Hydrogen for Heavy Duty Transport

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CAUTIONARY NOTE

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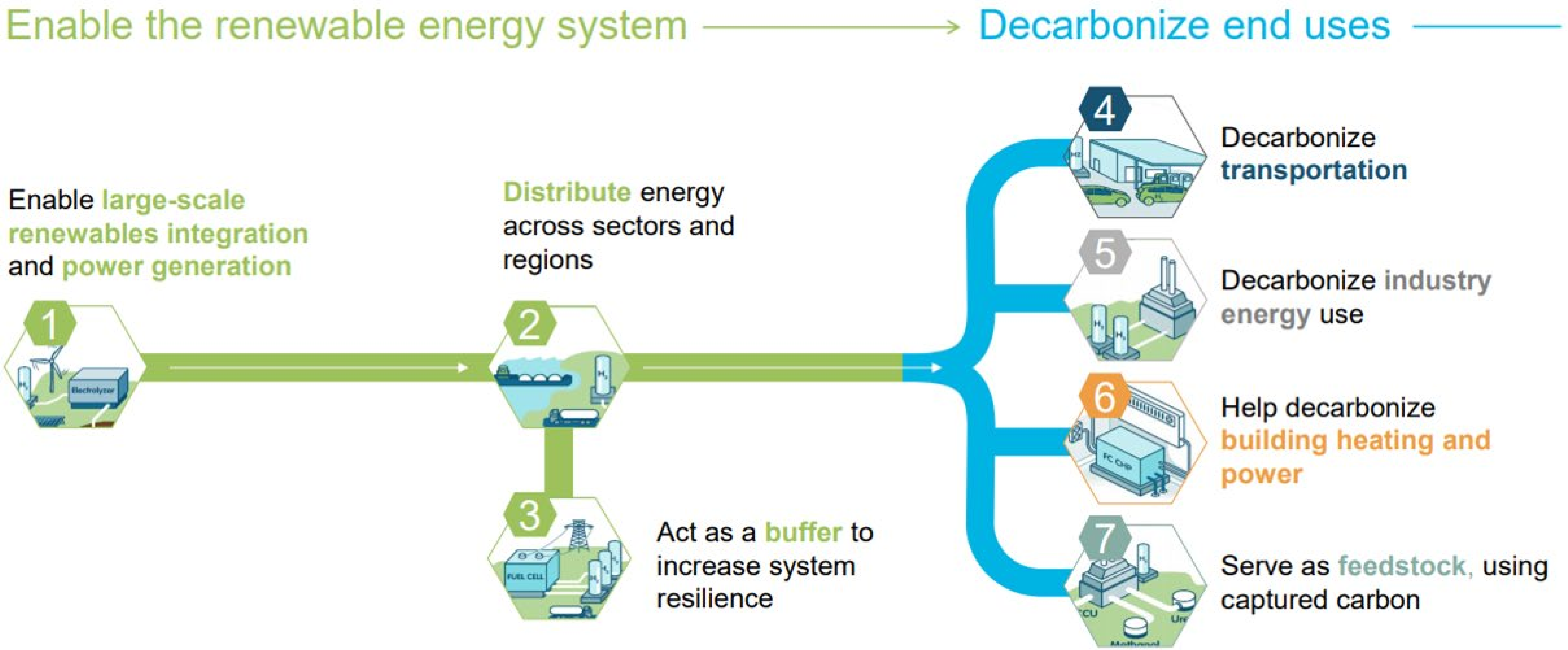
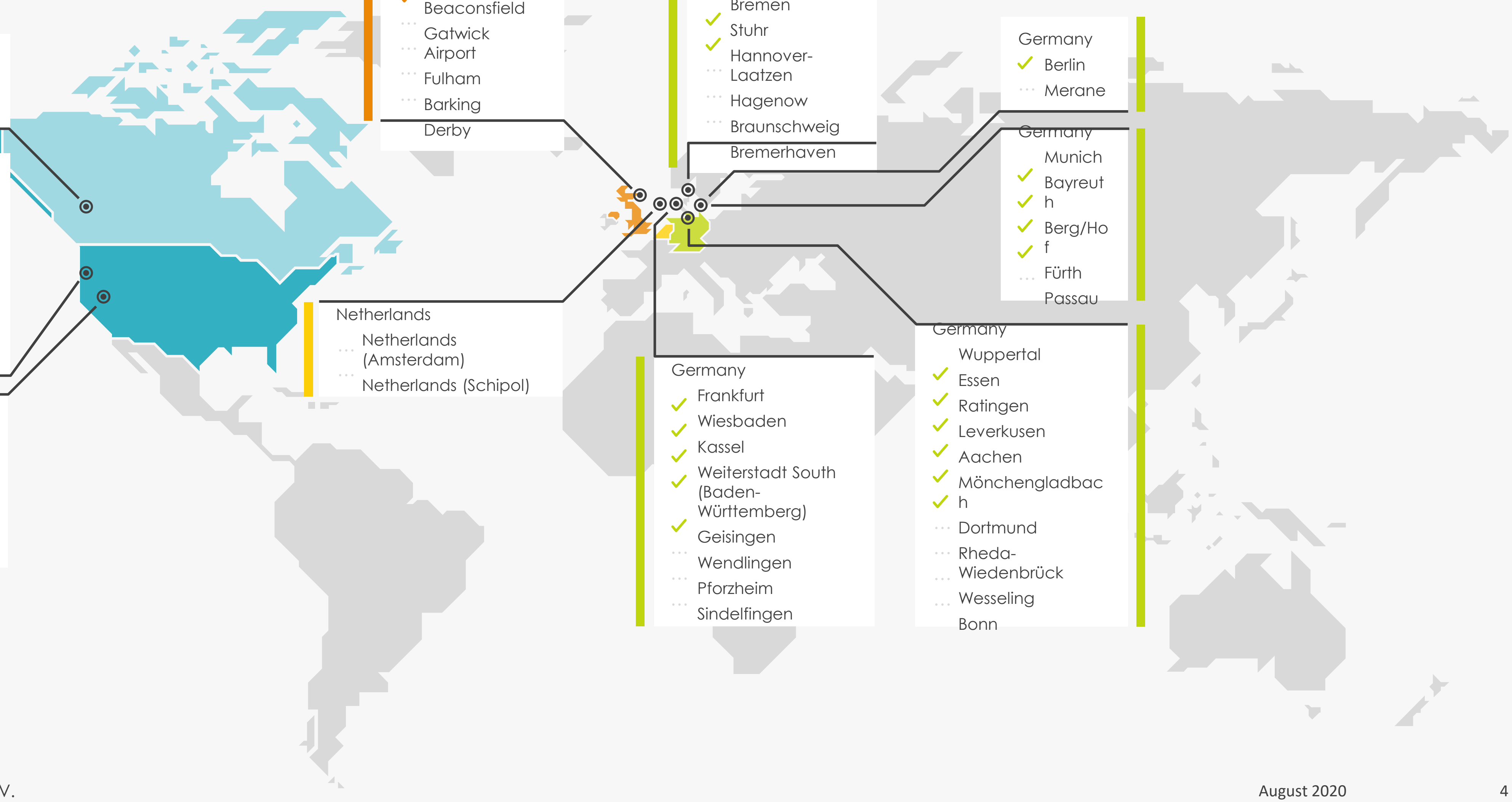
Hydrogen is the only molecular zero carbon vector and sits at the intersection of three systems: mobility, industrial and energy



We have significant experience in Hydrogen, including mobility



Canada
- Vancouver (Granville Street)
- Burnaby (Canada Way)

USA
- Sacramento (Citrus Heights)
- Sacramento (Fair Oaks Blvd)
- San Francisco (3rd Street)
- San Francisco (Harrison Street)
- San Francisco (Mission Street)
- Berkeley (University Avenue)
- San Jose (101 Bernal Rd)

USA
- Torrance
- New Port Beach
- Port of Long Beach
- Ontario (LA)
- Wilmington (LA)

UK
- Cobham
- Beaconsfield
- Gatwick Airport
- Fulham
- Barking
- Derby

Netherlands
- Netherlands (Amsterdam)
- Netherlands (Schipol)

Germany
- Flensburg
- 2x Hamburg
- Bremen
- Stuhr
- Hannover-Laatzen
- Hagenow
- Braunschweig
- Bremerhaven

Germany
- Berlin
- Merane

Germany
- Munich
- Bayreuth
- Berg/Hof
- Fürth
- Passau

Germany
- Frankfurt
- Wiesbaden
- Kassel
- Weiterstadt South (Baden-Württemberg)
- Geisingen
- Wendlingen
- Pforzheim
- Sindelfingen

Germany
- Wuppertal
- Essen
- Ratingen
- Leverkusen
- Aachen
- Mönchengladbach
- Dortmund
- Rheda-Wiedenbrück
- Wesseling
- Bonn

✓ Opened

… In Progress

Heavy-duty station in progress

Hydrogen Electric mobility is relevant for heavy duty operators

- The high specific energy density of compressed hydrogen
- The ability to pump significant energy in a short time (high power flux)
- High efficiency of the power train (the “fuel cell”) and high recyclability
- Ability to have low cost hydrogen today, close to diesel parity.
- Ability to generate renewable hydrogen from bio-gas or green power

1 kg H2 → 11.2 Nm^3 H2 → 33.3 kWhr (LHV)

High mass energy density → 1kg H2 =3.5 L diesel

Low volume energy density → 1 Nm^3 H2 = 0.31 L diesel

Hydrogen production from water electrolysis (5 kWhr/Nm^3 H2; 55 kWhr/kg H2)

Power: 1 MW electrolsyer → 200Nm^3 H2 → 18 kg/hr H2

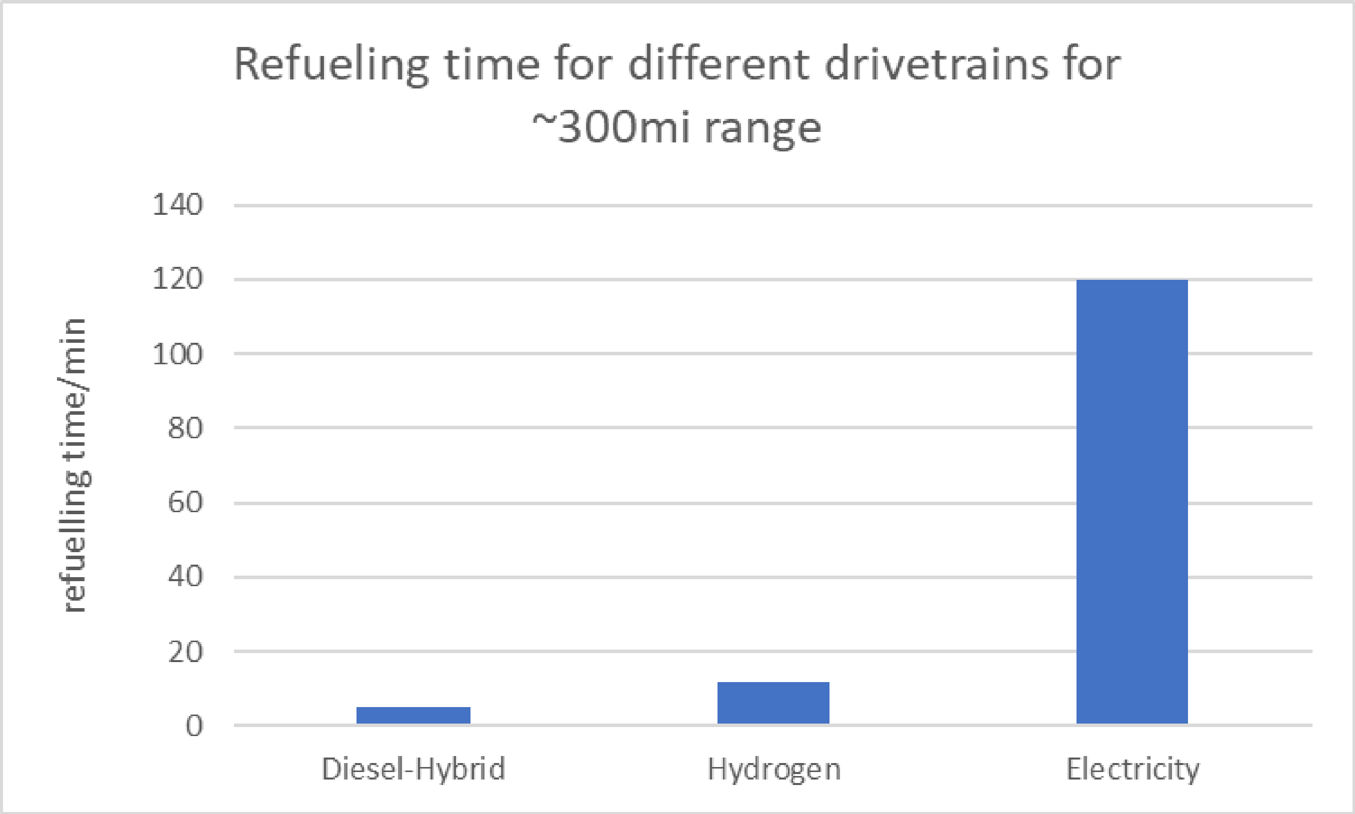
Energy: ~55 kWhr → 1 kg H2 → 10 L demineralised water

Power Production from a H2 PEM fuel cell/H2&O2 inputs: 1kg H2 → 16kWhr

Heavy Duty vehicle Energy Efficiency Ratio (EER = 1.2)

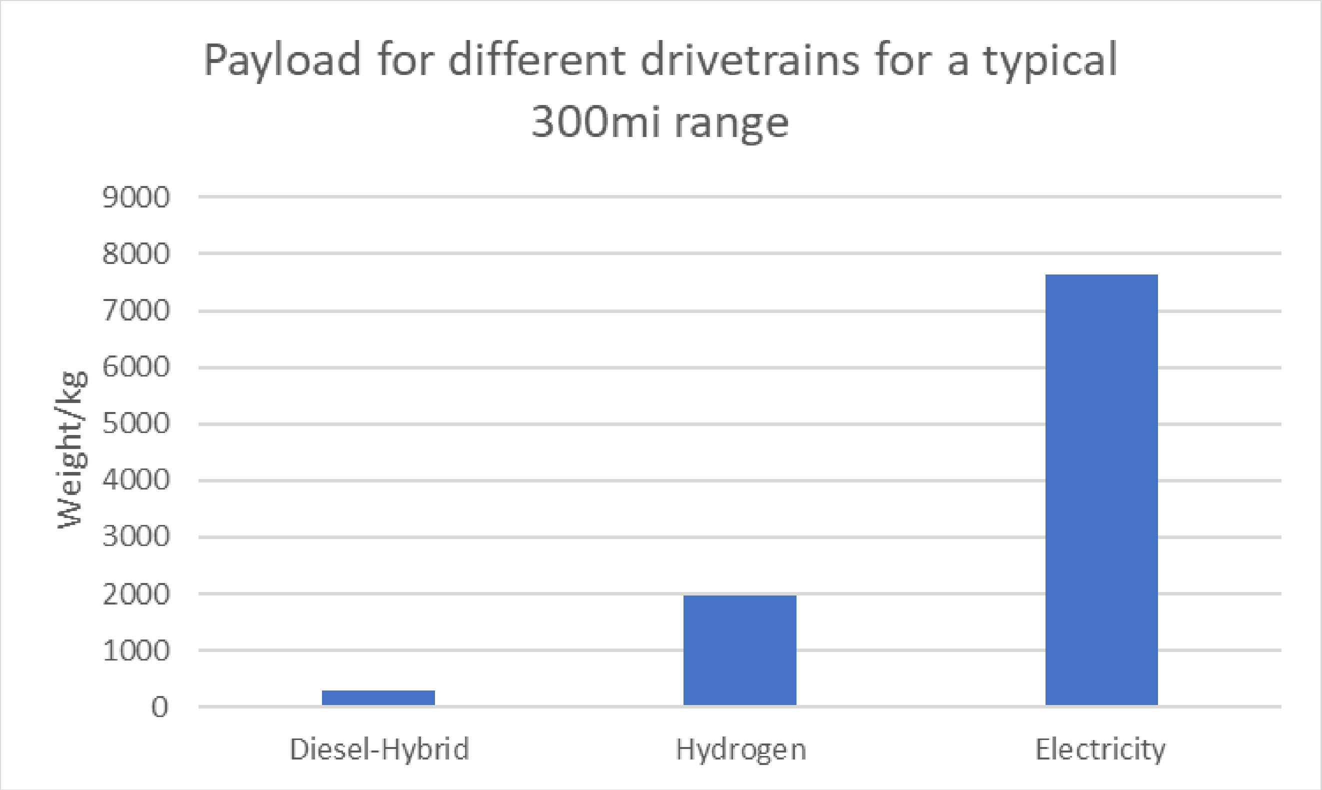
H2 tank	H2 consumption	Driving range	Annual driving distance	Annual H2 consumption
35 kg	8kg/100km	350 km	60,000km	5000kg

Achieving similar refuelling times to current infrastructure for zero-emission fuelling is critical for fleet operators



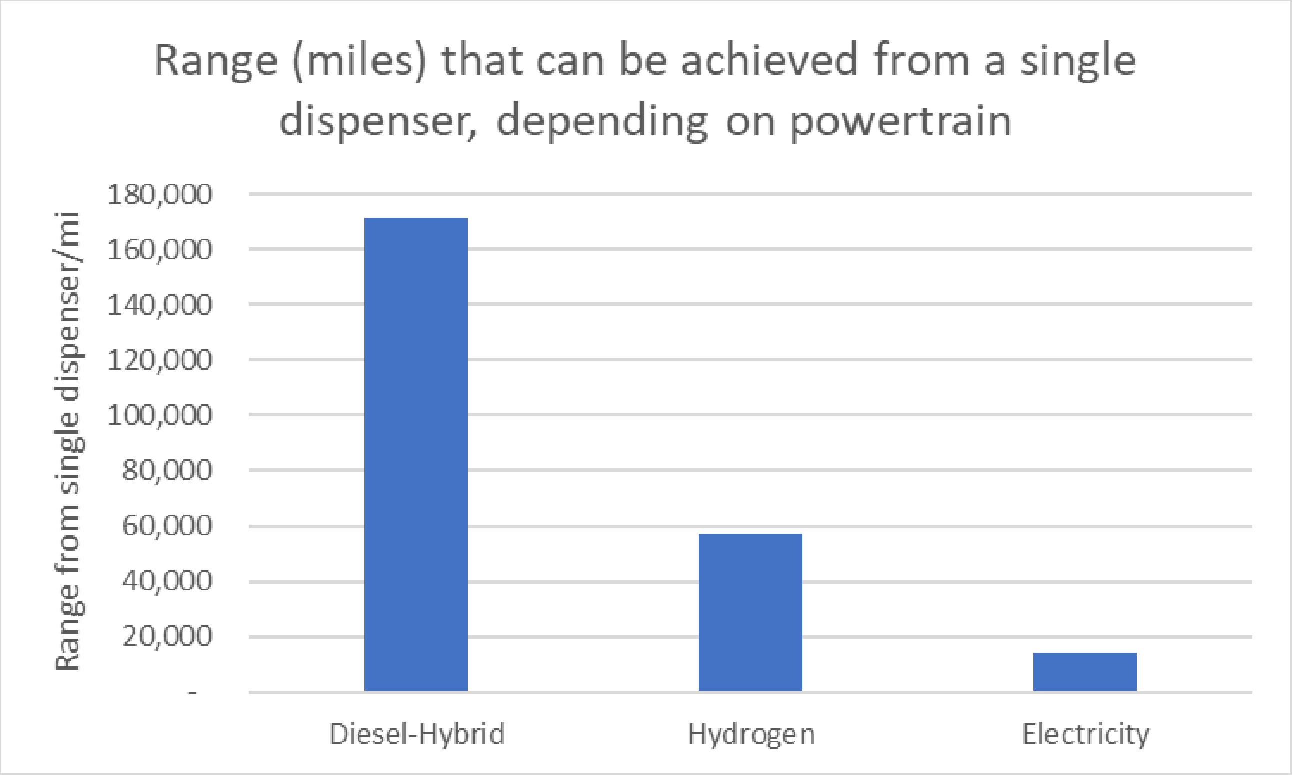
- 70 ga tank, diesel fuel, diesel-hybrid powertrain, refill data private communication bus OEMs
- 350bar H_2, current SAE filling protocol, Shell data
- 1000 kWhr battery; 500kW fast-charge,Shell internal data

Minimizing powertrain weight can maximise passenger and payload on trucks



- 70 ga tank, diesel fuel, diesel-hybrid powertrain, efficiency data from energy.gov
- 350bar H_2, current SAE filling protocol, efficiency data from NREL GREET model
- 1000 kWhr battery; 500kw fast-charge-Shell internal data

Footprint minimisation and operational scalability is an important factor for fleet operators



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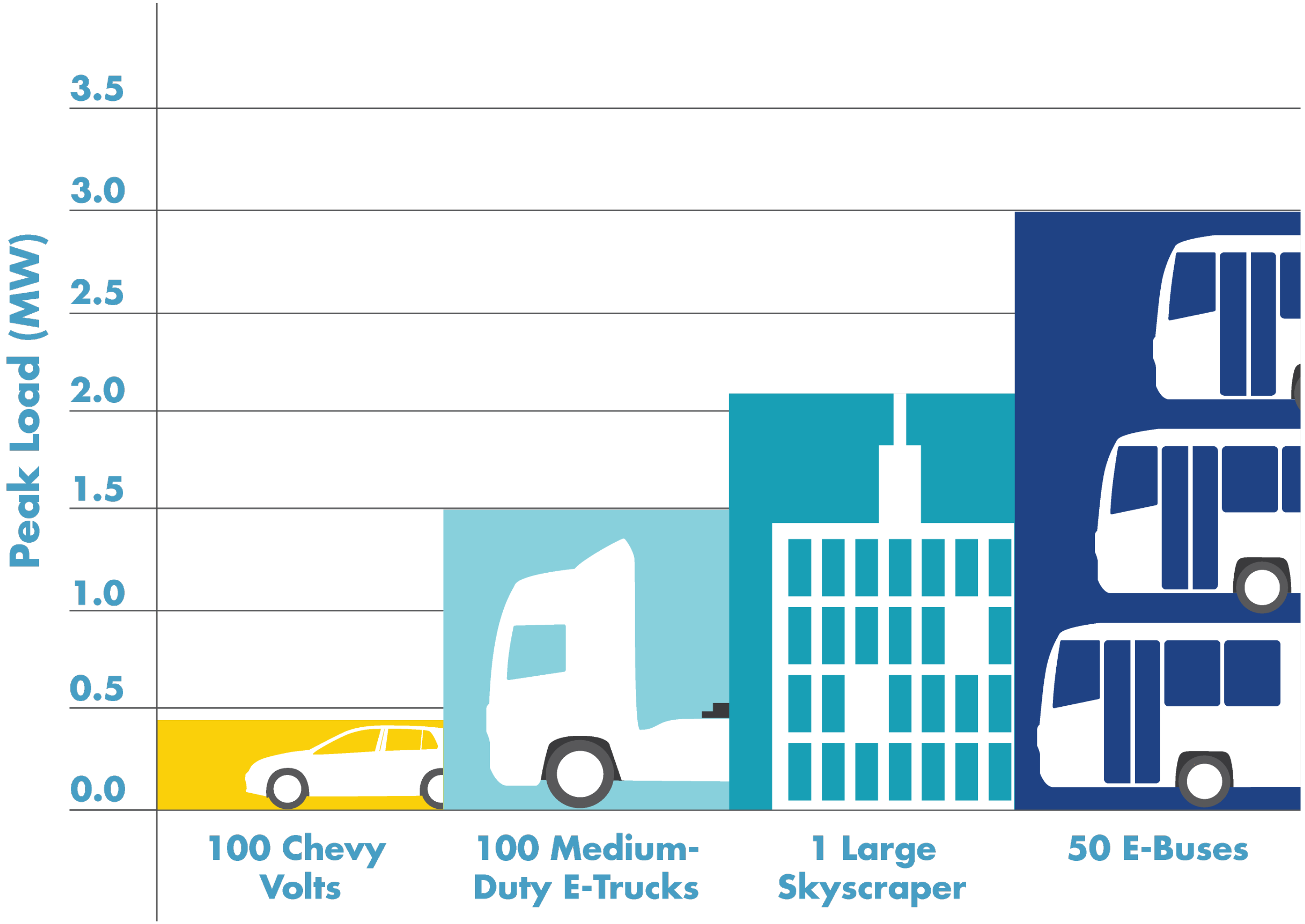
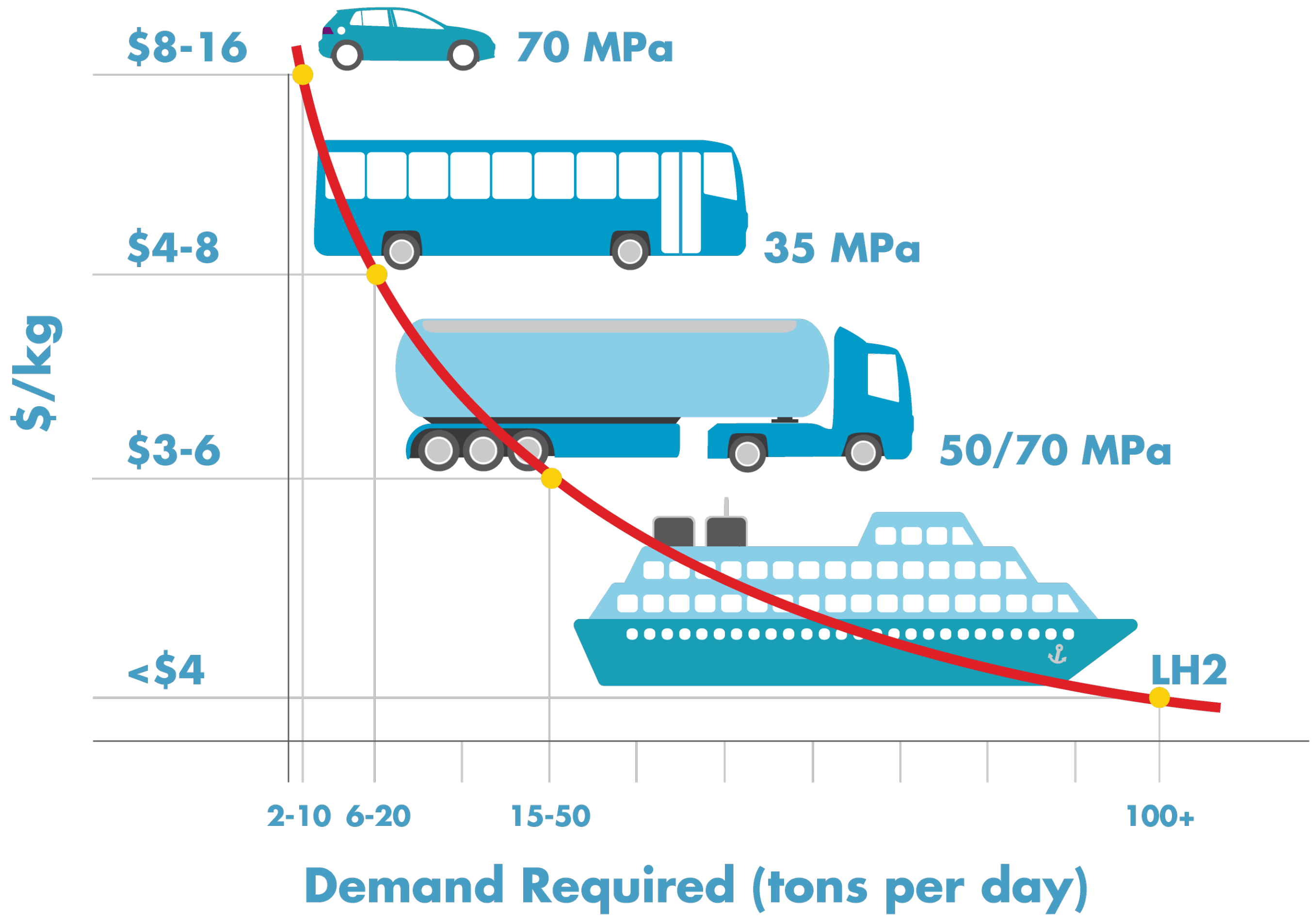
Why FCEV for HD? Infrastructure, Scaling, and Power Demand of EVs



- The peak load at the substation level is challenged by a B-EV fleet
- Volt charge rate 3.3 kw, truck 15 kw, bus 60kw (4-6 hours to full charge for a ~80 mile bus, much large for 300 mile buses)
- Peak HRS load for 50 FCETs is 100-200 kw for compression and cooling,
  - H2 equivalent of 7MW of power compared to BET charging

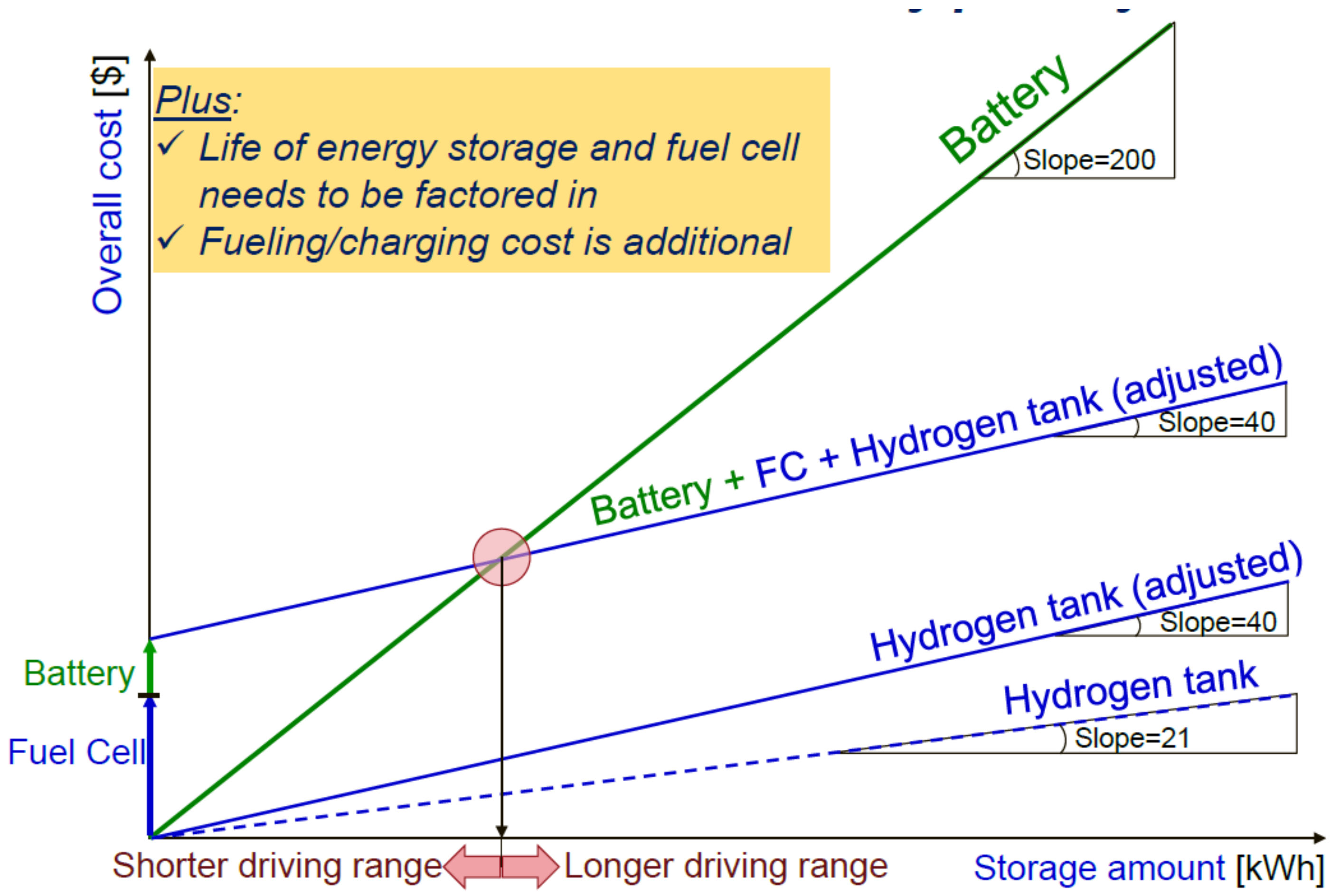
Shell has a vision to create Hydrogen hubs across mobility vectors, demand will drive down infrastructure cost



- Economies of scale will drive down infrastructure costs*; demand firmness will continue to drive innovation and economies of scope
- Lower levelized H_2 costs are opening the market for larger volume and scale opportunities, further reducing costs
- Standards and protocols for heavy duty systems are being defined currently
- The heaviest duty and longest haul vehicles will very likely need Liquid Hydrogen but we are not close to such demand levels yet

*Including capital costs for supply, distribution and compression/purification

FCEV vs BEV



El-gowainy, Amgad: Argonne National Lab

- Widescale BEVs market penetration will require local and regional grid upgrades
- Fleet scale refuelling or recharging systems will require local grid upgrades immediately
- At large scale (GW), marginal H2 infrastructure is lower cost than electrical infrastructure

Shell is participating in the ZANZEF programme funded by CEC, CARB and SCAQMD with the intent to structure clean operations for future goods movement

Shell Site development at Wilmington

- 2 Hydrogen Refueling Stations at 1 Tonne/Day in Port of LA;
- 1 station at Port of LB, operated by Shell for Toyota
- Capex $8mln/station;
- Capacity utilisation expected in year 4 of project
- Reduction of GHG by 500 tonnes over duration of project

Shell Hydrogen's 3 Heavy Duty stations enable LA Basin fleets

Big, fleet based, continuous consumption aids H2 planning

Alpha → Beta → ZANZEFF / Expanded Trials / Adoption → Larger Volumes → 2035

	2017	~2018	~2019	~2020	~2021	~2022	~2025	~2030
Potential HD FCEV UIO (Conservative Est.)	1	2	~5-10	~10-20	~40-50	~80-125	~1,000-1,600	~14,000- 16,000
Potential HD H2 Consumption (kg/day)	~40-50	~80-100	~200-500	~400-1,000	~1,600-2,500	~3,200-6,250	~40,000-80,000	~560,000-800,000
Hydrogen Stations (Cumulative)				3 (Shell)	+3 est	+5 est.	+15 est.	+75-100 est.