NC STATE UNIVERSITY

SUSTAINABLE FLEET TECHNOLOGY CONFERENCE & EXPO 2021

Session #10: Hydrogen as a Transportation Solution

October 14, 2021

NC CLEAN ENERGY TECHNOLOGY CENTER

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

SUSTAINABLE FLEET TECHNOLOGY
WEBINAR SERIES 2021

Sessions through December 09, 2021

SUSTAINABLE FLEET TECHNOLOGY
CONFERENCE & EXPO 2021

Sessions September 09, 2021 – October 19, 2021

https://www.sustainablefleetexpo.com/

NC CLEAN ENERGY TECHNOLOGY CENTER

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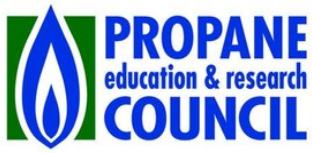
SFT Conference Series Upcoming Sessions

- 10/19: Future Proofing Electric Vehicle Charging Infrastructure
- 10/21: Best Practices of the Top Green Fleet Winners 2021
- 11/04: Product Feature--Sustainability Starts Here: XL Fleet Electrified Drivetrains
- 11/09: Electric Vehicle Use Case Deployment Examples
- 12/02: EPA SmartWay Technologies and Success Stories
- 12/09: Green Garage Winners Announcement 2021

2021 SFT Conference Series Sponsors




XLFleet
TM


NC CLEAN ENERGY
TECHNOLOGY CENTER


STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

Format

- Q&A at the end
- Submit questions and comments to “Panelists”
- Scheduled for 2:00p-3:30p
- Handout
- Recording

https://awards.nafa.org/

Accepting applications through October 29th.

NAFA Fleet Management Association

100 BEST FLEETS

NC CLEAN ENERGY TECHNOLOGY CENTER

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Hydrogen as a Transportation Solution
October 14, 2021

2:00-2:07 **Rick Sapienza NCCETC**--Introduction & Welcome

2:07-2:22 **Dr. Abas Goodarzi, US Hybrid**—Hydrogen Technology Overview and Applications

2:22-2:37 **Rick Mihelic, NACFE**—MD/HD Hydrogen Applications

2:37-2:45 **Jason Condon, Global Environmental** —Electric and Hydrogen Street Sweeper

2:45-3:00 **Joe Callaway, AC Transit**—AC Transit H2 Deployment & Real World Fuel Option Comparison

3:00-3:30 Q&A

Driving Clean Air & Renewable Energy
CleanTransportation.org
Supported by the NC Clean Energy Technology Center with funding from the North Carolina Department of Transportation

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Clean Transportation Program
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NC CLEAN ENERGY TECHNOLOGY CENTER

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

Dr. Abas Goodarzi
abas@ushybrid.com

- Chief Scientist of Ideanomics, President and CEO of US Hybrid and Chairman of Magmotor Technologies
- More than 40 years of Electric Powertrain experience
- Directs Technology and Product Development at US Hybrid, focusing on electric and hybrid powertrain design and manufacturing for medium and heavy-duty commercial and military vehicles, and integrated Fuel Cell engines system development and production for medium duty and heavy-duty vehicles
- Education & Certifications: MS and Ph.D. Power Electronics, University of Missouri, Columbia; BS Power System, California State University, Sacramento; Registered Professional Electrical Engineer, since 1985

ISO 9001

ISO 14001

SUSTAINABLE FLEET TECHNOLOGY
VIRTUAL CONFERENCE 2021

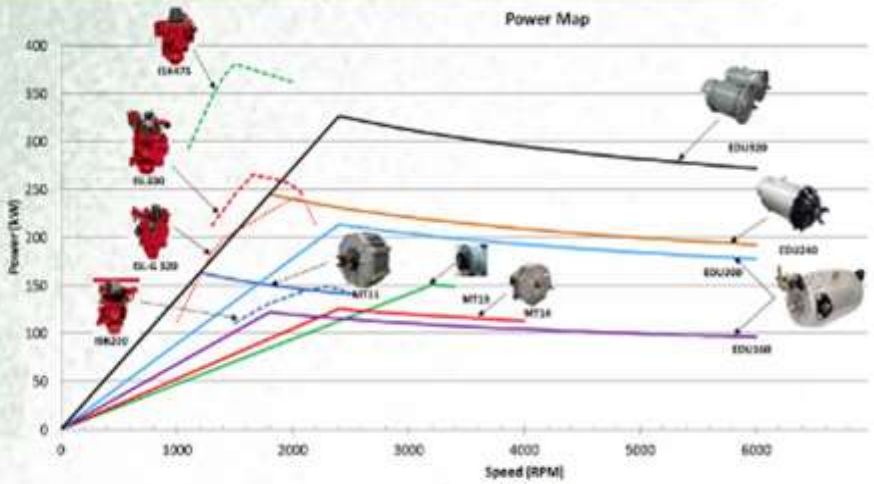
NC CLEAN ENERGY TECHNOLOGY CENTER

US HYBRID
by Ideanomics

Innovation

Quality

Service



NC Clean Energy Technology Center, Sustainable Fleet Technology Virtual Conference 2021

Integrated Electric, Fuel Cell and Hybrid Powertrain Components Powering Clean Mobility

Transportation Engineering
Why do we do, what we do; Decoupling Traffic

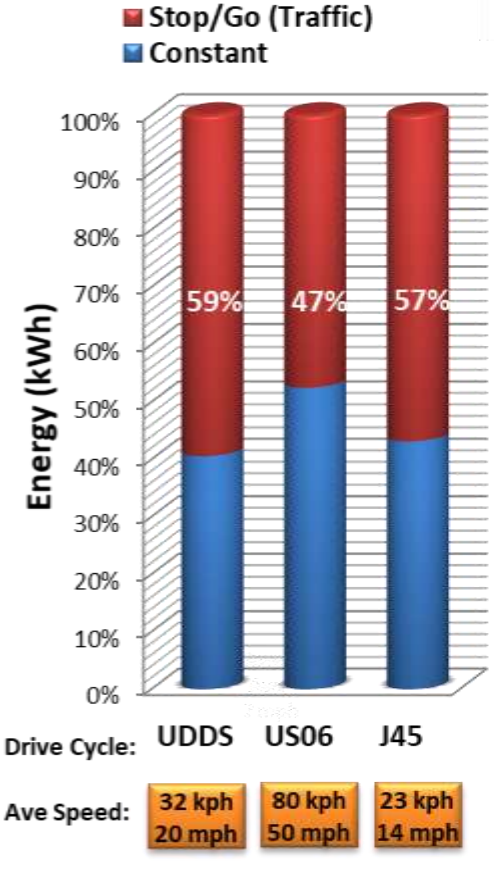
More than 50% of energy is wasted due to traffic

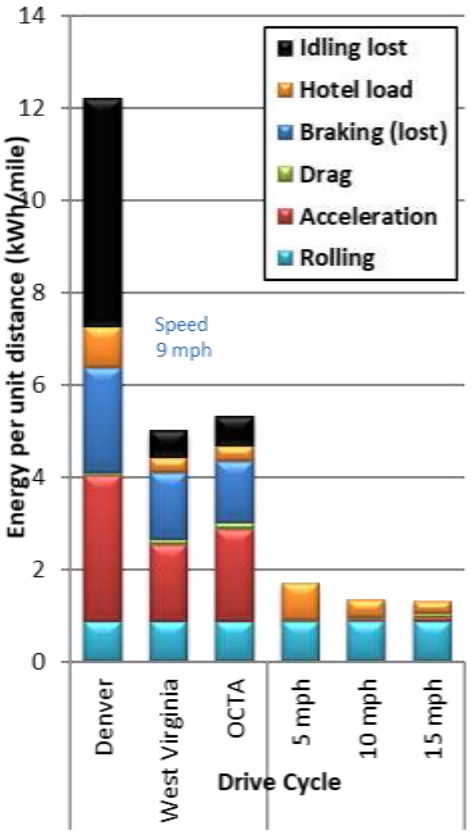
GVWR
1,800 kg

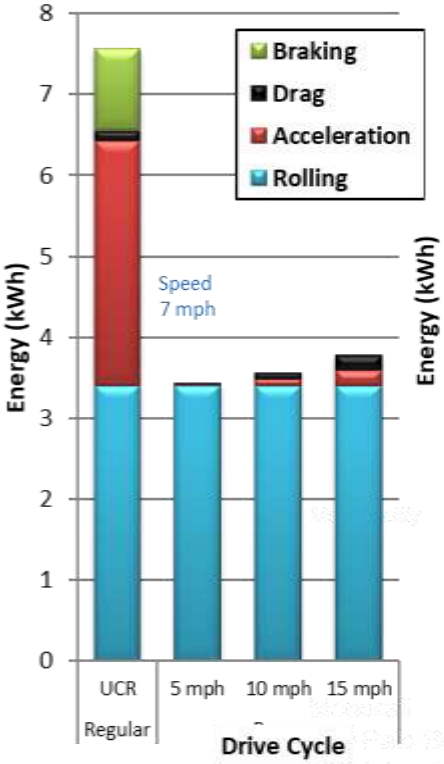
GVWR
20,450 kg
45,000 lbs.

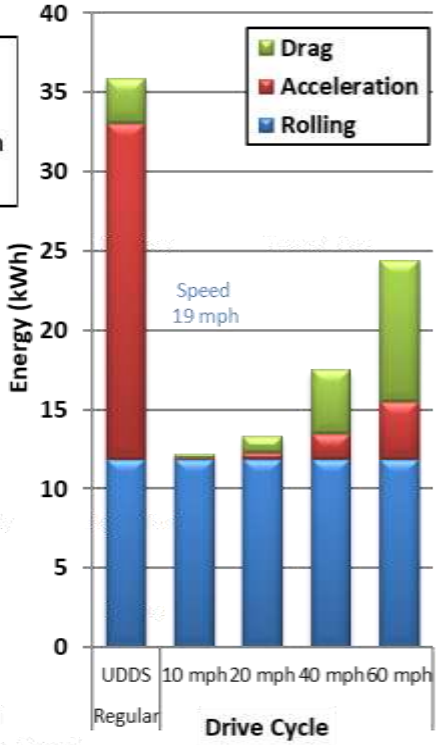
GVWR
36,300 kg
80,000 lbs.

GVWR
29,545 kg
65,000 lbs.







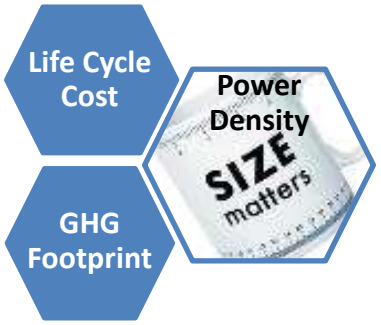


Long Term Solution;
FC Combustion-Less Engine delivering electric Power

Electric Propulsion is the future Powertrain

Our Product: Integrated Fuel Cell Engine

for Medium and Heavy Duty Transportation



Volume: 0.51 m^3
Weight: 292 kg

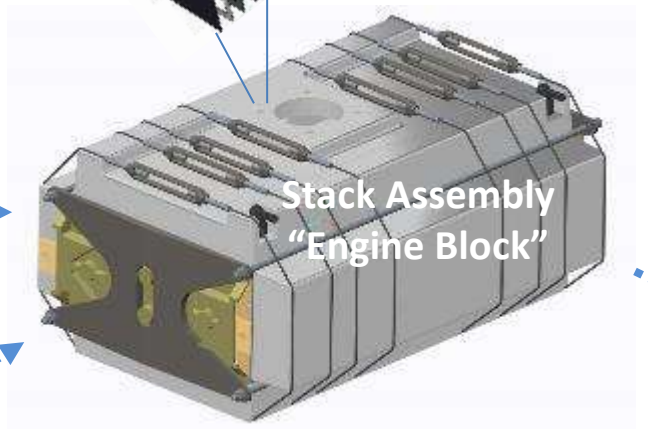
Volume: 1.6 m^3
Weight: 996 kg

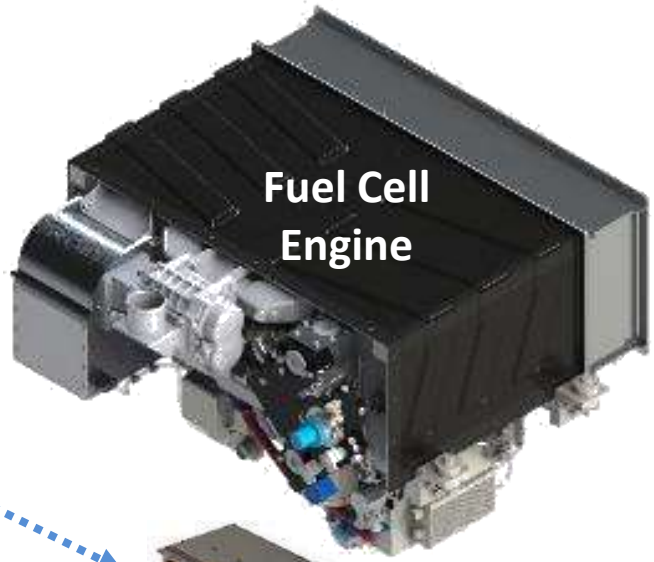
Fuel Cell Engine with no Combustion (Qualified supply chain)

