



Hydrogen Is the New Diesel:
Electrifying Heavy-Duty Vehicles
with Nuvera Fuel Cells

PORTS TODAY



Shipping ports are drivers of the global economy. They create jobs, provide entry points for goods and enable the export of products around the world.

But ports are also the source of air pollution and CO₂, compounded by emissions from vehicles and vessels that enter and leave the port.

A typical port looks like this.



53
CRANES



200
FORKLIFTS



107
CONTAINER
HANDLERS



308
STRADDLE
CARRIERS

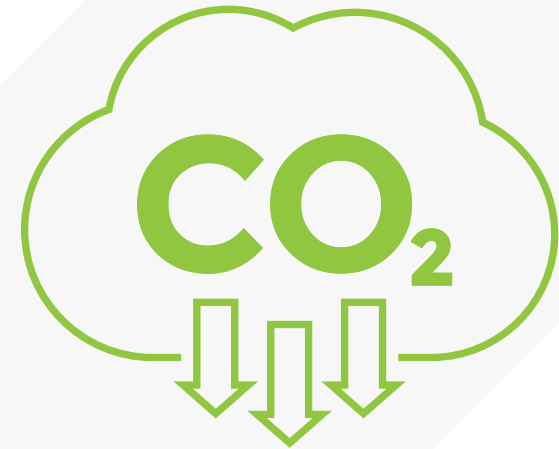


471
YARD
TRACTORS

ABOUT 90%
of world trade flows
through ports on
container ships.



More Than
900 MILLION TONS



A major port emits over

110,000

metric tons per year of carbon dioxide

NUVERA®

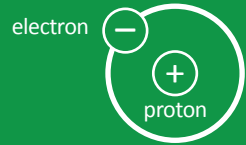


Dangerous Levels of Air Pollution



Why Hydrogen?

Hydrogen is abundant,
simple, clean



Hydrogen stores energy



HYDROGEN IS PORTABLE ELECTRICITY

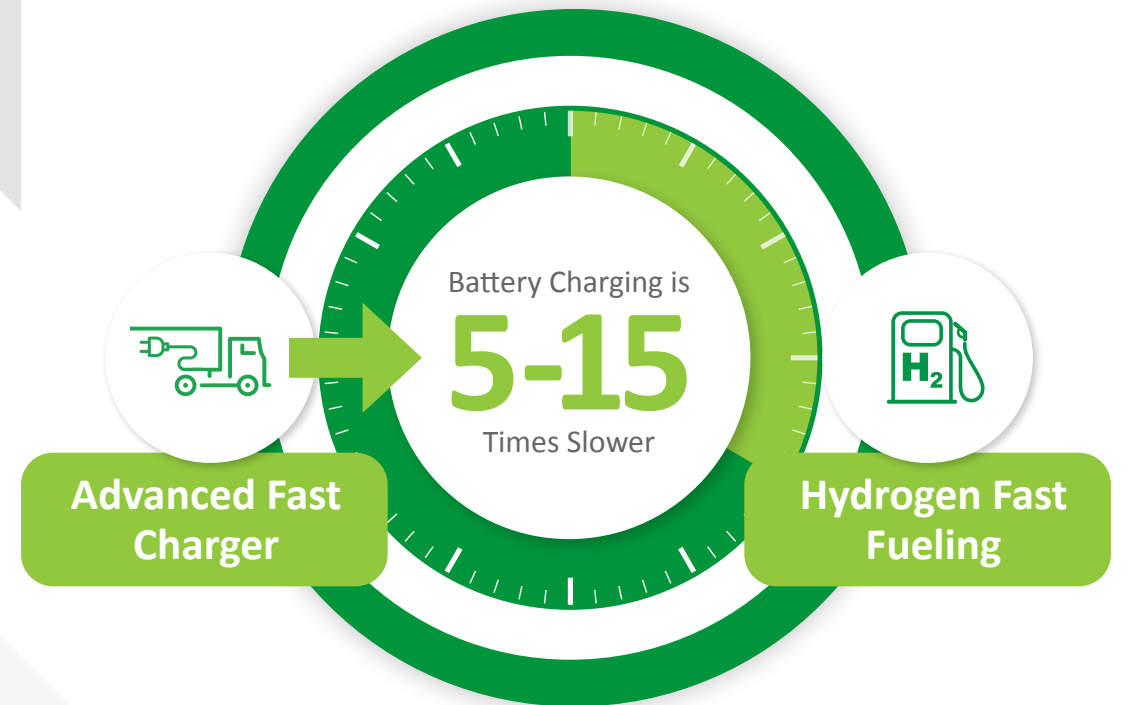
Hydrogen is electricity...



