Alane

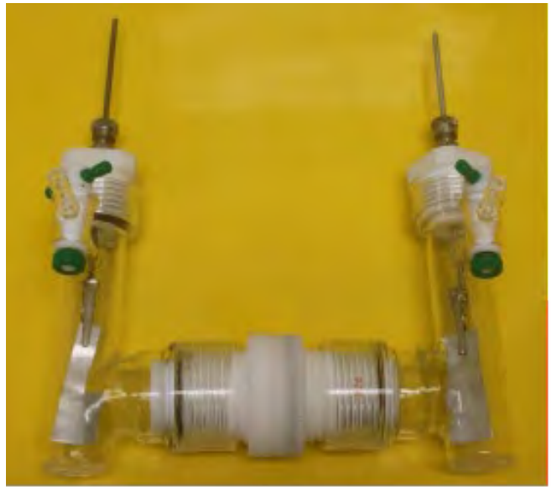
ST
Emerging

uspto
7 patents

- Developed by Savannah River National Laboratory in collaboration with multiple industry partners.
- Can be used to produce low-cost hydrogen storage materials for portable or stationary, fuel cell applications.
- Enables efficient and practical production of Aluminum hydride (Alane – AlH3).
- Provides desorption performance that approaches 2015 DOE onboard system targets.
- Increases Alane production by using more efficient electrochemical reactions.
- Avoids hazardous (flammable in air & water) material handling problems by surface passivation, which has minimal effect on material hydrogen storage capacity.
- Contract Number: DE-AC09-08SR22470 (2006)



SEM images of α-AlH_3 (left panel) and the resulting Al* (right panel) after dehydrogenation at 200 °C.



SRNL's Nafion® Film Electrochemical Cell for Producing Alane

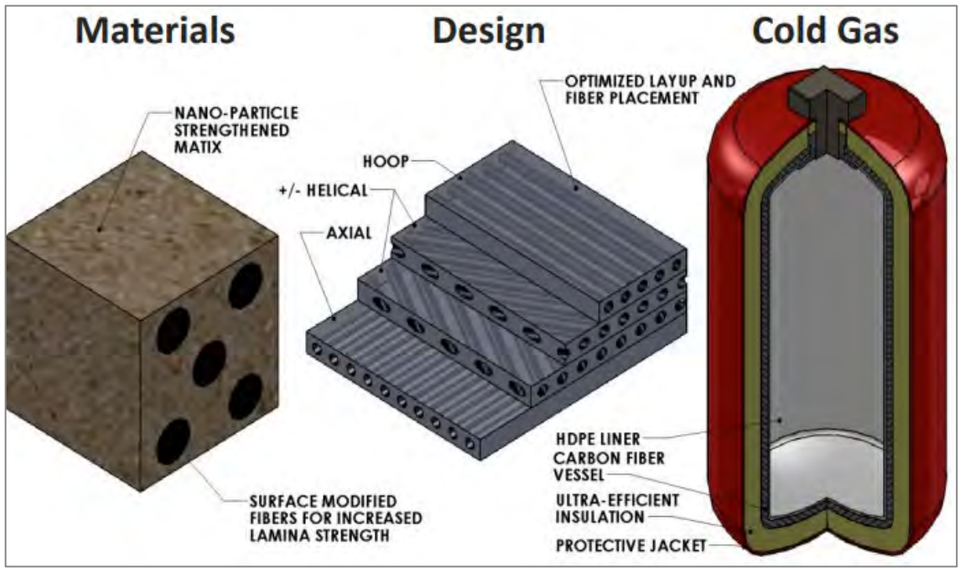
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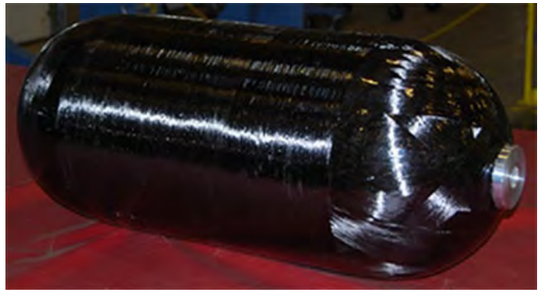
Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks

ST
Emerging

uspto
1 patent

- Developed by Pacific Northwest National Laboratory, Hexagon Lincoln, Toray Carbon Fibers America, AOC LLC, and Ford Motor Company.
- Continuing work to evaluate full-scale tank performance.
- Can be used for hydrogen storage, e.g., onboard storage in transportation applications.
- Provides optimized tank design for strength, weight, and cost reduction.
- Achieves reduced tank mass by up to 50%.
- Achieves reduced cost per tank by up to 60%.
- Optimized design provides high-pressure, cryogenic hydrogen storage with insulation dormancy of up to 18 days.
- Contract Number: DE-AC05-76RL01830 (2012)





PNNL's Hydrogen Storage Tank

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First Demonstration of a Commercial Scale LH2 Storage Tank Design for International Trade Applications

ST
Emerging

- Developed by: Shell USA with consortium partners: CB&I, GenH2, Univ. of Houston, and NASA KSC.
- A first-of-its-kind affordable large-scale liquid hydrogen (LH2) storage tank for international import and export applications.
- The project aims to design a large-scale tank that can be used in the range between 20,000 m3 and 100,000 m3.
- Developing a 3D thermal model for both the demonstration and large-scale LH2 tanks.
- Building an LH2 based cryogenic testing apparatus to measure insulation thermal properties down to 20 K.
- Currently, constructing a small-scale LH2 storage tank for a demonstration from construction, to startup and testing.
- Contract Number: DE-EE0009387 (2021)





Insulation Installation at Industrial Scale Applied by CB&I

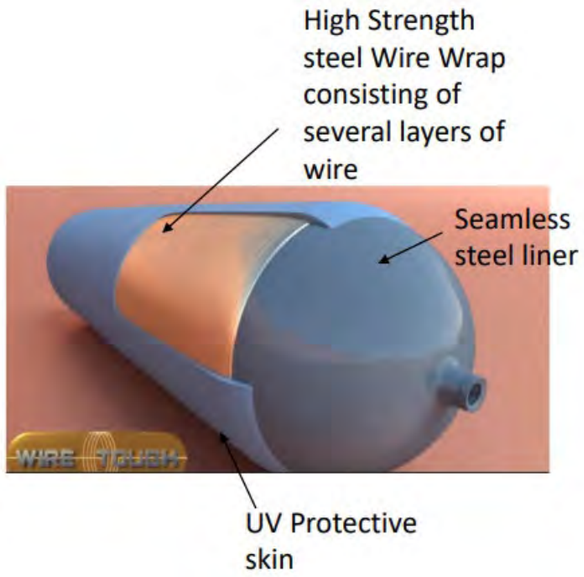
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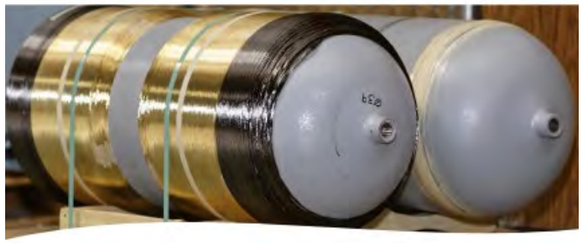
Low-Cost Hydrogen Storage at 875 Bar Using Steel Liner and Steel Wire Wrap

ST
Commercial

uspto
2 patents

- Developed by WireTough Cylinders LLC, in collaboration with Oak Ridge National Laboratory, Sandia National Laboratories, and the State of Virginia.
- Original version of technology commercialized in 2022.
- Newer Type II-S cylinders use a steel liner wrapped with high-strength steel wire, offering superior durability and the ability to withstand higher pressures compared to traditional fiberglass or carbon fiber-wrapped cylinders.
- Capable of storing up to 47.7 kg of hydrogen at pressures up to 875 bar. High pressure tanks have additional benefits such as reduced fatigue life. Expected cost (unchanged) <$1000/kg.
- Dissipates heat more rapidly than Type III and IV tanks, can hold 20-30% more compressed natural gas (CNG) under fast fill than Type IV tanks, and is about 20% lighter than all steel Type I cylinders of equivalent capacity and pressure rating.
- Looking for a private investor or industry partner to expand manufacturing operations.
- Contract Number: DE-EE0006668 (2014)







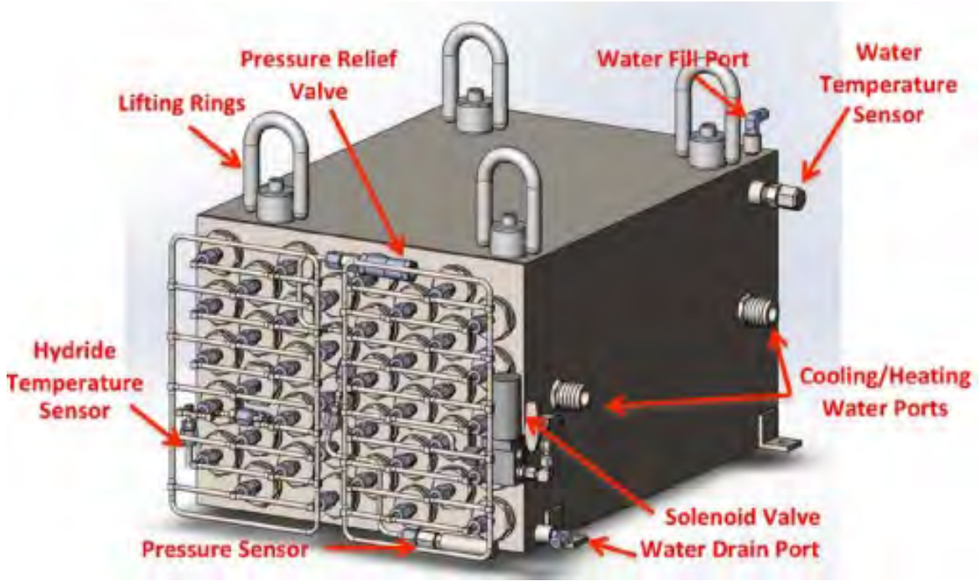
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Low-Cost, Efficient, Metal Hydride Hydrogen Storage System for Forklift Applications (SBIR)

ST
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Developed by HHC in collaboration with Sandia National Laboratories.
- Can be used to fuel a PEMFC-powered forklift, or other similar low-speed operations support vehicles.
- Provides increased energy storage, 28% over HP systems, and consistent versus decreasing power compared with BP systems.
- Reduces fueling times, 5 minutes, compared to 24 hours for standard BP and 15 minutes for fast charge Li-ion batteries.
- Reduces emissions and eliminates acid battery handling and disposal precautions and procedures.
- Provides capability to refuel using low pressures, 4 bar compared with 450 bar required in HP systems.
- Contract Number: DE-FG02-10ER85900 (2010)





Hawaii Hydrogen Carriers

Sandia National Laboratories

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Low-Cost, High Strength Commercial Textile Precursor (PAN-MA)

ST
Emerging

uspto
7 patents

- Developed by Oak Ridge National Laboratory and industry partners SGL Carbon Fibers and FISIPE.
- Can be used to improve strength-to-weight ratio of carbon fiber composite materials for a wide range of applications, including high-pressure hydrogen storage tanks.
- Targets fiber strengths > 650 KSI for more high-pressure applications (~ 575KSI currently).
- Targets $10-12 per pound compared with $15-20 per pound to meet DOE 2015 program goals.
- Carbon fiber can be manufactured using existing high volume textile production processes rather than highly specialized processes and materials.
- Contract Number: DE-AC05-00OR22725 (2011)



FIGURE 6. Top: "Fuzzing" of Filament Tow during Oxidative Stabilization. Bottom: Tow not exhibiting "Fuzzing"

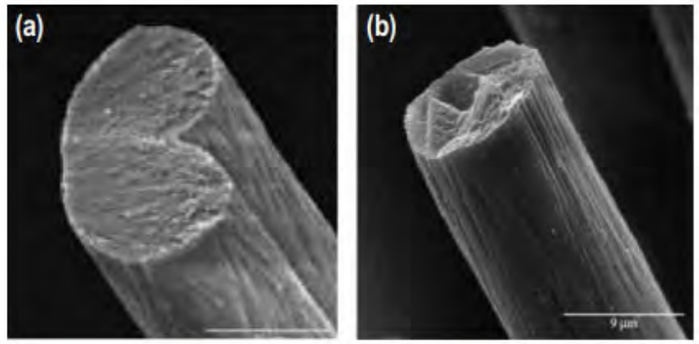


FIGURE 7. (A) Typical Textile-Produced PAN Fibers (B) Carbon Fiber-Grade PAN Fibers

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NDE Techniques for Pressure Vessels: Detection of Micron-Scale Flaws through Nonlinear Wave Mixing (SBIR)

ST
Emerging

- Being developed by Luna Innovations, working in collaboration with Innerspec Technologies, Sandia National Laboratory, and Murray State University.
- Developing tailored, non-destructive evaluation techniques for hydrogen storage vessels for improved manufacturing and potential tank re-certification in the field.
- Developed (and continue to develop) a specimen population for optimizing measurement approaches demonstrated during Phase I.
- Established a modeling framework to explore wave mixing physics.
- Applied wave mixing to experiments on fatigued bar specimens with seeded microstructural damage and microcracking.
- Completed initial designs for custom wave mixing sensing head.
- Contract Number: DE-SC0018766 (2019)

Bar specimens for point inspection and line scans

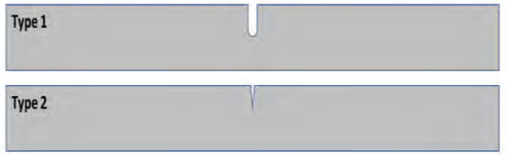
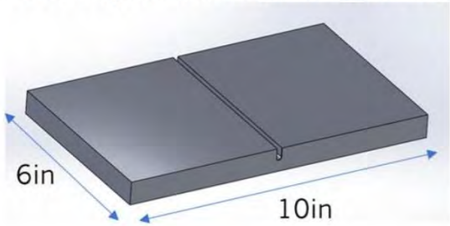


Plate specimens for surface scans



Material testing fixture designed for plate fatigue



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Onboard Monitoring Method for Detection of Damage to Carbon Fiber Composite Overwrap on Hydrogen Fuel Tanks (SBIR)

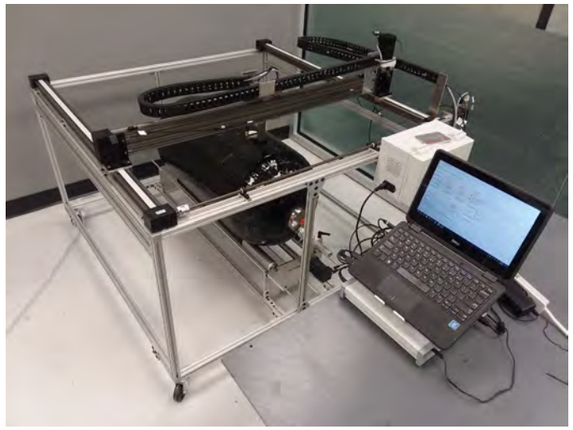
ST
Emerging

uspto
1 patent

- In development by TDA Research, Inc. in partnership with Steelhead Composites and other industry stakeholders.
- Verified the magnetic signature of carbon fiber and associated aluminum lining for Type III vessels can be assessed with TDA's method to identify damage undetected by visual inspection. Built an array of compact sensors to detect carbon-fiber or aluminum liner damage which could be reported to an on-board vehicle computer.
- Applied a new technology for damage detection in Type IV tanks (composite, 700bar), and development of a sensing array for larger H2 Composite Overwrapped Pressure Vessels (COPVs) used in heavy-duty vehicles.
- Currently have a fully functional carbon-fiber imaging device on-site at Steelhead Composites for evaluation. The improved technology can detect through the many layers of a COPV.
- Developed smart sensors for structural health monitoring (SHM) of COPVs in on-board hydrogen storage for fuel cell electric vehicles (FCEV). The goal is to reduce cost and manufacturing time of CPOVs if less carbon fiber is required.
- Regulatory path required to achieve commercialization.
- Contract Number: DE-SC0019981 (2019)



A sensing technology in H2 electric vehicles using an improved non-destructive evaluation (NDE) of the tank to provide early alert to damage to avoid a catastrophic failure.



CPOV imaging for QA/QC

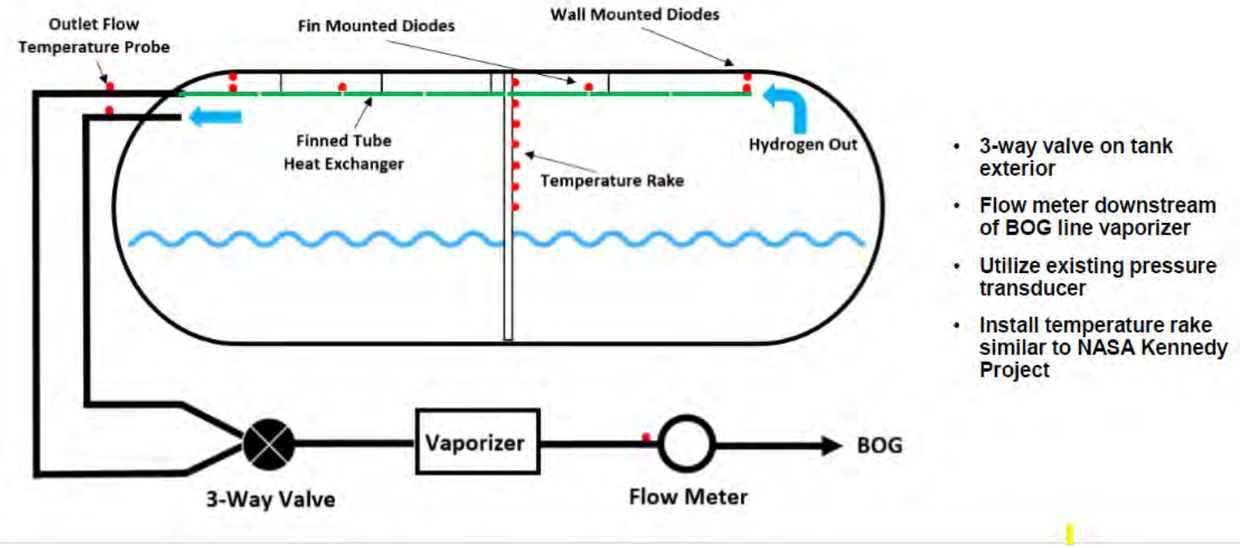
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Website: http://tda.com

Optimizing the Heisenberg Vortex Tube for Hydrogen Cooling

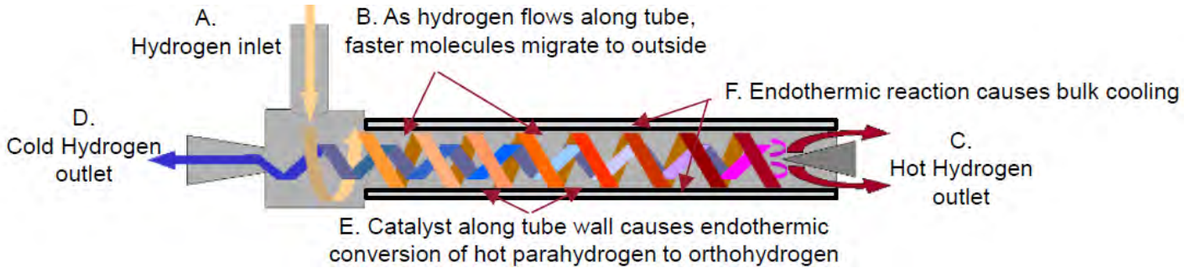
ST
Emerging

Pacific Northwest
NATIONAL LABORATORY

- Currently being developed by Washington State University in collaboration with Plug Power, Inc.
- The Heisenberg Vortex Tube (HVT) utilizes pressurized fluid power for separation into hot and cold streams.
- The HVT improves cryogenic hydrogen systems.
- Has the potential to improve the cost and efficiency of liquefaction through improved ortho-para catalysis.
- Can decrease liquid hydrogen storage tank boil-off losses by 20% through thermal vapor shielding (TVS).
- Contract Number: DE-EE0008429 (2019)

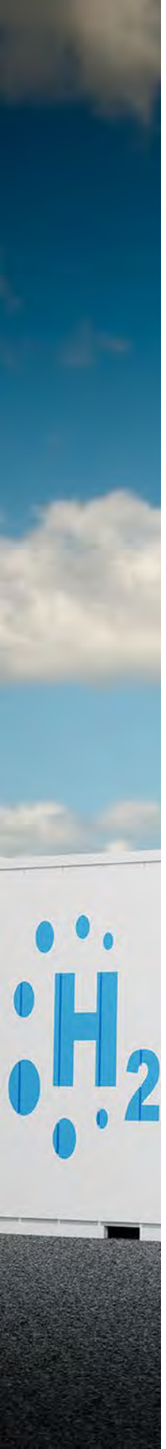


- 3-way valve on tank exterior
- Flow meter downstream of BOG line vaporizer
- Utilize existing pressure transducer
- Install temperature rake similar to NASA Kennedy Project



PLUG POWER

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Vessel Design and Fabrication Technology for Stationary High-Pressure Hydrogen Storage

Pacific Northwest NATIONAL LABORATORY

ST *Commercial*

uspto 3 patents

- Developed by ORNL in partnership with Kobe Steel, Foterra Pressure Pipe, Global Engineering & Technology, Ben C. Gerwick, Inc. Temple University, MegaStir Technologies, ArcelorMittal, U.S. Department of Transportation, and Harris Thermal Transfer. Commercialized in 2022.
- Can be used to design stationary hydrogen storage vessels, with a focus on optimizing safety and costs.
- Successfully demonstrated a design vessel designed to contain 90 kg of H_2 at 6250 psi (430 bar), and hydrostatically tested at 1.43 times the pressure (8940 psi, 615 bar) as part of code acceptance.
- Validated a finite element-based design and engineering tool for steel/concrete composite vessel (SCCV) design.
- Conducted long-term testing of SCCV performance under cyclic hydrogen pressure loading at 1-2 cycles per day from 100 to 430 bar for a total of 250 cycles.
- Planning to develop a second-generation SCCV for a follow-on project focusing on underground hydrogen storage at 875 bar with significant further cost reduction.
- Contract Number: DE-AC05-00OR22725 (2010)

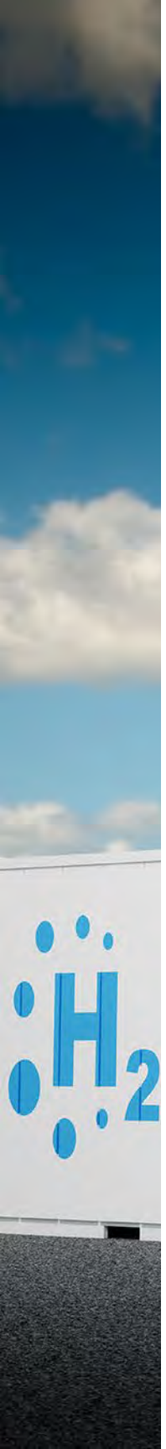


ORNL's demonstration SCCV undergoing long-term evaluation of cyclic hydrogen pressure loading to simulate service pressure cycling.

OAK RIDGE National Laboratory

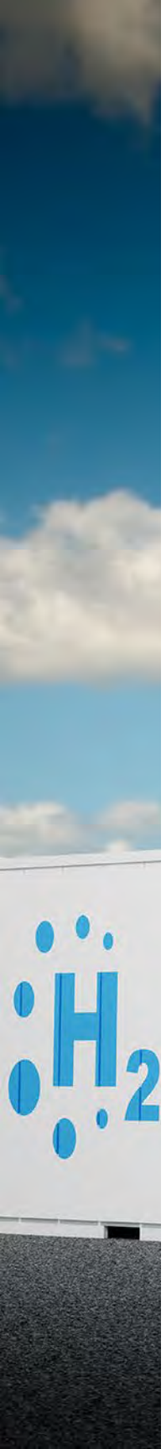
KOBELCO

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Pacific Northwest
NATIONAL LABORATORY

Historical Technologies



Historical Delivery Technologies

Technology	Organization
Centrifugal Hydrogen Pipeline Gas Compressor	Concepts NREC
Diode Laser Sensor for Contaminants in Hydrogen Fuel (SBIR)	Southwest Sciences, Inc.
FuelGen® Hydrogen Fueling Systems	Proton Energy Systems dba Nel Hydrogen
H2 ProGen: A Total Supply Solution for Hydrogen Vehicles	Atlas Copco (Formerly GreenField Compression)
Integrated Hydrogen Energy Station	Air Products and Chemicals, Inc.
Integrated Hydrogen Production, Purification, and Compression System	Linde Engineering North America, Inc.
Materials Solutions for Hydrogen Delivery in Pipelines	Secat, Inc.
Oil Free Hydrogen Compressor (SBIR)	Mohawk Innovative Technology, Inc.
Rapid High-Pressure Liquid Hydrogen Refueling for Maximum Range and Dormancy	Lawrence Livermore National Laboratory
Self-Healable Copolymer Composites for Extended Service Hydrogen Dispensing Hoses	Clemson University
Turnkey Hydrogen Fueling Station	Air Products and Chemicals, Inc.

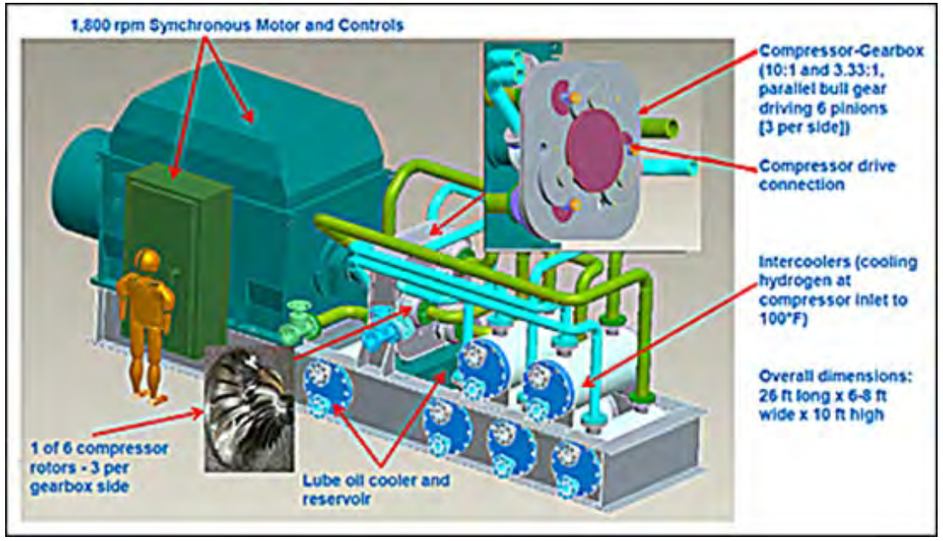
Centrifugal Hydrogen Pipeline Gas Compressor

DLVY Emerging

Historical

uspto 3 patents

- Developed by Concepts NREC, in partnership with Praxair (acquired by Linde in 2018), Texas A&M University, and HyGen Industries.
- Continuing work with assembly field testing and evaluation.
- Can be used to support existing hydrogen pipeline infrastructure in the industrial sector, as well as for future pipeline transport of high-pressure hydrogen from production sites to vehicle fueling stations.
- Delivers hydrogen at a rate of 240,000 kg/day at a discharge pressure of 1285 psig.
- Eliminates the threat of lubricant contamination in hydrogen supply line through the use of proven seal and bearing technology.
- Contract Number: DE-FG36-08GO18059 (2008)





7075-T6 Aluminum (bore-less) rotor shown after 5-axis machining. CN and TAMU testing has confirmed compatibility of alum. alloy with hydrogen

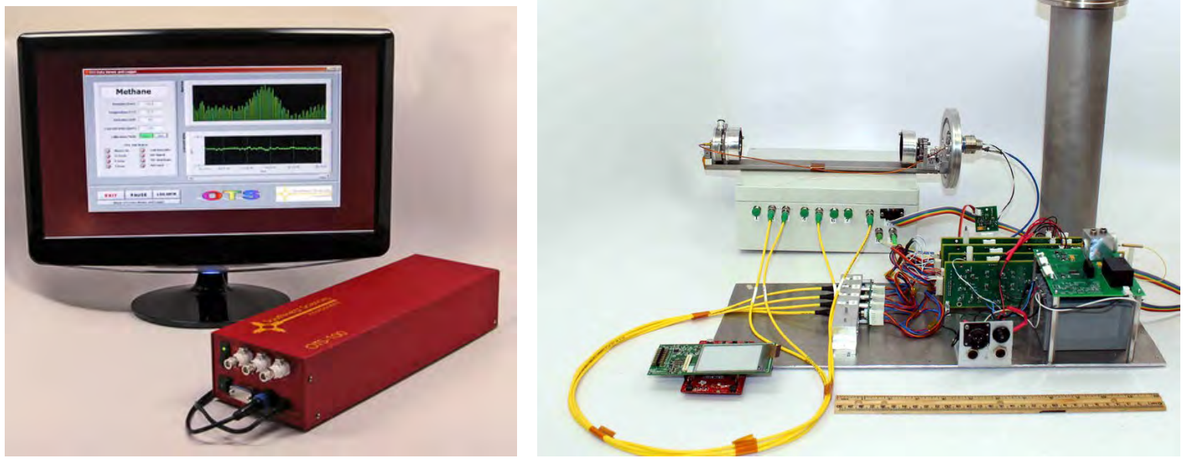
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Website: https://www.conceptsnrec.com

Diode Laser Sensor for Contaminants in Hydrogen Fuel (SBIR)

DLVY *Emerging*

Historical

- Developed by Southwest Sciences, Inc., in partnership with NLR and LANL.
- Can be used to detect contaminants in hydrogen fuel cells including carbon monoxide, ammonia, water vapor, carbon dioxide, methane, and formic acid, at 10% of the J2719 SAE level for these contaminants.
- Sensor can detect acetylene, hydrogen chloride, and hydrogen sulfide with the same sensitivity (10 times SAE level).
- In 2021, a diode laser hydrogen contaminant detector was developed using wavelength modulation spectroscopy.
- The system uses up to 6 lasers to probe a 30 cm long, 600 mL volume multipass cell containing the sample gas.
- The instrument can be configured to detect as many or as few contaminants as desired by swapping in different lasers and detectors.
- Contract Number: DE-SC0013147 (2015)



Southwest Sciences Inc.'s modular diode laser system, where lasers and boards can be switched out to detect specific contaminants as needed.

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Website: http://www.swsciences.com

FuelGen® Hydrogen Fueling Systems

DLVY
Commercial

Historical

- Developed by Proton Energy Systems.
- Creates transportation energy in a localized, decentralized, and sustainable manner and allows wind or solar energy to be used to produce the hydrogen.
- Available in packaged electrolyzer modules with hydrogen outputs ranging from 4 kg/day to 65 kg/day.
- Offers 2400 - 15000 psig hydrogen storage along with single or dual dispensing at 350 and 700 barg.
- Sold six units since 2007, with five units currently in operation.
- Contract Number: DE-FC36-04GO14237 (2004)





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H2 ProGen: A Total Supply Solution for Hydrogen Vehicles

DLVY
Commercial

Historical

uspto
1 patent

Pacific Northwest
NATIONAL LABORATORY

- Developed by Gas Technology Institute (GTI), now GTI Energy and marketed by GreenField Compression (a brand within the Atlas Copco Group).
- Can be used as a hydrogen supply station for all hydrogen-fueled vehicles that require high-pressure compressed hydrogen such as cars, trucks, buses, and industrial lift vehicles.
- Produces hydrogen by reformation of hydrocarbon fuels such as natural gas, propane, ethanol, biodiesel, or Fischer-Tropsch liquids.
- Compresses and stores hydrogen in an on-board storage assembly.
- Produces and delivers 20 to 200 kg of hydrogen per day.
- Contract Number: DE-FC04-02AL67607 (2001)





Hydrogen Dispenser Filed Test

GTI ENERGY
solutions that transform

Atlas Copco Group



Three-bank hydrogen cascade using composite pressure vessels.

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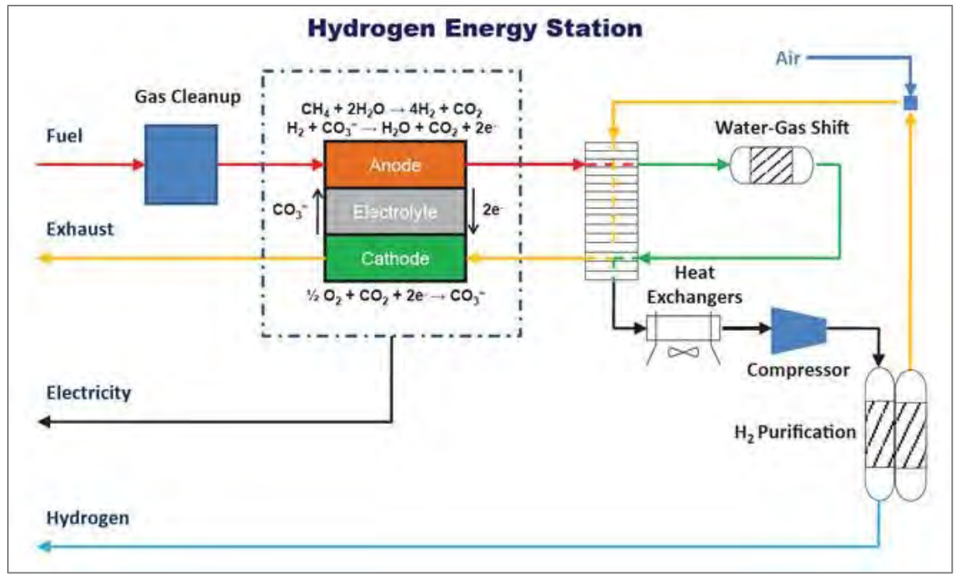
Integrated Hydrogen Energy Station

DLVY Emerging

Historical

uspto 1 patent

- Being developed by Air Products and Chemicals Inc., in collaboration with FuelCell Energy and Orange County Sanitation District.
- Continuing operations at the demonstration site with sponsorship from the California Air Resources Board and the South Coast Air Quality Management District.
- Can be used to co-produce hydrogen and electric power and provide hydrogen fueling services.
- Achieves hydrogen co-production costs in the range of $6 to $8 per kilogram of H2, at an overall system efficiency of 53.5% (50% goal).
- Produces hydrogen (100kg/day) and electricity from a variety of feedstock sources including anaerobic digester gas.
- Contract Number: DE-FC36-01GO11087 (2001)



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Integrated Hydrogen Production, Purification, and Compression System

DLVY Emerging

Historical

- Developed by Linde, Inc. (originally The BOC Group, Inc. and acquired by Linde in 2006), in partnership with Linde, MRT, and Energenics.
- Project objective was to meet the DOE target delivered hydrogen of <$1.50/gge, later revised by DOE to $2-$3/gge range for hydrogen to be competitive with gasoline as a fuel for vehicles.
- Project goal was to integrate the membrane reformer developed by MRT and the hydride compression system developed by Energenics in a single package.
- Reduces cost by combining unit operations for the entire generation, purification, and compression system.
- Contract Number: DE-FG36-05GO15017 (2005)

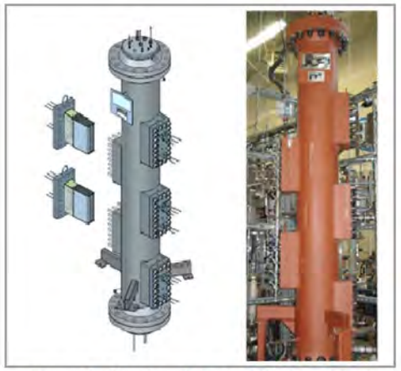


Figure 5 - Novel auto-thermal Fluidized Bed Membrane Reactor (FBMR) enables use of lower cost metals, while better membrane access eases maintenance.



Figure 6 - MRT's novel vaporizer increases efficiency by burning ROG.

