

Overcoming the Challenges to FCEB Fleet Adoption – Hydrogen Infrastructure

CHBC Workshop

Diving Deeper into Fuel Cell Electric Buses

September 11, 2018

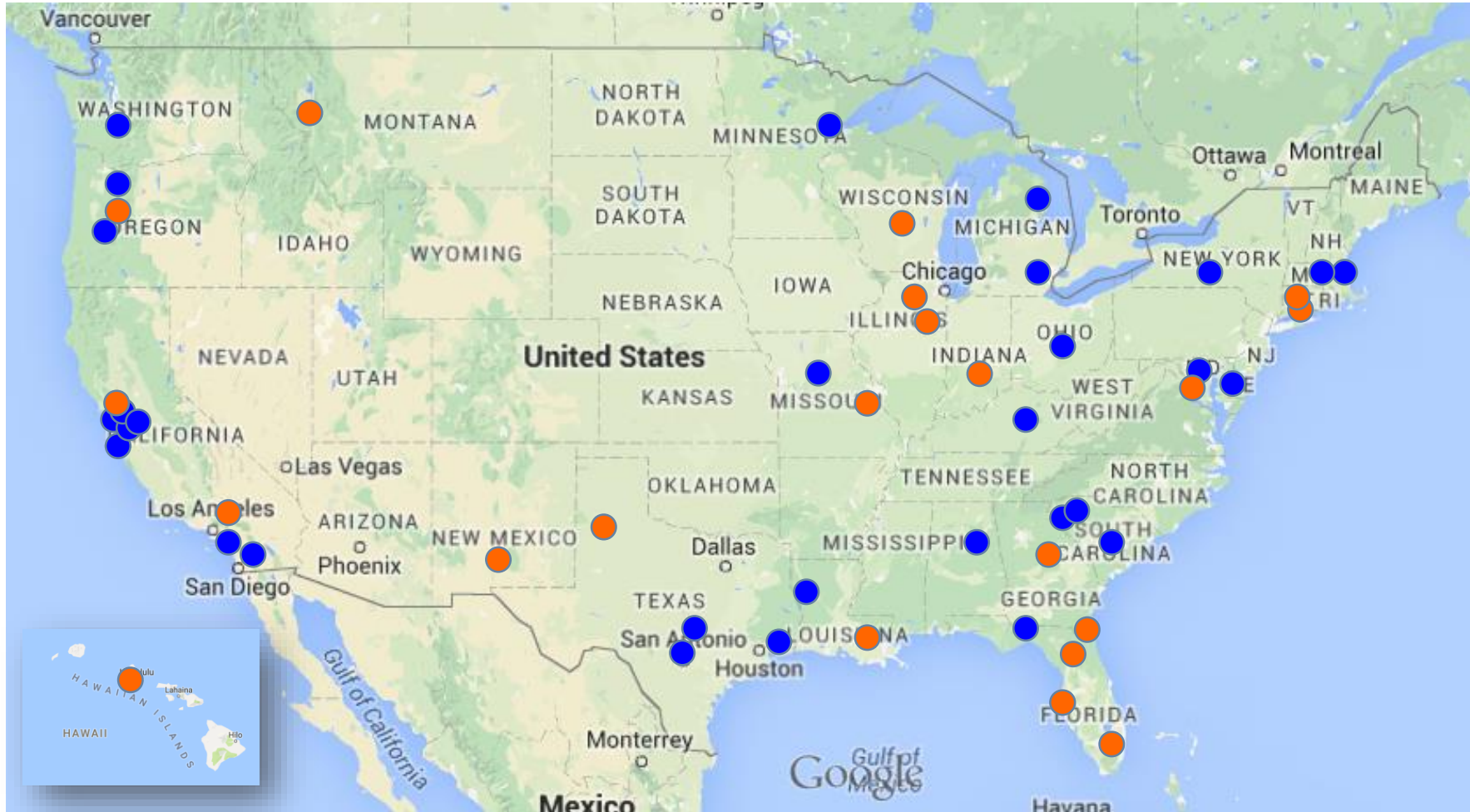


Hydrogen Means Business in California!



Jaimie Levin
Sr. Management Consultant
CTE

CTE ZEB Projects

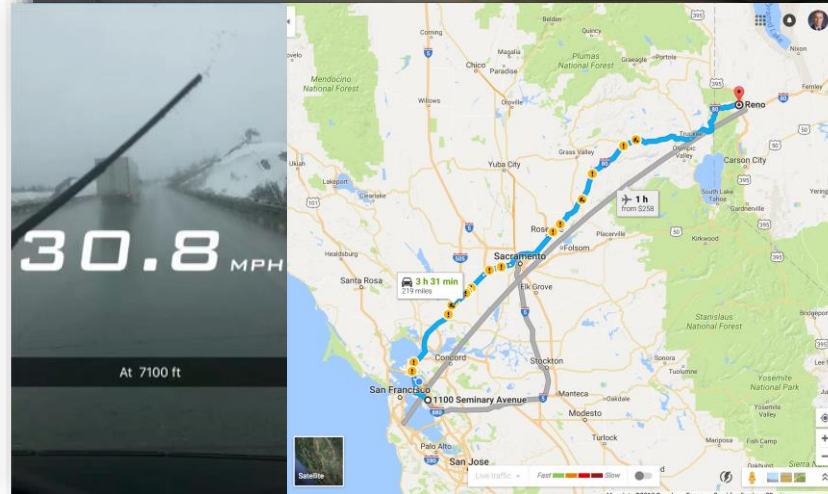


- Existing Zero Emission Bus (ZEB) Projects (more than 140 ZEB's with over 30 Transit Agencies)
- 2017 Low-No Awards with CTE (more than 50 ZEB's with 25 Agencies)

