THE MIDWEST HYDROGEN CENTER OF EXCELLENCE

A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative

Features and Benefits of Hydrogen Powered Transit

Andrew A. Rezin, Ph.D., Director
Midwest Hydrogen Center of Excellence

RENEWABLE HYDROGEN FUEL CELL COLLABORATIVE

FUELING OUR EVERYDAY LIFE

Current primary fuel sources:

Methane (CH_4) + oxygen ($2O_2$) $\longrightarrow$ $CO_2 + 2H_2O$ + **Energy**

Diesel + oxygen ($x\,O_2$) $\longrightarrow$ $x\,CO_2 + x\,H_2O$ + **Energy**

Coal + oxygen ($x\,O_2$) $\longrightarrow$ $x\,CO_2$ + **Energy**

Traditional fuel options are inefficient

- Burning fuels lose substantial energy as **Heat**, or thermal energy
- This is a chaotic, low-quality form of energy.
- Producing this form of energy … you must pay a penalty…*Low Efficiency*

Traditional fuel options are inefficient

- The loss of energy of the fuels as **Heat** uses up 1/2 to 2/3 of the their potential
- *Only about **1/3** of the fuel's potential is captured to do meaningful work.*
- *And then there are the byproducts …*

Burning fossil fuels results

- Air pollution
  - Nitrogen oxides
  - Sulfur dioxide
  - Carbon oxides
  - Volatile organic compounds
  - Resulting in acid rain, smog, and soot
- Water pollution
  - Water polluted by acid rain affecting plant life, animal life, and human life

Burning fossil fuels

- Water pollution
  - Water polluted by acid rain affecting plant life, animal life, and human life
- Noise pollution
- Climate change
  - Buildup of greenhouse gasses results in accelerated ozone layer depletion

Hydrogen is a clean fuel source

Hydrogen accounts for nearly all the mass in our *universe*.

Hydrogen = H = 73%

All other elements= 27%

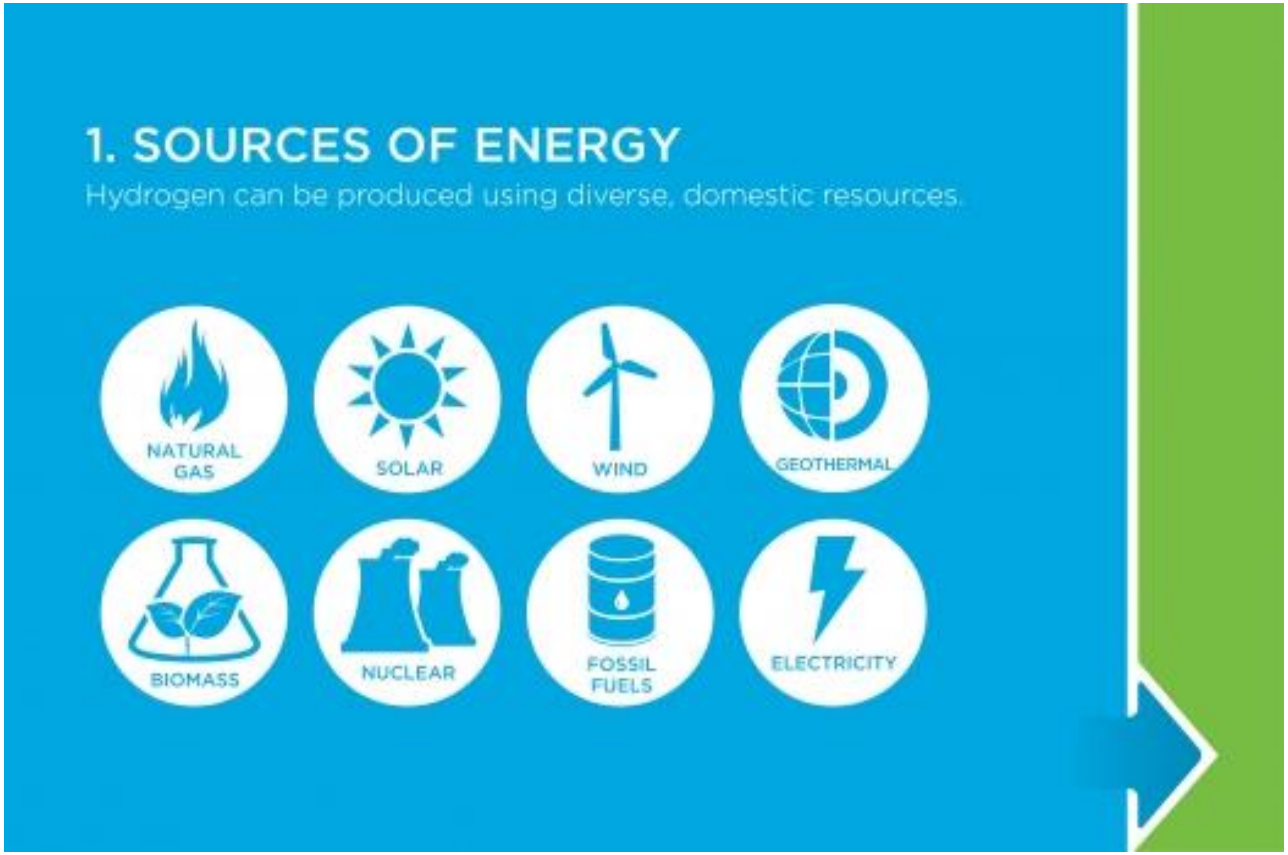
Hydrogen is a clean fuel source

Hydrogen (H_2) + oxygen ($½O_2$) ⟶ H_2O + **Energy**

The main byproducts are pure water and **Heat** (thermal energy)

Hydrogen is a clean fuel source

- Hydrogen fuel can be produced from domestic resources



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- Hydrogen: A Clean, Flexible Energy Carrier @ Energy.gov June 2017

Hydrogen is a clean fuel source

- National Renewable Energy Labs (NREL) studies have found that a total of 1 billion metric tons of hydrogen could be produced annually from wind, solar, and other biomass sources in the U.S.

Hydrogen is a clean fuel source

- Hydrogen fuel can be produced from renewable sources of energy

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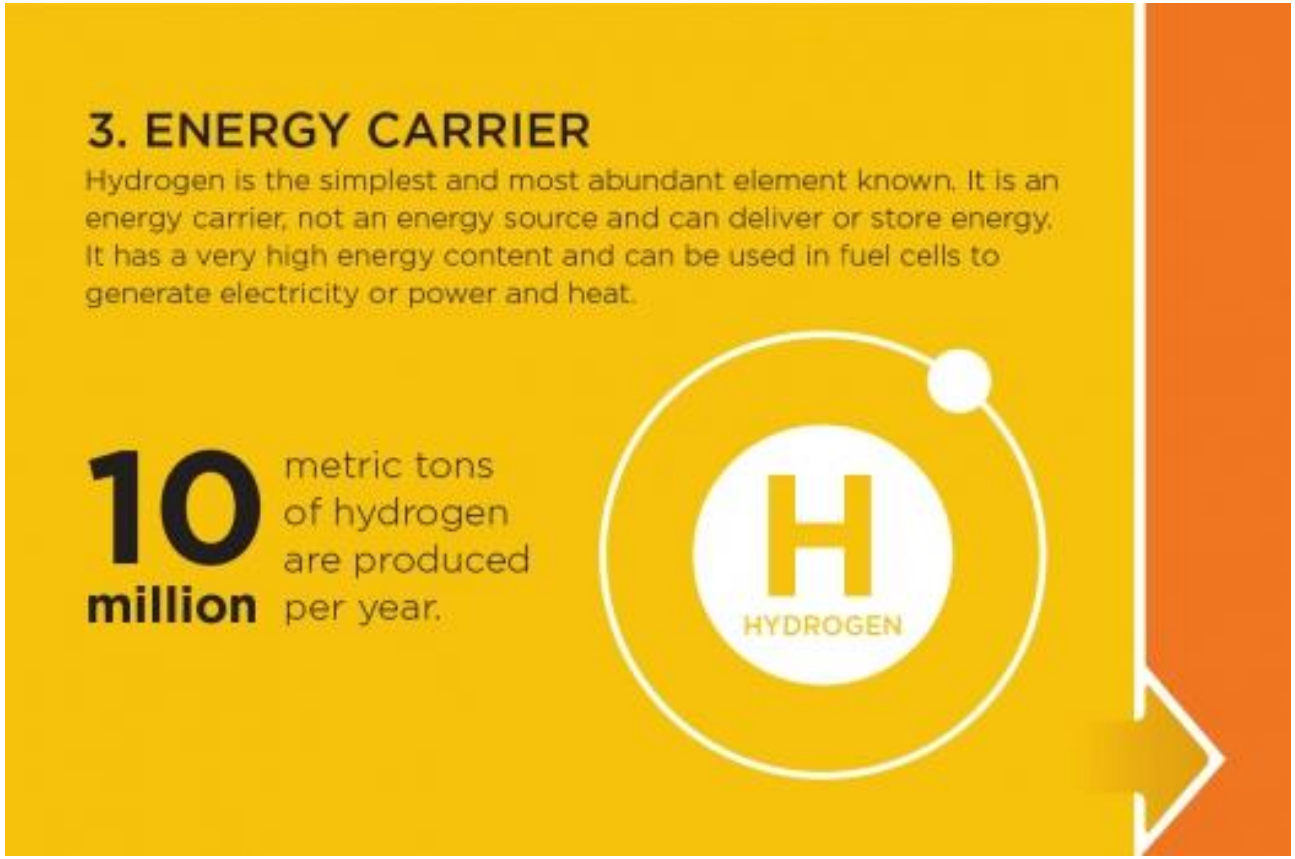

