



Hydrogen Vehicle Technology

APSE Energy
Adapting Services to Address Climate Change

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The Wrightbus Story So Far...

Since its inception in 1946, Wrightbus has cultivated a rich history and brand name recognized synonymously with manufacturing quality and innovation.

75 Years of Engineering Heritage

from Ballymena, Northern Ireland

- ▶ A leading industry innovator of low emission diesel, hybrid, and zero-emission hydrogen and electric buses.
- ▶ First Battery-EV built in 1998 / Diesel-hybrids in early 2000s.
- ▶ First single-deck hydrogen fuel-cell EV (2008).
- ▶ Manufacturer of Iconic Routemaster for London (2012).
- ▶ Unveiled world's first hydrogen powered double-deck (2016).
- ▶ Under new leadership from Jo Bamford (2019).
- ▶ Only manufacturer globally to offer single and double-deck hydrogen and battery electric buses (2022).



2021 Production
70% Low-Emission
30% Zero-Emission

2022 Production
70% Zero-Emission
30% Low-Emission

Wrightbus eyes Australian export market with Volgren deal

By routeone Team - May 11, 2022



Wrightbus lands "historic" deal with Republic's NTA for up to 800 electric buses



Irish Transport minister Eamon Ryan and NTA chief Anne Graham pictured with the Wrightbus Streetdeck Electroliner BEVs, which will roll out in the Republic from next year. Picture by Julien Behal.

BUS AND COACH TNB NEWS

Go-Ahead orders 20 Wrightbus hydrogen buses

11 NOVEMBER 2021 #BUS AND COACH #TNB NEWS

Wrightbus secures order for 60 hydrogen-powered buses from Germany

UTV | BUSINESS | TRANSPORT | ENVIRONMENT | Friday 27 May 2022, 12:57pm



60 Kite Hydroliner single deck buses will be delivered to German Bus operator Regionalverkehr Köln GmbH
Credit: Wrightbus

Translink: First zero-emission buses set to hit the streets

The 77 battery-electric and 23 hydrogen buses will form around a third of the Belfast fleet by this summer.



NEWS

MAY 6, 2022

Wrightbus Zero-Emission
Hydrogen Buses Travel 1 Million
Miles

Is Battery EV or Fuel Cell EV right for me?

Wrightbus are the only technology agnostic bus manufacturer that offers BEB and FCEB in both single and double deck, with the key emphasis on commonality

The Zero-Emission Challenge

What are the challenges to address to reach our Zero-Emission Goal?

- ◆ Total Cost of Ownership?
- ◆ Available range?
- ◆ Operational flexibility?
- ◆ Impact for longer duties?
- ◆ Operation from multiple depots?
- ◆ Time to recharge vs refuel?
- ◆ Availability of power / fuel?
- ◆ Infrastructure costs & timescales?
- ◆ Life cycle carbon footprint?

Efficient Diesel?



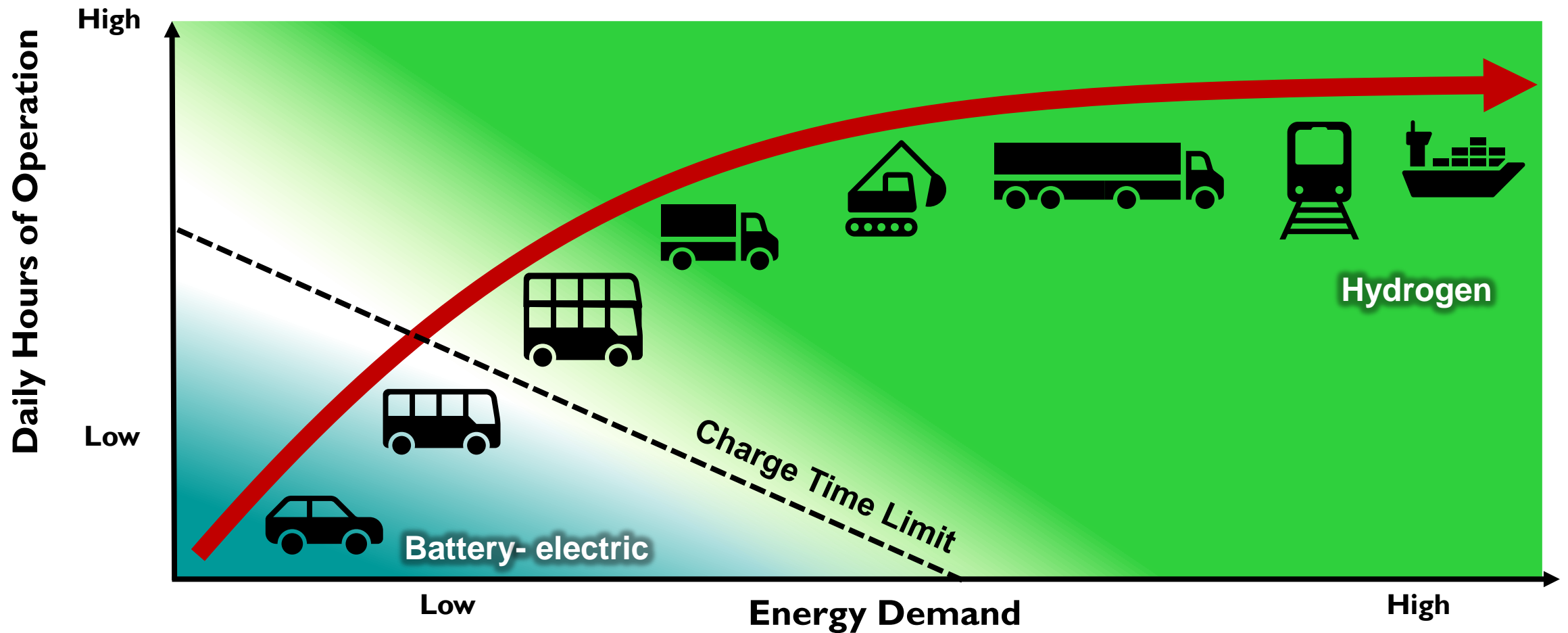
Battery EV?



