Hydrogen Winter School – University of Birmingham

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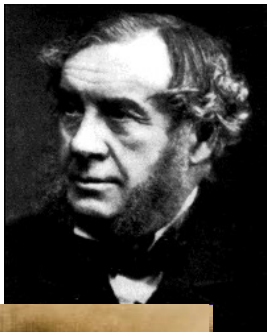
Fuel cells for transport applications & Hydrogen fuel infrastructure

Funded by UKRI Research England

Lead academic partners: Energy Research Accelerator, Keele University, Midlands Innovation

Fuel Cell History: Invention



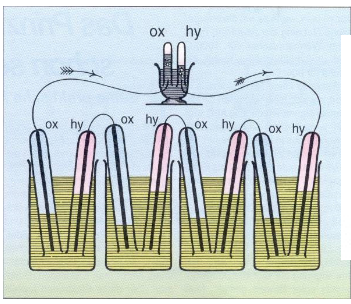
Sir William Grove 1811-1896

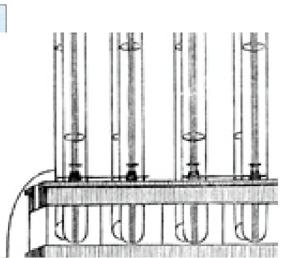
Christian Friedrich Schönbein 1799 – 1868

Fr. Wilh. Ostwald 1853-1932

Fundamentals of fuel cell principle:

- Reciprocal process to electrolysis: hydrogen and oxygen gasses recombine, producing electricity
- A battery in ‚permanent' operation





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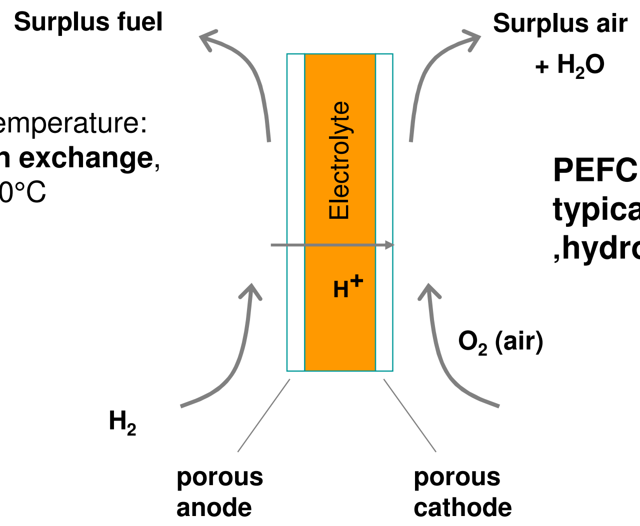
Fuel cells for dummies

- Low temperature: **proton exchange**, ca. 100°C



PEFC:
typical
‚hydrogen fuel cell‘

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Reaction Equilibrium: Fuel Cell Case

Cathode side	$1/2\ O_2 + 2H^+ + 2e^-$	$\longrightarrow$	H_2O
Anode side	H_2	$\longrightarrow$	$2\ H^+ + 2e^-$
Overall reaction	$H_2 + 1/2\ O_2$	$\longrightarrow$	H_2O

U_o (open circuit) is identical to that of electrolysis (but negative!)

$\Delta G^o = 2F\ U^o_o = -237$ kJ/mol (at STP, for H_2 - O_2 cell)

$U^o_o = 1{,}23$ V (for convenience, U is not marked as negative)

i.e. energy is released.

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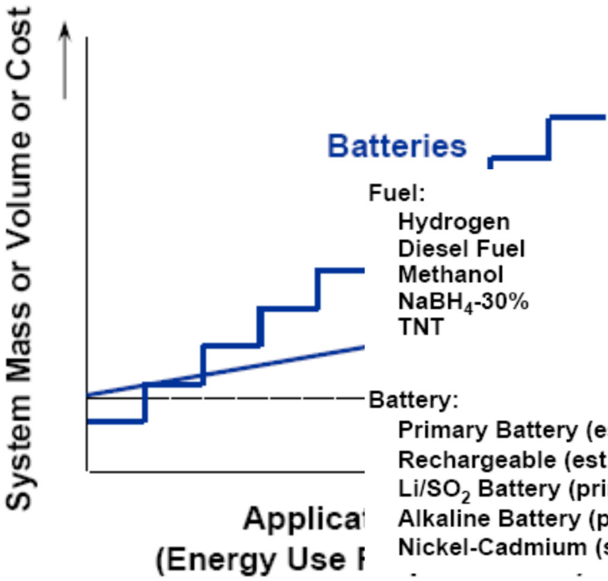
Competing with Batteries



Fuel:	Specific Energy (Wh/kg)
Hydrogen	33,000
Diesel Fuel	13,200
Methanol	6,200
$NaBH_4$-30%	2,500
TNT	1,400
Battery:	
Primary Battery (est. max.)	500
Rechargeable (est. max.)	200
Li/SO_2 Battery (primary)	176
Alkaline Battery (primary)	80
Nickel-Cadmium (secondary)	40