30,000 Hours

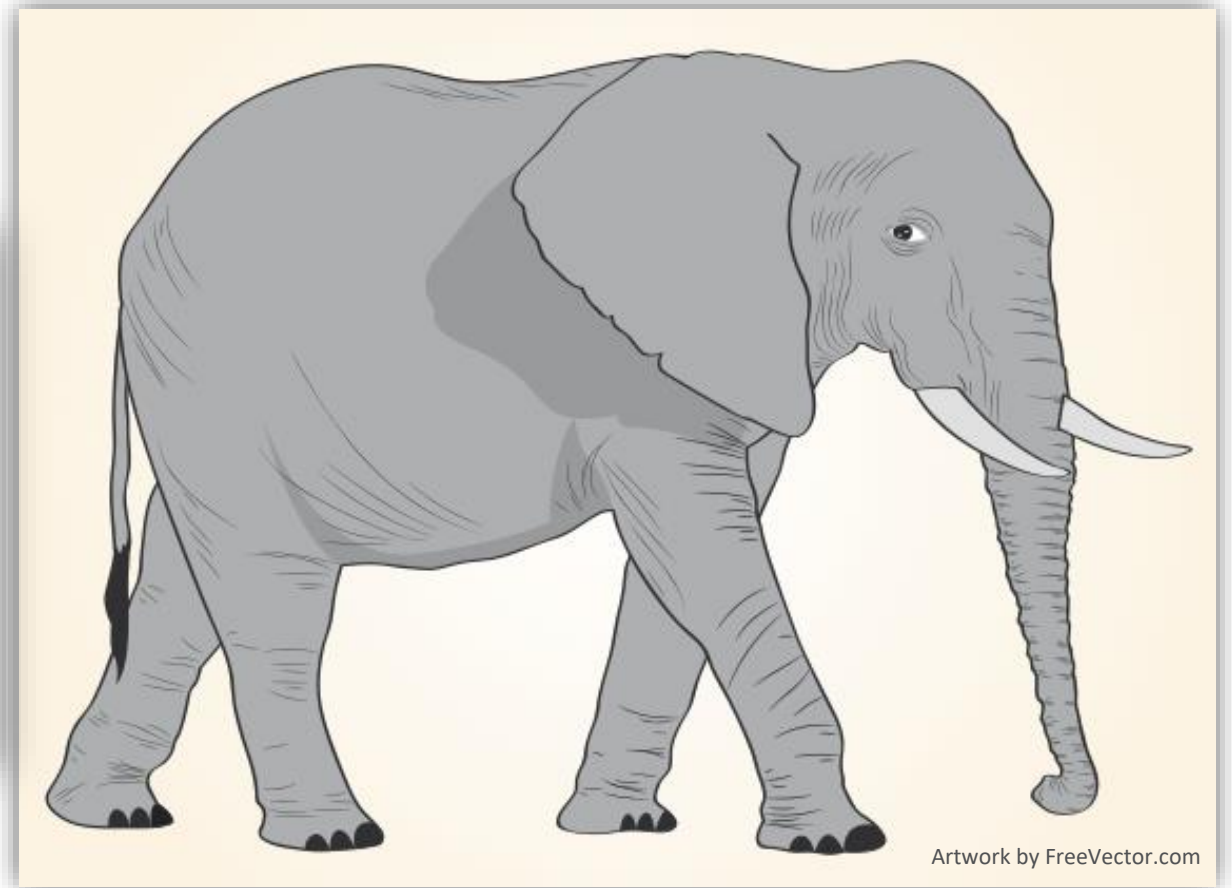
AC Transit FCEB Performance - 9/10/18		
Bus	FUEL CELL HOURS	Vehicle Miles Life to Date
FC4	23,340	222,250
FC5	23,263	219,754
FC6	23,599	188,556
FC7	29,998	203,165
FC8	22,665	157,606
FC9	22,537	194,259
FC10	24,992	223,714
FC11	25,675	221,296
FC12	25,960	220,000
FC13	14,455	143,502
FC14	26,119	221,145
FC15	21,126	181,086
FC16	25,899	206,176
TOTALS	309,628	2,602,509
Average	23,818	200,193

NOTE: FC7 and FC12 fuel cells were manufactured by UTC in 2003, 14 years ago with an expected EOL of 5,000 hours. The other 11 fuel cells were manufactured by UTC in 2008 and 2009



Oakland to Reno: 219 miles

The Elephant in The Room



How to Scale Refueling Stations?

H₂ Station Challenges

PARSE

- P** **Price** and delivery of H₂ on parity with conventional fuels.
Also equipment maintenance cost reduction.
- A** **Area** of fueling footprint to refuel 50, 100, or 200 buses.
- R** **Renewables** for hydrogen production; **Resiliency** - Natural Disasters;
Also **Redundancy** to ensure near 100% service reliability.
- S** **Speed** of refueling in the normal five- to seven-hour night window;
Also **Scalability** for future expansion.
- E** **Equity**, or CapEX, needed to build at a reasonable price utilizing
baseline components for future scale up.

Overcoming the Challenges to FCEB Fleet Adoption – Hydrogen Infrastructure

Chris Kretz

H2 Business Development Manager

Air Products and Hydrogen Bus Fueling



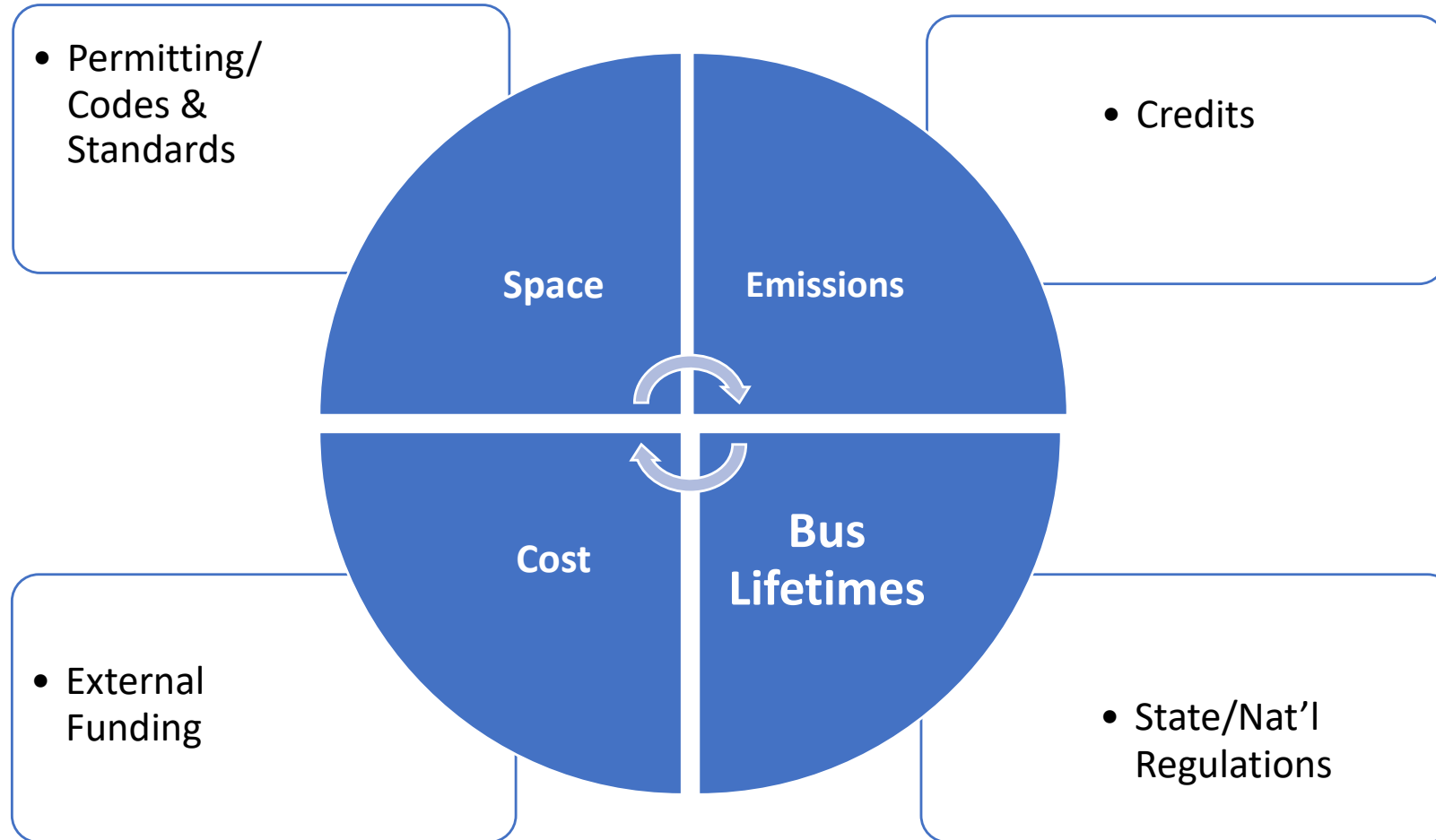
Hydrogen Means Business in California!