Fuel-cell EV?

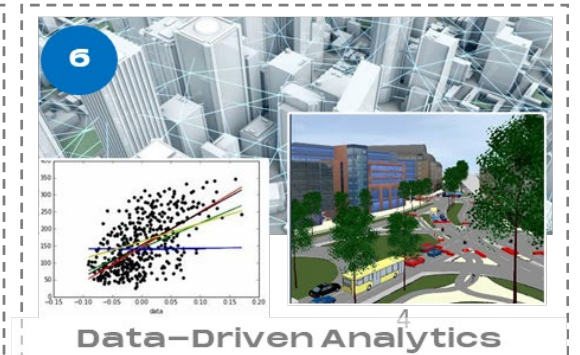
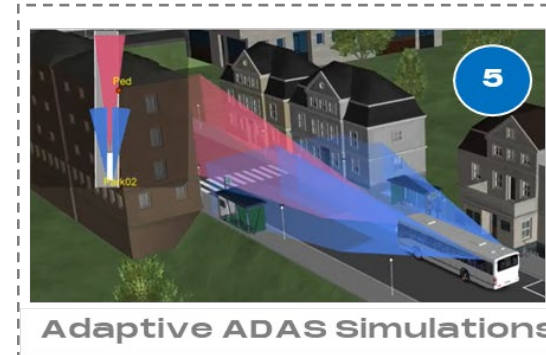
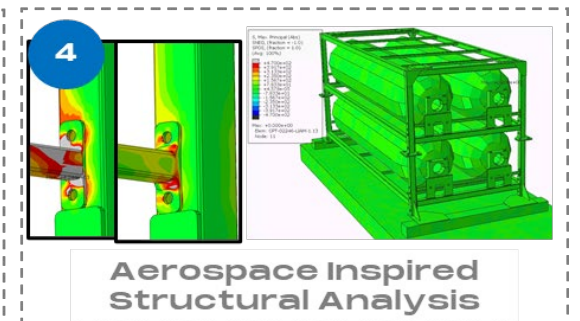
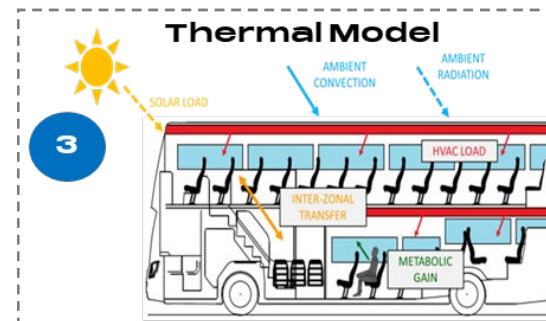
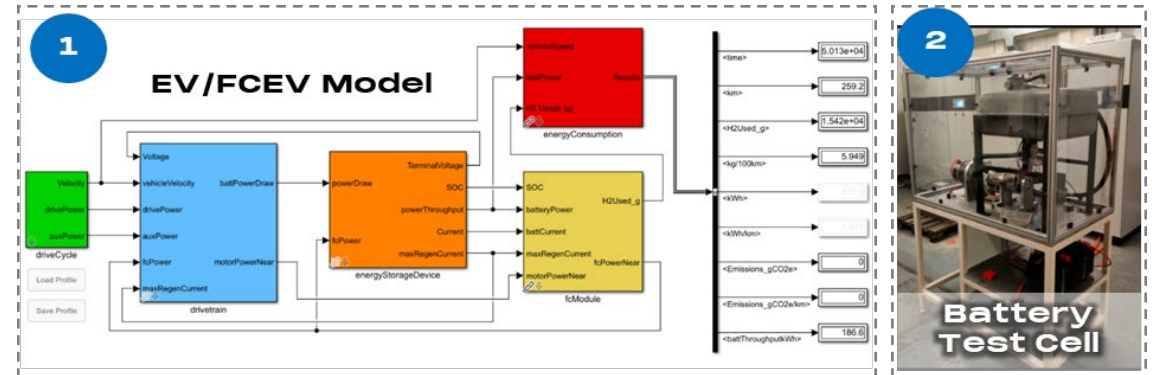


