Part 4:
Implementing green hydrogen supply for fuel cell buses in the Nordic countries

Dr. Uffe Borup

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About Nel Hydrogen

- World’s largest pure-play hydrogen company with a market cap of more than $250 million.
- 200 employees in Denmark, Norway and USA with world-class experience and skills.
- Offering hydrogen technology and solutions for industrial, energy and transport applications.
- More than 3500 hydrogen solutions delivered in 80 countries worldwide since 1927.
- World #1 on hydrogen electrolysers and hydrogen fueling – unrivalled performance and track-record.

**ALKALINE ELECTROLYSERS**
Dates back to 1927

**PEM ELECTROLYSERS**
Acquired in 2017

**HYDROGEN FUELING**
Acquired in 2015
Nel Hydrogen: Zero emission – Zero compromise

- Nel Hydrogen provides solutions for renewable production and fast fueling of hydrogen with long driving range.
- Enables zero emission transport based on renewable energy with the same convenience and performance as gasoline.

**Electrolysers**
Hydrogen production

**H2Station®**
Hydrogen fueling

**Fuel Cell Bus**
<10 min. fueling 400+km range
20-40 kg per fill

**Fuel Cell Car**
<5 min. fueling 500+km range
4-7 kg per fill
Large scale hydrogen electrolysers since 1927

Delivered the world’s largest electrolyser in 1950s on 135 MW / 30,000 Nm3/h
H2Station® hydrogen fueling solution

Turn-key standardized hydrogen fuelling station with dispensers for cars, busses, trucks and forklifts. 200kg per day at 70MPa or up to 600kg/day for 35MPa – all fast fuelling in accordance with SAE J2601. Flexible configuration of hydrogen storage and fuelling capacity – very compact total footprint. Can connect to various hydrogen supply sources e.g. onsite production or trucked-in delivery.
New H2Station® manufacturing facility in Denmark

H2Station® manufactured at world’s largest factory

300 H2Station® per year – sufficient for fueling 200,000 new FCEVs annually.
€9 million initial investment.
Nel Hydrogen has delivered more than 30% of 70MPa hydrogen fueling stations in Europe since 2011 and is now entering CA. In Denmark and Norway and Iceland entire countrywide networks are deployed in collaboration with oil and gas companies.

**DENMARK 2011-2016**
- 10 H2Station® and Hydrogen production

**NORWAY 2016-2020**
- Up to 20 H2Station® and Hydrogen production

**ICELAND 2017-2020**
- 3 H2Station® and Hydrogen production

**CALIFORNIA 2017-2018**
- Multiple H2Station® in San Francisco and Los Angeles
First H2Station® for busses (2013)

Customer: Solvay, Antwerp, Belgium.
Capacity: 400kg/day – prepared for upgrade to 800 kg/day.
Supply: Pipeline from nearby industrial surplus hydrogen production.
Fuelling: 35MPa – up to 40kg/fuelling in 10 minutes @ 25°C.
Protocol: Patented fueling protocol ensuring 10-15 min. fueling and high State-of-Charge.
Operation: Since Dec. 2013 – more than 13.799kg / 823 fuelings by June 2017

We are currently building new bus fueling stations in Riga and on Island
Integration of Renewable electricity is a key challenge

2017: 2.2 TWh curtailment in DK to avoid negative spot price.

- Electrolysis provide the needed flexibility. Conversion of wind overproduction to a valuable hydrogen fuel.

- Hydrogen can be easily stored
  - High pressure vessels
  - Or Salt caverns

- Transportation fuels are high value
Coupling sectors with mutual (green) benefits

- Via electrolysis, excess Wind Energy is converted to hydrogen and utilized in several sectors
  - Enables access to a cheap 100% green alternative for transportation and in numerous industrial applications
  - Sustains RE-business cases and drives the vital sector coupling - benefitting all participants

Hydrogen today:
- 100 B€ industry
- Ammonia
- Refineries
- Steel
- Food
- Chemicals
- Power2gas
- Transportation

Using green hydrogen will have a major impact on CO2 emissions
Hydrogen can store and balance renewable energy

Hydrogen production can cover large parts of the balancing needed in DK to integrate renewable energy in the system by 2035 and 2050

