2025

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352 INNOVATION PRESENTS…

THE CASE FOR HYDROGEN COMBUSTION ENGINES | H2ICE

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H_2ICE Will Advance America's ZEV Goals

The first **Internal Combustion Engine** (ICE) ignited its first power stroke on a "*dirty*" **hydrogen** (H_2) gas mix.
In 1807, Swiss engineer ***François Isaac de Rivaz*** invented a **Spark-Ignition** (SI) internal combustion engine on a dirty hydrogen gas mix since the fossil fuels of that time were too volatile and difficult to control ignition. That necessity brought us the carburetor and now, nearly two hundred years later, we have come full circle… *almost*.
Banning the sale of new vehicles powered by internal combustion engines is shutting out a market that will bring tremendous opportunity for economic growth in America, and globally, save and create jobs, further reduce emissions, and improve public opinion of **Zero Emission Vehicles** (ZEV).

(Vehicle Technologies Office (VTO): Internal Combustion Engine Basics, 2023) (Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (Wikipedia: Zero Emission Vehicle (ZEV), 2025) (Wikipedia: Internal Combustion Engine - History, 2025)

Topic I: Retain and Create Automotive Industry Jobs

H_2ICE will retain and create jobs for the automotive industry. Vehicle and engine manufacturers, aftermarket parts, independent shops, auto mechanics and engine builders.

Topic II: Rapid Decarbonization

H_2ICE will rapidly reduce emissions across the globe far faster than **Zero Emission Vehicles** (ZEV) can be built and sold.

(Wikipedia: Zero Emission Vehicle (ZEV), 2025)

Topic III: Drive Hydrogen Demand

H_2ICE will drive hydrogen (H_2) sales and reduce demand for liquid petroleum. Driving H_2 infrastructure faster than **Hydrogen Fuel Cell Vehicles** (HFCV) can be produced and sold.

H_2ICE can operate on a wide range of hydrogen gas mix quality, allowing sales of gaseous hydrogen that cannot be sold for use in **Hydrogen Fuel Cell Vehicles** (HFCV) since hydrogen fuel cells require gaseous hydrogen quality of 99%.

(Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (Alternative Fuels Data Center (AFDC): How Fuel Cell Vehicles Work, 2024)

Topic IV: Negligible Cybersecurity Risk

H_2ICE does *not* have the cybersecurity risk that electric powertrain vehicles have. Electric powertrains rely on software to operate sophisticated control systems. While mechanical powertrains also rely on software-based control systems to operate, they do *not* require access to the internet, nor can these control systems be hijacked.

(Wikipedia: Cyber Security, 2025) (Battery University BU-1002: Electric Powertrain, 2021)

Topic V: Operational Over Wide Range of Hydrogen Gas Quality

H_2ICE can run on a "*dirtier*" – i.e., less pure H_2 gas – than fuel cells, which allows for H_2 production, storage, and infrastructure to stabilize their H_2 quality.

(Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024)

Topic VI: Interim Option for Rapid Decarbonization

H_2ICE is an interim option to reduce emissions, buy time for development of clean energy, buy time for workforce training and development, and improve public opinion of clean vehicles. And a long-term solution to keeping classic cars classic and allow for the operation of combustion engine equipped vehicles long after fossil fuels are no longer sold.

Topic VII: Rapid Fleet Decarbonization – Cheaper Alternative to Fleet Replacement

H_2ICE conversions on small business fleet vehicles offers a significantly less costly means to reduce fleet emissions.

H_2ICE in the heavy haul transportation sector is being driven by engine manufacturers like Cummins, Volvo, Daimler, MAN, MAHLE, and more.
(Nebergall, Cummins Newsroom: Hydrogen Engines and Long Haul Trucking, 2023) (Volvo Trucks Press Release: Volvo to Launch Hydrogen-Powered Trucks, 2024) (Max, Hydrogen Fuel News: Engineers Retrofit Diesel Engine for Clean Hydrogen Combustion, 2022) (The West Volusia Beacon: Hydrogen & Retrofitting Engines, 2022) (Buckely, Power Progress: Keyou Makes First Customer Delivery of H2 ICE Truck, 2025) (MAHLE Newsroom: MAHLE Awarded Contract from MAN Truck & Bus for Hydrogen-Powered Truck, 2024) (Dokso, 2023) (Green Car Congress (GCC): MAN Plans Truck Series with Hydrogen Combustion for 2025; Initially Around 200 Vehicles for Selected Markets, 2024)

Topic VIII: Advantageous to Workforce Training for Mechanical and Electrical Powertrains

H_2ICE will buy time to get ***workforce training* completed** for electric powertrain technicians.

(Battery University BU-1002: Electric Powertrain, 2021) (Automotive Service Excellence (ASE): Statistics, 2024) (Automotive Service Excellence (ASE): L3 - Hybrid | Electric Vehicle Study Guide, 2022) (Bureau of Labor Statistics | Automotive Service Technicians and Mechanics, 2022) (Charette, 2023)

Topic IX: Drive Consumer Acceptance of Zero Emission Vehicles

H_2ICE can be built as dual fuel*, where it can operate on gasoline or hydrogen, thus eliminating any consumer range or fuel anxiety.

H_2ICE as an option for the consumer will drive consumer acceptance of Zero Emission Vehicles (ZEV).

(Green Car Congress: Volvo Penta & CMB.TECH Expand Partnership on Dual-Fuel Hydrogen Engines, 2022) (Irwin, WardsAuto: Global Survey: Internal Combustion Favored Over Battery Power, 2022) (Mazda H2ICE, 2022) (Alternative Fuels Data Center (AFDC): Various Types of Fuels, 2024) (Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (Wikipedia: Zero Emission Vehicle (ZEV), 2025) (California Hydrogen Business Council: Current Research & Obstacles, 2023) (California Hydrogen Business Council: 2023 Advocacy Activities, 2023)

Topic X: Motorsports Drives H2ICE Development and Showcases Performance Capabilities

H_2ICE has been built into competitive race cars by Toyota since 2022; supercars built by Alpine, Bosch and Toyota, and Ferrari's engine patent are driving optimization of hardware and performance that lead to improved commercialized engines.

(Toyota Newsroom: Expanding Possibilities with the Liquid Hydrogen-Powered GR Corolla in the Season Final Round, 2024) (Toyota Newsroom: HySE to Participate in the Dakar 2025 "Mission 1000 ACT2" with the HySE-X2, to Tackle Further Technical Challenges, 2024) (Toyota Times: Liquid Hydrogen Car Gears Up for 24-Hour Race, 2023) (Toyota Times: Le Mans with a Hydrogen Engine?! In France, Akio Shares His Vision for Motorsports, 2023) (Kiley, WardsAuto: Bosch Launching Hydrogen Combustion Engine, 2024) (Padeanu, InsideEVs: This Alpine Sports Car Has a Hydrogen Combustion Turbo Engine, 2024) (Race Engine Technology: Toyota Yaris H2 I3 Hydrogen, 2022) (Race Engine Technology: Toyota Corolla Liquid Hydrogen | H2L-ICE, 2023) (Schrader, 2022) (Stumpf, 2022) (Bierenkoven, 2024)

Topic XI: Off-Highway Industries Drives Alt-Fuel Engine Development | Hydrogen | Ammonia | Methanol | Dual Fuel Engines

H_2ICE, along with other alternative gaseous fuels, like ammonia, methanol, and various their blends, have made tremendous progress in the decarbonization of the marine, heavy-equipment industries, and other off-highway engine applications.

H_2ICE, and engines running on ammonia, methanol or their various blends being retrofitted for marine and stationary power is almost a necessity due to the size of the engines, leading to the optimization of retrofitting techniques for all engines.

H_2ICE development has reached aviation with Rolls Royce partnering with easyjet to develop a hydrogen combustion turbofan jet engine.

(Alternative Fuels Data Center (AFDC): Emerging Fuels, 2025) (Buchholz, SAE Truck & Off Hwy Engineering Magazine: In Pursuit of a Dedicated Hydrogen ICE for Heavy-Duty Vehicles, 2024) (Buckley, Power Progress: FPT Industrial Premieres the N67 Hythane Engine, 2024) (Green Car Congress (GCC): KIMM, Hyundai, Kia Researchers Develop 2-liter Ammonia Direct-Injection Engine, 2025) (Green Car Congress (GCC): MAN Begins Testing of Full-Scale Two-Stroke Engine Running on Ammonia, 2024) (Green Car Congress (GCC): DEUTZ Joins Consortium to Develop Hydrogen Engines for Off-Highway Applications, 2024) (Green Car Congress (GCC): Successful Engine-Retrofit of Very Large Container Vessel Maersk Halifax to Dual-Fuel ME-LGIM Unit; Blueprint for Future Projects, 2024) (Hydrogen Energy Association (UK): New Report Highlights Hydrogen Internal Combustion Engines as a Key Solution for Greener Off-Road Machinery, 2024) (JCB: Hydrogen Combustion Engines, 2024) (Wärtsilä Corp: Wärtsilä Launches World's First Large-Scale 100% Hydrogen-Ready Engine Power Plant, 2024) (MAN Press Release: World's First VLCV Methanol Retrofit Represents Blueprint for Future Projects, 2024) (Max, Hydrogen Fuel News: Engineers Retrofit Diesel Engine for Clean Hydrogen Combustion, 2022) (Myles, WardsAuto: German Energy Company Claims Methanol Is ICE Savior, 2024) (Green Car Congress (GCC): Yanmar Completes Land-Based Demo Test of Pilot-Ignition Hydrogen 4-Stroke High-Speed Engine for Vessels, 2024) (Yanmar Newsroom: Successful Operation at Rated Output in the Trial of a Hydrogen 4-Stroke High-Speed Engine for Coastal Vessels, 2024) (MAN Press Release: Methanol Orders Advance Multi-Fuel Future, 2024) (Green Car Congress (GCC): MAN Receives Multiple Orders for Methanol Engines for a Series of Very Large Container Vessels, 2024) (Green Car Congress: Rolls-Royce and EasyJet Mark First Run of Modern Aero Engine on Hydrogen, 2022) (Rolls Royce (home), 2024) (Rolls Royce: easyJet and Rolls-Royce Partner on Hydrogen Technology Demonstrator Programme | Press Release, 2022)

Topic XII: H_2ICE *CAN* be Zero Emission

H_2ICE ***can*** achieve zero emission status

(Quimby, 2022) (Wallner, 2011) (Martin, 2022) (H Lohse-Busch, 2006)

Topic XIII: H_2ICE – Decades of Development

H_2ICE was extensively studied under multiple US Department of Energy (DOE) funded projects. Every single research paper includes statements about the benefits of H_2ICE and how H_2ICE, specifically **Direct Injected** (DI), "*can be viewed as a high efficiency, low-emissions technology for bridging the transition to the hydrogen economy that's based on fuel cell technology…. It is estimated that DI H_2ICE can be integrated into a hybrid vehicle system to result in fuel consumption that's only ~15-20% greater than {2008} hybridized fuel cell vehicles of similar mass. Significantly lower hardware costs (compared to 2008 fuel cell systems) and the ability to use existing manufacturing facilities for conventional reciprocating engines makes this an attractive consideration.*" – 2008 VTO Materials Annual Progress Report | p.4

H_2ICE has only recently had purpose-built hardware, leading to optimized engines that will meet or exceed their fossil fuel counterparts in performance and reliability while further reducing emissions.