Source: AZ State Univ

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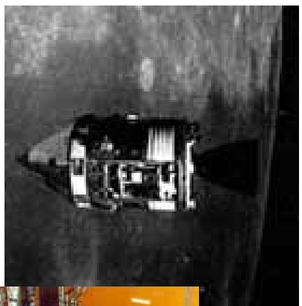
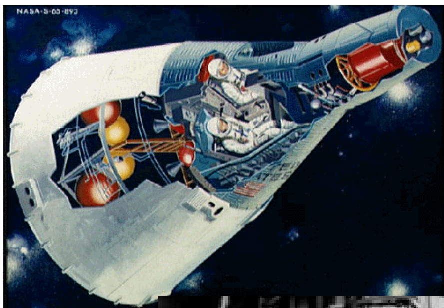
Fuel Cell Development in Space

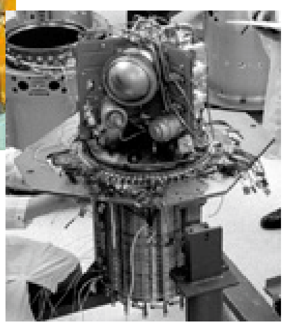


Apollo Missions

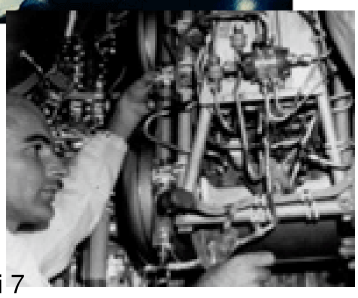


Gemini Missions

UTC Apollo Unit

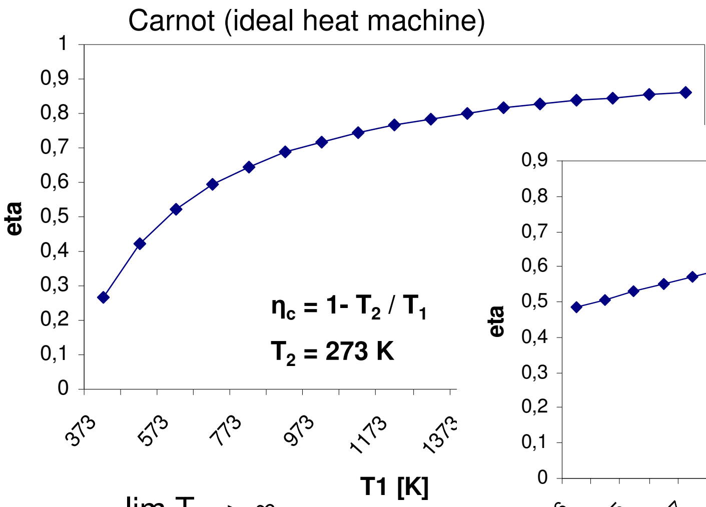


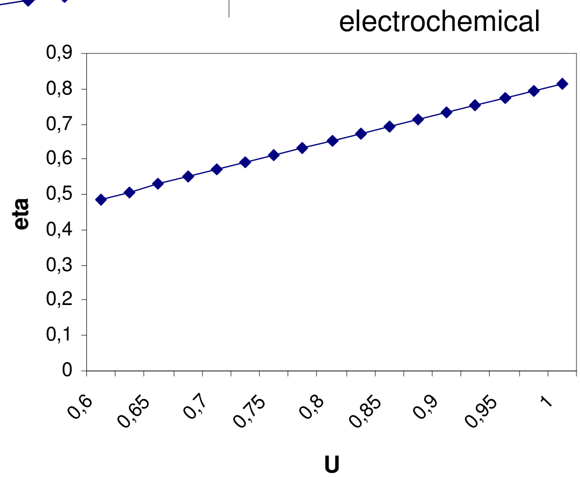
Pratt&Whitney AFC , Apollo 1964



Gemini 7 PEFC 1965

Limiting Efficiencies



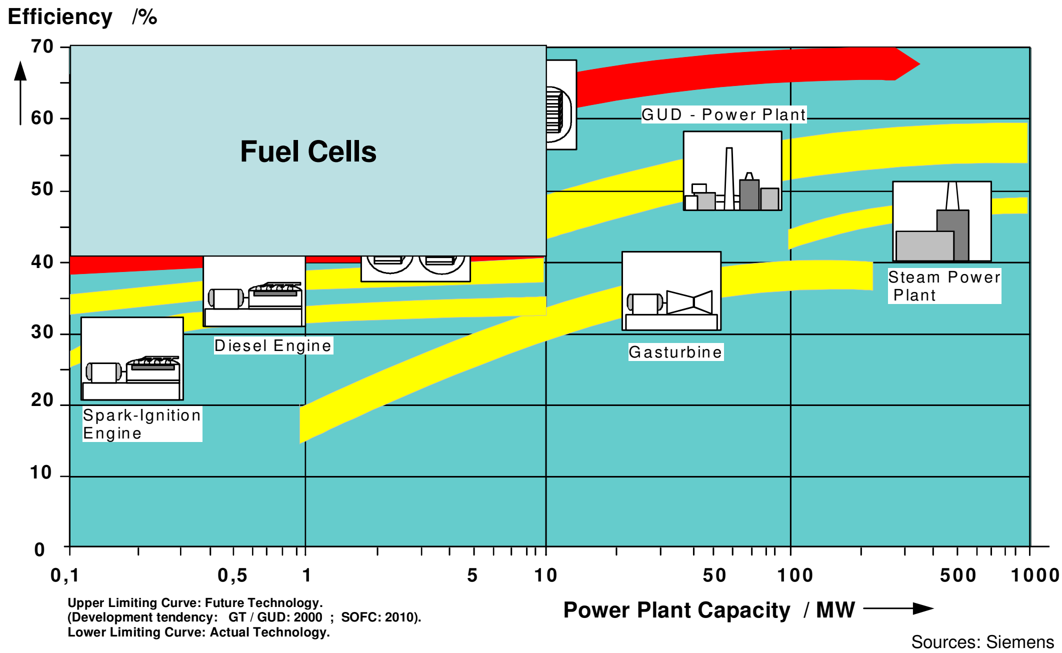


$\lim T_1 \to \infty$

$\lim T_2 \to 0$