- **2035**: 35% FCEV in car fleet cover the Danish balancing needs
- **2050**: 50% FCEV in the car fleet and Heavy duty cover 100% of the balancing needs

Source: MegaBalance project

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**Balancing of Power grid with Hydrogen production in 2035 and 2050**

<table>
<thead>
<tr>
<th>Year</th>
<th>Power Grid Peak MW</th>
<th>Balancing need</th>
<th>Wind Power</th>
<th>35% FCEV in car fleet</th>
<th>50% FCEV + Heavy Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>2035</td>
<td>8.500 MW</td>
<td>700 MW</td>
<td>35% FCEV</td>
<td>800 MW</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>17.500 MW</td>
<td>3.900 MW</td>
<td>50% FCEV</td>
<td></td>
<td>1.800 MW</td>
</tr>
</tbody>
</table>

Electrolyser capacity – installed MW

46%
Renewable energy is the key to cheap green hydrogen

• Electrolyser operation support the stability of the power system.

• Operation is highly flexible and can be aligned with the availability of excess electricity.

• Wind, Solar and Hydro have very low marginal cost and shift the spot price curves lower when production exceed demand.
H2 supply chain for Heavy Duty vehicles

- Optimized hydrogen supply chain
- Cheap renewable electricity is converted to hydrogen
- Distributed by truck, and dispensed competitively

Fueling infrastructure can be provided as part of the supply contract.

500kg/day, 10 year depreciation, <200km distribution:

H2 Supply contracts available for public transport sector:

8-10 year hydrogen contract at 5€ / kg
Hydrogen supply from Central Production

Central production, distribution, fueling, services

Competitive green hydrogen production in central location:
• Potential co-location with high demand customer
• Utilization of heat and oxygen byproducts

Efficient Hydrogen distribution:
• 1500kg pr. truck
• Swap of container or Dump-off

Scalable solution
• Bus depot capacity can be easily added or extended
• Production centers will be located throughout Scandinavia within proximity of 20 largest cities
Central Hydrogen Production plant

Plant Capacity: 2 – 100 T / day

60 / 10 kV substation

3 - 16 x Electrolysers
3 - 16 x 485 Nm3 / h

20MPa bulk storage

3MPa

2-stage Oil free Compressors

70MPa

3-stage Oil free Compressors

20MPa bulk storage

X x 70MPa mobile storage
20 - 40 ft
780 - 1560 kg capacity
Hydrogen Bus setup – case Hasselager

Centrally produced hydrogen

Trucked-in in pressurized tanks

Central H2Plant®

Busdepot Syd: Jegstrupvej 5, 8361 Hasselager

From high way to busdepot

Busdepot Syd: Jegstrupvej 5, 8361 Hasselager
HD bus station footprint (standard – drive thru)

2 Dispensers
Can be placed flexible

<100m² required for fueling equipment at the depot
20-50 bus capacity

H2 piping (under ground)
H2 piping (elevated)
Supply cabinet (HD)
Heavy duty dispenser (flexible placement)
Vent/connection-panel
H2Station 4 x 3.3m Controls and cooling
Concrete firewall (for H2 trailer docking’s)
Distance pole
Station siting example - Hasselager

Footprint of compact H2Station® HD
Up to 1000 kg /day
~ 20 - 50 FC busses
TCO of Fuel Cell busses will become equal to diesel!

Hydrogen supply and operation

• Cost of hydrogen dispensed 5€/kg
• **Fossil Parity** - (Hydrogen competitive with diesel)

Total BUS economy

• Hydrogen cost is linked to cost of wind and solar (Will show further declining cost trend over the next 10 year period)
• Risk of ban on diesel in the contract period, Pollution limits exceeded etc
• FC Bus with Green Hydrogen → CO2 reduction pr. bus over 10 years = 850 ton CO2 reduction
Price of Fuel Cell bus - Experience curve

- From the first projects the price has come down with every new demonstration project

- ~15% cost reduction from every doubling of accumulated shipment (learning curve)

- Volume will drive down cost further.