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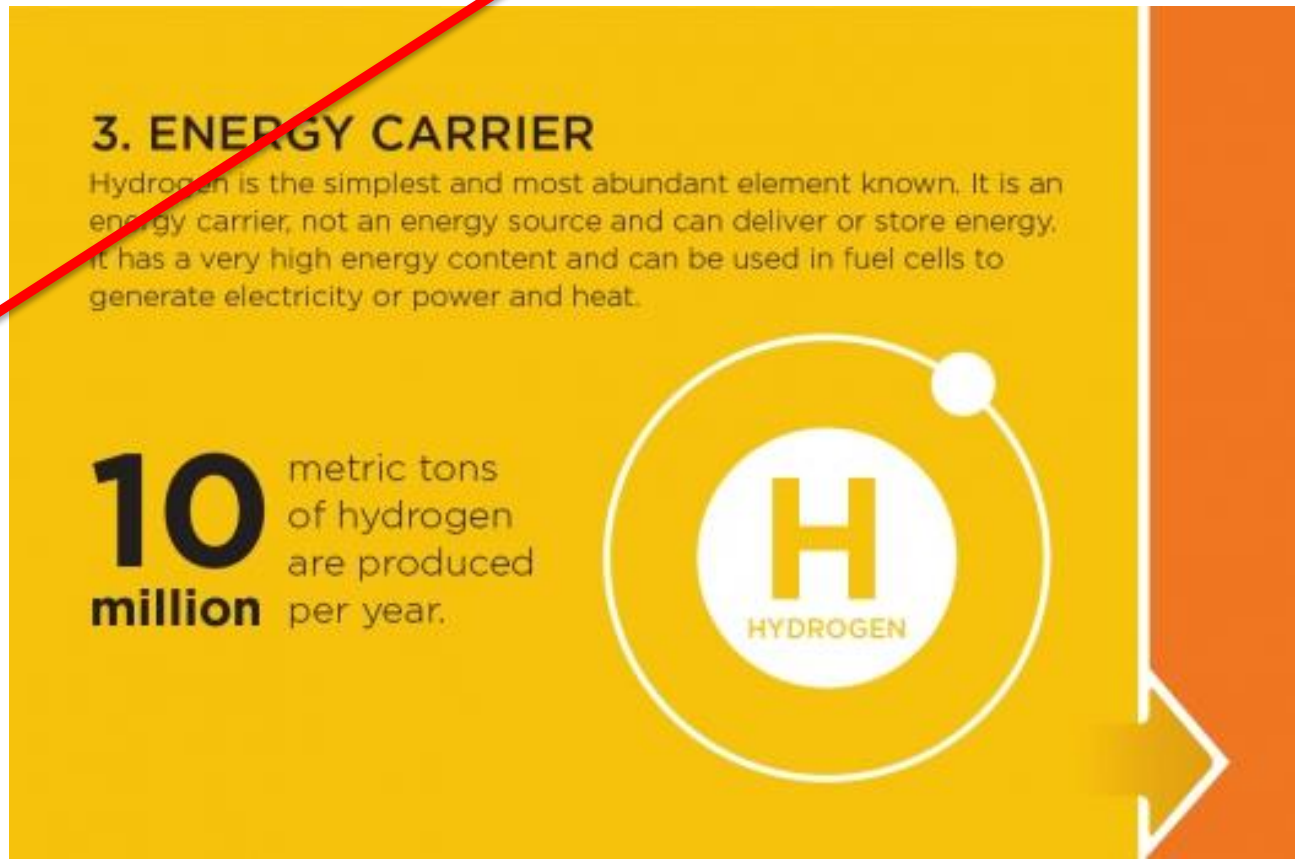
Hydrogen is a clean fuel source

- Hydrogen is an efficient energy carrier

  - Just like transit buses carry passengers, hydrogen carries potential energy … moving it from one place to another efficiently



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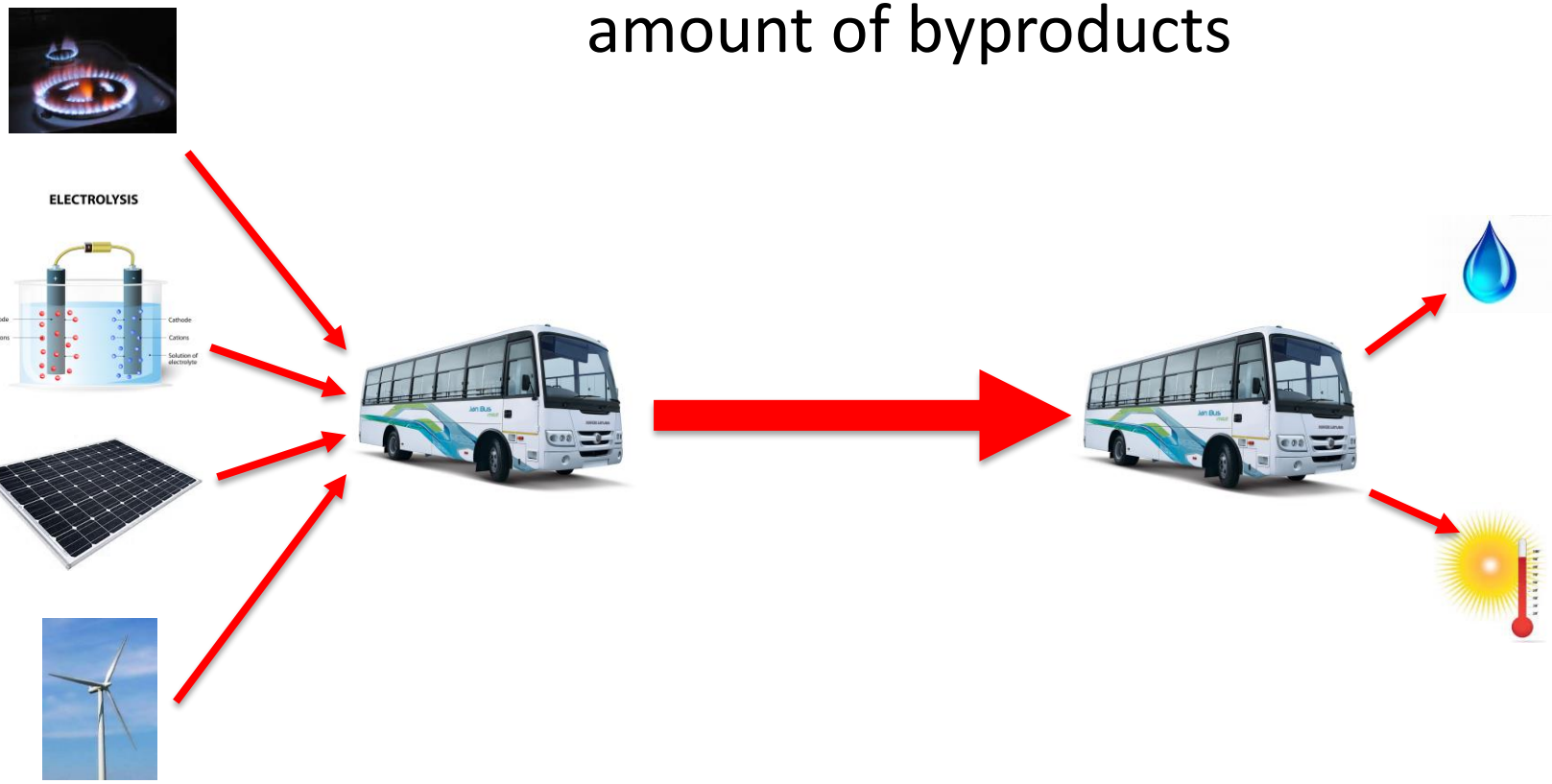
Hydrogen is an energy carrier

The vast majority of the energy is converted into electricity to drive the bus … leaving a small amount of byproducts



Hydrogen is a safe fuel source

H_2 Storage Technology

- H_2 is 16 times lighter than air
- H_2 will <u>immediately</u> dissipate into the atmosphere if released
- Rigorously tested

FUELING TRANSPORTATION WITH HYDROGEN

Transportation is a key energy user

- 29 % of U.S. energy consumption in 2016 was attributed to the transportation sector, and the carbon emissions from the transportation sector have now surpassed the power sector as measured on a 12-month rolling basis in the U.S - U.S. Energy Information Administration, 2017

Transportation is a key energy user

- Fuel cells enable a highly efficient energy conversion, operate quietly, require little maintenance, and are highly reliable. These factors can translate to reduced greenhouse gas emissions.

Transportation is a key energy user

- Fuel cell electric vehicles that operate on an overall efficiency of up to 60% can effectively cut the energy consumption and associated pollution levels compared to conventional vehicles that have a 30% efficiency

Transportation is a key energy user

- Hydrogen produced through steam methane reforming for the transportation sector can reduce greenhouse gas emissions by 50%
- Hydrogen produced by renewable sources can reduce overall greenhouse gas emissions associated with the transportation sector by 90%.

- U.S. Department of Energy, Fuel Cell Technologies Office

Transportation is a key energy user

- Depending on vehicle class, the efficiency of FCEVs are approximately two times better than a traditional internal combustion engine.
  - 40-60% of the available energy content in hydrogen is harnessed to move the vehicle forward
  - Only approximately 20% of the energy content of gasoline is used due to excessive loss of energy in the form of heat.

Transportation is a key energy user

- The significant local attributes for FCEVs include no tail pipe emissions since a fuel cell produces electricity through an electrochemical reaction that only produces water as the byproduct.
- Dependent on the hydrogen production method, the GHG savings can be significant.

Transportation is a key energy user

- Hydrogen fueled vehicles have no direct grid impacts that can result in potentially prohibitive demand charges, especially for fleets that deploy larger volumes of electric vehicles.

Transportation is a key energy user

- FCEVs are, in most cases, able to handle the same duty cycle as conventional vehicles with internal combustion engines, while the vehicles' fill-up processes closely resemble one another.

Transportation is a key energy user

Hydrogen Requirements

= 5 Kg

Energy content in 1 Kg H_2 is approximately equal to energy in 1 gallon of gasoline.