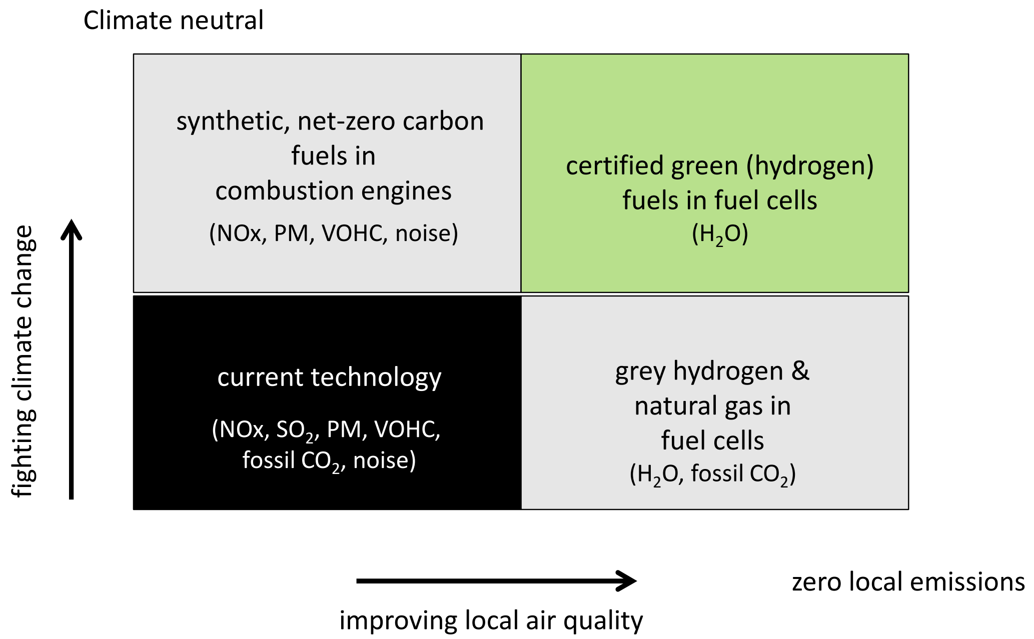
$\lim U \to U^o_o$

Fuel Cells: High Efficiency Electricity Production



Sources: Siemens

Global vs. Local Zero Emissions



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Overview Fuel Cell Types

	Low temperature			**High temperature**	
	AFC	**PEFC**	**PAFC**	**SOFC**	**MCFC**
Electrolyte	Alkaline	Polymer	Phosph.acid	Ceramic	Molten carbonate
Temperature	80-200°C	80-100°C	200°C	700-1000°C	650°C
Fuel	H_2	H_2	H_2	H_2/CO/CH_4	(H_2)/CO/CO_2 /CH_4
Oxidant	O_2/(air)	O_2/air	O_2/air	O_2/air	O_2/air
Efficiency (*)	50-60%	40-45%	40-45%	50-55%	50-55%