H_2ICE has and is being extensively studied globally with ongoing research efforts aimed at developing a hydrogen engine that emits zero tail pipe emissions while delivering performance equivalent or exceeding that of fossil fuel combustion engine counterparts.

H_2ICE has been studied by American Society of Mechanical Engineers (ASME) and their Internal Combustion Engine Division; with several published research papers.

H_2ICE has, and is currently, being extensively studied, tested, and optimized at **US Department of Energy** (DOE) National Labs, universities across the globe, and private research facilities, like **Southwest Research Institute** (SwRI). **SAE International** (SAE) has spearheaded hydrogen engine research by bringing industry, government and academia together for published studies. **Sandia National Laboratory** (SAND), **Idaho National Laboratory** (INL), and **Argonne National Laboratory** (ANL) have led hydrogen engine research projects for decades while ***Rudolf A. Erren*** published *Hydrogen: A Commercial Fuel for Internal Combustion Engines and Other Purposes* in 1933 in the Journal Institute of Fuel.

H_2ICE has been built into concept cars since the 1970s, starting with researchers at **Musashi Institute of Technology Setagaya**, in Tokyo, Japan, built a rally race car, in 1978, that ran on liquid hydrogen, **University of California Los Angeles** (UCLA) built a car to further the development of engine electronics in 1979, and BMW launched 100 concept cars in 2007, running on liquid hydrogen.

H_2ICE was prophesied as *"being near realization"* by ***Prof JBS Haldane*** in an article featured on the front page of the 1933 March issue of *The Commercial Motor.*
"*They made the following summary on the suitability of using hydrogen engines for the propulsion of road motors :— It can be a cheap and nationally produced fuel, requiring no transport for distribution, nor plant for compression ; containers of the right type are available ; no poisonous exhaust gases are produced ; no carbonization occurs in the engine ; and no dilution nor burning of lubricant can take place.*"

(Vehicle Technologies Office (VTO): 2008 Materials Annual Progress Report | H2ICE Mat'ls | Jan 2009, 2009) (United States Department of Energy (US DOE | home), 2025) (Vehicle Technologies Office (VTO | home), 2023) (Ionbond White Paper: Coatings for Tribological Hydrogen Applications, 2025) (B Heid, 2021) (Research & Innovation at Brunel: Hydrogen Combustion, 2023) (Buckley, Power Progress: Eaton Eaton to Show New H2 CV Power Solutions at IAA Transportation 2024, 2024) (Cockerill, 2022) (Boretti, 2010) (D Kovacs, 2022) (Green Car Congress: Westport Fuel Systems Introduces H2 HPDI Fuel System, 2022) (Green Car Congress (GCC): Cummins Launches Hydrogen Internal Combustion Engine Turbochargers for On-Highway Applications, 2025) (Green Car Congress (GCC): Brunel to Use Camcon Single Cylinder IVT in Researching Future Powertrain Concepts, 2019) (Green Car Congress (GCC): Researchers Significantly Improve SCR Catalytic Performance for NOx Reduction from Hydrogen-Fueled Combustion Engines, 2024) (H Iwasaki, 2011) (H Lohse-Busch, 2006) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Kendall, SAE Truck & Off Highway Engineering Magazine: Mahle, Liebherr Develop Active Pre-Chamber for Hydrogen ICE, 2021) (Kohler Engines: Kohler DI Hydrogen Engine | Kohler Engines Introduces Hydrogen Technology, 2025) (N Villenave, 2023) (C Bekdemir, 2022) (M Mohammed, 2024) (R Brayer, 2006) (Vehicle Technologies Office (VTO): USDRIVE Advanced Combustion & Emissions Control Roadmap (H2ICE p.50), 2018) (Egelton, 2009) (FuelCellWorks: Tokyo City University: Hydrogen Engine Car Realized Output Comparable to Diesel, 2022) (H Lohse-Busch, 2006) (J Damm, 2009) (S Szwaja, 2013) (Stumpf, 2022) (AL Boehman, 2009) (SK Addepalli, 2022) (X Dou, 2024) (J Laichter, 2023) (United States Department of Energy (US DOE): National Labs, 2024) (United States Department of Energy (US DOE | home), 2025) (Sandia National Laboratory (SAND | home), 2025) (Argonne National Laboratory (ANL | home), 2025) (SAE International (home), 2025) (Southwest Research Institute (SwRI | home), 2025) (Idaho National Laboratory (INL | home), 2025) (C White, 2005) (JX Wen, 2024) (J Francfort D. K., Hydrogen Fuel Pilot Plant And Hydrogen Internal Combustion Engine Vehicle Testing | Pre-Print Presentation from 2005 NHA Hydrogen Conference | INEEL/CON-04-02198 | OSTI 911070, 2005) (Wallner, 2011) (RW Schefer, 2007) (F Leach, 2020) (S Verhelst T. W., 2009) (S Verhelst P. M., 2009) (S Verhelst S. V., 2005) (HL Yip, 2019) (V Kumar, 2015) (H Fayaz, 2012) (R Scarcelli, 2009) (B Nagalingam, 1983) (T Wallner, 2008) (Nica, 2016) (BMW Press Release: Hydrogen Powered Internal Combustion Engine (H2ICE), 2007) (S Furuhama, 1978) (University of California Los Angeles (UCLA | home), 2025) (CA MacCarley, 1979) (Wikipedia: Liquid Hydrogen, 2024) (M Canton, 2010) (American Society of Mechanical Engineers (ASME | home), 2024) (American Society of Mechanical Engineers (ASME): Internal Combustion Engine (ICE) Division, 2024) (American Society of Mechanical Engineers (ASME): Digital Collection, 2025) (Haldane, 1933)

Topic XIV: H_2ICE Alliance | Global Advocacy | H_2ICE Classified Zero Emission

H_2ICE was classified as ***Zero Emission*** by the **European Union** (EU) in 2024 and the EU has re-evaluated its stance on eliminating the Internal Combustion Engine for new vehicles. Construction equipment manufacturer, JCB has been awarded eleven (11) licenses for their **H_2ICE** powered equipment. China has been doing extensive research and development on **H_2ICE,** and it has been speculated that China will be the next to classify **H_2ICE** as ZE and embrace the technology as part of their decarbonization efforts – and utilize to drive hydrogen sales.

H_2ICE allows the global engine manufacturing and automotive industry to support decarbonization at a significantly reduced cost by keeping the majority of their manufacturing infrastructure intact. Many **H_2ICE Consortiums** have formed across the globe – **Southwest Research Institute** (SwRI) – MAHLE – DEUTZ have announced their consortiums.

H_2ICE advocacy has experienced significant growth and momentum with Germany's ***Allianz Wasserstoff Motor*** - **Hydrogen Engine Alliance** and with Cummins leading the way.
Allianz Wasserstoff Motor issued a position paper advocating for **H_2ICE** acceptance while highlighting the tremendous benefits - similar to this paper.
Inspired by Germany's Allianz; the **Hydrogen Engine Alliance of North America** launched this year and will be hosting their inaugural **Hydrogen Engine Alliance Conference** at the **California Air Resources Board** (CARB) Headquarters in Riverside, California May 1-2, 2025

H_2ICE development, and the development of engines operating on e-fuels, has created alliances and collaborations between engine manufacturers. Toyota, Subaru, Mazda, Toyota and Yamaha; and more.

(Collier, 2024) (Cummins Newsroom: Hydrogen Engine Alliance Makes Case for Commitment to Hydrogen Combustion at IAA, 2024) (Allianz Wasserstoff Motor: Position Paper on Hydrogen Combustion Engines, 2022) (Joshi, 2024) (Quimby, 2022) (Buckely, Power Progress: JCB Receives Type Approval from 11 Licensing Authorities for H2 ICE, 2025) (DEUTZ Press Release: DEUTZ Joins Consortium to Develop Hydrogen Engines for Off-Highway Applications, 2024) (Southwest Research Institute (SwRI): H2ICE Consortium, 2024) (Kiley, WardsAuto: Cummins Becoming Big Player in Hydrogen Transition, 2023) (Hydrogen Central: Policy Brief – Hydrogen Combustion Engines as a Key Part of Reaching Net Zero, 2024) (MAHLE Newsroom: Consortium Led by MAHLE Developing Hydrogen Engines for Off-Road Applications, 2024) (Kottasova, 2023) (JCB: Hydrogen Combustion Engines, 2024) (Allianz Wasserstoff Motor | Germany's H2ICE Alliance | home, 2025) (Allianz Wasserstoff Motor: Position on Hydrogen Combustion Engines, 2025) (Hydrogen Engine Alliance of North America | home, 2025) (Toyota Newsroom: Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality, 2024) (Mazda Newsroom: Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality, 2024) (Subaru Press Release: Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality, 2024) (Hydrogen Engine Alliance of North America | home, 2025) (California Air Resources Board (CARB | home), 2024) (Menon, 2022) (Wikipedia: European Union (EU), 2025)

How H_2ICE Will Advance America's ZEV Goals

America's goals to rapidly reduce emissions from hydrocarbons and drive demand of clean energy sources for fuels to power our transportation needs are admirable, and achievable.