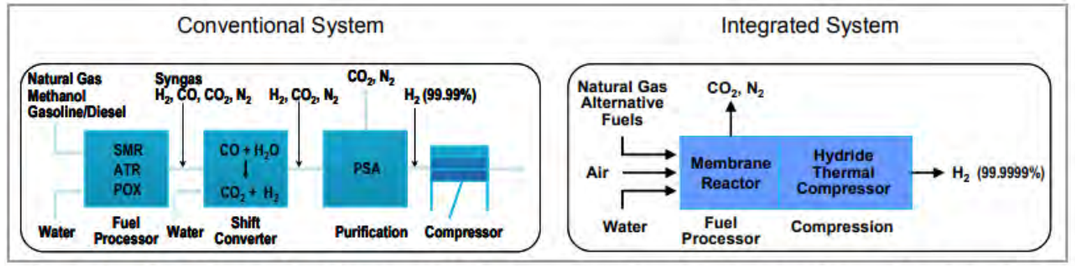


Figure 1 - The integrated hydrogen production, purification and compression system intends to reduce component count and costs while increasing efficiency

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Materials Solutions for Hydrogen Delivery in Pipelines

Pacific Northwest NATIONAL LABORATORY

DLVY *Emerging*

Historical

- Being developed by Secat, Inc., in collaboration with multiple industry partners.
- Can be used to select steel composites that would be suitable for safe transmissions of hydrogen at high pressures (800 – 3000 psi).
- Allows failure detection, performance, and characterization of the mechanical properties of pipeline steel compositions.
- Potentially reduces pipeline infrastructure “hydrogen readiness” costs by identifying suitable existing pipelines and avoiding replacement cost.
- Provides technical information and understanding of pipeline steel fracture and fatigue, enabling further development of hydrogen related American Society of Mechanical Engineers codes and standards.
- Contract Number: DE-FG36-05-GO15036 (2005)



Test Sample Failures (LHS Cup & Cone RHS Faceted Surface) and High-Pressure Test Equipment

SECAT EXCELLENCE IN METALLURGY

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Secat, Inc.
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Website: http://www.secat.com

Oil Free Hydrogen Compressor (SBIR)

Pacific Northwest NATIONAL LABORATORY

DLVY *Emerging*

Historical

- Developed by Mohawk Innovative Technology, Inc.
- Establishing partnerships with large pipeline compressor equipment manufacturers.
- Can be deployed in pipeline-sized distribution systems for hydrogen and natural gas from production facilities through end use.
- Centrifugal compressor with foil bearings eliminates the need for oil lubrication.
- Provides flow rates up to one million kilograms of hydrogen per day with output pressures of 1,200 psi.
- Provides improved compressor reliability and efficiency.
- Contract Number: DE-FG02-05ER84245 (2005)



Mohawk Innovative Technology, Inc.®

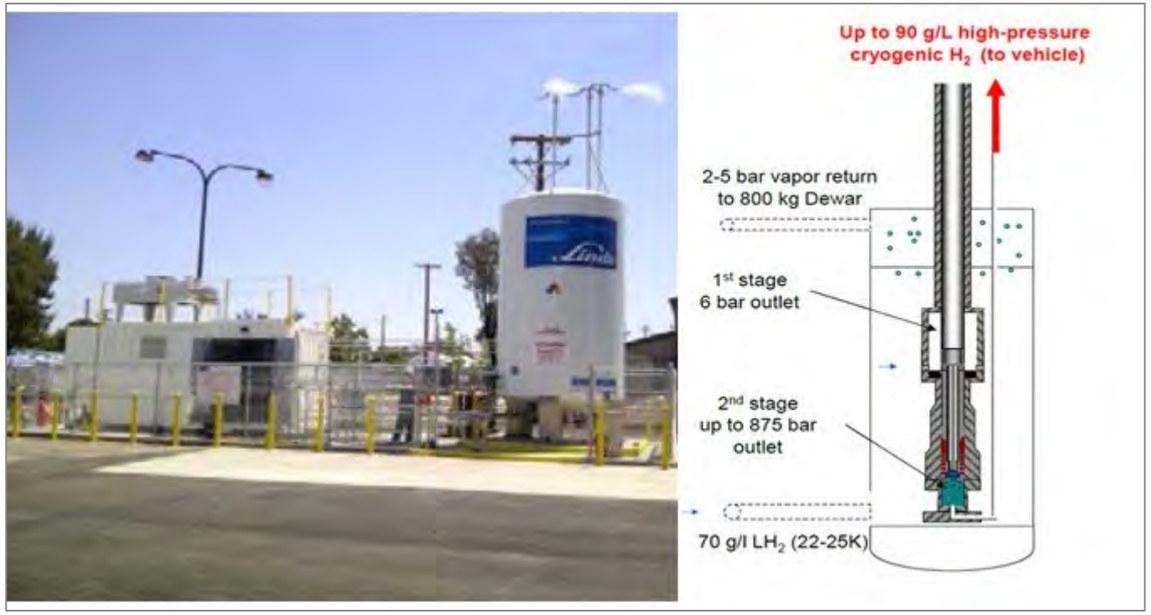
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Mohawk Innovative Technology, Inc.
1037 Watervliet-Shaker Rd
Albany, NY 12205
Website: https://mohawkinnovative.com

Rapid High-Pressure Liquid Hydrogen Refueling for Maximum Range and Dormancy

DLVY *Emerging*

Historical

- Developed by Lawrence Livermore National Laboratory, Linde, and BMW.
- Can be used to quickly refuel hydrogen vehicles with high-pressure cryogenic storage tanks.
- Achieves hydrogen flow rate of 100 kg per hour.
- Operates with less than 3% hydrogen boil-off.
- Can operate regardless of onboard storage temperature.
- Self-regulates storage tank temperature.
- Contract Number: DE-AC52-07NA27344 (2009)



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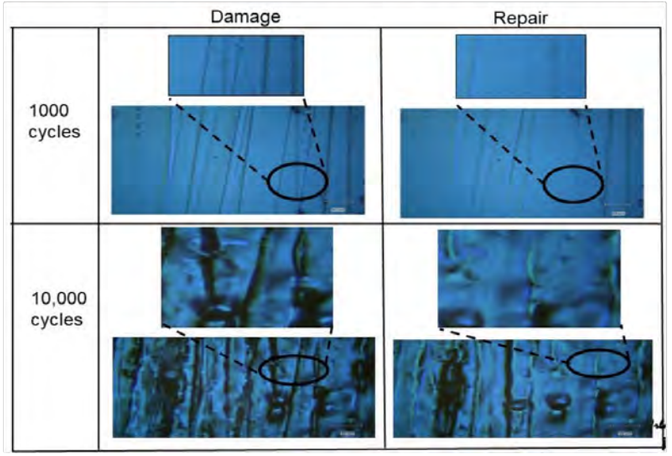
Self-Healable Copolymer Composites for Extended Service Hydrogen Dispensing Hoses

DLVY
Emerging

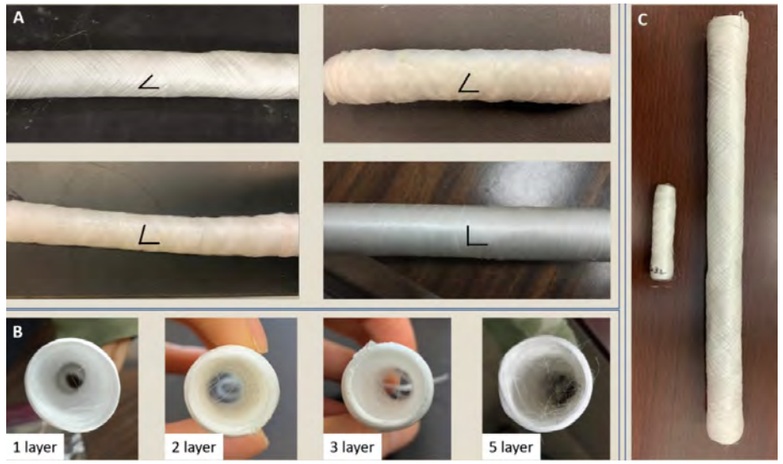
Historical

- Currently being developed by Clemson University in partnership with Savannah River National Laboratory, Sandia National Laboratory, and Pacific Northwest National Laboratory.
- Addresses the problem of the hydrogen hoses being prone to cracking and promoting inner layer damage from extreme temperatures and high pressure.
- Self-healable copolymer composites increase sustainability of H2 dispensing hoses, extending the life of the hoses.
- Optical image analysis is utilized to determine optimum molar ratios to achieve self-healing properties.
- Contract Number: DE-EE0008827 (2020)

A. (Cnt'd) 10,000 Damage-Repair Cycle Tests of Copolymer Films
10,000 Damage-Repair Cycles = 10,000 cuts and 10,000 repairs



A target value of 10,000 damage-repair cycles has been met



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Turnkey Hydrogen Fueling Station

DLVY
Emerging

Historical

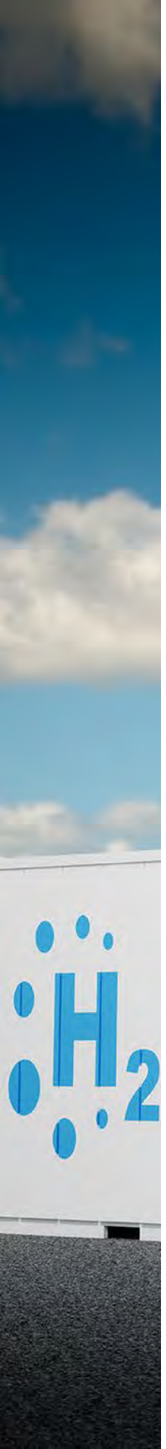
uspto
1 patent

- Developed by Air Products and Chemicals, Inc., in partnership with Penn State University.
- Can demonstrate the potential for a stand-alone, fully integrated hydrogen fueling station based on the reformation of natural gas.
- Can operate at 65% overall system efficiency.
- Can produce hydrogen at 108 kg/day at a cost of $13.98/kg H_2.
- According to H2A modeling parameters can scale up production to 1,500 kg/day of hydrogen and reduce the production cost to meet the DOE target goal of $3.00/kg H_2.
- Test unit entered an "Operating Period" level field test for a 6-month period at the Penn State testing site starting in April 2006.
- Contract Number: DE-FC36-02AL67613 (2002)



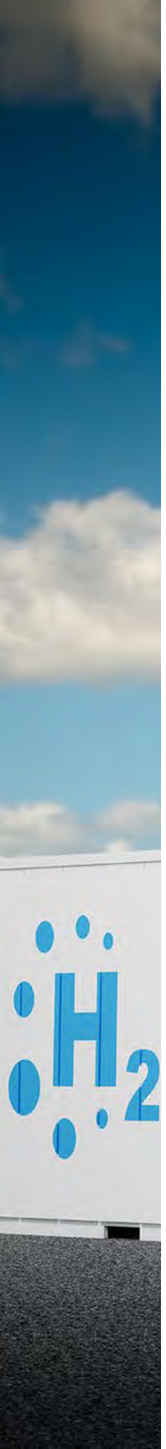
Air Products and Chemicals Inc.'s H_2 Refueling Station at Penn State

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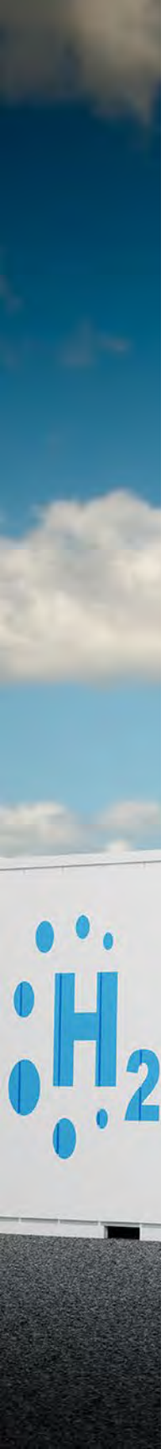
Historical Fuel Cell Technologies

Technology	Organization
Alternative and Durable High-Performance Cathode Supports for PEM Fuel Cells	Pacific Northwest National Laboratory
Cathode Catalysts and Supports for PEM Fuel Cells	3M Company
Direct Methanol Fuel Cell (DMFC) Anode Catalysts	National Renewable Energy Laboratory
Direct Methanol Fuel Cell Power Supply for All-Day True Wireless Mobile Computing	PolyFuel, Inc.
Dimensionally-Stable High-Performance Membrane (SBIR)	Giner, Inc.
Durable Catalysts for Fuel Cell Protection during Transient Conditions	3M Company
Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells	OneD Material, LLC
Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes	National Renewable Energy Laboratory
Fuel Cell Hybrid Electric Delivery Van	Center for Transportation and the Environment
GCTool: Fuel Cell Systems Analysis Software Model	Argonne National Laboratory
GenCore® Backup Fuel Cell Systems	Plug Power, Inc.
GenSys® Blue: High-Temperature CHP Fuel Cell System (ARRA)	Plug Power, Inc.
Ground Support Equipment Demonstration	Plug Power, Inc.
High-Efficiency Polymer Electrolyte Membrane Fuel Cell Combined Heat and Power System	Intelligent Energy, Inc.
High-Performance, Long-Lifetime Catalysts for Proton Exchange Membrane Electrolysis (SBIR)	Giner, Inc.
High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure	Cabot Superior MicroPowders
High-Speed, Low-Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
High-Temperature Membrane with Humidification-Independent Cluster Structure	FuelCell Energy, Inc.



Historical Fuel Cell Technologies (continued 2/3)

Technology	Organization
Improved Catalyst Coated Membrane (CCM) Manufacturing	IRD Fuel Cells LLC (Acquired from Cabot Corporation)
Improved Low-Cost, Durable Fuel Cell Membranes	Arkema Inc.
Integrated Manufacturing for Advanced Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
Ionomer Dispersion Impact on Advanced Fuel Cell and Electrolyzer Performance and Durability (SBIR)	Giner, Inc.
Lifetime Improvements for PEM Fuel Cells	DuPont Fuel Cells
Low-Cost Co-Production of Hydrogen and Electricity	Bloom Energy Corporation
Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies (MEAs)	W.L. Gore and Associates, Inc.
Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers	W.L. Gore and Associates, Inc.
Membranes and Membrane Electrode Assemblies (MEAs) for Dry, Hot Operating Conditions	3M Company
Nanostructured Proton Exchange Membrane (SBIR)	eSpin Technologies, Inc,
Nectar™: Mobile Power System: Silicon-Based SOFC for Portable Consumer Electronics	Lilliputian Systems, Inc.
New Fuel Cell Membranes with Improved Durability and Performance	3M Company
Nitrided Metallic Bipolar Plates for PEM Fuel Cells	Oak Ridge National Laboratory
Novel Fluorinated Ionomer for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR)	Giner, Inc.
Novel Materials for High Efficiency Direct Methanol Fuel Cells (SBIR)	Arkema Inc.
Off-Road Fuel Cell Applications	IdaTech, LLC
Platinum-Group-Metal Recycling Technology	BASF Catalysts, LLC
Polymer Electrolyte Membrane (PEM) Fuel Cell Power Plant Development and Verification	ClearEdge Power (Formerly UTC Power)



Historical Fuel Cell Technologies (continued 3/3)

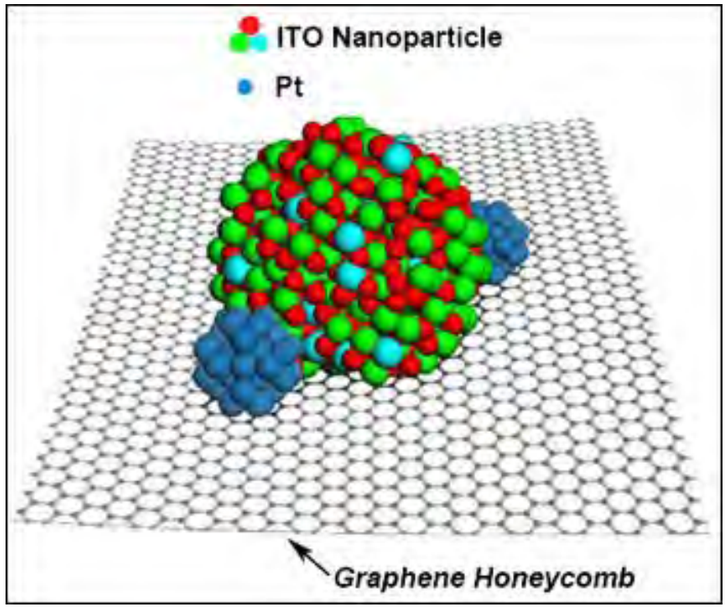
Technology	Organization
PureMotion® 120 Fuel Cell Power Plant	ClearEdge Power (Formerly UTC Power)
Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates	GrafTech International Ltd.
Roots Air Management System with Integrated Expander	Eaton Corporation
Scale-Up of Carbon-Carbon Composite Bipolar Plates	Oak Ridge National Laboratory w/Porvair Advanced Materials, Inc.
Sensors for Automotive Fuel Cell Systems	Nexceris LLC (Formerly NexTech Materials, Ltd.)
Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications	SAFCell, Inc.
Solid Oxide Fuel Cell Auxiliary Power Unit	Delphi Corporation
Thermal and Water Management Systems for PEM Fuel Cells	Honeywell Aerospace
Ultrasonics and Diagnostics for High-Temperature PEM MEA Manufacture	Rensselaer Polytechnic Institute

Alternative and Durable High-Performance Cathode Supports for PEM Fuel Cells

FC
Emerging

Historical

- Developed by PNNL in partnership with ORNL, University of Delaware, Princeton University, and the Automotive Fuel Cell Cooperation Corporation.
- Can produce durable low-carbon and noncarbon cathode catalyst supports for PEM fuel cells which can be used for automotive or stationary fuel cell applications.
- Uses a wet chemistry synthesis method that is scalable to high-volume production manufacturing.
- Can achieve an activity of 137 mA/mgPt with 2 times reduction in carbon corrosion over baseline carbon-supported cathode catalysts in Rotating Disc Electrode tests.
- Exceeded the target goals of 20% greater cathode support durability and less than 20% loss in activity after a 1.2V hold test.
- In 2016, an LDRD project was done and improved the in-situ testing of the membrane electrode assembly, with 2-3 times greater performance over previous results.
- Contract Number: DE-AC05-76RL01830 (2007)



PNNL's cathode support for PEM fuel cells consisting of uniformly-coated Pt nanoparticles on porous 3-D ITO-graphene nanocomposite

Automotive Fuel Cell Cooperation

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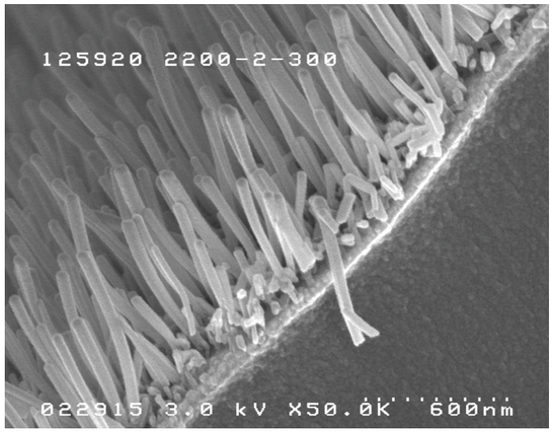
Cathode Catalysts and Supports for PEM Fuel Cells

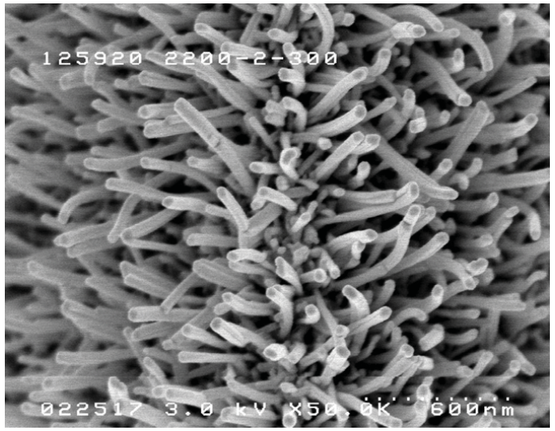
FC
Commercial

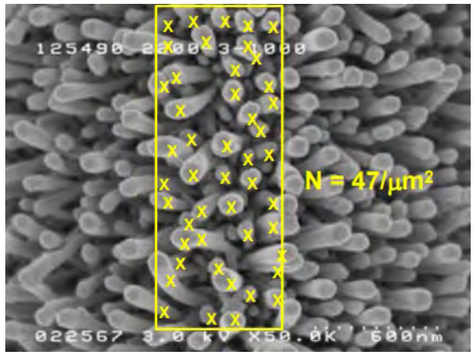
Historical

uspto
5 patents

- Developed by 3M Company over a 10-year period, commercialized in 2007.
- Used in demanding hydrogen-fueled fuel cell systems where conditions require high resistance to catalyst corrosion and membrane degradation.
- Uses less precious metals, lower-cost manufacturing, and smaller fuel cell stack size.
- Demonstrates over a ten-fold gain in lifetime under many accelerated and load-cycling tests.
- Results in higher current and power density with reduced catalyst loading.
- Contract Number: DE-FG36-07GO17007 (2007)







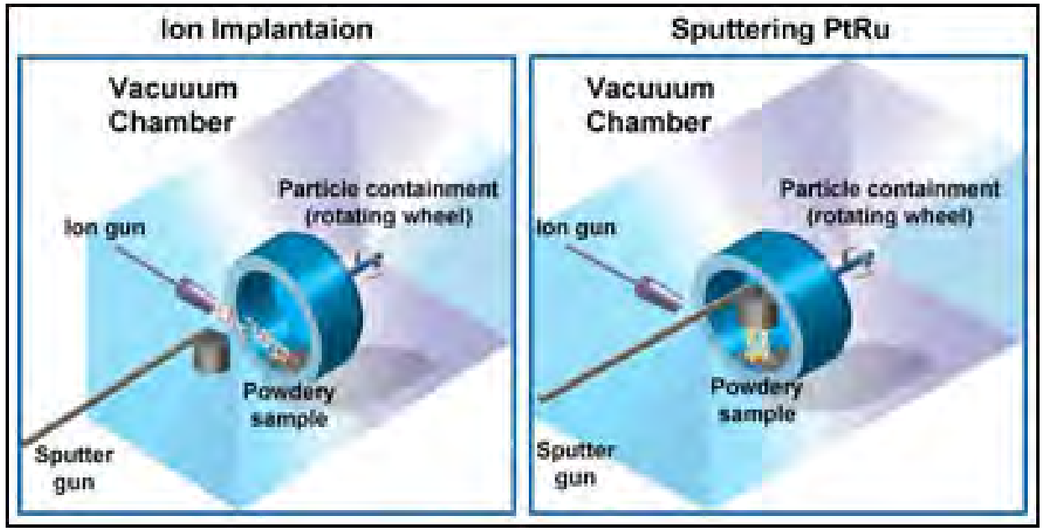
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Direct Methanol Fuel Cell (DMFC) Anode Catalysts

FC
Emerging

Historical

- Developed by the National Laboratory of the Rockies (NLR) in partnership with the Colorado School of Mines.
- System contaminants have been shown to affect performance/durability of fuel cell systems (GM).
- Can be used in constructing fuel cells for portable power applications.
- Reduces material cost of catalyst by an optimized deposition process, enhanced catalyst activity, and improved durability.
- Provides dry scalable process for ion implantation and sputter deposition to high surface-area carbon materials.
- Improves catalyst performance and durability.
- Produces catalyst compositions on high surface area carbon materials using PtRu nanoparticles from a single composition PtRu alloy.
- Contract Number: DE-AC36-08GO28308 (2011)



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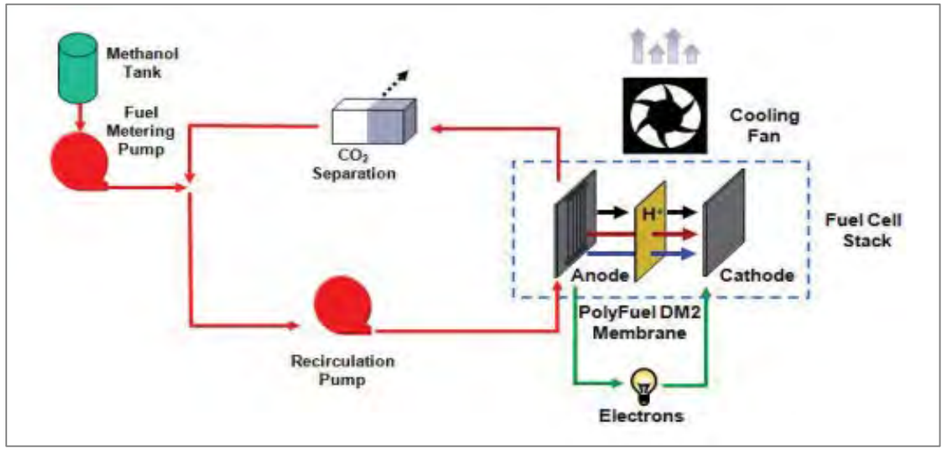
Direct Methanol Fuel Cell Power Supply for All-Day True Wireless Mobile Computing

Pacific Northwest NATIONAL LABORATORY

FC Emerging

Historical

- Developed by PolyFuel Inc.
- Developed a novel membrane electrode assembly (MEA) structure with a new cathode gas diffusion layer (GDL) and novel membrane that enables the transport of water from the cathode directly to the anode within the fuel cell.
- Developed a miniature recirculation pump for diluted alcohol solutions.
- Operated a complete DMFC system that has very low BOP parasitic loads.
- Demonstrated the operation of a complete DMFC system fully integrated with a laptop computer.
- Contract Number: DE-FC36-04GO14302/A000 (2004)



System Schematic for Passive Water Recovery

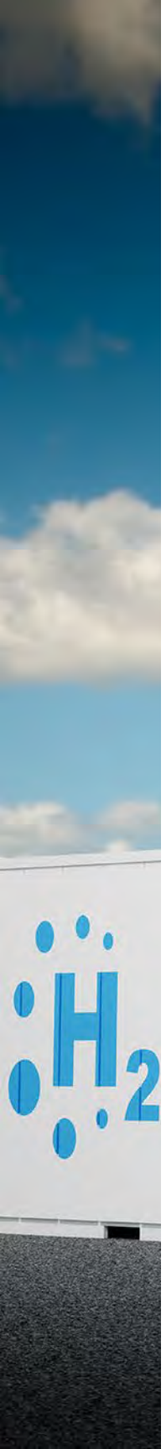


Fully Integrated DMFC Power Supply for a Laptop Computer

polyfuel

Contact Information:

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PolyFuel, Inc.
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Website: n/a



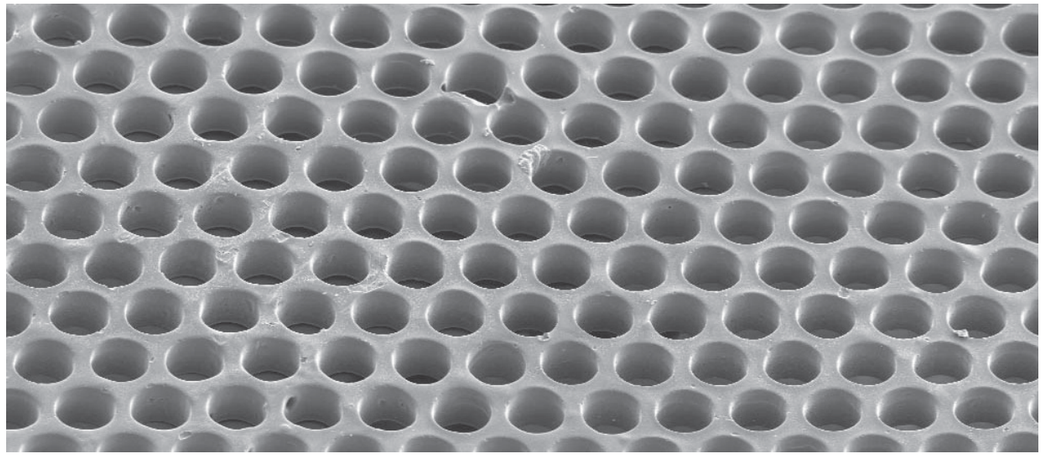
Dimensionally-Stable High-Performance Membrane (SBIR)

FC
Commercial

uspto
4 patents

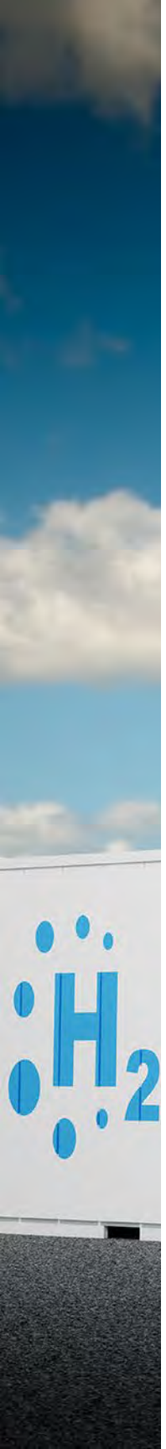
Historical

- Developed by Giner, Inc. in collaboration with UMass – Amherst, and Impattern Technologies. Commercialized since 2023.
- Membrane patterns are customizable, allowing for the enhancement of the membrane support structure to include the use of lower-equivalent-weight ionomers without sacrificing mechanical durability.
- The DSM™ incorporates low equivalent weight (EW) ionomers (700 EW), which have better mechanical properties than Nafion, and far superior performance.
- By employing local reinforcement strategies, the lifetime of DSM™ is about three times longer than traditional membranes.
- Contract Number: DE-FG36-04GO13029 (2003)
  DE-FG02-05ER84322 (2005 Phase I & II)
  DE-FG36-06GO16035 (2009) and
  DE-EE0004533 (2010 Phase III - Xlerator)



Giner's DSM™ membrane construction has high strength polymers with controlled pore dimensions, optimized electromechanical performance, and properties that can operate at higher temperatures and pressures.

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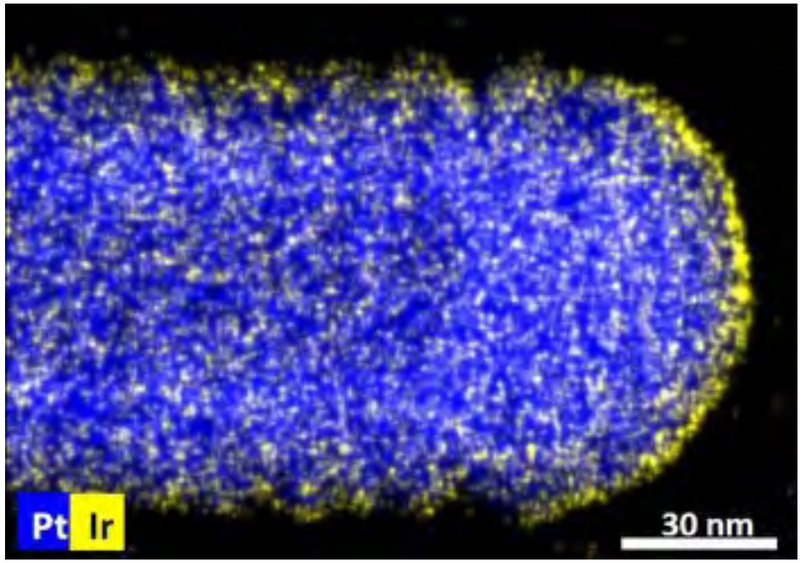
Durable Catalysts for Fuel Cell Protection during Transient Conditions

FC
Emerging

Historical

uspto
1 patent

- Being developed by 3M Company in collaboration with AFCC, Dalhousie University, ORNL, and ANL.
- Fuel cell catalysts are modified to alleviate the damaging conditions in individual fuel cells during transient periods of fuel starvation by prioritizing the oxidation of water over carbon corrosion.
- Balancing of the reduction and oxidation reactions within the fuel cell lowers the overpotential for a given current demand and reduces carbon and platinum dissolution.
- Achieves DOE technical targets for performance, platinum group metal loading, and durability.
- Decreases cost by reducing the amount of high-cost material required.
- Contract Number: DE-EE0000456 (2009)



Energy Dispersive Spectroscopic Map of 3M's Self-Protecting Catalyst

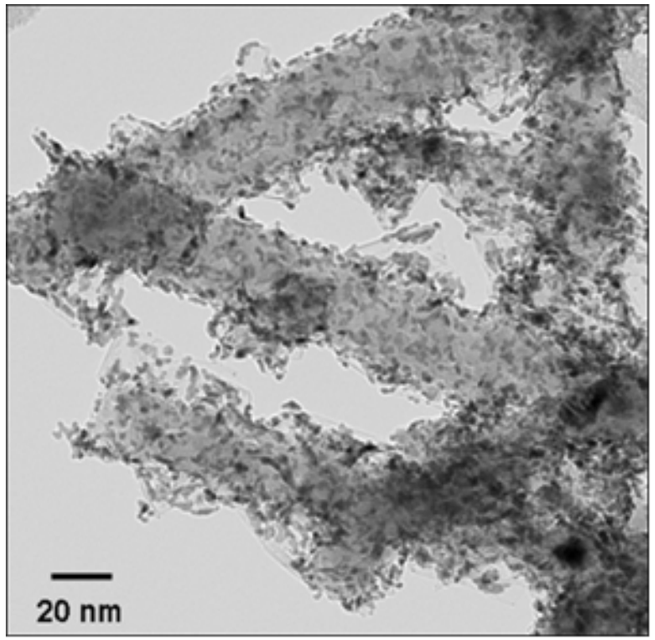
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Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells

FC
Emerging

Historical

- Developed by Nanosys, Inc., and planned to be commercialized by OneD Material, LLC.
- A catalyst support technology for use in hydrogen fuel cell vehicles, based on engineered nanostructures that improve performance characteristics.
- Can be used to increase performance and durability and reduce costs of PEM fuel cells.
- Enables high power density operation using reduced amounts of precious metal catalyst.
- Resists corrosive attack by acids or alkalis using nanographite shell covalently bonded to silicon carbide (SiC) nanowire core (which increases the total nanowire surface area to 125 m^2/g).
- Contract Number: DE-FG36-08GO88097 (2008)



TEM Image for PtRu Distribution on Nanowire Support

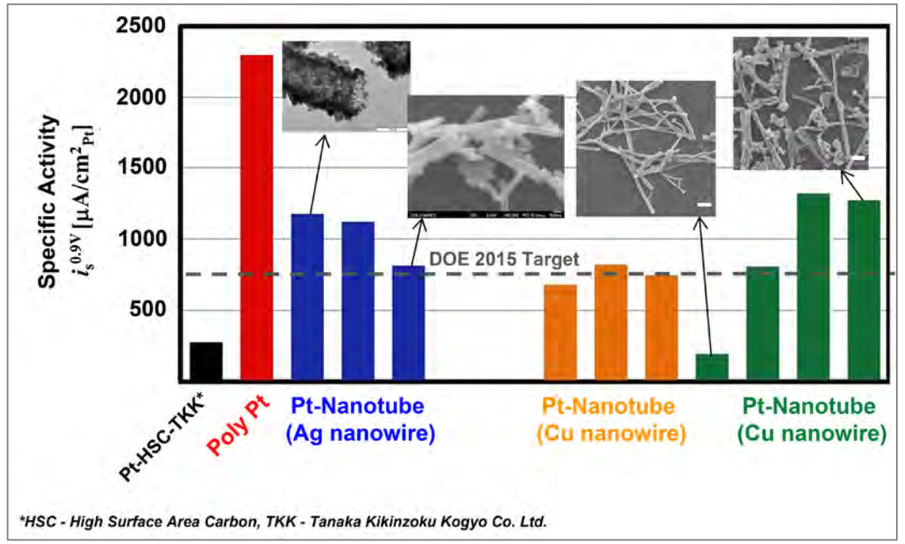
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2625 Hanover St
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Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes

FC
Emerging

Historical

- Being developed by NLR in collaboration with ORNL, LANL, University of California-Riverside, State University of New York – Albany, Stanford University, University of Tennessee, University of Texas-Austin, Nissan Technical Center North America, Cabot Fuel Cells, and Tanaka Kikinzoku Kogyo.
- Can be used in polymer electrolyte fuel cells to extend the surfaces of Pt nanocatalysts to address the low specific activities and durability of traditional Pt catalysts supported on carbon.
- Uses galvanic displacement to produce continuous Pt nanostructures.
- Achieves increased specific activity and durability against cycling and carbon corrosion compared with traditional Pt/C systems.
- Uses less Pt material to reduce material costs and the balance of plant cost to process the materials.
- Uses a scalable wet chemical production process to produce material quantities required for mass production.
- Contract Number: DE-AC36-08GO28308 (2009)



NLR's Pt Electrode Nanostructured Technology

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Fuel Cell Hybrid Electric Delivery Van