- Fueling buses with hydrogen for 20 years
 - SARTA
 - Transport for London
 - Koln Germany
 - Penn State
 - Flint MTA
 - Allentown
 - BP Beijing
- Supplying equipment, design, and hydrogen for OCTA Santa Ana; 6-10 min. fueling for 10 buses (Jan. 2019)
- Complete hydrogen fueling station provider
- Offering delivered gas, delivered liquid, on-site generation (SMR & electrolyzer), and pipeline hydrogen



Internal and External Drivers Affecting Bus and Fueling Selection



H₂ Infrastructure Challenges for FCEBs

- **Footprint** - most bus fleet depots are landlocked/space constrained
- **Scalability** - most fleet managers will introduce a new technology in phases
- **Renewable Content** - achievable at current SB 1505 levels but costly at 100% levels
- **Price** – matching public service with developing market

Addressing the Challenges

➤ Footprint & Scalability

- Understand the fueling options at your site for...
 - 5-10 buses
 - 25-50 buses (or max.)
 - 100-200 buses (or max.)
- Consider best/worst case scenarios
- If possible, be flexible
- Vocalize operational limitations early

➤ Renewable Content

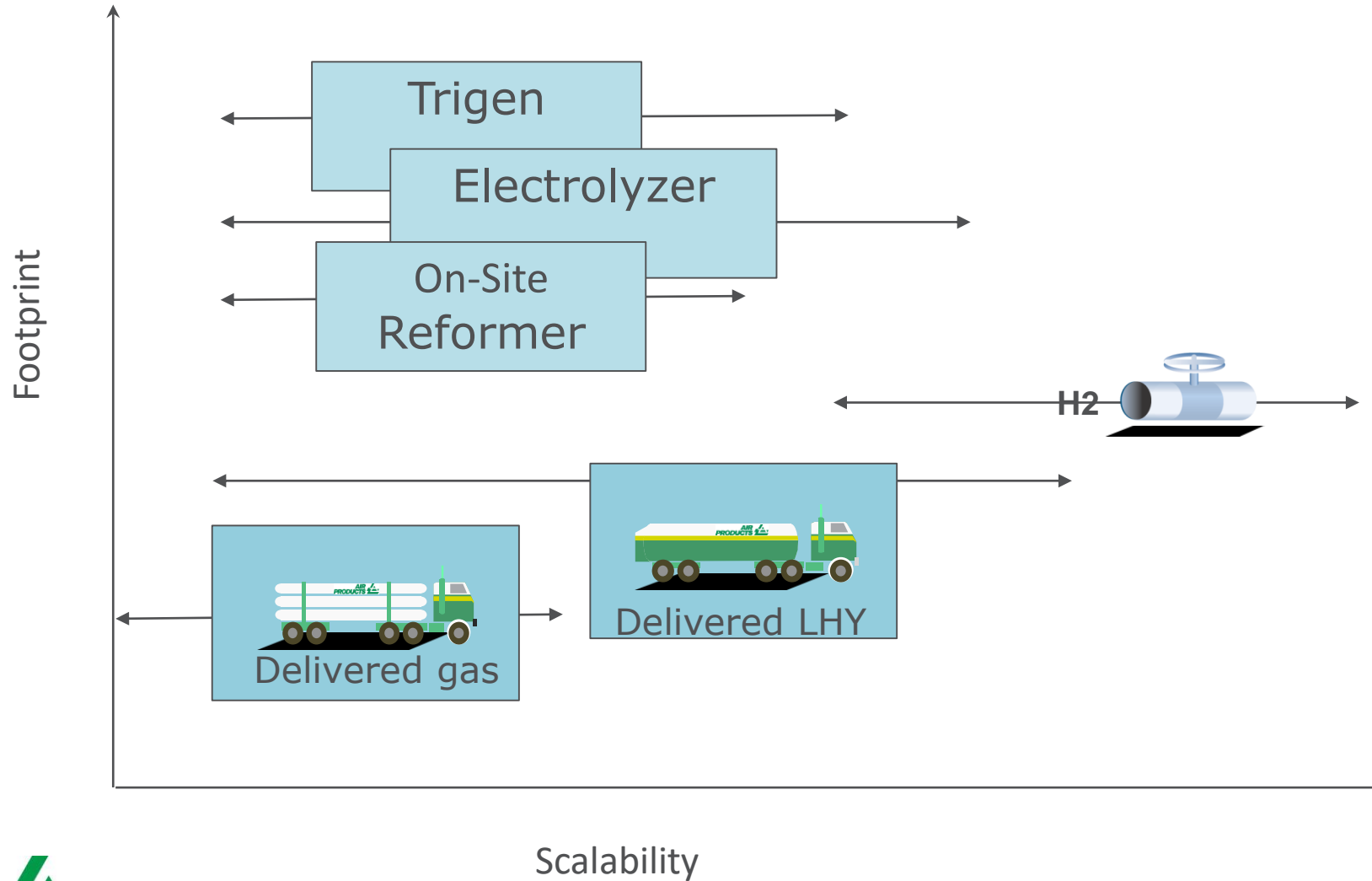
- Must have vs. nice to have
- No one right answer
- Use your local assets

➤ Price- consider TCO, demo vs. full adoption

- Pathways to lower price and larger scale exist



Hydrogen Supply Options vs. Challenges



Thank you
tell me more

Chris Kretz, PhD/MBA
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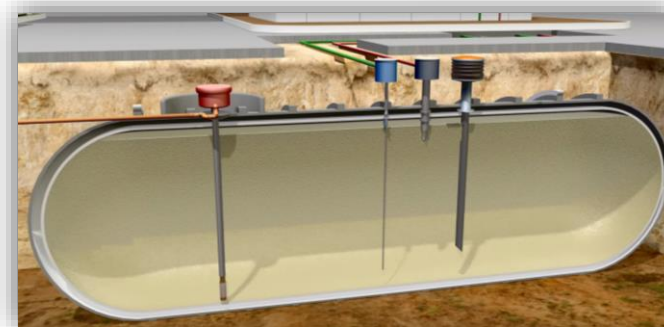
Overcoming the Challenges to FCEB Fleet Adoption – Hydrogen Infrastructure

Jeff Pickles, Principal
Green Grid, Inc.