Vehicle Use Case

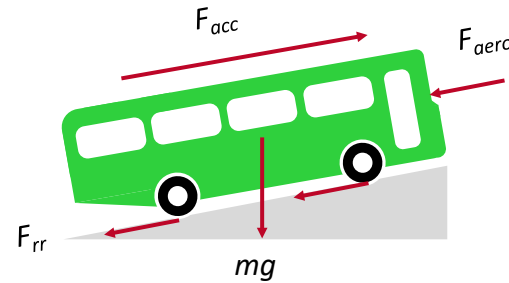
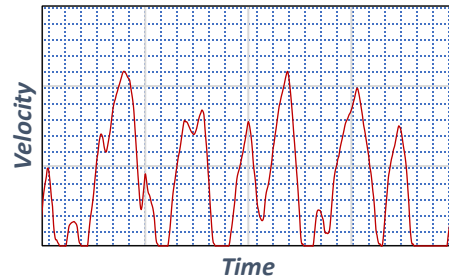


Academic Foundations

- ▶ Over 25 years of direct collaboration between Wrightbus and Queens University, Belfast.
- ▶ Establishment of Wright Technology & Research Centre at Queen's University Belfast, formally launched in 2016.
- ▶ Key aim to promote research and advanced engineering which can meet the future needs of the industry.
- ▶ £28M in collaborative research projects.
- ▶ Vital research & collaboration for net-zero:
 - ▶ Pushing forward emerging tech & innovations.
 - ▶ Upskilling next generation of engineers.
 - ▶ Positively impacting economy & environment.



Technology Recommendation



(1) Identify Routes for Analysis

- ▶ Bus/route cards
- ▶ Scheduling/timetable data
- ▶ Dedicated/intertwined services
- ▶ Routes for tender

(2) Generate Duty Cycles

- ▶ Velocity/elevation profile of the bus: *bus-stops, traffic, driver behaviour acceleration/braking, etc*

(3) Vehicle Simulations

- ▶ Power demands.
- ▶ Energy/ fuel-consumption.
- ▶ HVAC settings / variable temperature setpoints.

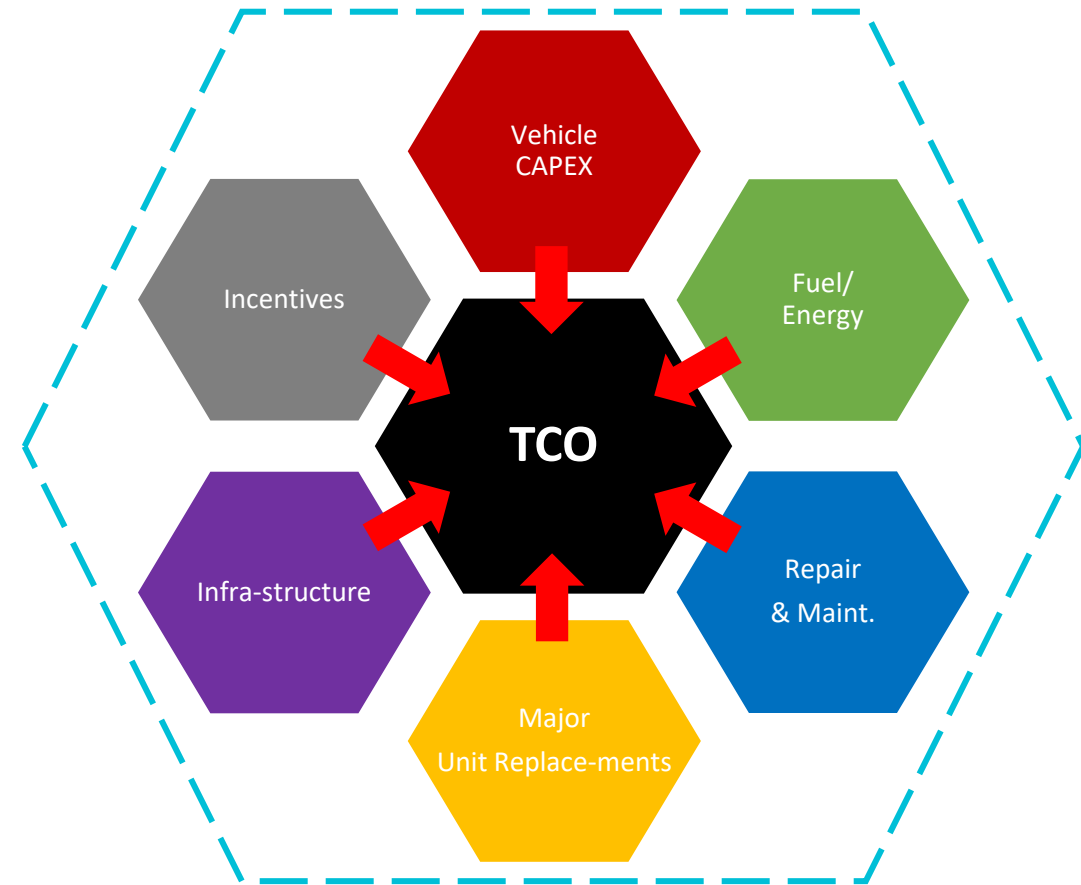
Technology Recommendation (FCEV or EV?)