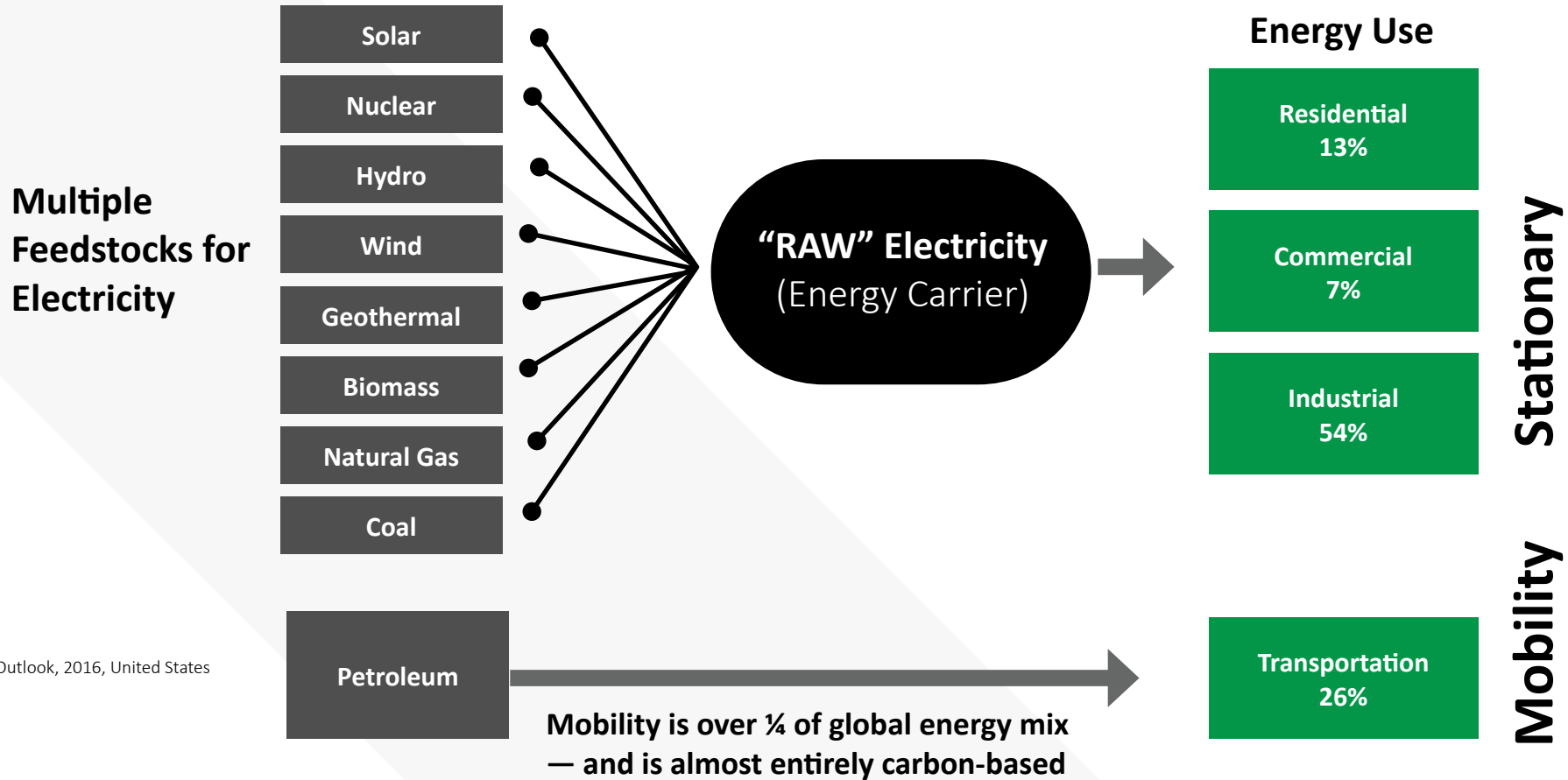
...with the convenience of fuel



You can refuel a fuel cell electric vehicle in about the same amount of time as a diesel vehicle.



WORLD ENERGY MIX TODAY



Source: Table F1, International Energy Outlook, 2016, United States Department of Energy.