(*) LHV

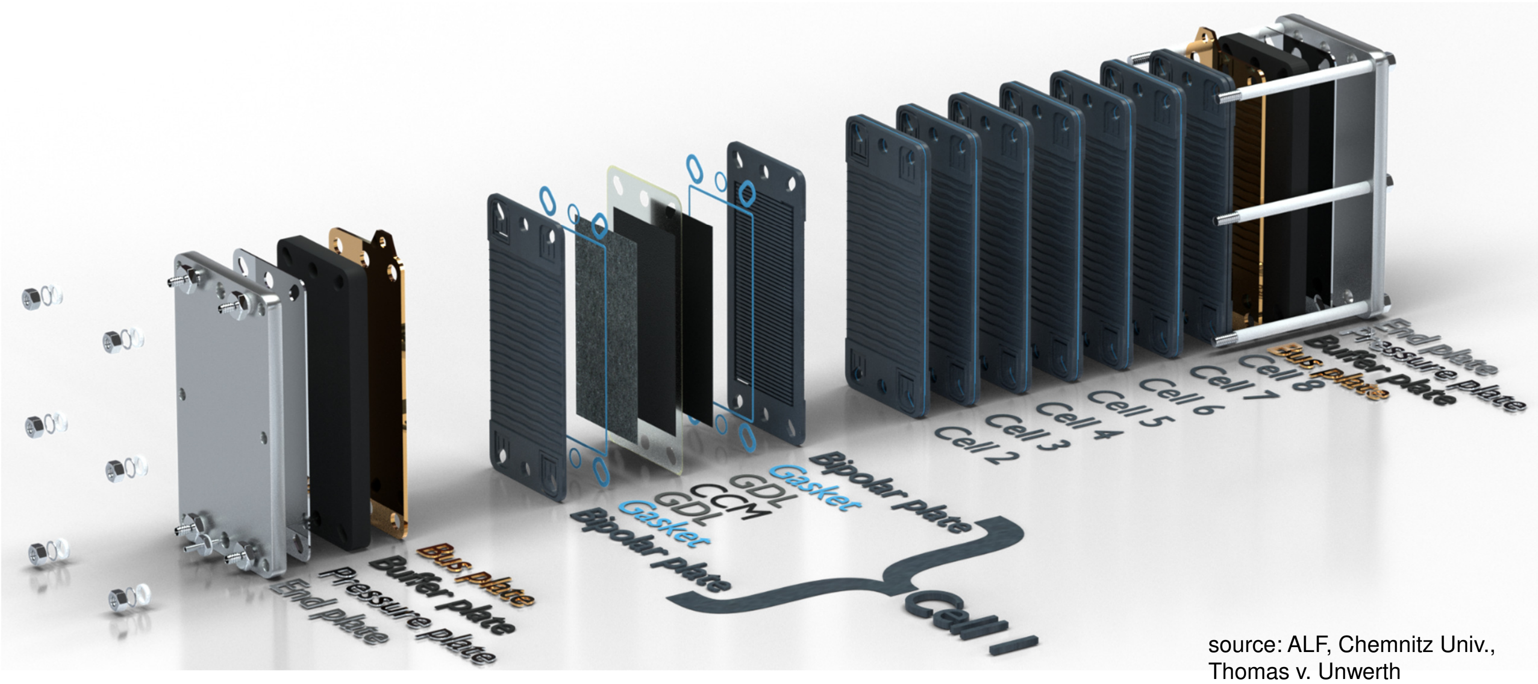
PEFC →

DMFC	**HT-PEFC**
80-100°C	120-180°C
MeOH	H_2 (CO)
25-30%	40-50%

SOFC →

LT-SOFC
500-650°C
H_2/(CO)/CH_4
50-55%

Anatomy of a fuel cell stack



source: ALF, Chemnitz Univ.,
Thomas v. Unwerth

Key components

Sources: Audi, Daimler, Hyundai VW, TU Chemnitz

Hyundai iX35

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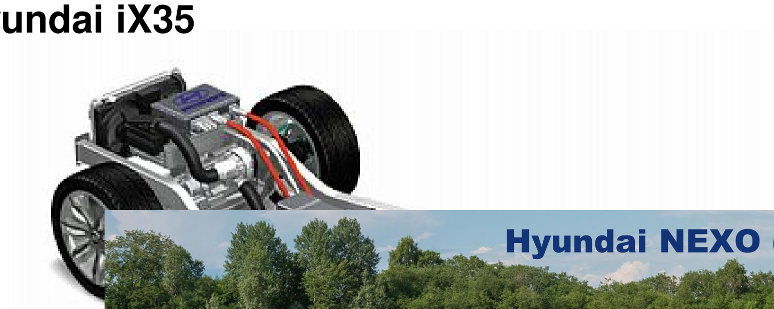

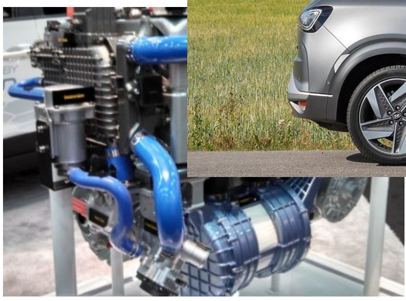

	4,410 mm
	1,820 mm
	1,655 mm
	594 km
	.95 kgH_2/100km
	7.8km/ℓ (NEDC)
Top speed	160 km/hr
Acceleration, 0 to 100 km/hr	12.5 seconds
Fuel cell output power	100 kW
Energy storage system	Battery, 24 kW
Fuel	Hydrogen (700 bar, 5.6 kg)
Exhaust gas	Water vapour

source: Hyundai, ALF, Chemnitz Univ., Thomas v. Unwerth

Toyota Mirai

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- 5 kg of compressed H_2 @ 700 bar = range of ~ 500 km
- 114 kW fuel cell system & small battery, 113 kW electric motor
- Curb weight: 1850 kg
- Top speed: 178 km/h