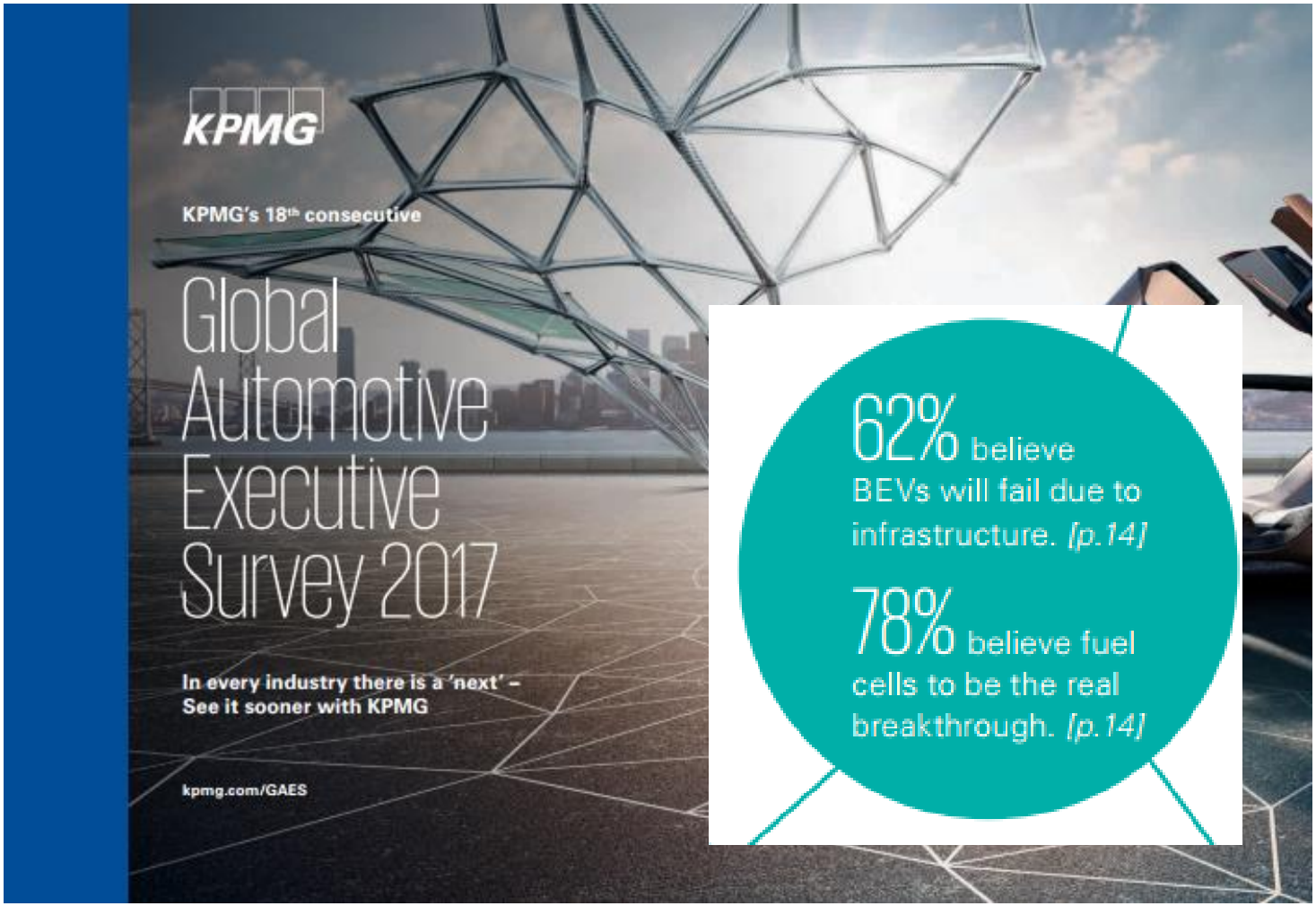
114,000 Btu LHV

= 50 Kg

The obvious answer for the future is

Fuel Cells

Hydrogen is the future of transportation fuel



Hydrogen is the future of transportation fuel

John Leech

Automotive Leader UK

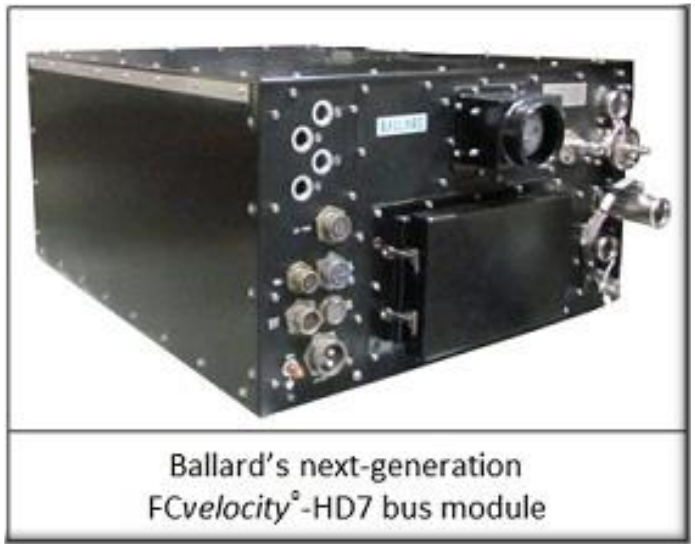
"Execs are hesitant regarding cooperation and unsolved infrastructure challenges. The reason for execs to believe in fuel cells may be their strong attachment to the existing infrastructures and traditional vehicle applications."

WHAT IS A FUEL CELL?

What is a fuel cell?

A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity. If hydrogen is the fuel, electricity, water, and heat are the only products.

– U.S. Dept. of Energy, June 16, 2017

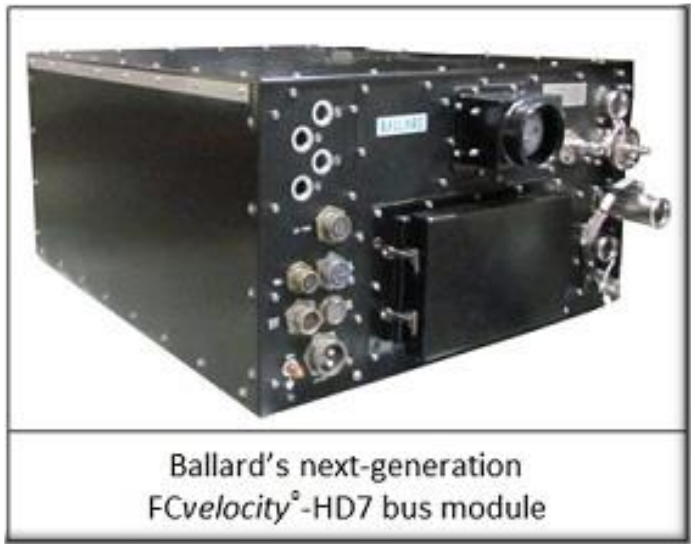


Ballard's next-generation FC*velocity*®-HD7 bus module

What is a fuel cell?

Fuel cells are unique in terms of the variety of their potential applications; they can provide power for systems as large as a utility power station and as small as a laptop computer.

– U.S. Dept. of Energy, June 16, 2017

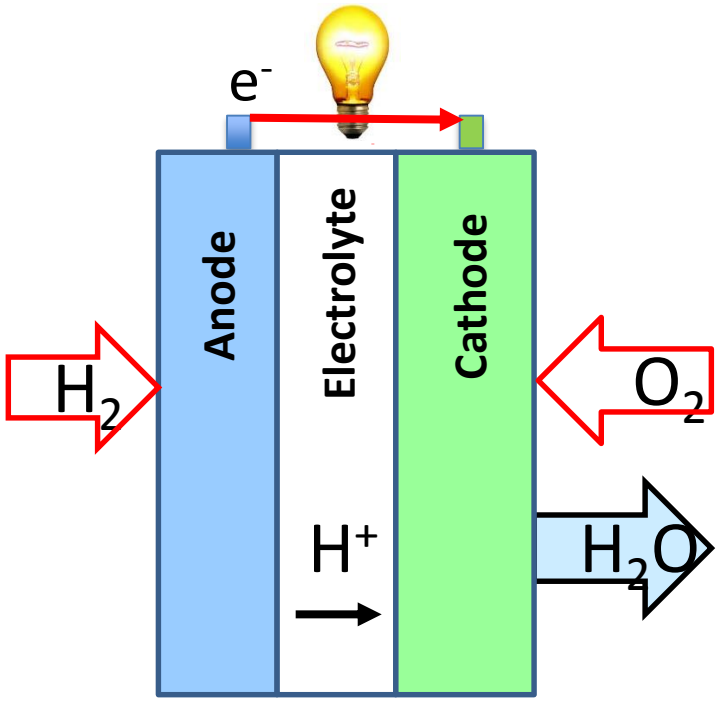


Ballard's next-generation FC*velocity*®-HD7 bus module

What is a fuel cell?

Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied.

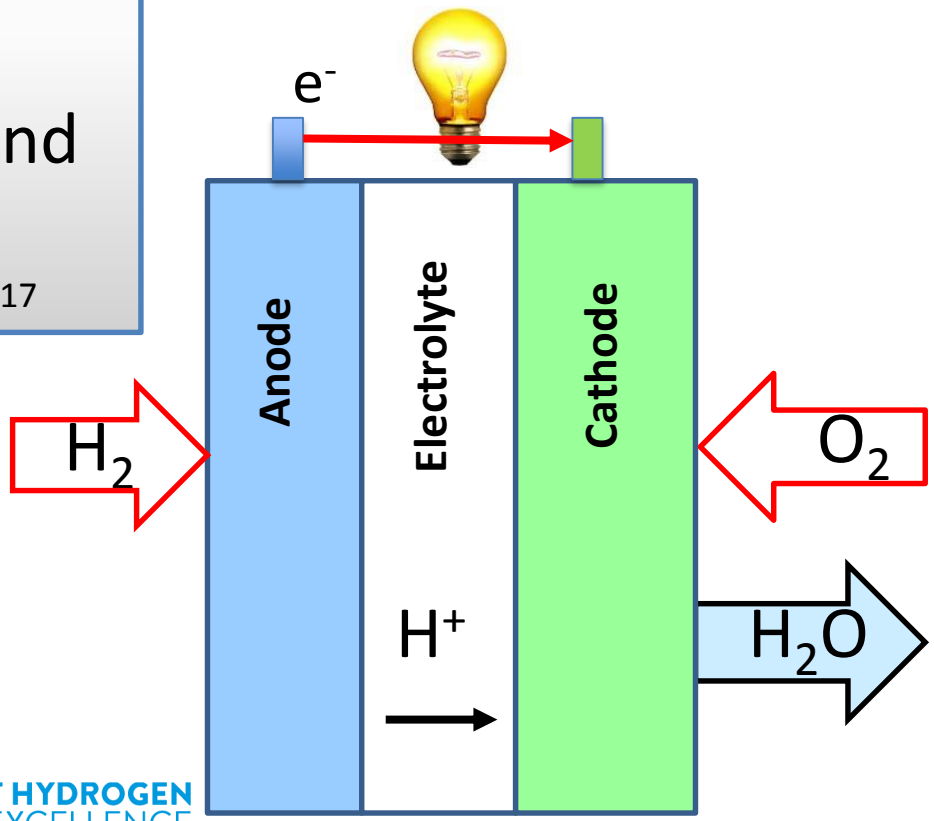
- U.S. Department of Energy, June, 2017



What is a fuel cell?