HYDROGEN AT PORTS



Improve
AIR QUALITY



Reduce
CO₂ EMISSIONS



Increase
ENERGY EFFICIENCY



Reduce
AMBIENT NOISE

Fuel Cell Power for Electric Trucks



Nuvera Fuel Cell Systems

Fast-fueled drop-in battery replacements
for electric lift trucks

Engine Specifications



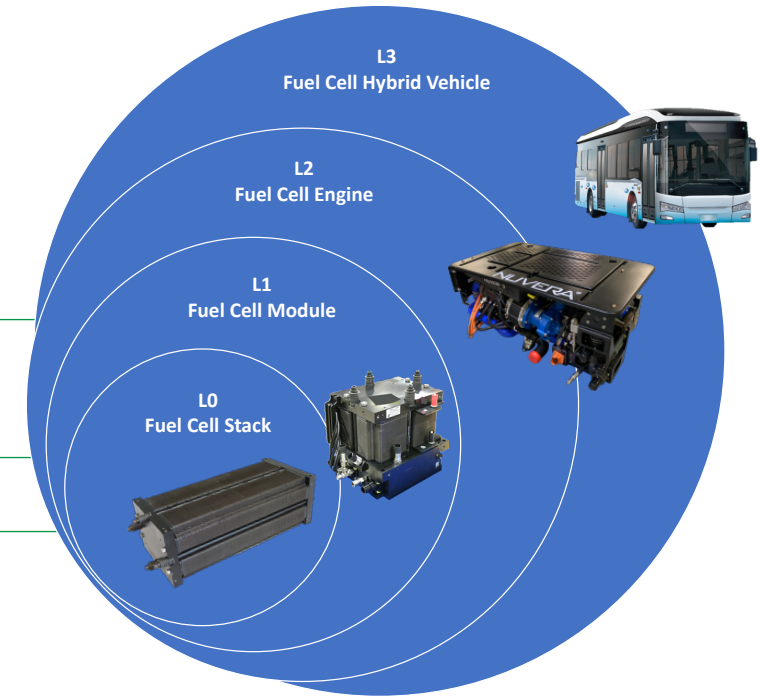
Nuvera® E-Series HD Fuel Cell Engines

Model	E-45-HD	E-60-HD
Net Power Output	45 kW	59 kW
Mass	187 kg	190 kg
Dimensions	1000 x 600 x 500 mm	
Efficiency	58%	