Cell Assembly
"Cylinders"

Fuel Processing Unit
"Injectors"

Hydrogen
Fuel IN

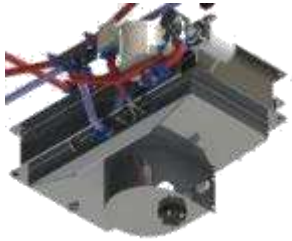




Power Processing Unit
"ECU"

Air IN

Air Processing Unit
"Compressor"



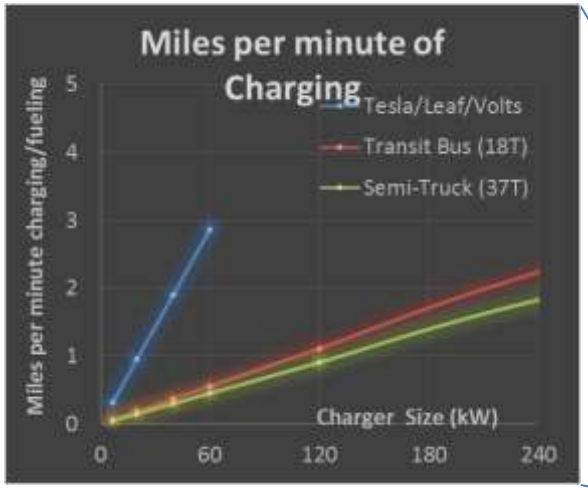
Thermal Management System
"Radiator"

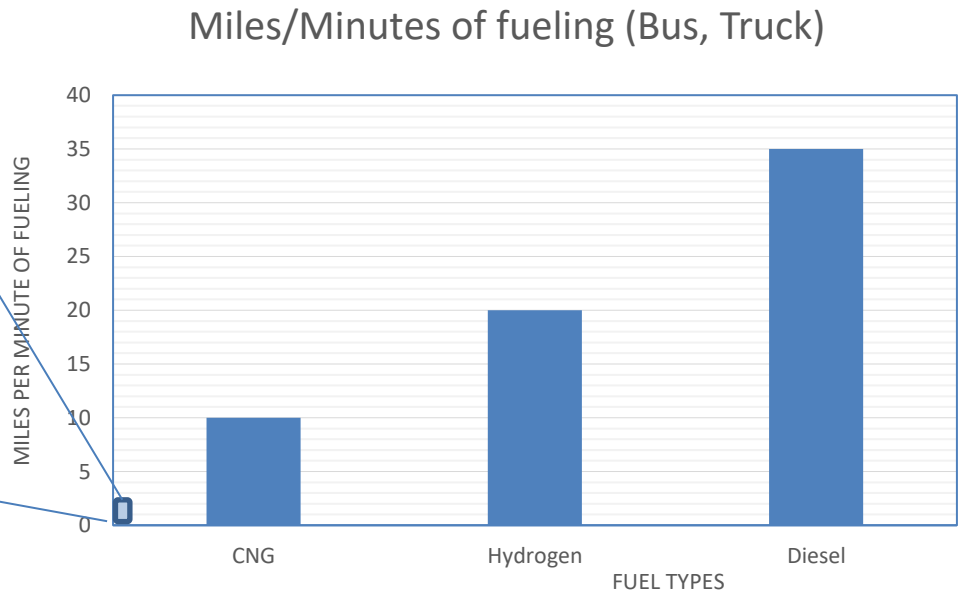
Exhaust
Water Vapor

OUTPUT
Electric Power

Fuel Cell Engines enable;

1. 24/7 operation
2. No payload, productivity and range compromise
3. Most Efficient Zero Emission transportation engine
4. **Faster fueling than CNG, higher productivity & performance than battery Electric**

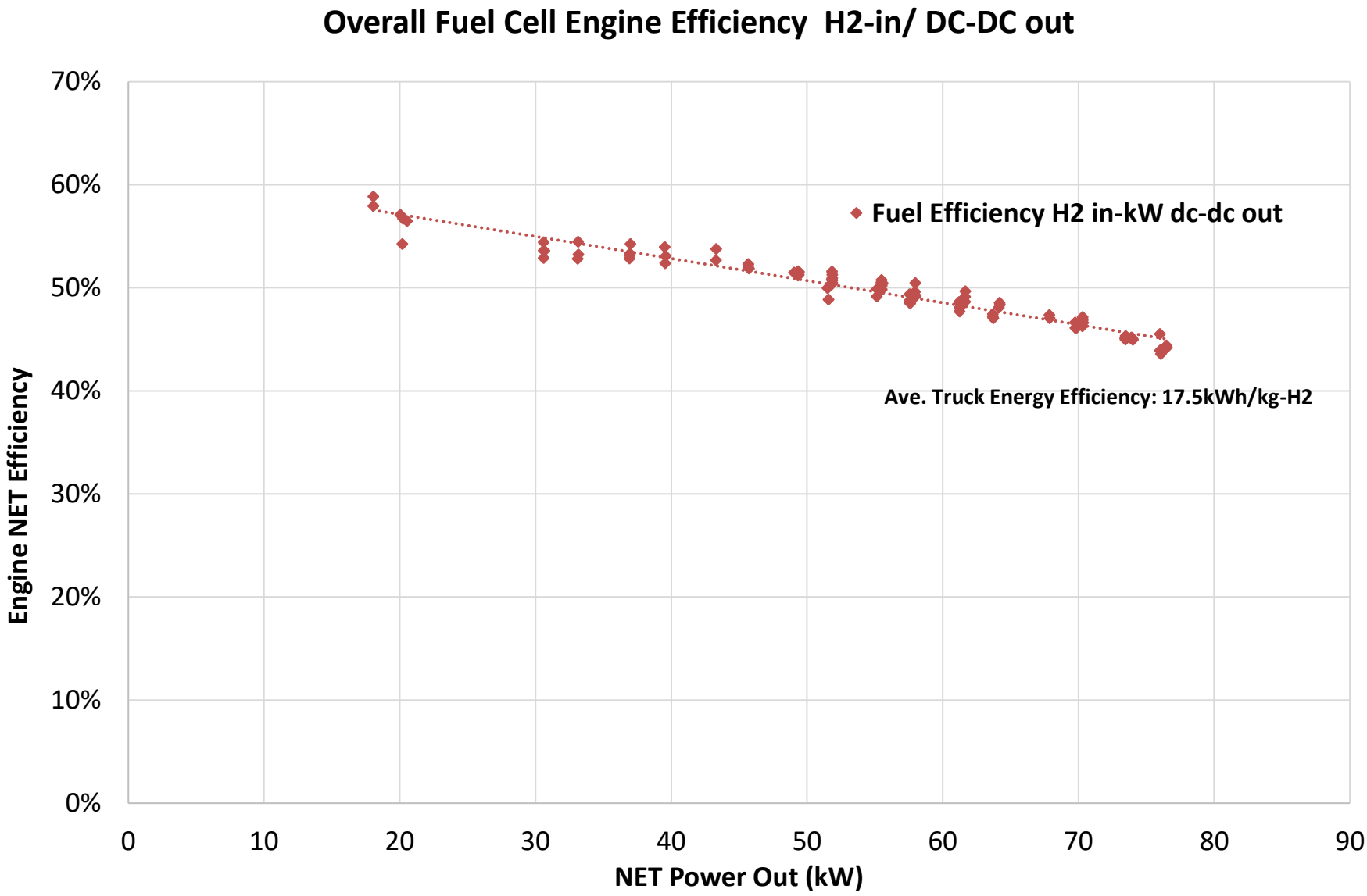




Fuel Type and Energy Content	Net Engine Output (Drayage Cycle)
Diesel: 37.1 kwh/gal	**2.7 kWh/kg** (4 mpg)
Natural Gas 33.4 kWh/gge	**1.8 kWh/kg** (3.1 m/gge)
Hydrogen: 39.7 kWh/kg	**17 kWh/kg** (8 mile/kg)
Gasoline: 32.9 kWh/gal	**1.9 kWh/kg** (3 mpg)
Li-Ion Battery: (180 Wh/kg)	**0.17 kWh/Kg** (1/11 mile/kg)

FC Engine Efficiency

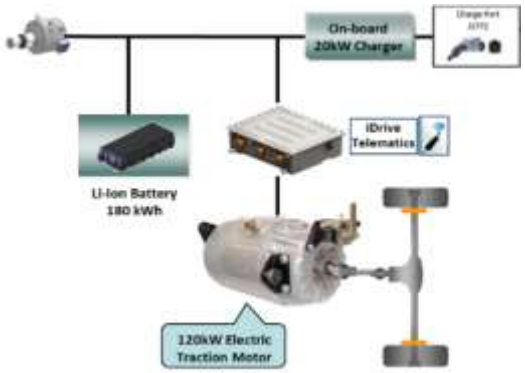
–Most Efficient Engine Generating Electric Power

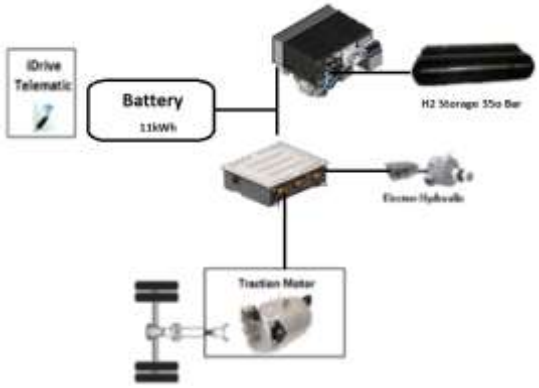


Fuel Cell Electric & Battery Electric vehicle comparison

Fuel Cell powertrain is same as Battery Electric with smaller battery and an on-board FC engine charger, that can be fueled rapidly.

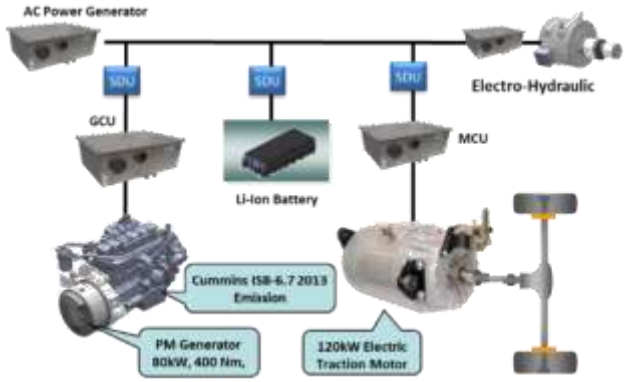
Battery Electric Sweeper	Fuel Cell Electric Sweeper
Battery: 210 kWh, 4900lb.	Battery: 11 kWh, 150 lb. FC & Tanks: 850 lbs., 25 kg, 410kWh, Net
110 miles Range (6 Hrs.)	240 miles Range (14 Hrs.)
15% loss of payload	Comparable Curb as CNG.
Winter Operation (~40% loss of Range)	30kW of free cabin heating
Charge time: 8 Hrs.	Fueling time: 10 minutes