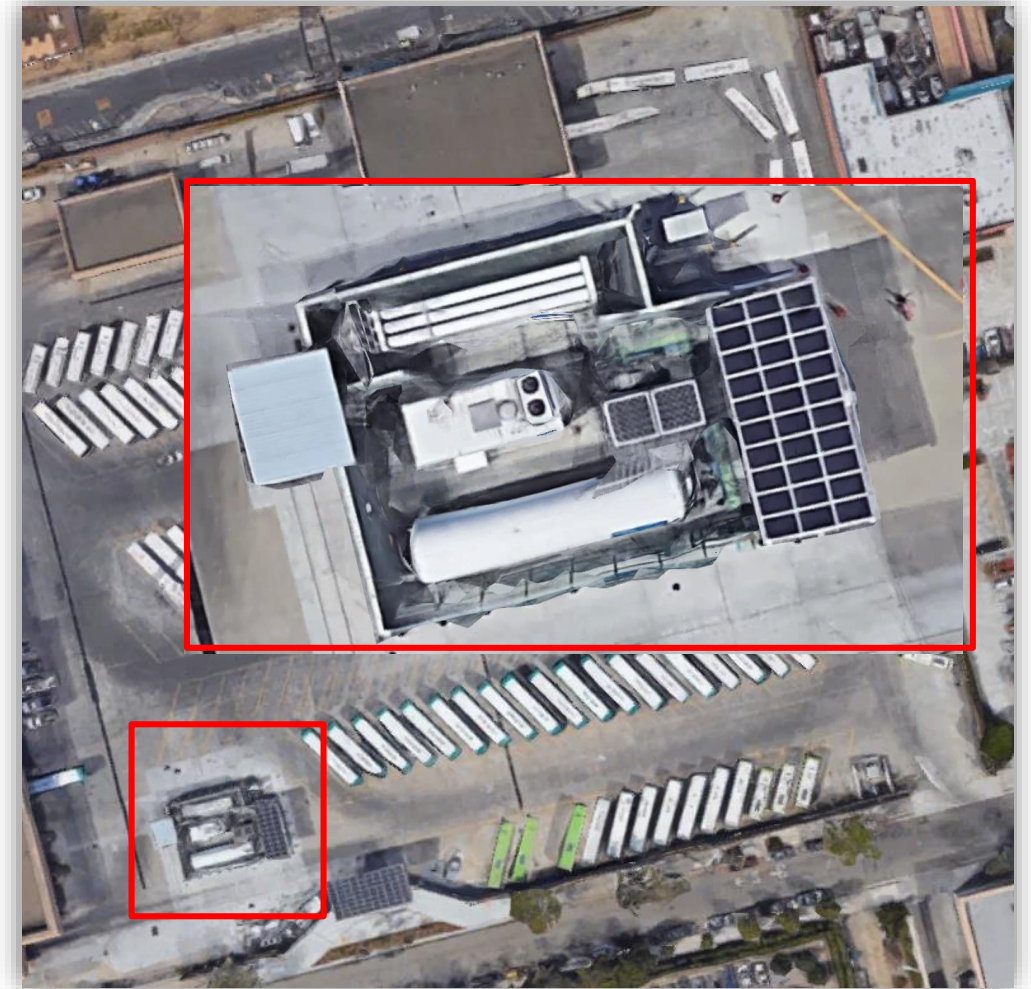
Vision of Hydrogen Fuel

- Leverage technology from LNG and NASA
- Renewable LH2 as energy storage and fuel
- Lowest cost clean feed stock, CA to meet SB 100 for 100% renewable by 2045
- Liquid trailer and pipeline distribution
- Underground tanks and direct pump fast fill
- Engineer fail safe systems superior to NFPA 2
- Flexible direct fill dispensing, 350 bar, 700 bar, Cryo-Compressed
- 100% Renewable Hydrogen Fuel, zero GHG
- Costs go down with increased demand
- LCFS promotes RLH2



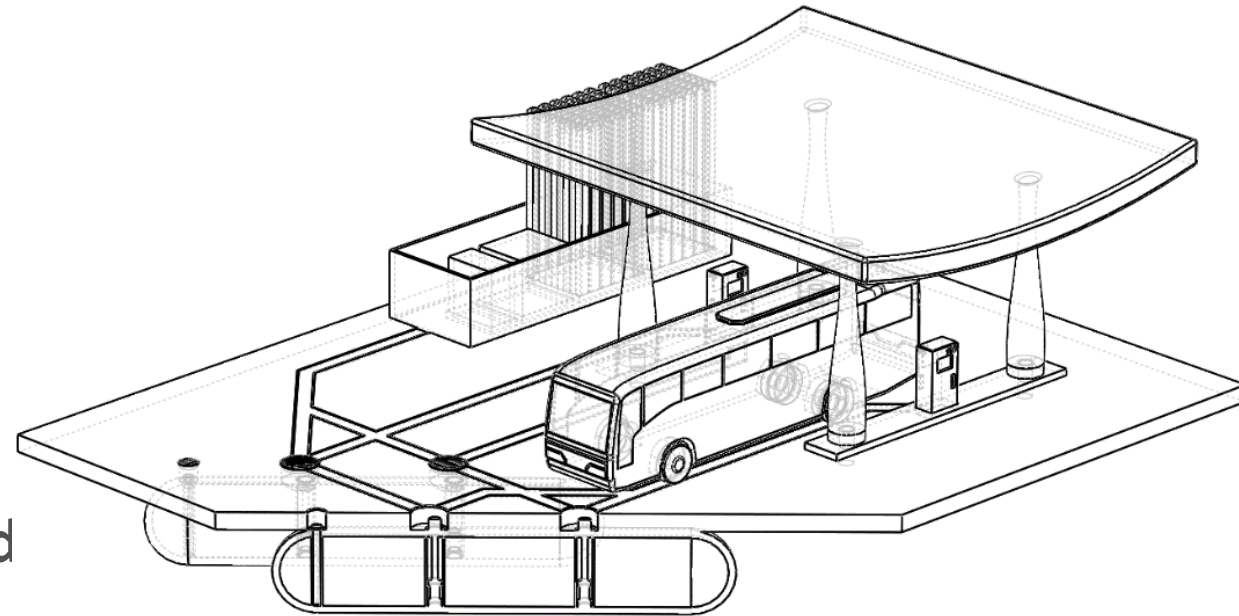
AC Transit Hydrogen Station Upgrade

- 4,000 kg LH₂ Storage
- 2 x gas compressor being upgraded to liquid pumps
- Cascade Storage
- Dispensers (2) integrated into diesel fueling island
- Public LDV dispenser on street (Linde)
- 13 buses/day, upgraded to 30
- 50 ft. x 70 ft., 3500 ft² footprint



Future Liquid Hydrogen Station

- 250 buses per day is feasible
- Underground 3 x 4,000 kg LH₂ Storage
- Direct fill Liquid pump, No Cascade Storage
- 4 to 8 simultaneous fueling positions
- Continuous Fast Fills, 350 bar, 30 kg in 5 min, J2601-2
- Only above ground equipment, vaporizers, controls and motors
- Future compatible with **Cryo-compressed** (eliminates vaporizers)