FC
Commercial

Historical

- Currently being developed by the Center for Transportation and the Environment (CTE) with sponsors California Air Resources Board (CARB), South Coast Air Quality Management District (SCAQMD), California Energy Commission (CEC).
- Partners include United Parcel Service (UPS), Hydrogenics, Unique Electric Solutions (UES), and subcontractors University of Texas – Austin Center for Electromechanics (UT-CEM).
- Increases zero-emission driving range and commercial viability of electric drive medium-duty trucks.
- Performance objectives include 125-mile driving range and cover over 95% of UPS routes.
- Could positively impact commercial viability of electric drive medium-duty trucks.
- Demonstrated proof-of-concept vehicle with UPS for one year.
- Public fueling infrastructure enabled successful operation out of multiple UPS centers.
- Phase 2 began with plans to deploy an additional 15 fuel cell hybrid electric walk-in delivery vans within the UPS delivery fleet.
- Contract Number: DE-EE0006523 (2014)



UES photo of vehicle updated based on phase 1 issues



The vehicle fueling at the Linde station in West Sacramento

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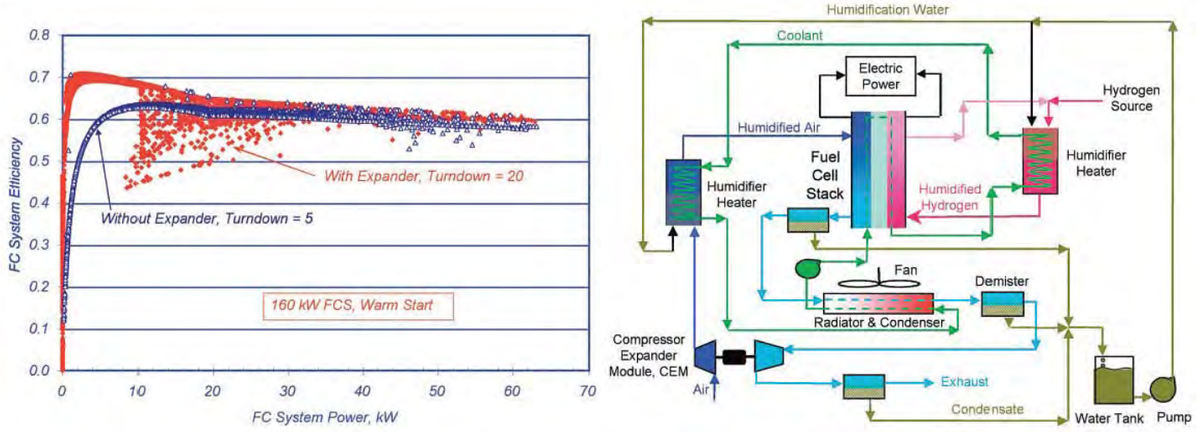
GCTool: Fuel Cell Systems Analysis Software Model

Pacific Northwest NATIONAL LABORATORY

FC Commercial

Historical

- Developed by Argonne National Laboratory (ANL) and commercialized in 1999.
- Can be used to develop component or system configurations and simulations to evaluate developmental components and systems against efficiency targets for fuel cell deployment.
- Enables modeling and analysis of various fuel cell subsystems and portfolios, including polymer electrolyte, molten carbonate, phosphoric acid, and solid oxide fuel cells' designs.
- Offers a library of models for subcomponents and property tables common to many systems and allows users to add their own component models, if needed.
- Allows for modeling and simulation of systems with rapid turnaround time for analysis and troubleshooting, as well as testing and validation without incurring the time and costs of building a prototype.
- Over 70 licenses for GCTool have been sold to Universities, Commercial Research and Manufacturing organizations, and U.S. Government Contractors.
- GCTool has not been actively being licensed since 2012, but further developments and improvements to the program are continuing to be done internally at ANL.
- Contract Number: W-31-109-ENG-38 (1998)



Effect of Expander on Dynamic System Efficiency over an Urban Drive Cycle (Left)
Schematic Diagram of a Hydrogen-Fueled Polymer Electrolyte Fuel Cell System for Automotive Applications (Right)

Argonne NATIONAL LABORATORY

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GenCore® Backup Fuel Cell Systems

FC
Commercial

Historical

- Developed by Plug Power, Inc., in collaboration with BellSouth, Airgas, ANL, and Telcordia Labs.
- Hydrogen fuel cell power supplies that provide backup power fueled by clean hydrogen.
- Can be used anywhere backup power is required.
- The system produces power silently, and the only byproduct is water.
- Helps lessen dependency on foreign oil.
- Instant startup and low maintenance requirements.
- Modular design allows multiple unit installations for more power. Duration may be increased by adding more hydrogen cylinders.
- Contract Number: DE-SC36-03GO13097 (2003)



Figure 1. GC5T Installed at Host's Cell Tower

Plug Power 5U at New Mexico National Guard



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GenSys® Blue: High-Temperature CHP Fuel Cell System (ARRA)

FC Emerging

Historical

- Developed by Plug Power, Inc., and demonstrated units with partners Sempra Energy and University of California - Irvine.
- A high-temperature PEM system that provides efficient electricity generation and high-quality waste heat (GenSys Blue).
- Can be used to provide electricity, space heating, and hot water for residential and light commercial buildings.
- Integrates easily with existing hydronic and forced-air heating systems.
- Reduces residential utility bills by 20%-40%.
- Reduces residential CO2 emissions by 25%-35%.
- Contract Number: DE-EE0000480 (2009)

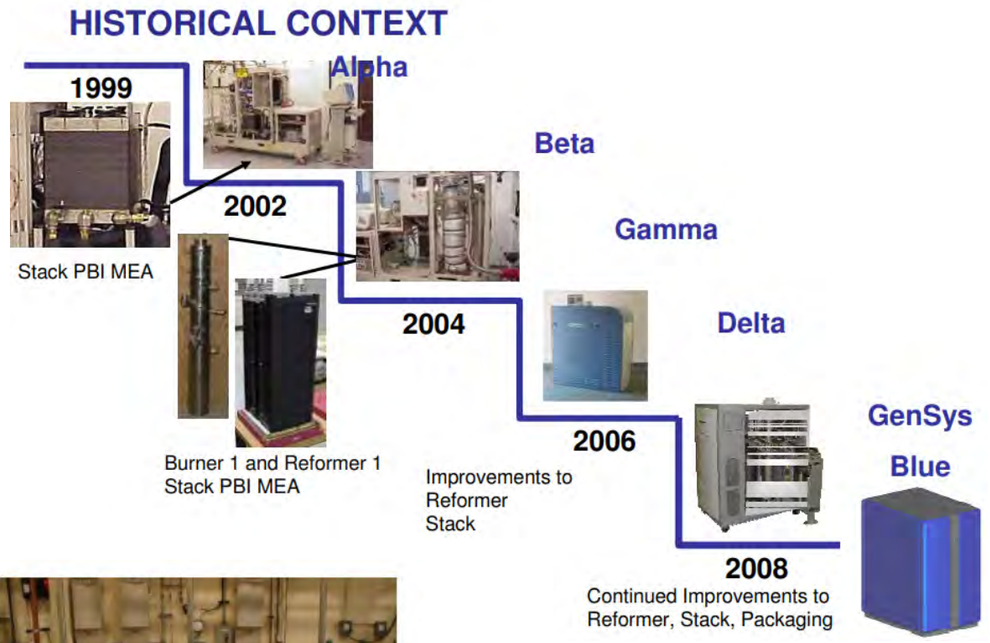




Figure 2: Plug Power Reliability Testing Fleet (Plug Power lab, left; UCI lab, right)

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Ground Support Equipment Demonstration

FC
Emerging

Historical

- Developed by Plug Power, Inc. in collaboration with FedEx Express and Charlatte.
- Can be used as an alternative power system for ground support applications, e.g., tow-tractors, baggage, and materials handling.
- Provides a hydrogen-fuel-cell-based power source alternative to petroleum or battery power sources.
- Drawbar capacity of 5,000 lb. (40,000 lb. of pulling capacity).
- Eliminates CO2 emissions when compared to petroleum-based power units that in the case of diesel, release 10.1 kg of CO2 per gallon.
- Fuel savings for medium and large fleets above 30 units and elimination of downtime when compared to diesel equipment which requires particulate filter regeneration.
- Contract Number: DE-EE0006093 (2013)



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High-Efficiency Polymer Electrolyte Membrane Fuel Cell Combined Heat and Power System

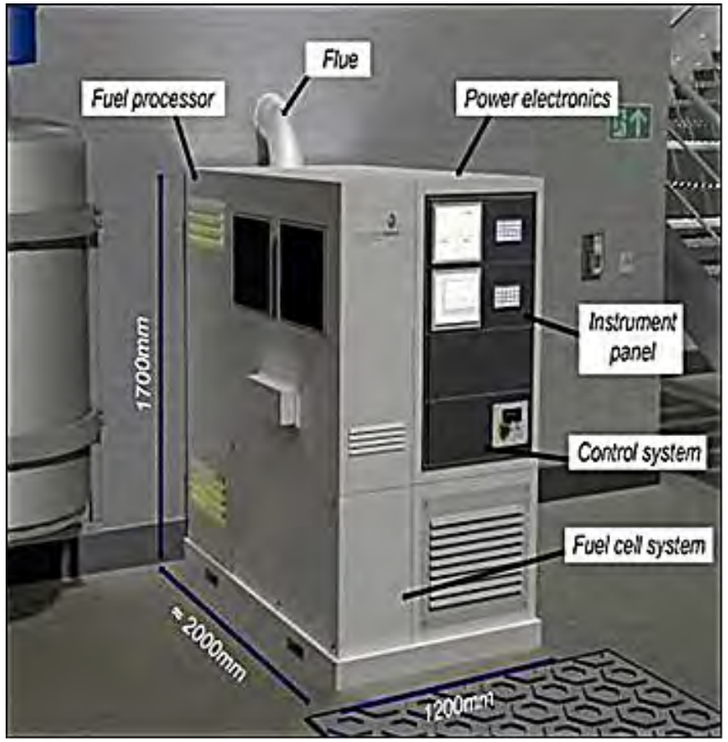
Pacific Northwest NATIONAL LABORATORY

FC Emerging

Historical

uspto 6 patents

- Developed by Intelligent Energy, Inc. in collaboration with Scottish and Southern Energy Ltd.
- Can be used to provide electrical and space heating requirement for light-industrial installations or multi-residential dwellings.
- Achieves 35% electrical efficiency, with greater than 70% combined efficiency possible (dependent on application).
- Reduces the frequency of maintenance periods by using local and remote systems health monitoring.
- Reduces CO2 emissions by five tons per year relative to similarly-sized conventional gas engine systems.
- Contract Number: DE-FG36-07GO17013 (2007)



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Intelligent Energy

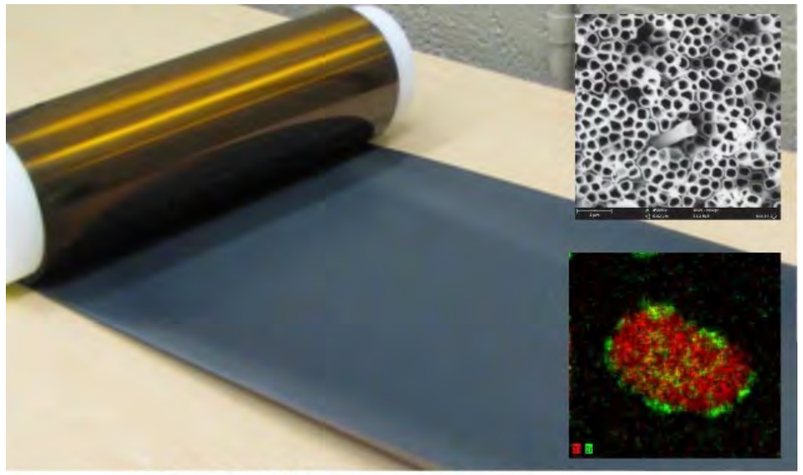
Scottish and Southern Energy

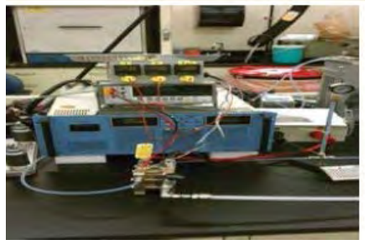
High-Performance, Long-Lifetime Catalysts for Proton Exchange Membrane Electrolysis (SBIR)

FC
Emerging

Historical

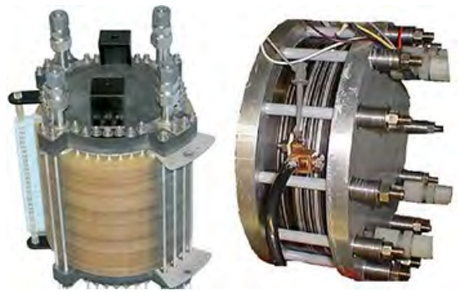
- Developed by Giner, Inc. in collaboration with 3M Company and NLR.
- Currently further optimizing the process for catalyst synthesis scale-up conducting durability tests.
- Can be used for hydrogen production by water electrolysis.
- Provides enhanced catalyst performance by increasing the oxygen evolution reaction (OER), mass and specific activities compared to the baseline Ir black catalyst.
- Produces up to 10g/batch of the Ir/W-TiO_2 catalyst.
- Reduces electrolyzer capital cost by producing high performance catalysts that enables the use of less costly materials (PGMs).
- Contract Number: DE-SC0007471 (2013)











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High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure

FC
Emerging

Historical

uspto
1 patent

- Developed by Cabot Superior MicroPowders in partnership with DuPont Fuel Cells, CFD Research Corp., and Hydrogenics Corp.
- A complete system for combinatorial discovery of fuel cell electrocatalysts consisting of rapid powder synthesis, primary electrochemical testing screen, automated electrode printing, and testing in MEA configurations.
- Can be used to develop and test new MEAs.
- Provides a combinatorial electrocatalyst synthesis platform based on spray conversion.
- Allows rapid synthesis and testing of electrocatalysts and reduces research costs.
- Contract Number: DE-FC0402AL67620 (2001)



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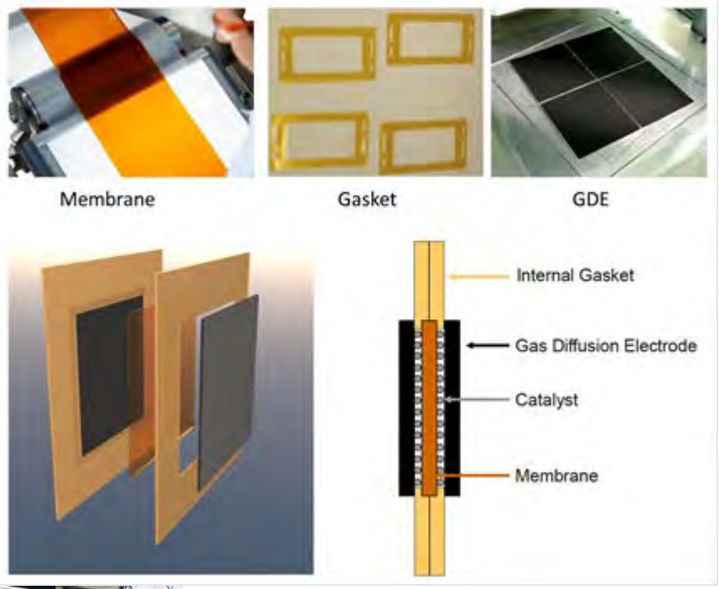
High-Speed, Low-Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies

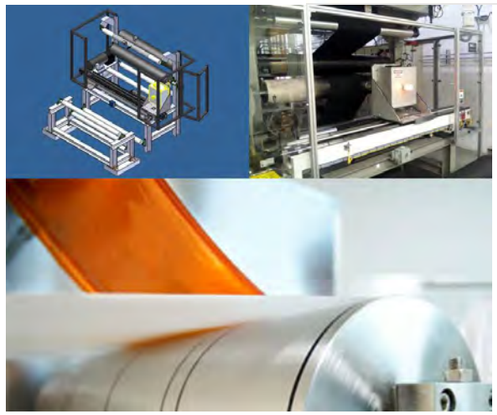
FC
Commercial

Historical

uspto
3 patents

- Developed by BASF in collaboration with Case Western Reserve University.
- Product from this work was commercially deployed since Q2 2012 (Celtec® P1100W MEA).
- Used for manufacturing high temperature PEM fuel cells for a wide variety of stationary and mobile power systems.
- Electrodes improve performance and lower MEA cost of manufacturing high-temperature PEM fuel cells.
- Process lowers catalyst coating variation, allows “one pass” coating on carbon paper, and reduces Pt loading without impacting performance.
- Contract Number: DE-EE0000384 (2009)





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BASF Fuel Cell Inc.
Address: n/a
Website: n/a

- Note: BASF elected to get out of MEA market on 8/1/2013

High-Temperature Membrane with Humidification-Independent Cluster Structure

FC Emerging

Historical

- Developed by FuelCell Energy, Inc., in partnership with the University of Central Florida, Scribner Associates, Inc., and Oak Ridge National Laboratory.
- Improved cathode electrode formulation enabled a fuel cell with mC2 membrane to reach performance at a rated power of 1247 mW/cm^2 (DOE 2017 target: 1000 mW/cm^2).
- Can be used to improve the performance of polymer electrolyte membrane fuel cells over a wide range of temperature and humidity.
- Lowers overall system cost by reducing fuel cell system complexity.
- Increases mechanical strength.
- Contract Number: DE-FC36-06GO16033 (2006)

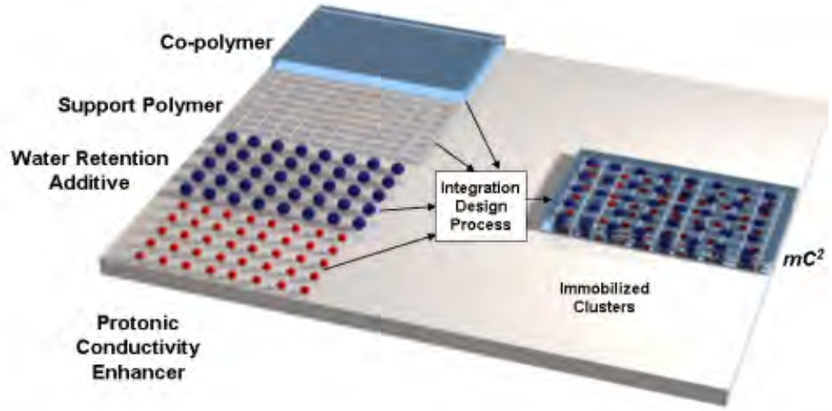


Figure 3. Multi-Component Composite Membrane (mC^2) Concept: Multi-Component System with Functionalized Additives.

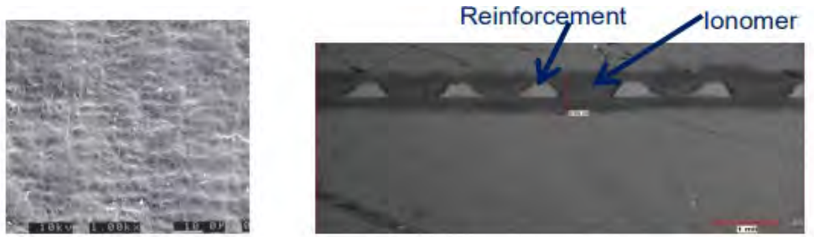


Figure 29. Improvements in Fabrication of Supported Membrane of ≤25 µm: Improved membrane and MEA fabrication protocols resulted in an increased yield of >50% in laboratory fabrication.

Contact Information:

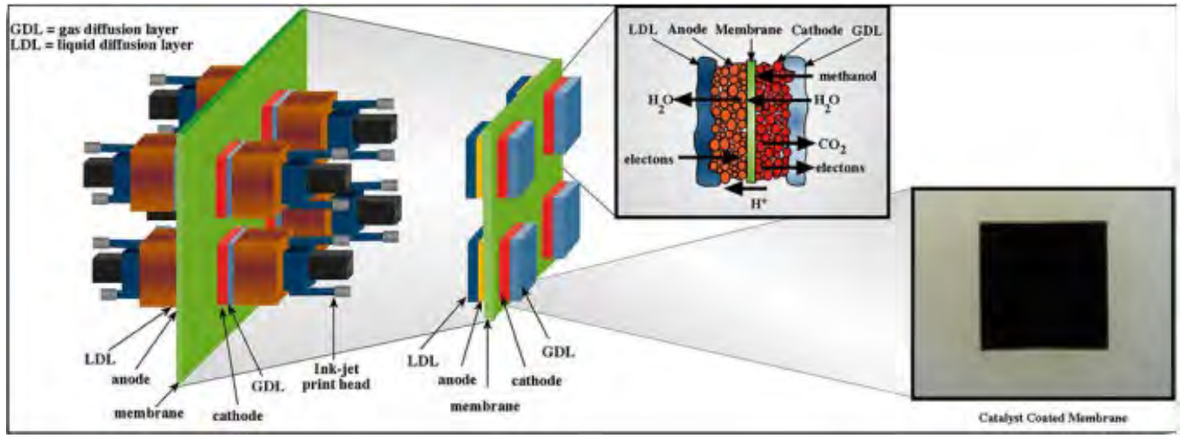
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Improved Catalyst Coated Membrane (CCM) Manufacturing

FC Commercial

Historical

- Developed by Cabot Corporation. IRD Fuel Cells, LLC is now operating MEA manufacturing process. IRD is further developing the process and MEA materials. Commercialized in 2008.
- Can be used to manufacture CCMs/MEAs for DMFCs or other industries, e.g., membrane reactors, gas separation membranes coated with selective catalysts, other types of fuel cells (e.g., solid oxide fuel cells), electrolyzers, ultracapacitors, batteries, and other coated membrane applications.
- Reduces the cost of manufacturing CCMs/MEAs and the amount of expensive precious metals used in a fuel cell.
- Allows higher production and higher yields.
- Can be used with existing spray deposition systems and allows quick changeover to different materials.
- Contract Number: DE-FC36-04GO14217 (2004)



Catalyst Coated Membrane Manufacturing Process

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Improved Low-Cost, Durable Fuel Cell Membranes

FC
Emerging

Historical

uspto
4 patents

- Developed by Arkema, Inc., in partnership with Johnson Matthey Fuel Cells, Inc., Oak Ridge National Laboratory, Virginia Polytechnic Institute and State University, and the University of Hawaii.
- Can be used in membrane electrode assemblies in fuel cells suitable for both automotive and stationary applications.
- Increases the durability of membrane electrode assemblies in fuel cells.
- Can be mass-produced because of simpler preparation process.
- Contract Number: DE-FC36-04GO14051 (2007)

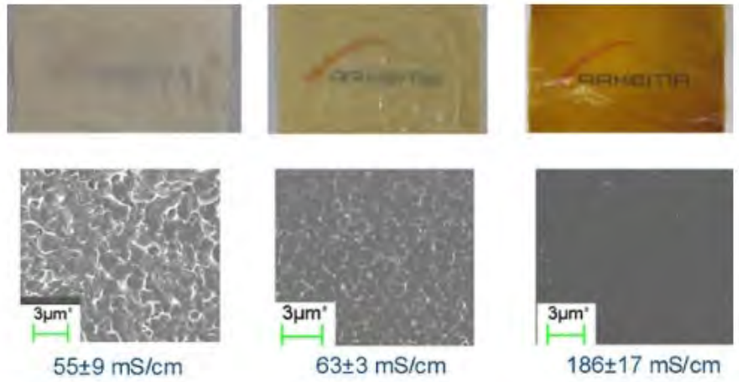
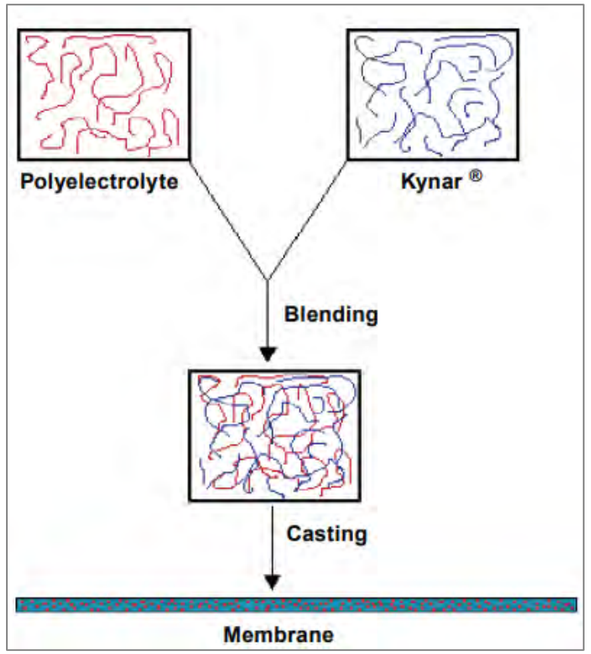


FIGURE 3. Depiction of blending process optimization. Left to right – improved polymer blending. Top row: optical micrographs of membrane samples showing increasing transparency. Bottom row: scanning electron microscopy images of membrane microstructure.



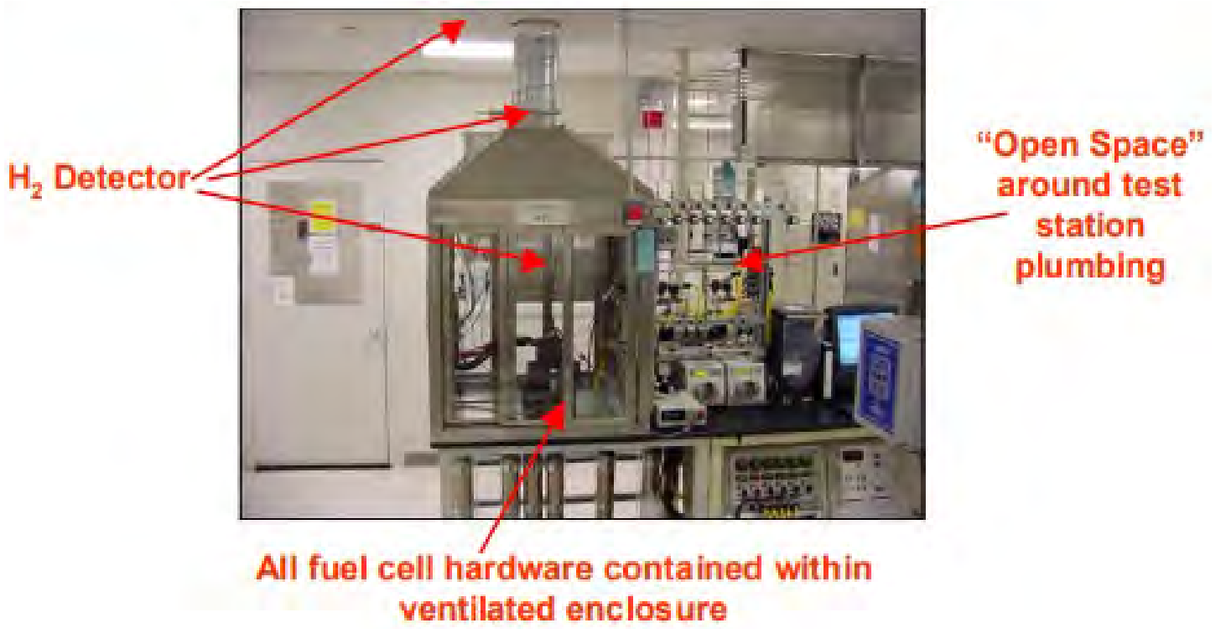
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Integrated Manufacturing for Advanced Membrane Electrode Assemblies

FC Commercial

Historical

- Developed by BASF Fuel Cell, Inc.
- Objectives included allowing an overall cell performance greater or equal to 0.4A/cm^2 at 0.8V or 0.1A/cm^2 at 0.85V operating on hydrogen/air with precious metal loadings of 0.3mg/cm^2 or less and scales to mass manufacturing technology.
- Achieved a 50% reduction in platinum powder density.
- Created a low-temperature process (<200 deg C) for alloy formation.
- Were working to achieve simultaneously three properties of conductivity, thermal stability, and swelling.
- Contract Number: DE-FC04-02AL67606 (2001)



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Address: n/a
Website: n./a

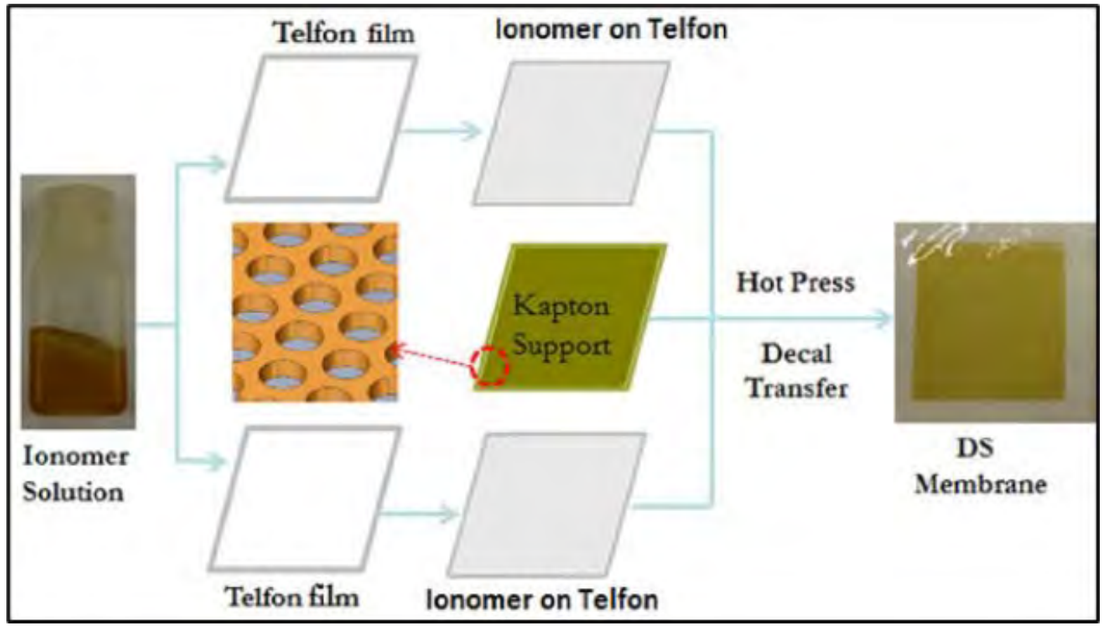
Note: BASF elected to get out of MEA market on 8/1/2013

Ionomer Dispersion Impact on Advanced Fuel Cell and Electrolyzer Performance and Durability (SBIR)

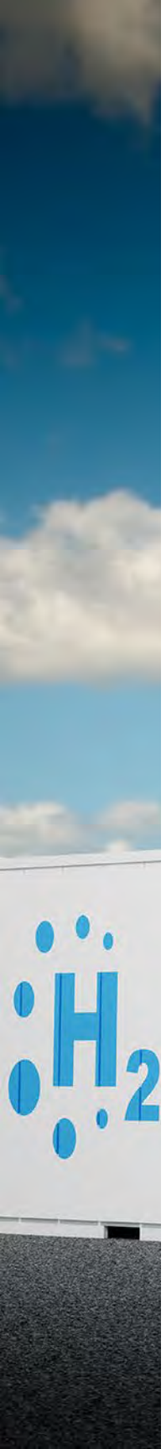
FC
Emerging

Historical

- Being developed by Giner, Inc. with assistance from Los Alamos National Laboratory (LANL).
- Can be used to create hybrid PEMs using LANL's ionomer technology and Giner's DSM supports.
- Exhibits high proton conductivity and improved mechanical properties.
- Creates processable and scalable membranes and MEAs that are chemically and mechanically stable.
- Reduces the cost of PEM electrolyzer stacks.
- Contract Number: DE-SC0012409 (2014)



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Lifetime Improvements for PEM Fuel Cells

FC
Commercial

Historical

- Initially researched by DuPont Fuel Cells in 2003 where they have marketed the first chemically stable Nafion® products (resins, dispersions, membranes, and membrane electrode assemblies) in 2005.
- Can be used in both fuel cells and water electrolyzers using PEMs.
- Achieves significantly improved lifetime in fuel cell applications.
- Demonstrates 50% reduction in swell compared with an earlier DuPont Nafion® NRE211 membrane.
- Reduces replacement costs of increased membrane durability.
- Significantly improves membrane lifetime in accelerated lifetime testing for simulating an automotive drive-cycle.
- Contract Number: DE-FC36-03GO13100 (2003)



DuPont Nafion Resins, Dispersions, Membranes, and Membrane Electrode Assemblies

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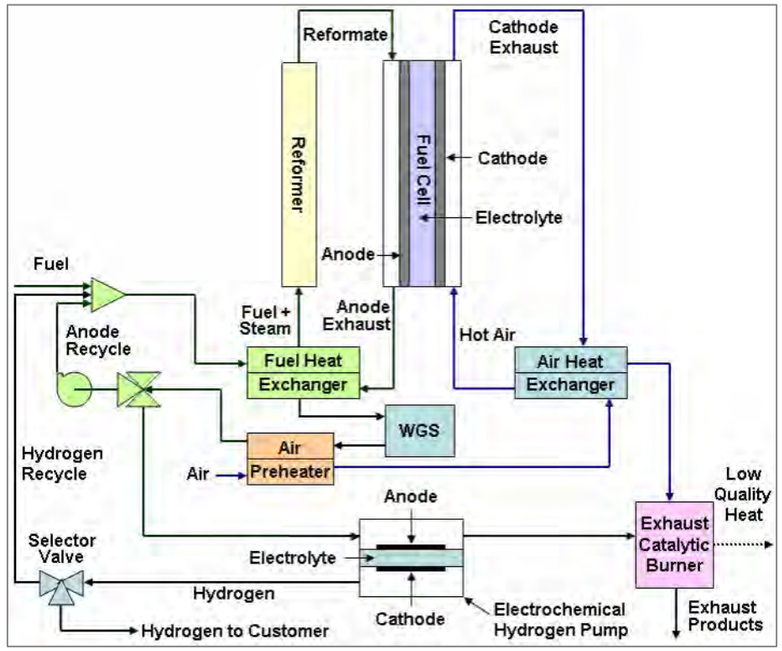
Low-Cost Co-Production of Hydrogen and Electricity

FC
Emerging

Historical

Pacific Northwest
NATIONAL LABORATORY

- Developed by Bloom Energy Corporation in partnership with the University of Alaska and Udelhoven Oilfield System Services.
- May be used to increase the efficiency of SOFCs or to generate pure hydrogen for use by PEM fuel cells.
- Utilizes waste gas from SOFCs to generate pure hydrogen.
- Increases the efficiency of SOFCs when the pure hydrogen gas is recycled.
- Integrated SOFC system with a full-scale hydrogen pump from H2 Pump, LLC, with a successful demonstration at their site in Moffett Field, CA.
- Contract Number: DE-FC36-0515195 (2006)



Flow diagram of Bloom Energy's SOFC System



FIGURE 4. Prototype Electrochemical Hydrogen Pump from H2 Pump LLC (Latham, NY)

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Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies (MEAs)

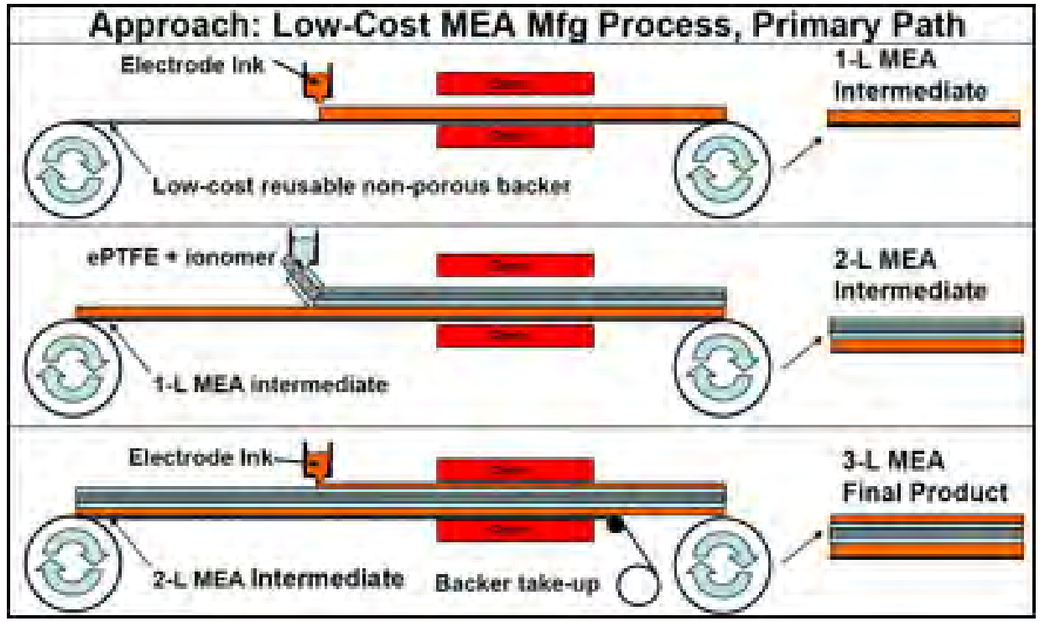
Pacific Northwest NATIONAL LABORATORY

FC Emerging

Historical

uspto 1 patent

- Developed by Gore in collaboration with UTC Power, National Laboratory of the Rockies, Strategic Analysis, Inc., University of Delaware, and University of Tennessee, Knoxville.
- Can be used in fuel cell applications for transportation, backup power, and portable power.
- Achieves DOE 2015 targets for high-volume manufacturing and durability and MEA conditioning times of less than four hours.
- Offers scalable high-volume manufacturing process.
- Achieves MEA manufacturing consistent with achieving DOE's cost target of $15/kWe.
- Reduces waste material and solvent during processing.
- Produces a product that is compatible with automotive assembly line manufacturing.
- Contract Number: DE-FC36-086018052 (2008)



GORE

UTC Power
A United Technologies Company

National Laboratory of the Rockies

STRATEGIC ANALYSIS INC

UNIVERSITY OF DELAWARE

THE UNIVERSITY OF TENNESSEE KNOXVILLE

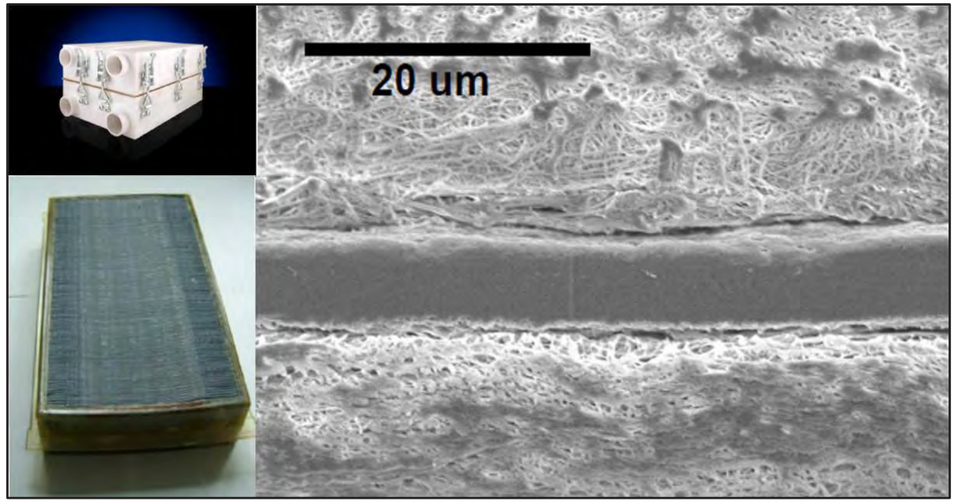
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Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers

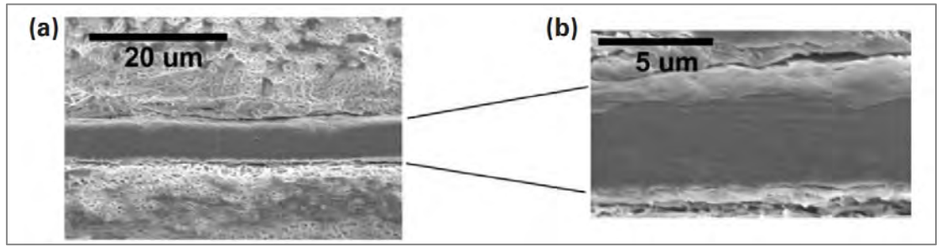
FC
Emerging

Historical

- Developed by W.L. Gore & Associates, Inc., and subcontracted to dPoint Technologies Inc., in collaboration with industry partners.
- Continuing work involves collaboration with Automotive OEMs in fuel cell applications.
- Can be used for transportation or stationary applications.
- Increases water transport within a cell.
- Reduces system costs by using less expensive materials and decreasing overall system size.
- Can be used for non-fuel-cell applications that require optimized systems with high water transport rates.
- Contract Number: DE-EE0000465 (2010)



W.L. Gore's Membrane and High Transport Rate Modulus



Composite microstructure shown in (a), ability to prepare very thin ionomer layers in the composite shown in (b).