- Complete the daily maximum distance?
- Range/remaining capacity
- Complete in winter/summer conditions?
- Number of refuel/ recharge events?
- Opportunity charging required?

TCO Estimates

TCO Modelling

- ▶ **In-house TCO (Total Cost of Ownership) modelling capability** linked with vehicle simulation models.
- ▶ Analysis of **Diesel vs. FCEV vs. BEV**.
- ▶ Life cycle modelling of CAPEX, Fuel, Maintenance, Infrastructure, Incentives, etc.
- ▶ **1 to 15 year cost forecasting**, sensitive to an operators annual distance (km), operating hours, duty cycle, etc..
- ▶ **Scenario analysis** of present/future fuel costs, energy consumption, R&M metrics, inflation, tariffs, fleet sizing, etc.
- ▶ **'What if?' Analysis**, E.g....what does hydrogen/electricity target cost need to be to reach parity with diesel?





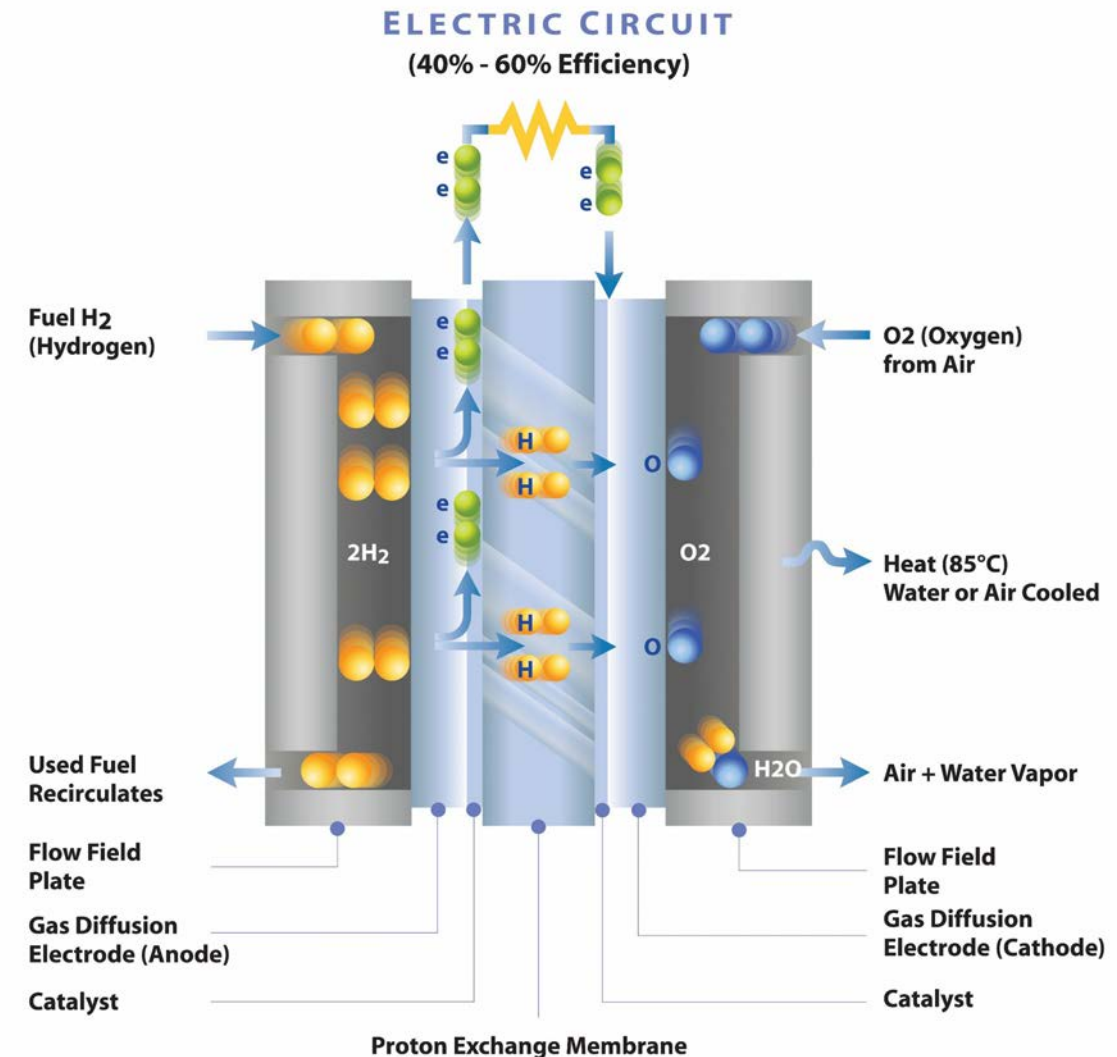
Zero Emission Product Range