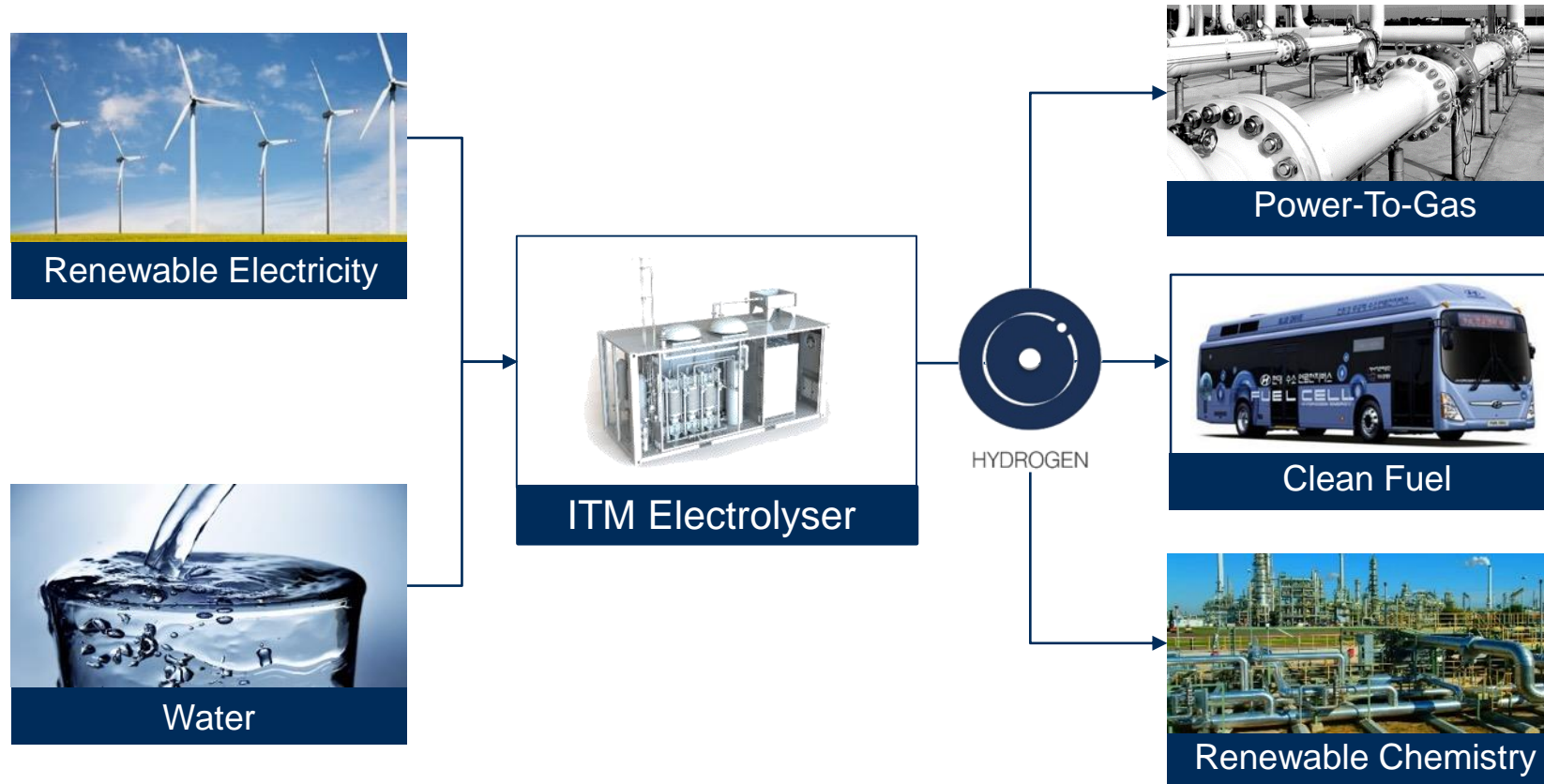
HYDROGEN BUS FUEL



ENERGY STORAGE | CLEAN FUEL
SJ@ITM-POWER.COM

ITM POWER | WHAT WE DO

ITM Power manufactures integrated hydrogen energy systems



ITM POWER | WHAT WE DO

HYDROGEN ENERGY SYSTEMS

GRID BALANCING

FREQUENCY
SUPPLY SIDE
DEMAND SIDE

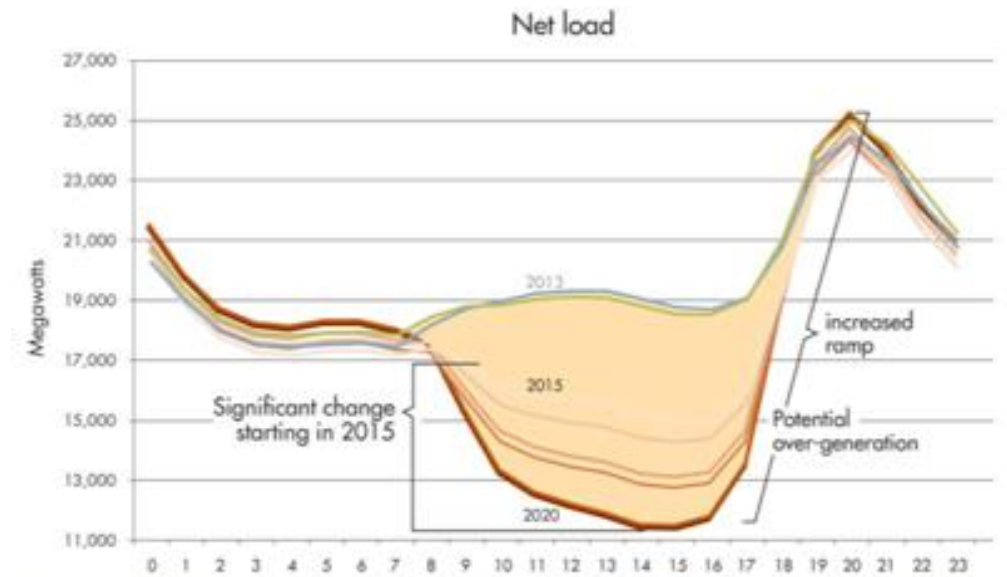
ENERGY STORAGE



CURTAILMENT = WASTED ENERGY AND MONEY

- RE curtailment is a growing occurrence = cheaper power
- GWhrs (weeks/months) of energy storage is only achievable with hydrogen – linked to CAs 100% goals
- CA curtailed 85GWhrs in March 2017, Enough for 1.5million kg or 12 million bus miles
- Low cost power will be available throughout the day when the buses are on the road – BEV struggles here
- Electrolysis can capture this either on site or centrally at liquid facilities
- Hydrogen provides massive flexibility