- 1.000 busses needed to make Fuel Cell bus a competitive zero emission vehicle

- At 20.000 busses FCV will compete with current diesel bus cost

- *CHIC: [http://chic-project.eu/](http://chic-project.eu/)
- *3Emotion: [http://www.3emotion.eu/](http://www.3emotion.eu/)
- *JIVE2: Upcomming
7% CO2 reduction of total Municipality emissions

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>H2 electrolysis from Renewable</th>
</tr>
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<tbody>
<tr>
<td>Average consumption</td>
<td>39 l/100km</td>
<td>8kg/100km</td>
</tr>
<tr>
<td>Fuel consumption (1,000,000 km/year)</td>
<td>389,000 l/y</td>
<td>80,000 kg/y</td>
</tr>
<tr>
<td>CO2 emission (@2,66 kg / L)</td>
<td>1.034 tCO2/y</td>
<td>0</td>
</tr>
<tr>
<td>Herning Kommune footprint 2015</td>
<td>15.415 tCO2/y</td>
<td>~7%</td>
</tr>
<tr>
<td>City emission reduction with 10 Fuel Cell busses</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Reduction of CO2 emission in Bus fleet</td>
<td></td>
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Case Herning – can be applied in other municipalities

- City buses converted to Hydrogen – previously EURO4
- Implementing hydrogen buses saves 7% of the total CO2 emissions in the entire municipality
- Savings in emissions: SO2, NOx, CO, HC, PM saves money and lives.

CO2 footprint of electricity is crucial

CO2 emissions of bus fuel (well-to-wheel) in 2015 [kg/100 km]

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>CO2 Emission [kg/100 km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>122</td>
</tr>
<tr>
<td>H2 steam reforming natural gas</td>
<td>108</td>
</tr>
<tr>
<td>H2 electrolysis grid electricity Germany</td>
<td>125</td>
</tr>
<tr>
<td>H2 electrolysis grid electricity UK</td>
<td>201</td>
</tr>
<tr>
<td>H2 electrolysis grid electricity Netherlands</td>
<td>180</td>
</tr>
<tr>
<td>H2 electrolysis grid electricity France</td>
<td>38</td>
</tr>
<tr>
<td>H2 electrolysis grid electricity Norway</td>
<td>0</td>
</tr>
<tr>
<td>H2 electrolysis from RES</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 19: WTW CO2 emissions of diesel and hydrogen in 2015 [kg/100 km]
Implement Hydrogen Fuel Cell city Busses in Scandinavia at competitive TCO

How?
• Gathering of significant demand (1000 Fuel Cell Buses through 2022)
• Develop infrastructure at scale
• Start by signing a non-binding LOI that we can present to OEM’s – Volume production is what is needed to bring down the bus and hydrogen cost

Hydrogen Infrastructure?
• Hydrogen will be provided in the contract period at fixed price – safe, green and reliable
• Easy installation of fueling infrastructure at the depot – no interference in townscape

Choosing a solution
• In the tenders choose the best solution for your Municipality based on your criteria
Summing up

Fuel Cell busses are 1 : 1 substitution for diesel buses
• Range of the buses can service the existing routes - no on-route infrastructure
• Refueling is done at depot once a day (takes 10 minutes)

No expensive investment in fueling / charging infrastructure is needed
• Supplier of hydrogen provides the refueling infrastructure
• The refueling is done at the depot – no interference with traffic / problem for the city during setup and operation.

Total Cost of Ownership will become equal to Diesel!
• Hydrogen supplied at fixed price for 10 year period.

Environmental benefits
• 100% renewable electricity = save 85t CO2/ year pr. bus at 85.000km
• Zero Emissions: SO$_2$, NO$_x$, CO, HC, PM reduce cost to society and saves lives.
• Low Noise Level (Stress, property value, operability)
What we ask of you:

Reach out to us for more information or for help to assess your **fuel cell bus** potential

Send clear “market signal” that fuel cell busses are a desired zero emission solution
- By including Fuel Cell busses in your next bus tender
- Non-binding FCB – Letter of Intent (LOI) this fall

Green Hydrogen and Fuel Cell busses are ready for action - We are here to help you

Help us to bring 1000 fuel cell busses on the roads in Scandinavia by 2022
End of presentation

Thank you for your attention

Questions?

www.nelhydrogen.com