Techno-economic study of hydrogen as a heavy-duty truck fuel
A case study of Oslo – Trondheim transport corridor

By Janis Danebergs
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- Background
- Methodology
- The truck
- The infrastructure
- Summary & Outlook
Norway's greenhouse gas emissions

![Graph showing Norwegian total emissions from 1990 to 2030](image)

**Greenhouse gas emissions 2018**

- Oil and gas extraction: 27%
- Manufacturing industries and mining: 23%
- Road traffic: 17%
- Aviation, navigation, fishing, motor equip. etc.: 14%
- Agriculture: 9%
- Other: 5%
- Energy supply: 3%
- Heating in other industries and households: 2%

Sources:
Emission free HD transport

- Battery powered
- Biodiesel powered
- Hydrogen powered

Case study

Background

### Table

<table>
<thead>
<tr>
<th></th>
<th>Now</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly transport of cargo</td>
<td>932 000 tons (average last 10 years)¹</td>
<td>1 149 000²</td>
</tr>
<tr>
<td>Trips per working day</td>
<td>~260</td>
<td>~330</td>
</tr>
<tr>
<td>Zero emission trucks</td>
<td>0</td>
<td>~100³</td>
</tr>
</tbody>
</table>

¹ Source: [https://www.ssb.no/transport-og-reiseliv/statistikker/godstrans](https://www.ssb.no/transport-og-reiseliv/statistikker/godstrans)

² TØI report “Forecasts for Norwegian freight transport, 2016-2050”

³ When using national forecast by Norwegian Environment Agency
Research questions

- What is an optimal design of Fuel Cell Electric Truck (FCET) in the transport corridor between Oslo and Trondheim?
- What is the Total Cost of Ownership (TCO) of an FCET in comparison with other net-zero carbon dioxide fuels such as biodiesel?
- What is the best techno-economic design and scale-up of hydrogen refueling infrastructure in the corridor, dependent on hydrogen demand (fleet size)?
- Background
- Methodology
- The truck
- The infrastructure
- Summary & Outlook
Approach

The truck

- Truck energy demand
- Truck component design
- TCO for 2020 & 2030

The Infrastructure

- Model different HRS and electrolyzers
- Evaluate created models
- Find LCOH for different scenarios in 2020 & 2030

LCOH as free variable

Combine results and conclude upon feasibility in 2020 & 2030

Number of trucks as free variable
Background
Methodology
The truck
The infrastructure
Summary & Outlook
Assumption for truck

- The freight is done with a semi-trailer truck (50 ton)
- The first owner will use the truck for 6 years
- Discount rate of 8%
- A hybrid truck with fuel cell and battery

![Image of a truck](https://www.volvotrucks.no/no-no/trucks/volvo-fh16/media-gallery.html)
Due to regeneration the hybrid truck requires 10.6% less energy.
The truck

Truck specifications

<table>
<thead>
<tr>
<th>Sized components</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max traction power</td>
<td>$402 \text{ kW}_{\text{mech}}$</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>$200 \text{ kW}_{\text{el}}$</td>
</tr>
<tr>
<td>Battery</td>
<td>100 kWh</td>
</tr>
<tr>
<td>Fuel tank</td>
<td>$46 \text{ kg}_{\text{H}_2}$</td>
</tr>
</tbody>
</table>

## Truck CAPEX & OPEX

<table>
<thead>
<tr>
<th>Truck type</th>
<th>Purchase price (NOK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td>1 152 175</td>
</tr>
<tr>
<td>FCET 2020</td>
<td>1 936 340</td>
</tr>
<tr>
<td>FCET 2030</td>
<td>1 361 893</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Biodiesel</th>
<th>FCET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>1.27 [1]</td>
<td>0.91 [1,2]</td>
</tr>
<tr>
<td>Road taxes</td>
<td>0.71 [3]</td>
<td>0</td>
</tr>
</tbody>
</table>

[4] Circle K. Norge. (2019, 2019/06/21/). Prishistorikk for truckdiesel Retrieved from [https://m.circlek.no/cs/Satellite?c=Page&childpagename=NO1%2FLayout&cid=1334077141669&p=1334077141669&packedargs=lang%3Dno_NO%26site%3DNO1&pagename=NO1Wrapper](https://m.circlek.no/cs/Satellite?c=Page&childpagename=NO1%2FLayout&cid=1334077141669&p=1334077141669&packedargs=lang%3Dno_NO%26site%3DNO1&pagename=NO1Wrapper)
The truck

Total Cost of Ownership (TCO)

\[
TC \ O/k \ m = \frac{\left( IPC - \frac{RV}{(1 + r)^n} \right) \cdot CRF + \frac{1}{n} \sum_{t=1}^{n} \frac{AOC}{(1 + r)^t}}{AKT}
\]