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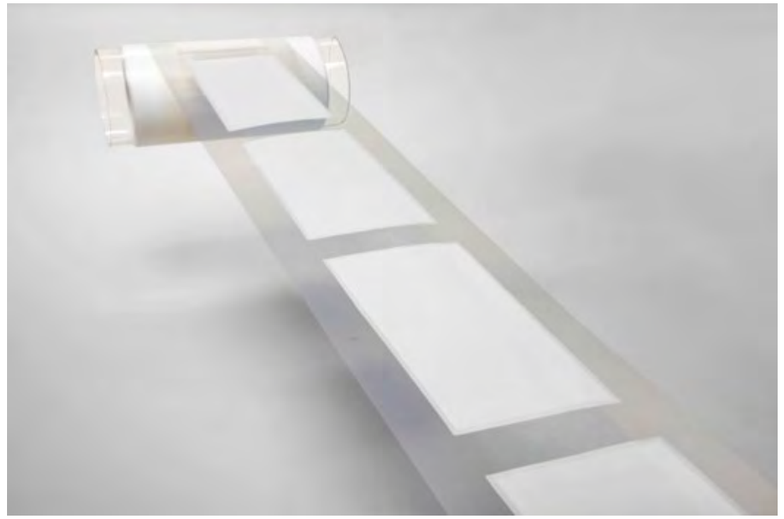
Membranes and Membrane Electrode Assemblies (MEAs) for Dry, Hot Operating Conditions

FC Commercial

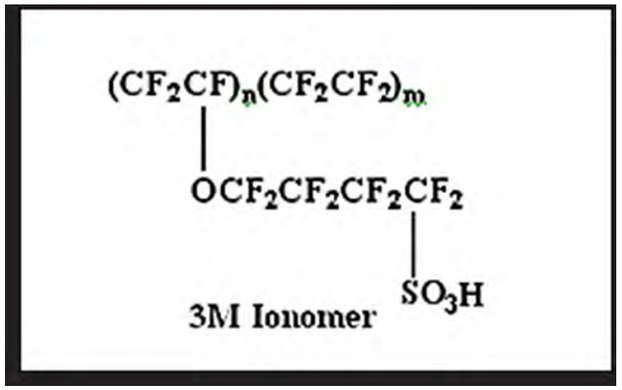
Historical

uspto 24 patents

- Developed by 3M Company and commercialized in 2006.
- Used in PEM fuel cells for transportation, stationary, and back-up power applications.
- Provides lower cell resistance and improved performance under hot and dry conditions. This allows the use of fewer cells, and thus less humidification or cooling equipment is required.
- Provides higher cell voltage in fuel cell systems running at higher temperatures and/or lower humidification, allowing greater fuel efficiency.
- Improves system performance by enabling operation under a wider range of temperature and humidity.
- Contract Number: DE-FC36-02AL67621 (2002) and DE-FG36-07GO17006 (2007)



Membrane Windows in a Roll Good Film Subgasket



The 3M Ionomer with Lower Equivalent Weight Side Chain than Standard PFSA Ionomers

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Nanostructured Proton Exchange Membrane (SBIR)

FC
Emerging

Historical

- Developed by eSpin Technologies, Inc.
- A low-cost nanofiber-reinforced polymer electrolyte membrane that is thin, strong, and chemically robust, and does not swell when in contact with water.
- Will be produced using low-cost non-fluorinated polymers.
- Will be composed of a robust ionomer having inorganic backbone embedded in a reinforcing network of sub-micron diameter fibers co-electrospun from a thermally and chemically stable polymer.
- Aims to accelerate the deployment of automotive fuel cells and have a significant positive environmental impact.
- Cost effective and works with existing PEM fuel cell systems manufacturing infrastructure (all will be manufactured in Chattanooga, TN, USA).
- Contract Number: DE-SC0019876 (2019)





eSpin's nanofiber manufacturing facilities

Nanofibers for a Better World®

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Nectar™ : Mobile Power System: Silicon-Based SOFC for Portable Consumer Electronics

FC
Commercial

Historical

- Developed by Lilliputian Systems Inc. (LSI) in partnership with Alfred University and the Missouri University of Science and Technology.
- In 2012, Brookstone was announced as first retail partner.
- Can be used as an alternative to conventional wall outlet and battery-based devices for charging portable consumer electronics.
- Delivers 2.5 watts of power with a run time of more than 30 hours per cartridge.
- Increases energy efficiency and reduces carbon footprint relative to using electricity provided from a wall outlet.
- Provides convenient, on-the-go power and eliminates the need for a wall outlet to recharge electronic devices.
- Contract Number: DE-FG36-08GO88102 (2008)





Contact Information:

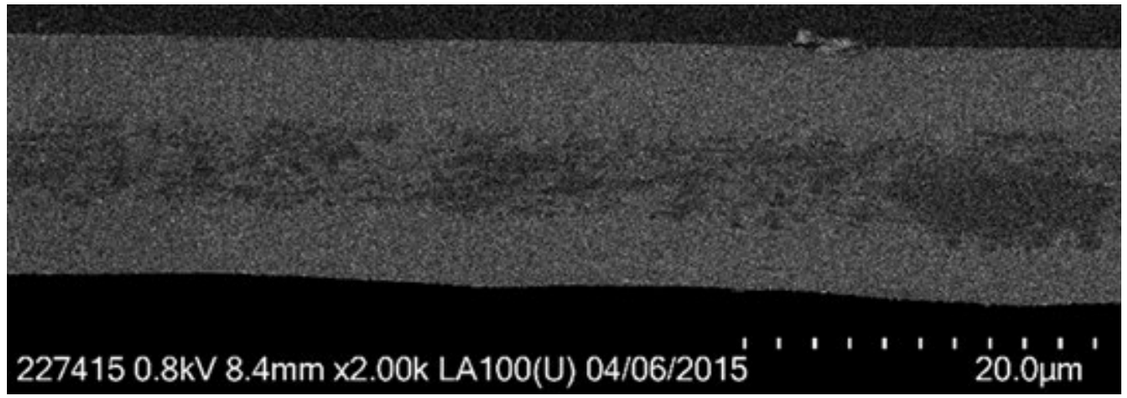
Email: n/a
Phone: n/a
Lilliputian Systems, Inc.
Address: n/a
Website: n/a

New Fuel Cell Membranes with Improved Durability and Performance

FC
Emerging

Historical

- Developed by 3M Company with assistance from General Motors and Vanderbilt University.
- Currently testing the membranes in a fuel cell stack.
- Can be used in PEM fuel cells for automotive or stationary applications.
- Exceeds DOE 2020 target for mechanical durability (>20,000 cycles until >15 mA/cm^2 H2 crossover).
- Exceeds DOE 2020 target for chemical durability (>500 hours of operation until >15 mA/cm^2 H2 crossover or >20% loss in open circuit voltage).
- Contract Number: DE-EE0006362 (2013)



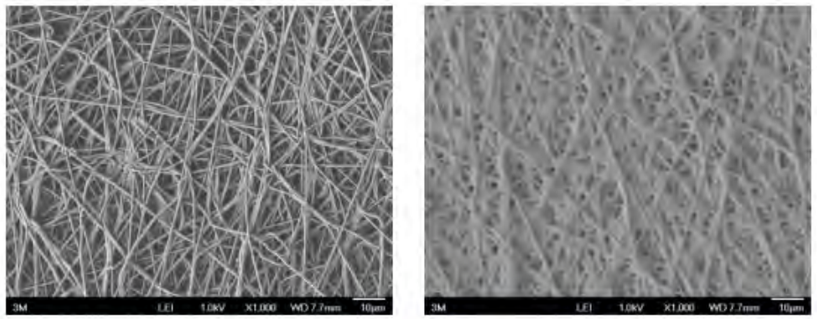


Figure 10. Electron microscope images of nanofiber samples S18 (left) and S19 (right).

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Nitrided Metallic Bipolar Plates for PEM Fuel Cells

FC
Emerging

Historical

uspto
3 patents

- Developed by ORNL, in collaboration with Arizona State University, ATI Allegheny Ludlum Corp., LANL, and NLR.
- Can be used for PEM fuel cell bipolar plates but may be applicable to any electrochemical device component requiring high electrical conductivity and corrosion resistance (e.g., batteries, sensors, and supercapacitors).
- Allows formation of continuous surface nitride layers on complex-shaped components.
- Lowers interfacial contact resistance (ICR) in fuel cells.
- Reduces corrosion in fuel cells.
- Extends the lifespan of fuel cell bipolar plates by reducing corrosion.
- Contract Number: DE-AC05-00OR22725 (2007)



ORNL's Nitrided Metallic Bipolar Plates (Produced in Collaboration with DANA Corp., Tennessee Technological University, and the Universita of South Carolina)

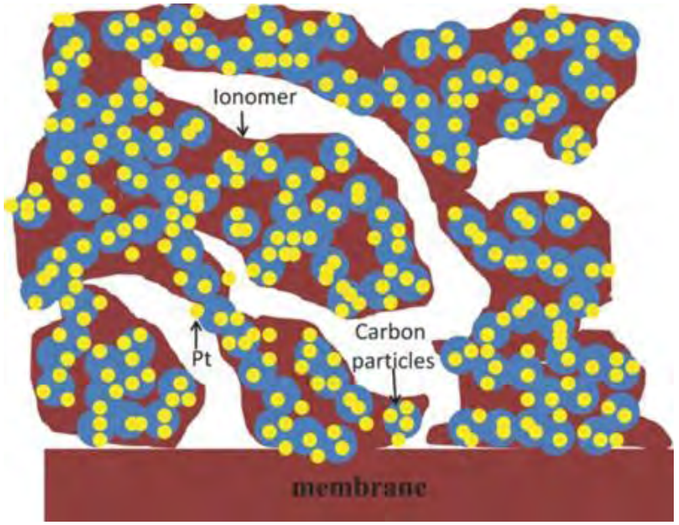
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Novel Fluorinated Ionomer for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR)

FC
Emerging

Historical

- Currently being developed by Giner, Inc., in collaboration with Compact Membrane Systems, the University of Connecticut, and the University of California, Irvine.
- Developing a high oxygen permeability ionomer (HOPI) to reduce local oxygen transport loss.
- This will be done by utilizing a polymer backbone to contain molecules with more space available for gas transport.
- Improves O_2 permeability by 5x compared to Nafion® baseline.
- Potentially introduce alternative ionomer materials to the market that enable higher power densities.
- Contract Number: DE-SC0018597 (2019)



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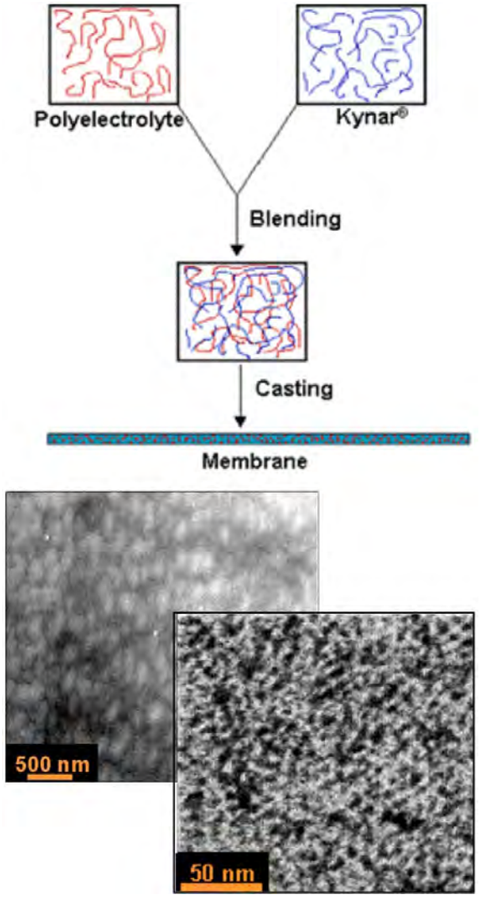
Novel Materials for High Efficiency Direct Methanol Fuel Cells (SBIR)

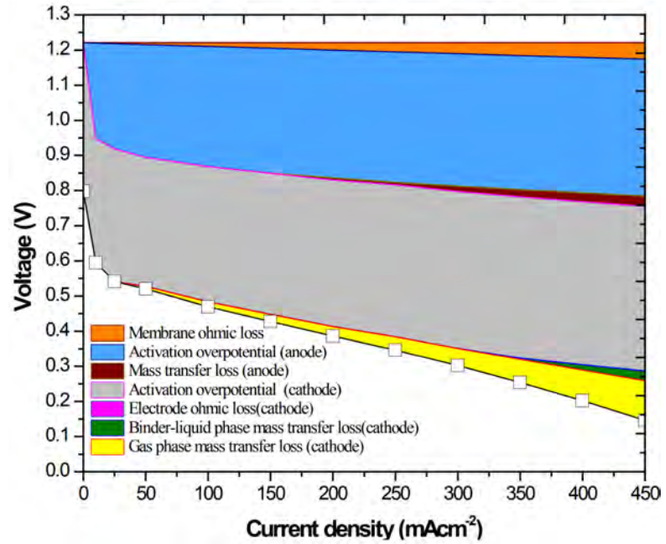
FC
Emerging

uspto
5 patents

Historical

- Developed by Arkema, Inc., in collaboration with Illinois Institute of Technology (IIT) and QuantumSphere Inc. (QSI).
- Developed two metal alloy catalysts that showed > 75 mW/mg PGM specific power in 0.1M MeOH.
- Developed a cathode preparation process using Pt/C.
- Composite membranes were successfully prepared with sulfonic acid containing precursor and showed improved selectivity compared to previous composites.
- 120mW/cm^2 (Go/No-Go target) was achieved with Arkema membrane and a commercial GDE or lab-made GDE with commercial Pt catalyst in 1-2M methanol.
- Initiated investigation of electrode fabrication techniques for MEA development.
- Contract Number: DE-EE0000474 (2010)





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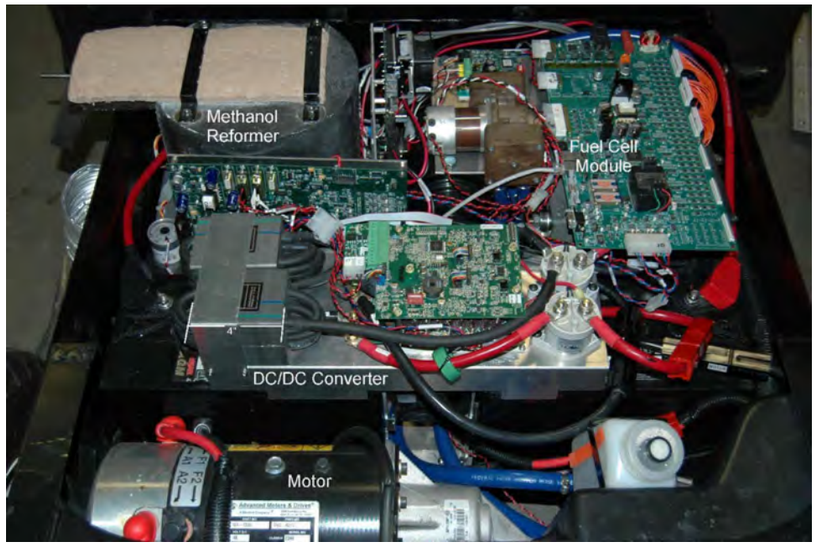
Off-Road Fuel Cell Applications

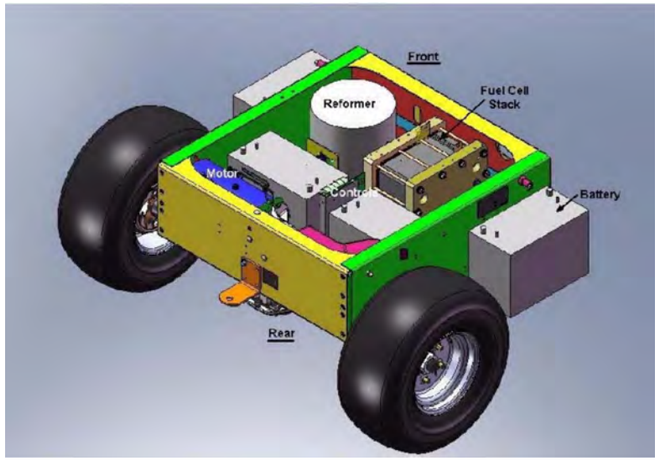
FC
Emerging

Historical

Pacific Northwest
NATIONAL LABORATORY

- Developed by IdaTech, LLC, in collaboration with The Toro Company, University of California, Davis, and Donaldson.
- S&V field tests on the Toro Workman® vehicle with IdaTech FCS 3000 Liquid Fueled Fuel Cell System performed.
- Established a comprehensive data base of Fuel Cell System requirements for Off-Road Vehicles.
- Developed two generations of advanced PEM Fuel Cell Systems.
- Prototype vehicle project great success making significant progress toward the manufacturing of Green Vehicle for golf course, parks, and recreation maintenance vehicles.
- Potential for liquid-fueled fuel cell-powered vehicles in industrial settings.
- Contract Number: DE-FG36-04G014303 (2007)







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IDATECH SOLUTIONS

TORO®

UC DAVIS
UNIVERSITY OF CALIFORNIA

Donaldson.

Platinum-Group-Metal Recycling Technology

FC Emerging

Historical

uspto 5 patents

- Developed by BASF Catalysts, LLC, in partnership with Ceralink, Inc.
- Technology will be ready for commercialization once a market for precious metal recovery from fuel cells developes.
- Can be used to provide a recycling option for used fuel cells that eliminates the formation of hydrogen fluoride fumes.
- Allows for single process batching of multiple fuel cell types.
- Achieves high process yields independent of MEA aging history, membrane construction, or electrocatalyst composition.
- Recovers > 98% of the platinum in MEAs.
- Contract Number: DE-FC36-03GO13104 (2003)

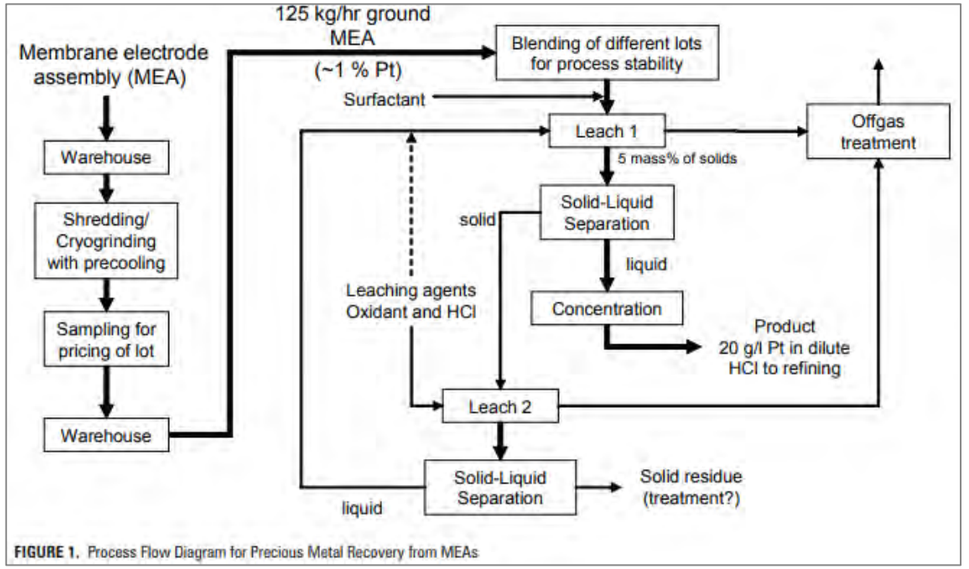
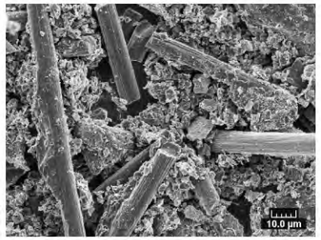
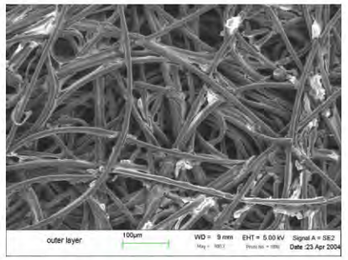


FIGURE 1. Process Flow Diagram for Precious Metal Recovery from MEAs



Ground CCM MEA, 1000x magnification



Intact GDL from a CCM MEA, 500x magnification

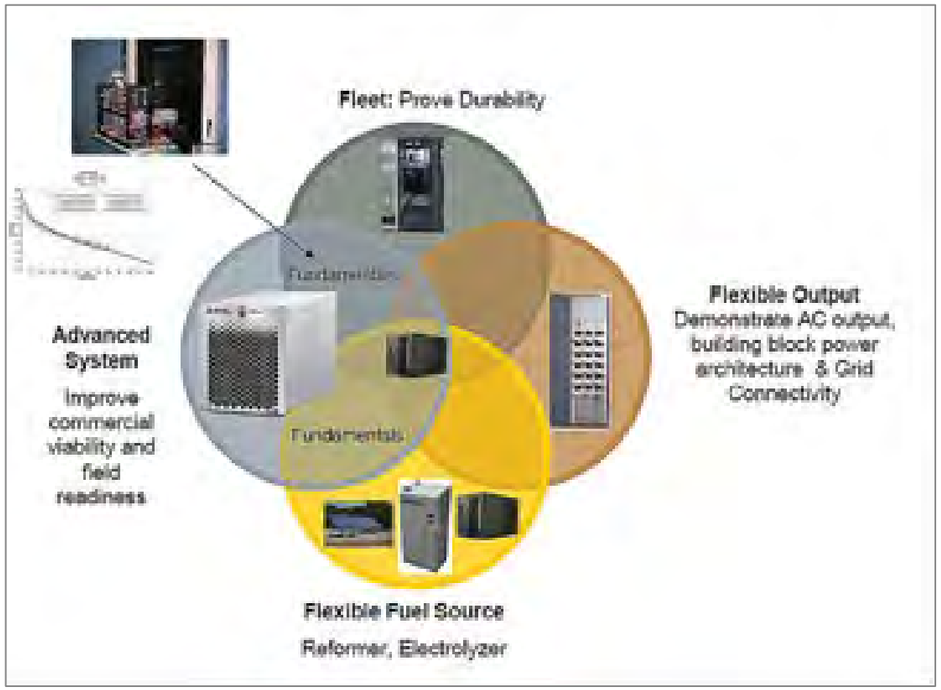
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Polymer Electrolyte Membrane (PEM) Fuel Cell Power Plant Development and Verification

FC
Emerging

Historical

- Developed by UTC Power in partnership with the Houston Advanced Research Center, U.S. Hybrid Corporation, TDI Power, and Avalence, LLC.
- Technology for low-cost, high-durability stationary fuel cells using a 5-kW system platform to verify fundamental technologies in a complete system environment.
- Can be used to provide clean, efficient power for stationary applications.
- Eliminates noise and pollution associated with conventional supplies.
- Reduces development costs to close technology gaps by using a 5-kW platform for the powerplant.
- Exceeds program requirements for membrane internal resistance, open circuit voltage, falloff time, and conductivity.
- Contract Number: DE-FG36-05GO15093 (2005)



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Website: n/a

PureMotion® 120 Fuel Cell Power Plant

FC
Commercial

Historical

- Developed and commercialized for transit bus market by UTC Power, a United Technologies Company.
- Deployed the first unit in 2005, with a total of six units delivered by 2007. Sixteen additional units with improved performance were delivered in 2010.
- Can be used to power hydrogen-fueled vehicles or as a modular stationary 120-kW power source (with appropriate power management and interface controls).
- Generates up to 120 kW of power.
- Achieves up to 2X increase in fuel efficiency compared with conventional diesel-fueled buses.
- Demonstrated on-road operation in excess of 7,000 hours at rated power without a single fuel cell replacement.
- Eliminates greenhouse gas emissions and excessive noise associated with the operation of traditional diesel-fueled buses.
- Contract Number: DE-FC36-04GO14286 (2004)



Next Generation CT TRANSIT Fuel Cell Bus powered by the PureMotion Model 120 FCPP

Contact Information:

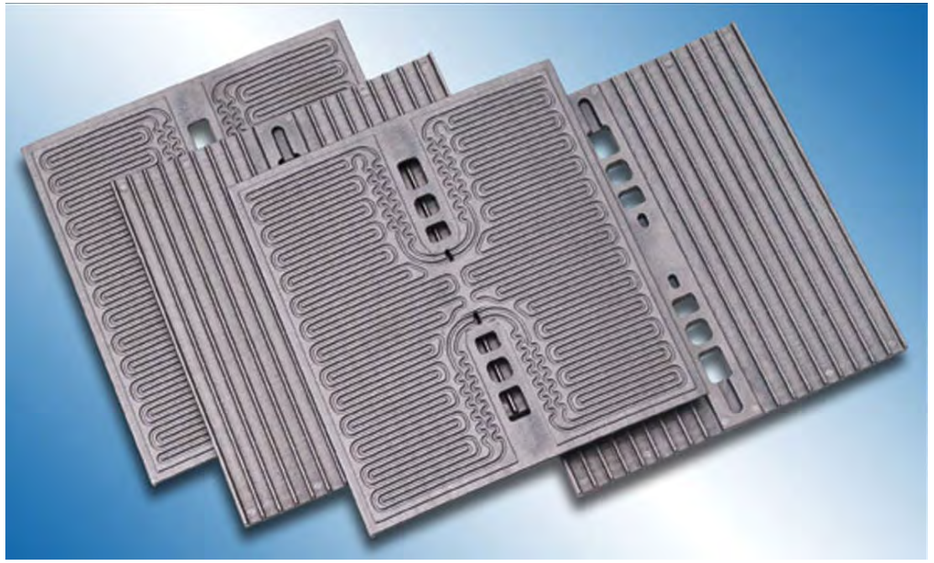
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ClearEdge Power, LLC
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Website: n/a

Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates

FC
Emerging

Historical

- Developed by GrafTech International Ltd., in collaboration with Ballard Power Systems, Inc., Huntsman Advanced Materials, and Case Western Reserve University.
- Can be used in high-temperature PEM fuel cells for transportation, materials handling, and stationary power.
- Achieves high process yields independent of aging history, membrane construction or electrocatalyst composition of the membrane electrode assembly.
- Provides continuous PEM fuel cell operation at 120°C and operates at temperatures up to 120°C.
- Can be fabricated using high-volume manufacturing processes.
- Contract Number: DE-FG36-07GO17012 (2007)



Typical Resin-Impregnated, Flexible-Graphite GRAFCELL Composite Flow

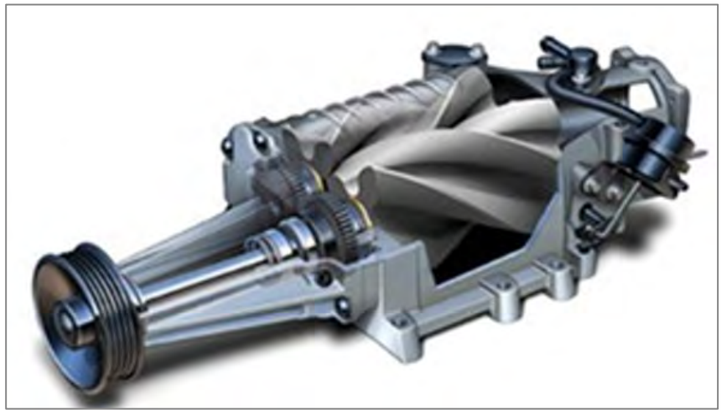
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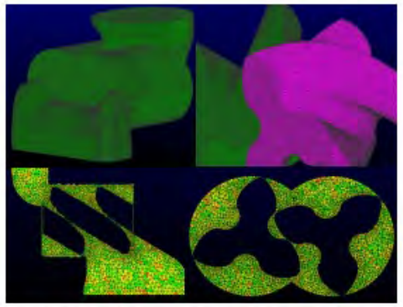
Roots Air Management System with Integrated Expander

FC
Emerging

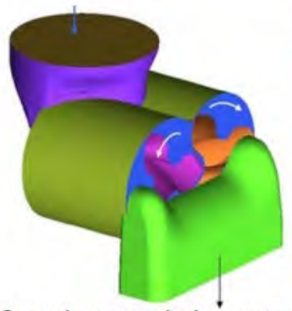
Historical

- Developed by Eaton Corporation in partnership with Ballard Power Systems, Kettering University, Argonne National Laboratory, Strategic Analysis, and Electricore, Inc.
- Can be used to improve PEM fuel cell performance on transportation applications, e.g., onboard vehicles.
- Reduces the compressor and expander speed to improve power consumption.
- Provides an overall higher drive cycle fuel economy via a broad efficiency map.
- Reduces AMS cost with an economic system design.
- Contract Number: DE-EE0005665 (2012)

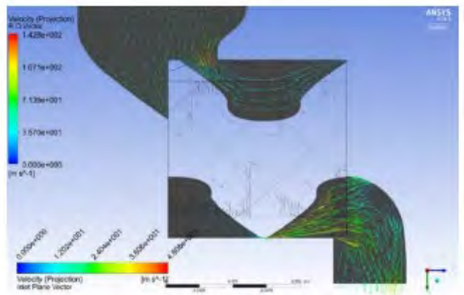




Mesh of the supercharger-expander



Supercharger meshed geometry



CFD Results

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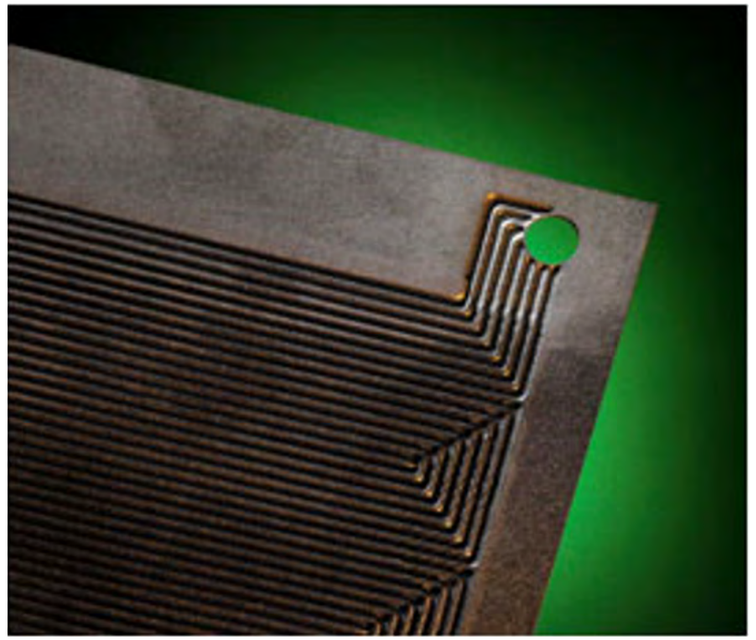
Scale-Up of Carbon-Carbon Composite Bipolar Plates

FC
Commercial

Historical

uspto
1 patent

- Developed and commercialized in 2003 by Porvair Advanced Materials, Inc.
- Manufactured more than 50,000 bipolar plates since 2003.
- Provides high-volume manufacturing with no machining, reducing the cost of the plates.
- Allows for molding of a wide array of product designs because of process flexibility.
- Resists the corrosive environment in the fuel cell and minimizes contact resistance between cells.
- Provides an extremely lightweight product with a density of about 1.2 grams per cc.
- Contract Number: DE-FC04-02AL67627 (2002)



Fully molded Porvair Bipolar Plate

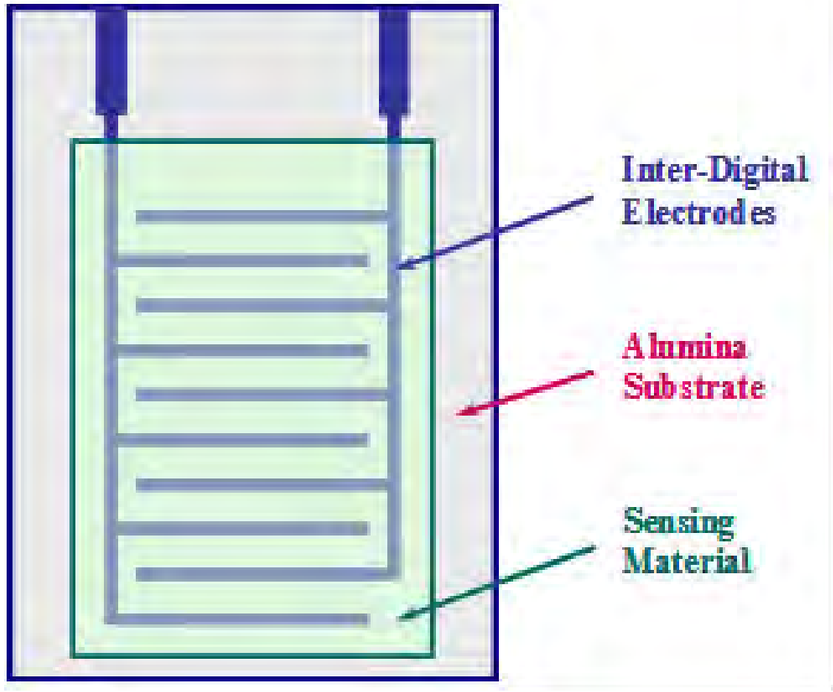
Contact Information:
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Website: www.porvair.com

Sensors for Automotive Fuel Cell Systems

FC
Emerging

Historical

- Developed by Nexceris, LLC, as part of the DOE's Partnership for a New Generation of Vehicles Program.
- Gas sensors required for automotive fuel cell systems.
- Can be used for fuel cell power plants using hydrogen generation from hydrocarbon fuels through reforming.
- Provides a response time of less than one minute
- Reduces the replacement cost of fuel cells by increasing the life of membranes.
- Enables fuel cells to stay on-line without frequent changing of fuel cell components due to damage from H_2S.
- Contract Number: DE-FC36-02AL67616 (2002)



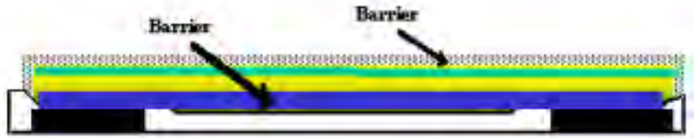


Figure 2. ATMI Micro-Hotplate Sensor Platform for H_2 Sensing

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Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications

FC
Emerging

Historical

- Developed by SAFCell, Inc., in partnership with Nordic Power Systems.
- Continuing development of stacks up to 1.5 kW for portable power applications and up to 5 kW for residential power applications.
- Can be used for both mobile and stationary applications requiring auxiliary power generation.
- Operates on a wide range of reformate from commercially available fuels.
- Near silent operation and quick start-up time.
- Ability to handle start-stop cycling.
- Contract Number: DE-FG36-08GO88099 (2008)



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Solid Oxide Fuel Cell Auxiliary Power Unit

FC
Emerging

Historical

uspto
8 patents

- Developed by Delphi Automotive Systems, LLC.
- Could be used to provide auxiliary electrical power for a variety of mobile applications such as heavy-duty trucks, boats, military vehicles, etc.
- Operates on a wide range of commercially-available fuels such as natural gas, diesel, bio-diesel, propane, gasoline, coal-derived fuel, and military logistics fuel.
- Achieves Tier 4 emissions standards set by the Environmental Protection Agency for non-road diesel engines.
- Saves up to 85% of the fuel currently required for the operation of the main diesel engine during idling.
- Contract Number: DE-FC36-04GO14319 (2004) and DE-EE0000478 (2009)



A demonstration model of the Delphi Solid Oxide Fuel Cell Auxiliary Power Unit is shown mounted to a commercial vehicle.