source: Toyota, ALF, Chemnitz Univ., Thomas v. Unwerth

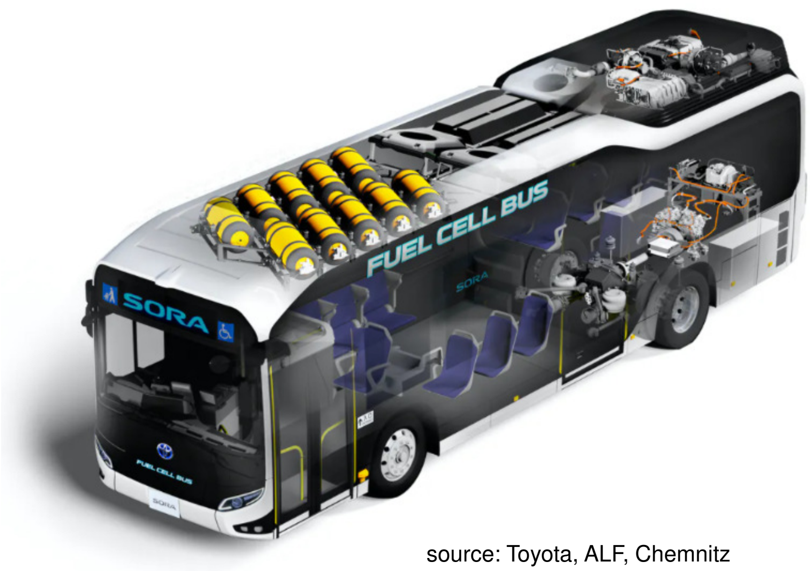
Hyundai Xcient HDV truck

Vehicle	Hyundai Xcient Fuel Cell
Power	350 kW
max. Torque	3.400 Nm
Gearbox	6-gear + 1 back
Battery	
Supplier	Akasol
Capacity	73,2 kWh
Wärmemanagement	Liquid cooled
Battery voltage	661 V
Fuel Cell	
Type	2x Proton exchange membrane (PEM)
Power FC	190 kW (2x 95 kW)
Hydrogen storage	32,09 kg bei 350 bar
V max	85 km/h
Range	ca. 400 km
L x W (without mirrors) x H	9,745 m/2,515 m/3,730 m
Wheelbase	5,130 m
Empty weight	9,795 t
Gross weight	34 t with trailer, 19 t as box wagon

source: Hyundai, ALF, Chemnitz Univ., Thomas v. Unwerth

FC Buses – design and package samples

Toyota Fuel Cell Bus (2018)



source: Toyota, ALF, Chemnitz Univ., Thomas v. Unwerth

Vehicle	**Name**	**Sora**
	Length / width / height	10,525 / 2,490 / 3,350 mm
	Capacity (seated, standing, and driver)	79 (22+56+1)
FC stack	Name (type)	Toyota FC Stack (solid polymer electrolyte)
	Maximum output	114 kW × 2 (155PS × 2)
Motor	Type	AC synchronous
	Maximum output	113 kW × 2 (154PS × 2)
	Maximum torque	335 N·m × 2 (34.2 kgf·m × 2)
High-pressure hydrogen tank	Number of tanks (nominal working pressure)	10 (70 MPa)
	Tank internal volume	600 liters
Drive battery	Type	Nickel-metal hydride
External power supply system*2	Maximum output / power supply amount	9 kW / 235 kWh

Wrightbus (UK)

- Belfast-based, established 1946
- only manufacturer of double decker FC buses

- Streetdeck (double decker) and GB Kite types
- 27 kg H_2, 35 Mpa
- battery capacity 48 kWh, plug-in hybrid
- range on hydrogen 250 mi, total range 280 mi

source: Wrightbus

China‘s increasing activities

source: ALF, Chemnitz Univ., Thomas v. Unwerth

KING LONG

King Long Buses go into service at Fuzhou 2019 (Fujian Province)

YUTONG

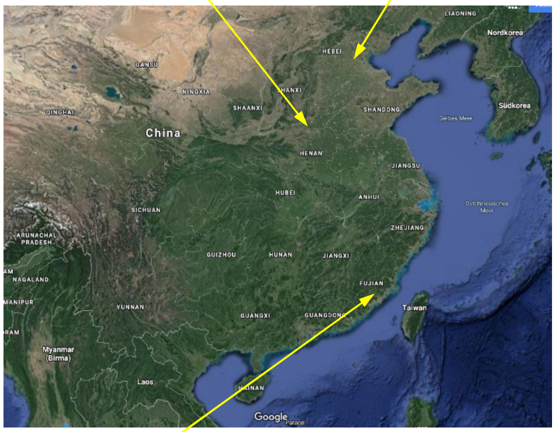
20 Yutong buses for Zhengzhou 2019 (Henan province)

FOTON

40 Foton buses for Zhangjiakou 2019 (Hebei Province)

Yutong Bus, Zhengzhou (100.000 buses / year)

Foton Motor, Beijing (70.000 buses / year)



King Long Bus, Xiamen (>10.000 buses / year)