The first **Internal Combustion Engine** (ICE) ignited its first power stroke on a "*dirty*" **hydrogen** (H_2) gas mix.
In 1807, Swiss engineer ***François Isaac de Rivaz*** invented a **Spark-Ignition** (SI) internal combustion engine on a dirty hydrogen gas mix since the fossil fuels of that time were too volatile and difficult to control ignition. That necessity brought us the carburetor and now, nearly two hundred years later, we have come full circle… *almost*.

Banning the sale of new vehicles powered by internal combustion engines is shutting out a market that will bring tremendous opportunity for economic growth in America, and globally, save and create jobs, further reduce emissions, and improve public opinion of **Zero Emission Vehicles** (ZEV).

By embracing the development of hydrogen as the combustible fuel for internal combustion engines (H_2ICE), America can reach their ZEV goals, drive hydrogen production, use and storage goals, buy time to complete ZEV workforce training, ZEV infrastructure development, and improve consumer confidence and acceptance of electric powertrain vehicles.

America will have more time to build up electric and hydrogen infrastructure. Improve the power grid so the goals of all electric homes and all electric cars can be met without risk to the current power grid capacity and operational limitations. Implement bi-directional charging, vehicle to grid integration (V2G | VGI), and buy time to develop hydrogen production. From building new plants and fueling stations to converting natural gas infrastructure to carry hydrogen.
A Western Power Grid study found potential bottleneck issues in two California transmission lines.
Reference a 2020 **Pacific Northwest National Laboratory** (PNNL) study PNNL-29894.

(Pacific Northwest National Laboratory (PNNL | home), 2024) (M Kintner-Meyer, 2020) (United States Department of Energy (US DOE | home), 2025) (Hydrogen & Fuel Cell Technologies Office (HFTO | home), 2024) (H2IQ by the Hydrogen & Fuel Cell Technologies Office (HFTO), 2024) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (Wikipedia: Zero Emission Vehicle (ZEV), 2025) (Vehicle Technologies Office (VTO): Internal Combustion Engine Basics, 2023) (United States Department of Energy (US DOE): DOE Hydrogen Program, 2023) (United States Department of Energy (US DOE): Hydrogen Shot, 2025) (Hydrogen & Fuel Cell Technologies Office (HFTO): 2024 HFTO mypp - Ch 4 Hydrogen Infrastructure, 2024) (Automotive Service Excellence (ASE): Statistics, 2024) (California Hydrogen Business Council: Current Research & Obstacles, 2023) (California Electric Transportation Coalition (CalETC): Workforce Projections to Support Battery Electric Vehicle Charging Infrastructure Installation, 2021) (Electric Vehicle Infrastructure Training Program (EVITP): EVITP and MUST Workforce Solutions Announce New "Electric Fast Track" Work-Based Learning Initiative Powered by Siemens Foundation, 2024) (Battery University BU-1002: Electric Powertrain, 2021) (A Brown, 2020) (Visnic, SAE International: The Bi-Directional Bonus for Electric Vehicles, 2022) (United States Department of Energy (US DOE): Biden-Harris Administration Announces $13 Billion To Modernize And Expand America's Power Grid, 2022) (H2 Tools: Hydrogen Infrastructure, 2025) (Hydrogen & Fuel Cell Technologies Office (HFTO): Hydrogen Production, 2024) (National Renewable Energy Laboratory (NREL): Vehicle to Grid (V2G) Integration (VGI), 2023) (Wikipedia: Vehicle to Grid (V2G), 2023)

Supporting Materials:

Workforce Training | Automotive Industry Jobs | Consumer Acceptance | H_2ICE Alliance

Supporting Topic(s):
Topic I: Retain and Create Automotive Industry Jobs
Topic VI: Interim Option for Rapid Decarbonization
Topic VIII: Advantageous to Workforce Training for Mechanical and Electrical Powertrains
Topic IX: Drive Consumer Acceptance of Zero Emission Vehicles
Topic XIV: H2ICE Alliance | Global Advocacy | H2ICE Classified Zero Emission

Auto Industry Jobs / Workforce Training

Nadia Lopez, from CalMatters, published an article on May 24, 2022, that cited data, directly from the **California Air Resources Board** (CARB), that an ***estimated 30,000 mechanics*** are going ***to lose their jobs*** due to electric powertrain vehicles by 2040. And that was well before the **California Energy Commission** (CEC) forecasted California to meet their **5 million Zero Emission Vehicles** (ZEV) on California roads **by 2025**, and 10 million by the original goal date of 2030.
Reference Figure I: California Energy Commission (CEC) Forecasted Zero Emission Vehicle (ZEV) Growth | Screenshot from Dec 8, 2022, Webinar

Keeping combustion engines in the mix will significantly reduce the number of small businesses closing down and the subsequent jobs lost. Businesses and jobs that support the automotive industry.
The small independent auto service shops that give consumers an alternative to high priced dealerships, and, in many cases, those dealerships are hundreds of miles away.
Communities rely on their local independent shops, particularly in rural areas. The loss of trusted shops will result in a reduction in ZEV sales.

As Ford switches over to manufacturing electric powertrain only vehicles, there will be a ''tidal wave of layoffs''. Keeping combustion engines in the picture won't just save big manufacturers money, it will save small businesses, and auto service industry jobs.
The jobs of auto workers assembling and testing engines.
The jobs of factory workers creating engine hardware from raw materials.
The jobs of engine builders and service technicians.
May create a new job – trainers to train technicians and engine builders how to build, tune, and service engines that run on gaseous fuels – fuels that require training on their behavior, combustion process, equipment requirements, and their safe handling.

Keeping combustion engines in the short-term, provide more than job safety – they provide the means for shops and techs to maintain financial stability *while* the business upgrades their infrastructure, write new service policies, and time to pursue training. Keeping combustion engines provides a window of extended opportunity for the entire automotive industry to prepare themselves to embrace electric drivetrain vehicles.

Shops can offer custom clean energy conversions of conventional vehicles. Converting combustion engines from fossil fuels to e-fuels in addition to conversions to electric drivetrain configurations.
Shops and engine builders can support the conversion of fleet diesels to run on hydrogen, which supports the rapid decarbonization of the heavy and long-haul trucking industry. And further support commercial truck service shops with an option to perform engine swaps – diesels to engines running on e-fuels like hydrogen, ammonia, methanol, propane, natural gas, their various blends, or dual fuel set-ups. KEYOU, in Germany, has found success converting commercial trucks to H_2ICE and, as a result, has helped drive the hydrogen industry in Germany and the greater EU.

At the time of this writing, public and private educational institutions are scrambling to launch training curriculums for electric powertrain vehicles. Less than thirty (30) institutions currently offer EV courses. And less than five (5) offer fuel cell vehicle service training.

Automotive Service Excellence (ASE) currently offers a Certification in ***L3 - Battery and Hybrid Electric Vehicles***. For **Battery Electric Vehicle** (BEV), **Hybrid Electric Vehicle** (HEV), and **Plug-In Hybrid Electric Vehicle** (PHEV).
Certifications for **Fuel Cell Electric Vehicles** (FCEV) are still in development.
As of **Spring 2024**, ASE stats show **3,879 techs hold the L3 Certification**…. ***In** the United States*.

For California to support the forecasted 5 million ZEVs by 2025, at least 11,000* **trained technicians will be needed** to service **Battery Electric Vehicles** (BEV) and **Fuel Cell Electric Vehicles** (FCEV).
Per California's definition of ZEV, that 5MM only applies to BEVs and FCEVs.
*ASE Certifications are voluntary, and their stats *do not* include certifications earned by techs working at dealerships. Techs can hold ASE Certifications and earn Certifications from the dealership's specific brands.

According to a 2020 Press Release by **TechForce**, there is a **five-to-one auto service technician shortage across the US**. For every five auto service jobs, only one service technician is available. The tech shortage is causing long wait times for service at nearly all shops, including dealerships.

Developing conversion kits to convert older engines to be able to run on hydrogen enables classic cars, hot rods, movie set cars, and automobiles kept for the pure love of beautifully engineered machinery to continue to drive to car shows, cruise the coastline, support movie productions, bring the symphony of horsepower back to the race tracks, and, most importantly, keep that heavenly sound echoing through the still summer air as precision combustion sends pressure pulses dancing down polished metal alloy pipes.

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Industry Alliance

Engine manufacturers, automakers, their suppliers, and the consumer will be able to support decarbonization of the transportation sector at a significantly lower cost thanks to manufacturers not having to re-tool, design and build new prototype parts, overhaul their assembly process, and re-train nearly the entire workforce. A tremendous cost that is ultimately passed on to the consumer in vehicle price.
Overhauling these extensive and sophisticated manufacturing processes are a financial driver for nearly all engine and automotive manufacturers.
ZEVs are made with significantly less widgets per vehicle, and the Internal Combustion Engine will eventually be phased out thanks to the exponentially greater number of widgets per vehicle. Allowing the market and the consumer to drive that transition allows manufacturers to transition in a financially sustainable way.
A White Paper by McKinsey & Co – *How Hydrogen Combustion Engines Can Contribute to Zero Emissions* – highlights the supply chain and manufacturing challenges mentioned above.

The industry has embraced *Consortiums* and *Hydrogen Engine Alliances*. Inspired by Germany's **Allianz Wasserstoff Motor**, the **Hydrogen Engine Alliance of North America** launched in 2025 to advocate for hydrogen engines in California, the US, and North America.
Allianz Wasserstoff Motor issued a position paper, available for download on their website, to further advocate for hydrogen engines.

Heavy and long-haul truck manufacturers are ready for their hydrogen engines to hit the roads here in America. Many of the European based manufacturers are at an advantage in that the EU has allowed vehicles equipped with hydrogen engines to operate on their roads.
Hydrogen Combustion Engine (H_2ICE) has gained *tremendous momentum* over the last year, and now that the **European Union** (EU) has classified H_2ICE as *Zero Emission*, **China** rumored to be the next to pin the ZE badge on H_2ICE,and the possibility of **California**, and subsequently, the **United States**, poised to embrace H_2ICE; the green flag seems to have dropped on the hydrogen engine race.