Contact Information:

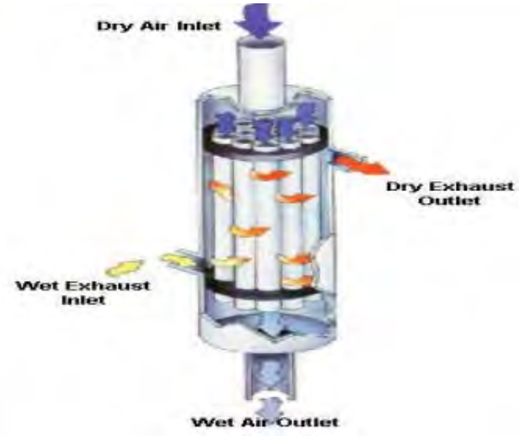
Email: n/a
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Thermal and Water Management Systems for PEM Fuel Cells

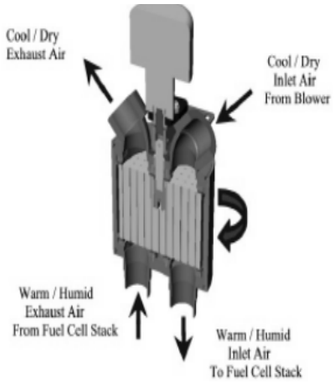
FC Emerging

Historical

- Developed by Honeywell Aerospace in partnership with Argonne National Laboratory, Emprise Corporation, and FreedomCAR Tech Team.
- Can be used to maintain a fuel cell inlet air stream at or above 60% relative humidity (at 80 degrees C) and efficiently reject heat generated by the fuel cell stack to the ambient air.
- Meets the 80-kW PEM fuel cell stack cooling requirements of 50 kW with radiator face area of 0.32 m2 and 70 mm max depth.
- Uses advanced fin configuration to minimize the size and weight of the radiator.
- Eliminates the need for an external water source y transferring moisture from a fuel cell's outlet air to its inlet air.
- Contract Number: DE-FC36-03G013109 (2002)









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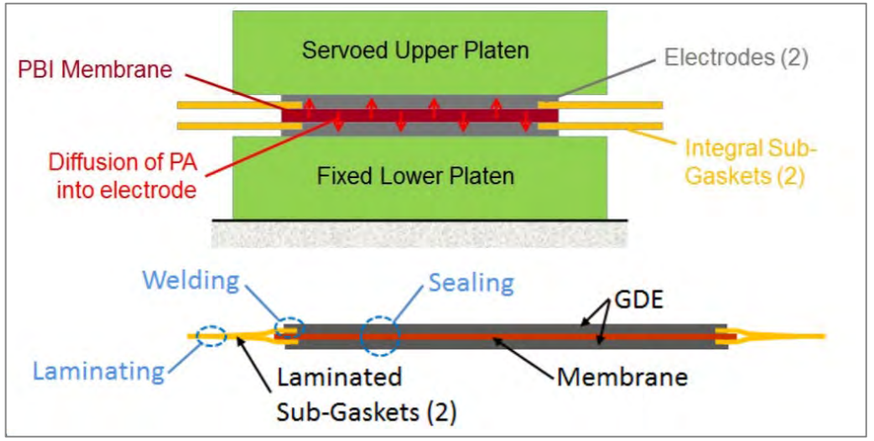
Ultrasonics and Diagnostics for High-Temperature PEM MEA Manufacture

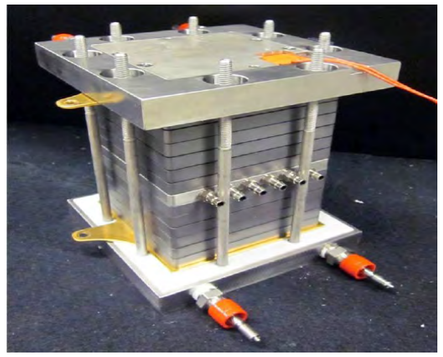
FC
Commercial

Historical

Pacific Northwest
NATIONAL LABORATORY

- Developed by Rensselaer Polytechnic Institute's Center for Automation Technologies and Systems.
- Continuing work includes developing and modeling ultrasonic bonding processes and using advanced diagnostics to improve quality control.
- Can be used for manufacturing various types of high- and low-temperature proton exchange membranes and MEAs for hydrogen fuel cell applications.
- Reduces energy consumption and unit cycle time by >90%.
- Achieves cost reduction of 90% for MEA bonding.
- Offers a scalable process.
- Achieves comparable MEA performance to those made using conventional bonding processes.
- Contract Number: DE-FG36-08GO18053 (2008)

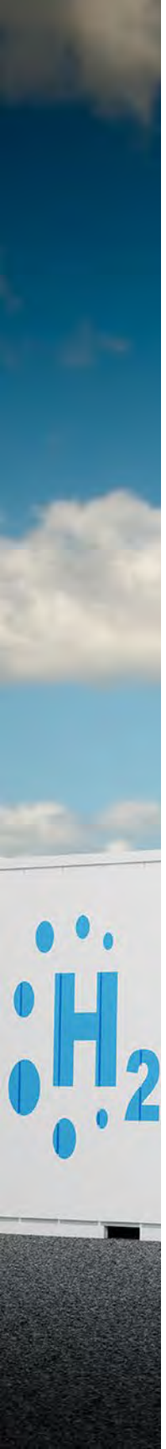




RPI's Test Fuel Cell Stack Using 50 cm^2 MEAs

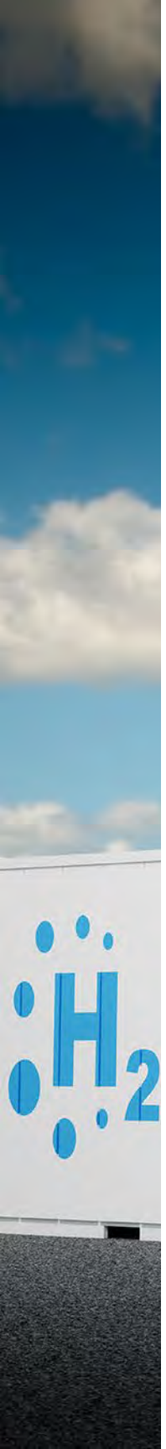
Rensselaer

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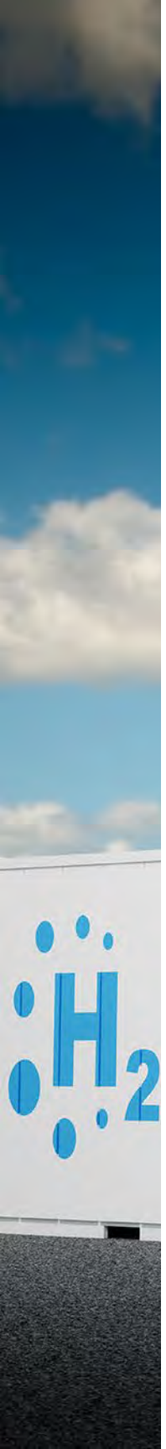
Historical Production Technologies

Technology	Organization
Automation of Solid Oxide Electrolyzer Cell (SOEC) & Stack Assembly	Cummins, Inc.
Binary Chloride Salts as Catalysts for Methane to Hydrogen and Graphitic Powder	C-Zero, LLC
Catalysts/Electrodes for Hydrogen Production by Water Electrolysis (SBIR)	Nel Hydrogen (Formerly Proton Onsite)
Ceramic Membrane Reactor Systems for Converting Natural Gas to H2 and Synthesis Gas (ITM Syngas)	Air Products and Chemicals, Inc.
Efficient Solid-State Electrochemical Hydrogen Compressor (SBIR)	FuelCell Energy, Inc.
High-Performance Palladium-Based Membrane	Pall Corporation
High-Efficiency, High-Pressure Electrolysis via Photovoltaic Arrays (SBIR)	Avalence, LLC
High-Pressure Distributed Ethanol Reforming	Argonne National Laboratory
High-Pressure PEM Electrolyzer and Composite Tube Hydrogen Storage	Nel Hydrogen (Formerly Proton Onsite)
High Temperature, High Pressure Electrolysis (SBIR)	Giner, Inc.
Hydrogen By Wire – Home Fueling System (SBIR)	Nel Hydrogen (Formerly Proton Onsite)
Hydrogen Generation from Biomass-Derived Carbohydrates via Aqueous-Phase Reforming	Virent Energy Systems, Inc.
Integrated Ceramic Membrane System for Hydrogen Production	Praxair, Inc.
Integrated Short Contact Time Hydrogen Generator	GE Global Research Center
Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures	University of California - Berkeley
Membrane Structures for Hydrogen Separation (SBIR)	Genesis Fueltech, Inc.
Nanotube Array Photocatalysts (SBIR)	Synkera Technologies, Inc. (Acquired by Integrated Device Technology, Inc)
Novel Catalytic Fuel Reforming	InnovaTek, Inc.



Historical Production Technologies (continued 2/2)

Technology	Organization
Photoelectrochemical Hydrogen Production	MVSystems, Inc. (Prior project from University of Hawaii)
Portable Solid Oxide Fuel Cell Generator	Jadoo Power Systems, Inc.
Renewable Electrolysis Integrated System Development and Testing	National Renewable Energy Laboratory
Scalable Steam Methane Reformer System for Distributed Hydrogen Production	Catacel Corporation (Acquired by Johnson Matthey Plc)
Scale up of Hydrogen Transport Membranes for Integrated Gasification-Combined Cycle Operation	Eltron Research & Development, Inc.
Sodium Silicide (NaSi) Hydrogen Generation System	SiGNa Chemistry, Inc. (IP Acquired by Intelligent Energy Ltd.)
Solar-Thermal Production of Hydrogen Using Renewable Feedstock	University of Colorado-Boulder

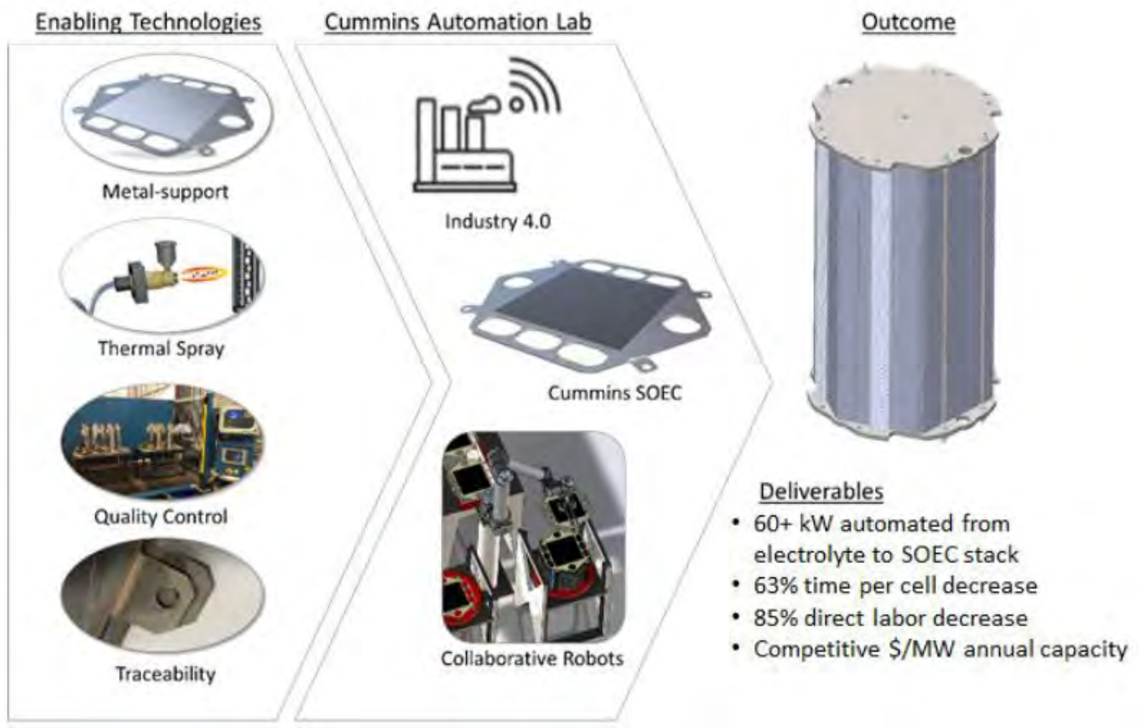


Automation of Solid Oxide Electrolyzer Cell (SOEC) & Stack Assembly

PROD
Emerging

Historical

- Currently being developed by Cummins, Inc.
- Developing manufacturing processes for solid oxide electrolyzer cells and stacks.
- These new manufacturing processes have the capability to lower cycle time by 63% per cell, as well as lower direct labor requirements by 85%.
- Currently developing controls, and data acquisition architecture.
- Cummins, Inc. is committed to low-carbon technologies and has efforts in battery storage, fuel cell, and hydrogen production.
- Contract Number: DE-EE0009622 (2022)



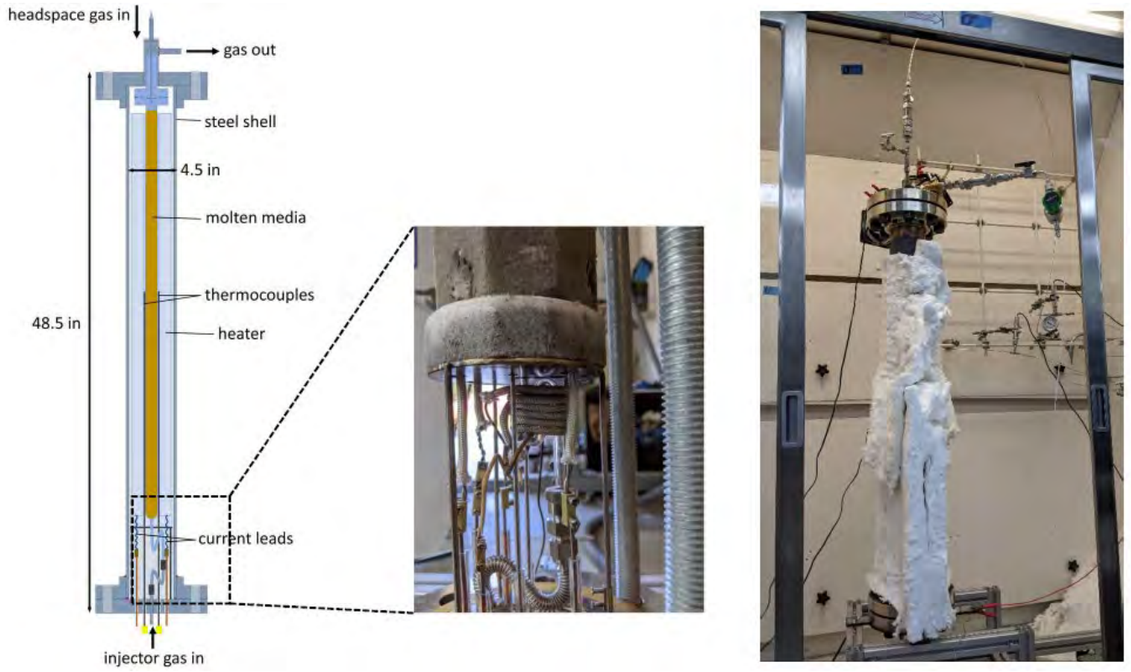
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Binary Chloride Salts as Catalysts for Methane to Hydrogen and Graphitic Powder

PROD
Emerging

Historical

- Currently being developed by C-Zero, LLC, in collaboration with the University of California, Santa Barbara.
- Currently developing a scalable methane pyrolysis process to reduce the cost of low emission hydrogen from natural gas.
- Enables reduction >75% in CO_2 emissions that are a result of hydrogen production from natural gas .
- Awarded Early-Stage Company of the Year in the 2022 Global Cleantech 100.
- C&EN's 2021 10 Start-Ups to Watch.
- Contract Number: DE-EE0008845 (2020)



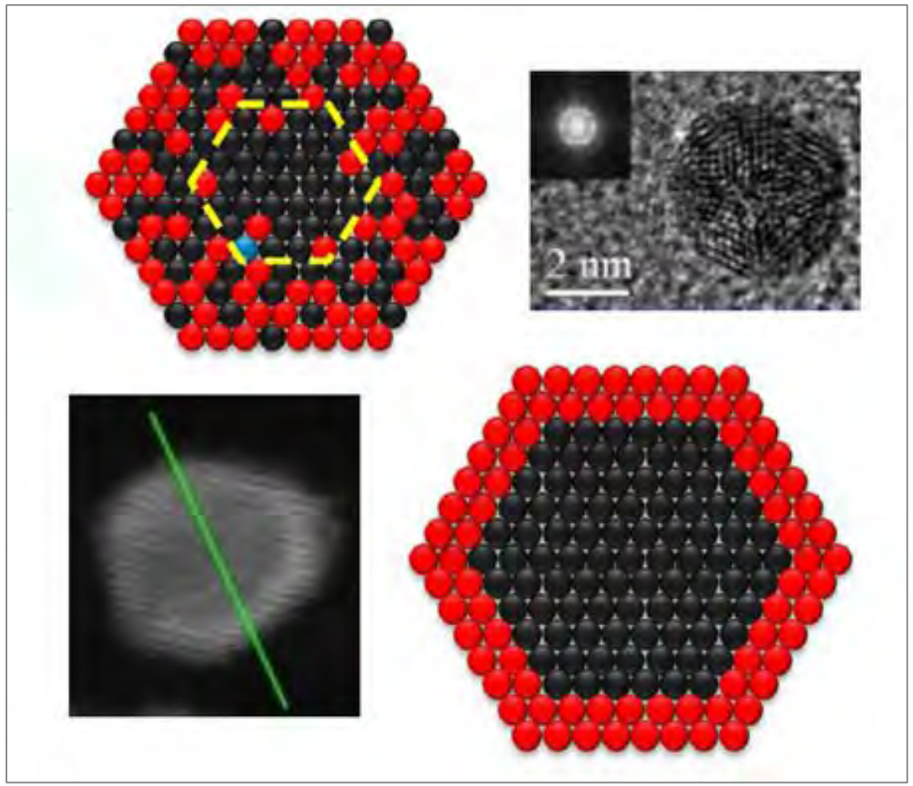
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Catalysts/Electrodes for Hydrogen Production by Water Electrolysis (SBIR)

PROD
Emerging

Historical

- Developed by Proton Energy Systems, Inc., (acquired by Nel Hydrogen) in collaboration with Brookhaven National Laboratory.
- Continuing work to deploy catalyst and electrode manufacturing process.
- Can be used to produce hydrogen using water electrolysis.
- Reduces catalyst PGM content by more than 90%.
- Targets 2020 DOE electrolyzer system capital costs of $300 per kW.
- Reduces costs by using less expensive electrode and catalyst materials for MEA construction.
- Contract Number: DE-SC0008251 (2012)



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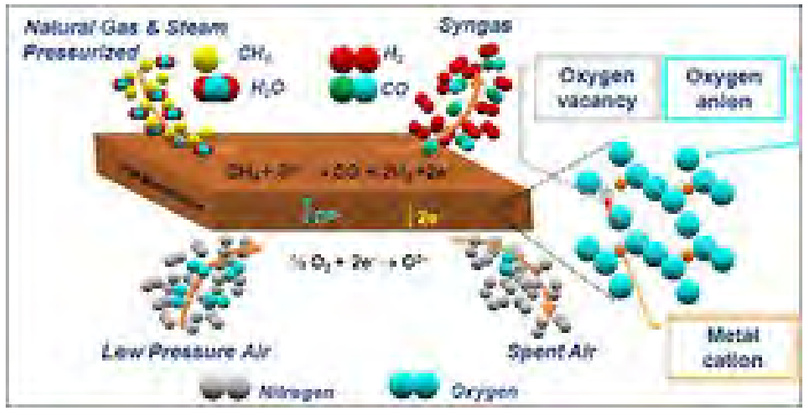
Ceramic Membrane Reactor Systems for Converting Natural Gas to H2 and Synthesis Gas (ITM Syngas)

PROD
Emerging

Historical

uspto
36 patents

- Developed by Air Products and Chemicals, Inc, in collaboration with Chevron, Sasol, Ceramatec, and others.
- Can be used to generate syngas, which is used to manufacture synthetic ultraclean liquid fuels, hydrogen, and chemicals.
- Generates syngas and hydrogen in more compact, lower cost and higher efficiency process than competing state-of-the-art technologies.
- Retrofits into existing H_2 reforming facilities to increase capacity and efficiency.
- Offers feed flexibility when combined with feed gas pre-reforming.
- Offers a projected 30% lower capital and has a 1% to 2.5% improvement in plant thermal.
- Enables up to 40% footprint reduction over an ATR/ASU.
- Contract Number: DE-FC26-97FT96052 (1995)





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Efficient Solid-State Electrochemical Hydrogen Compressor (SBIR)

PROD
Emerging

Historical

- Developed by FuelCell Energy, Inc., in collaboration with Sustainable Innovations, LLC.
- Continuing development to demonstrate a full-scale fueling station system.
- Can be used to compress or co-produce hydrogen in fueling, industrial, or smart grid applications.
- Produces hydrogen fuel at pressures up to 12,000 psi using multi-stage compression.
- Produces 1-2 kg per day (1-2 gasoline gallon equivalent).
- Achieves a single-step compression ratio of 300:1.
- Achieves operation using a solid-state EHC design with no moving parts.
- Contract Number: DE-FG02-07ER84772 (2007) and DE-EE0003727 (2010)

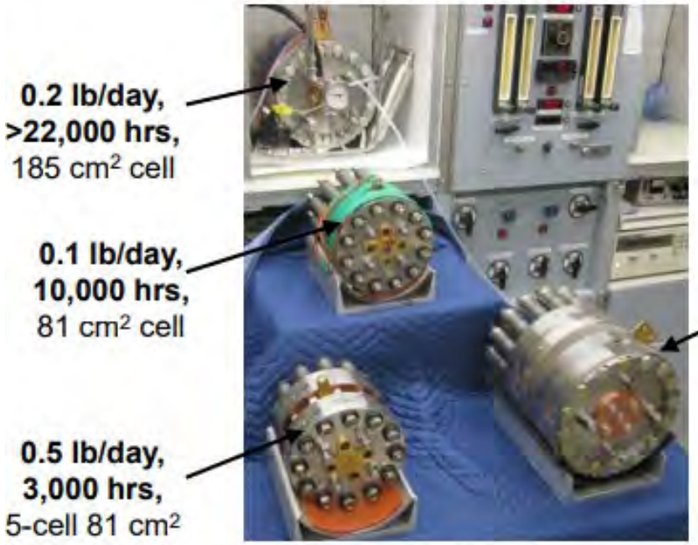


Figure 2. EHC Cells and Stacks:
Cumulatively >40,000 hr operation with increasing hydrogen capacity.



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High-Performance Palladium-Based Membrane

PROD
Commercial

Historical

- Developed by Pall Corporation and commercialized in 2011.
- Separates hydrogen from a variety of mixed gas streams.
- Enables the production of high-purity hydrogen.
- Offers high-temperature and high-pressure operation.
- Several full-scale units operating in the U.S.
- Contract Number: DE-FC36-05GO15093 (2005)







Multi-Tube Module

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High-Efficiency, High-Pressure Electrolysis via Photovoltaic Arrays (SBIR)

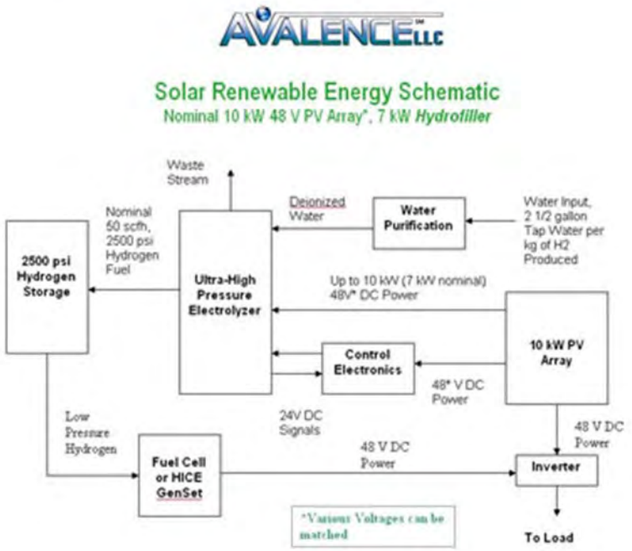
PROD
Commercial

Historical

uspto
1 patent

- Developed by Avalence, LLC., and commercialized in 2007.
- Generates and delivers high-pressure hydrogen (over 5,000 psig) and can be coupled to a renewable energy generation source such as photovoltaic arrays.
- Can deliver 1 to 30 kg/day of hydrogen, with models up to 300 kg/day that were in development.
- Cuts the point-of-use cost of hydrogen production up to 50% and operating expenses by 20%.
- Provides flexible integration with renewable energy sources, which increases the use of green power, and provides an emission-free platform for hydrogen generation.
- Contract Number: DE-FG02-04ER83905 (2005)





Contact Information:

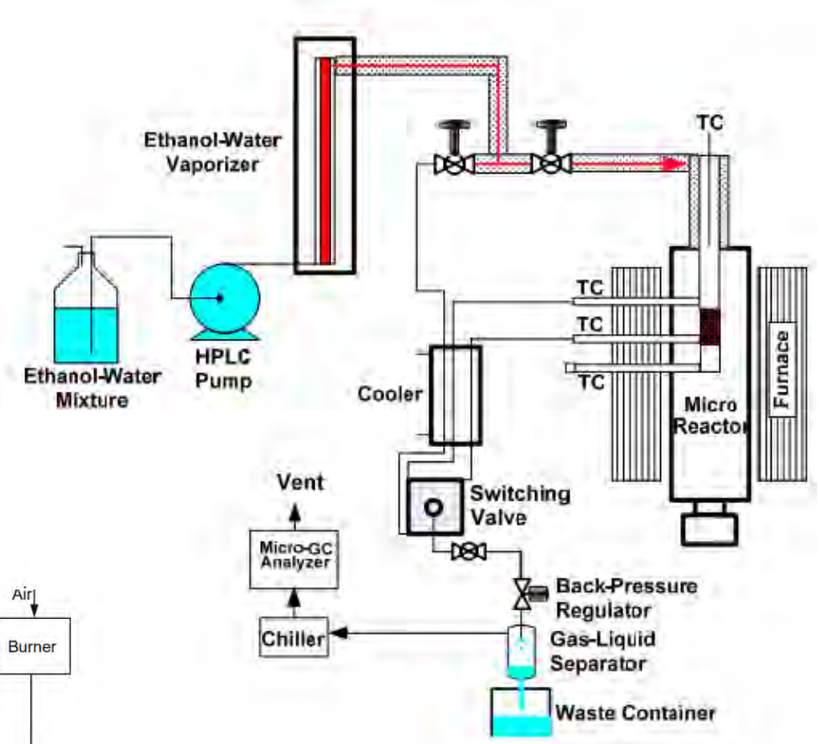
Email: n/a
Phone: n/a
Avalence, LLC
Address: n/a
Website: n/a

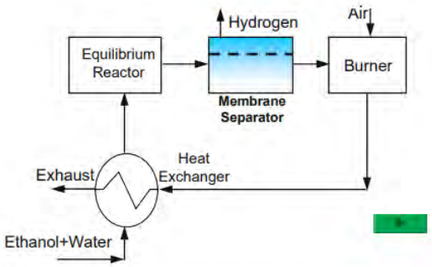
High-Pressure Distributed Ethanol Reforming

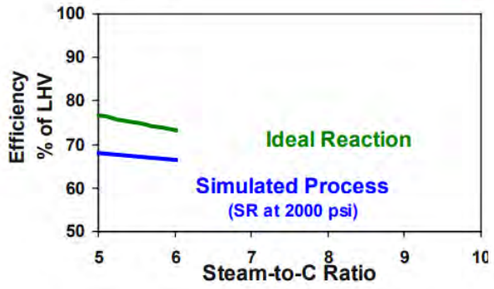
PROD
Emerging

Historical

- Developed by Argonne National Laboratory, in partnership with Pacific Northwest National Laboratory.
- Project goal to study steam reforming of ethanol at high pressure and evaluate high-pressure reforming options.
- Steam reforming of liquid fuels generates a pressurized reformate with little energy penalty.
- Hydrated ethanol is less expensive than fuel-grade ethanol.
- Ethanol is a bio-derived renewable liquid fuel and is easy to transport (liquid state).
- Contract Number: DE-AC02-06CH11357 (2004)







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High-Pressure PEM Electrolyzer and Composite Tube Hydrogen Storage

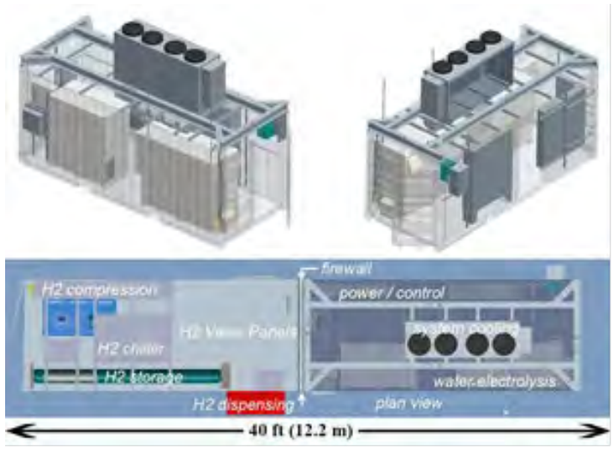
PROD
Emerging

Historical

- Developed by Proton Energy Systems, Inc., (Acquired by Nel Hydrogen) in collaborations with SunHydro LLC.
- Continuing work to complete pilot station system upgrades and installation, and to commercialize and expand hydrogen fueling service and systems.
- This technology was designed to meet initial demand for a small, manufactured hydrogen fueling infrastructure such that it is scalable and can be deployed quickly.
- Provides high pressure hydrogen generation (30 bar and 55 bar)
- Provides modular and scalable hydrogen generation, storage, and fueling.
- Simple installation with compact footprint that is intended to be compliant with hydrogen code and safety regulation requirements.
- Contract Number: DE-EE0005887 (2012)







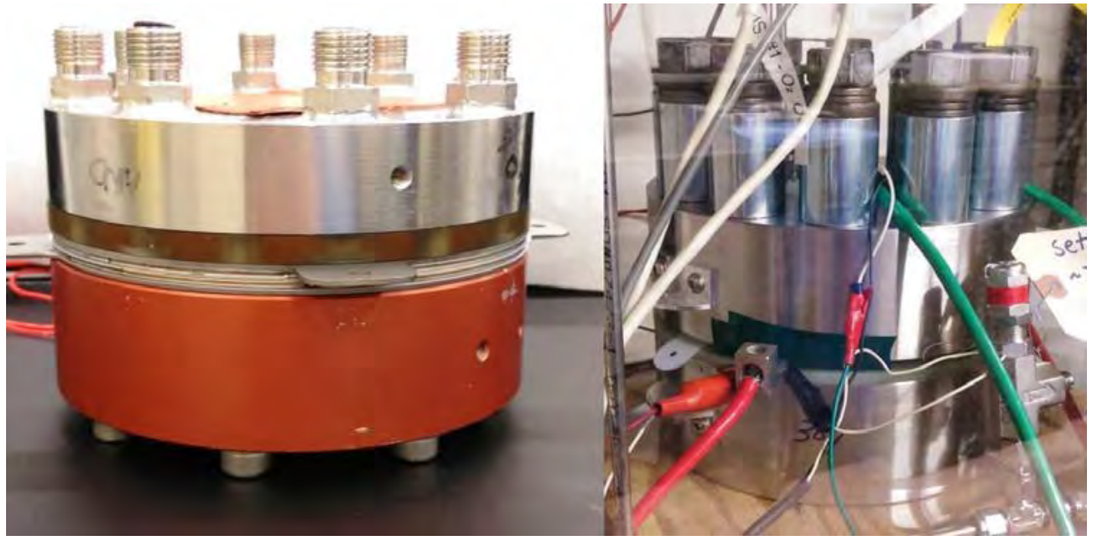
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High Temperature, High Pressure Electrolysis (SBIR)

PROD
Emerging

Historical

- Developed by Giner, Inc., in partnership with Virginia Tech. Commercialized since 2023.
- Can be used to increase the efficiency of the PEM while providing hydrogen at high temperatures and pressures.
- Developed three hydrocarbon-based membranes that have a conductivity to permeability ratio greater than 2.0 times that of Nafion® membranes.
- Can operate for 1000 hours at 95°C and 500 hours at 95°C and 1000 psi with minimal degradation.
- Achieves 76% lower heating value electrolyzer efficiency.
- Further testing has been done to operate at pressures as high as 350 bar.
- Contract Number: DE-SC0011310 (2014)



Giner, Inc.'s Fuel Cell Stack Hardware



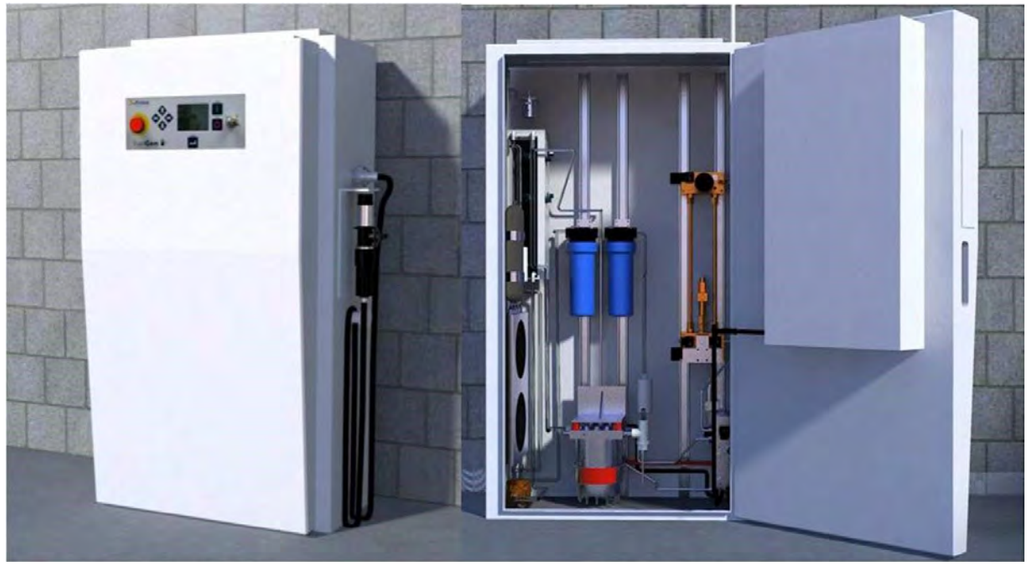
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Hydrogen By Wire – Home Fueling System (SBIR)

PROD
Emerging

Historical

- Developed by ProtonOnsite (acquired by Nel Hydrogen) with support from Oak Ridge National Laboratory and other industry component suppliers.
- Can be used for refueling hydrogen-powered vehicles, or stationary or portable power devices.
- Produces hydrogen at <$4.00/gasoline gallon equivalent, including capital cost, and greater than 50% electrolyzer efficiency compared with fossil fuel combustion.
- First generators can produce up to 2 kg/day of hydrogen fuel at a differential pressure of 350 bar.
- In 2017, Nel Hydrogen acquired ProtonOnsite with preparation for commercialization.
- In 2017, a new generator was developed to provide 4.4 kg/day of hydrogen fuel at a differential pressure of 350 bar.
- Contract Number: DE-SC0001149 (2010)



Rendering of Nel Hydrogen's Home Fueling System product package sized at 2' x 3' x 5'.