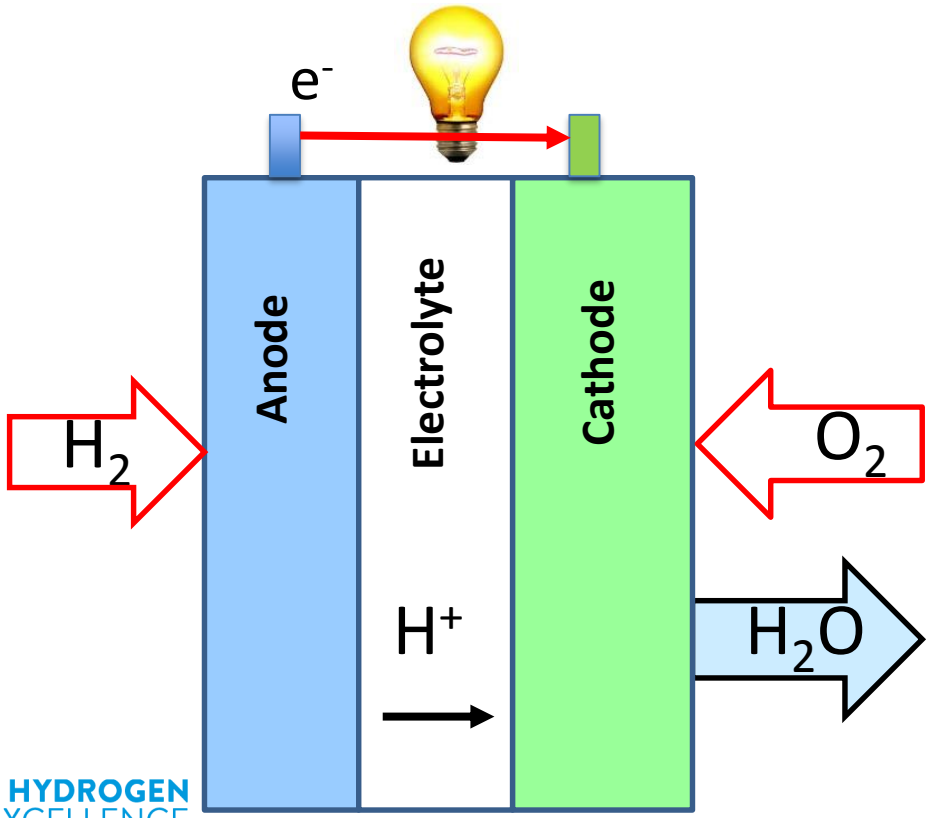
A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte.

- U.S. Department of Energy, June, 2017



What is a fuel cell?

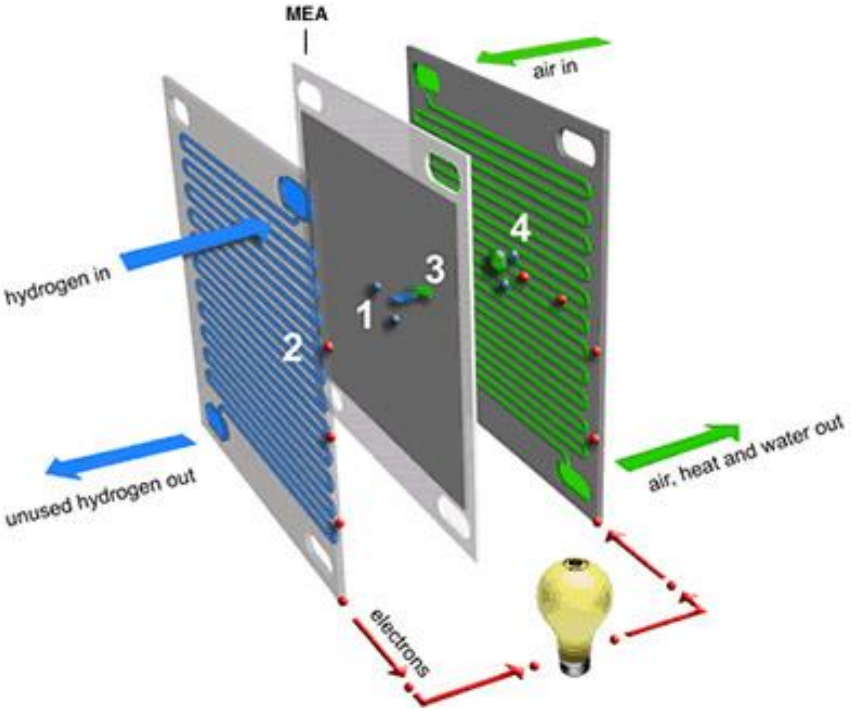
Fuel cells force the reactants to swap outer electrons from a distance, such as between two electrodes…
…thereby, converting a substantial portion of the reaction energy (**up to 83%**) to electrical energy.



What is a fuel cell?

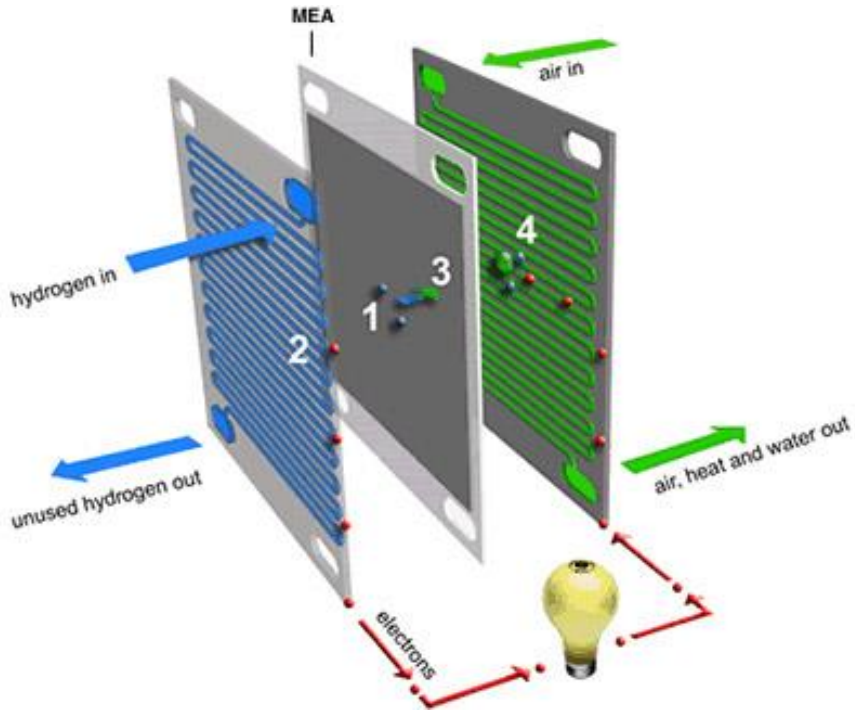
A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity.

- U.S. Department of Energy, June, 2017



How fuel cells work

Electrical energy generated in this way is a more ordered, high-quality form of energy



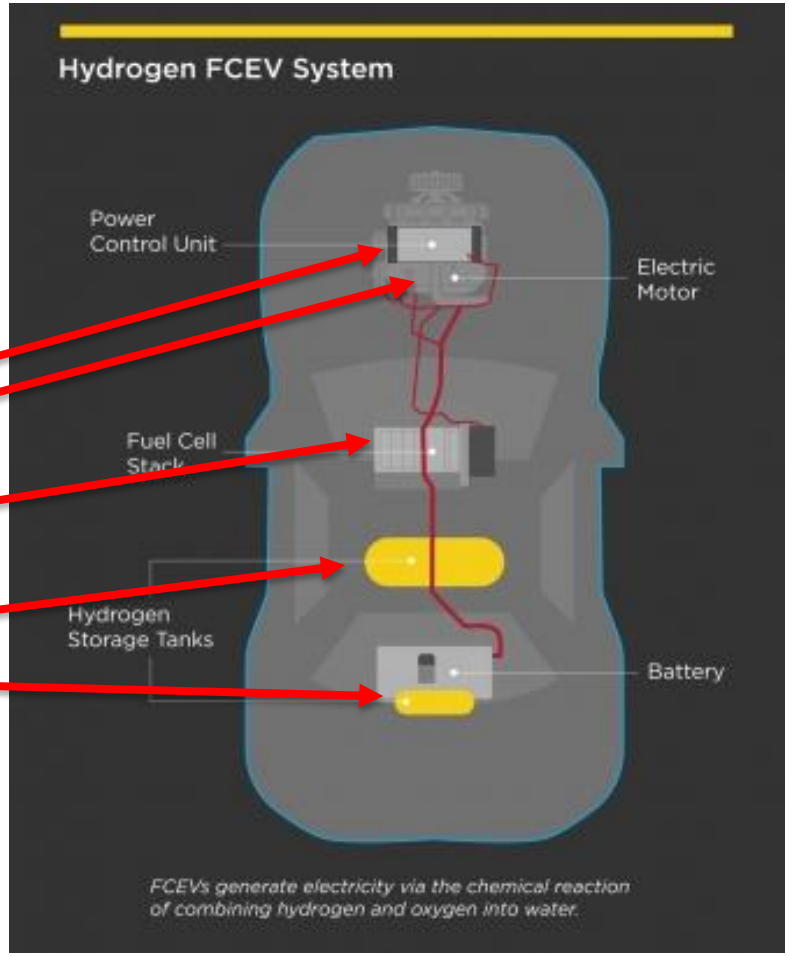
How fuel cells work

Traditional vehicles generate power with an internal combustion engine

- They BURN fuel to generate power
- This releases impurities in the source fuel as pollutants
- Generate significant environmental noise