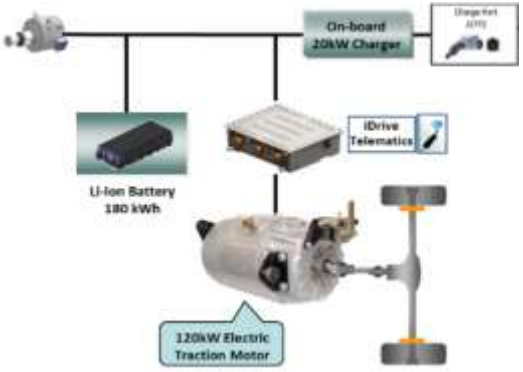


Hybrid, Battery & FC Street Sweepers CA, NY, Tokyo

Diesel Electric Hybrid



Battery Electric

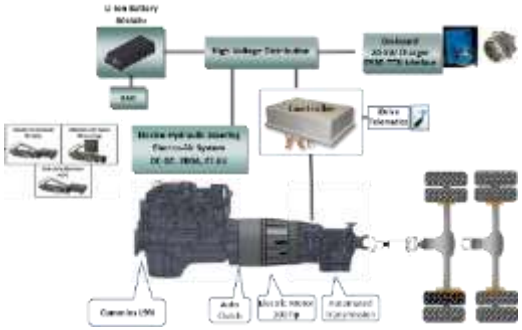


FuelCell Electric

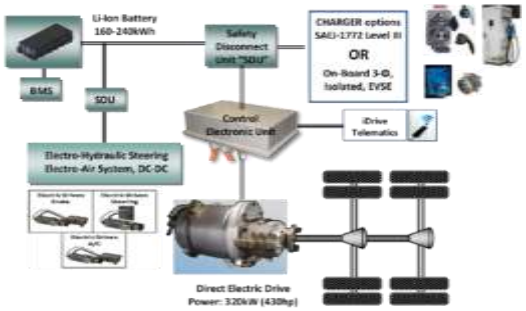
Drives like Electric Fuels like CNG

Hybrid, Battery & Fuel Cell Electric Drayage Truck (POLA/POLB)

CNG/LNG Hybrid Electric

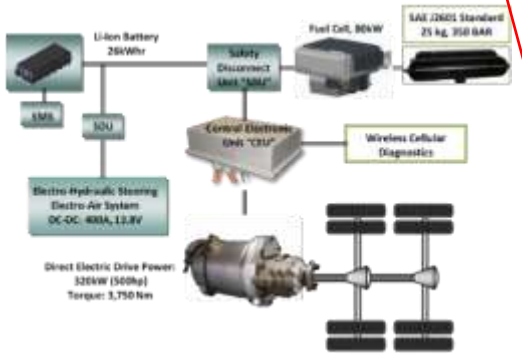


Battery Electric



Fuel Cell Electric

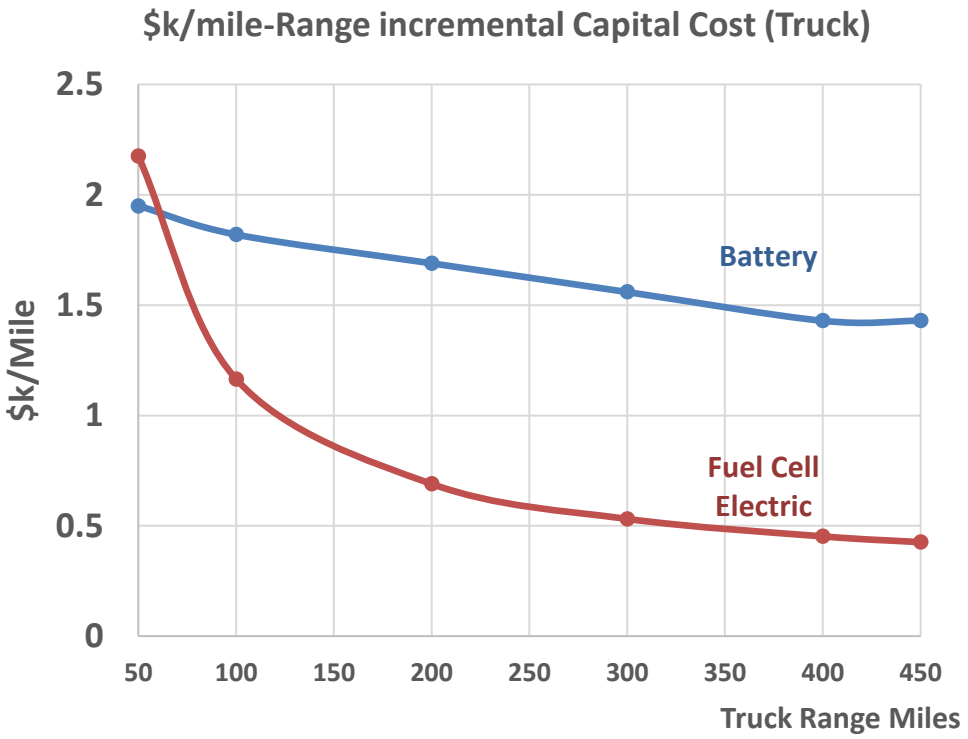
Drives like Electric Fuels like CNG

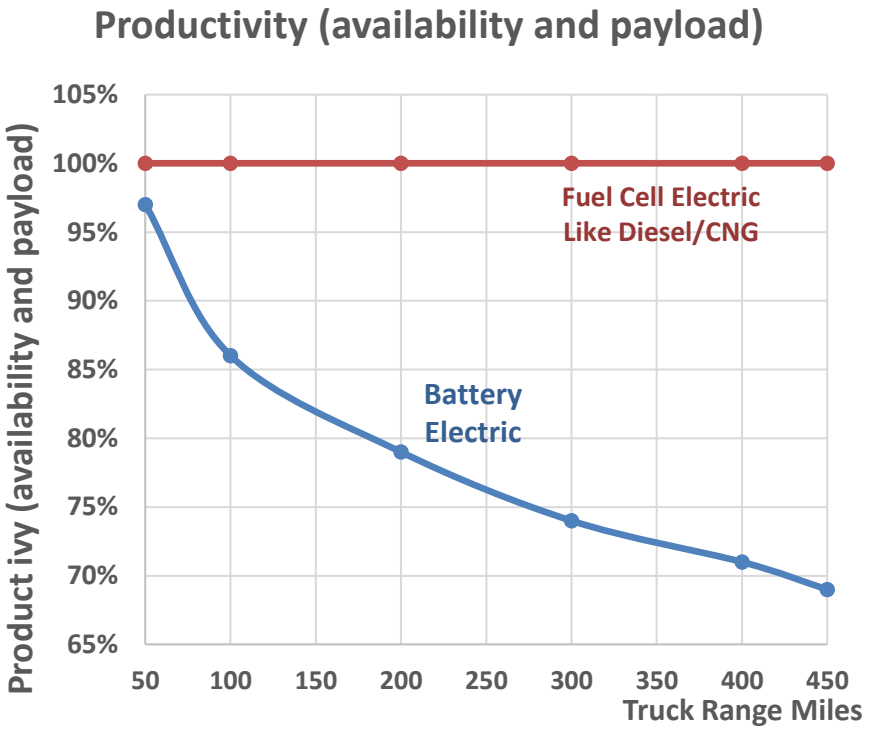


FC engine mounted under hood

Capital Cost and Operation Productivity Comparison

Fuel Cell & Battery Electric Drayage Class8 Truck





In summary

- ✓ Battery Electric more attractive for short range (single shift) operation
- ✓ Fuel Cell Truck capital cost is commercially viable beyond 200 miles range
- ✓ Fuel Cell truck productively (payload, refueling time) is comparable to Diesel and CNG.
- ✓ Fuel Cell infrastructure planning is comparable to CNG with lower cost per vehicle.

FC Shuttle Bus Experience; Para-Transit Van

Available to Buy or Lease

SARTA	Sunline
5 Vans	4 Vans
13.5 kg-H2 @350bar, Type 3.	5.5 kg-H2 @350bar, Type 4.
250 miles Range	300 miles Range
ADA Compliance 6+1	ADA Compliance 4+2

Available to Buy or Lease

Powered by US Hybrid; Fuel Cell Transit Buses

FC Shuttle bus, deployed in 2002, life <100 hrs.

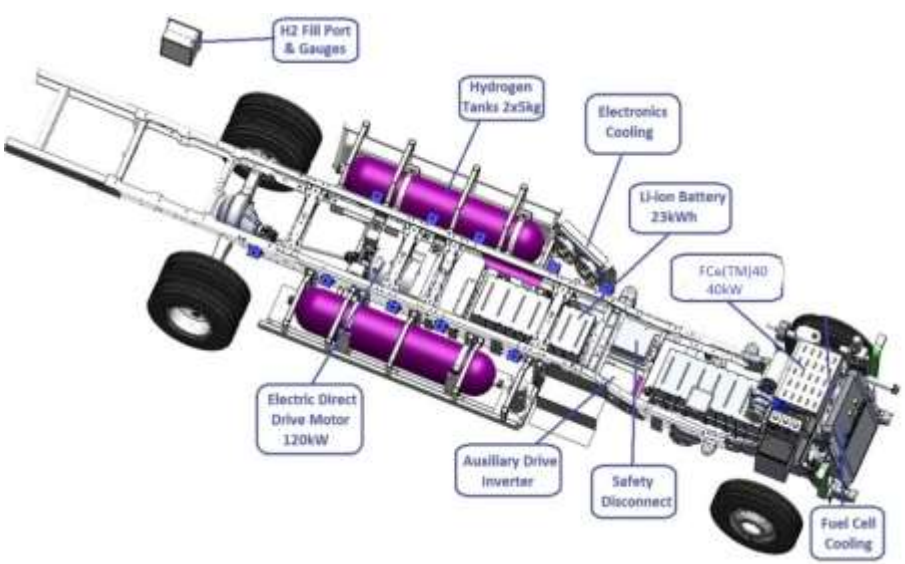
FC engines are installed in the engine bay using OBDII CAN Diagnostic tools

Air Force Fuel Cell GSE (TUG U-30, R-12 Aircraft Refueler & Weapon Loader)

Fuel Cell Plug-In Hybrid Electric Re-Fueler (R12)

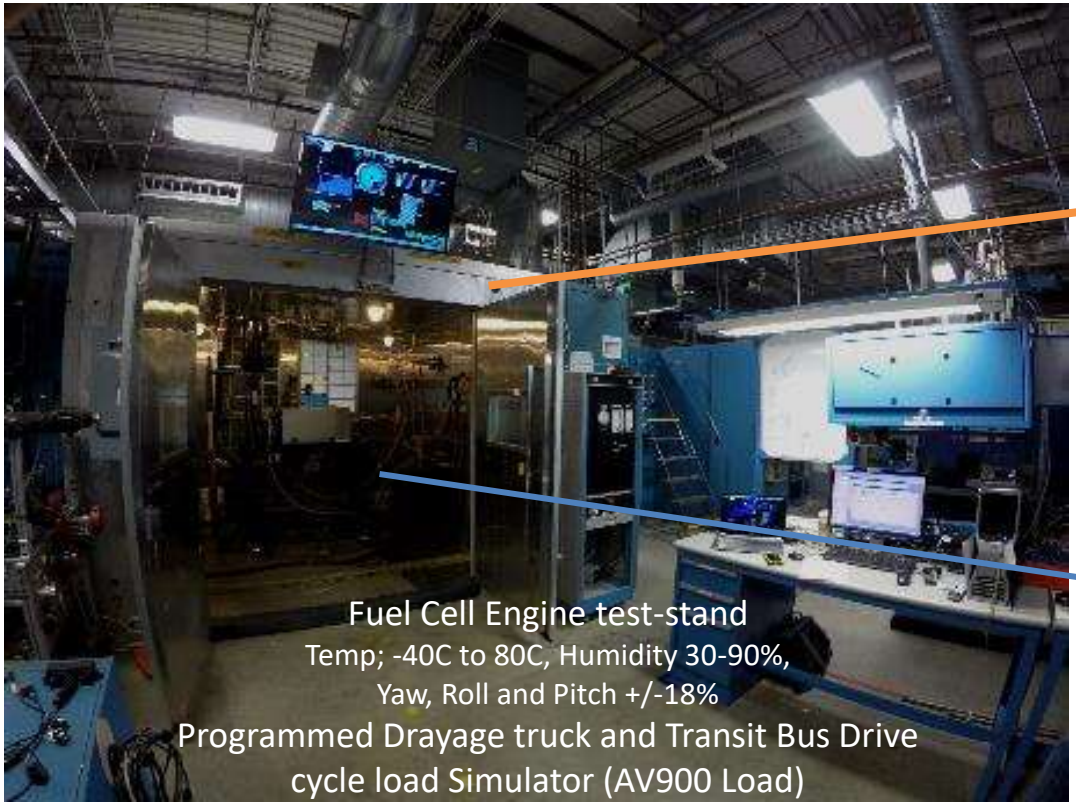
FC R12 Fueler, fueling at H_2 station

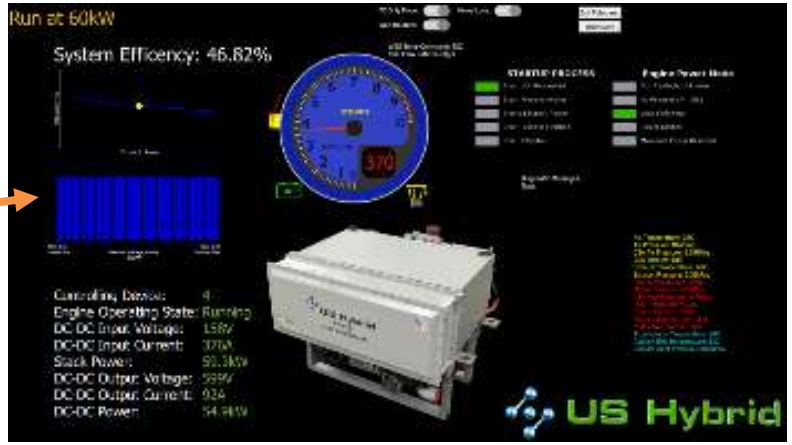
Air Force FC Vehicles: Secure Power On Demand "SPOD"