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Hydrogen Generation from Biomass-Derived Carbohydrates via Aqueous-Phase Reforming

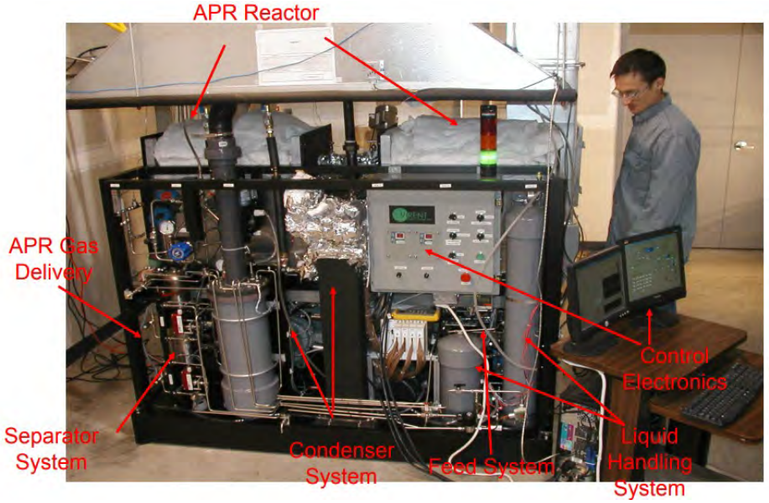
PROD
Emerging

Historical

uspto
6 patents

- Developed by Virent Energy Systems, Inc., in partnership with Archer Daniels Midland Co. and the University of Wisconsin.
- Can be deployed to produce hydrogen using biomass-derived carbohydrates.
- Uses renewable biomass-derived feedstock to generate hydrogen.
- Produces hydrogen at low temperatures without forming carbon monoxide.
- Does not require fossil fuels and generates carbon-neutral hydrogen from widely available biomass-derived feedstocks.
- Uses various sugars and sugar alcohols in addition to feedstocks.
- Contract Number: DE-FG36-05G15046 (2005)





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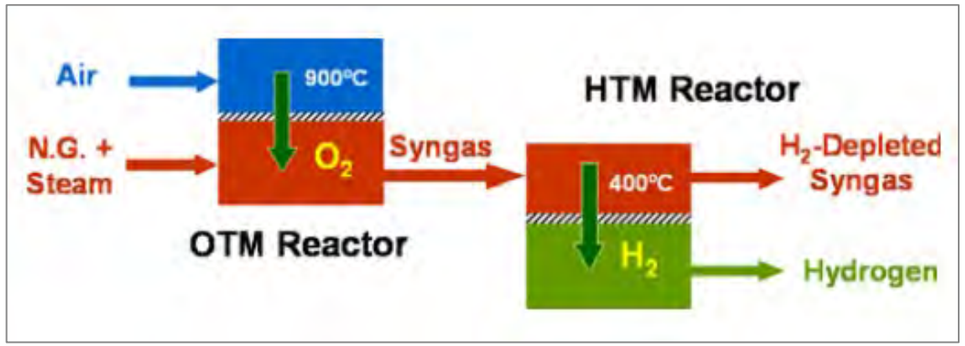
Integrated Ceramic Membrane System for Hydrogen Production

PROD
Emerging

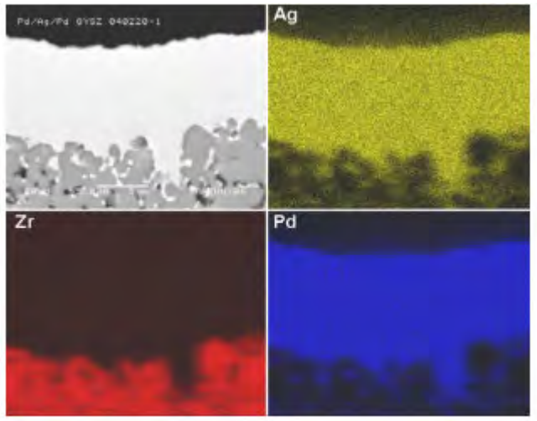
Historical

uspto
1 patent

- Developed by Praxair, Inc. (Praxair has since merged and formed Linde), with prior assistance from the Research Triangle Institute.
- Continuing work to improve the palladium-based membrane, reducing its cost, and testing the performance of the system.
- Can be used to generate hydrogen for use in hydrogen-powered vehicles.
- Increases hydrogen yield from any synthesis gas generator, including OTM processes and reforming.
- Achieves strength with porosity through advanced ceramic substrate technology.
- Increases production of high-purity hydrogen from syngas.
- Contract Number: DE-FC36-00GO10534 (2000)



Integrated Membrane Reactor System



Elemental Analysis of the Membrane

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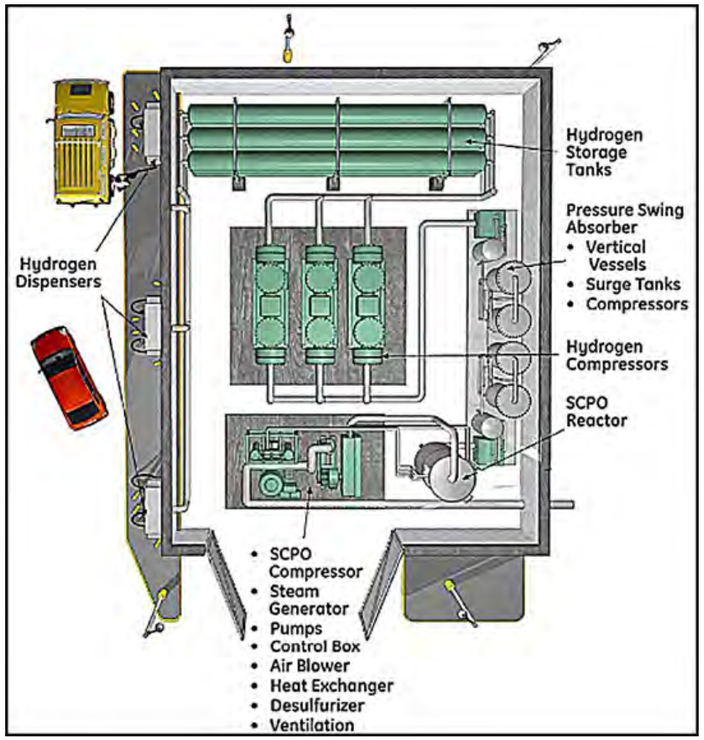
Integrated Short Contact Time Hydrogen Generator

PROD
Emerging

Historical

uspto
2 patents

- Being developed by GE Global Research Center in partnership with Argonne National Laboratory and the University of Minnesota.
- Evaluating potential application opportunities.
- Can be used in different industries when syngas and hydrogen production are needed.
- Can be mass-produced because of its modular design.
- Achieves H2 production of 60 Kg/day using test units and working on a system to produce 1,500 kg/day.
- Reduces peak metal temperature in the entire system to <600°C to allow the use of low-cost stainless steel.
- Contract Number: DE-FG36-05GO15023 (2005)



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Website: https://www.ge.com/research

Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures

PROD
Emerging

Historical

uspto
2 patents

- Developed by the UC-Berkeley Plant & Microbial Biology Department.
- Can be used to produce hydrogen using algae and sunlight.
- Potentially energy efficient, producing carbon-neutral hydrogen using only renewable microalgae and sunlight without producing unwanted byproducts.
- Uses genetically engineered algae to modify the size of the chlorophyll in the algal cells as it absorbs light to prevent blocking cells deeper in the culture, thus decreasing heat dissipation and improving the light utilization. The test strain of algae improved light utilization compared to the wild type from 3% to 15%.
- Achieved enhanced growth of the truncated light-harvesting chlorophyll antenna (TLA) algae type to grow 55-60% more biomass than the wild type algae.
- The team was also able to apply the TLA concept to cyanobacteria.
- Contract Number: DE-FC36-00GO10536 and DE-FG36-05GO15041 (2004)

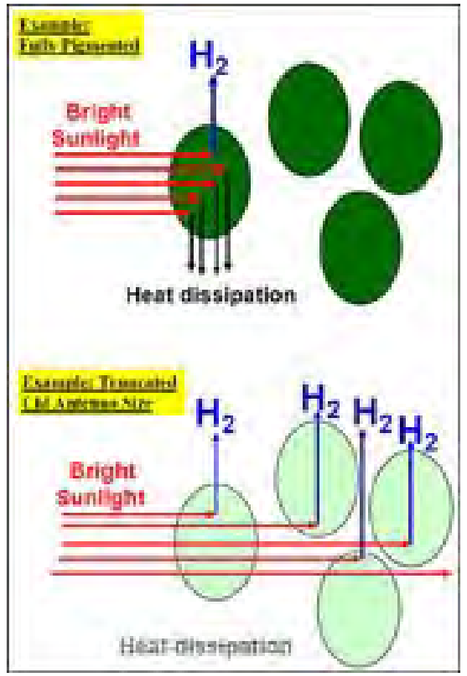


Diagram showing UC-Berkeley's TLA-modified algal cells allowing for greater penetration of sunlight into the cell culture.

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Membrane Structures for Hydrogen Separation (SBIR)

PROD
Commercial

Historical

uspto
2 patents

- Developed by Genesis Fueltech Inc., technology has been licensed with product commercialized in 2009.
- Membranes used in methanol reformers to produce ultra-pure hydrogen for fuel cells.
- Maintains higher hydrogen output than existing conventional units.
- Allows purifiers using these membranes to be an order of magnitude less expensive than conventional units.
- Handles mechanical stress without failure.
- Can scale existing designs for industrial applications.
- Contract Number: DE-FG02-06ER84535 (2005)



Contact Information:

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Genesis Fueltech, Inc.
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Website: n/a

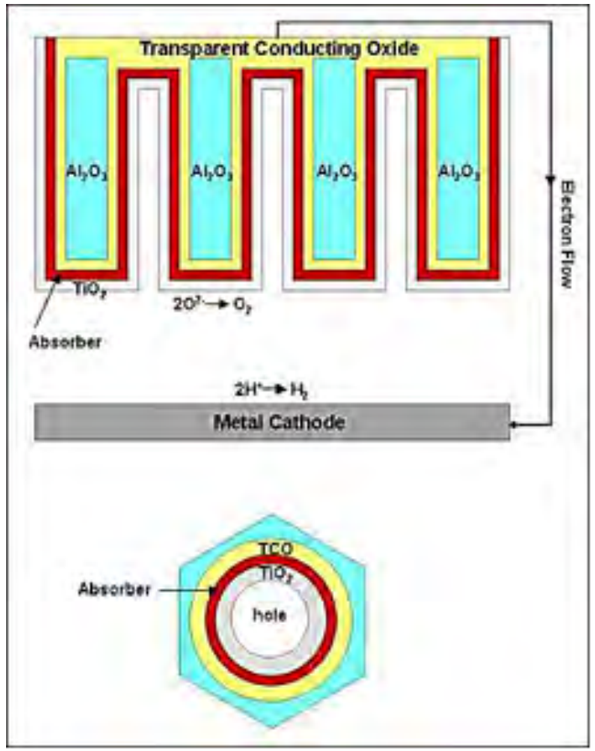
Nanotube Array Photocatalysts (SBIR)

PROD
Emerging

Historical

uspto
1 patent

- Developed by Synkera Technologies, Inc., (Synkera acquired by Renesas).
- Currently applying technology to other applications as well as exploring partnerships and funding opportunities.
- Can be used for the production of hydrogen from solar energy.
- Enhances light harvesting through a large absorption cross-section and a high surface area to promote catalytic chemistry.
- Minimizes recombination losses through rapid and efficient charge separation in a very thin absorber.
- Increases efficiency through broadband light absorption and a vertically graded bandgap.
- Contract Number: DE-FG02-07ER84871 (2008)



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Integrated Device Technologies, Inc.
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Website: https://www.renesas.com/

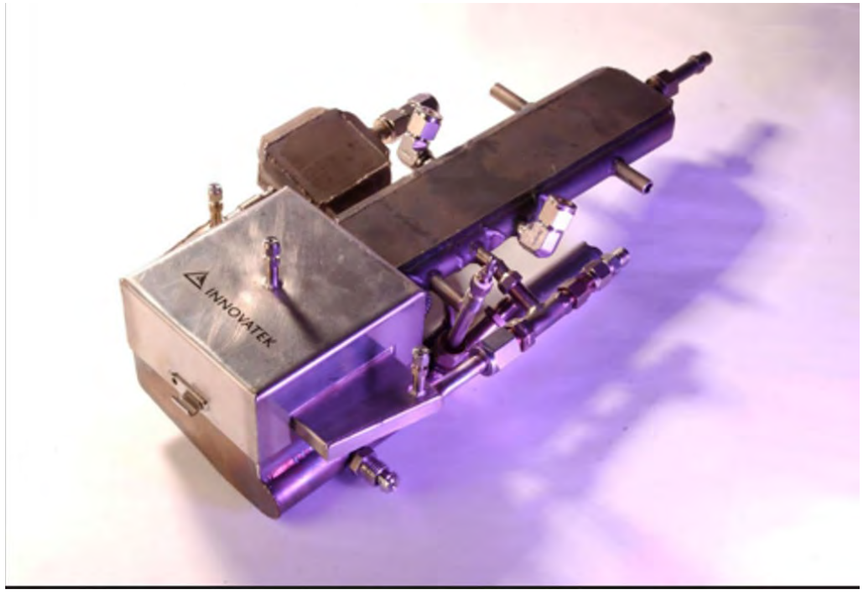
Novel Catalytic Fuel Reforming

PROD
Commercial

Historical

uspto
1 patent

- Developed by InnovaTek, Inc., and commercialized in 2015.
- A Hydrogen generator that reforms multiple fuel types (natural gas, gasoline, diesel, and biodiesel) to produce hydrogen by integrating microreactor and microchannel heat exchanger technology with proprietary catalysts.
- Produces 60 grams/hour of hydrogen.
- Provides an integrated package of reformer components.
- Increases the efficiency of the reformer by integrating the micro-structured steam reformer, heat exchangers, and fuel injector.
- Demonstrates system CHP efficiency of 76%.
- Contract Number: DE-FC36-996O10452 (1999)



InnovaTek's Catalytic Fuel Processor



InnovaTek's InnovaGen® Energy System

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Photoelectrochemical Hydrogen Production

PROD
Emerging

Historical

Pacific Northwest
NATIONAL LABORATORY

- Developed by MVSystems, LLC (previously MVSystems, Inc.), in partnership with the University of Hawaii.
- Can be used to produce “solar fuels” such as hydrogen methanol from solar energy.
- Achieves DOE’s target of 5% STH conversion efficiency, as well as operational life up to 500 hours.
- Produces H2 at a lower cost ($2 – 4/Kg).
- Eliminates extra components for higher STH conversion efficiency.
- Reduces costs by using new, less expensive materials and controlling the size and morphology of nanostructures.
- Contract Number: DE-FG36-07GO17105 (2007)

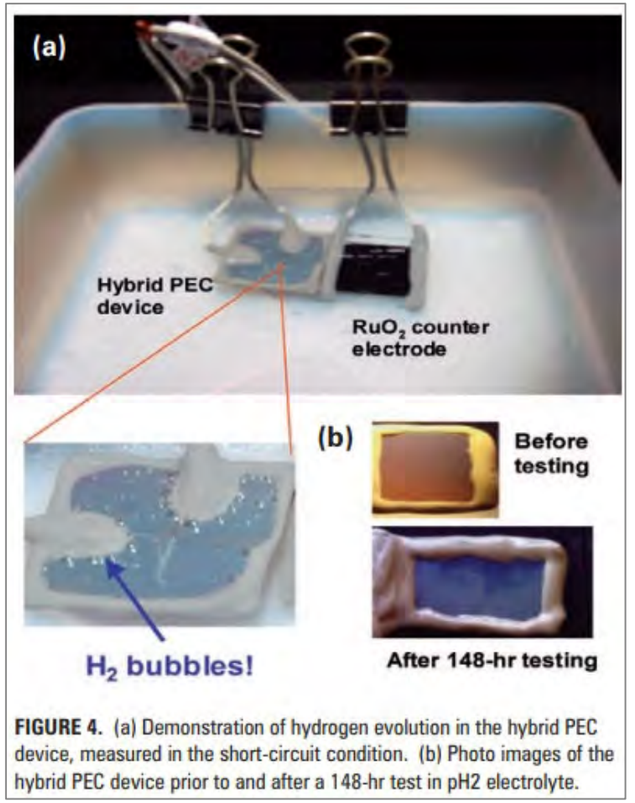
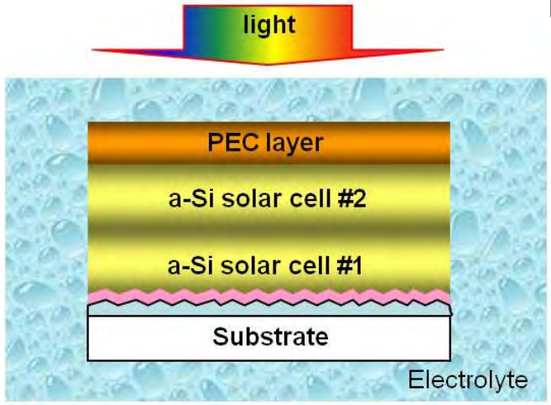


FIGURE 4. (a) Demonstration of hydrogen evolution in the hybrid PEC device, measured in the short-circuit condition. (b) Photo images of the hybrid PEC device prior to and after a 148-hr test in pH2 electrolyte.



MVS’ Monolithic Hybrid PEC Device Powered By a Tandem Solar Cell

MVSystems LLC
Thin Film Technologies

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Portable Solid Oxide Fuel Cell Generator

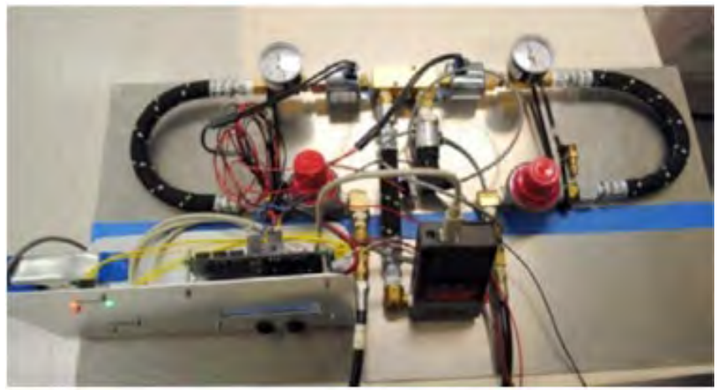
PROD
Emerging

Historical

Pacific Northwest
NATIONAL LABORATORY

- Developed by Jadoo Power Systems, Inc., in partnership with Delphi Automotive, LLP.
- Can be used to power portable video and lighting equipment at large sporting events or emergency equipment used by first responders (e.g., police and firefighters) in off-grid situations.
- Produces 1 kW of power for up to 8 continuous hours.
- Operates at ≥ 30% efficiency for at least 2000 cumulative hours of runtime.
- Reduces localized noise problems associated with using internal combustion engine generators close to staff and fans at large sporting events.
- Reduces emissions (lb-CO_2/kWh) compared with conventional gasoline-fueled, internal combustion engine portable generators.
- Contract Number: DE-EE0000479 (2010)





LPG Fuel Interface.

jadoo Power

DELPHI

Contact Information:

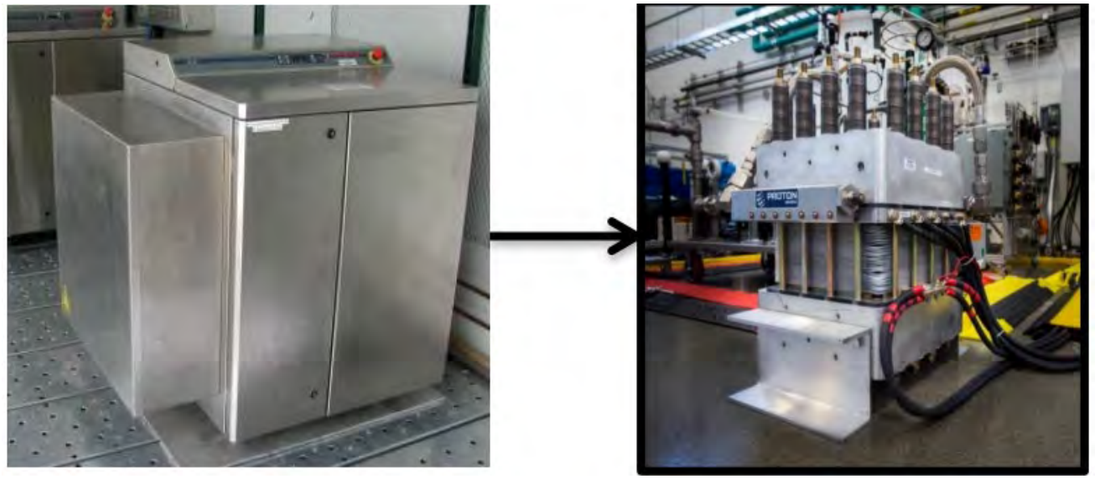
Email: n/a
Phone: n/a
Jadoo Power Systems, Inc.
Address: n/a
Website: n/a

Renewable Electrolysis Integrated System Development and Testing

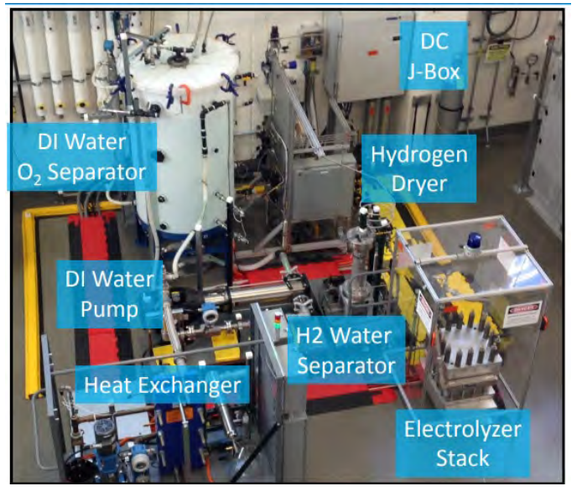
PROD
Emerging

Historical

- Developed by NLR in partnership with Xcel Energy, Proton Onsite (acquired by Nel Hydrogen), Teledyne Energy Systems, Giner Electrochemical Systems/Giner, Inc., SoCal Gas, University of North Dakota, and University of Minnesota.
- Can be used to generate hydrogen from renewable energy sources.
- Stores renewable energy in the form of hydrogen.
- Uses power electronics to regulate variable outputs from various renewable sources.
- Eliminates pollution from energy production by using clean renewables.
- Saves renewable energy that would be wasted if it wasn't needed at the time of generation, resulting in cost savings as well.
- Contract Number: DE-AC36-08GO28308 (2003)



Example of improved electrolyzers (size, power conversion, cost, and efficiency)



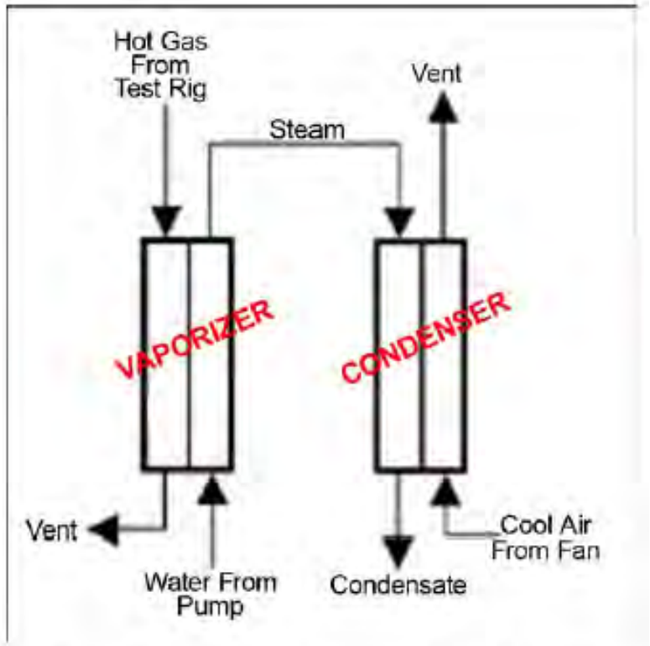
Contact Information:
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Scalable Steam Methane Reformer System for Distributed Hydrogen Production

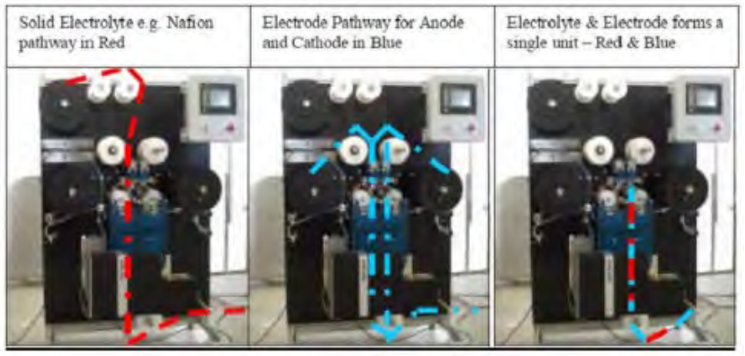
PROD
Emerging

Historical

- Developed by Catacel Corporation (acquired by Johnson Matthey in 2014) as part of Edison Materials Technology Center's (EMTEC)'s "Developing Improved Materials to Support the Hydrogen Economy" project.
- Partnership with NexTech Materials, Ltd., and the University of Toledo.
- Can be used to generate hydrogen from methane in scalable quantities up to commercial amounts.
- Eliminates the problem of scaling down large-scale systems while maintaining efficiency using a modular design.
- Achieves high solar collection and feedstock conversion efficiencies.
- Generates hydrogen at 20 kg/day (10 kW fuel value) based on the Catacel heat exchanger platform.
- Contract Number: DE-FC36-04GO14215 (2004)



Catacel's Vaporizer/Condenser Heat Exhanger



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Scale up of Hydrogen Transport Membranes for Integrated Gasification-Combined Cycle Operation

PROD
Emerging

Historical

uspto
3 patents

- Developed by Eltron Research & Development.
- A low-cost hydrogen separation technology.
- Original project focused on research and development for scale-up of hydrogen separation membrane for a FutureGen type power plant.
- Produces high-purity hydrogen from coal-derived synthesis gas (syngas).
- Operates near water-gas shift (WGS) conditions.
- Tolerates reasonably achievable levels of coal-derived syngas contaminants.
- Delivers pure H_2 for use in fuel cells, gas turbines, and hydrocarbon processing.
- Contract Number: DE-FC26-00NT40762 (2000) and DE-FC26-05NT42469 (2005)



FIGURE 1. Digital image of as-received tubular membranes. A yardstick is included on the right side of the picture for reference.



FIGURE 2. Surface of tubular membrane before and after catalyst deposition. An as-received tube is shown on the bottom and a tube with deposited catalyst is shown on the top.

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Sodium Silicide (NaSi) Hydrogen Generation System

PROD
Commercial

Historical

uspto
7 patents

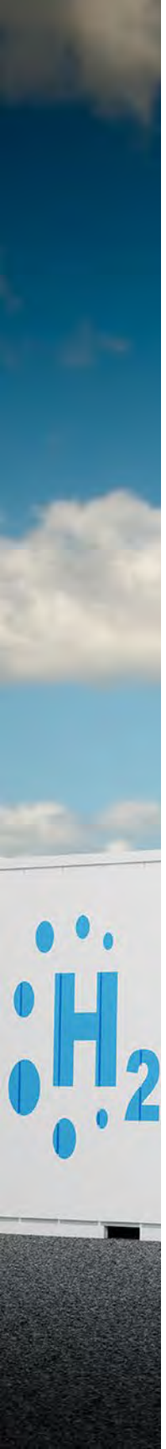
- Developed by SiGNa Chemistry, Inc., (technology and IP acquired by Intelligent Energy) and commercialized in 2012.
- Stable powder reacts with water to produce hydrogen.
- Used as power source for PowerTrekk portable electronics charger.
- Many different cartridge shapes are possible, including flat packs and bendable cartridges.
- Scalable (1 W to 3 kW) for a wide range of applications and future technology needs.
- Currently manufacturing cartridges for U.S. retail debut of the PowerTrekk.
- Contract Number: DE-FG36-08G088108 (2008)







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Solar-Thermal Production of Hydrogen Using Renewable Feedstock

Pacific Northwest NATIONAL LABORATORY

PROD *Emerging*

Historical

uspto 3 patents

- Developed by University of Colorado – Boulder and Copernican Energy (acquired by Sundrop Fuels, Inc.).
- Can use solar-thermal energy to generate hydrogen.
- Can use rapid chemical kinetics and favorable thermodynamics to create an integrated hydrogen production process.
- Can avoid energy and emission penalties of conventional processes that use fossil fuels to generate hydrogen.
- Aspects of this technology were adapted into Sundrop Fuels' solar gasification facilities to produce liquid biofuels in 2010.
- Contract Number: DE-FG36-03GO13062 (2001) and DE-FG36-05GO15044 (2005)

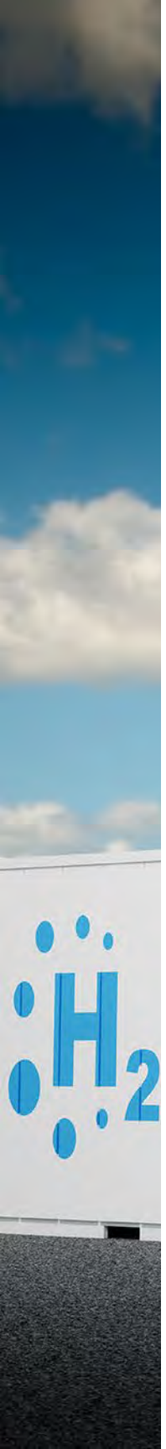


Sundrop Fuel's Solar-Thermal System

University of Colorado Boulder

sundropfuels™

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Historical Safety Technologies

Technology	Organization
Leak Detection and Hydrogen Sensor Development	Los Alamos National Laboratory
Non-Destructive Ultrasonic Scanning Technology	Hexagon Digital Wave, LLC (formerly Digital Wave Corporation)
PVDF-Film for Robust Online Assessment of Composite Tanks (PROACT) (SBIR)	Advent Innovations, Ltd.

Leak Detection and Hydrogen Sensor Development

SFTY
Emerging

Historical

uspto
3 patents

- Developed by Los Alamos National Laboratory and Lawrence Livermore National Laboratory.
- Can be used for on-vehicle leak detection and refueling and for production and storage applications for hydrogen safety.
- Exceeds targets for minimum detection threshold of 1% H_2 in air (10,000 ppm) and response time of ≤1 minute.
- Measures hydrogen from 0.04 – 4%, with an accuracy of ± 1%.
- Provides long-term durability and stability of response using similar automotive oxygen lambda sensor design and ceramic materials.
- Low-power, compact fit sensor with direct voltage readout, circumventing the need for additional conditioning circuitry.
- Contract Number: DE-AC52-06NA25396 (2007)



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Non-Destructive Ultrasonic Scanning Technology

SFTY Commercial

Historical

- Developed by Hexagon Digital Wave, LLC, (formerly Digital Wave Corporation), in partnership with ASME Standards Technology, LLC, Lincoln Composites, Inc., and TC Energy (formerly TransCanada CG Technologies), and commercialized in 2008.
- Can be used for non-destructive testing of high-pressure hydrogen cylinders used on FC powered vehicles to check structural integrity and failures.
- Uses stacked polyvinylidene film (PVDF) piezoelectric transducers in Modal Acoustic Emission (MAE) phased arrays to inspect composite gas pressure vessels whose construction materials make ultrasound or x-ray analyses difficult.
- Proprietary data analysis software is used to allow for adaptability to a wide range of gas cylinder geometries and material types while providing rapid analysis and accurate flaw location.
- Digital Wave Corporation commercially produced the UE-1, and UE-23 standalone testing devices of ultrasonic scanning technology, Hexagon Digital Wave now offers UE-17 and UE-29 models are currently being offered.
- Contract Number: DE-EG36-04GO14217 (2004)



A hydrogen cylinder undergoing a non-destructive integrity analysis with Digital Wave's Modal AE Sensors.