Automotive manufacturers have formed a commitment and collaboration for further development of engines that run on e-fuels, including hydrogen.

Southwest Research Institute (SwRI) launched their **Hydrogen Combustion Engine** (H_2ICE) Consortium and is advancing H_2ICE optimization by solving problems like contamination of the lubricating oil by hydrogen re-bonding with atmospheric oxygen when the tiny H2 molecule gets passed the rings and into the crankcase.
With **Cummins** as a Consortium member, they provided SwRI with an ***X15N Natural Gas engine*** that SwRI proceeded to convert to run on pure gaseous hydrogen. The Class 8 Demo Truck has traveled around the US showing off the hydrogen engine technology.
This author had the privilege of chatting with the Program Manager of SwRI's H_2ICE Consortium, **Ryan Williams**, while the demo Class 8 truck was on display outside the **2024 California Hydrogen Leadership Summit** in Sacramento. He mentioned how they were running the crankcase at a positive pressure in an effort to prevent hydrogen from getting into the crankcase and mitigate the risk of lubricating oil contamination and/or crankcase explosion.

Thanks in large part to Toyota's H_2ICE advancement, their suppliers have stepped up to make hydrogen compatible and H_2ICE optimized components, like piston rings and the **Engine Control Unit** (ECU) Borg Warner is developing.

Off-highway and marine engine manufacturers have launched a Consortium for the advocacy and development of e-fuel engines that include hydrogen, hydrogen blends, natural gas, ammonia, methanol, various gaseous blends, and dual fuel engines that combine renewable or biodiesel with various gaseous fuels.

Engine and automotive manufacturers are creating strategic partnerships for further advanced development and optimization of Hydrogen Combustion Engines (H_2ICE). From marine to commercial trucking to gen-sets and turbofan jet engines.
Rolls Royce collaborated with **EasyJet** to develop the first hydrogen burning turbofan jet engine.
RR has also worked on developing hydrogen engines for use as stationary power.
Toyota has collaborated with Yamaha to develop a 500-hp V8 Hydrogen Combustion Engine..

(Alternative Fuels Data Center (AFDC): Maps & Data - Vehicle Registration Numbers by State & Fuel (BEV | PHEV | HEV | E85 | H2 | Biodiesel | Methanol +), 2023) (Hydrogen Central: Policy Brief – Hydrogen Combustion Engines as a Key Part of Reaching Net Zero, 2024) (Aiello, Power Progress: Industry Experts Talk Hydrogen IC Engines in Decarbonization, 2024) (B Heid, 2021) (Irwin, WardsAuto: Global Survey: Internal Combustion Favored Over Battery Power, 2022) (Cummins Newsroom: Cummins and Versatile Hydrogen Engine Partnership Announced, 2022) (Green Car Congress (GCC): DEUTZ Joins Consortium to Develop Hydrogen Engines for Off-Highway Applications, 2024) (Green Car Congress (GCC): Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality, 2024) (Green Car Congress (GCC): Wärtsilä Joins New Consortium to Explore Hydrogen-Argon Power Cycle for Net-Zero Power Generation, 2024) (Gehm, SAE Article: Regulatory Landscape Challenges Commercial-Vehicle Engine Development, 2020) (Gehm, SAE Mobility Engineering: Hydrogen ICE Is Heating Up, 2023) (Hydrogen Engine Alliance of North America | home, 2025) (Allianz Wasserstoff Motor: Position on Hydrogen Combustion Engines, 2025) (Allianz Wasserstoff Motor | Germany's H2ICE Alliance | home, 2025) (Hirsch, 2023) (Hood, 2024) (Korn, 2020) (MAN Press Release: Full-Scale Ammonia Engine Opens New Chapter, 2024) (MAN Press Release: World's First VLCV Methanol Retrofit Represents Blueprint for Future Projects, 2024) (MAN Press Release: Methanol Orders Advance Multi-Fuel Future, 2024) (Macaulay, 2023) (Quimby, 2022) (Roy, 2024) (Schaeffer, Engine Technology Forum (ETF): Exploring the Future for H2-ICE as a Decarbonization Strategy | Webinar, 2024) (Stumpf, 2022) (Southwest Research Institute (SwRI | home), 2025) (Schultz, Power Progress: Mercedes-Benz Hydrogen-Powered Trucks Hit the Road, 2023) (Southwest Research Institute (SwRI): H2ICE Consortium, 2024) (Southwest Research Institute (SwRI): SwRI Unveils Promisting Findings on Lubricant Durability in Hydrogen Engines, 2024) (Wallner, 2011) (Williams, 2024) (Wolfe, SAE Mobility Engineering: Merecedes: H2ICE is READY fo Primetime in Commercial Trucks, 2024) (Yanmar Newsroom: Successful Operation at Rated Output in the Trial of a Hydrogen 4-Stroke High-Speed Engine for Coastal Vessels, 2024) (Menon, 2022) (Wikipedia: Engine Control Unit (ECU), 2022) (Collier, 2024) (California Hydrogen Leadership Summit | home, 2024) (Cummins Newsroom: United States' First Class 8 H2-ICE Demo Showcased for Fleets, 2024) (Green Car Congress: Rolls-Royce and EasyJet Mark First Run of Modern Aero Engine on Hydrogen, 2022) (Rolls Royce: easyJet and Rolls-Royce Partner on Hydrogen Technology Demonstrator Programme | Press Release, 2022) (Bergenson, 2024) (Wolfe, SAE International: Hitting the Gas on Hhydrogen Tech for Commercial Trucks | H2ICE | HFC, 2022) (Korzeniewski, 2025)

Consumer Acceptance / Infrastructure Development

Consumers who feel intimidated by **Electric Vehicles** (EV), can't afford to purchase a new car, and/or simply don't want to give up a car they feel comfortable with.
Hydrogen Combustion Engines (H_2ICE) provide a cheaper alternative for the consumer in purchase price of a newer vehicle and the option to convert their favorite car to run on hydrogen. A conversion that will bring significant business to auto shops and engine builders.

The **California Hydrogen Business Council** cited Consumer Acceptance as one of the greatest obstacles to Zero Emission Vehicle (ZEV) adoption, and have dedicated advocacy activities in an effort to drive ZEV sales by way of increased consumer acceptance.

H_2ICE provides an option that is more likely to be accepted by all consumers, thereby putting more vehicles on roadways across the globe that are now contributing to decarbonization efforts. Consumers who reject ZEVs because they feel like the government is "*forcing*" them to discard their conventional vehicle in a perceived ZEV "*mandate*" will very likely be more amenable to a change of fuel type. Consumers who may be initially unwilling to accept hydrogen as a fuel almost always fit a demographic that will quickly come around when they find out how much more power hydrogen engines make with respect to a fossil fuel engine of equivalent displacement. "*Rolling coal*" loses its "*cool factor*" as quickly as the driver of the soot-spewing vehicle gets smoked off the light by the hydrogen engine in the next lane.

For low income and disadvantaged communities, rebates could be offered for converting their existing vehicle to run on hydrogen, which removes the significant financial burden of purchasing a new car – especially when obtaining financing for that new car may not be attainable.

(Alternative Fuels Data Center (AFDC): Alternative Fuel Vehicles (AFV), 2024) (Alternative Fuels Data Center (AFDC): Conversion Basics, 2024) (Alternative Fuels Data Center (AFDC): Converting Older Vehicles to Zero Emission | Vehicle Conversions, 2024) (California Air Resources Board (CARB): Alternative Fuel Retrofit Systems (Aftermarket), 2024) (Akhim, 2022) (Aiello, Power Progress: Industry Experts Talk Hydrogen IC Engines in Decarbonization, 2024) (Aiello, Power Progress: Schaeffer Talks Future of Advanced IC Engines, 2025) (The West Volusia Beacon: Hydrogen & Retrofitting Engines, 2022) (Buchholz, SAE Truck & Off Hwy Engineering Magazine: In Pursuit of a Dedicated Hydrogen ICE for Heavy-Duty Vehicles, 2024) (Bureau of Transportation Statistics (BTS): Transportation Stats - Employment in Transportation (Auto Repair Techs & Mechanics & more), 2023) (United States Department of Transportation (US DOT | home), 2023) (Dokso, 2023) (Gehm, SAE Article: Regulatory Landscape Challenges Commercial-Vehicle Engine Development, 2020) (Cummins Newsroom: Hydrogen Engine Alliance Makes Case for Commitment to Hydrogen Combustion at IAA, 2024) (Allianz Wasserstoff Motor: Position Paper on Hydrogen Combustion Engines, 2022) (Joshi, 2024) (Kottasova, 2023) (Lopez, CalMatters: Electric Car Mandate: California Air Board Questions Cost, Practicality, 2022) (Max, Hydrogen Fuel News: Engineers Retrofit Diesel Engine for Clean Hydrogen Combustion, 2022) (Macaulay, 2023) (Smith, 2022) (Stumpf, 2022) (TechForce Press Release: TechForce Report Reveals Demand for New Technicians Nearly Doubled Since 2020 - Estimated to Outpace Supply by 5 to 1, 2021) (Visnic, SAE International: Keeping Combustion in the Conversation, 2022) (Williams, 2024) (Alternative Fuels Data Center (AFDC): How Electric Vehicles Work, 2025) (Alternative Fuels Data Center (AFDC): Electric Vehicles, 2024) (Wikipedia: Zero Emission Vehicle (ZEV), 2025) (Akhim, 2022) (The West Volusia Beacon: Hydrogen & Retrofitting Engines, 2022) (Aiello, Power Progress: Cummins' Nebergall Discusses the Future of Hydrogen IC Engines, 2024) (Cummins: Hydrogen Engines | webpage, 2025) (Green Car Congress: Toyota Developing Prototype Hydrogen Combustion Engine Corolla Cross H2 Concept Road Car, 2022) (Green Car Congress (GCC): Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality, 2024) (Toyota: Prototype Corolla Cross Hydrogen Concept, 2022) (KEYOU: Converting Fleet Trucks into H2ICE (Germany | EU, 2025) (Joshi, 2024) (Kilgore, 2022) (Kottasova, 2023) (FuelEconomy.Gov: Fuel Cell Vehicles - Benefits and Challenges, 2024) (Lopez, CalMatters: Electric Car Mandate: California Air Board Questions Cost, Practicality, 2022) (Allianz Wasserstoff Motor | Germany's H2ICE Alliance | home, 2025) (Hydrogen Engine Alliance of North America | home, 2025) (Allianz Wasserstoff Motor: Position on Hydrogen Combustion Engines, 2025) (Cummins Newsroom: Hydrogen Engine Alliance Makes Case for Commitment to Hydrogen Combustion at IAA, 2024) (Hydrogen Central: How Hydrogen Combustion Engines Will Challenge The EV Market At Its Core – TopSpeed, 2024) (Hydrogen Central: Astron Aerospace – Hydrogen Engine Achieves Record 60% Efficiency with 0 Emissions, 2024) (Hydrogen Central: This Hydrogen Combustion Engine Is The EV Alternative We've Been Waiting for – HotCars, 2023) (Menon, 2022) (Kable, 2023) (Rojas, 2024)