How a Fuel Cell Electric Vehicle Works

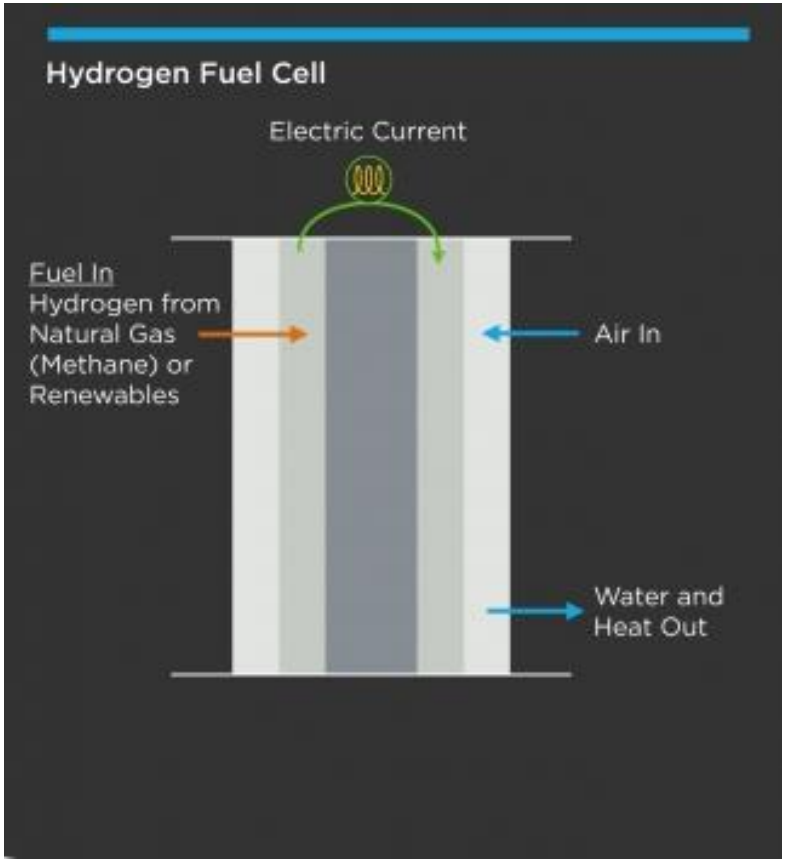
- The system is similar to a traditional drivetrain:
  - Control Electronics
  - Drivetrain
  - Engine
  - Fuel storage



- U.S. D.O.E., Office of Energy Efficiency and Renewable Energy, June 2017

How a Fuel Cell Electric Vehicle Works

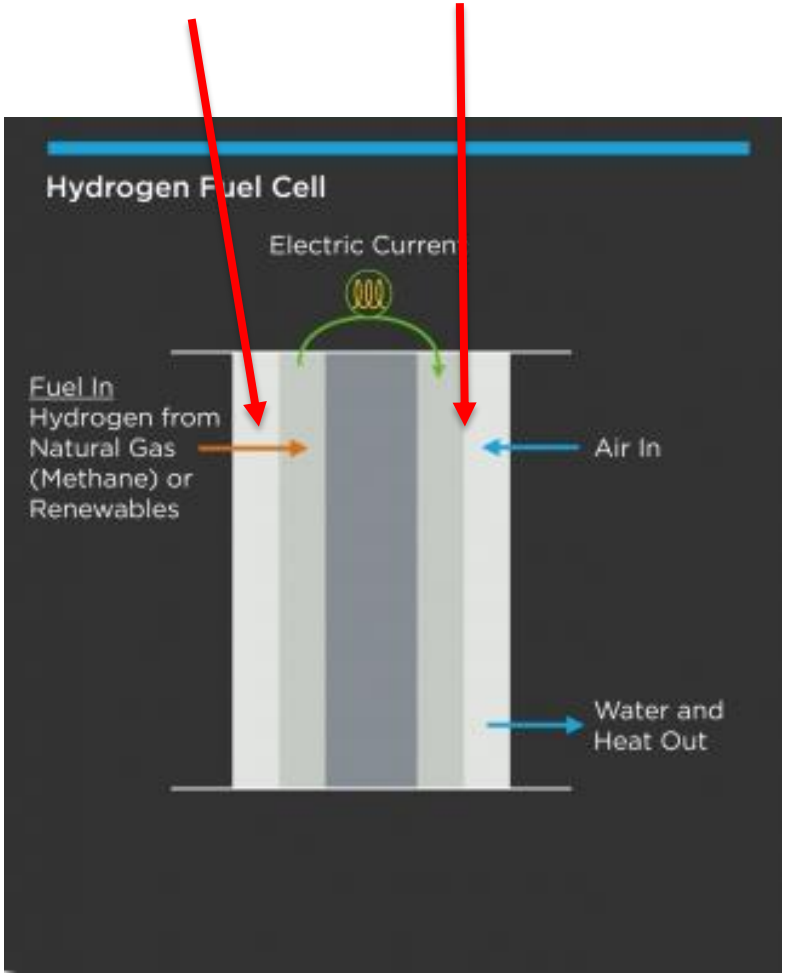
The basic purpose is the same:
Convert energy into motion



- U.S. D.O.E., Office of Energy Efficiency and Renewable Energy, June 2017

How a Fuel Cell Electric Vehicle Works

As FUEL and AIR are used



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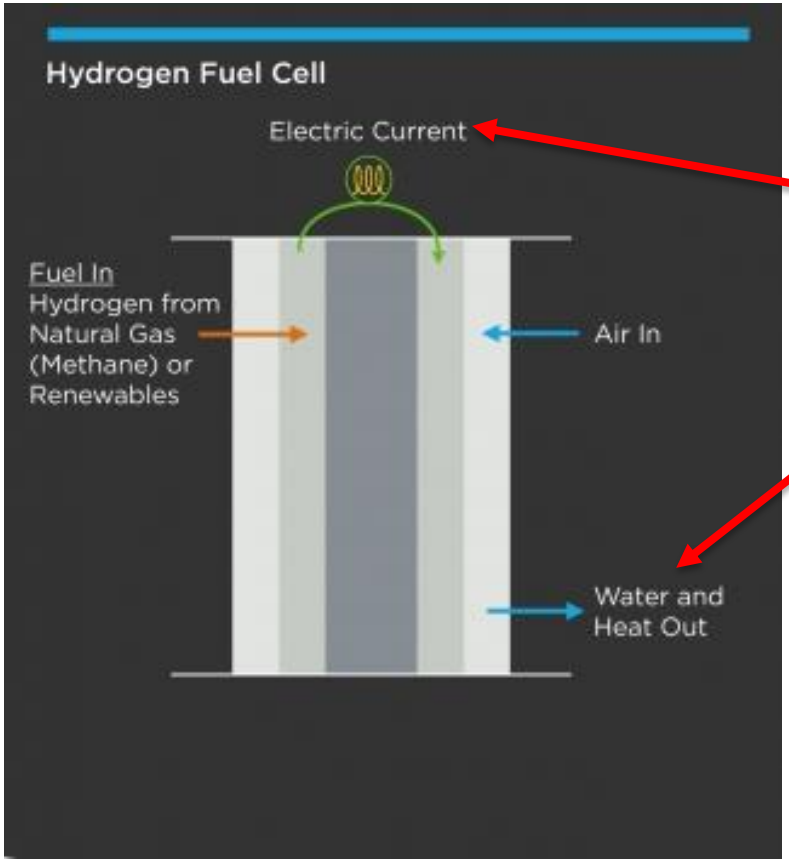
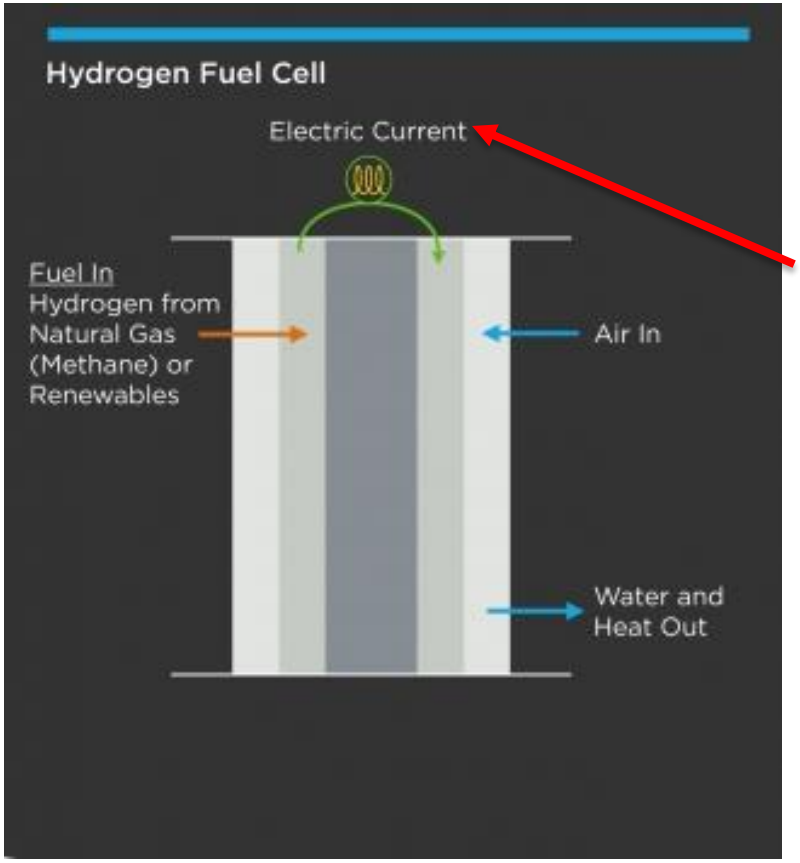
How a Fuel Cell Electric Vehicle Works