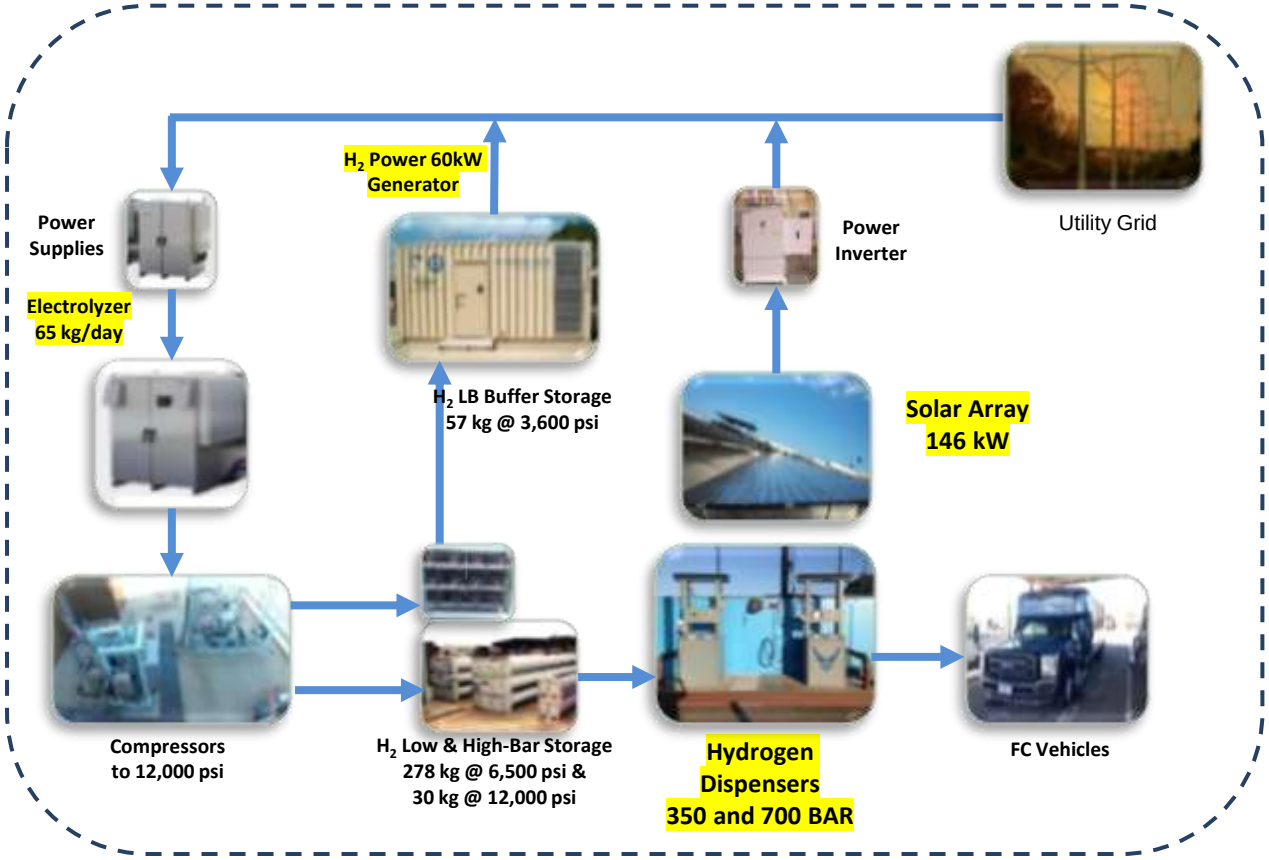
FCe™80 FC engine

at the test-stand running Sunline Line 111 Drive cycle.





Renewable Energy Hydrogen Station



Controller, PLC, GUI & Telematics

Thank You

Abas Goodarzi, Ph.D., PE.
President, CEO
abas@ushybrid.com, US Hybrid.com

Rick Mihelic
mihelic2@verizon.net

- Director of Emerging Technologies at NACFE
- Authored Guidance Reports on electric and alternative fuel medium- and heavy-duty trucks and Confidence Reports and insights on efficiency, aerodynamics, platooning, regional haul and production
- 39 years' experience in the trucking and aerospace industries including
- President of Mihelic Vehicle Consulting LLC
- Associate editor for the SAE Journal of Commercial Vehicles and active member of multiple SAE groups
- 2016 SAE L. Ray Buckendale Award and 2020 SAE Crawford Award

RUN ON LESS

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NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Hydrogen as a Transportation Solution

Fleet Sustainability Technology

Rick Mihelic

October 14, 2021

North American Council for Freight Efficiency

- Unbiased, non-profit
- Mission to double freight efficiency
- All stakeholders
- Scale available technologies, guide future change and Run on Less demonstrations.
- Primary focus: Tractor-trailers

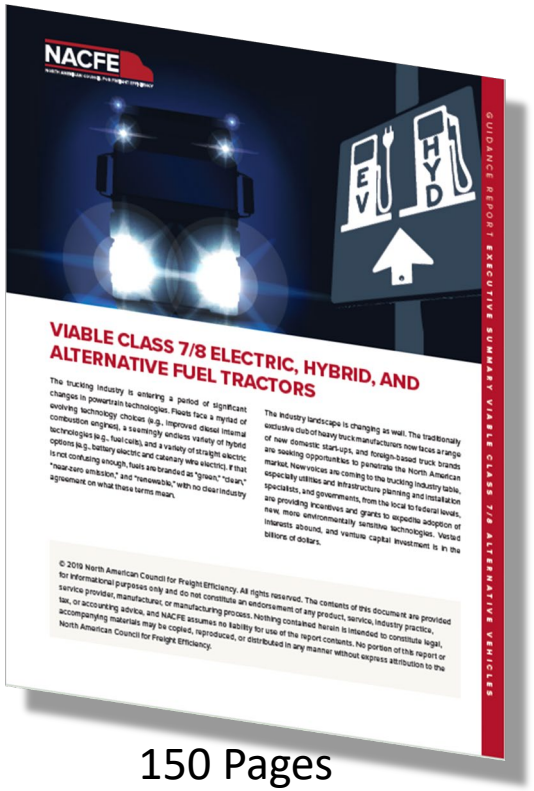
www.NACFE.org

10 YEARS NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Guidance on Hydrogen

Making Sense of Heavy Duty Hydrogen Fuel Cell Tractors

143 Pages
235 References



150 Pages
222 References

Viable Class 7/8 Electric, Hybrid, and Alternative Fuel Tractors

https://www.nacfe.org

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Many Bridges to the Future

PRESENT

Technology immature

Many unknowns & challenges

"MESSY MIDDLE"

Many optimized solutions

Growing infrastructure

Multi fuel choices

Innovation & maturation

Facts replace estimates

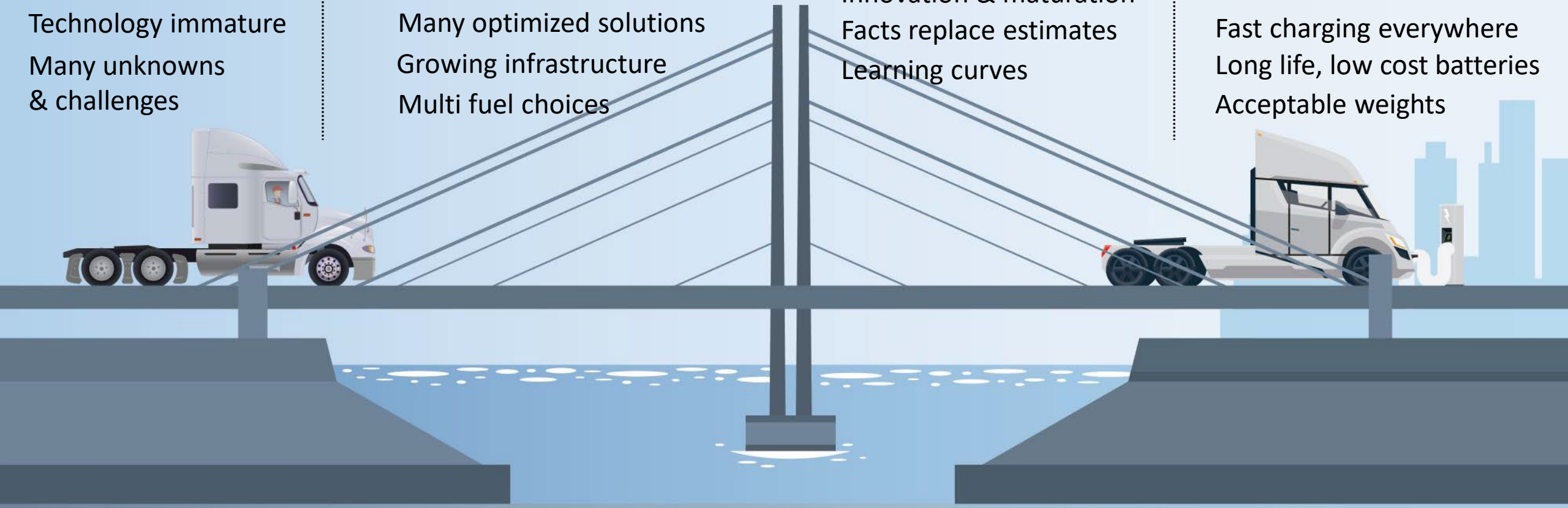
Learning curves

FUTURE 2050

Fast charging everywhere

Long life, low cost batteries

Acceptable weights



Legacy Diesels
Natural Gas

Diesel Advancements
Natural Gas
Hybrids

Battery Electric
Hydrogen Fuel Cells
Renewable Natural Gas & Diesel

CBEV & FCEV from Clean Energy

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Technology and Zero Emission Future

Horse Race?

Team Pull?