California Energy Commission (CEC) Webinar – Screenshot of Forecasted LD ZEV Growth

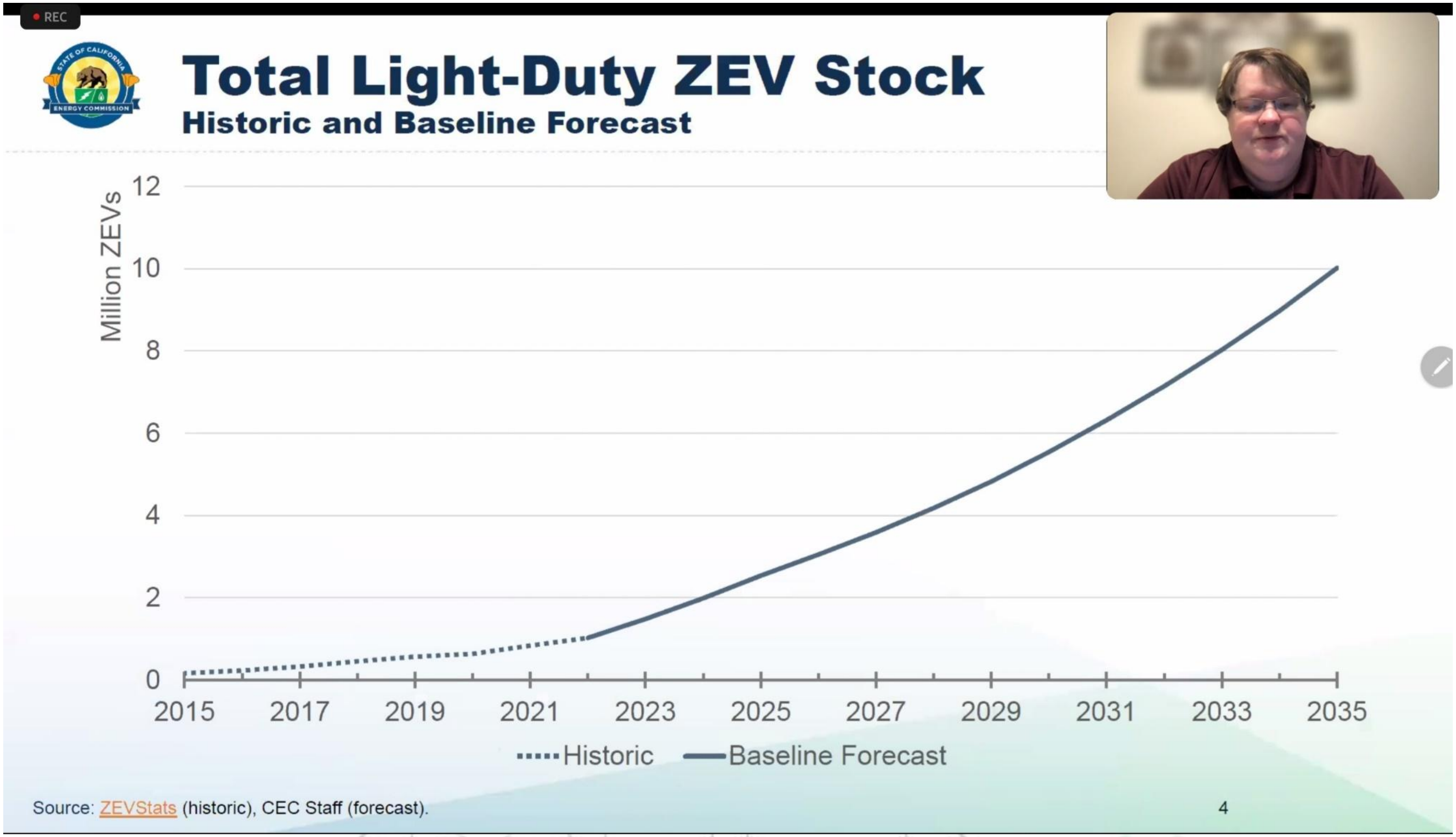


Figure I: California Energy Commission (CEC) Forecasted Zero Emission Vehicle (ZEV) Growth | Screenshot from Dec 8, 2022, Webinar

Hydrogen Combustion Engine Project Results & Emissions

Supporting Topics:
Topic II: Rapid Decarbonization
Topic V: Operational Over Wide Range of Hydrogen Gas Quality
Topic VI: Interim Option for Rapid Decarbonization
Topic IX: Drive Consumer Acceptance of Zero Emission Vehicles
Topic XII: H2ICE *CAN* be Zero Emission
Topic XIII: H2ICE – Decades of Development

HYDROGEN ICE TESTING ACTIVITIES | INL – ARIZONA PROJECT | 2000-2003 | INL/EXT-06-11689

The **Idaho National Laboratory** (INL) Arizona fleet project, mentioned above, was able to meet California's **Super Ultra Low Emissions Vehicle** (SULEV) emissions standards. This classification, from 2004, is based on producing 90% fewer emissions than the average gasoline-powered vehicle. **Idaho National Engineering & Environmental Laboratory** (INEEL) – now just INL - released their report (INEEl-03-00007) in **January 2003** after two years and 4,700 miles of testing. The team took a stock 2001 Ford F-150, factory built to run on gasoline and optimized the 5.4L tor performance and emissions to run on a 30% H_2 blend with 70% **Compressed Natural Gas** (CNG). This engine, optimized to run on the 30% H_2/CNG blend, recorded near *zero* NO_x and a 97% reduction, with overall emissions test results classifying the 5.4L F-150 as SULEV per California's emissions standards.

The only emission created by **Hydrogen Combustion Engines** (H_2ICE) is **Oxides of Nitrous** (NO_x) but this only occurs when the combustion temperature reaches the temperature required for NO_x formation. Several independent H_2ICE research project reports have repeatedly shown that a short range of air-H_2 ratios did not allow NO_x formation to occur, thus zero emission from hydrogen combustion; any lubricating oil that enters the combustion chamber is often the only emission contributor.

If an engine, running with only 30% H_2 - and 70% hydrocarbon-based CNG produced emissions that low, with hardware from the late 1990s/early 2000s; imagine what purpose-built hardware and firing on 100% H_2 could do for decarbonization and still provide that sweet symphony of controlled combustion that so many of us love!

NOTE: These reports are publicly available for download via **INL's Digital Library** and/or the **US Department of Energy** (DOE)'s **Office of Scientific and Technical Information** (OSTI). Links are embedded in the report numbers and listed in citations and Works Cited.

Important Note Regarding INL/EXT-06-11689
INL report INL/EXT-06-11689 holds an extensive summary of the entire project, with several individual vehicle reports in the appendix. This updated report is, at the time of this writing, *ONLY* available for download at INL's Digital Library. The report with the added appendices will be over 300 pages while the same report number, available for download via OSTI, will only be 44 pages.

Reference prequel reports: INEEL/CON-03-00780 (Nov 2003), INEEL/EXT-03-01313 (Nov 2003 | *Appendix G in INL-11689*), INEEL-EXT-03-00976 (Dec 2003 | *Appendix B in INL-11689*), INEEL/EXT-03-00008 (Jan 2003 | *Appendix E in INL-11689*), INEEL/CON-04-02198 (Apr 2005), INEEL/EXT-03-00007 (Jan 2003 | *Appendix F in INL-11689*), INEEL/EXT-03-00009 (Jan 2003 | *Appendix D in INL-11689*), and INL/CON-06-00414 (Apr 2006) was presented at the 2006 SAE World Congress.

Note - INEEL/EXT-03-00006 (Jan 2003) is no longer available as a stand-alone report; it has been moved to *Appendix C* of INL-11689.