Power and Exhaust are generated

- U.S. D.O.E., Office of Energy Efficiency and Renewable Energy, June 2017

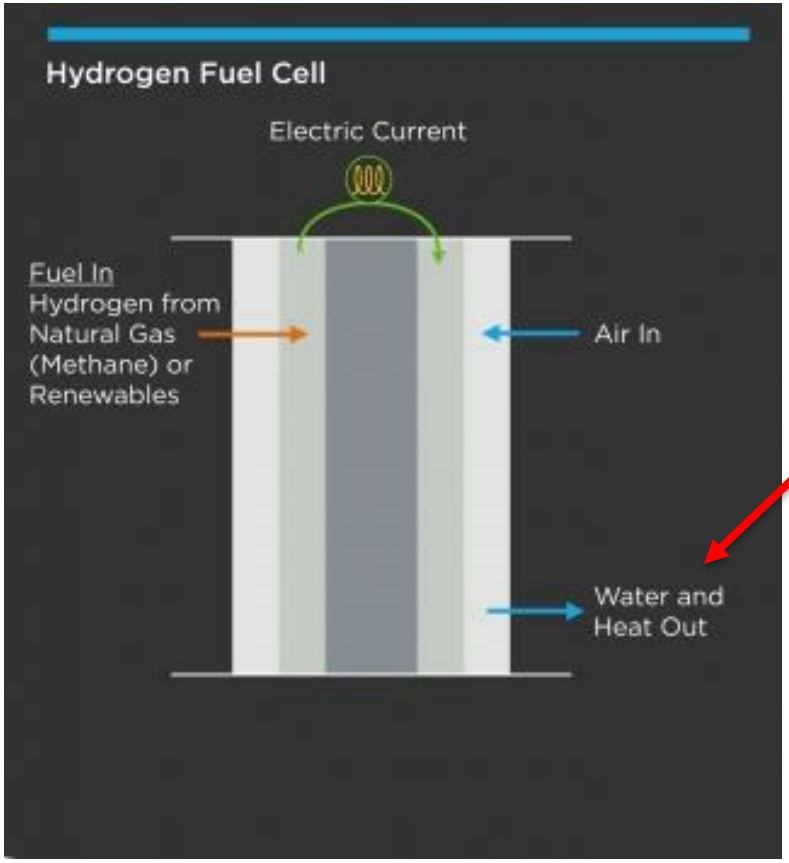
How a Fuel Cell Electric Vehicle Works



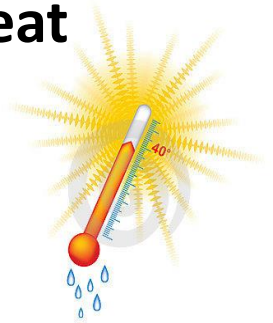
The power generated goes to drives the vehicle

- U.S. D.O.E., Office of Energy Efficiency and Renewable Energy, June 2017

How a Fuel Cell Electric Vehicle Works



ONLY this time the exhaust is only PURE WATER and heat



- U.S. D.O.E., Office of Energy Efficiency and Renewable Energy, June 2017

How fuel cells work

Fuel cells generate electrical power

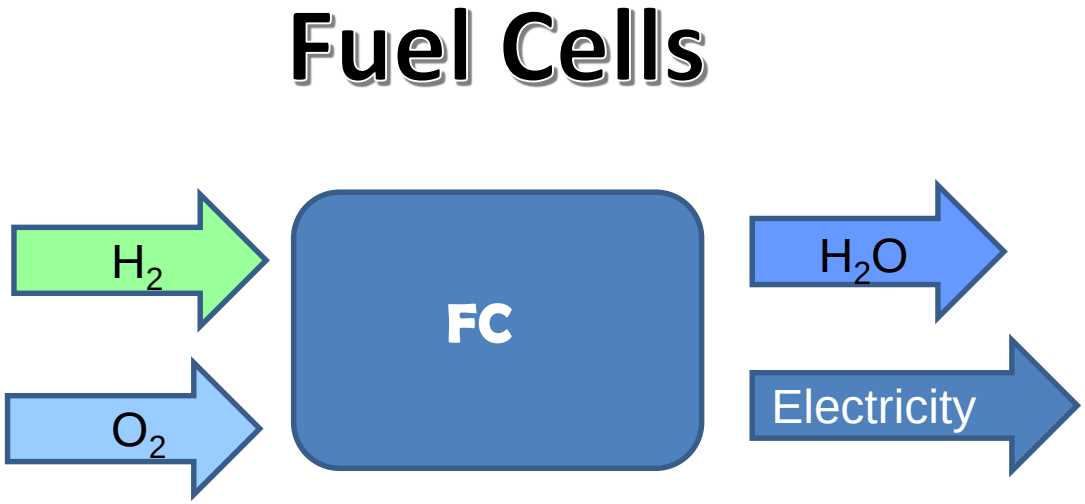
Without combustion, the fuel cell produces virtually no pollutants

The byproducts of combustion (Nitrogen oxides (NOx), sulfur oxides (SOx) and particulate matter) are not generated

- *65% reduction* from diesel – NREL, Whistler Study, 2014

The result is **ultra-clean power**

How fuel cells work



Think of a fuel cell as a little “factory” that takes fuel as input and produces electricity and water as output

$$H_2 + \tfrac{1}{2}O_2 = H_2O + \text{electricity}$$

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GENERAL MOTORS HONDA

EMBARGOED For Release: Monday, Jan. 30, 2017, 11 a.m. EST

GM and Honda to Establish Industry-First Joint Fuel Cell System Manufacturing Operation in Michigan

Advanced fuel cell technology will be applied to each company's future products

Mass production of fuel cell systems is expected to begin around 2020 and create nearly 100 new jobs. The companies are making equal investments totaling $85 million in the joint venture.

ANATOMY OF A FUEL CELL VEHICLE

Fuel cell electric vehicles (FCEV's) run on hydrogen

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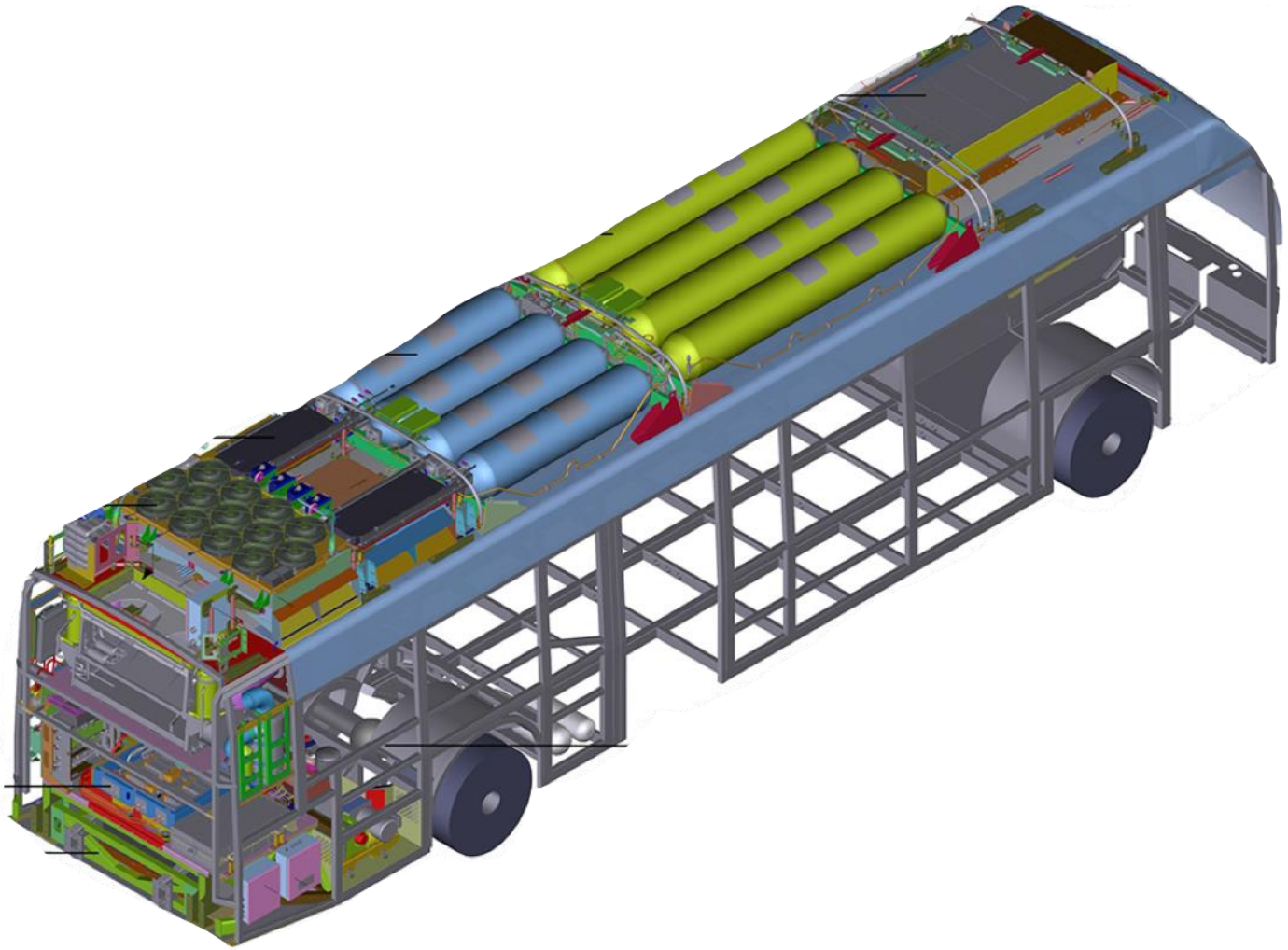
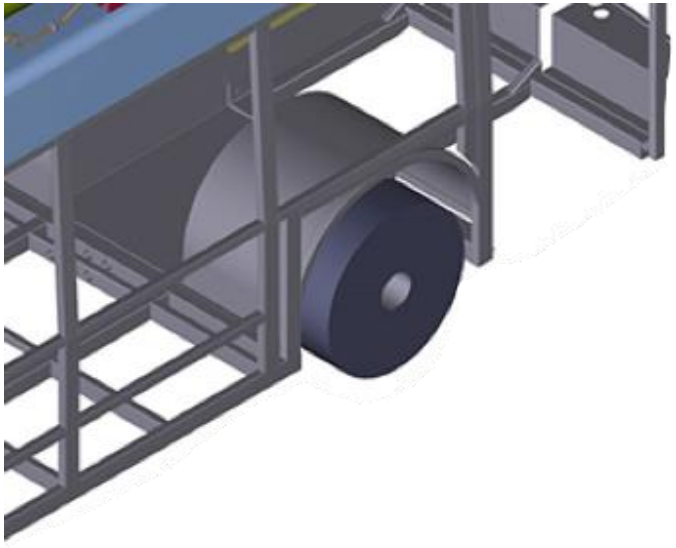
… including transit buses