Compact, Easily Integrated Fuel Cell

Primary Power or Range Extension for
Medium- and Heavy-Duty Electric Vehicles

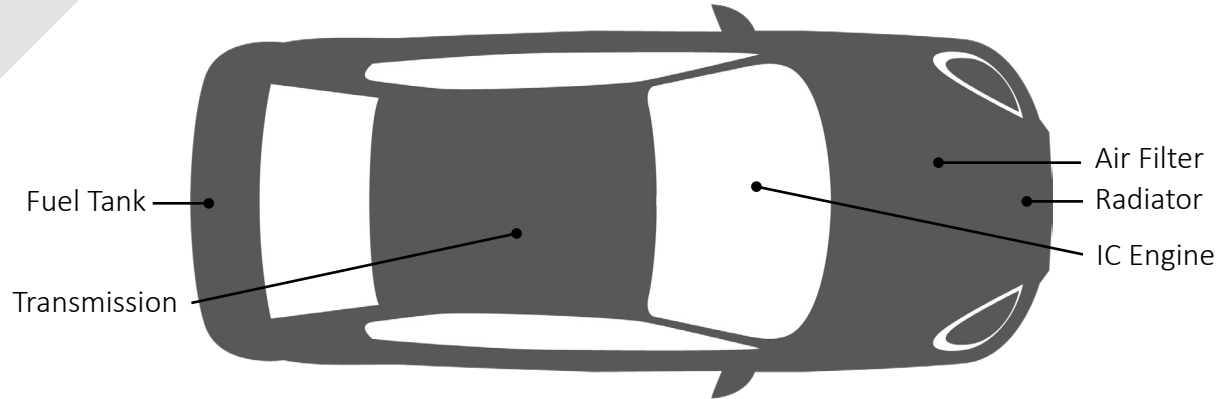
Definition: Fuel Cell Levels



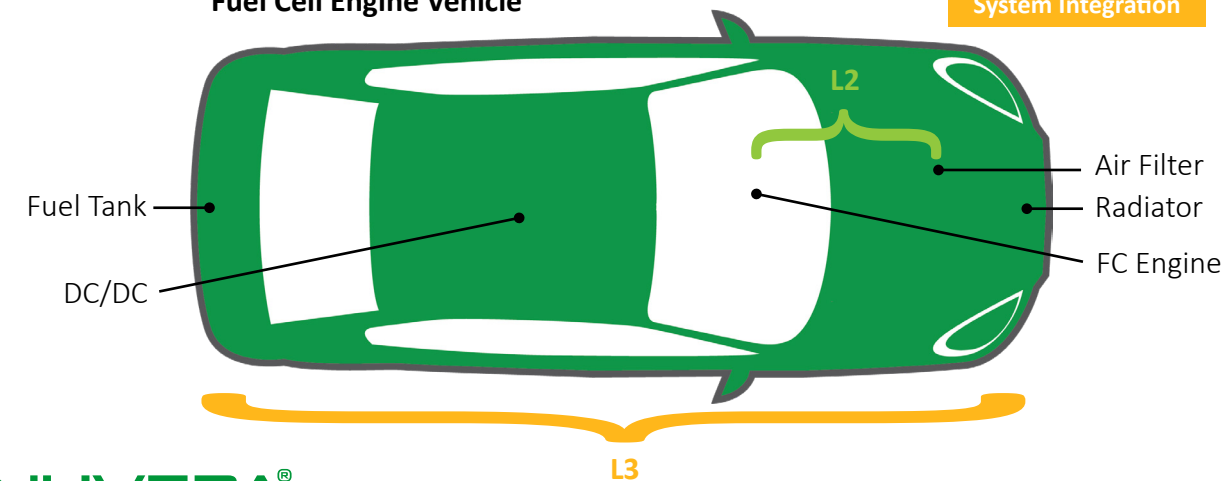
L0: FC Stack	<ul style="list-style-type: none"> • End-plate to end-plate • Nuvera maintains all IP rights and manufacturing
L1: FC Module	<ul style="list-style-type: none"> • Hydrogen management • Process manifold • Sensors and CVM connections • Covers
L2: FC Engine	<ul style="list-style-type: none"> • Air compressor / motor / control • Coolant pump / motor / control • Cooling thermostat / sensors • Stack control / water balance software • Hydrogen valve • Electronic control unit (ECU) • Air sensors (pressure, temp., relative humidity)
L3: FC Hybrid Vehicle, Power System, or Battery Box Replacement (BBR)	<ul style="list-style-type: none"> • Air filtration • Fuel tanks / regulators • DC power modules / auxiliary BOP • Energy storage (battery) • Thermal management (radiator) • Exhaust system • Vehicle hybrid control unit • Enclosure with ventilation

Example Vehicle Functions

Traditional IC Engine Vehicle

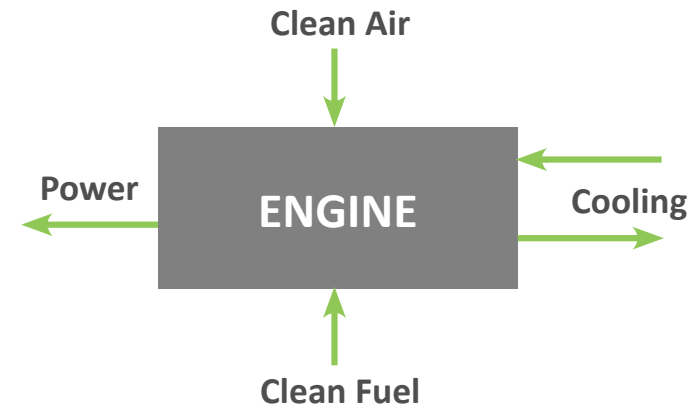


Fuel Cell Engine Vehicle



Nuvera FC Engine

System Integration



FUEL CELLS

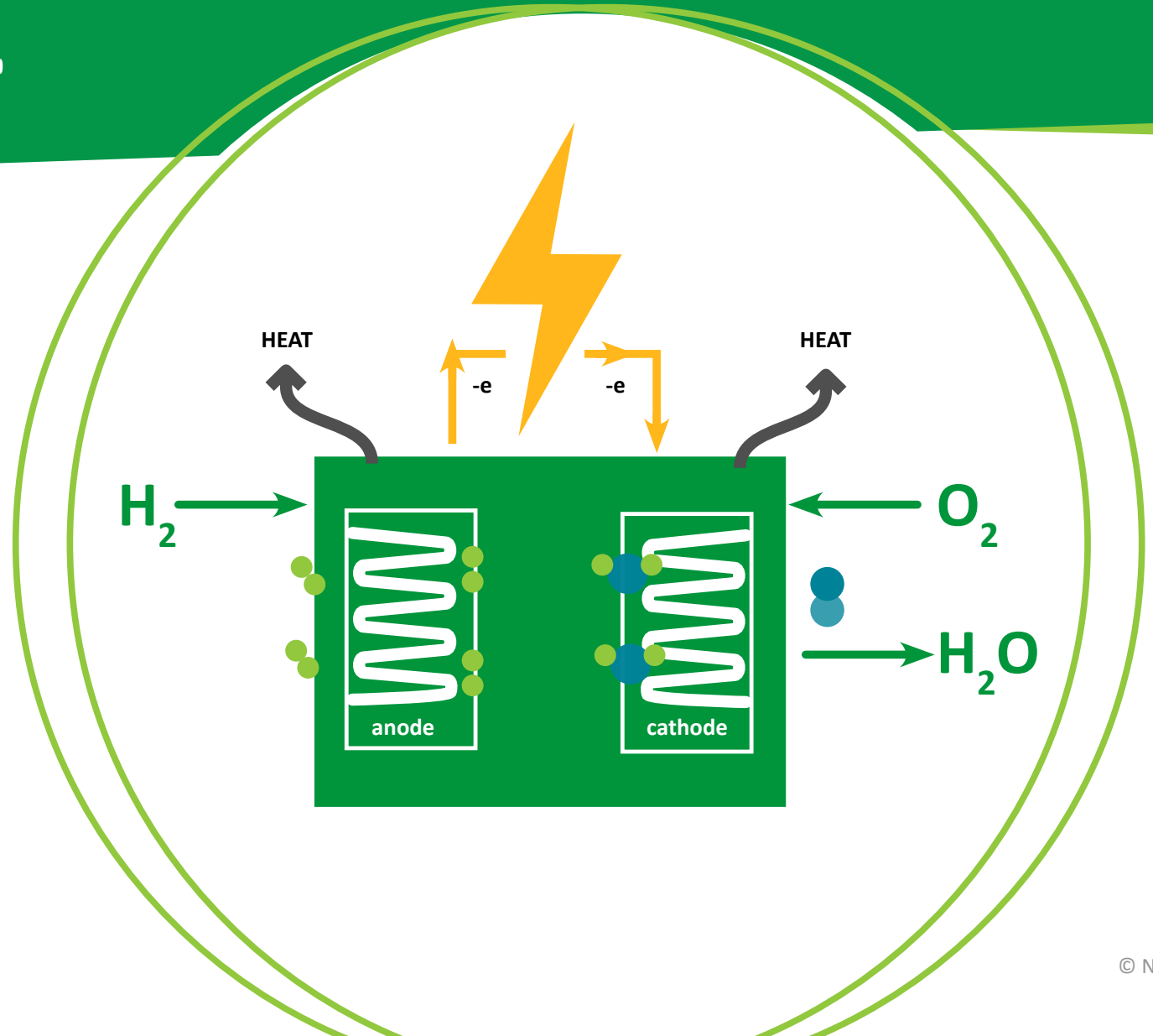
have emerged as a
clear path forward to
REDUCE EMISSIONS.