The Hill Climb To Zero Emission

NA Trucks in Commercial Use

- 2.8M Tractors
- 8.8M Single Unit Trucks

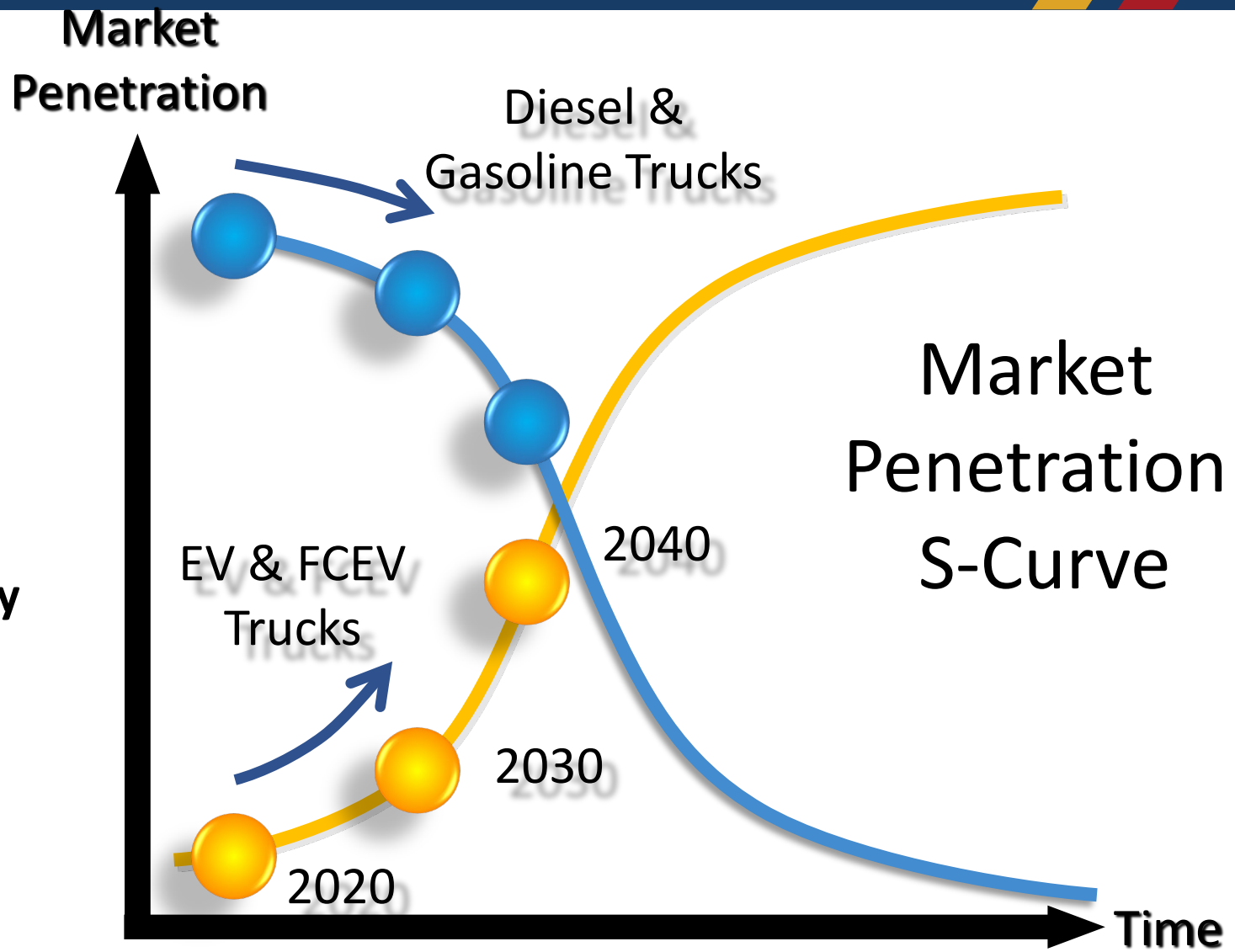
NA Annual Production Capacity

- ~320k HD Truck/Tractors
- ~350k MD Trucks

NA Production EV/FCEV Trucks Today

- < 100 HD
- < 5,000 MD

NA = North America



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Nomenclature

FCEV – Fuel Cell Electric Vehicle

Range Extended Electric Hybrid Vehicle

Zero Emission

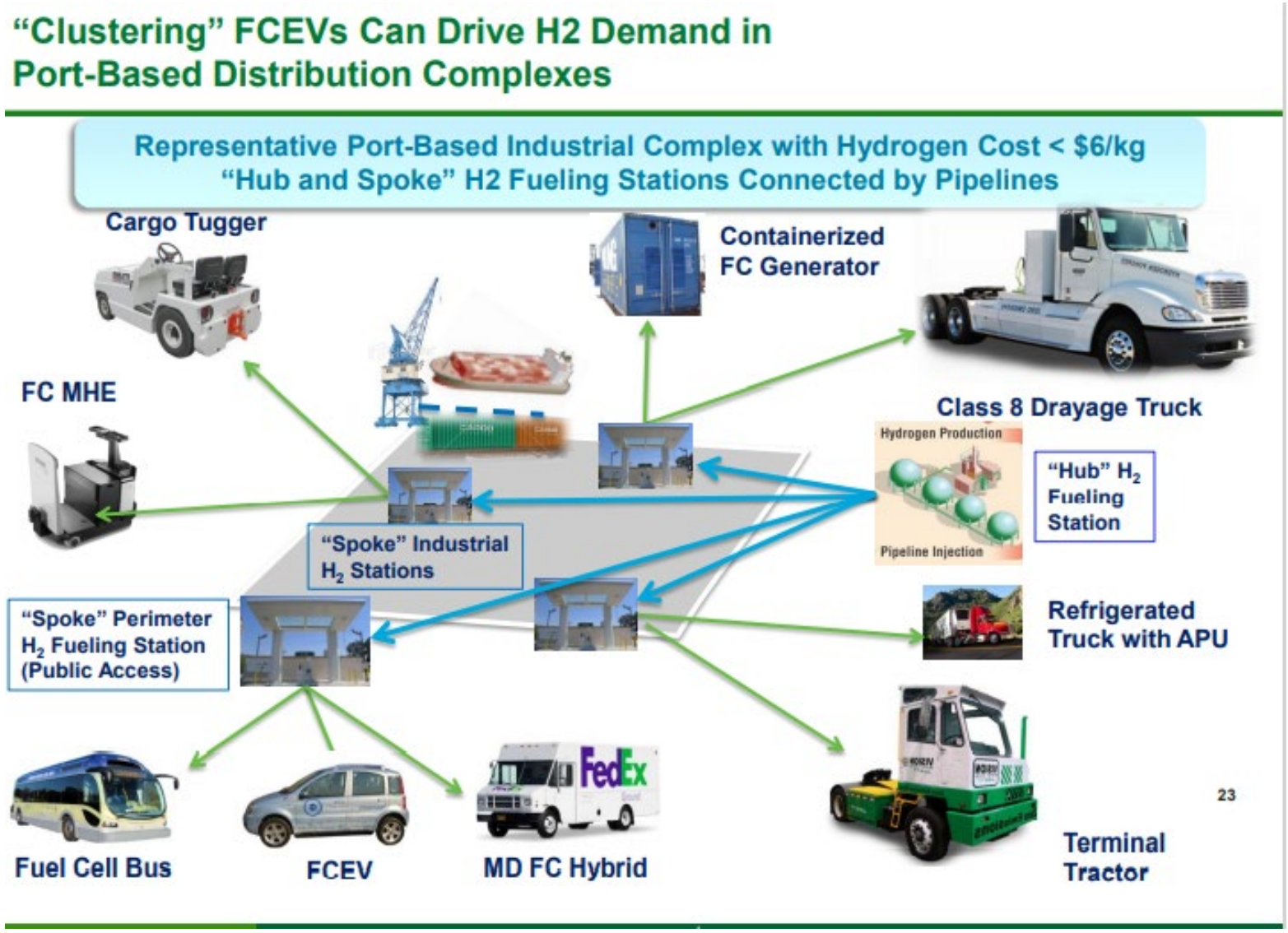
Net Zero Emission

Green Energy

Hydrogen is Complicated

- A regional decision
- More than just trucking
- More than just debating efficiency
- More than debating fill times
- Its not H_2 vs EV
- Requires innovation
- Green hydrogen requires green electricity

Scaling is Regional

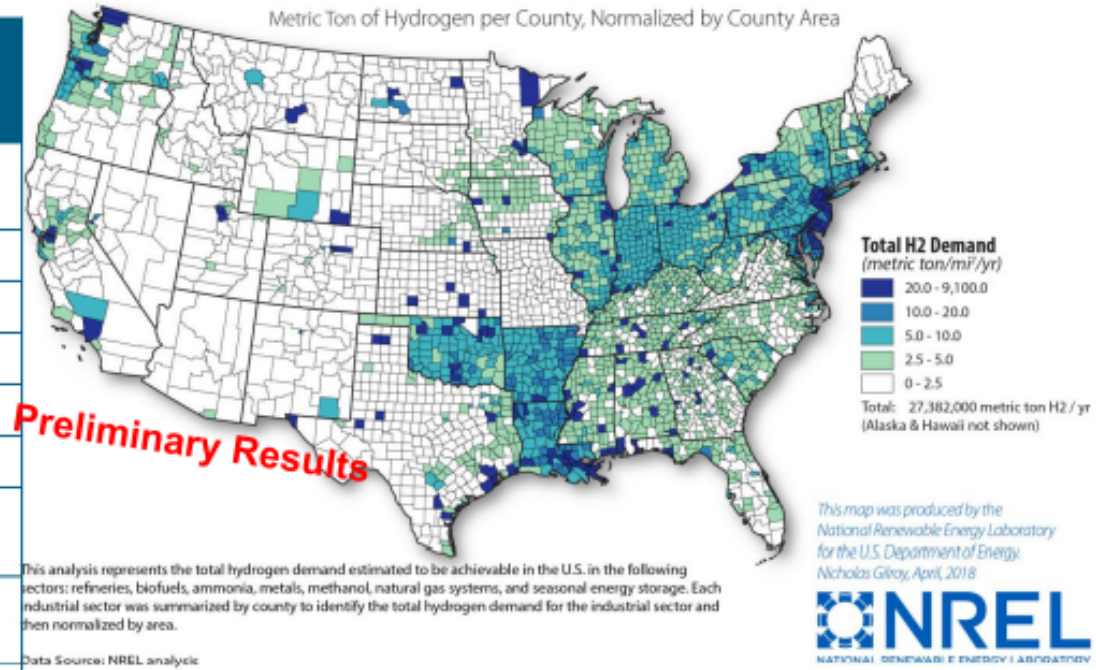


https://www.californiahydrogen.org/wp-content/uploads/2017/10/1620-Devlin-DOE.pdf

Scaling is not just Trucks

H2@Scale Analysis: Estimated Technical Potential Hydrogen Demand

Demand	Technical potential (MMT* / year)
Refineries & CPI§	8
Metals	6
Ammonia	5
Methanol	1
Biofuels	1
Natural Gas	7
Light Duty Vehicles	28
Other Transport	3
Electricity Storage	28
Total	87



This analysis represents the total hydrogen demand estimated to be achievable in the U.S. in the following sectors: refineries, biofuels, ammonia, metals, methanol, natural gas systems, and seasonal energy storage. Each industrial sector was summarized by county to identify the total hydrogen demand for the industrial sector and then normalized by area.

Data Source: NREL analysis

Technical Potential Demand: 87 MMT/yr

Current U.S. market: ≈ 13 MMT/yr

Including captive generation for ammonia and refining

* MMT: Million metric tonnes

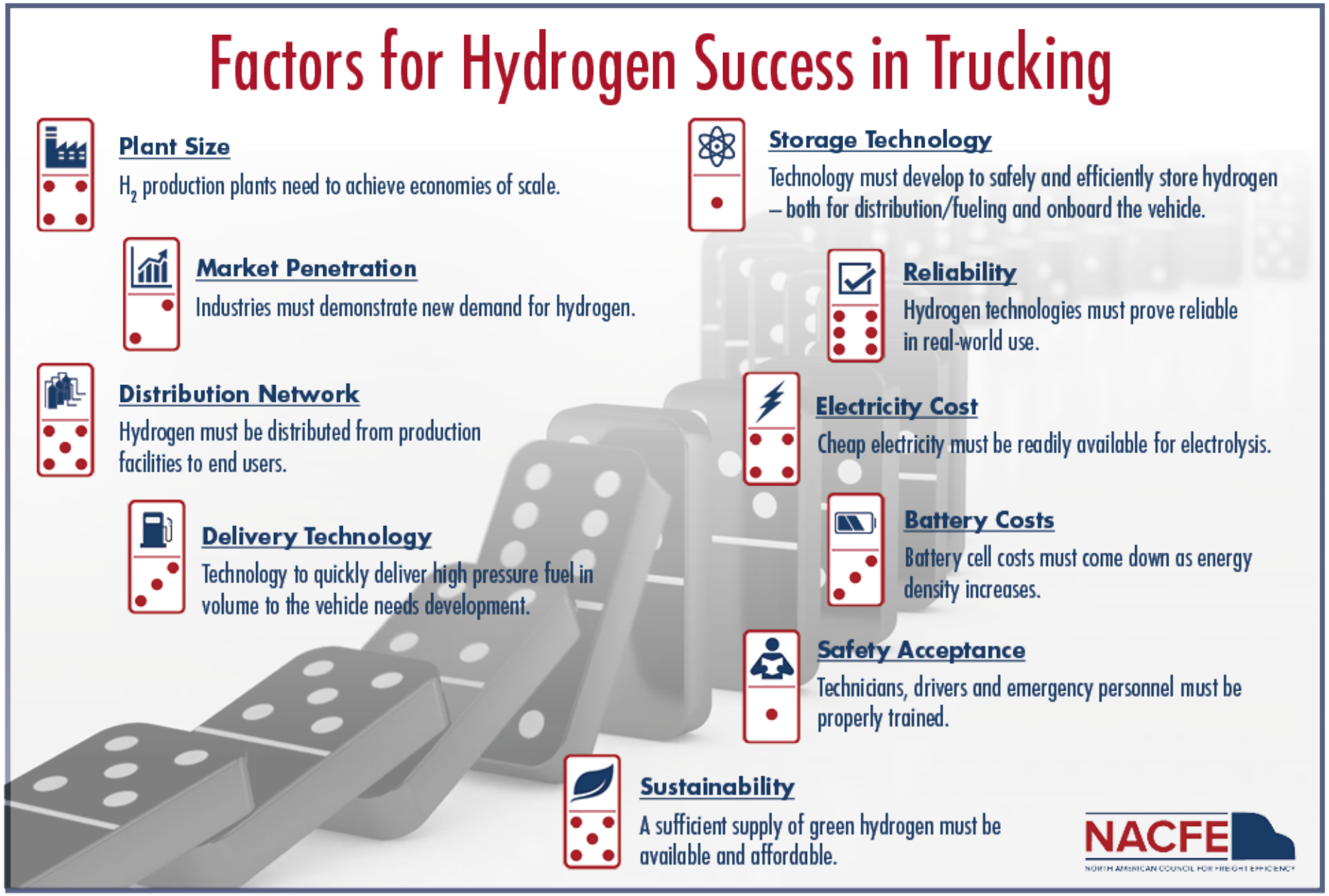
§ CPI: Chemical Processing Industry not including metals, ammonia, methanol, or biofuels

Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

U.S. DEPARTMENT OF ENERGY | OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY | FUEL CELL TECHNOLOGIES OFFICE | 20

https://www.californiahydrogen.org/wp-content/uploads/2017/10/1620-Devlin-DOE.pdf

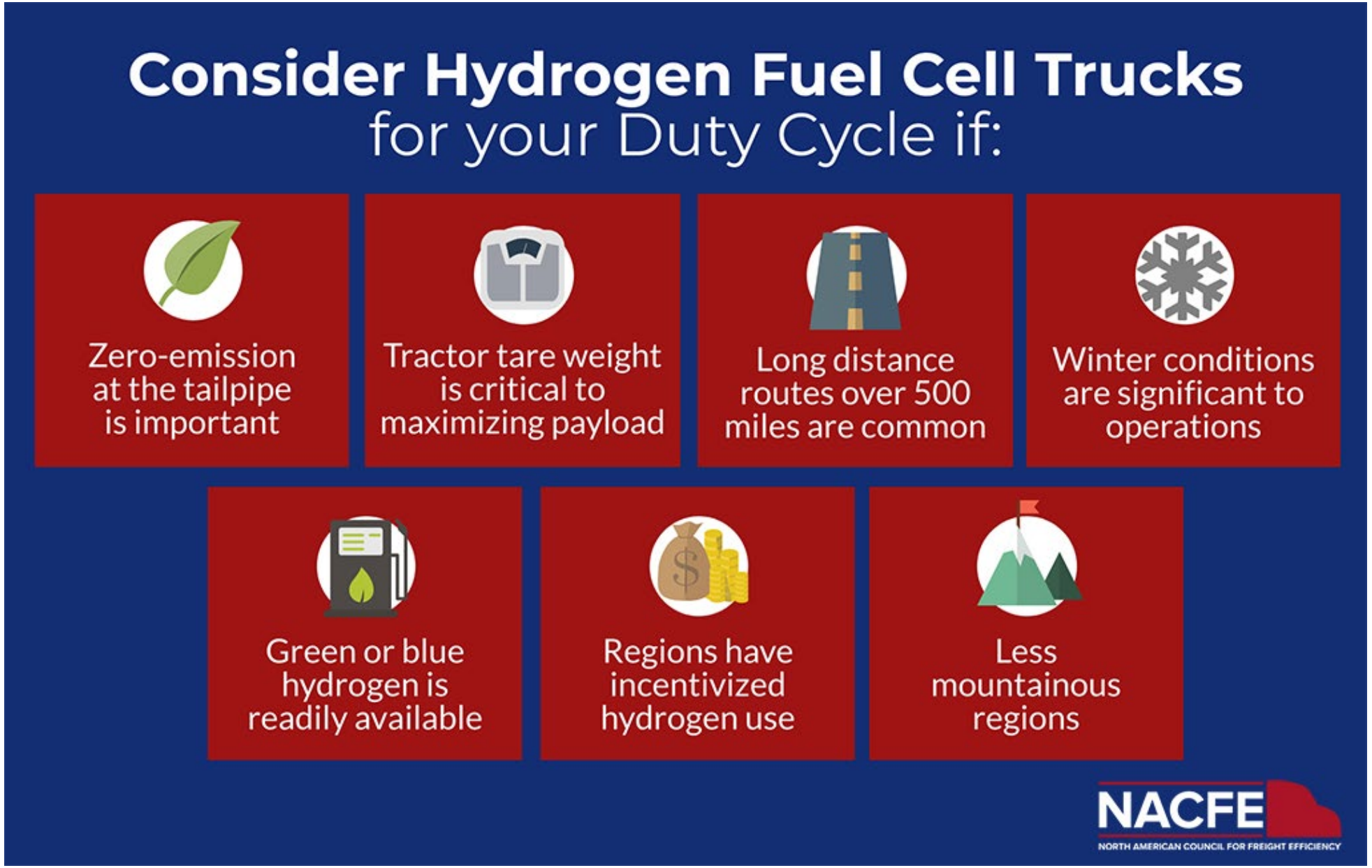
Hydrogen Success Factors



Hydrogen Fuel Cell Trucks

- Several in fleet test
- OEM development
- Production plans
- Compressed & Liquid Hydrogen

Hydrogen Opportunities



Hydrogen Fuel Cell Conclusions

- Hydrogen fuel cell trucks are just starting to see real-world use and their adoption is being driven by regional or national considerations that are much bigger than what exists for trucking fleets.
- Battery electric trucks should be the baseline for hydrogen fuel cell electric vehicle (HFCEV) comparisons, rather than any internal combustion engine alternative.
- As for all alternatives, fleets should optimize the specifications of FCEVs for the job they should perform while expecting that the trade cycles will lengthen.
- The future acceleration of FCEVs is likely not about the vehicles or the fueling but more about the creation and distribution of the hydrogen itself.
- Finally, the potential for autonomous fuel cell trucks to operate 24 hours a day adds significant opportunity for making sense of capital and operational investment in hydrogen.

THANK YOU

https://www.NACFE.org

Jason Condon

- Co-Owner and Director of Sales of Global Environmental Products, Inc.
- Focuses on dealer development for municipal sales and service as well as continued product development
- Over 25 years of experience in Public Works environmental equipment sales and support

Contact: 585-944-1969 | jcondon@globalsweeper.com

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San Bernardino, CA 92407 USA
Phone: 909-713-1600
info@globalsweeper.com

HYDROGEN AS A TRANSPORTATION SOLUTION

Clean Fuel,
Clean Streets
Clean Air

We build Purpose Built, Heavy Duty,
and simply Tough Street Sweepers.

- *Reliable, Affordable and Innovative Products*
- *Protect our Environment and Reduce our Carbon Footprint*
- *Save our Planet and Clean the Streets*

OUR SPECIALTY…

PURPOSE BUILT CHASSIS PROVIDES FLEXIBILITY TO LEAD INDUSTRY:

ALTERNATIVE FUEL/GREEN TECHNOLOGIES

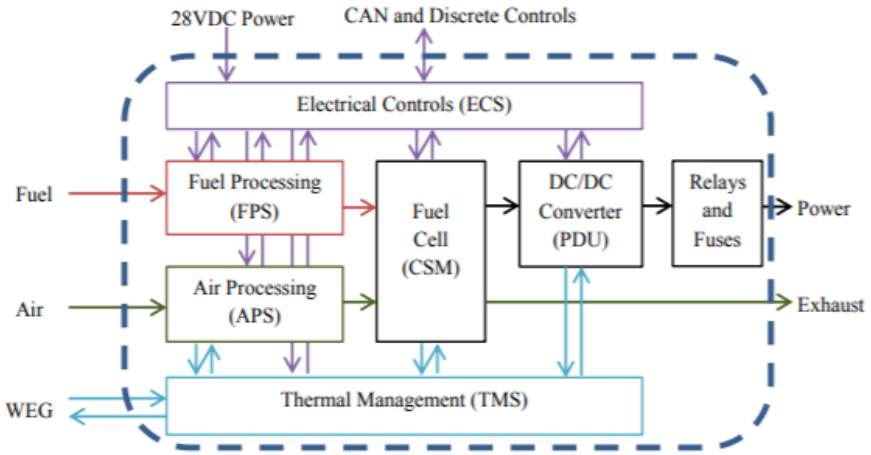
- **GLOBAL M4 HYDROGEN FUEL CELL**
- **GLOBAL M3/M4EV SWEEPERS**
- **DIESEL/ELECTRIC SWEEPERS**

1st Heavy-Duty Hydrogen Fuel-Cell Powered Street Sweeper in USA!

- CLASS 7– 55-65 MPH TRAVEL SPEED
- Rear Dump and Side Dump Hopper Available.
- Extremely quiet operation.
- ZERO EMISSIONS
- Electric Motor Drives the Sweeper.
- Heavy-Duty Sweeping System Sweeps up to 3-Tons of sand per minute.

GLOBAL ENVIRONMENTAL PRODUCTS

- The fuel cell and hydrogen tanks take the place of a battery-electric vehicle's battery pack.
- Diesel engine is no longer required.
- The by-product of electro-chemical reaction is energy and H2O.



FCe™80 Integrated FC engine diagram

- Specifically designed for medium and heavy duty, transit bus, drayage trucks, GSE, ports and logistics equipment and off-road applications.
- Meets SAE J1455 shock and vibration and environmental requirement
- Safety disconnect and protection system with high voltage isolation

FCe™ 80
Fuel Cell Engine

Startup / Shutdown

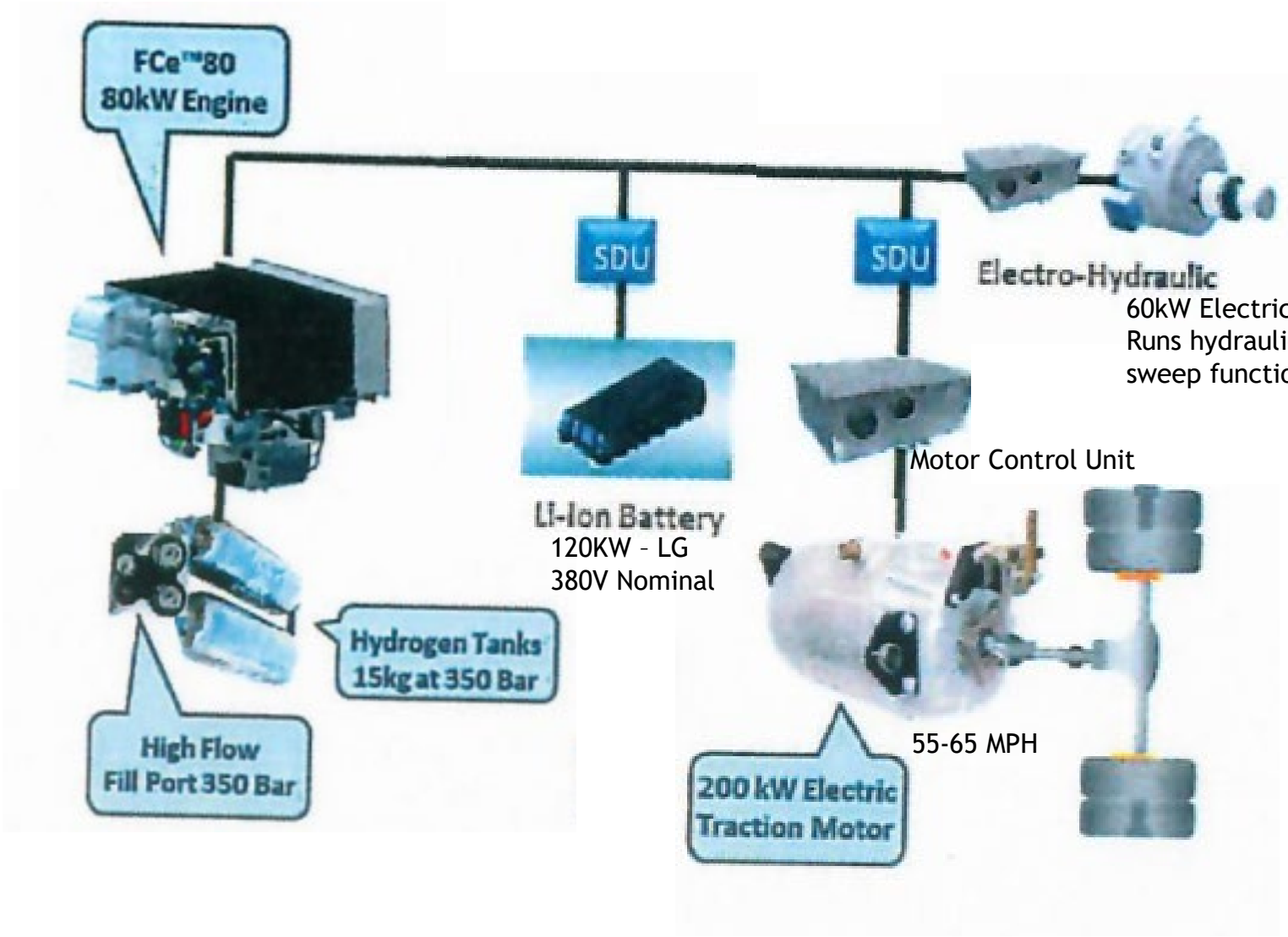
Startup Time	30 seconds
Startup from Frozen Time	6 minutes
Shutdown Time	10 seconds