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Hexagon Digital Wave, LLC
13760 E Arapahoe Rd
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Website: https://hexagondigitalwave.com

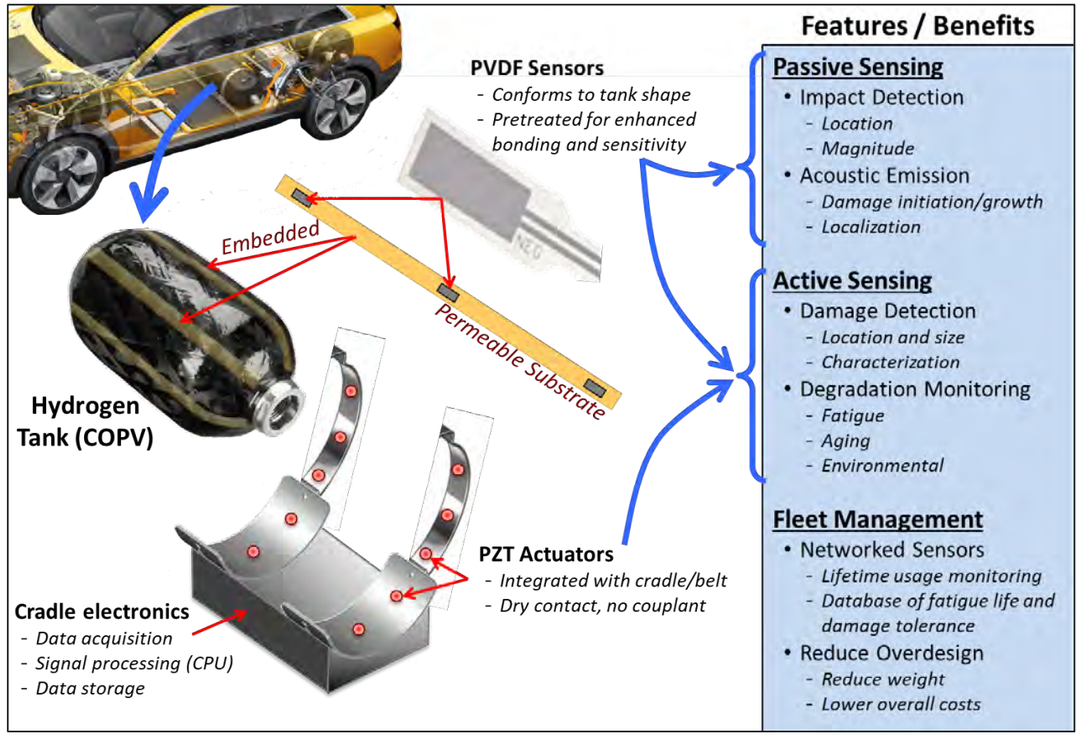
PVDF-Film for Robust Online Assessment of Composite Tanks (PROACT) (SBIR)

Pacific Northwest NATIONAL LABORATORY

SFTY *Emerging*

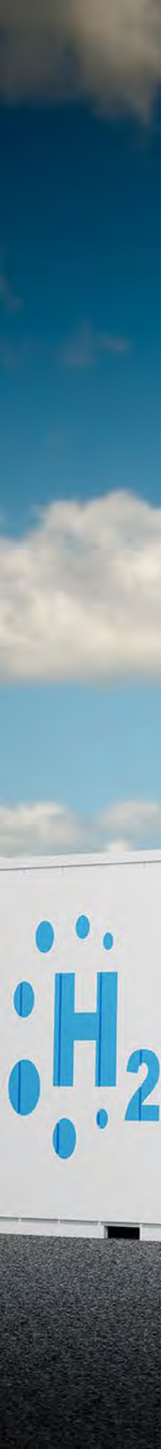
Historical

- Developed by Advent Innovations, Ltd.
- Project aims to develop an intelligent sensor system specifically optimized for composite overwrapped pressure vessels.
- The sensor will be integrated with composite tanks to continuously monitor the structural health.
- Enables structural health of the composite overwraps and prevents unexpected failure.
- Potential ability for online monitoring of tank structural integrity.
- Proper hydrogen storage can enable adopt hydrogen technology adoption and reduce dependence on foreign oil.
- Contract Number: DE-SC0019991 (2019)



Advent Innovations

Contact Information:
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Historical Storage Technologies

Technology	Organization
Achieving Hydrogen Storage Goals through High-Strength Fiber Glass	PPG Industries, Inc.
Compressed Hydrogen Gas Integrated Storage System	Johns Hopkins University Applied Physics Laboratory
High-Strength, Low-Cost Microballoons for Hydrogen Storage	Powdermet, Inc.
Hydrogen Composite Tanks	Quantum Fuel Systems, LLC (Formerly Quantum Fuel System Technologies Worldwide, Inc.)
Hydrogen Storage in Cryo-Compressed Vessels	Lawrence Livermore National Laboratory
Low-Cost Materials, High-Efficiency, High-Pressure Hydrogen Storage	Quantum Fuel Systems, LLC (Formerly Quantum Fuel System Technologies Worldwide, Inc.)
Manufacturable Chemical Hydride Cartridges for Hydrogen Fuel Systems	Millennium Cell, Inc.
Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels	Quantum Fuel Systems, LLC (Formerly Quantum Fuel System Technologies Worldwide, Inc.)
Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders	Profile Composites Inc.
Reversible Liquid Carriers	Air Products and Chemicals, Inc.
Safe and Effective Storage and Transmission of Hydrogen	Safe Hydrogen, LLC
Ultralightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes (SBIR)	Applied Nanotech, Inc.

Achieving Hydrogen Storage Goals through High-Strength Fiber Glass

ST
Emerging

Historical

- Developed by PPG Industries, Inc., with assistance from Hexagon Lincoln and Pacific Northwest National Laboratory.
- Can be used to store compressed hydrogen gas in FCVs or stationary applications.
- Achieves a volumetric capacity of 0.86 kWh/L (26 g H_2/L). DOE 2020 targets: 1.3 kWh/L (40 g H_2/L).
- Achieves a gravimetric capacity of 1.3 kWh/kg (4 wt% H_2). DOE 2020 targets: 1.8 kWh/kg (5.5 wt% H_2).
- Reduces the cost of the fibers for vessel reinforcement by about 50%. This lowers fiber costs down to <$6/lb.
- Improves the ability of hydrogen storage tanks to withstand high pressures without bursting.
- Contract Number: DE-EE0006626 (2014)



PPG's Pilot Fiber Production Process

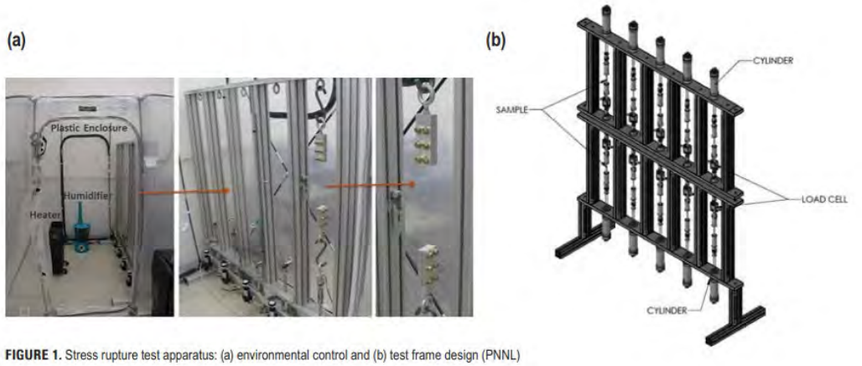


FIGURE 1. Stress rupture test apparatus: (a) environmental control and (b) test frame design (PNNL)

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Phone: (412) 820-8132
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Website: https://www.ppg.com

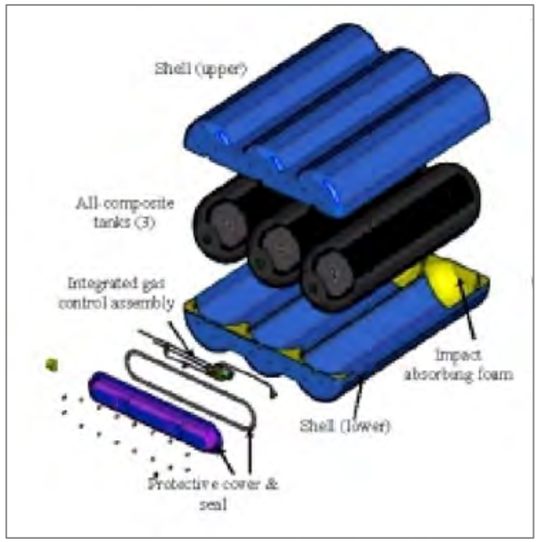
Compressed Hydrogen Gas Integrated Storage System

ST
Emerging

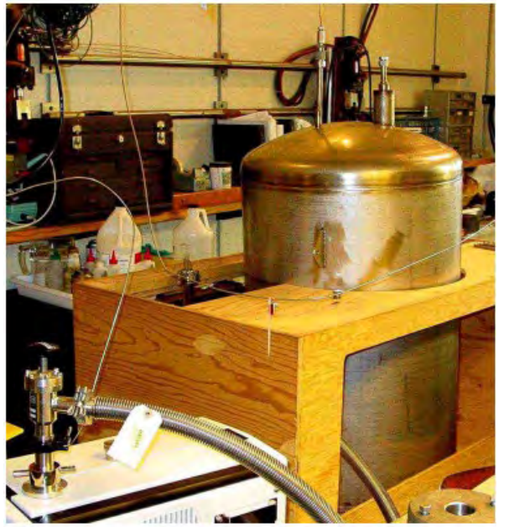
Historical

uspto
2 patents

- Developed by Johns Hopkins University Applied Physics Laboratory in collaboration with General Dynamics Armament & Technical Products.
- Overall objective was to advance the technology elements required to develop a semi-conformal, compressed Hydrogen gas integrated storage system (CH2-ISS) for light-duty vehicles.
- Improved tank gravimetric energy density through toughened epoxy resins.
- Developed idea of storage-to-vehicle attachment system (Crash Management System) that preserves vehicle “crumple zone” while reducing impact load to the storage unit.
- Contract Number: DE-FC36-01G011003 (2003)



Assembly View of the CH2-ISS


Finished Vessel Used for Testing

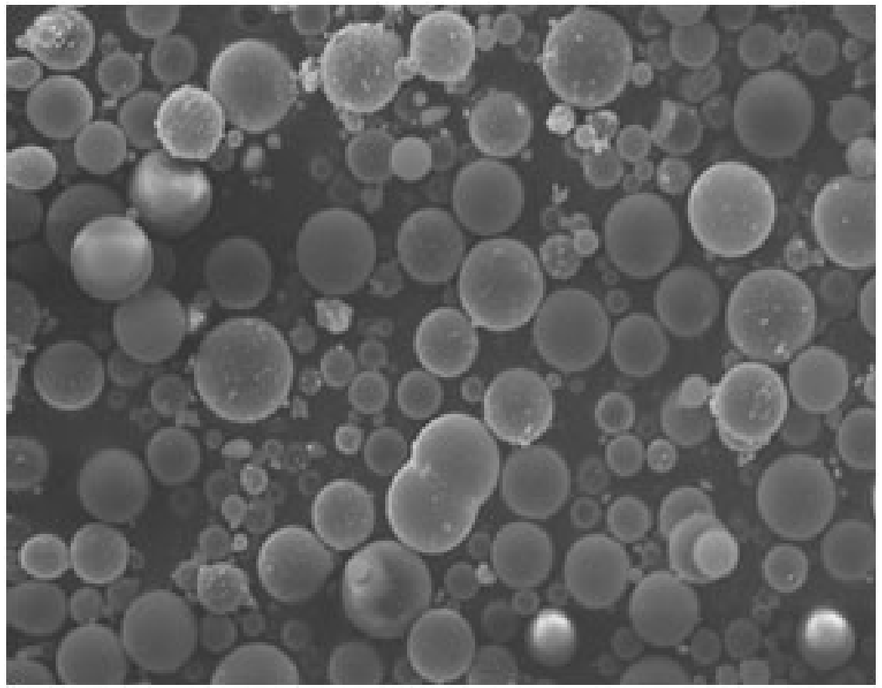
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High-Strength, Low-Cost Microballoons for Hydrogen Storage

ST
Emerging

Historical

- Developed by Powdermet, Inc., in collaboration with AF Research Labs, Precision Energy and Technology, and Protonex Technology Corporation.
- Designing, building, and testing hydrogen storage and delivery systems for microballoons.
- Can be used to safely and effectively store hydrogen gas for use in vehicles or other applications.
- Stores over 18 weight percent of hydrogen with a practical limit of about 12 weight percent of hydrogen in 1 mm spheres.
- Can be used as a storage and delivery system and to create structural foam.
- Produces harmless waste products after hydrogen release.
- Flows like water and conforms to any shape container.
- Uses pressurized microballoons, but the storage container is at atmospheric pressure.
- Contract Number: DE-FC36-04GO14215 (2004)



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Website: https://powdermetinc.com

Precision Energy & Technology

Hydrogen Composite Tanks

ST
Commercial

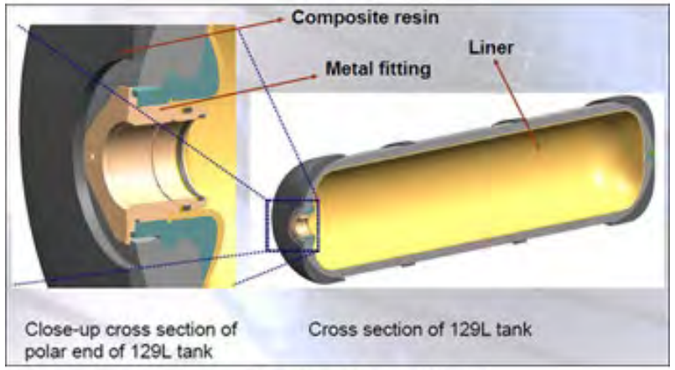
Historical

uspto
1 patent

- Developed by Quantum Fuel Systems Technologies Worldwide, Inc., and commercially offered in 2001.
- Catering to hydrogen fuel supply market, including hydrogen tanks, trailers, and virtual pipelines.
- More than 2,000 storage tank systems installed, primarily by major automobile manufacturers.
- Optimized tank design to achieve safety and structural performance targets while reducing cost, weight, and size.
- Can be used for compressed hydrogen fuel storage applications at 5,000 and 10,000 psig (700 bar).
- Contract Number: DE-AC36-GO10494 (2000)



Quantum's Hydrogen Storage System



Quantum Technologies' Optimized 129L Tank

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Lake Forest, CA 92630
Website: http://www.qtww.com

Hydrogen Storage in Cryo-Compressed Vessels

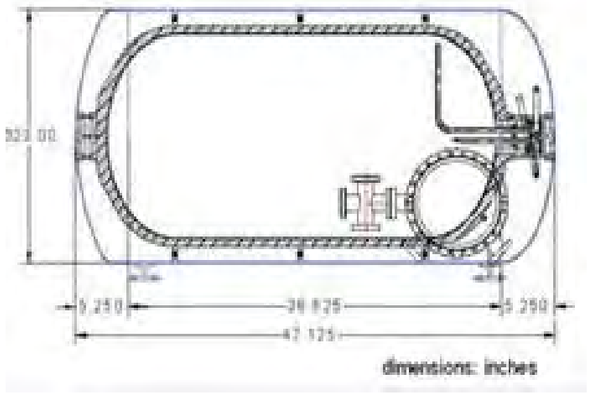
ST
Emerging

Historical

uspto
10 patents

- Developed by LLNL in partnership with Structural Composite Industries.
- Additional work on designing, manufacturing, and full-cycle testing of a new cryogenic pressure vessel for onboard vehicle hydrogen storage.
- Provides high specific energy and high energy density storage.
- Achieves flexible refueling with either compressed or liquid hydrogen.
- Can be dormant for extended periods with no measured loss of fuel from the vessel.
- The cryo-compressed hydrogen storage systems have achieved a storage density of 43g H_2/L; weight fraction of 7.3%; and cost of $11.3/kWh.
- Can be used with either compressed or liquid hydrogen.
- Contract Number: DE-AC52-07NA27344 (2007)





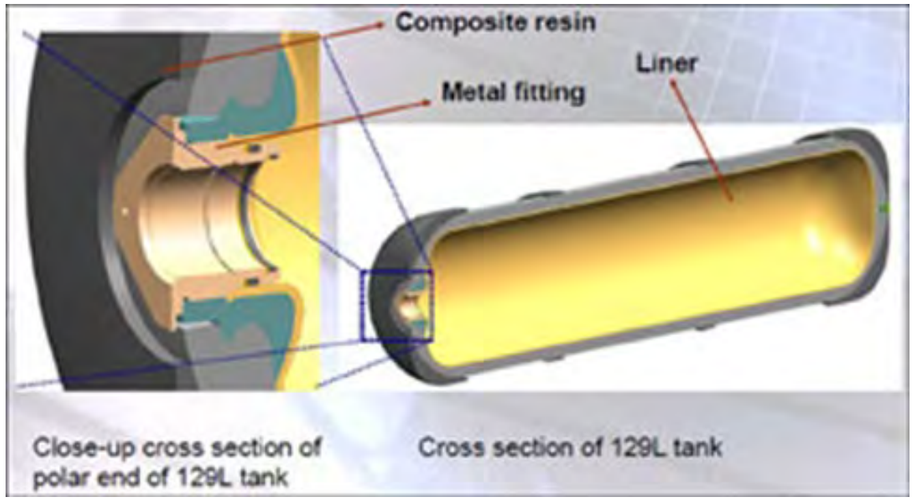
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Lawrence Livermore National Laboratory
7000 East Ave
Livermore, CA 94550
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Low-Cost Materials, High-Efficiency, High-Pressure Hydrogen Storage

ST
Emerging

Historical

- Developed by Quantum Fuel Systems, LLC.
- Can be deployed in both stationary and portable environments that require low-cost, high-efficiency, high-pressure hydrogen storage.
- Reduces cycle fatigue associated with refilling composite tanks.
- Reduces cost of manufacturing existing storage systems.
- Increases safety and reliability of hydrogen storage systems.
- Reduces system expense by using cost-competitive materials with high structural integrity.
- Uses composite tanks designed to withstand higher-cycling fatigue.
- Contract Number: DE-FC36-04GO15010 (2004)



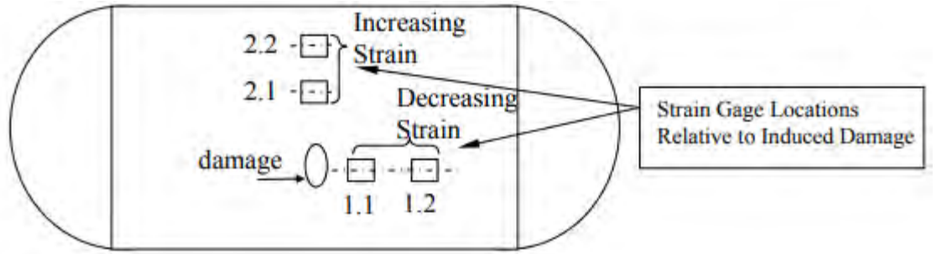


FIGURE 1. Strain Measurements During Pressure Cycling Test

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Manufacturable Chemical Hydride Cartridges for Hydrogen Fuel Systems

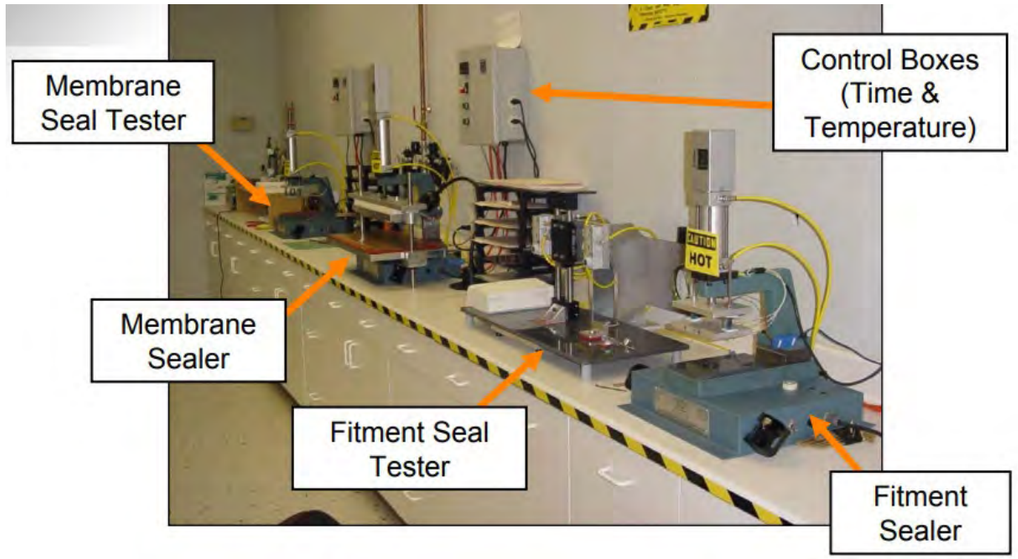
Pacific Northwest NATIONAL LABORATORY

ST *Emerging*

Historical

uspto 5 patents

- Developed by Millennium Cell, Inc., in partnership with Dow Chemical Company, Edison Welding Institute, and NextEnergy.
- A fuel canister with injection molded Delrin body, brass valve FC gas interface, and ring board FC electrical interface, along with a fuel bladder with polypropylene (PP) film, PP fitments, polytetrafluoroethylene (PTFE) hydrophobic membrane, and all heat-sealed components.
- Tested operating at ~1000 sccm H_2 flow and ~20 psig pressure.
- All cartridge subcomponents except PTFE membrane and hydrogen valve body are directly recyclable.
- Allows high-volume manufacturability of hydrogen generation cartridge components.
- Contract Number: DE-FC36-04GO14008 (2003) & DE-FC36-05GO15056 (2005)





Contact Information:

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Millennium Cell, Inc.
Address: n/a
Website: n/a

Millenniumcell DOW® EWI® NextEnergy

Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels

ST
Emerging

Historical

uspto
2 patents

- Developed by Quantum Technologies and the Boeing Company.
- Can be used to manufacture high-pressure vessels for fuel storage at lower weight and cost.
- Produces pressure vessels using less carbon fiber.
- Reduces weight without compromising pressure rating.
- Enables hydrogen and compressed natural gas vehicles to be more cost competitive.
- Reduced the cost and weight of hydrogen storage composite tanks by more than 15% using AFP manufacturing techniques.
- Contract Number: DE-FG36-08GO18055 (2008)



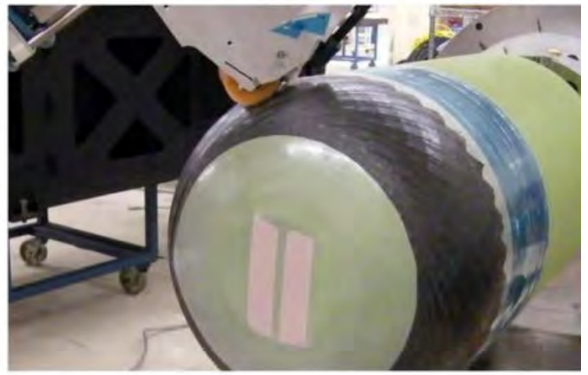


FIGURE 1. Fiber Placement of the End Cap (Older Generation Head)

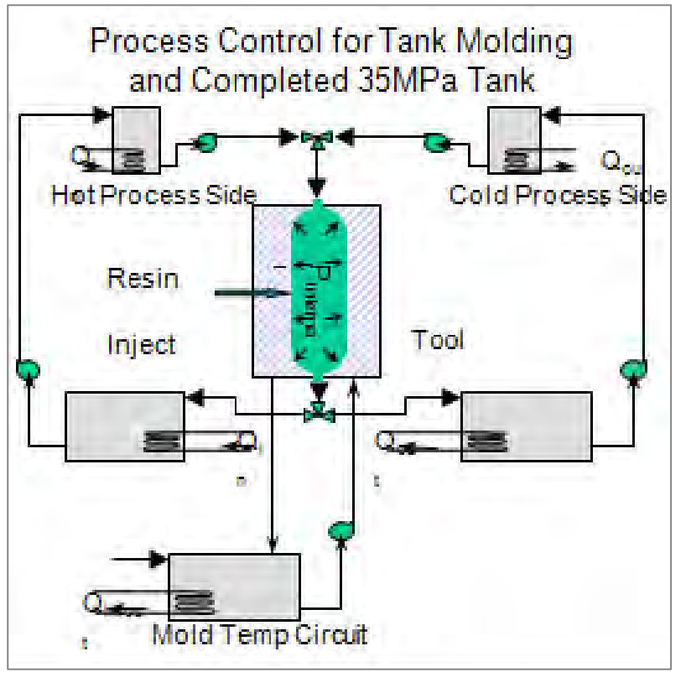
Contact Information:
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Phone: (949) 399-4521
Quantum Fuel System Technologies Worldwide, Inc.
25242 Arctic Ocean Dr.
Lake Forest, CA 92630
Website: n/a

Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders

ST
Emerging

Historical

- Developed by Profile Composites Inc., in partnership with Toyota Motor Engineering and Manufacturing North America, Inc., MAG Cincinnati Automation & Test, A&P Technology, Inc., and Bayer MaterialScience LLC.
- Planning to commercialize a 5,000 psi cylinder and begin developing a 10,000 psi cylinder. Awaiting certification of the tank so commercialization can start.
- Can be used to manufacture gas cylinders for hydrogen, methane, or natural gas.
- Allows fabrication of high-pressure hydrogen storage tanks in under 20 minutes total cycle time.
- Produces tanks at rates approaching vehicle production.
- Reduces the number of parallel tooling lines needed for production.
- Contract Number: DE-FG36-05GO15093 (2005)



Profile Composites' Hydrogen Tank Fabrication Process

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Website: n/a

Reversible Liquid Carriers

ST
Emerging

Historical

uspto
7 patents

- Developed by Air Products and Chemicals, Inc., in partnership with the United Technologies Research Corporation, Pacific Northwest National Laboratory, and BMW AG.
- Project completed in late 2010, and investigation of commercial opportunities has been underway.
- Can be used in both stationary and portable environments that require the stable, efficient, and safe delivery of hydrogen.
- Allows hydrogen to be stored as gas in a stable, hydrogenated liquid.
- Stores in simple, non-pressurized tank.
- Allows for multiple cycles and long life because of the selective, reversible reaction.
- Contract Number: DE–FG36-05GO15015 (2005)

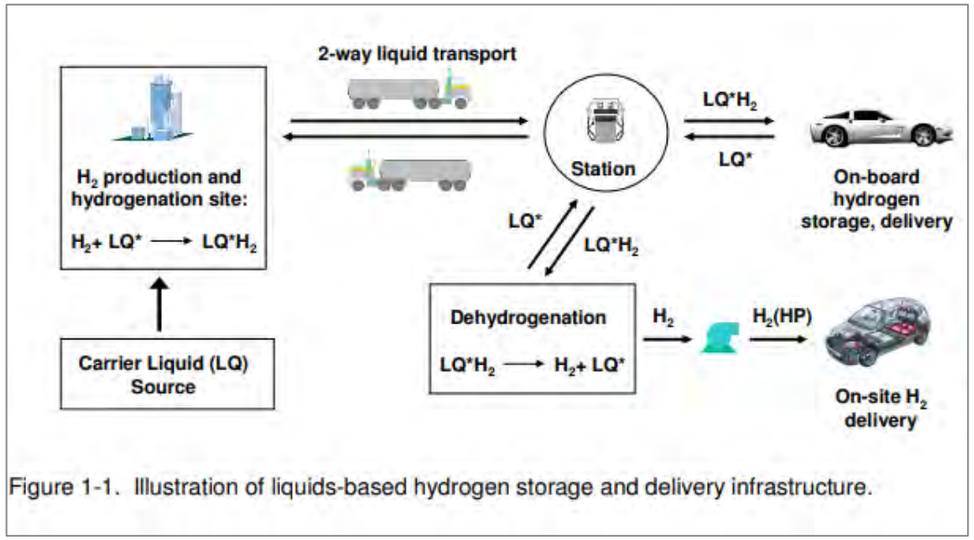
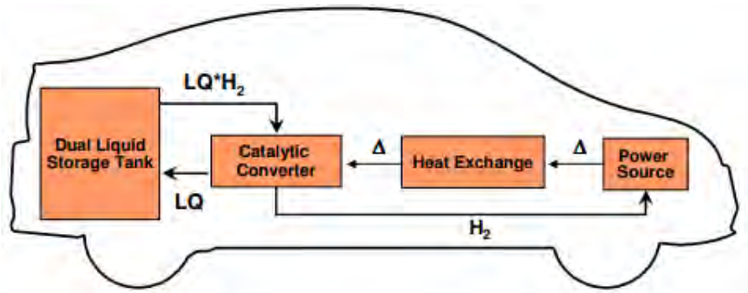


Figure 1-1. Illustration of liquids-based hydrogen storage and delivery infrastructure.



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Safe and Effective Storage and Transmission of Hydrogen

Pacific Northwest NATIONAL LABORATORY

ST *Emerging*

Historical

uspto 4 patents

- Developed by Safe Hydrogen, LLC.
- Establishing its application using conventional pumping and transportation mediums and infrastructure.
- Can be used anywhere consistent delivery of gaseous hydrogen is needed.
- Delivers hydrogen with low input energy.
- Provides a nonexplosive, noncorrosive hydrogen source.
- Can be reused by recycling the byproducts into the original hydride.
- Contract Number: DE-FC36-04GO14011 (2004)

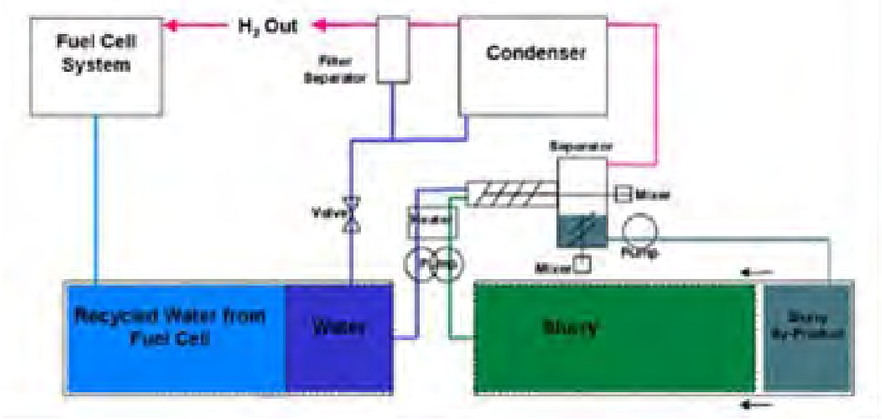




FIGURE 2. Mixer Showing Reactor and Pumps

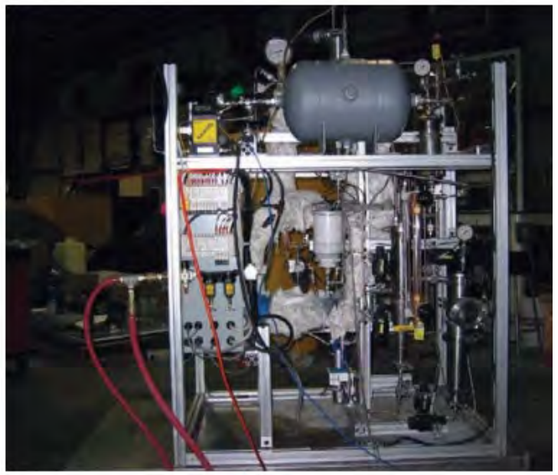


FIGURE 3. Mixer Showing H_2 and Water Control Systems

Safe Hydrogen, LLC

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Ultralightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes (SBIR)

ST
Emerging

Historical

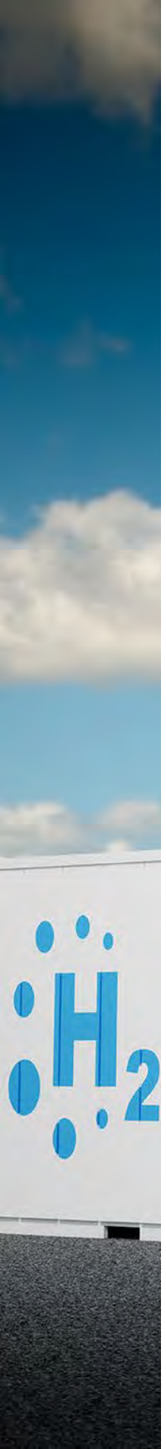
- Developed by Applied Nanotech, Inc. (dba Nano Magic, LLC), in collaboration with multiple industry partners.
- Can be used to cost effectively construct high pressure hydrogen storage tanks while maintaining mechanical integrity and performance.
- Reduces tank waste by up to 30% when compared to conventional carbon-fiber-reinforced polymer (CFRP).
- Improves tank mechanical performance using carbon nanotubes (CNT) reinforced CFRP when compared to conventional CFRP.
- Operates in the pressures range 5000 – 10,000 psi.
- Lowers tank cost by reducing the amount of carbon fiber material which can account for ~75% of overall tank cost.
- Contract Number: DE-FG02-11ER90183 (2012)



Glassfiber Layer Wound with CNT Epoxy (Top) and After Epoxy Resin is Smoothed (Bottom)

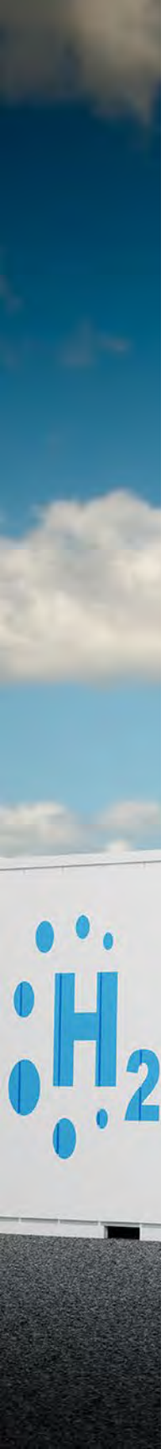
NEW

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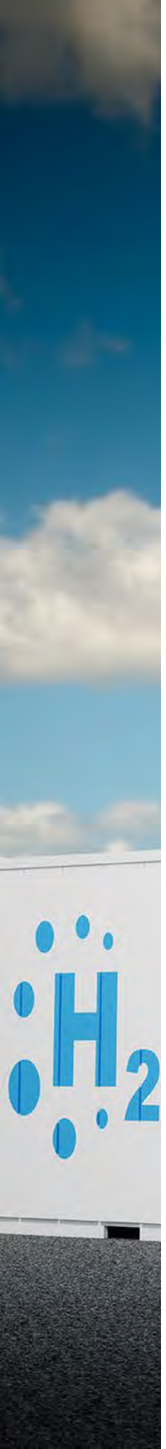
Organization Index

Organization	Technology
3M Company	Cathode Catalysts and Supports for PEM Fuel Cells (FC)
	Durable Catalysts for Fuel Cell Protection during Transient Conditions (FC)
	High Performance, Durable, Low-Cost Membrane Electrode Assemblies for Transportation Applications (FC)
	Highly Active, Durable, and Ultra-low PGM NSTF Thin Film ORR Catalysts and Supports (FC)
	Low-Cost, High-Performance Catalyst Coated Membranes for Proton Exchange Membrane Water Electrolyzers (FC)
	Membranes and Membrane Electrode Assemblies (MEAs) for Dry, Hot Operating Conditions (FC)
	New Fuel Cell Membranes with Improved Durability and Performance (FC)
	Advanced Manufacturing Processes for Gigawatt Scale Proton Exchange Membrane Water Electrolyzer Oxygen Evolution Reaction Catalysts and Electrodes (PROD)
Advent Innovations, Ltd.	PVDF-Film for Robust Online Assessment of Composite Tanks (PROACT) (SBIR) (SFTY)
Advent Technologies	L'Innovator Program – Next Generation HT PEM MEAs (FC)
Air Liquide Process and Construction, Inc.	Hydrogen Distributed Production System (PROD)
Air Products and Chemicals, Inc.	California Hydrogen Refueling Stations (DLVY)
	Integrated Hydrogen Energy Station (DLVY)
	Turnkey Hydrogen Fueling Station (DLVY)
	Ceramic Membrane Reactor Systems for Converting Natural Gas to H2 and Synthesis Gas (ITM Syngas) (PROD)
	Reversible Liquid Carriers (ST)



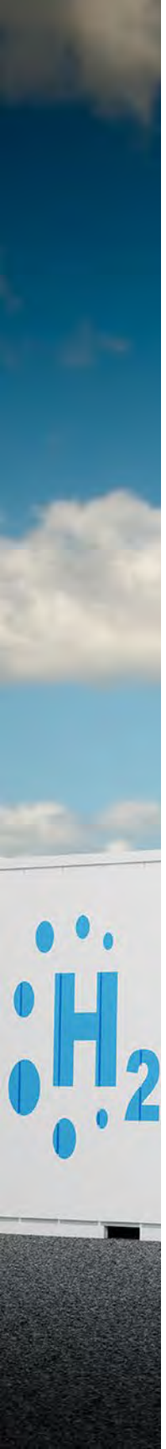
Organization Index (continued 2/18)

Organization	Technology
Altex Technologies Corporation	Compact and Low-Cost Thermal Management for Heavy-Duty Vehicle Fuel Cells (SBIR) (FC)
Applied Nanotech, Inc.	Ultralightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes (SBIR) (ST)
Argonne National Laboratory	GCTool: Fuel Cell Systems Analysis Software Model (FC)
	High-Pressure Distributed Ethanol Reforming (PROD)
Arkema Inc.	Improved Low-Cost, Durable Fuel Cell Membranes (FC)
	Novel Materials for High Efficiency Direct Methanol Fuel Cells (SBIR) (FC)
Atlas Copco (Formerly GreenField Compression)	H2 ProGen: A Total Supply Solution for Hydrogen Vehicles (DLVY)
Avalence, LLC	High-Efficiency, High-Pressure Electrolysis via Photovoltaic Arrays (SBIR) (PROD)
AvCarb, LLC (Formerly Ballard Material Products, Inc.)	Reduction in Fabrication Costs of Gas Diffusion Layers (FC)
BASF Catalysts, LLC	Platinum-Group-Metal Recycling Technology (FC)
BASF Fuel Cell, Inc.	High-Speed, Low-Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies (FC)
	Integrated Manufacturing for Advanced Membrane Electrode Assemblies (FC)
Bettergy Corporation	Composite Membrane for High Temperature Hydrogen Separation (SBIR) (PROD)
Bloom Energy Corporation	Low-Cost Co-Production of Hydrogen and Electricity (FC)
Brookhaven National Laboratory	Low Platinum Loading Fuel Cell Electrocatalysts (FC)
	Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports (FC)