How does this work?

FUEL CELL



Zero-Emission Infrastructure Comparison

HYDROGEN



1,500 kg/day

3-10 minutes

30' x 50'

3.75 MW

\$

STATION CAPACITY

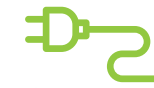
150 forklifts, 50 yard hustlers, and 90 delivery vans

DISPENSER / CHARGER TIMES

REAL ESTATE

5 Dispensers

30-40 Charging Stations



ELECTRICITY

348.75 MWh/day

1-2+ hours

20-30X

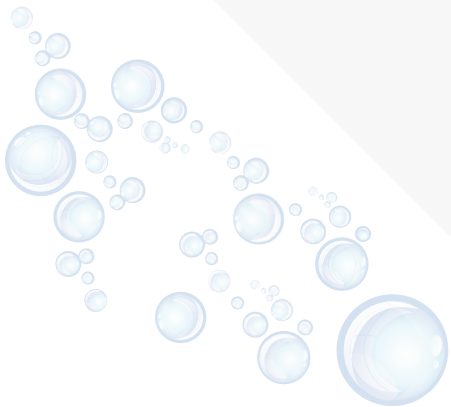
150 MW

\$\$\$

Fuel Cell and Battery Options

Like electricity, hydrogen can be produced renewably

- + Fuel cell vehicles have greater range than pure battery vehicles
- + Unaffected performance in cold temperatures/environments
- + Payload capacity comparable to gasoline and diesel vehicles