Just a sample number for Beijing: ~36.000 conventional buses in service

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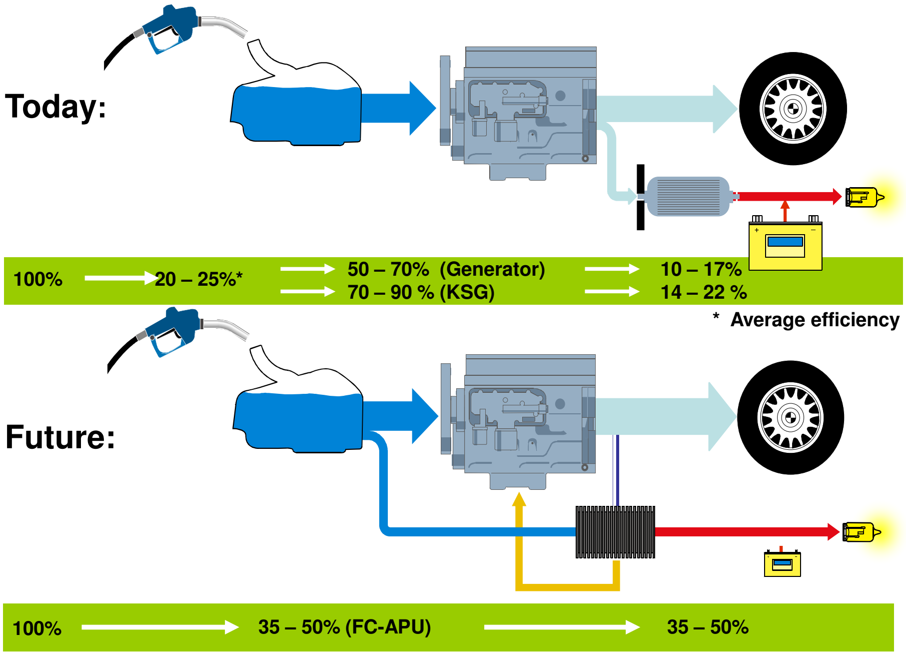
Auxiliary Power Units (APU)



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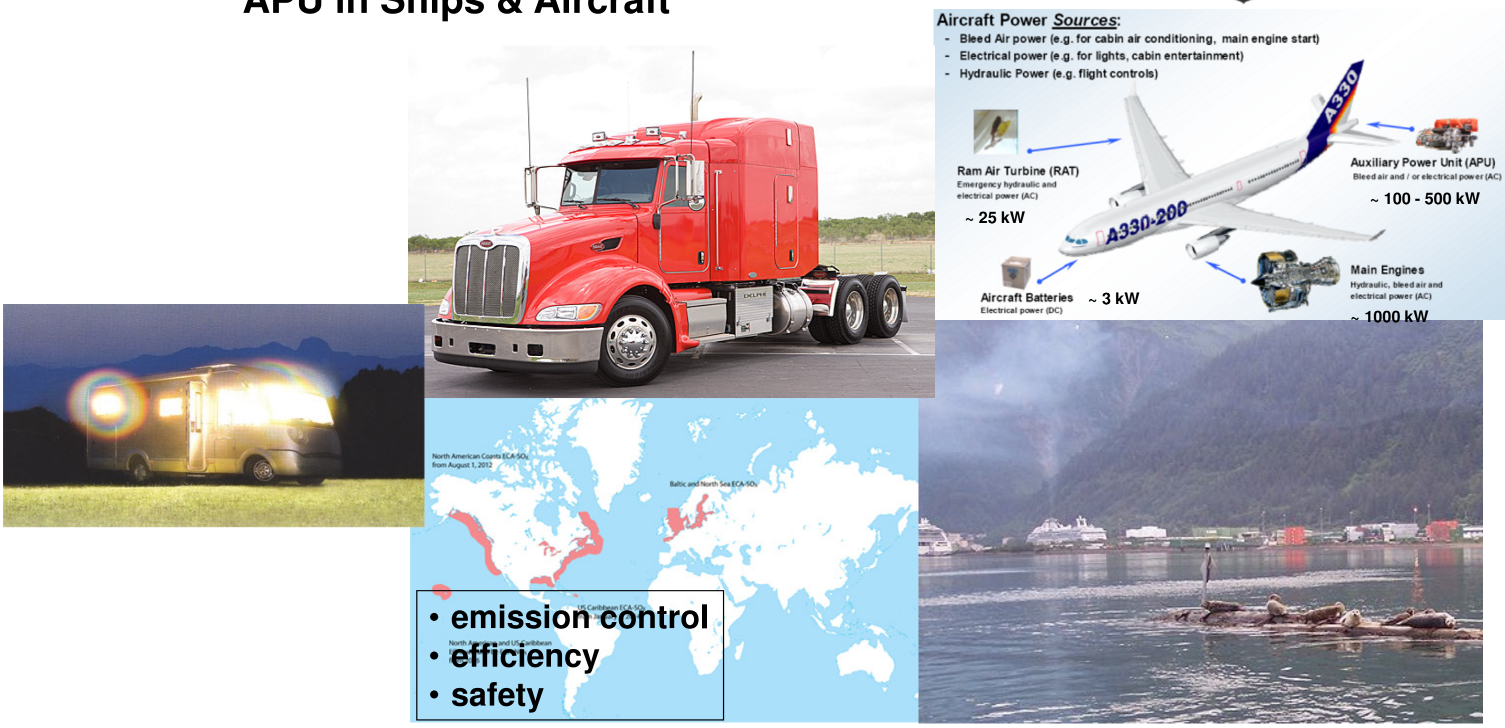
APU in Ships & Aircraft