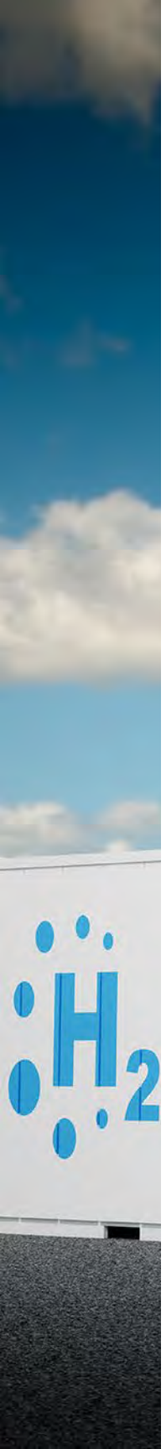
Organization Index (continued 3/18)

Organization	Technology
Cabot Superior MicroPowders	High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure (FC)
California Fuel Cell Partnership	Station Operational Status System (SOSS) 3.0 and Station Map Upgrade Project (DLVY)
California State University LA	Sustainable Hydrogen Fueling Station - Performance Evaluation and Optimization (DLVY)
Catacel Corporation (Acquired by Johnson Matthey Plc)	Scalable Steam Methane Reformer System for Distributed Hydrogen Production (PROD)
	Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production (PROD)
Caterpillar, Inc.	System Demonstration for Supplying Clean, Reliable and Affordable Electric Power to Data Centers using Hydrogen Fuel (DLVY)
Center for Transportation and the Environment	Fuel Cell Hybrid Electric Delivery Van (FC)
ClearEdge Power (Formerly UTC Power)	Polymer Electrolyte Membrane (PEM) Fuel Cell Power Plant Development and Verification (FC)
	PureMotion® 120 Fuel Cell Power Plant (FC)
Clemson University	Self-Healable Copolymer Composites for Extended Service Hydrogen Dispensing Hoses (DLVY)
	Laser 3-D Printing of Highly Compacted Protonic Ceramic Electrolyzer Stack (FC)
Clenersys Inc. (Nano-C, Inc spin-off)	Solution Based Nanostructured Carbon Coatings for Reusable, Corrosion Resistant, Stamped Metallic Bipolar Plates (SBIR) (FC)
Colorado School of Mines	Solid State Based Hydrogen Loss Recovery During LH2 Transfer (DLVY)
Concepts NREC	Centrifugal Hydrogen Pipeline Gas Compressor (DLVY)
Constellation Energy Corp. (formerly Exelon Corporation)	Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply (PROD)



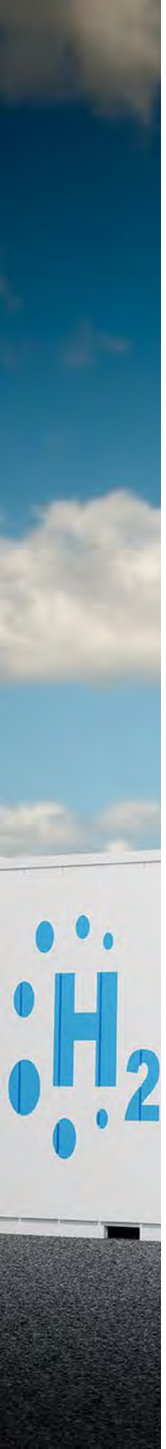
Organization Index (continued 4/18)

Organization	Technology
Cummins, Inc.	Automation of Solid Oxide Electrolyzer Cell (SOEC) & Stack Assembly (PROD)
C-Zero, LLC	Binary Chloride Salts as Catalysts for Methane to Hydrogen and Graphitic Powder (PROD)
Delphi Corporation	Solid Oxide Fuel Cell Auxiliary Power Unit (FC)
Drexel University	Polymerized Ionic Liquid Block Copolymer/Ionic Liquid Composite Ionomers for High Current Density Performance (FC)
DuPont Fuel Cells	Lifetime Improvements for PEM Fuel Cells (FC)
Dynalene, Inc.	Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR) (FC)
E.I. du Pont de Nemours and Company w/Canegie Mellon University	Durable High Power Density Fuel Cell Cathodes for Heavy-Duty Vehicles (FC)
Eaton Corporation	Roots Air Management System with Integrated Expander (FC)
Electric Power Research Institute	Performance Testing of a Moving-Bed Gasifier using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen (PROD)
Electricore, Inc.	High Pressure, High Flow Rate Dispenser and Nozzle Assembly for Heavy Duty Vehicles (DLVY)
	Innovative Advanced Hydrogen Mobile Fueler (DLVY)
Element One, Inc. w/National Laboratory of the Rockies	DetecTape™: Early Warning Visual Hydrogen Leak Detector (SFTY)
Eltron Research & Development, Inc.	Scale up of Hydrogen Transport Membranes for Integrated Gasification-Combined Cycle Operation (PROD)



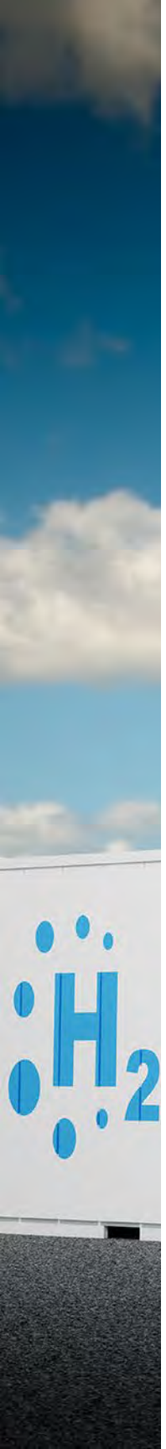
Organization Index (continued 5/18)

Organization	Technology
Emerald Energy NW, LLC (Acquired technology from Prometheus Energy Group, Inc.) & Pacific Northwest National Laboratory	Active Magnetic Regenerative Liquefier (PROD)
eSpin Technologies, Inc,	Nanostructured Proton Exchange Membrane (SBIR) (FC)
Faraday Technology, Inc.	FARADAYIC® ElectroEtching of Stainless Steel Bipolar Plates (SBIR) (FC)
Forge Nano	Highly Robust Low PGM MEAs Based upon Composite Supports (FC)
Freudenberg-NOK General Partnership	Manufacture of Durable Seals for PEM Fuel Cells (FC)
Frontier Energy Inc.	Demonstration and Framework for H2@Scale in Texas and Beyond (PROD)
Fuel Cell & Hydrogen Energy Association (FCHEA)	Fuel Cell & Hydrogen Energy Association Codes and Standards Support (SFTY)
FuelCell Energy, Inc.	High Efficiency Reversible Solid Oxide System (FC)
	High-Temperature Membrane with Humidification-Independent Cluster Structure (FC)
	Smart Matrix Development for Direct Carbonate Fuel Cell (FC)
	Efficient Solid-State Electrochemical Hydrogen Compressor (SBIR) (PROD)
	Modular Solid Oxide Electrolysis Cell System for Efficient Hydrogen Production at High Current Density (PROD)
	Reformer-Electrolyzer-Purifier (REP) for Production of Hydrogen [CO2 Pump] (PROD)
	Solid Oxide Electrolysis System Demonstration (PROD)



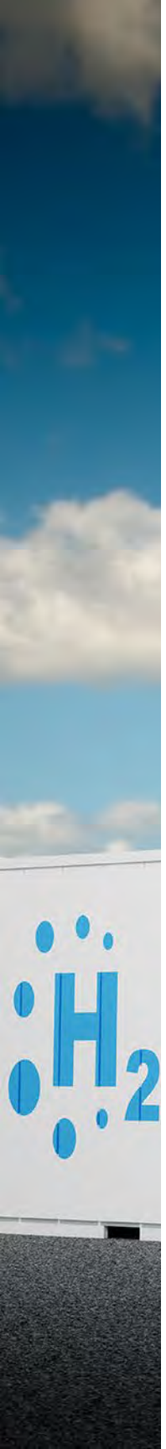
Organization Index (continued 6/18)

Organization	Technology
Gas Technology Institute	Performance Evaluation of Delivered Hydrogen Fueling Stations (DLVY)
GE Global Research Center	Integrated Short Contact Time Hydrogen Generator (PROD)
General Engineering & Research, LLC	Low-Cost Alloys for Magnetocaloric Refrigeration (SBIR) (PROD)
General Motors Company (GM)	Durable High-Power Membrane Electrode Assemblies with Low Pt Loading (FC)
	Highly-Accessible Catalysts for Durable High-Power Performance (FC)
Genesis Fueltech, Inc.	Membrane Structures for Hydrogen Separation (SBIR) (PROD)
Georgia Institute of Technology	High-Performance AEM LTE with Advanced Membranes, Ionomers and PGM-Free Electrodes (FC)
Giner, Inc.	Dimensionally-Stable High-Performance Membrane (SBIR) (FC)
	ElectroCat: Durable Mn-Based Platinum-Group-Metal-Free Catalysts for Polymer Electrolyte Membrane Fuel Cells (FC)
	High-Performance, Long-Lifetime Catalysts for Proton Exchange Membrane Electrolysis (SBIR) (FC)
	Ionomer Dispersion Impact on Advanced Fuel Cell and Electrolyzer Performance and Durability (SBIR) (FC)
	Novel Fluorinated Ionomer for Polymer Electrolyte Membrane (PEM) Fuel Cells (SBIR) (FC)
	High Temperature, High Pressure Electrolysis (SBIR) (PROD)
	PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane (SBIR) (PROD)
	Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi (SBIR) (PROD)
GrafTech International Ltd.	Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates (FC)



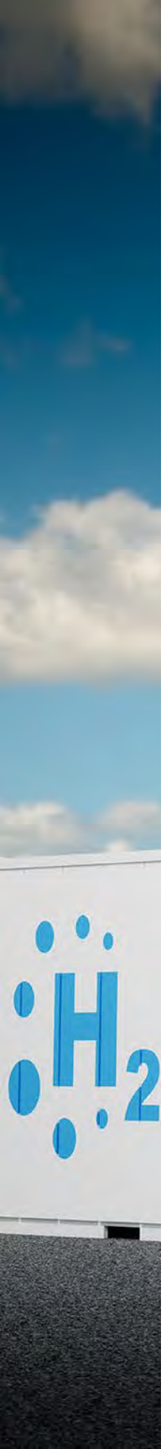
Organization Index (continued 7/18)

Organization	Technology
GVD Corporation	Advanced Barrier Coatings for Harsh Environments (DLVY)
	Coatings for Compressor Seals (FC)
Hawaii Hydrogen Carriers, LLC	Low-Cost, Efficient, Metal Hydride Hydrogen Storage System for Forklift Applications (SBIR) (ST)
Hexagon Digital Wave, LLC (formerly Digital Wave Corporation)	Non-Destructive Ultrasonic Scanning Technology (SFTY)
Hexagon Lincoln (Formerly Lincoln Composites, Inc.)	TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery (DLVY)
Honeywell Aerospace	Thermal and Water Management Systems for PEM Fuel Cells (FC)
Honeywell International, Inc.	Fuel Cell Turbocompressor (FC)
HySense Technology LLC (UCFL Start Up)	Intellipigment™: Visible Hydrogen Gas Leak Detection Material (SFTY)
IdaTech, LLC	Off-Road Fuel Cell Applications (FC)
InnoSense, LLC	Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors (SBIR) (SFTY)
InnovaTek, Inc.	Novel Catalytic Fuel Reforming (PROD)
Intelligent Energy, Inc.	High-Efficiency Polymer Electrolyte Membrane Fuel Cell Combined Heat and Power System (FC)
Intelligent Optical Systems, Inc.	Hydrogen Gas Sensing System (SFTY)
Ion Power, Inc.	Platinum and Fluoropolymer Recovery from PEM Fuel Cells (FC)
IRD Fuel Cells LLC (Acquired from Cabot Corporation)	Improved Catalyst Coated Membrane (CCM) Manufacturing (FC)



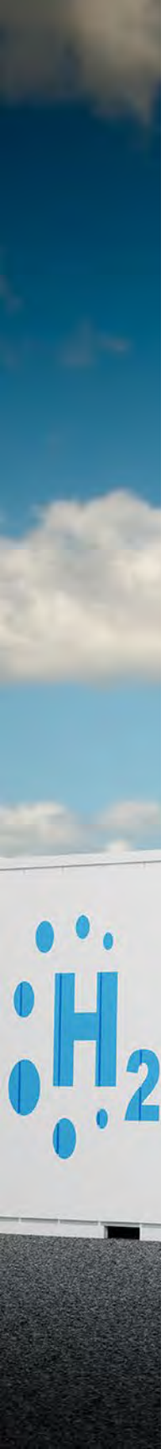
Organization Index (continued 8/18)

Organization	Technology
Ivys Energy Solutions	Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks (DLVY)
Jadoo Power Systems, Inc.	Portable Solid Oxide Fuel Cell Generator (PROD)
Johns Hopkins University Applied Physics Laboratory	Compressed Hydrogen Gas Integrated Storage System (ST)
Lawrence Livermore National Laboratory	Rapid High-Pressure Liquid Hydrogen Refueling for Maximum Range and Dormancy (DLVY)
	Hydrogen Storage in Cryo-Compressed Vessels (ST)
Lawrence Livermore National Laboratory w/UltraCell Corporation (Acquired by Advent Technologies, LLC)	Portable Reformed Methanol Fuel Cells (FC)
Lilliputian Systems, Inc.	Nectar™: Mobile Power System: Silicon-Based SOFC for Portable Consumer Electronics (FC)
Linde Engineering North America, Inc.	Integrated Hydrogen Production, Purification, and Compression System (DLVY)
Los Alamos National Laboratory	Hydrogen Fuel Quality (DLVY)
	Leak Detection and Hydrogen Sensor Development (SFTY)
Los Alamos National Laboratory w\Lyondellbasell Industries Holdings B.V. (Formerly Bulk Molding Compounds, Inc.)	Conductive Compound for Molding Fuel Cell Bipolar Plates (FC)
Los Alamos National Laboratory w/Fuel Cell Technologies, Inc.	Corrosion Test Cell for PEM Bipolar Plate Materials (FC)
Luna Innovations	NDE Techniques for Pressure Vessels: Detection of Micron-Scale Flaws through Nonlinear Wave Mixing (SBIR) (ST)



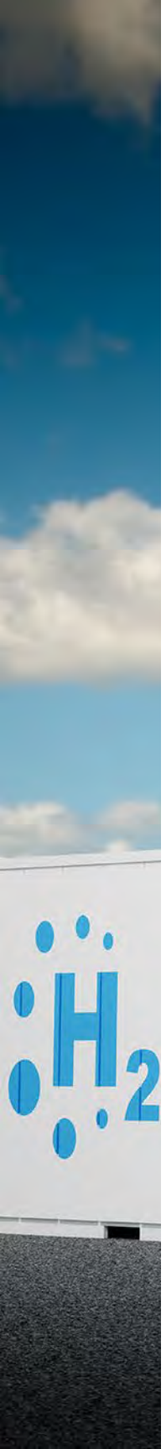
Organization Index (continued 9/18)

Organization	Technology
Mahle Powertrain, LLC	Durable and Efficient Centrifugal Compressor-Based Filtered Air Management System and Optimized BOP (FC)
Mainstream Engineering Corporation	Cross-Polarized Near-Ultraviolet/Visible (CPNUVV) Detector for In-Line Quality Control of Polymer Electrolyte Membrane Materials (SBIR) (FC)
Makel Engineering, Inc.	Low-Cost Hydrogen Sensor for Transportation Safety (SFTY)
Media and Process Technology, Inc.	Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor (PROD)
MeOH Power (Formerly MTI Micro Fuel Cells, Inc.)	Direct Methanol Fuel Cell (DMFC) for Handheld Electronics Applications (FC)
Millennium Cell, Inc.	Manufacturable Chemical Hydride Cartridges for Hydrogen Fuel Systems (ST)
Missouri University of Science & Technology	Grid-Interactive Steelmaking with Hydrogen (GISH) (DLVY)
Mohawk Innovative Technology, Inc.	Oil Free Hydrogen Compressor (SBIR) (DLVY)
MVSystems, Inc. (Prior project from University of Hawaii)	Photoelectrochemical Hydrogen Production (PROD)
NanoSonic, Inc.	Flexhose: Cryogenically Flexible, Low Permeability Thoraeus Rubber Hydrogen Dispenser Hose (SBIR) (DLVY)
	High-Pressure, Low-Temperature Composite Nozzles for Long-Term Hydrogen Dispensing (SBIR) (DLVY)
Nanotek Instruments, Inc.	Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells (SBIR) (FC)



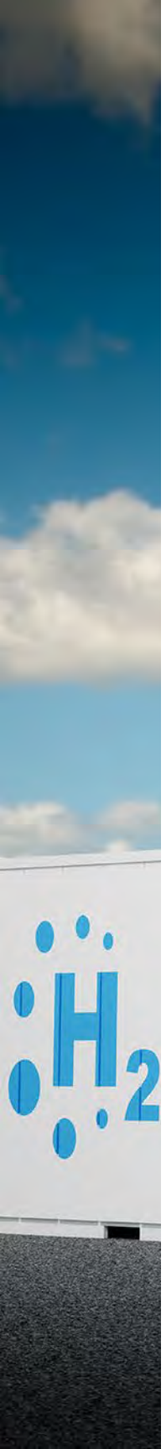
Organization Index (continued 10/18)

Organization	Technology
National Laboratory of the Rockies (formerly NREL)	Fuel Cell Bus Evaluations (DLVY)
	MC Formula Protocol for H35HF Fueling (DLVY)
	High Efficacy Validation of Hydride Mega Tanks at the ARIES Lab (HEVHY METAL) (ST)
	ARIES / Flatirons Facility - Hydrogen System Capability Buildout (DLVY)
	Innovating Hydrogen Station: Heavy-Duty Fueling (DLVY)
	Direct Methanol Fuel Cell (DMFC) Anode Catalysts (FC)
	Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes (FC)
	Fuel Cell Membrane Electrode Assembly Manufacturing R&D (FC)
	In-Line Membrane Thickness Mapping with Real-Time Data Processing (FC)
	Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids (FC)
	Renewable Electrolysis Integrated System Development and Testing (PROD)
Nel Hydrogen	Enabling Low Cost PEM Electrolysis at Scale Through Optimization of Transport Components and Electrode Interfaces (PROD)
Nel Hydrogen (Formerly Proton Onsite)	HydroGEN Seedling: High-Efficiency Proton Exchange Membrane Water Electrolysis Enabled by Advanced Catalysts, Membranes, and Processes (FC)
	Catalysts/Electrodes for Hydrogen Production by Water Electrolysis (SBIR) (PROD)
	Economical Production of Hydrogen Through Development of Novel, High Efficiency Electrocatalysts for Alkaline Membrane Electrolysis (SBIR) (PROD)
	High Performance, Low-Cost Hydrogen Generation from Renewable Energy (SBIR) (PROD)
	High-Pressure PEM Electrolyzer and Composite Tube Hydrogen Storage (PROD)
	Hydrogen By Wire – Home Fueling System (SBIR) (PROD)



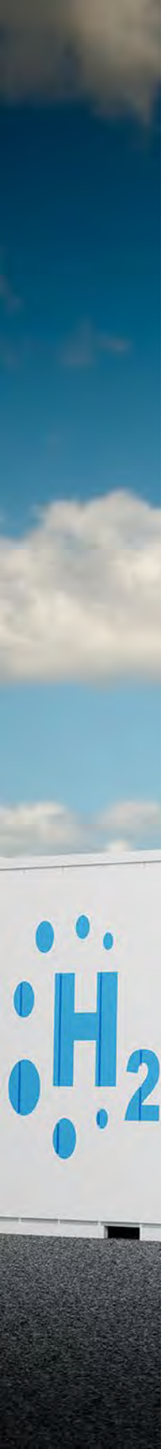
Organization Index (continued 11/18)

Organization	Technology
Nel Hydrogen (Formerly Proton Onsite)	Hydrogen Generation from PEM Electrolysis (PROD)
	Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage (SBIR) (PROD)
NeoGraf Solutions, LLC	Development of Low Cost, Thin Flexible Graphite Bipolar Plates for Heavy Duty Fuel Cell Applications (FC)
Nexceris LLC (formerly NexTech Materials, Ltd.)	Nanoscale Water Gas Shift Catalysts (FC)
	Sensors for Automotive Fuel Cell Systems (FC)
	Hydrogen Safety Sensor for Advanced Energy Applications (SFTY)
	Advanced Coatings to Enhance the Durability of SOEC Stacks (PROD)
Northeastern University	Development of Novel Non-PGM Electrocatalysts for Proton Exchange Membrane Fuel Cell Applications (FC)
NuVant Systems Inc.	Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods (SBIR) (FC)
Nuvera Fuel Cells, Inc. (Acquired by Hyster-Yale)	Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM) (FC)
	Nuvera® Fuel Cell System (ARRA) (FC)
	Orion™: Fuel Cell Technology for Hybrid Power Applications (FC)
Oak Ridge National Laboratory	Composite Pipeline Technology for Hydrogen Delivery (DLVY)
	Advanced FC Vehicle DC-DC Converter Development (FC)
	Nitrided Metallic Bipolar Plates for PEM Fuel Cells (FC)
	MEMS Hydrogen Sensor for Leak Detection (SFTY)
	Low-Cost, High Strength Commercial Textile Precursor (PAN-MA) (ST)
	Vessel Design and Fabrication Technology for Stationary High-Pressure Hydrogen Storage (ST)



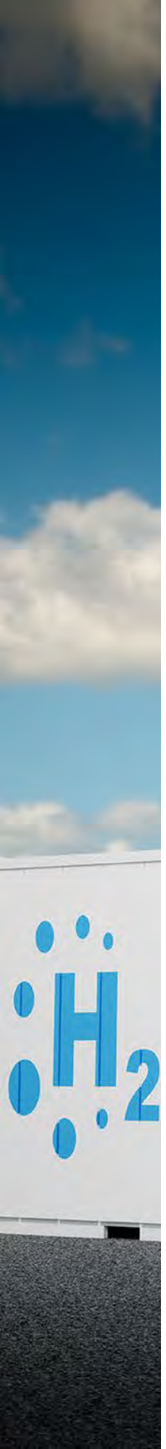
Organization Index (continued 12/18)

Organization	Technology
Oak Ridge National Laboratory w/Porvair Advanced Materials, Inc.	Scale-Up of Carbon-Carbon Composite Bipolar Plates (FC)
OneD Material, LLC	Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells (FC)
Oregon State University	Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass (PROD)
	Scalable and Highly Efficient Microbial Electrochemical Reactor for Hydrogen Generation from Lignocellulosic Biomass and Waste (PROD)
Pacific Hydrogen (formerly Hornblower Energy, LLC)	Waterfront Maritime Hydrogen Demonstration Project (PROD)
Pacific Northwest National Laboratory	Alternative and Durable High-Performance Cathode Supports for PEM Fuel Cells (FC)
	MagnetoCaloric Hydrogen Liquefaction (PROD)
	Hydrogen Safety Outreach to Expedite H2 Fueling and Energy Project Deployment and Promote Public Acceptance for Zero Emission Vehicles and Reliable Distributed Power Generation (SFTY)
	Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources (SFTY)
	Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks (ST)
Pajarito Powder, LLC	Active and Durable Platinum-Group-Metal-Free Cathodic Electrocatalysts for Fuel Cell Application (FC)
	Development of Durable Active Supports for Low Platinum Group Metal Catalysts (SBIR) (FC)
Pall Corporation	High-Performance Palladium-Based Membrane (PROD)
pH Matter, LLC	Multi-Functional Catalyst Support (SBIR) (FC)
	Regenerative Fuel Cell System (SBIR) (FC)



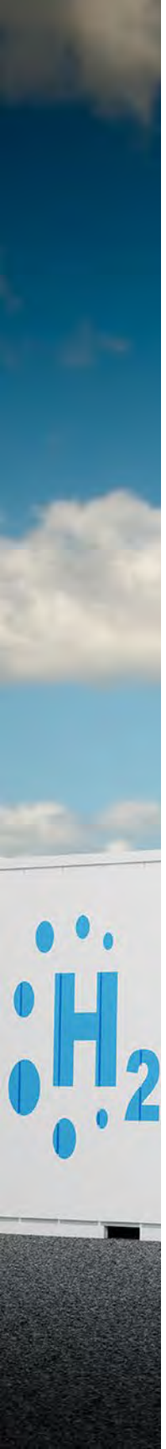
Organization Index (continued 13/18)

Organization	Technology
Plug Power, Inc.	Domestically Manufactured Fuel Cells for Heavy-Duty Applications (FC)
	Fuel-Cell-Powered Airport Ground Support Equipment Deployment (FC)
	GenCore® Backup Fuel Cell Systems (FC)
	GenDrive™: Fuel Cell Power System (ARRA) (FC)
	GenSys® Blue: High-Temperature CHP Fuel Cell System (ARRA) (FC)
	Ground Support Equipment Demonstration (FC)
	Integrated Membrane Anode Assembly & Scale-Up (PROD)
PolyFuel, Inc.	Direct Methanol Fuel Cell Power Supply for All-Day True Wireless Mobile Computing (FC)
Powdermet, Inc.	High-Strength, Low-Cost Microballoons for Hydrogen Storage (ST)
PPG Industries, Inc.	Achieving Hydrogen Storage Goals through High-Strength Fiber Glass (ST)
Praxair, Inc.	Integrated Ceramic Membrane System for Hydrogen Production (PROD)
Profile Composites Inc.	Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders (ST)
Proton Energy Systems dba Nel Hydrogen	FuelGen® Hydrogen Fueling Systems (DLVY)
Protonex Technology Corporation (Acquired by Ballard Power Systems)	Novel Manufacturing Process for PEM Fuel Cell Stacks (FC)
Quantum Fuel Systems, LLC (Formerly Quantum Fuel System Technologies Worldwide, Inc.)	Hydrogen Composite Tanks (ST)
	Low-Cost Materials, High-Efficiency, High-Pressure Hydrogen Storage (ST)
	Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels (ST)



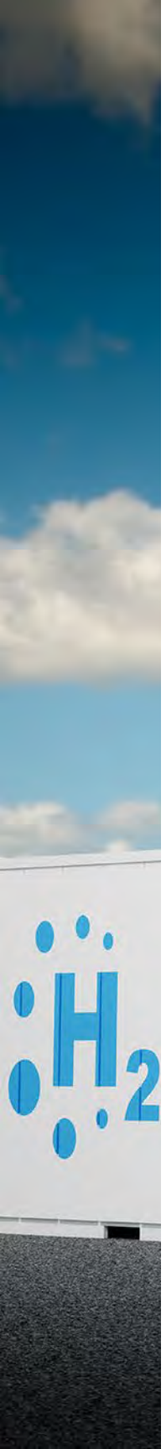
Organization Index (continued 14/18)

Organization	Technology
R&D Dynamics Corporation	Foil Bearing Supported Compressor-Expander (FC)
REB Research & Consulting	ME100 Methanol Reforming Hydrogen Generator (SBIR) (PROD)
Redox Power Systems	Affordable, High Performance, Intermediate Temperature Solid Oxide Fuel Cells (FC)
Rensselaer Polytechnic Institute	Channeling Engineering of Hydroxide Ion Exchange Polymers and Reinforced Membranes (FC)
	Ultrasonics and Diagnostics for High-Temperature PEM MEA Manufacture (FC)
Rice University	Scalable Halide Perovskite Photoelectrochemical Cell Modules with 20% Solar-to-Hydrogen Efficiency and 1,000 Hours of Diurnal Durability (PROD)
RockeTruck, Inc.	Fuel Cell Integrated Power Electronics Module (FCIPEM) (SBIR) (FC)
	Mobile Fuel Cell Generator (STTR) (FC)
Rockytech, Ltd.	Modification of Nafion Thermoplastic Precursor to Enable Reprocessing of Fuel Cell Manufacturing Scraps (SBIR) (FC)
RTX Technology Research Center (formerly UTRC)	High Performance Hydrocarbon Membrane Electrode Assembly (FC)
SAFCell, Inc.	Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications (FC)
Safe Hydrogen, LLC	Safe and Effective Storage and Transmission of Hydrogen (ST)
Saint-Gobain	Development of Durable Materials for Cost Effective Advanced Water Splitting Utilizing All Ceramic Solid Oxide Electrolyzer Stack Technology (PROD)
Sandia National Laboratories	Enabling Hydrogen Infrastructure Through Science-Based Codes and Standards (SFTY)
	Hydrogen Blending into Natural Gas Pipelines (DLVY)



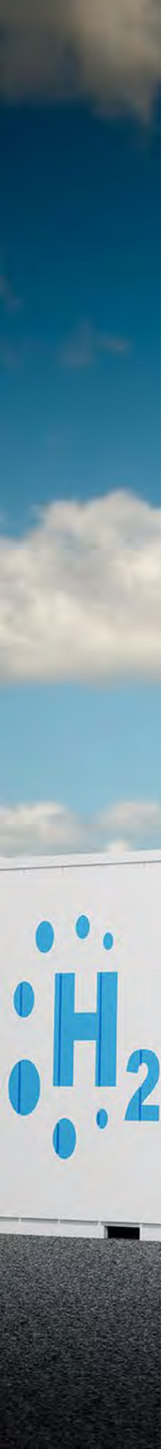
Organization Index (continued 15/18)

Organization	Technology
Sandia National Laboratories (continued)	Hydrogen Station Equipment Performance (HyStEP) Device (SFTY)
	Maritime Fuel Cell Generator (MarFC) Project (FC)
	Port Demand Assessment: MARAD Co-Fund / Hydrogen for Maritime and Rail Fuel Cell Technologies (DLVY)
	R&D for Safety, Codes and Standards: Materials and Components Compatibility (SFTY)
Sandia National Laboratories w/Stray Light Optical Technologies	Fuel-Cell-Based Mobile Lighting (FC)
Savannah River National Laboratory	Electrochemical Reversible Formation of Alane (ST)
Scribner Associates, Inc.	Fuel Cell Membrane Measurement System for Manufacturing (SBIR) (FC)
Secat, Inc.	Materials Solutions for Hydrogen Delivery in Pipelines (DLVY)
Shell	First Demonstration of a Commercial Scale LH2 Storage Tank Design for International Trade Applications (ST)
SiGNa Chemistry, Inc. (IP Acquired by Intelligent Energy Ltd.)	Sodium Silicide (NaSi) Hydrogen Generation System (PROD)
Skyre, Inc. (formerly Sustainable Innovations, LLC)	HRS-100™: Hydrogen Recycling System (SBIR) (PROD)
	Hydrogen Contamination Detection (SBIR) (PROD)
Southern Company Services, Inc.	Novel Microbial Electrolysis System for Conversion of Biowastes into Low-Cost Renewable Hydrogen (PROD)
Southwest Research Institute	Hydrogen Compression Application of the Linear Motor Reciprocating Compressor (LMRC) (DLVY)
Southwest Sciences, Inc.	Diode Laser Sensor for Contaminants in Hydrogen Fuel (SBIR) (DLVY)



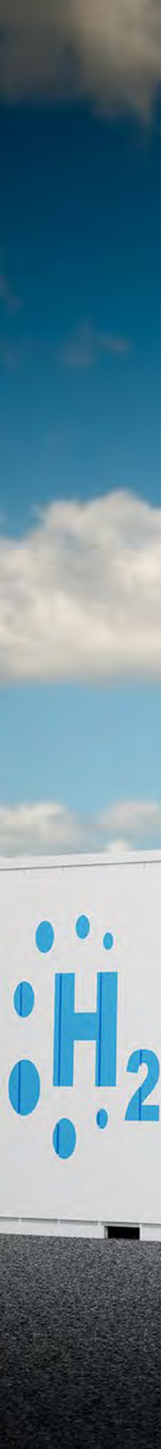
Organization Index (continued 16/18)

Organization	Technology
SPEC Sensors, LLC	Robust and Reliable Hydrogen Leak Detection and Warning Systems (SBIR) (SFTY)
Special Power Sources, LLC (Formerly Atrex Energy, Inc.)	Low-Cost 3-10 kW Tubular SOFC Power System (FC)
SRI International (formerly PARC)	DECIPHER: DEtection System Comprising Inexpensive Printed Sensor Arrays for Hydrogen Gas Emission Monitoring and Reporting (SFTY)
Starfire Industries LLC	Bipolar Plate Manufacturing and Reconditioning Using Next-Generation IMPULSE HiPIMS Etching, Surface Preparation, and Pinhole-Free Deposition of Corrosion-Resistant, Low-ICR Coatings (SBIR) (FC)
SulfaTrap, Inc.	Bio-Fueled Solid Oxide Fuel Cells (SBIR) (FC)
Synkera Technologies, Inc. (Acquired by Integrated Device Technology, Inc)	Nanotube Array Photocatalysts (SBIR) (PROD)
TDA Research, Inc.	Hydrogen Production for Refineries (SBIR) (PROD)
	Onboard Monitoring Method for Detection of Damage to Carbon Fiber Composite Overwrap on Hydrogen Fuel Tanks (SBIR) (ST)
Technology Management, Inc.	Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System (FC)
Tetramer Technologies, LLC	High-Performance Water Vapor Membranes to Improve Fuel Cell Balance of Plant Efficiency and Lower Costs (SBIR) (FC)
The Chemours Company FC, LLC	Performance and Durability Investigation of Thin, Low Crossover Proton Exchange Membranes for Water Electrolyzers (PROD)



Organization Index (continued 17/18)

Organization	Technology
Treadstone Technologies, Inc.	Development and Manufacturing for Precious Metal Free Metal Bipolar Plate Coatings for PEM Fuel Cells (FC)
	Low Cost Metal Bipolar Plate Carbon Coating Technology for Heavy Duty Fuel Cells (SBIR) (FC)
	Low-Cost PEM Fuel Cell Metal Bipolar Plates (FC)
	Novel Structured Metal Bipolar Plates for Low-Cost Manufacturing (SBIR) (FC)
University of California - Berkeley	Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures (PROD)
University of Colorado-Boulder	Extremely Durable Concrete Using Methane Decarbonization Nanofiber Co-Products with Hydrogen (PROD)
	Solar-Thermal Production of Hydrogen Using Renewable Feedstock (PROD)
University of Georgia	The Electrical Hydrogen Sensor Technology with a Sub-Minute Response Time and a Part-Per-Billion Detection Limit for Hydrogen Environmental Monitoring (SFTY)
University of Hawaii at Manoa - Hawaii Natural Energy Institute	Hydrogen Energy Systems as a Grid Management Tool (PROD)
University of Kentucky	Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks (ST)
University of Missouri	Real-Time Ionic Liquid Electrochemical Sensor for Highly Sensitive and Selective Hydrogen Detection and Quantification (SFTY)
University of New Mexico (UNM)	Development of PGM-free Catalysts for Hydrogen Oxidation Reaction in Alkaline Media (FC)
University of Oregon	Pure Hydrogen Production through Precious-Metal-Free Membrane Electrolysis of Dirty Water (PROD)
University of South Carolina	Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells (FC)
University of Utah	Enabling Entrained-Flow Gasification of Blends of Coal, Biomass and Plastics (PROD)



Organization Index (continued 18/18)

Organization	Technology
US Hybrid Corporation	Northeast Demonstration and Deployment of FCRx200 (FC)
Vanderbilt University	Bipolar Membranes with an Electrospun 3D Junction (FC)
	Fuel Cell Membrane Electrode Assemblies with Ultra-Low-Platinum Nanofiber Electrodes (FC)
Virent Energy Systems, Inc.	Hydrogen Generation from Biomass-Derived Carbohydrates via Aqueous-Phase Reforming (PROD)
W.L. Gore and Associates, Inc.	Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies (MEAs) (FC)
	Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers (FC)
Washington State University	Optimizing the Heisenberg Vortex Tube for Hydrogen Cooling (ST)
WETO/NREL	Accelerated Deployment of Fully Integrated Wind-H2 Systems (PROD)
Wiretough Cylinders, LLC	Low-Cost Hydrogen Storage at 875 Bar Using Steel Liner and Steel Wire Wrap (ST)