Growing need for flexibility starting 2015



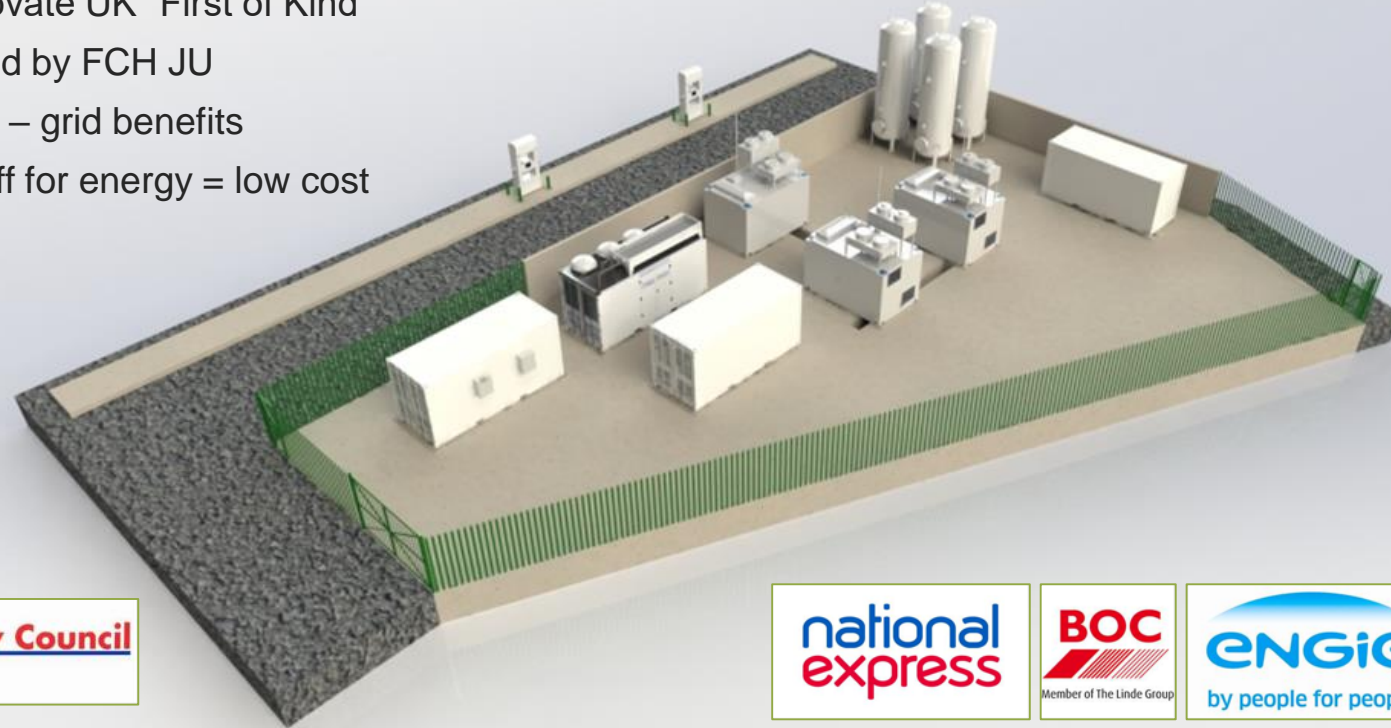
ENERGY STORAGE

ENERGY STORAGE | CLEAN FUEL

BIRMINGHAM FCEB

Tyesley Energy Park | 3MW | 1,500kg/day

- 3MW Grid Balancing Electrolyser
- Funded by Innovate UK “First of Kind”
- 20 buses funded by FCH JU
- Energy storage – grid benefits
- Renewable tariff for energy = low cost



BIRMINGHAM FCEB

BUS REFUELLING STATIONS

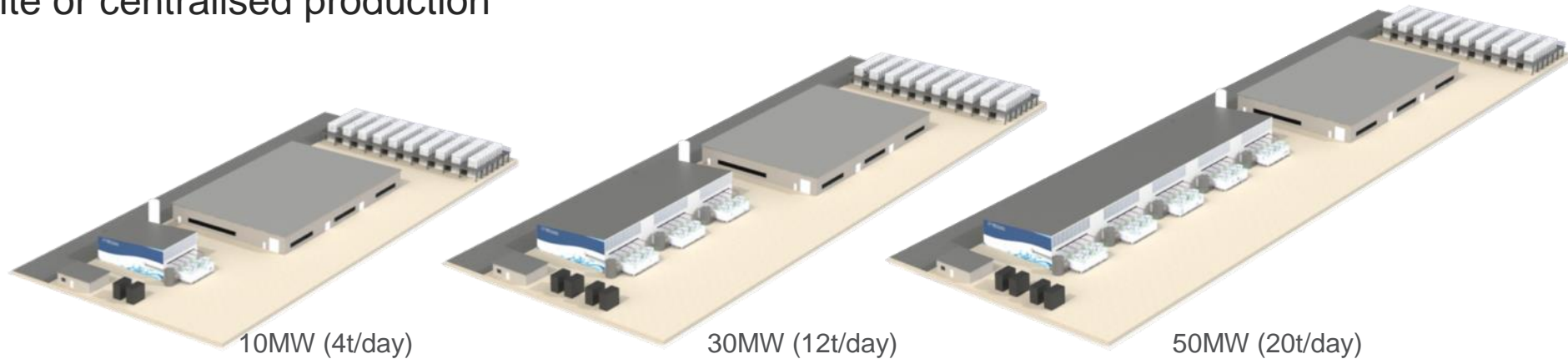


REPLICABLE 10MW MODULE

HRS scale up through replication

- Ability to satisfy specific refuelling profiles
- Sophisticated modelling to size systems correctly
- Use of proven compressor technology
- Modularity provides flexibility
- On-site or centralised production

Vehicle	Capacity (kg)	Refuels/Day			
		5MW (2t/day)	10MW (4t/day)	30 MW (12t/day)	50MW (20 t/day)
Cars	4	500	1,000	3,000	5,000
Buses	30	67	134	402	670
Trucks	75	27	54	162	270
Trains	180	11	22	66	110
Ferries	500	4	8	24	40



REPLICABLE 10MW MODULE
 HYDROGEN REFUELLING SYSTEMS



Renewable hydrogen supply from electrolysis: How do we get to a relevant scale for transit?

Stephen Szymanski, Director of Business Development



Company Overview

Public Company, Pure H₂ Play

- 3 Manufacturing Sites**
- 3,500+ Electrolyzers Installed**
- 40+ H₂ Fueling Stations**
- 90+ Years Experience**



USA (Wallingford, CT)
PEM Electrolyzers



Denmark (Herning)
H₂ Fueling Stations



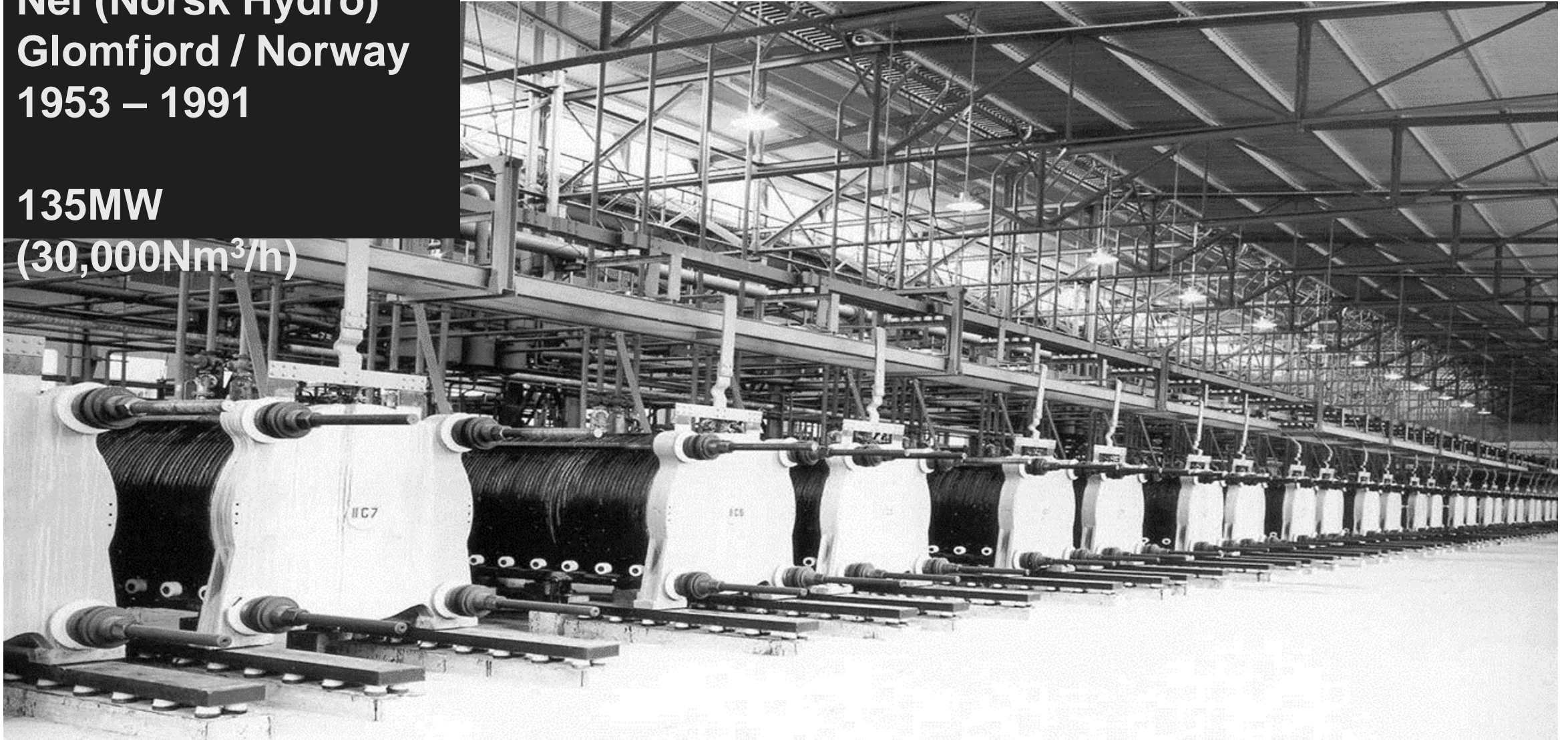
Norway (Notodden)
Alkaline Electrolyzers