sources: Delphi, wikipedia & Lloyd's register

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Hydrogen boats

- Ross Barlow canal boat in Birmingham
- fuel cell and Metal Hydride storage

FC Electric Flight

Motivation

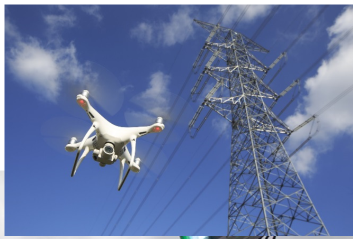
- noise
- pollutant emissions from airports.
- extending airport operations into the night
- more efficiency from electric motors
- less GHG emissons from transport

Zero Avia

First flight from Cranfield, UK, Sept 2020

Off-Road and Building Site Equipment

- Increasing number of electrical building site equipment since 2018
- Issues with daily operating time and range



Source: Construction Enquirer, EcoPlantHire

Hydrogen road and non-road applications

source: ALF, Chemnitz Univ., Thomas v. Unwerth

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Mobile Applications: Road, Off-road, Logistics, Aviation, Rail, Maritime

Fuel cell vehicles (Source: CaFCP)
Fuel cell HDV in Switzerland (Source: Hyundai)
Fuel cell garbage truck (Source: Baden-Würtemmberg.de)

Fuel cell bus from Toyota (Source: Toyota)
Fuel cell fork lift (Source: Still)
Fuel cell excavator (Source: JCB)

Coradia iLint (Source: Alstom)
Zero-e (Source: Airbus)
Yacht hydrogen powered (Source: Toyota)

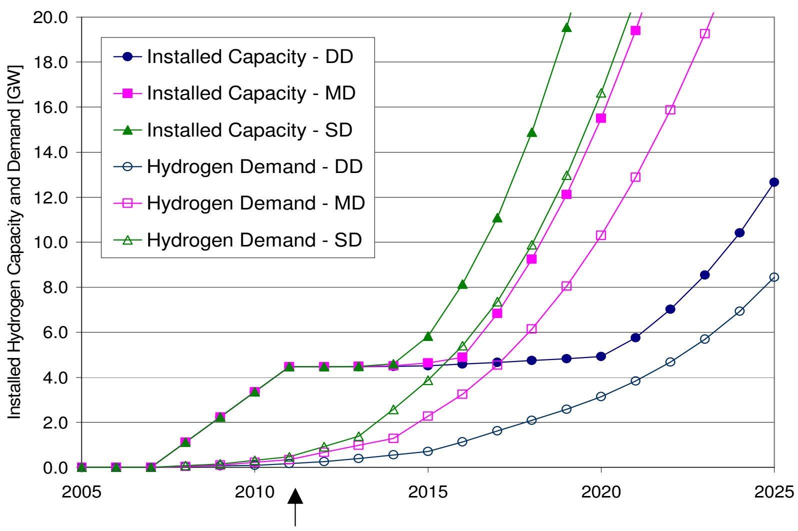
Loco with 5x200kW (Source. Nuvera)
Antares H2-plane (Source: DLR)
Ship, onboard power supply (Source: HDW)

Aberdeen Bus Depot (HyVeloCity project)

- Linde technology (BOC)
- status 09/2019:
- 3,000 fillings
- 99.9 % availability
- 55 MPa tube storage, cascading
- 2 x 35 MPa dispensing
- Linde IC90 compressor
- local hydrogen production via electrolysis

source: Linde

Infrastructure: U.S. Scenario (fuel stations)