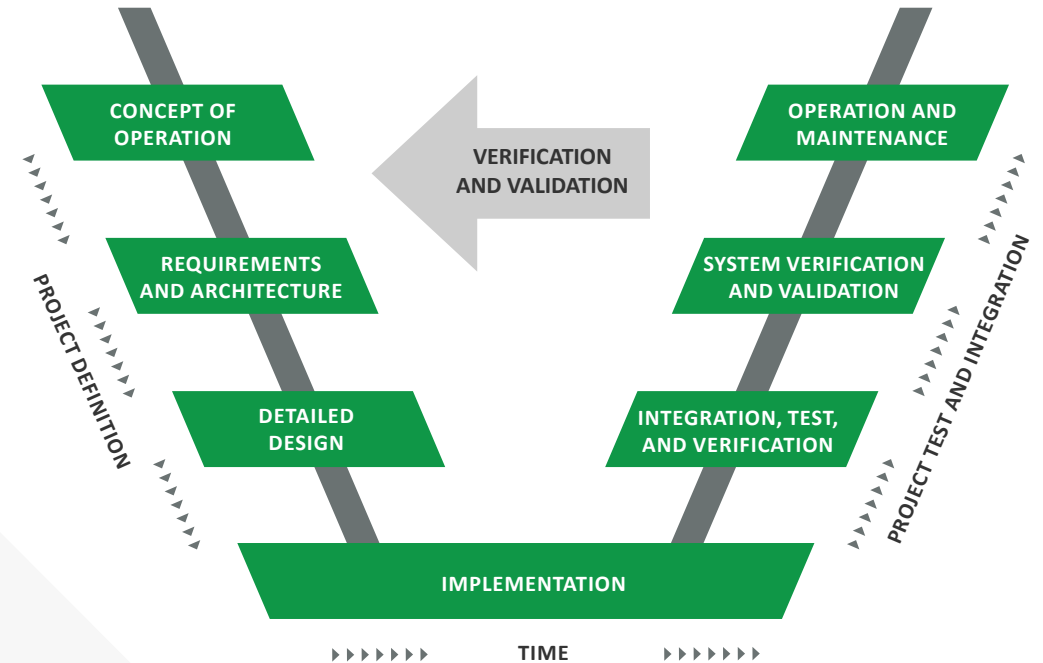




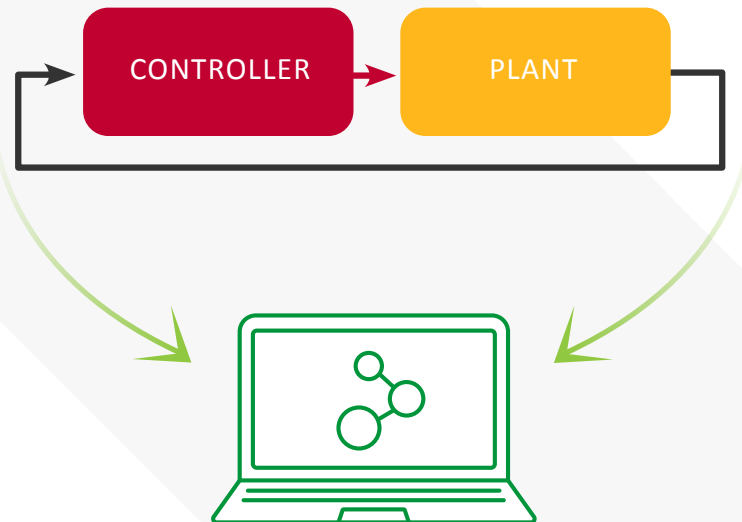
How does MathWorks come in?

Why Model-Based Design?

- + Fuel cell engines are still in early development (vs. 150 years for ICE)
 - + Want to avoid damaging prototype engines
- + Before working on hardware, beneficial to work on a virtual system
 - + Rapid design iterations
 - + Identify and fix errors
 - + Simulate scenarios without putting a real engine at risk
- + Save time by automatically generating code from model

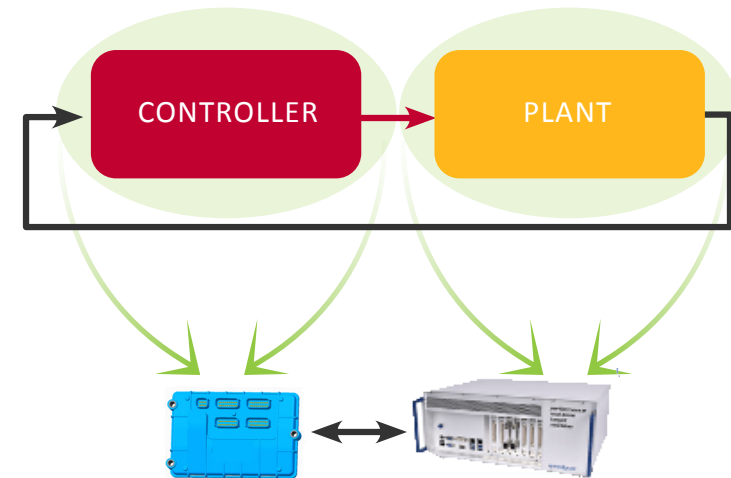


Model-Based Design approach using Simulink



Model-in-the-Loop (MIL)