Wrightbus has focused on cutting edge powertrain technology, developing our first EV in 1998, our first diesel hybrid in 2002, our first FCEB in 2006.

How a fuel-cell works

A fuel cell combines hydrogen fuel and oxygen from the air to produce electrical energy efficiently, quietly and reliably. The only by-products are water and heat.

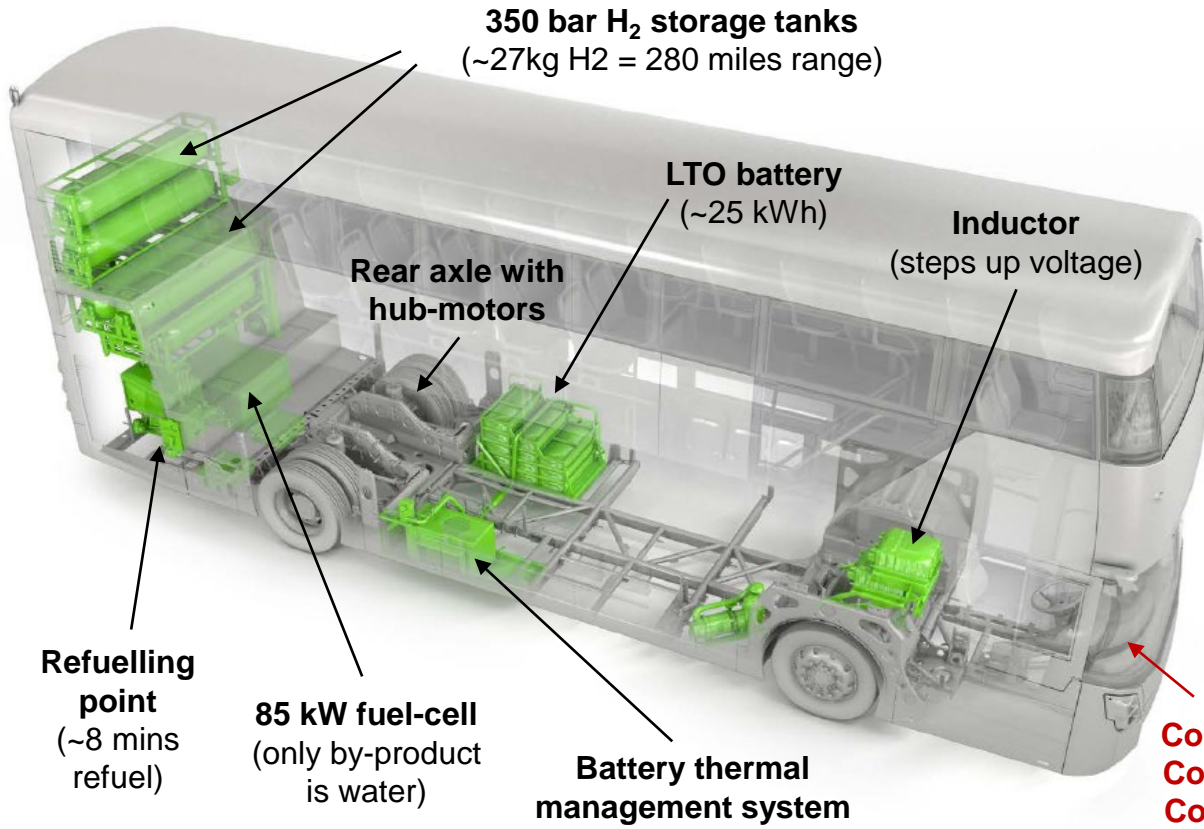
- ▶ Fuel cells produce electricity without combustion.
- ▶ Generate little (if any) noise and vibration.
- ▶ No air pollutants (NO_x, CO, Particulate matter, soot, etc.)
- ▶ No greenhouse gases (CO₂, Methane, Nitrous Oxides)
- ▶ Unlike batteries, fuel cells do not have a need for replacement or lengthy recharging when its fuel is spent.
- ▶ Fuel stored in external tanks, so the maximum operating range of a fuel cell-powered device is limited only by the amount of fuel that can be carried.