Projection for U.S.:
- DD delayed
- MD moderate
- SD successful development

From: M.Melaina, J.Hydrogen Energy, 2003

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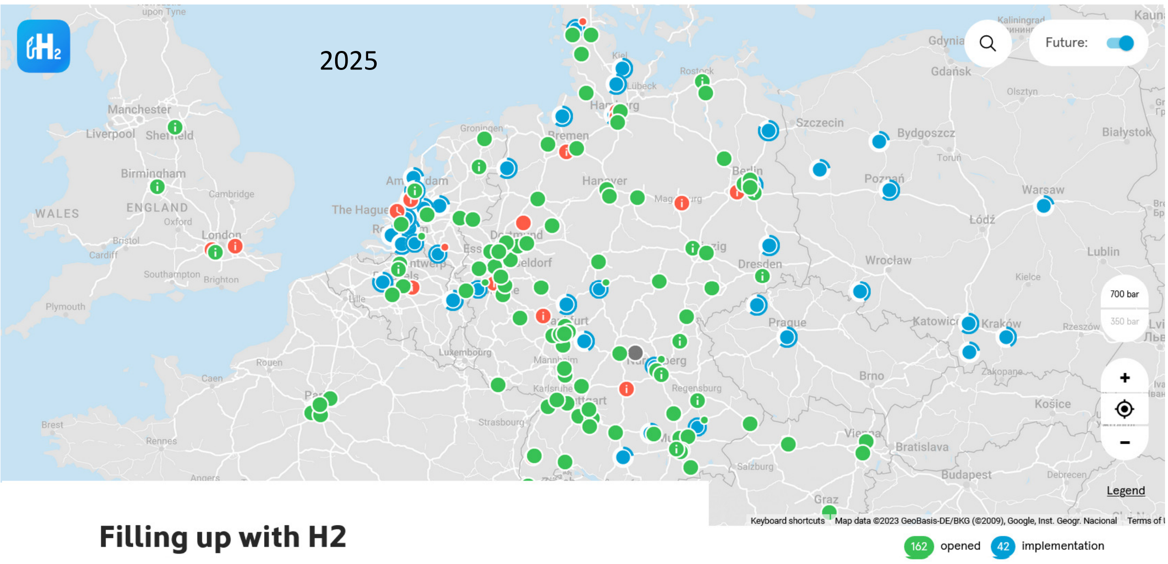
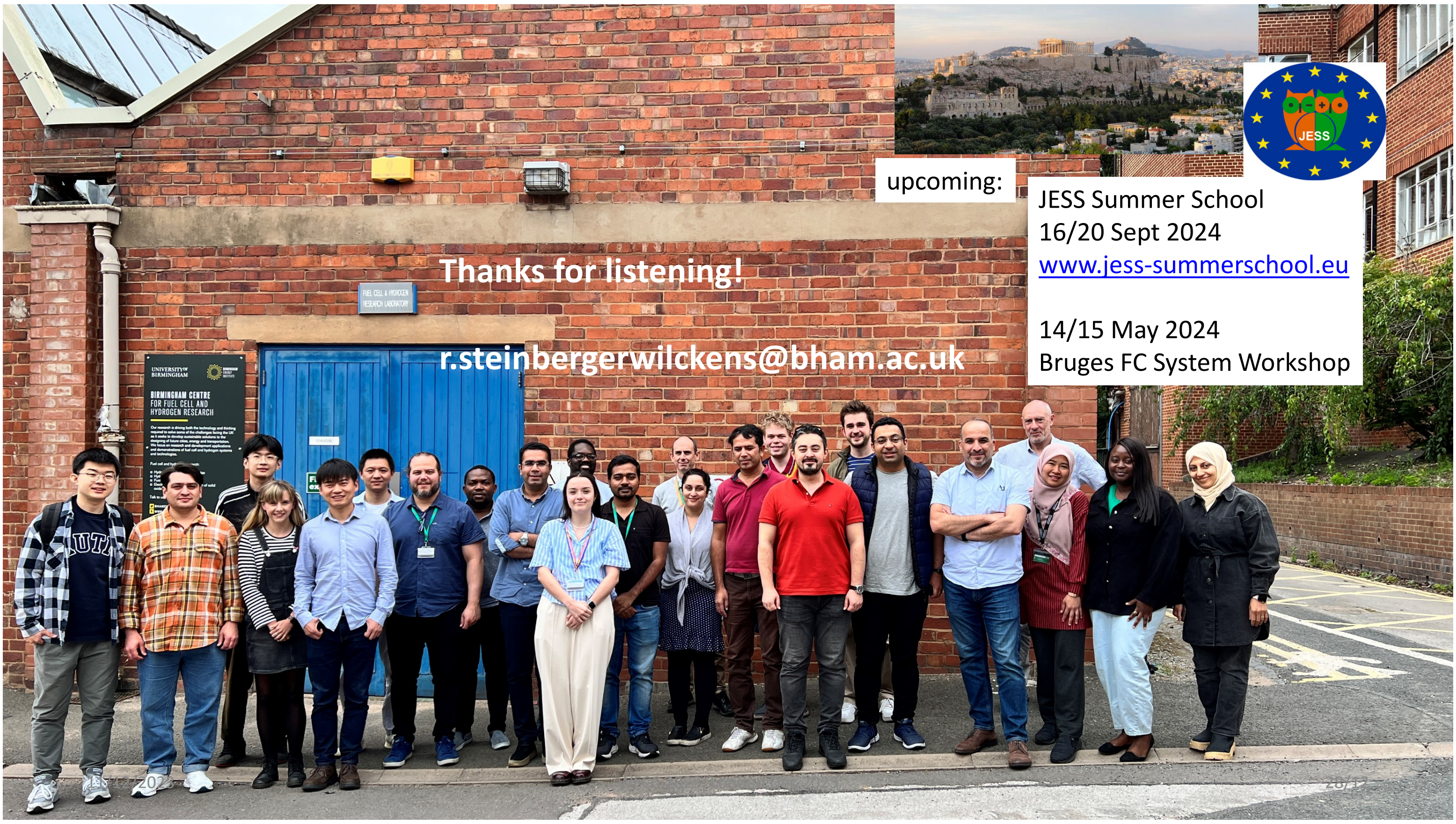
European Hydrogen Infrastructure



Filling up with H2

- hydrogen refuelling infrastructure is cheaper than public electrical charging and has less impact on the electricity grid operation

Source: h2.live



Thanks for listening!

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upcoming:

JESS Summer School
16/20 Sept 2024
www.jess-summerschool.eu

14/15 May 2024
Bruges FC System Workshop