Controller and Plant models are simulated

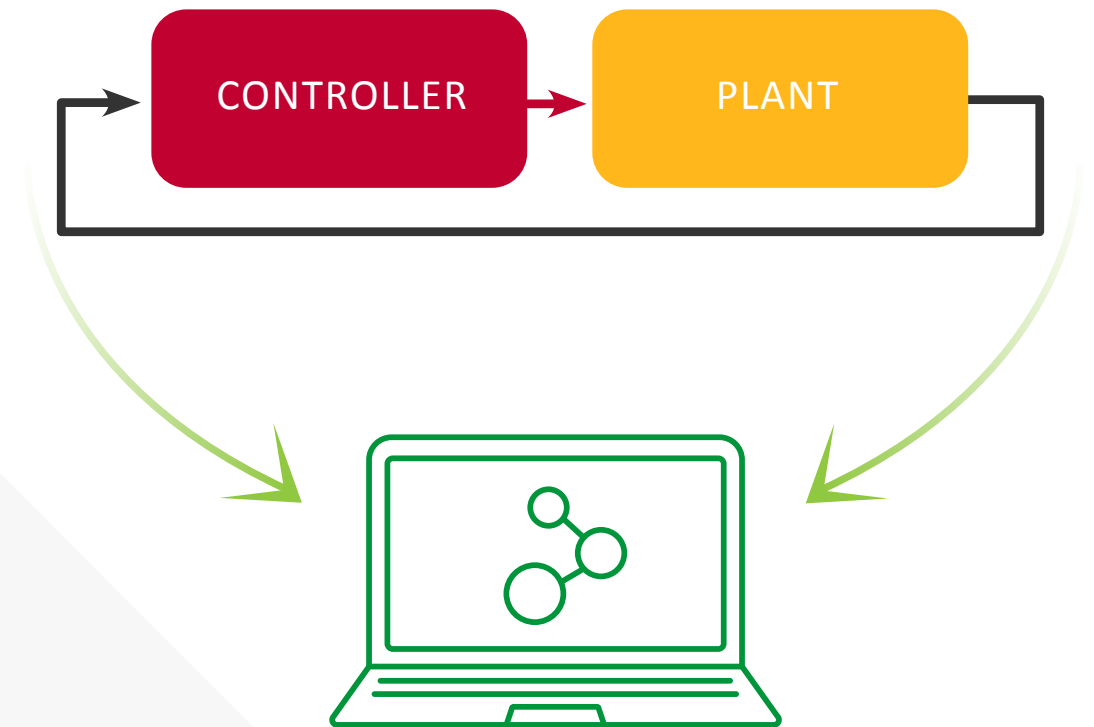


Hardware-in-the-Loop (HiL)

Controller implemented on engine's ECU
Plant model implemented on real-time computer

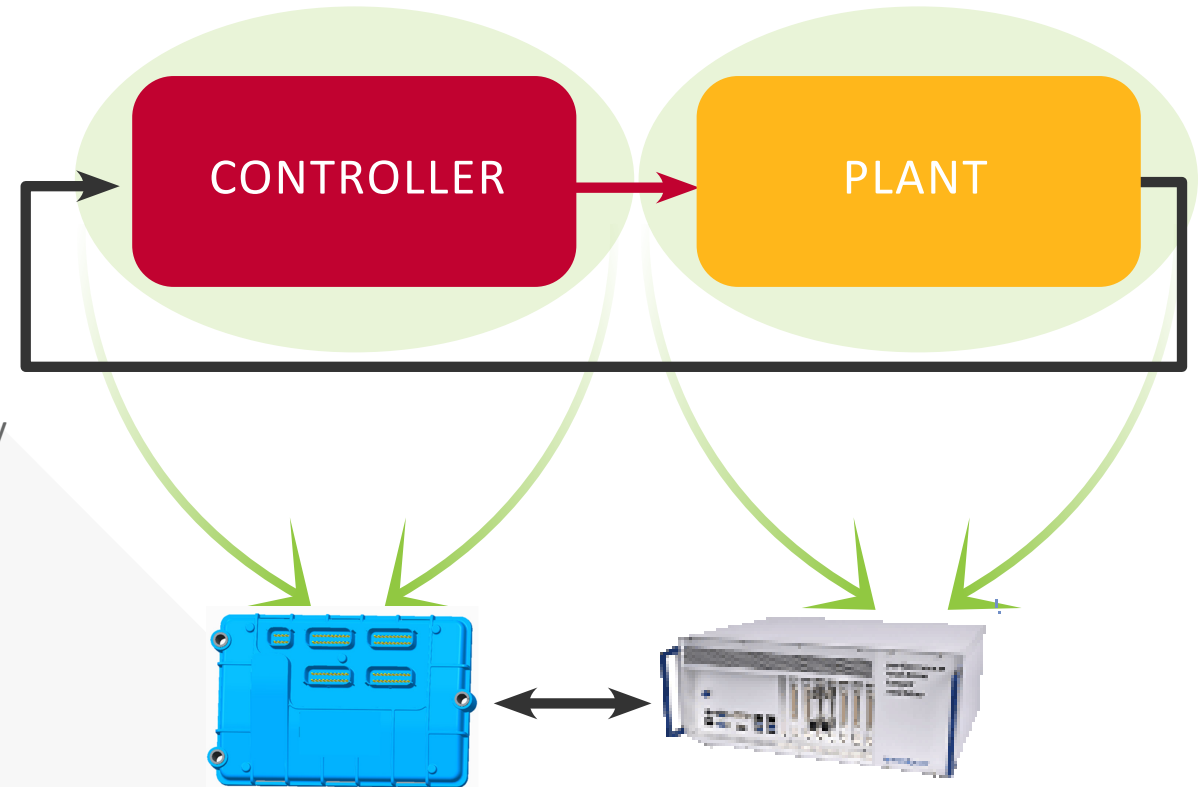
How Model-in-the-Loop helped develop and refine features/functions