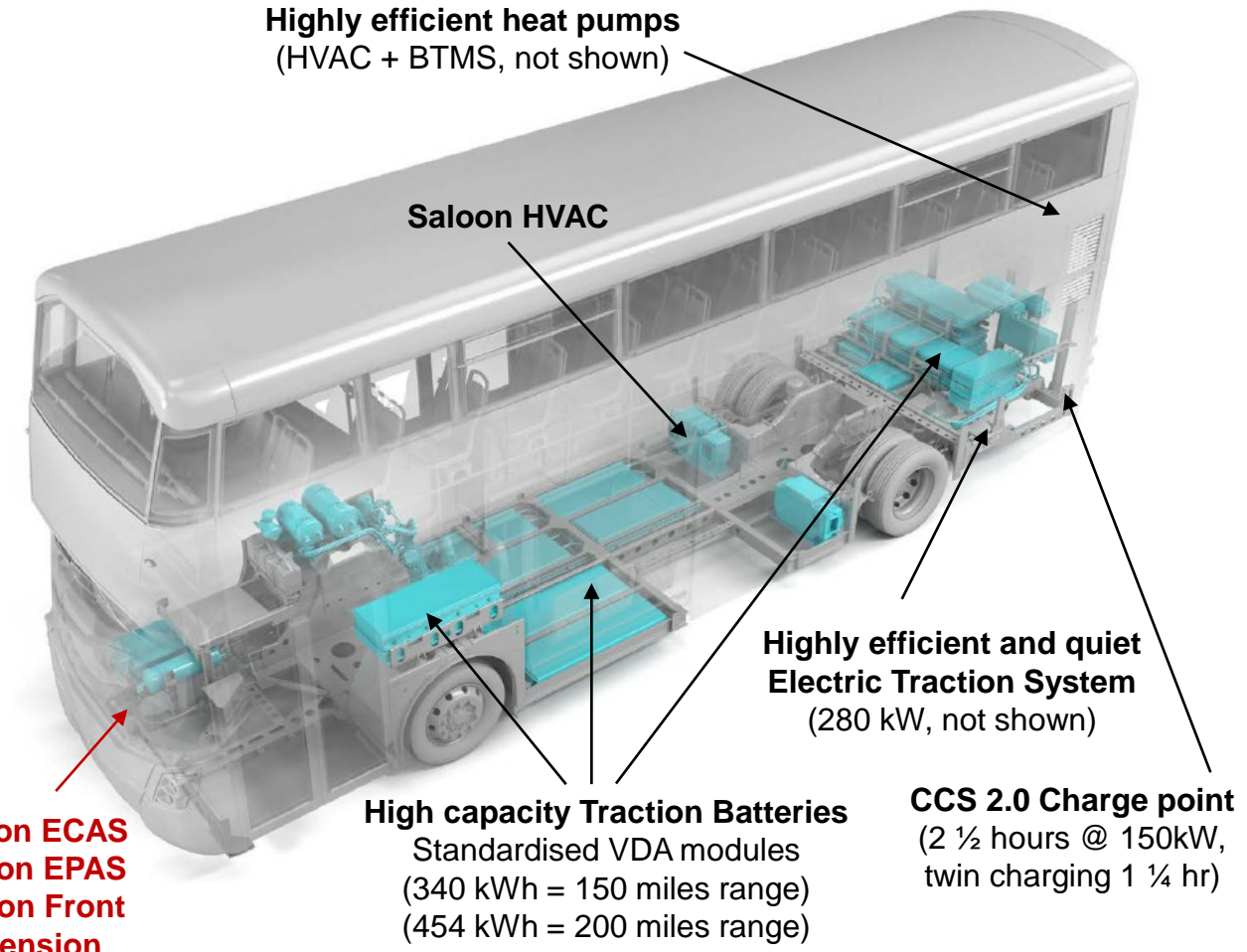


STREETDECK FCEV | **HYDROLINER**

Hydrogen Fuel-Cell



Common ECAS
Common EPAS
Common Front Suspension



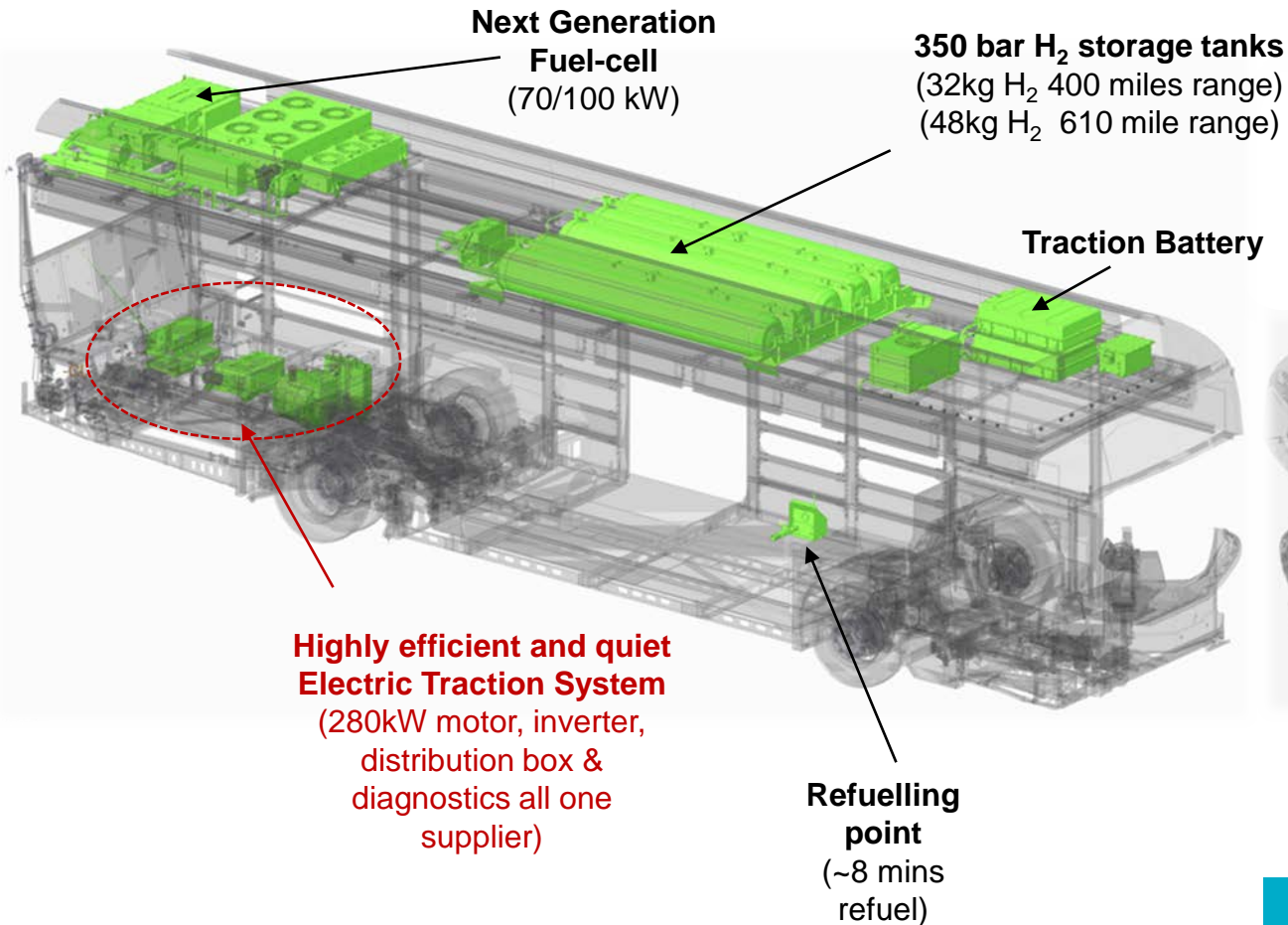
Battery-Electric

STREETDECK BEV | **ELECTROLINER**



GB KITE DF FCEV | **HYDROLINER**

Hydrogen Fuel-Cell

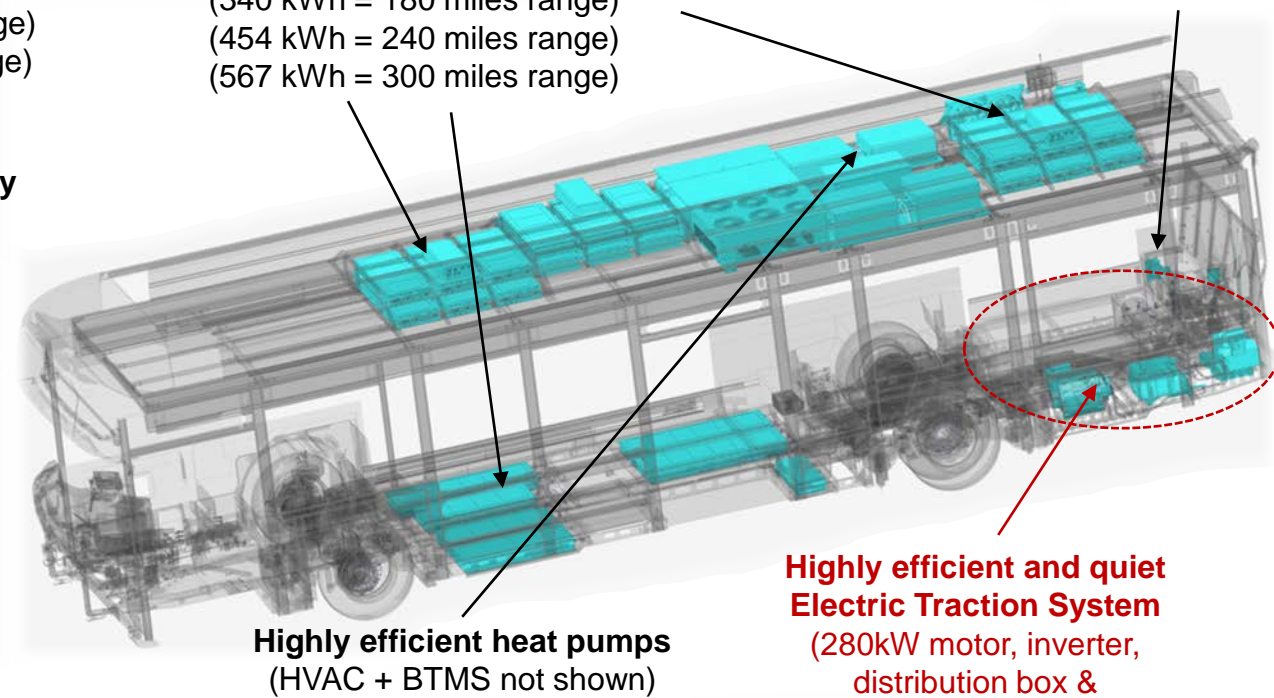


High capacity Traction Batteries

- Standardised VDA modules
- (340 kWh = 180 miles range)
- (454 kWh = 240 miles range)
- (567 kWh = 300 miles range)

CCS 2.0 Charge point

(2 ½ hours @ 150kW, twin charging 1 ¼ hr)



Battery-Electric

GB KITE DF BEV | **ELECTROLINER**

Energy Efficiency / Operational Flexibility

Diesel Euro IV			Hydrogen			Battery Electric				