(Idaho National Laboratory (INL | home), 2025) (Wikipedia: Ultra-Low Emissions Vehicle (ULEV | California Emissions Rating), 2022) (D Karner, 2003) (Alternative Fuels Data Center (AFDC): Natural Gas, 2024) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Wikipedia: Nitrogen Oxides (NOx), 2023) (Gehm, SAE Mobility Engineering: Hydrogen ICE Is Heating Up, 2023) (R Brayer, 2006) (Idaho National Laboratory (INL) Digital Library | home, 2025) (Francfort, 2003) (Office of Scientific and Technical Information (OSTI | home), 2024) (J Francfort D. K., US Department of Energy FreedomCAR & Vehicle Technologies Program Advanced Vehicle Testing Activity, Hydrogen/CNG Blended Fuels Performance Testing in a Ford F-150 | INEEL/EXT-03-01313 | OSTI 910730, 2003) (J Francfort D. K., US Department of Energy FreedomCAR & Vehicle Technologies Program Advanced Vehicle Testing Activity Arizona Public Service – Alterative Fuel (Hydrogen) Pilot Plant Design Report | INEEL/EXT-03-00976 | OSTI 910735, 2003) (J Francfort D. K., US Department of Energy FreedomCAR & Vehicle Technologies Advanced Vehicle Testing Activity: Low-Percentage Hydrogen/CNG Blend Ford F-150 Operating Summary | INEEL/EXT-03-00008 | OSTI 809114, 2003) (J Francfort D. K., Hydrogen Fuel Pilot Plant And Hydrogen Internal Combustion Engine Vehicle Testing | Pre-Print Presentation from 2005 NHA Hydrogen Conference | INEEL/CON-04-02198 | OSTI 911070, 2005) (J Francfort D. K., US Department of Energy FreedomCAR & Vehicle Technologies Advanced Vehicle Testing Activity: Hydrogen-Fueled Mercedes Sprinter Van Operating Summary | INEEL/EXT-03-00009 | OSTI 809115, 2003) (J Francfort D. K., 2006) (United States Department of Energy (US DOE | home), 2025)

Southern Nevada Alternative Fuels Demonstration Project | Jan 2010 | DOE/GO-86068-1

From **August 2006** to **January 2010**, the **US Department of Energy** (DOE) placed two of **Ford Motor Company** (FoMoCo)'s E-450 Shuttle Busses, each equipped with purpose-built 6.8L Ford Triton V-8 **Hydrogen Combustion Engines** (H_2ICE), in service with the **City of Las Vegas** for the DOE's **Southern Nevada Alternative Fuels Demonstration Project** (DOE/GO-86068-1). The City of Las Vegas was expected to gather emission test result data, but per **§VI.D**, of **DOE-86068**, no emission data was collected – over the two-year period because the City's emission test equipment *could **not** read tail-pipe emissions* from the Ford buses. Any tail-pipe emissions emitted from the hydrogen engines were below the threshold of the City's equipment to read it.

NOTE: This report is publicly available for download from the **US Department of Energy** (DOE)'s **Office of Scientific and Technical Information** (OSTI). Links are embedded in the report numbers and listed in citations and Works Cited.

(Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (United States Department of Energy (US DOE | home), 2025) (Office of Scientific and Technical Information (OSTI | home), 2024) (J Damm, 2009) (Wikipedia: Ford Motor Company | FoMoCo, 2025)

Detroit Commuter Project | Sept 2009 | OSTI-1005125

From March through September of 2009, two more **FoMoCo** purpose-built **Hydrogen Combustion Engines** (H_2ICE) shuttle buses were placed in service to shuttle people around the Detroit Metro Airport for the **US Department of Energy** (DOE)'s **Detroit Commuter Project** (OSTI-1005125)
While the 20-month project was truncated to six months, due to hydrogen fuel availability, the buses logged 50,000 and 32,400 miles respectively. While no emission data was collected during the six-month period, maintenance records and fuel consumption data were collected. Both buses were reported to run great and require only minor maintenance services.

NOTE: This report is publicly available for download from the **US Department of Energy** (DOE)'s **Office of Scientific and Technical Information** (OSTI). Links are embedded in the report numbers and listed in citations and Works Cited.

(Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023; Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (United States Department of Energy (US DOE | home), 2025) (Egelton, 2009) (Office of Scientific and Technical Information (OSTI | home), 2024)

Southwest Research Institute H_2ICE Consortium Class 8 Demo Truck | Cummins X15N Purpose Built for H_2 Combustion

Southwest Research Institute (SwRI) launched their **Hydrogen Combustion Engine** (H_2ICE) Consortium and is advancing H_2ICE optimization by solving problems like contamination of the lubricating oil by hydrogen re-bonding with atmospheric oxygen when the tiny hydrogen molecule gets passed the rings and into the crankcase.
With Cummins as a Consortium member, they provided SwRI with an **X15N Natural Gas engine** that SwRI proceeded to convert to **Port Fuel Injection** (PFI) gaseous hydrogen. The Class 8 Demo Truck has traveled around the US showing off the hydrogen engine technology.
This author had the privilege of chatting with the head of SwRI's H_2ICE Consortium, **Ryan Williams**, while the demo Class 8 truck was on display outside the **2024 California Hydrogen Leadership Summit** in Sacramento. He mentioned how they were running the crankcase at a positive pressure in an effort to prevent hydrogen from getting into the crankcase and mitigate the risk of lubricating oil contamination and/or crankcase explosion.

SwRI was able to repeatedly demonstrate **Oxides of Nitrogen** (NOx) emissions – *the only emissions from hydrogen combustion* – well below **California Air Resources Board** (CARB)'s *voluntary* ultra-low NOx standard of 20 milligrams. As part of this Demo Truck project, Cummins developed an aftertreatment system specifically for use with hydrogen engines and hydrogen compatible, this system was used to mitigate transient rises in NOx and help to achieve the consistently low NOx readings.
*SAE's **Matt Wolfe*** showcased SwRI, the truck, the Consortium and their significant accomplishments developing and optimizing H_2ICE in an October 2024 SAE article.
Ryan Williams told SAE's ***Matt Wolfe*** "*we were able to demonstrate is below 10 milligrams on every regulatory cycle*."

The **SwRI H_2ICE Consortium** has ,and is, contributed significantly to the optimization of hydrogen engines by working with Consortium members to develop engine hardware that is hydrogen compatible, and is able to handle the unique behavior and properties of hydrogen – like the oil contamination and the "*ghost spark*" phenomena – a unique engine performance issue that can be contributed entirely to the behavior and properties of gaseous hydrogen.

Cummins as been a vocal and active member of **Germany's Allianz Wasserstoff Motor**, **SwRI H_2ICE Consortium**, and one of the first members of the newly launched **Hydrogen Engine Alliance of North America**. Thanks to the innovation and advocacy by SwRI, Cummins and all the members of the Consortiums, Hydrogen Engine Alliances in the US and Germany; advances in the hydrogen engine hardware is being commercialized.
Ionbond has developed a hydrogen compatible coating for use with hydrogen engine hardware that was previously obtained lubrication thanks to the properties of liquid fossil fuels. Since hydrogen has no lubricating properties, components like fuel injectors require an alternative, hydrogen compatible, solution.

(Southwest Research Institute (SwRI | home), 2025) (Southwest Research Institute (SwRI): H2ICE Consortium, 2024) (C Bekdemir, 2022) (Cummins: Next Generation of X15 | Next in the Cummins Fuel-Agnostic 15-Liter Platform, 2024) (Gehm, SAE Mobility Engineering: Hydrogen ICE Is Heating Up, 2023) (Hydrogen Engine Alliance of North America | home, 2025) (Cummins Newsroom: Cummins Unveils Integrated Drivetrain Concept Featuring HELM™ Engine Platforms at IAA Transportation 2024, 2024) (Cummins Newsroom: Cummins to Reveal Zero-Carbon H2-ICE Concept Truck at IAA Expo Powered by the B6.7H Hydrogen Engine, 2022) (Cummins Newsroom: Hydrogen Engine Alliance Makes Case for Commitment to Hydrogen Combustion at IAA, 2024) (Cummins Newsroom: Cummins Announces Innovative Next Generation X15 Diesel Engine, Part of Cummins HELM™ 15 Liter Fuel Agnostic Platform, Launching in North America to Meet Aligned 2027 Regulations, 2024) (Cummins Newsroom: Hydrogen Engine Alliance Makes Case for Commitment to Hydrogen Combustion at IAA, 2024) (Cummins Newsroom: United States' First Class 8 H2-ICE Demo Showcased for Fleets, 2024) (Allianz Wasserstoff Motor: Position on Hydrogen Combustion Engines, 2025) (Allianz Wasserstoff Motor | Germany's H2ICE Alliance | home, 2025) (Bosch Mobility: Port Fuel Injecction (PFI) for H2ICE | product home page, 2024) (Hydrogen & Fuel Cell Technologies Office (HFTO): Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | Webinar Slides, 2023) (Hirsch, 2023) (Ionbond | home, 2025) (Ionbond Press Release: Ionbond joins Hydrogen Engine Alliance to Advance the Hydrogen Internal Combustion Engine, 2025) (Ionbond White Paper: Coatings for Tribological Hydrogen Applications, 2025) (California Hydrogen Leadership Summit | home, 2024) (Wikipedia: Nitrogen Oxides (NOx), 2023) (Williams, 2024) (Wolfe, SAE International: Hitting the Gas on Hhydrogen Tech for Commercial Trucks | H2ICE | HFC, 2022) (California Air Resources Board (CARB | home), 2024) (Cummins Newsroom: How do Aftertreatment Systems Differ between Hydrogen and Diesel Engines?, 2024) (Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (H2 Tools: Best Practices - Material Compatibility, 2024)

With Respect to What is Battery and Fuel Cell EVs Zero Emission?

Zero Emission Vehicles (ZEV) may have "zero emissions" at the tail-pipe but that doesn't mean they're literally zero emissions. Disregarding the source of electricity, there's still the emissions from mining for the rare earth materials necessary to manufacture the batteries, and the toxic materials, like aqueous electrolyte, which need to be disposed of whether the batteries are successfully recycled or not. That toxic electrolyte goes down storm drains whenever there's a battery fire, in addition to the toxic smoke from the fire.
Battery degradation requires a second and end of life policy to prevent the toxic materials from seeping into the ground.