ANATOMY of a Hydrogen Fuel Cell Bus



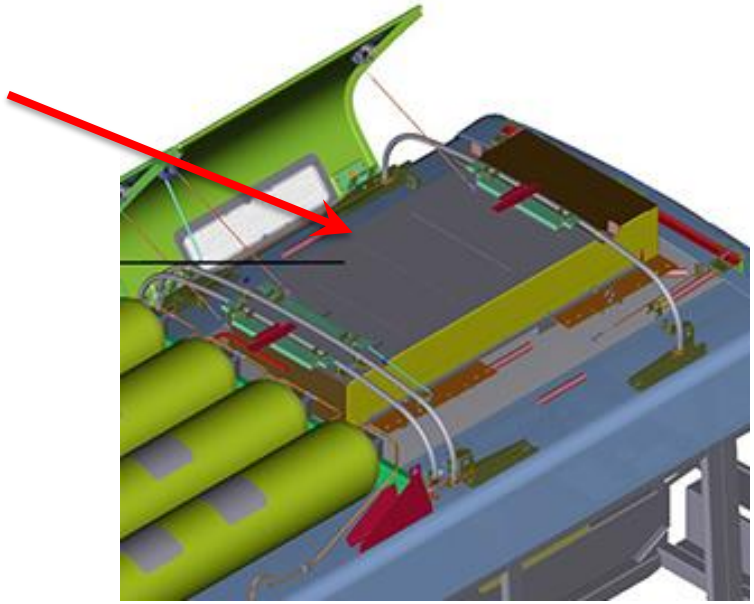
ANATOMY of a Hydrogen Fuel Cell Bus

- Begin by building a standard transit bus chassis



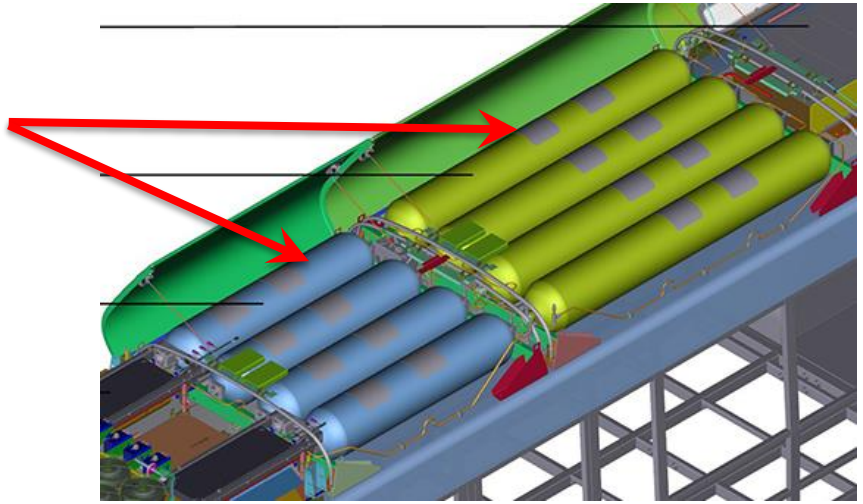
ANATOMY of a Hydrogen Fuel Cell Bus

- Lithium-ion battery pack to store electricity on site



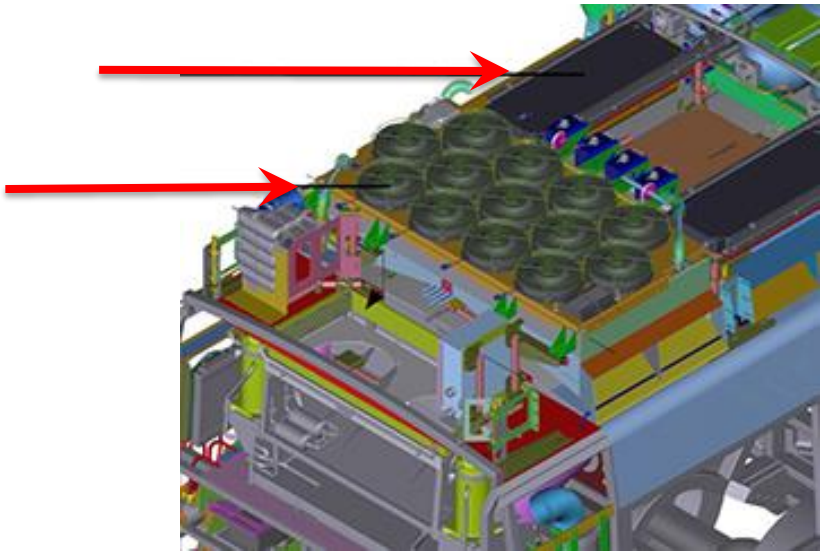
ANATOMY of a Hydrogen Fuel Cell Bus

- Rooftop high pressure hydrogen storage tanks



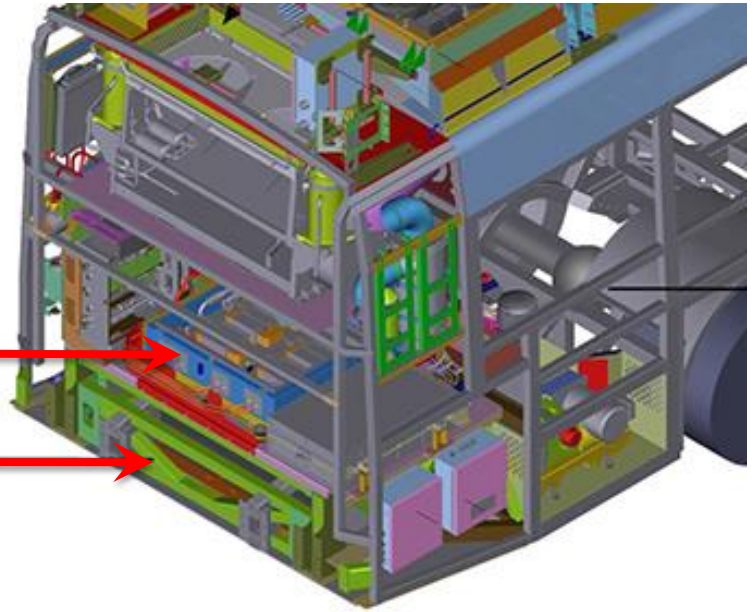
ANATOMY of a Hydrogen Fuel Cell Bus

- Electronics cooling system
- Fuel cell cooling system



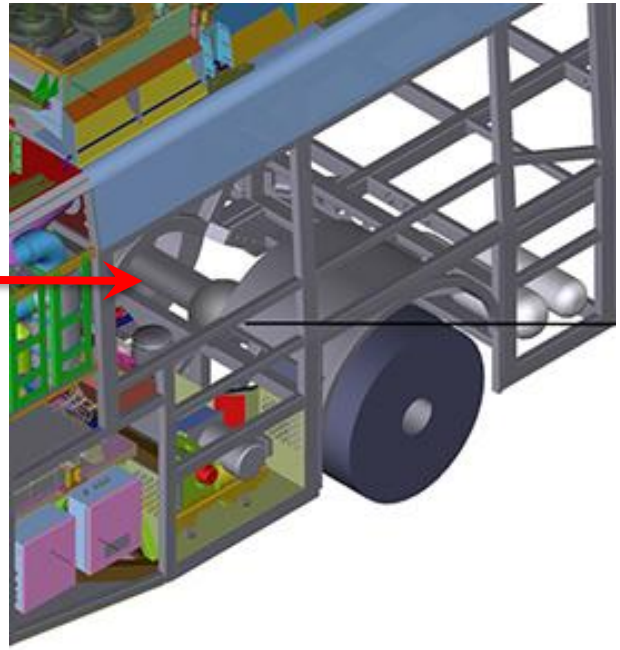
ANATOMY of a Hydrogen Fuel Cell Bus

- Power electronics
- Fuel cell stack

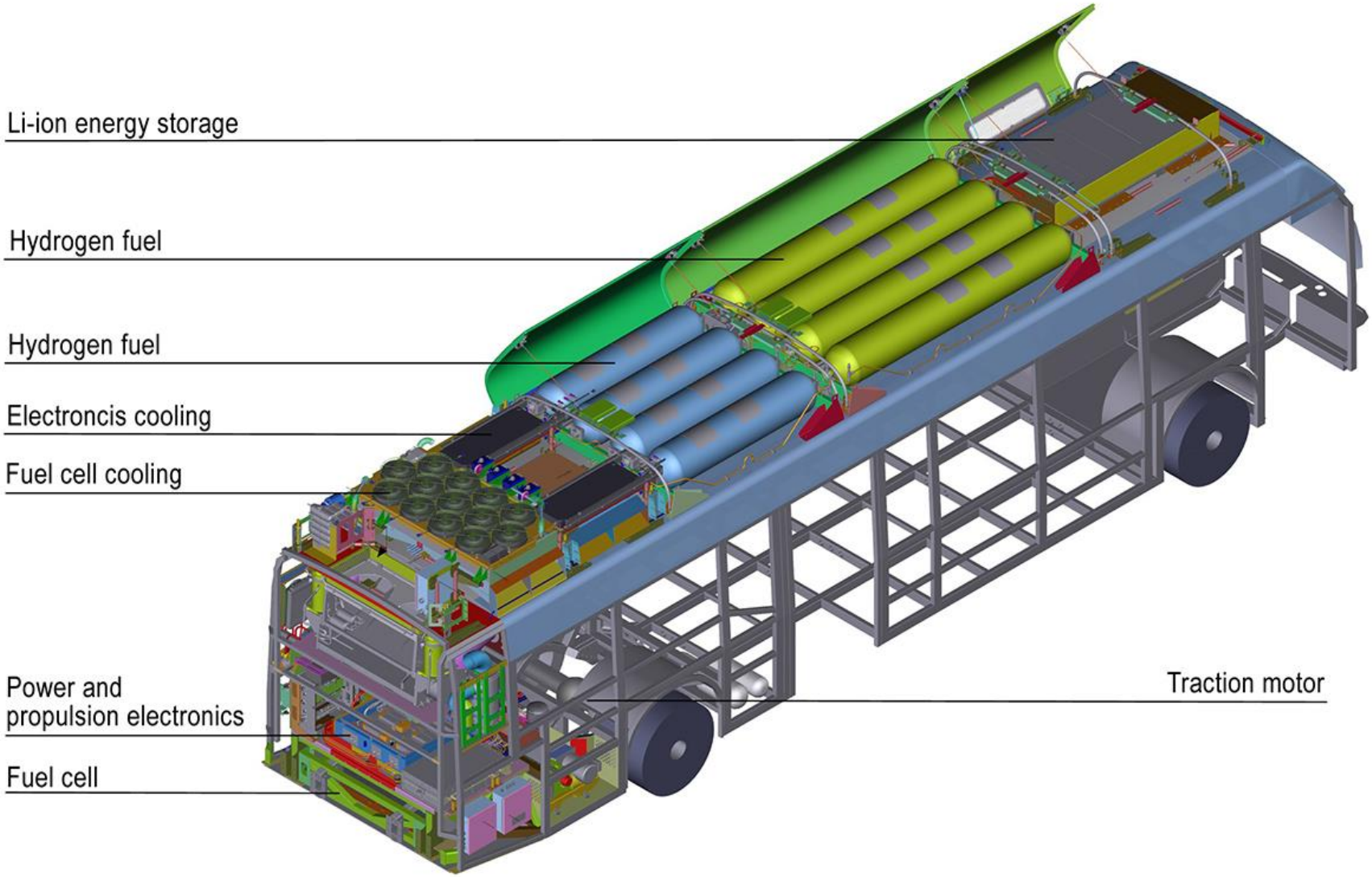


ANATOMY of a Hydrogen Fuel Cell Bus

- Electric Traction Motor



ANATOMY of a Hydrogen Fuel Cell Bus



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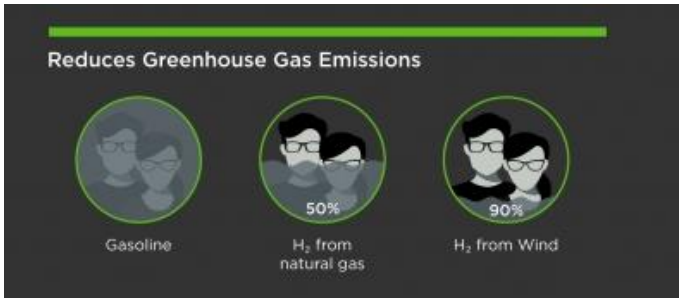

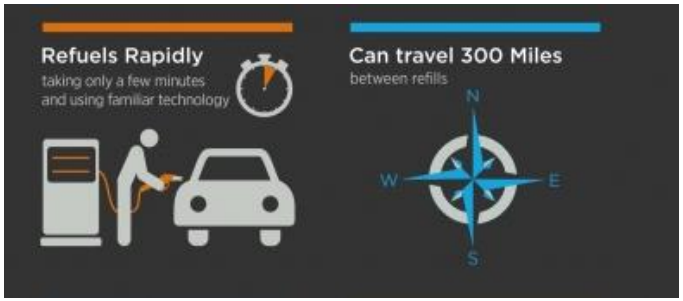

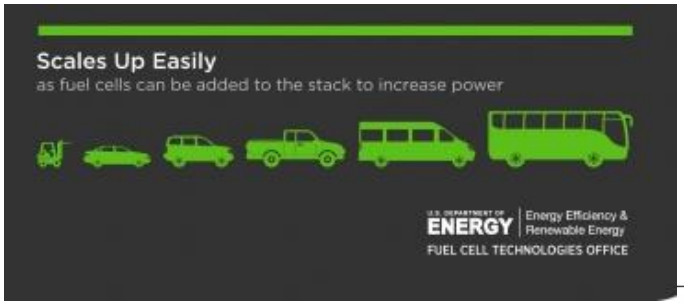

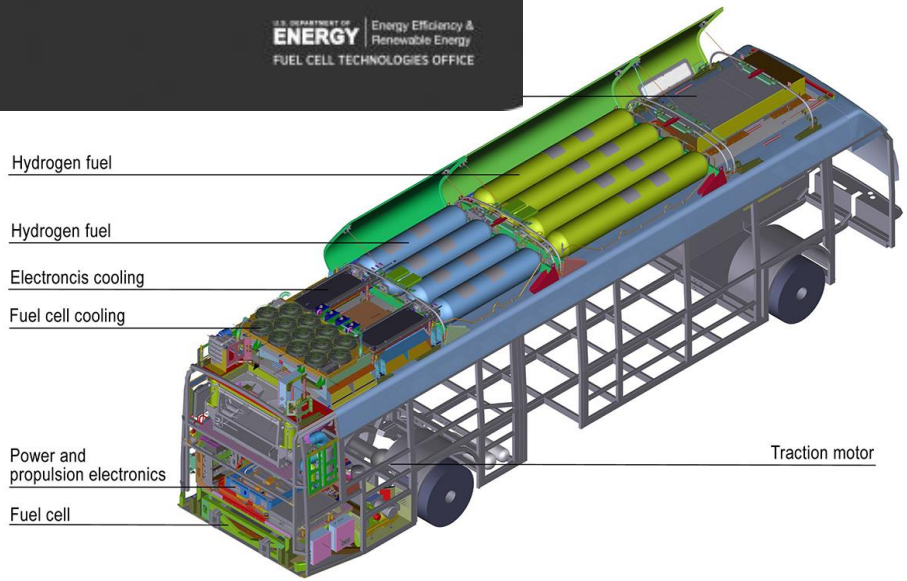

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FUEL CELLS IN THE TRANSIT INDUSTRY TODAY

Sunline Transit - Thousand Palms, CA

AC Transit – Oakland, CA

MTA – Flint, Michigan

SARTA – Canton, OH

London, England – Transport for London

"Transport for London (via their contractor Tower Transit) has been running zero emission hydrogen fuel cell buses on route RV1 between Covent Garden and Tower Gateway since 2011. They now have 8 buses in operation which means it is the first time a whole route has been fully operated by hydrogen powered buses in the UK. " (Hydrogen London, 10/28/13)

Tokyo, Japan

“Toyota Motor Corporation delivered the first fuel cell bus (FC bus) sold under the Toyota brand to the Bureau of Transportation of the Tokyo Metropolitan Government.” - Toyota Global Newsroom 2/24/17)

Hamburg, Germany: HyFleet

- 2003: 9 fuel cell buses
- 2011: New generation of fuel cell hybrid buses,
- consumption: 8 kg hydrogen/100 km; range: 350 km
- 2014: 2 battery buses with a fuel cell as range extender
- Next generation fuel cell buses expected in 2017/18 (hySolutions GmbH, 2016)

Europe:

Launch of project JIVE - for a large scale deployment of fuel cell buses in Europe

The 25th of January 2017 marks the launch of a game changing project in sustainable and clean urban transportation in Europe: JIVE, which stands for Joint Initiative for hydrogen Vehicles across Europe.