Electrical

Output Power‡	6 - 80kW
Output voltage	375 - 750V_{DC} (Integrated Isolated dc-dc converter)
Ramp rate	40 kW/sec

Fuel

Fuel Flow	5.2 kg/hr @ full power
Fuel Pressure	1200 ±300 kPa_g (KILOPASCAL GAUGE)
Fuel Type	SAE J2719 Hydrogen



60kW Electric Motor
Runs hydraulic gear pumps for sweep functions

Motor Control Unit

120KW – LG
380V Nominal

55-65 MPH

At a glance

California Department of Transportation utilizes 170-plus street sweepers daily. Each M4 ZE produces 43 gallons of water per shift so that equals 7,310 gallons of water produced by operating street sweepers.

REGISTERED WITH FEDERAL EPA AND AIR RESEARCH BOARD (ARB)

The Global M4ZE Street Sweeper is North America's first Hydrogen Fuel Cell Street Sweeper whose only by-product is pure H2O!

The water produced through this chemical reaction is diverted to the sweeper's water tank system, providing an additional 43 gallons of water per shift to use for dust suppression.

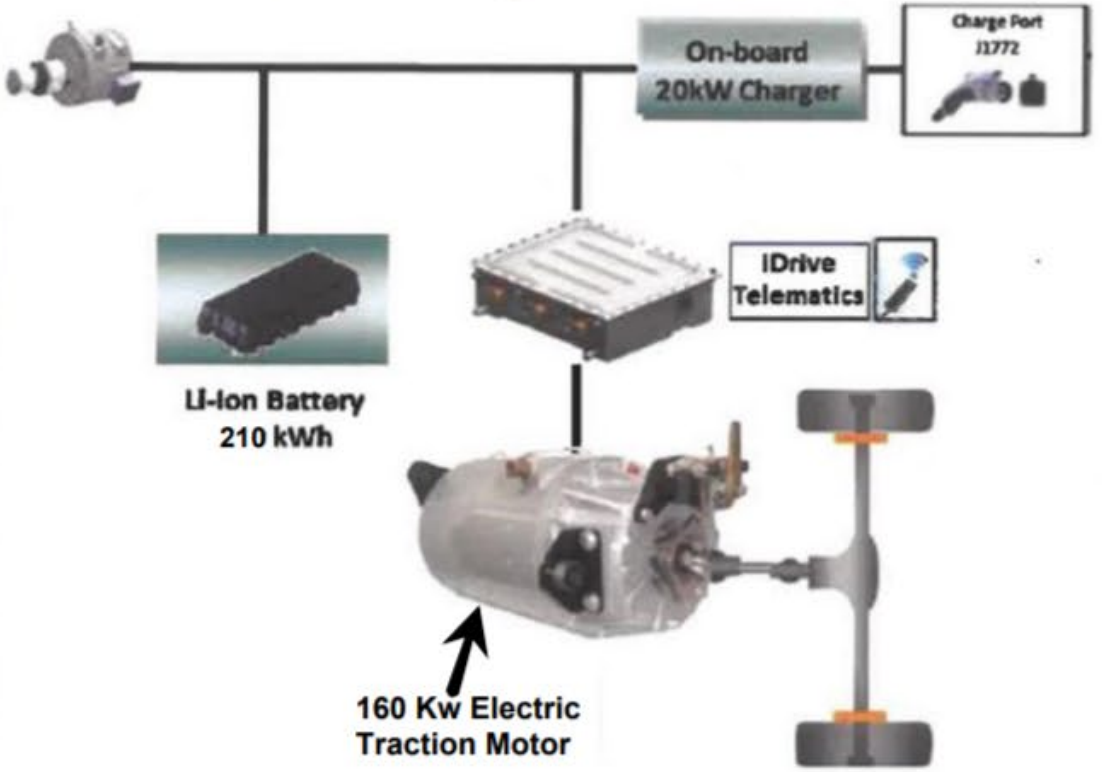
- 10 Hours of Operation Time
- 30 Mins – Battery Only Mode
- Highway Speeds up to 65 MPH
- Sweep Speeds up to 12 MPH
- PM10 Compliant

GLOBAL M4 ELECTRIC SWEEPER

THE FIRST 100% ELECTRIC HEAVY DUTY STREET SWEEPER IN THE USA!

CLASS 7 STREET SWEEPER – (26,001–33,000 LBS GVWR)

Battery Electric Zero Emission Sweeper DSNY



ZERO CO2 EMISSIONS TO REDUCE GLOBAL POLLUTION

NO ENGINE - No NOISE, NO HEAT

NO DPF FILTER

NO MORE ENGINE OR TRACTION SYSTEM PMS

- No Oil Changes
- No Hydraulic Drive System
- No Coolant and Radiator to Clean
- No Fuel Filters

5 Years Battery Warranty

8 Years expected life - Anticipated Battery efficiency loss of 15%

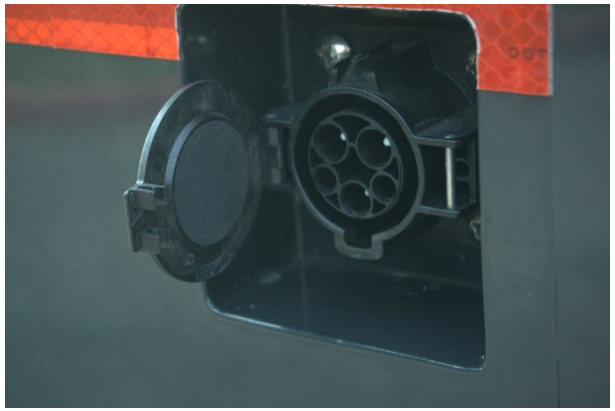
WORK AUTONOMY:

GLOBAL M3/M4 – 9-11 HOURS OPERATIONAL TIME

SAE 1772 Level II Charging System Standard: 240 Volts with Minimum 50 Amp Requirement

9-11 HR Charge Time

- J1772 SAE Level III Supercharging System is available as an option, recharging time of 4 hours.



TRACTION SYSTEM:

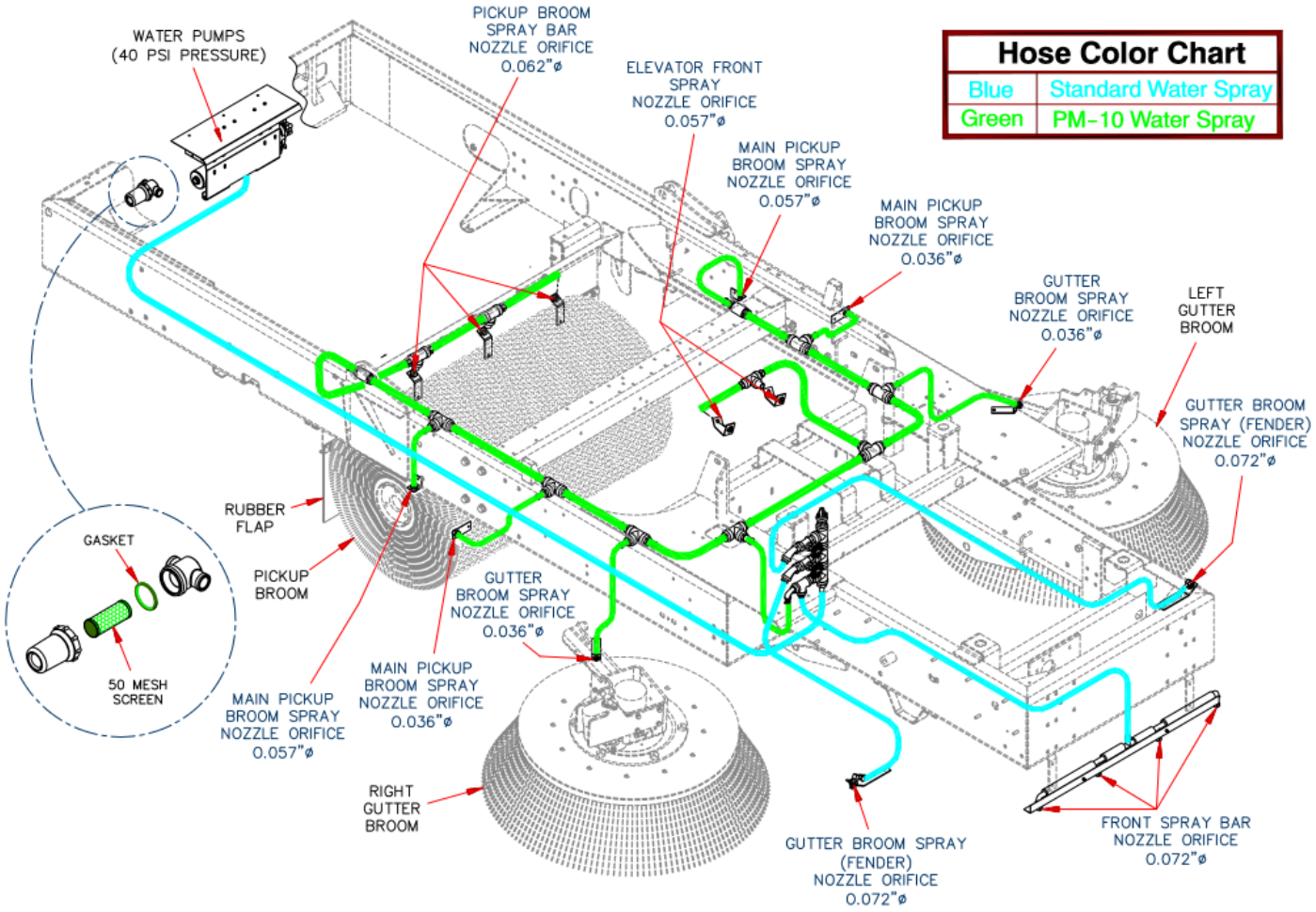
CONVENTIONAL REAR AXLE DRIVEN BY ELECTRIC MOTOR

MOTOR TYPE: ASYNCHRONOUS ALTERNATE CURRENT

MOTOR POWER: 160 kW DRIVE POWER ON CONTINUOUS DUTY

DUST CONTROL SYSTEM:

POLY WATER TANK CAPACITY: 250 GALLONS



GLOBAL ENVIRONMENTAL PRODUCTS

ISO9001:2008

5405 Industrial Parkway
San Bernardino, CA 92407 USA
Phone: 909-713-1600
info@globalsweeper.com

THANK YOU!