- + E.g. of problems to solve
 - + Maintain proper hydration
 - + Test fault management
- + Physical system modeling with Simulink
 - + Electrochemical reaction
 - + Fluids flow, temperature, pressure (H2, air, coolant)
- + Control system modeling with Simulink/Stateflow
 - + Power management, Hydration management, Fault management
 - + Control algorithms to optimally operate the fuel cell engine
- + Simulations
 - + Test startup, shutdown sequences
 - + Simulate effects of failure
 - + Simulate low and high ambient temperatures
 - + Simulate low and high humidity environments



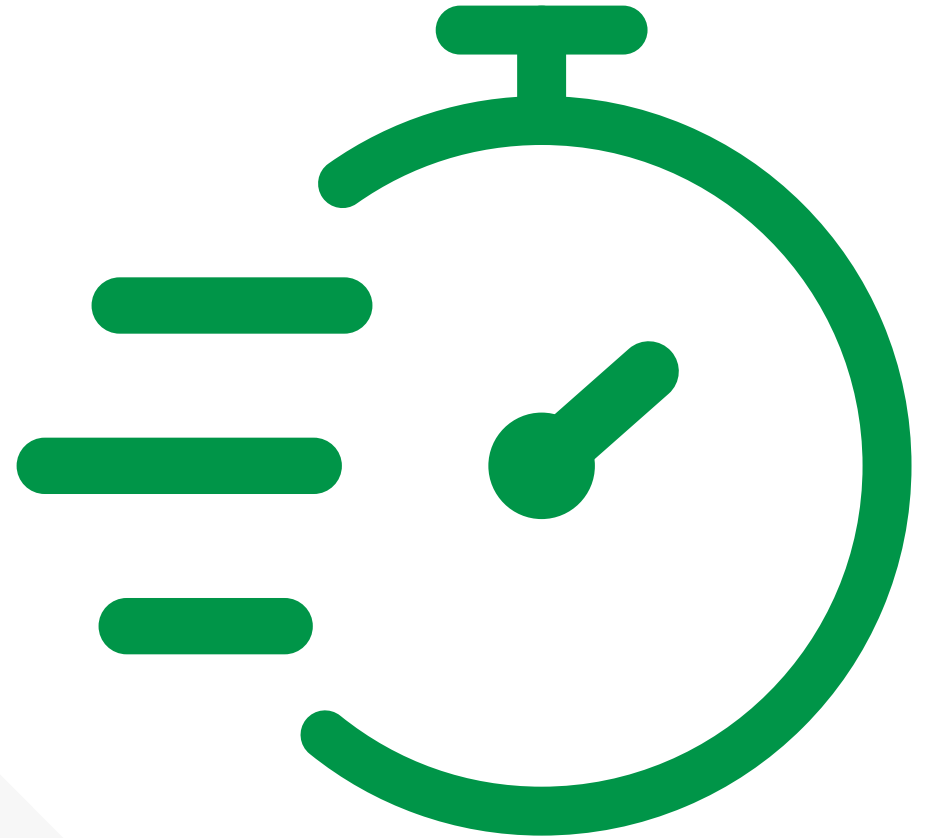
How Hardware-in-the-Loop helped test features/functions on target ECU

- + Plant → Speedgoat's Performance real-time target machine
 - + Simulink Real-Time
- + Controller → Engine ECU
 - + c code autogenerated by MathWorks' Embedded Coder
 - + Autogeneration avoids introduction of manually programmed bugs
- + ECU verification
 - + Firmware, impact of analog input accuracy, impact of latency in CAN communication on control logic
- + Adds rigor without putting a real engine at risk
 - + Simulation of hardware failures like cooling pump, compressor, valves



Benefits of Model-Based Design to Nuvera

- + Speed up design iterations (days vs. weeks pre-MBD)
 - + Simulations catch bugs early and permit assessment of
 - performance in a variety of environmental conditions
 - effects of hardware failures
 - + Autogeneration eliminates hand-coding errors
- + Design reuse for derivative systems
 - + Nuvera E-60-HD software developed in weeks thanks to reuse of E-45-HD models



Fuel Cell Engines

Enable Zero Emission Mobility

Growing global demand for clean, convenient power makes fuel cell transformation inevitable.

Fuel cells provide:

- + Zero emissions
- + Fast refueling
- + High efficiency
- + Driving range
- + Comparable payload
- + Reduced EV infrastructure requirements



Enabling the Pathway to Zero Emissions at Ports

Nuvera's fuel cell engines are ready for:

- + Container Handlers
- + Yard Tractors
- + Drayage Trucks
- + Rubber Tire Gantries
- + Forklifts
- + Buses

We are poised to work with port authorities, terminal operators, truckers, and community groups to meet the goals for emission-free transportation.





ZERO EMISSIONS LIMITLESS POSSIBILITIES