The project is co-financed by the FCH 2 JU under the European Union - Horizon 2020 framework program for research and innovation.
The project aims at the largest ever deployment of fuel cell buses in Europe and will introduce new fleets of fuel cell buses into urban bus operations at a scale never attempted before . (fch.europa.eu/news)

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The Ohio State University

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China:

Boom! China Adds 333 Fuel Cell Electric Buses

Like the US, China has been slow to adopt fuel cell electric vehicles, but it looks like things are stepping up in a big way. The cities of Foshan and Yunfu are jumping into the lead with a $17 million order for 300 fuel cell electric buses

(Clean Technica **9/29/15)**

Major Collaborative Project to Deploy Fuel Cell Buses across Europe

A new collaborative initiative is ready to deploy 144 hydrogen fuel cell buses, as part of the JIVE project, and seven large hydrogen refueling stations, per the MEHRLIN project, across Europe. Worth approximately EUR 125 million, these projects represent “a step change for the hydrogen bus sector,” moving from a technology demonstration stage to a day-to-day offering for zero-emission public transport.

(NGTNews – Next Gen Transportation 1/30/17)

Korea

Gov’t mulls trading CNG buses for new hydrogens

The government is considering replacing 26,000 compressed natural gas (CNG) buses with zero-emission hydrogen fuel cell buses at the request of Hyundai Motor, it announced Wednesday.

(Korea JoongAng Daily, 3/17/16)

Recent news about Hydrogen:

"Hydrogen energy is an ace in the hole for energy security and measures against global warming,"

– Shinzo Abe, Prime Minister of Japan (Japan Times 2/10/17)

Recent news about Hydrogen:

Hydrogenics to provide 1,000 fuel cell bus power modules to Blue-G in China; $50M deal

Delivery of the fuel cells and the associated payments are expected to occur over the next two to three years.

- Green Car Congress, June 9, 2017

THE MIDWEST HYDROGEN CENTER OF EXCELLENCE

A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative

THANK YOU

FOR YOUR TIME AND YOUR ATTENTION

… ANY QUESTIONS???

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