(Wikipedia: Zero Emission Vehicle (ZEV), 2025) (Halvorson, 2021) (Hanley, 2020) (JP Rugh, 2011) (National Fire Protection Assoc (NFPA): Lithium-Ion Battery Safety, 2023) (National Fire Protection Assoc (NFPA): Referenced Standards Fact Sheet, 2018) (Portable Rechargeable Battery Association (PRBA): Safety Policy on Use & Handling of Stand-Alone Cylindrical Lithium Ion Cells, 2018) (Portable Rechargeable Battery Association (PRBA): Lithium Batteries and Fire Codes, 2021) (Underwriters Laboratories (UL): Research Institute: Lithium-Based Battery Thermal Runaway, 2021) (Alternative Fuels Data Center (AFDC): Electric Vehicle Battery Recycling, 2024) (Sloop, 2022) (Bieker, 2021) (United States Environmental Protection Agency (US EPA): Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard, 2022) (Kunz, 2019) (TL Curtis, 2021) (Alternative Fuels Data Center (AFDC): Battery Second Life FAQ by Argonne National Laboratory, 2020)

H_2ICE Decades of Development | Advancing America's Zero Emission Vehicle Goals

Feb 22, 2023, **US Department of Energy** (DOE)'s **Office of Energy Efficiency & Renewable Energy** (EERE)'s **Hydrogen & Fuel Cells Technologies Office** (HFTO) H_2IQ Program hosted a webinar on **H_2ICE** development and advancement across the globe cited these notable facts:

- Every ICE manufacturer across the globe has some kind of **H_2ICE** development in process
- The **European Union** (EU) voted ***YES*** to allow new internal combustion engine vehicles to be registered *after* 2035 ***if*** they ran on an e-fuel, which includes **H_2ICE**
- Existing exhaust treatment systems are sufficient to eliminate unburnt H_2 in the exhaust, a safety issue, and eliminate any transient emissions – notably NOx is the only emissions
- **H_2ICE** has been shown to operate at 30%+ more thermally efficient than our most thermally efficient ICE, the diesel.
- **H_2ICE** made **more horsepower** and runs **more thermally efficient** than the engine it was converted from. Also noted in a **SAE International** (SAE) *High Efficiency HD Hydrogen Combustion Engines: Improvement Potentials for Future Regulations* (2022-01-0477)
- **H_2ICE** Webinar

(United States Department of Energy (US DOE | home), 2025) (Office of Energy Efficiency and Renewable Energy (EERE | home), 2024) (Hydrogen & Fuel Cell Technologies Office (HFTO | home), 2024) (H2IQ by the Hydrogen & Fuel Cell Technologies Office (HFTO), 2024) (SAE International (home), 2025) (D Kovacs, 2022) (Cummins Newsroom: How do Aftertreatment Systems Differ between Hydrogen and Diesel Engines?, 2024) (Paleja, 2024) (Kottasova, 2023) (Wikipedia: European Union (EU), 2025)

SAE International (SAE) has several technical papers available for purchase, like the one mentioned above (*SAE 2022-01-0477*) among several additional papers as **H_2ICE** development over the years, including papers in the Journal of Engines.

(SAE International (home), 2025) (C Bekdemir, 2022) (D Kovacs, 2022) (J Laichter, 2023) (B Nagalingam, 1983) (H Iwasaki, 2011) (M Flekiewicz, SAE International: Hydrogen Enriched CNG - a Tool for Dual Fuel Engine Overall Performance Improvement | 2009-01-2681, 2009) (M Flekiewicz, SAE International: Identification of Optimal CNG-Hydrogen Enrichment Ratio in the Small SI Engines | 2012-32-0015, 2012)

According to California vehicle data, and vehicle data from the **US Department of Transportation** (DOT)'s **Bureau of Transportation Statistics** (BTS), the average US consumer is keeping their vehicle 12 years, up from 8.5 years in the mid-1990s. According to the **Alternative Fuels Data Center** (AFDC), Californians burned 12.7B gallons of gasoline in 2021. If all those vehicles ran on hydrogen instead of gasoline, that would result in the sale of nearly **13 billion kg of hydrogen**. Per the same data sheet, there are 11,897 fuel cell vehicles registered in California and 26.2 million gasoline vehicles registered in California. Converting existing IC Engines to run on hydrogen is profoundly cheaper than purchasing a new car, and if California offered consumers incentives to convert their vehicles to operate on hydrogen as the combustible fuel, it would encourage disadvantaged and low-income communities to become zero emission, well, *nearly* zero emission until **H_2ICE** advances to reach zero emission status.

(United States Department of Transportation (US DOT | home), 2023) (Bureau of Transportation Statistics (BTS | home), 2024) (Bureau of Transportation Statitics (BTS): Table 1-26, 2023) (Alternative Fuels Data Center (AFDC | home), 2025) (Alternative Fuels Data Center (AFDC): California Vehicle Registration Data, 2023) (California Energy Commission (CEC): California Vehicle Registration Data, 2023)

US Department of Energy (DOE) funded a Consumer Showcase Study, by the **National Renewable Energies Laboratory** (NREL) (NREL/TP-5400-75707, 2020) hosted a consumer showcase for **Battery Electric Vehicles** (BEVs) and **Plug-in Hybrid Electric Vehicles** (PHEVs) and their supporting infrastructure in the Pacific Northwest, seven Mid-Western States, and several Northeastern States. The Midwest had the lowest consumer acceptance before the showcase and the highest increase in acceptance post showcase, at nearly 40% increase in electric powertrain acceptance.

(United States Department of Energy (US DOE | home), 2025) (National Renewable Energy Laboratory (NREL | home), 2024) (Singer, 2020) (Alternative Fuels Data Center (AFDC): How Electric Vehicles Work, 2025) (Alternative Fuels Data Center (AFDC): How Plug-In Hybrid Electric Vehicles (PHEV) Work, 2024)

The **Transportation Energy** **Institute** researched the *Decarbonizing Combustion Vehicles: A Portfolio Approach to GHG Reductions* and issued an article regarding emissions from all vehicle types.

(Eichberger, 2021) (Transportation Energy Institute | home, 2025) (Transportation Energy Institute: Decarbonizing Combustion Vehicles: A Portfolio Approach to GHG Reductions, 2023)

The **California Energy Commission** (CEC) issued their *Final Draft Clean Energy Reliability Investment Plan* (CEC-200-2023-03) and page sixteen lists California's next two fiscal year investment targets:
"*Innovation Grants: Evaluate strategies not previously deployed but that appear to have the potential to unlock greater demand-side value. This initiative would solicit new strategies for deploying clean energy technologies. Innovation grants would be structured to demonstrate a new approach to supporting customers and the grid through demand-side applications. Grants would fund projects that are a combination of new approaches and either newly commercial or commercially ready technologies in applications that can be readily transferrable across the state.*" – CEC-200-2023-03 p.16
Filed under CEC 21-ESR-01 | TN #248969 | CEC-200-2023-03
21-ESR-01 is also outlined on the webpage under 2023 Advocacy Activities.

(California Energy Commission (CEC | home), 2024) (California Energy Commission (CEC): 21-ESR-01 | TN #248969 | CEC #200-2023-03, 2023) (California Hydrogen Business Council: 2023 Advocacy Activities, 2023)

The **California Hydrogen Business Council** cites *Public Opinion* as the greatest obstacle.

(California Hydrogen Business Council, 2023) (California Hydrogen Business Council: Current Research & Obstacles, 2023)

The tagline of the upcoming California Hydrogen Leadership Summit is "explore *the policies, programs, and incentives needed to accelerate production, use, and storage of hydrogen*" California has already explicitly cited, within its stated clean energy goals, the reasons to embrace, support, and advance hydrogen as the combustible fuel for internal combustion engines, **H_2ICE**. A perfect description of what hydrogen combustion engines can be.

(California Hydrogen Leadership Summit | home, 2024)

Reference **National Renewable Energies Laboratory** (NREL) (NREL/TP-5400-75707, 2020) and the **California Hydrogen Business** **Council** cited public opinion as one of the greatest challenges to increasing **Zero Emission Vehicle** (ZEV) sales.

(Singer, 2020) (National Renewable Energy Laboratory (NREL | home), 2024) (California Hydrogen Business Council, 2023) (California Hydrogen Business Council: Current Research & Obstacles, 2023) (Wikipedia: Zero Emission Vehicle (ZEV), 2025) (Alternative Fuels Data Center (AFDC): Maps & Data - Vehicle Registration Numbers by State & Fuel (BEV | PHEV | HEV | E85 | H2 | Biodiesel | Methanol +), 2023)

US Department of Energy (DOE) **Vehicle Technologies Office** (VTO) **Propulsion Materials Program** worked with **Ford Research & Advanced Engineering** to develop a fuel injector, and its actuator to work with hydrogen. This three-year project laid the foundation for hydrogen safe fuel injectors, fuel systems, and the single cylinder engine, in Ford's test cell proved that early H_2ICE was capable of ***reaching 45% thermal efficiency***. This testing helped develop the hydrogen safe engine components currently in production at engine component manufacturers across the world, and has made production H_2ICE possible with Toyota, Mazda, Ford, and Cummins offering production engines.

VTO Propulsion Materials Annual Progress Reports from 2007 through 2011 detail the research and development projects involving hydrogen materials compatibility.

(United States Department of Energy (US DOE | home), 2025) (Vehicle Technologies Office (VTO | home), 2023) (Vehicle Technologies Office (VTO): 2007 Propulsion Materials Annual Progress Report | OSTI-1217087, 2008) (Vehicle Technologies Office (VTO): 2008 Propulsion Materials Annual Progress Report, 2009) (Vehicle Technologies Office (VTO): 2009 Propulsion Materials Annual Progress Report, 2010) (Vehicle Technologies Office (VTO): 2010 Propulsion Materials Annual Progress Report | ORNL-28101, 2011) (Vehicle Technologies Office (VTO): 2011 Propulsion Materials Annual Progress Report | ORNL-34212, 2011) (Stumpf, 2022) (Toyota Times: Liquid Hydrogen Car Gears Up for 24-Hour Race, 2023) (Mazda H2ICE, 2022) (Max, Hydrogen Fuel News: Ford Files for US Patent of Hydrogen Combustion Engine, 2022) (Cummins Hydrogen ICE Truck Powered by B6.7H | Cummins, 2023) (Cummins H2ICE: The Vehicle Technology Centre - Manitoba Canada, 2022) (Green Car Congress: Westport Fuel Systems Introduces H2 HPDI Fuel System, 2022) (H2 Tools: Best Practices - Material Compatibility, 2024) (Ionbond White Paper: Coatings for Tribological Hydrogen Applications, 2025)

Every single research paper includes statements about the benefits of H_2ICE and how H_2ICE, specifically **Direct Injected** (DI), "*can be viewed as a high efficiency, low-emissions technology for bridging the transition to the hydrogen economy that's based on fuel cell technology…. It is estimated that DI H_2ICE can be integrated into a hybrid vehicle system to result in fuel consumption that's only ~15-20% greater than {2008} hybridized fuel cell vehicles of similar mass. Significantly lower hardware costs (compared to 2008 fuel cell systems) and the ability to use existing manufacturing facilities for conventional reciprocating engines makes this an attractive consideration.*" – 2008 VTO Materials Annual Progress Report | p.4