Tank capacity	200	litres	H ₂ storage	35	50	kg	Battery capacity	340	454	kWh
Typical Efficiency	8.5	MPG	Typical Efficiency	6		kg/100km	Typical Efficiency			
	4.2	kWh/km		2.0	2.0	kWh/km		0.95	0.97	kWh/km
Range	~600	km	Range	~585	~830	km	Range	~280	~375	km
	~375	Mile		~365	~520	miles		~180	~235	miles

- ▶ **BEVs more energy efficient** on less energy demanding routes, but limited on range without on-route infrastructure.
- ▶ **FCEVs provide greater operational flexibility** (not route/depot locked).
- ▶ **Both technologies complementary** – stakeholders should identify best fit to satisfy operational & cost constraints.
- ▶ **Consider daily operational demands**, e.g. minimum mileage, available charging time, # buses + drivers.
- ▶ **Low/zero-carbon sources** of both electricity/hydrogen should always be sourced where possible.

Future of Hydrogen

Falling Total Cost of Ownership

- Step change in costs of fuel-cell modules, H₂ storage tanks and EV drivelines.
- Scaling up production of low carbon H₂ via water electrolysis.
- Increasing fuel-cell stack durability, decreasing maintenance costs.

Improving efficiency

- Control and optimization of powertrain to minimize fuel-consumption.
- Greater use of fuel-cell waste heat for heating interior of bus.

Links with Other Industries

- Coach, shipping and off highway are now turning to Hydrogen
- H₂ combustion engines for coach, ships, trains, off-highway, etc...



Thanks for Listening!

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