AKT = Annual Kilometers Travelled
AOC = Annual Operation Costs
CRF = Capital Recovery Factor
IPC = Initial Purchase Cost

The truck

Comparison of TCO

The most sensitive parameters:
- Economic lifetime (6 years)
- Annual mileage (81 100 km)
- CAPEX (1 839 144 NOK)
Comparison of TCO

Total cost of ownership depending on hydrogen retail price

- TCO H2 truck 2020
- TCO H2 truck 2030
- TCO Biofuel truck
Background
Methodology
The truck
The infrastructure
Summary & Outlook
Location is chosen based on:

- A full tank is enough for a one-way trip
- Allow the truck to make deliveries nearby the cities
- Allows refilling during obligatory rest period in the middle of the route
- Have resilience
The infrastructure

Supply chain

**Electrolysis (Ely)**
- PEM or Alkaline
- Distributed or centralized production

**Transport**
- In case fueling station and electrolysis is separated

**Hydrogen Refueling Station (HRS)**
- 350 or 700 bar
The infrastructure

Supply chain

Cheapest option:

Electrolysis (Ely)

PEM or Alkaline

Distributed or centralized production

Hydrogen Refueling Station (HRS)

350 or 700 bar
The infrastructure

Electrolyzer set-up

Electrolyzer unit

Electrolyzer

Compressor

Storage 350 bar

Hydrogen refuelling station – 350 bar

Cooling (Optional)

450 bar
Levelized Cost Of Hydrogen

\[ LCOH = \frac{\sum_{t=1}^{n} \left( \frac{I_t + M_t + E_t}{(1 + r)^t} \right)}{\sum_{t=1}^{n} \frac{H_t}{(1 + r)^t}} \]

- \( I_t \) = Investment costs year \( t \)
- \( M_t \) = Maintenance cost year \( t \)
- \( E_t \) = Energy costs year \( t \)
- \( H_t \) = Hydrogen produced year \( t \)
- \( N \) = Lifetime (30 year)
- \( r \) = Interest rate (8%)
The infrastructure

LCOH based on local electrolyzer

The most sensitive parameters:
- Amount of trucks
- Interest rate (8%)
- Electricity price (0.36 NOK/kWh$_{el}$)

39 kg per refueling
The infrastructure

LCOH based on local electrolyzer

The most sensitive parameters:
• Amount of trucks
• Interest rate (8%)
• Electricity price (0.36 NOK/kWh_{el})

39 kg per refueling
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The infrastructure

Profitability depending on infrastructure

![Graph showing profitability depending on infrastructure]

- **700 bar 2020**
- **350 bar 2020**
The infrastructure

Profitability depending on infrastructure

Refueling events per HRS & day

Cost of hydrogen (NOK/kgH2)

- 700 bar 2020
- 350 bar 2020
Profitability depending on infrastructure

Summary and Outlook

39 kg per refueling

2020 Scenario

- Refueling events per HRS & day
- Cost of hydrogen (NOK/kgH2)
- TCO (NOK/km)

350 bar
700 bar
TCO H2 truck 2020
TCO Biofuel truck

Profitability depending on infrastructure

TCO (NOK/km)

Cost of hydrogen (NOK/kgH2)
Profitability depending on infrastructure

39 kg per refueling

Summary and Outlook
# Profitability depending on infrastructure

## Price parity with biodiesel (HVO)

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>35 refuelings per day and station</td>
<td>5 refuelings per day and station</td>
</tr>
</tbody>
</table>

## Feasibility in comparison with biodiesel (HVO)

- 15 trucks refueling daily per HRS
- 3 HRS stations
- Truck fleet of 72 units in total

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>- 9 937 kNOK/year</td>
<td>- 3 755 kNOK/year</td>
</tr>
<tr>
<td></td>
<td>1 412 kNOK/year</td>
<td>4 771 kNOK/year</td>
</tr>
</tbody>
</table>
Summary & Outlook

- Based on current theoretical cost levels FCET are not competitive with HVO fueled trucks.

- There are expected price reduction both for trucks and infrastructure that could make FCET an attractive option.
  - For example in 2030 it is forecasted that a HRS serving 5 trucks would become a feasible option both for truck and HRS owner.

- Considering the future expected price reduction, short term subsidies should be considered to help to meet national emission reduction targets.

- Strongest gains from economy of scale is found for HRS serving up to 10-15 trucks

- Production of hydrogen at HRS is the least cost option, due to high transport costs

- Demand ramp-up is not included in the calculation. It would increase LCOH.
Thank you for your attention!

Questions?

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