(Vehicle Technologies Office (VTO): 2008 Materials Annual Progress Report | H2ICE Mat'ls | Jan 2009, 2009) (United States Department of Energy (US DOE | home), 2025) (Vehicle Technologies Office (VTO | home), 2023) (H Lohse-Busch, 2006) (Egelton, 2009) (B Heid, 2021) (D Kovacs, 2022) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Green Car Congress: Westport Fuel Systems Introduces H2 HPDI Fuel System, 2022) (SK Addepalli, 2022) (R Scarcelli, 2009) (J Laichter, 2023)

Cyber Security | Indifferent to Hydrogen Gas Quality

Supporting Topic(s):
Topic IV: Negligible Cybersecurity Risk
Topic V: Operational Over Wide Range of Hydrogen Gas Quality

CYBERSECURITY RISK

While all software-based systems are susceptible to cyber security risks, hydrogen engines are controlled by a closed loop system that does not require software updates like the electric powertrain vehicles whose entire operation is dependent on software-based control systems, and due to the requirement of the vehicle to have external internet access to support software updates; the vehicle is also open to cyber security risks.
Hydrogen engines would have closed loop systems nearly identical to fossil fuel combustion engine vehicles today.
Extensive efforts are underway to protect charging infrastructure, vehicle to grid integration (V2G | VGI), and the vehicles.
Every time a **Battery Electric Vehicle** (BEV) uses a public charging station, the vehicle must communicate with the equipment, the financial institutions for payment, and communication with the power grid is also established – all of which are susceptible to cyber security risks.

If auto repair shops fail to recognize a comprised **Electric Vehicle** (EV), the risk of comprising several other vehicles in for service is increased as many OBD II code readers are used from vehicle to vehicle.

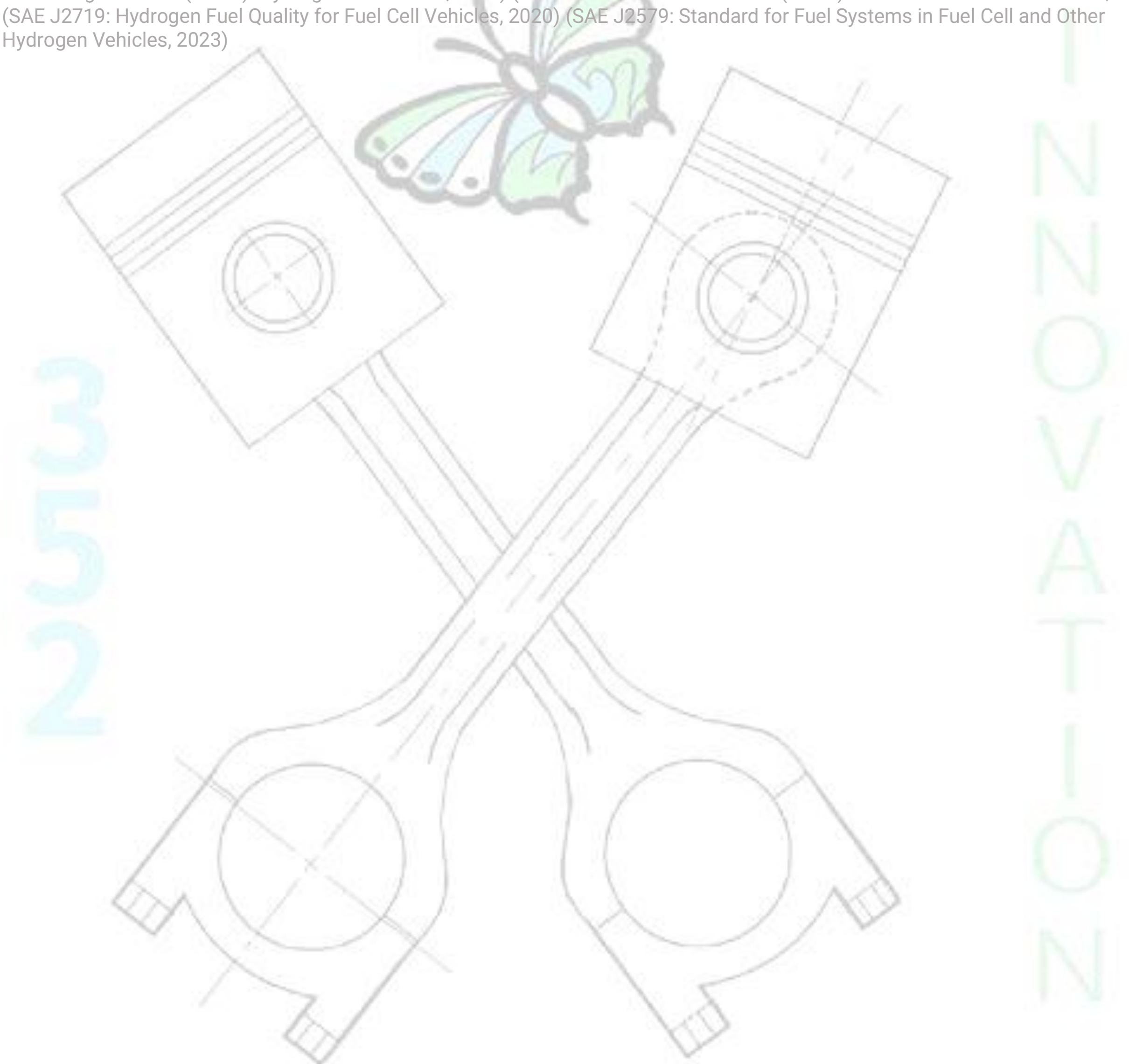
Hydrogen engines are not susceptible to battery fraud. Battery fraud poses a significant safety risk to the vehicle owner. Per **Wheels CA** article, Tesla's were witnessed coming out of auto auctions with sandbags were some battery modules should have been and the software wiped to ensure nothing appeared amiss. When the control system, designed to regulate the battery for reliability, performance, and safety, receives inaccurate data, that battery may have degraded performance, or worse, become a safety hazard.

(Wikipedia: Cyber Security, 2025) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Battery University BU-1002: Electric Powertrain, 2021) (J Johnson B. A., 2022) (Kagubare, 2022) (J Johnson T. B., 2022) (Markel, 2023) (National Highway Traffic Safety Admin (NHTSA): Vehicle Cyber Security, 2024) (National Institute for Standards & Technology (NIST): Electric Vehicle Cyber Security & Extreme Fast Charging Infrastructure, 2023) (SAE International Technical Paper: Hardware-Based Cyber Security for Connected Vehicles | 2023-01-0038, 2023) (Clavey, 2021) (Wikipedia: Tesla, Inc, 2023) (Battery University BU-908: Battery Management System (BMS), 2021) (Battery University BU-305: Building a Lithium-Ion Pack, 2021) (Wikipedia: Control Systems, 2023) (Underwriters Laboratories (UL): Cybersecurity, 2023) (Alternative Fuels Data Center (AFDC): Electric Vehicles, 2024) (SAE J3061: Cybersecurity Guidebook for Cyber-Physical Vehicle Systems, 2021) (Alternative Fuels Data Center (AFDC): How Electric Vehicles Work, 2025) (Buchholz, SAE International: Survey Reveals Cyber, Quality Challenges of Vehicle Connectivity, 2022) (Berman, 2020) (Carlson, 2022) (Institute of Electrical and Electronics Engineers (IEEE): Cyber Security Issues of Internet of Electric Vehicles, 2022) (National Highway Traffic Safety Admin (NHTSA): Cybersecurity Best Practices for Modern Vehicles, 2016) (National Highway Traffic Safety Admin (NHTSA): Automotive Cyber Security, 2025) (National Renewable Energy Laboratory (NREL): Cyber Security Technology Innovation | Grid Infrastructure | Projects | Publications, 2023) (National Renewable Energy Laboratory (NREL): EVs@Scale: US DOE Lab Consortium - Smart Charging | HiPower Charging (HPC) | Wireless Power Transfer (WPT) | Cyber-Physical-Security (CPS) | Codes & Standards (CS) - Summary Report | NREL/PR-5400-84093, 2022) (National Renewable Energy Laboratory (NREL): Vehicle to Grid (V2G) Integration (VGI), 2023) (Wikipedia: Onboard Diagnostics (OBD), 2023)

Hydrogen Sales of All Gaseous Mix Qualities

Thanks to engine control electronics and their response times, hydrogen engines are able to operate on a wide range of gaseous hydrogen mix quality.
Hydrogen powered fuel cells require strict adherence to a gaseous hydrogen mix quality of 99% or better to prevent degraded operation and/or damage.
As hydrogen gas production and infrastructure are developed, any reduction in hydrogen gas quality may still be sold, eliminating the need to put it in storage and/or refine it further to achieve the 99% or higher quality required for selling to **Fuel Cell Electric Vehicle** (FCEV).

(Alternative Fuels Data Center (AFDC): Hydrogen Basics, 2024) (C Bekdemir, 2022) (Wikipedia: Engine Control Unit (ECU), 2022) (Hydrogen & Fuel Cell Technologies Office (HFTO): H2IQ: February H2IQ Hour: Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies | webinar replay, 2023) (Hydrogen & Fuel Cell Technologies Office (HFTO): Fuel Cell Basics, 2024) (Hydrogen & Fuel Cell Technologies Office (HFTO): Fuel Cell Systems, 2024) (H2 Tools: Hydrogen Infrastructure, 2025) (Hydrogen & Fuel Cell Technologies Office (HFTO): Hydrogen Production, 2024) (Alternative Fuels Data Center (AFDC): How Fuel Cell Vehicles Work, 2024) (SAE J2719: Hydrogen Fuel Quality for Fuel Cell Vehicles, 2020) (SAE J2579: Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles, 2023)



In conclusion…

The future of zero emissions does not have to be one technology, and internal combustion engines can play a key role in reducing emissions while saving jobs and improving consumer confidence and acceptance of zero emission vehicles.
Thank you for your time.

Sincerely,
Krystyna Kubran

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