Size matters! Scale drives down cost...

Largest single electrolysis plant ever built

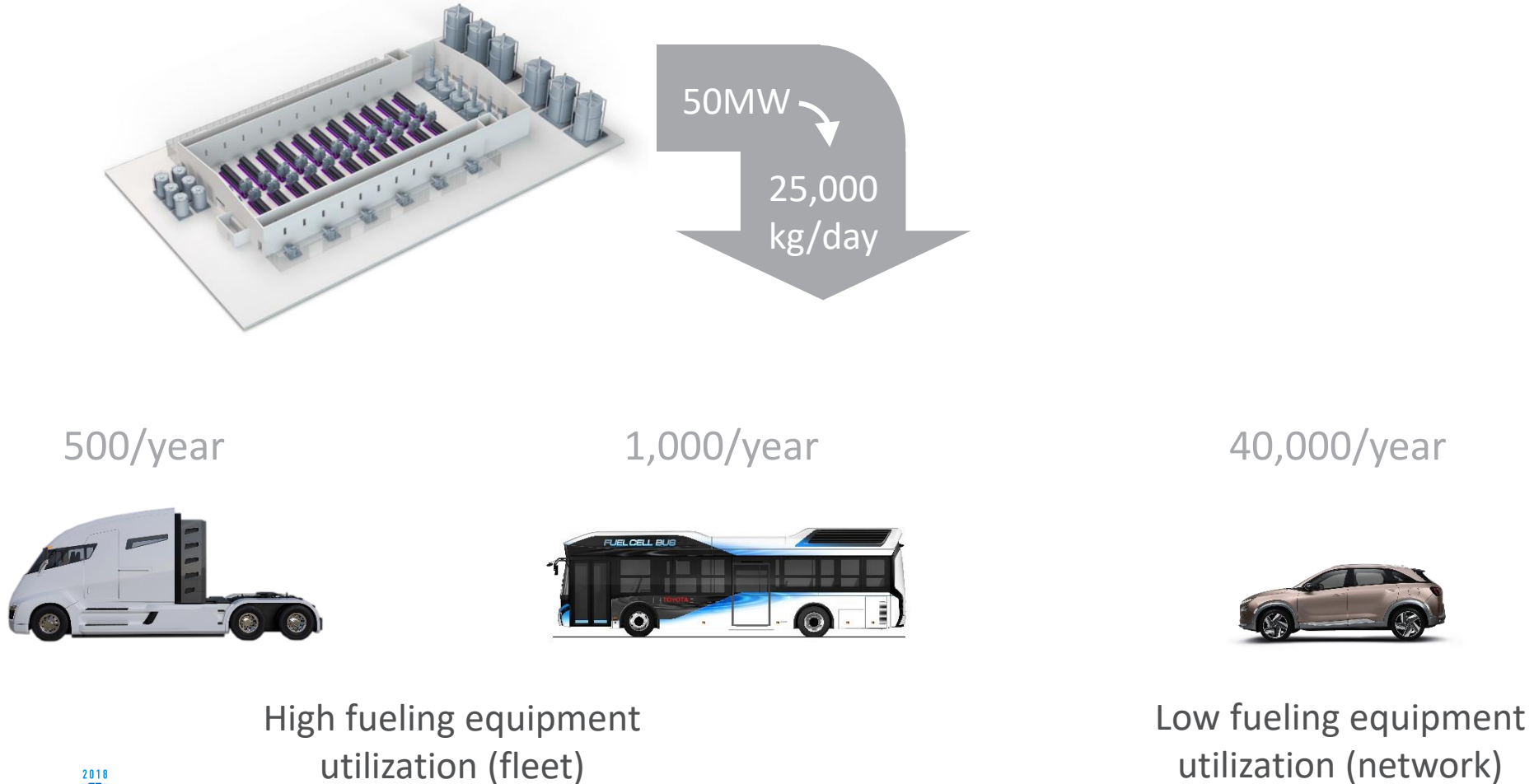
**Nel (Norsk Hydro)
Glomfjord / Norway
1953 – 1991**

**135MW
(30,000Nm³/h)**



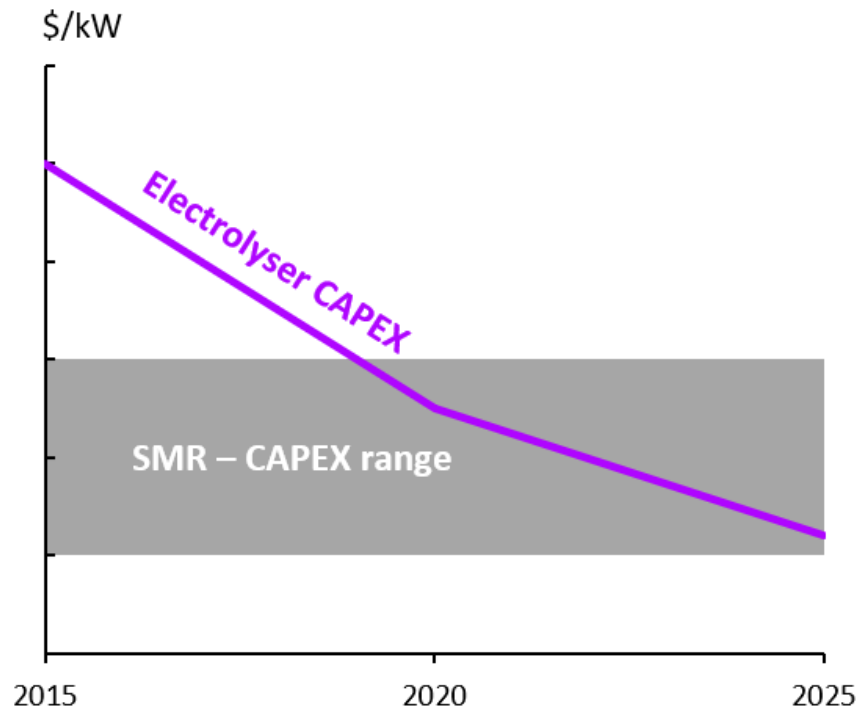
HDV's and buses will help provide scale to hydrogen

HDVs consumes much more hydrogen than LDVs and fleet operation enables high fueling equipment utilization.

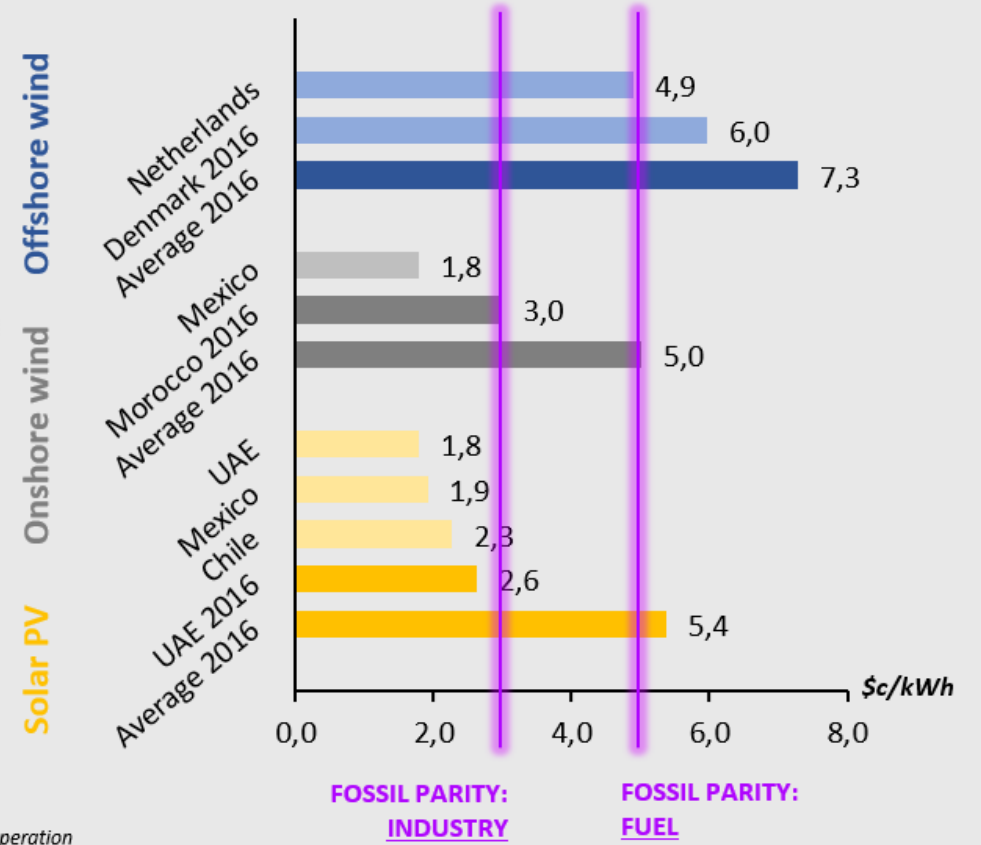
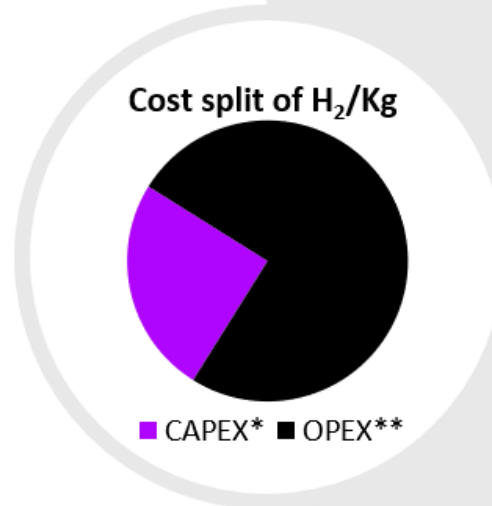


Renewable energy enables fossil parity for hydrogen

CAPEX: Electrolysers becoming competitive with SMR via scale



OPEX: Renewable energy already enables fossil parity for hydrogen (Industry + Fuel)



Source: Pareto Securities
 EUR/USD: 1:1.2
 * Incl. maintenance and operation
 ** Electricity only

Hydrogen price parity with diesel/CNG for buses

Achieving hydrogen price parity with diesel/hybrid and CNG will be important for the TCO experienced by Transit Agencies.

FCEB consumption ranging from 0.13 – 0.16 mile/kg results in the following fossil parity price with Diesel/Hybrid and CNG:

- Diesel: \$4.5 - \$5.6 per kg hydrogen
- Diesel hybrid: \$3.6 - \$4.5 per kg hydrogen
- CNG: \$3.5 - \$4.3 per kg hydrogen

Price parity with diesel is within reach today.

Diesel hybrid and CNG price parity requires scale.



Hydrogen price parity with diesel/CNG for busses in California

Fuel	Diesel	Unit	Diesel Hybrid	Unit	CNG	Unit
Fuel consumption	3.87	miles/DGE	4.84	miles/DGE	2.91	miles/DGE
Fuel price (incl. O&M)	\$2.79	/DGE	\$2.79	/DGE	\$1.62	/DGE
Fuel cost per distance	\$0.7	/mile	\$0.6	/mile	\$0.6	/mile
H2 parity price - 1	\$5.6	/kg	\$4.5	/kg	\$4.3	/kg
H2 parity price - 2	\$4.5	/kg	\$3.6	/kg	\$3.5	/kg

Hydrogen	1	2	Unit
Fuel consumption	8.00	9.85	kg/100km
	0.08	0.10	kg/1km
	0.13	0.16	kg/mile
	7.77	6.308	mile/kg

Data based on ARB:
 "Innovative Clean
 Transit - Cost Data and
 Sources - Update on
 6/26/2017"

Large Scale Renewable Hydrogen Case Study

Nikola Motors supply agreement will drive automation, scale-up, and cost reduction

- Nikola Class 8 trucks
- Several thousand pre-orders
- Hydrogen included in lease
- 800 to Anheuser-Busch
 - Up to a 750 mile range
 - Fueling time: ~10 min
 - Rollout: 2021
- Target: Hundreds of HRS in the US
- Represents more than 1 GW of electrolysis
- External sale of hydrogen also planned

“We’re looking at a total contract volume which is many times higher than the current annual production capacity at Notodden. While we have not reached any conclusions on an expansion to accommodate the order, we want to reiterate our plans to develop the Notodden facility into the world’s largest electrolyzer stack manufacturing facility, aiming at a cost reduction of around 40 percent,” Jon Løkke, CEO.



Source: Nikola

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number one by nature...

www.nelhydrogen.com

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