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Fax: 909.713.1613
www.globalsweeper.com

GLOBAL SWEEPER 55

Joe Callaway
jcallaway@actransit.org
510.891.7220

- Director of Capital Projects for the Alameda-Contra Costa Transit in Oakland, CA
- Direct accountability for the architecture, development and implementation of AC Transit's zero-emission infrastructure plan
- 25 years of progressive experience in transit infrastructure, alternative fuels, and zero emission bus infrastructure development
- Construction Engineering and Business Management from California Polytechnic State University


AC TRANSIT
CLEAN ENERGY TECH CENTER
H2 as a Transportation Solution
Joe Callaway
Director of Capital Projects
AC Transit
October 14, 2021

Hydrogen as a Transportation Solution

- **About AC Transit – Who are we?**
- **Why are you implementing a ZEB Fleet**
  - What Motivates you to Implement ZEBS
- **How will you Develop your ZEB Program**
  - Having a Long-Range Plan
- **Key's to Success (aka Lessons Learned)**
- **You've Deployed ZEBs – Now What?**
  - Crunch the Numbers

About AC Transit

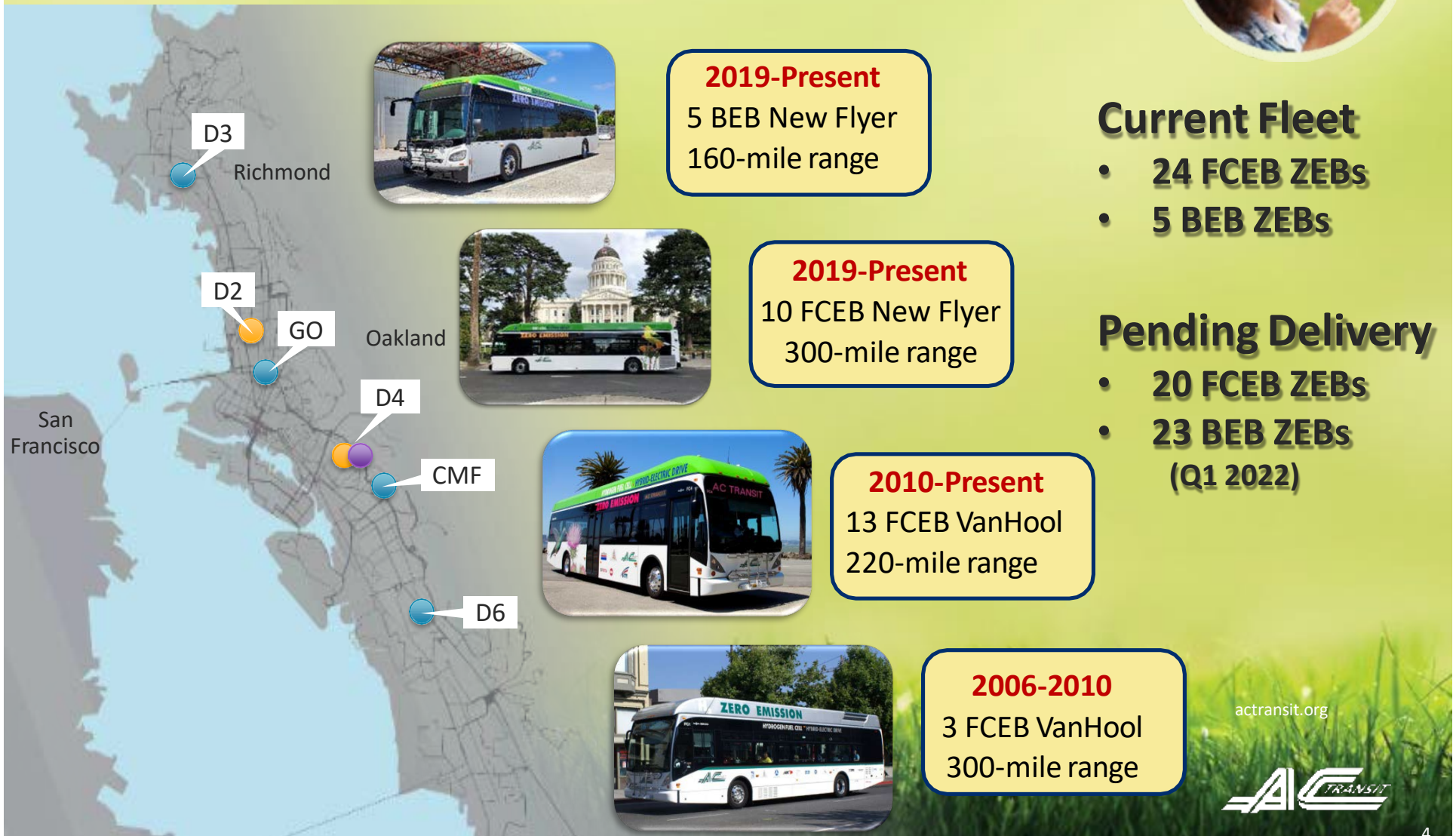
Based in the San Francisco East Bay

- General Office Headquarters in Oakland
- Serving Riders since 1960 (roots in the Key System)
- 364 Square Mile Service Area with 1.5M Riders
- Two Counties – 13 Cities – Unincorporated Areas

Proud History of Embracing Clean Technology

- Over two Decades of History in Zero Emission Technology
- Recognized as a Leader in Transit ZEB

AC Transit
ZEB Fleet



2019-Present
5 BEB New Flyer
160-mile range

2019-Present
10 FCEB New Flyer
300-mile range

2010-Present
13 FCEB VanHool
220-mile range

2006-2010
3 FCEB VanHool
300-mile range

Current Fleet
- **24 FCEB ZEBs**
- **5 BEB ZEBs**

Pending Delivery
- **20 FCEB ZEBs**
- **23 BEB ZEBs (Q1 2022)**

actransit.org

AC Transit

ZEB Infrastructure

2009-Present
D2 (Emeryville)
Hydrogen Station
Liquid Compression
65 Buses / day

In Construction
D2 (Emeryville)
Battery Electric Bus
Charging Facility
30 Charging Stations

2020-Present
D4 (Oakland)
Battery Electric Bus
Charging Facility
6 Charging Stations

Coming Q1 2023
D4 (Oakland)
Battery Electric Bus
Charging Facility
25-50 Charging Stations

2014-Present
D4 (Oakland)
Hydrogen Station
Gaseous Compression
13 Buses / Day

Upgrade Pending
D4 (Oakland)
Hydrogen Station
Liquid Compression
70 Buses / Day

D3 Richmond

Emeryville

D2

GO

Oakland

D4

San Francisco

CMF

Hayward

D6

- Hydrogen Fueling Facility
- BEB Charging Facility
- Future BEB Charging Facility

Innovative Clean Transit Regulation (ICT)

CALIFORNIA
AIR RESOURCES BOARD

AC TRANSIT

Zero-Emissions Bus Rollout Plan

VERSION 1

ALAMEDA CONTRA COSTA TRANSIT DISTRICT
OAKLAND, CA

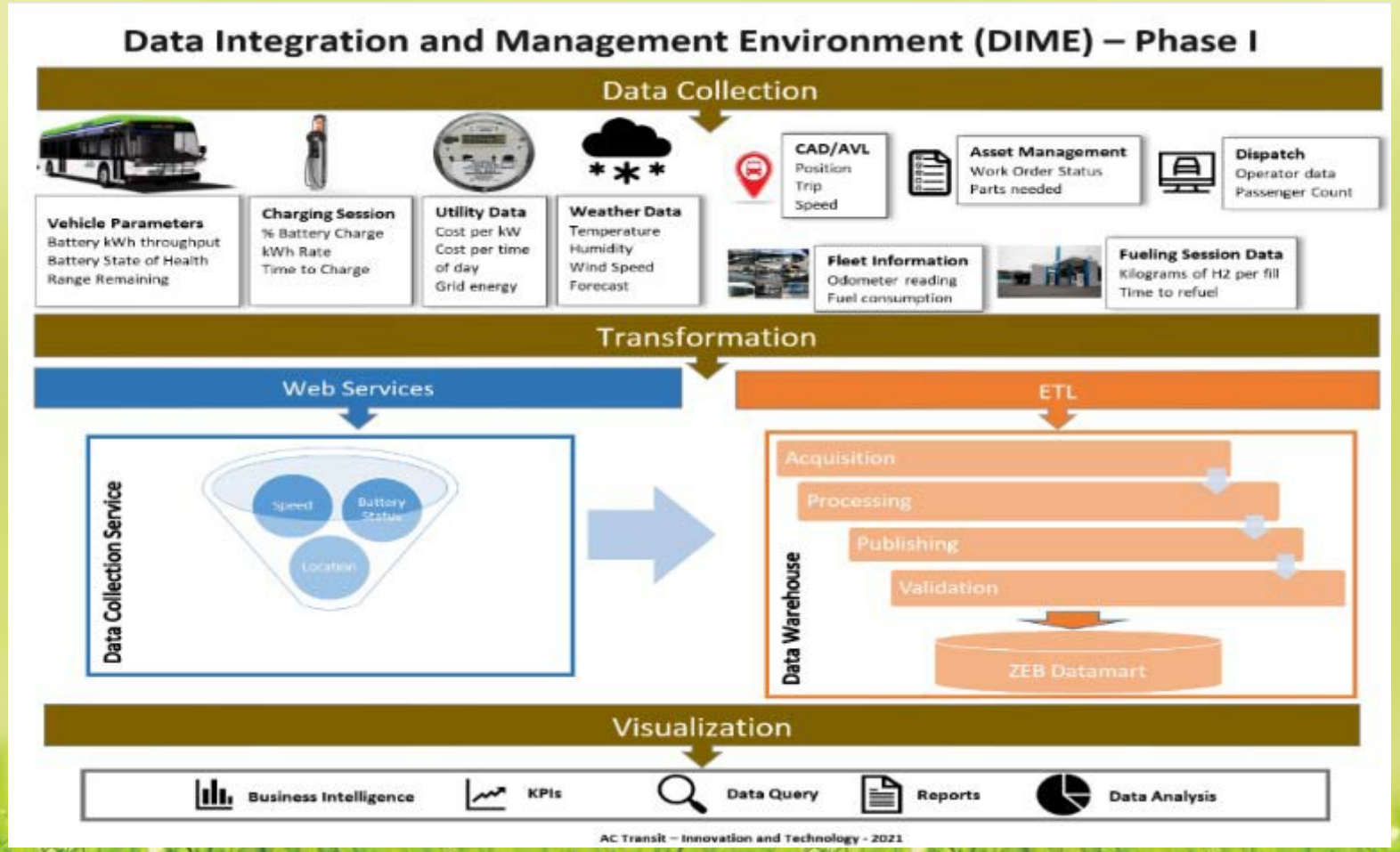
Leading the way to a **ZERO EMISSION FUTURE.**

Hydrogen as a Transportation Solution

Keys to Success

- Be true to your agency's mission
- Understand your ridership
- Understand your service territory
- Be realistic about footprint and on-route
- Be realistic about training needs
- Choose partners wisely
  - Utilities as a partner
  - AHJs as a partner
- Understand what "Emerging" means
- ZEB is a program - not a project
  - Collect and Utilize the Data

Hydrogen as a Transportation Solution



After ZEB Deployment

Zero Emission Transit Bus Technical Analysis

True Side by Side Evaluation of Five Bus Technologies

Five buses from each of five Technologies

- Conventional Diesel
- Hybrid Diesel
- FCEB – Battery Dominate
- FCEB – Fuel Cell Dominate
- Batter Electric Bus
- Same Routes from the same Division
- Same key performance indicators

Zero Emission Transit Bus Technical Analysi

(5 X 5 Study)

Performance Statistics

FLEET	DIESEL (BASELINE)	DIESEL HYBRID	FUEL CELL ELECTRIC (FCEB)	BATTERY ELECTRIC (BEB)	LEGACY FUEL CELL
Series Grouping	1600	1550	7000	8000	FC
Technology Type	Diesel	Hybrid	Fuel Cell	Battery	Fuel Cell
Bus Qty	5	5	5	5	5
Manufacturer	Gillig	Gillig	New Flyer	New Flyer	Van Hool
Year	2018	2016	2019	2019	2010
Length	40′	40′	40′	40′	40′
Data Summary (July - December 2020)					
Fleet Mileage	110,293	95,383	112,233	64,648	82,710
Cost/Mile	$0.93	$1.11	$1.51	$1.39	$2.84
Cost/Mile (w/ credits)	$0.88	$1.09	$1.11	$0.78	$2.84
Emissions (CO_2 Metric Tons)	275	183	0	0	0
Fleet Availability	94%	85%	90%	57%	84%
Reliability (MBCRC)	15,226	8,033	10,406	8,109	3,024

Hydrogen as a Transportation Solution
Next Steps for ZEBs

- Final Thoughts
- ZEBs are certainly still an emerging technology in the transportation space
- The core technology is here now and Ready to be implement at a commercial scale
- Both FCEB's and BEB's can be deployed at fleet scale
  - Implementation costs are decreasing with scale
- Technical maturity will only come with implementation
- Risks for the future … Supply Chain Issues
  - Buses and Infrastructure Components
  - Fuel

Thank You!

For more information, please visit actransit.org

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NC CLEAN ENERGY TECHNOLOGY CENTER

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION