REAL-WORLD APPLICATIONS OF FUEL CELLS IN HEAVY VEHICLES

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Senior researcher

May 2019

Research Institutes of Sweden

RISE VIKTORIA

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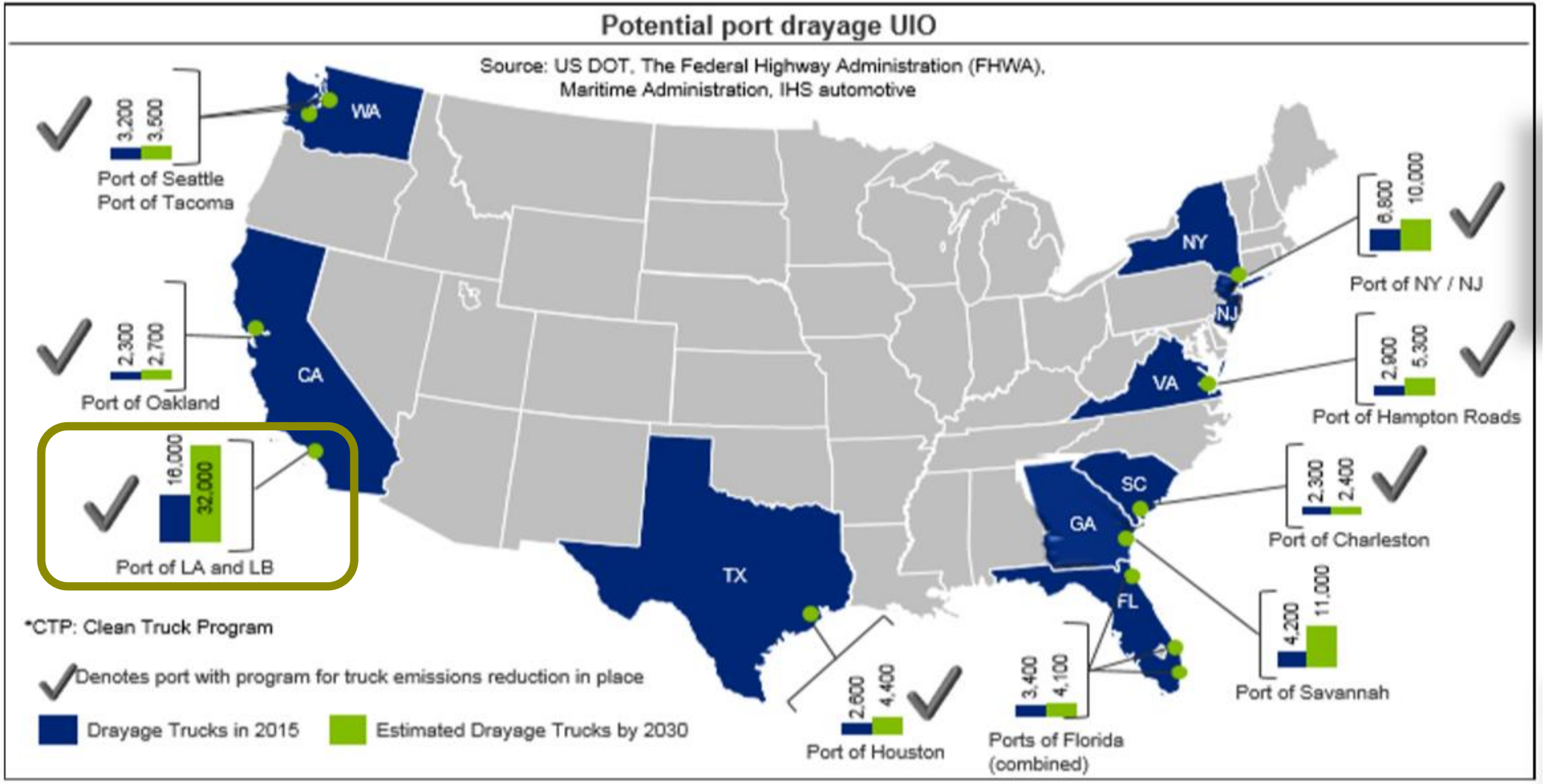
Outline

- Introduction
- Case studies:
  - Toyota Project Portal cargo from port
  - Scania Asko deliveries to supermarkets
  - Scania Renova refuse collection
- Other initiatives:
  - Nikola Motor Company
  - Hyundai and H2 Energy 1,600 trucks
- Discussion
- Conclusion

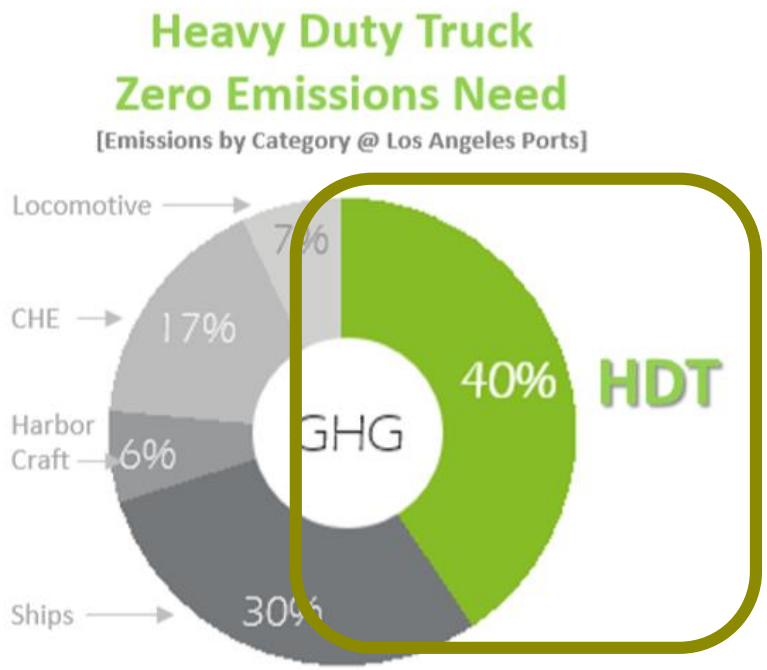
Introduction

- Ambition is to study practical considerations and experiences from fuel cell truck applications
- Timing is difficult, several projects in pipeline but very few fuel cell trucks in operation
- Still, possible to learn something from the projects
- Two large markets not covered (yet):
  - China
  - Fuel cell buses

Toyota Project PORTAL in Los Angeles



Toyota Project PORTAL in Los Angeles



Desire to expand while reducing emissions

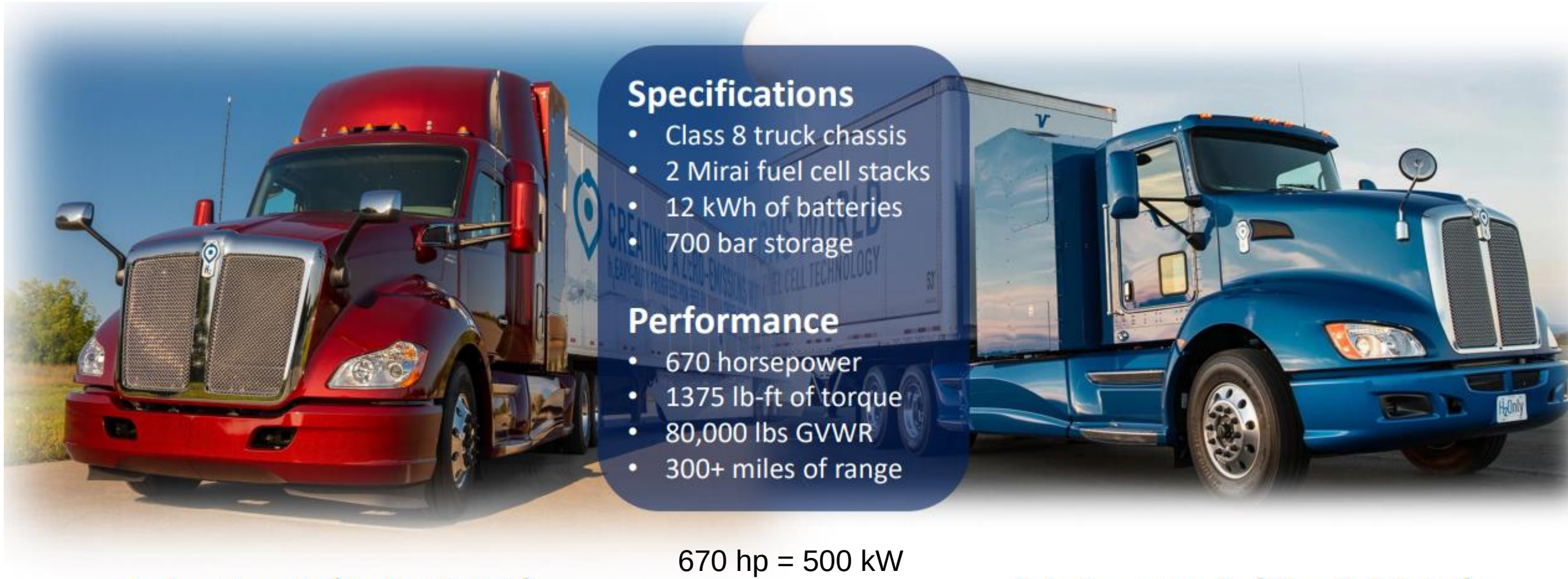
High impact to disadvantaged communities

Clean Air Action Plan

- 2030: Terminal Trucks ZEV
- 2035: All Trucks ZEV

Requires ZEV solution

Toyota Project PORTAL in Los Angeles



Beta Truck (July 2018)

670 hp = 500 kW
80,000 lbs = 36,300 kg
300+ miles = 483 km

Alpha Truck (April 2017)

Toyota Project PORTAL in Los Angeles

ZANZEFF Project

California Environmental Protection Agency AIR RESOURCES BOARD

$41MM Grant

THE PORT OF LOS ANGELES

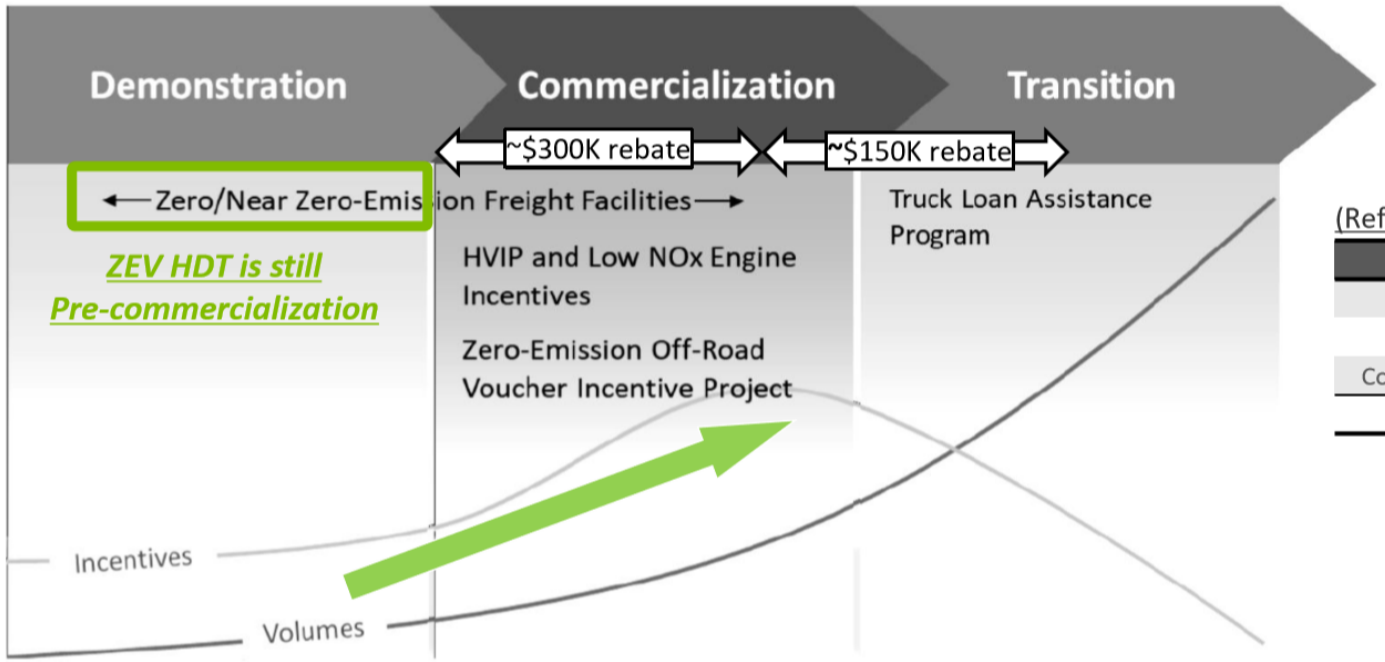
TOYOTA Shell KENWORTH

Demonstration 2019 ~ 2020

10 Class 8 FC Trucks

2 H2 stations to support HDTs

CARB Incentive Policy by Phase



(Ref.) 3-yr HD Strategy Investment Plan (CARB)

	FY18-19	FY19-20	FY20-21
Demos	$70-135M	$50-80M	$55-85M
Pilots	$110-225M	$150-250M	$160-275M
Commercial	$175-280M	$240-425M	$335-595M
TTL	**$355-640M**	**$440-755M**	**$550-955M**

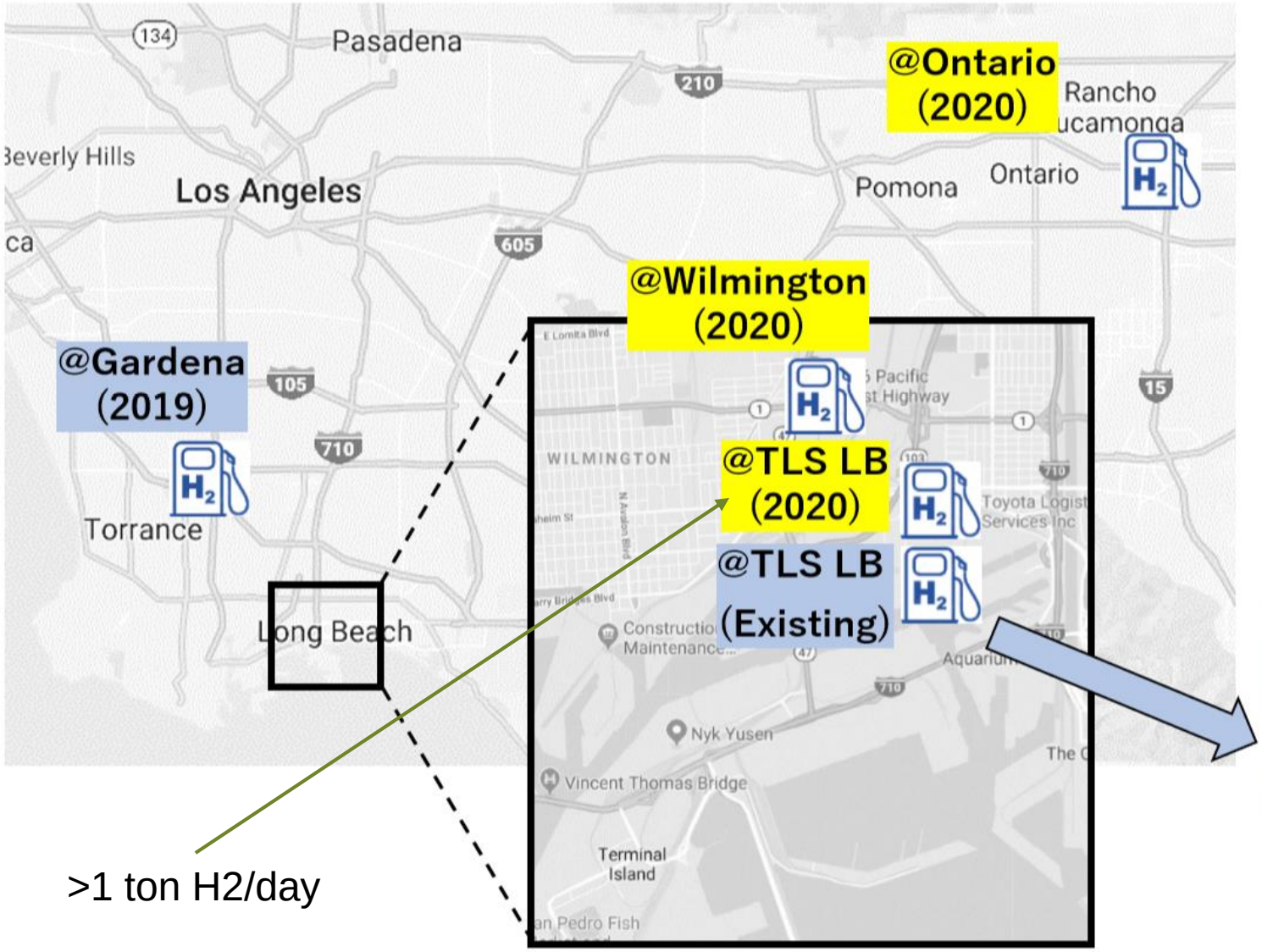
ZEV Drayage Focus Area

Source: CARB (Low Carbon Transportation Investments and AQIP Funding Plan)

ZANZEFF

- First truck delivered April 23, 2019
- Users of trucks:
  - Toyota Logistics Services (4)
  - United Parcel Services (3)
  - Total Transportation Services (2)
  - Southern Counties Express (1)

Refuelling stations for trucks



Near Term Station Network

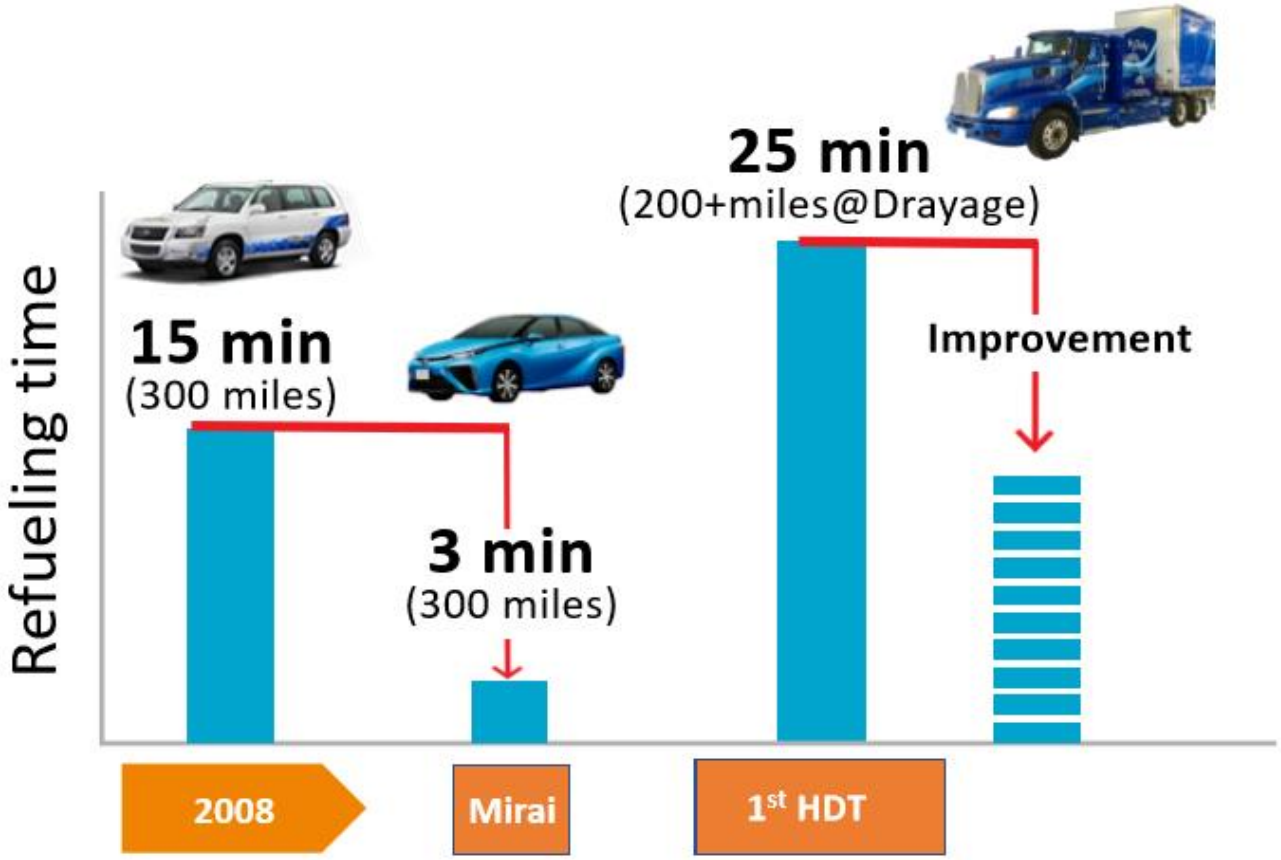
Expansion to a 5 station regional port network

Key locations in the Ports and Inland Empire

Future expansion and scale with multiple partners is needed to support more FC trucks

Toyota’s experiences

- Drivers very happy
- Truck weight to be reduced
- Refuelling time today up to 40 minutes, to be reduced to less than 15 minutes
- Hydrogen cost today 2 – 3 times diesel, expected to be comparable 2025 – 2030
- TCO competitive towards 2030
- Toyota plans to sell fuel cell systems to others for medium or heavy duty



Asko Regional Distribution Trucks

- Four fuel cell trucks for food deliveries
- Asko in Trondheim project manager and user
- Scania battery-electric truck and some integration
- Hydrogenics fuel cell systems and hydrogen tanks (from Hexagon)
- NEL hydrogen production and refuelling station

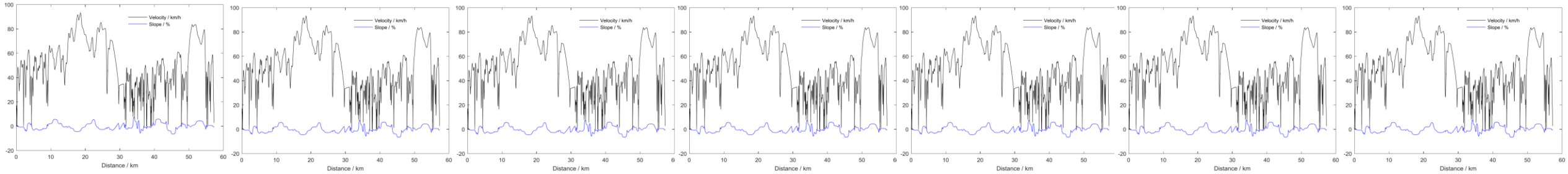
ASKO

- Norway's largest grocery wholesaler
- Ambitious environmental goals
- Homemade electricity: "Approximately 80,000 m2 of solar panels and five wind turbines which will account for approximately 85 per cent of ASKO's energy needs."

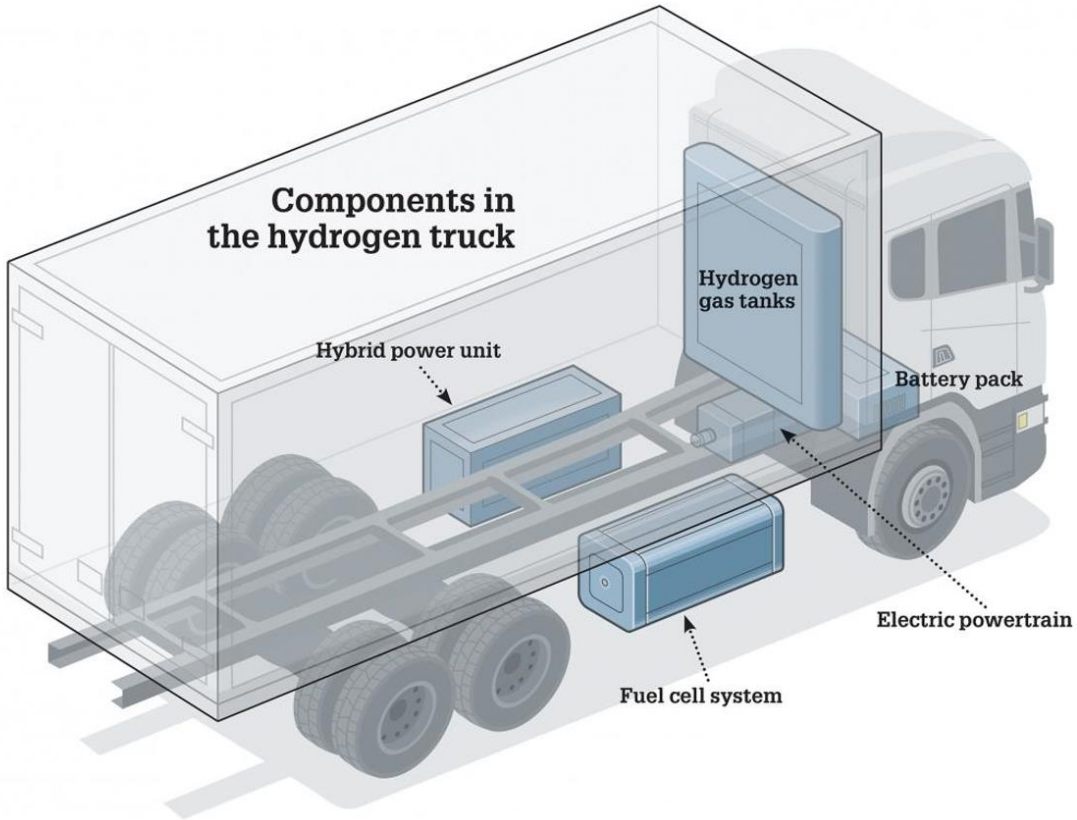
ASKO's environmental goals by 2020 are:

- to reduce energy consumption by 20 per cent
- to be a self-sufficient provider of clean energy
- to use 100 per cent renewable fuel

Some data



- Specification based on demanding Norwegian drive cycle, 9 times, gives range of ~500 km
- Fuel cells 3*30 = 90 kW
- Batteries 56 kWh
- Electric machine 290 kW
- Hydrogen 33 kg @350 bar



Hydrogen refuelling station

- Supplier: NEL Hydrogen Solutions
- Electrolyzer with electricity from photovoltaics
- 350 and 700 bar dispensers for cars (700 bar), fork lifts and trucks
- Capacity 300 kg hydrogen per day

ASKO project experiences

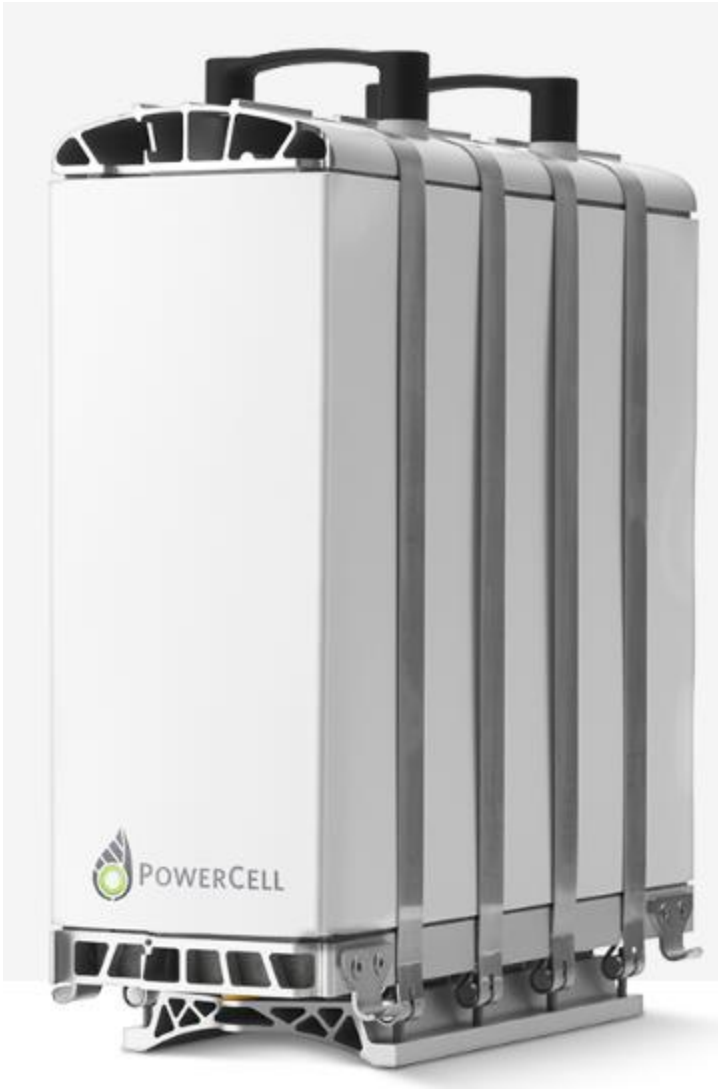
- Fork lifts operating on hydrogen
- Refuelling station open
- Trucks, one in Trondheim, soon in commercial operation, three in Södertälje to be shipped soon
- Fuel cells more expensive than expected
- DC/DC converter has caused minor delay, otherwise as planned
- Heating/cooling: five systems(!)

Renova: Refuse collection in Gothenburg

- Renova: pioneer in green vehicle technologies
- BEV truck from Volvo soon in operation:
  - 150 kWh batteries
  - Capacity 4.7 tonnes (standard capacity 5.8 – 6.0 tonnes)
  - Range 80 km (standard range min. 180 km)
- Renova says that the fuel cell truck will not compromise anything, compared to a diesel truck

Preliminary specification

- Truck from Scania with similar specification as for ASKO
- Batteries 56 kWh
- Fuel cell system from PowerCell 90 kW (S3, up to 125 kW)
- Hydrogen tanks from PowerCell/Hexagon; 23 kg @350 bar
- Equipment and integration at JOAB in Gothenburg



Project outline

- Specification of truck currently in its final stage
- Hydrogen station not yet confirmed
- BEV truck(s) delivered from Scania towards the end of 2019
- In operation during 2020:
  - Test 6 months
  - Regular 12 – 18 months
- KTH evaluates

”Scania – hur stavar man det???”

(Receptionist at Renova, 2018)

Nikola Motor Company

- Five year old company based in Phoenix, Arizona
- Leasing of long haul trucks including hydrogen for up to 16,000,000 km, maintenance, tires and more (or purchase)
- Nikola will establish 700 hydrogen stations in the USA
- Three truck types for long haul:

  Electric machines up to ~750 kW
  Range up to 800 – 1,600 (Tre: 1,200) km
  Batteries 240 – 320 kWh
  Hydrogen @700 bar
  Fuel cell power in first truck demonstrated in April 2019
  approximately 200 kW

- Announced in February 2019; also BEV versions of Two and Tre for short haul with batteries 500 kWh, 750 kWh or 1,000 kWh

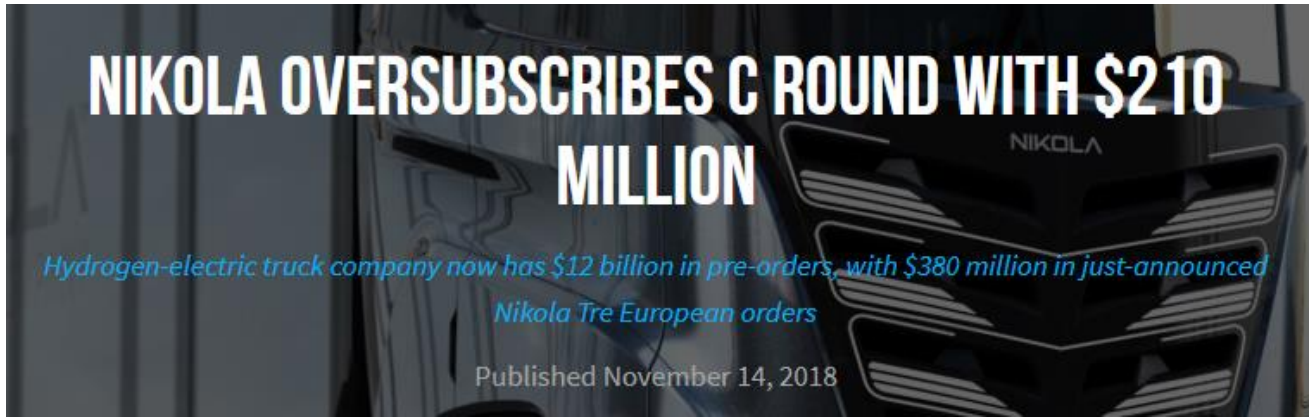
Nikola Motor Company – partners (examples)

- NEL for hydrogen stations
- Bosch for some technologies; digital vision system, steering system, keyless digital key
- AVL for the (fuel cell) laboratory
- Wabco for brakes
- Ryder System for sales and maintenance

Trucks and fuel cells will be developed and manufactured in-house(!?)

Nikola Motor Company – huge ambitions

- Big Nikola World event April 16-17, 2019
- Limited news about fuel cell trucks
- Customers (examples):
  - U.S. Xpress Enterprises
  - Anheuser-Busch (800 Nikola Two)



USD 14 billion in truck pre-orders (not accepting new orders at this time…)

1,600 trucks in Switzerland

- Joint-venture formed with Hyundai and H2 Energy AG: Hyundai Hydrogen Mobility (HHM)
- Hyundai delivers 1,600 heavy-duty fuel cell trucks from 2019 through 2025 to HHM
- HHM leases trucks to H2 Mobility Switzerland Association
- H2 Energy produces hydrogen based on PEM electrolysis and hydropower and distributes it
- NEL will deliver a 2 MW electrolyzer during autumn 2019 (part of 30 MW agreement)

Operating MAN plug-in fuel cell truck

The chicken **and** the egg

The Swiss Hydrogen Association is coordinating built-up of HRS-network and members will operate fc-truck-fleet

+Shell

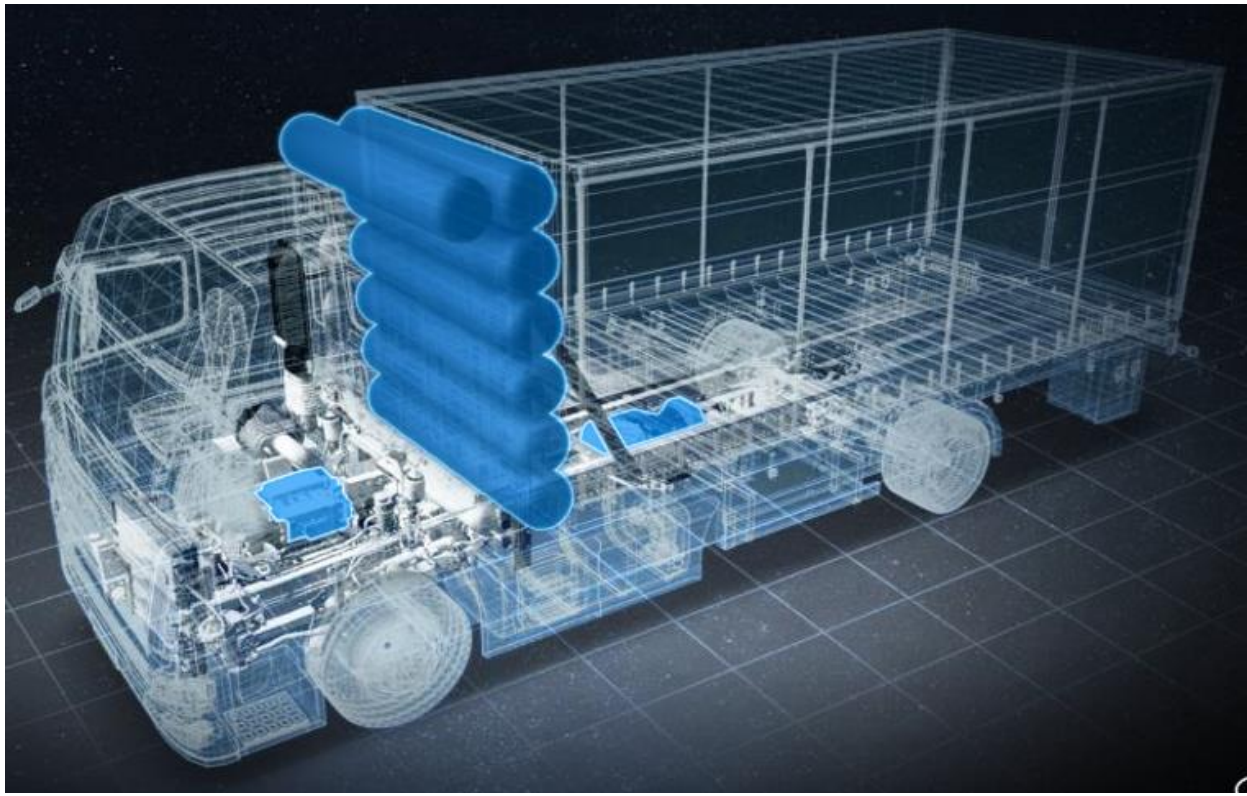
- Association founded May 17th, 2018
  - Jointly operating ~1'600 petrol stations (>50%) and ~2'000 heavy duty trucks in operation
  - Associated to major third party logistic partners
  - Dedicated to jointly establish nationwide refueling station network in Switzerland until 2023

Egg

Chicken

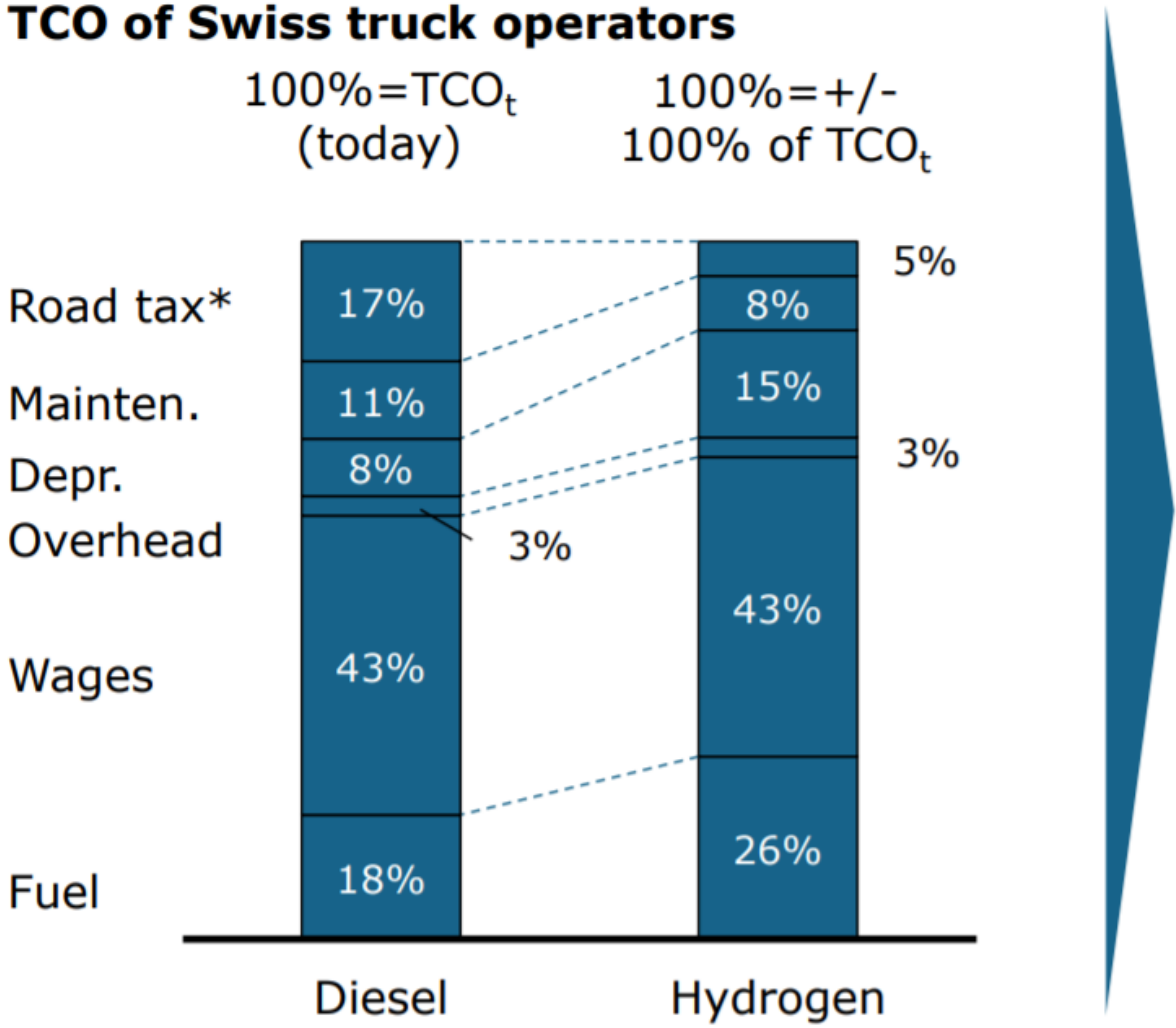
Hyundai truck specification

- 190 kW fuel cell system (2 * 95 from Nexo car)
- 350 kW electric motor
- ~50 kWh batteries? (my guess)
- 33 kg hydrogen @350 bar
- ~400 km range
- Refuelling time ~7 minutes



Cost competitiveness

- TCO similar today thanks to tax exemption
- Leistungsabhängige Schwerverkehrsabgabe (LSVA) tax depends on weight, emission standard and distance traveled
- Example:
  - 40 ton Euro 6: 91.2 CHF/100 km (824 SEK/100 km)
  - ~500,000 SEK per 40 ton truck and year



* Including insurance and interests, exemption of LSVA

Discussion – time to market?

- Small-scale demo projects:
  - Scania – Renova
  - Scania – ASKO
- Medium-scale demo projects:
  - Toyota Project Portal
  - Toyota Fuel Cell Buses in Tokyo (100 vehicles)
- Large-scale market introduction ambitions:
  - Hyundai & H2 Energy
  - Nikola Motor Company

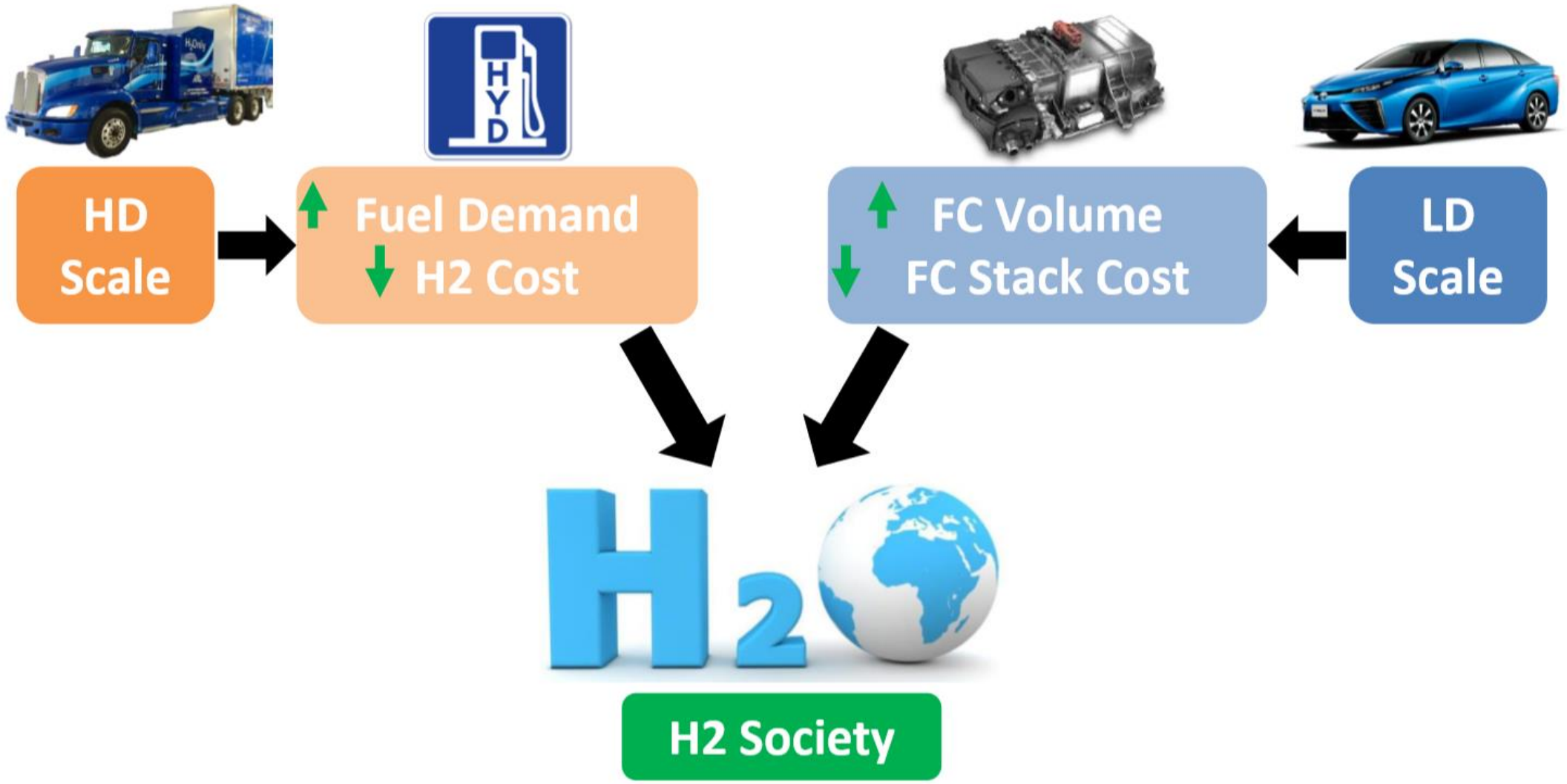
Discussion – hydrogen supply

- Vehicles and hydrogen stations in the same project
  - Scania – ASKO (350 bar)
  - Hyundai and H2 Energy (350 bar)
  - Nikola Motor Company (700 bar t b c)
- Vehicles and hydrogen mainly in separate projects
  - Toyota Project Portal (700 bar)
  - Scania – Renova (350 bar)

Discussion – powertrain configuration

Project	Fuel cells	Batteries	Comments
Toyota trucks and buses	2 * Mirai fuel cells	Small hybrid power	Car fuel cells
Hyundai	2 * Nexo fuel cells	Medium hybrid plug-in (tbc.)	Car fuel cells
Scania trucks	~100 kW fuel cells	Large plug-in	Heavy-duty fuel cells
Nikola MC	~200 kW fuel cells (tbc.)	Large plug-in (tbc.)	Heavy-duty fuel cells (tbc.)

Synergies heavy and light duty vehicles



Concluding summary

- Rapidly growing interest for fuel cell trucks
- Huge market potential
- Limited worries about technology
- Cost competitiveness depends on:
  - Hydrogen cost
  - Incentives and regulations
- Still an early stage - it would be interesting to do the same study in one or two years

THANK YOU!

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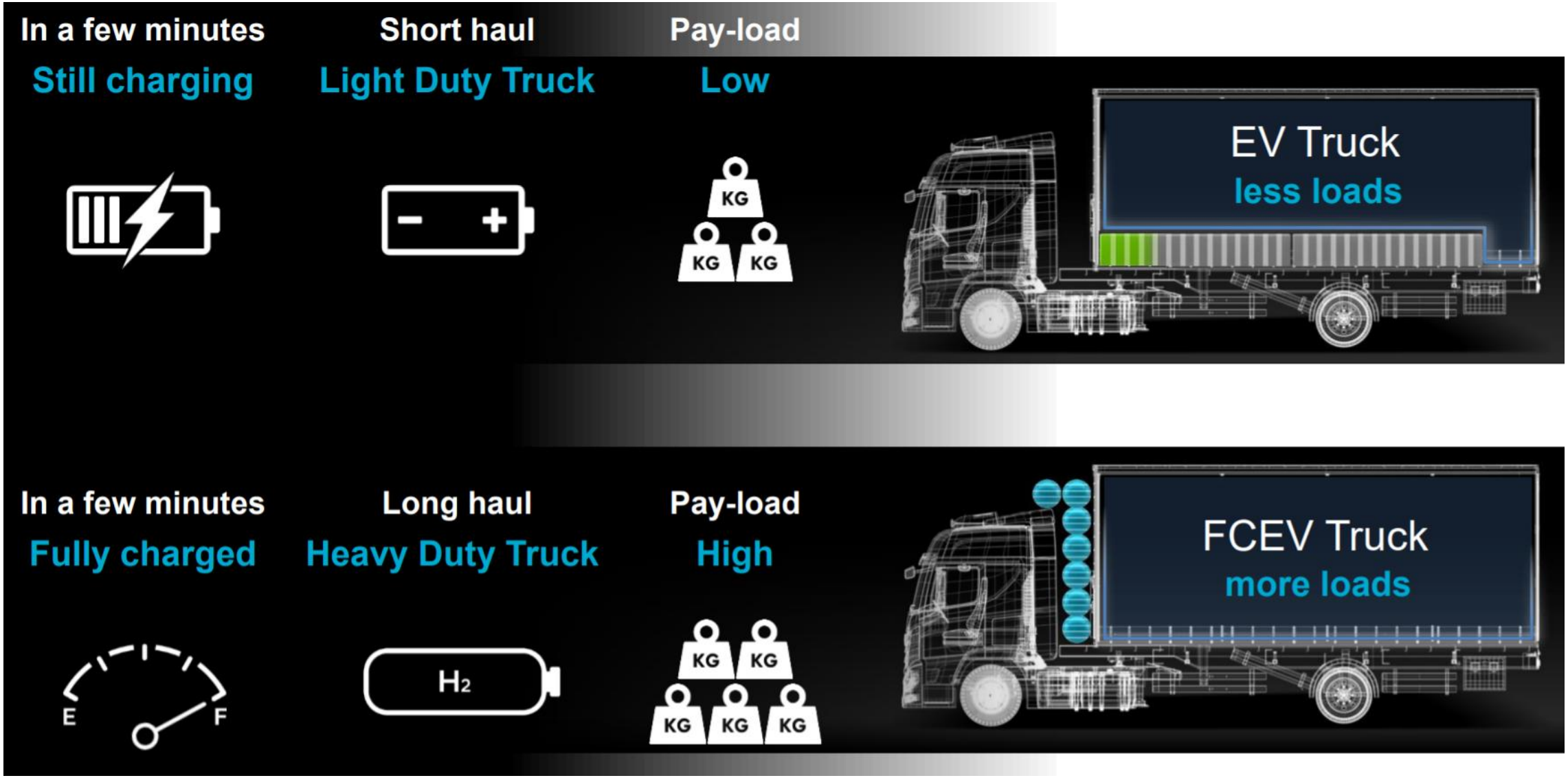
Comparison fuel cell and battery trucks



Toyota Project PORTAL in Los Angeles

16 ton