

## Batteries and hydrogen for heavy transport applications in an industrial park

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# Outline

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Introduction: Mo Industrial Park

Zero-Emission Technologies

- Batteries

- Hydrogen

- Other Alternatives

Comparison of Zero-Emission Alternatives

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# Mo i Rana and Mo Industrial Park

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- Town in Nordland, Norway (18,000)
- Became industrial town in 1955
- Mo Industrial Park (MIP) employs 2300
- Over 100 companies
- Industry very close to residential areas
- History with industrial pollution
- Interest in industrial ZEVs



# Industrial Vehicles at MIP

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- Owned by Mo Industritransport (MIT)
- Represent 80 % of diesel consumption
  - 3 Svetruck 15120-35 forklifts
  - 3 Caterpillar 980 wheel loaders
  - 11 Volvo A25 dump trucks
  - 2 Volvo A40 dump trucks
- Diesel cost: 0.75 €/L (VAT excluded)
- Focus on *local* emissions (PM, NO<sub>x</sub>, etc.)



Clockwise from top left: Svetruck 15120-35, Caterpillar 980, Volvo A40 and Volvo A25

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# Batteries

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- No time for charging stops during day
- Dimension battery for 16 h (two shifts)
- Degradation margin: divide by 80 %
- Li-ion battery type: **LFP**
  - 140 Wh/kg
  - Lifetime 7200 cycles
  - Cost 900 \$/kWh (BYD)

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Vehicle	Battery kWh	t	CAPEX k€/pc.
Svetruck	718	5.1	566
C980	1340	9.6	1057
A25	1006	7.2	764
A40	1161	8.3	916

(A Tesla Model S has 60 to 100 kWh)



# Chargers

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- Dimension for full charge overnight, 8 h
- Current cost of fast chargers: 571 €/kW
- Power tariff in Norway: 29 €/kW/year



A CCS connector can handle up to 200 kW

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Vehicle	Power kW	CAPEX k€/pc.	Tariffs k€/y/pc.
Svetruck	72	38	2.4
C980	134	70	4.5
A25	101	53	3.4
A40	116	61	3.9

# Fuel Cells

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  - 2000 \$/kW (today, single orders)
  - 300 \$/kW (1000 units/year)
  - 80 \$/kW (100,000 units/year)

Vehicle	Power kW	Weight kg	Cost k€/pc.
Svetruck	144	219	273
C980	300	455	568
A25	235	357	445
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# Hydrogen Tanks

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- Assume 350 bar CH<sub>2</sub> tanks
- Commercial CAPEX 30 \$/kWh
- Lifetime: likely more than vehicle



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Vehicle	Capacity kg <sub>H<sub>2</sub></sub>	Weight kg	Cost k€/pc.
Svetruck	29	586	25
C980	54	1094	47
A25	41	822	35
A40	47	948	41



# Hydrogen Refuelling Station

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- Common electrolyser station
- CAPEX 4400 \$/(kg/d)
- Efficiency 72 %
- Lower tariffs for power:
  - Dimension for average, not peak
  - Energy spread across all 24 h
  - Can accept temporary disconnection
- *Oxygen* has a value too
  - Industrial users in MIP
  - Also aquaculture industry close by
  - Current price is confidential



Air Liquide's HRS in Rosenholm, Oslo

# Other Alternatives

Not considered in this study

- Biodiesel
  - Not a zero-emission solution
  - Local emissions are main concern
- Dynamic power supply
  - Catenary or inductive
  - Dismissed by MIP as impractical
  - Height constraints
  - Low flexibility, high CAPEX
  - Difficult to set up a pilot



Siemens and Scania's prototype

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# Equivalent Annual Cost

## Comparison Criterion

- Different lifetimes
- Use Equivalent Annual Cost  $A$ , equivalent to Net Present Value

$$I \equiv NPV = \sum_{i=1}^n A (1+r)^{-i}$$

- Simply add to OPEX

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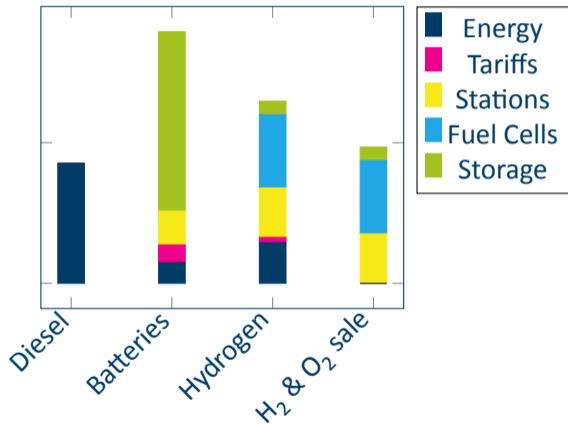
### Example

- CAPEX  $I$ : 1 million €
- Lifetime  $n$ : 20 years
- Interest rate  $r$ : 4 %
- Annualised CAPEX  $A$ : 73 582 €
- OPEX 15 000 €
- Equivalent annual cost: 88 582 €

# Techno-Economic Results

Classified by equivalent annual cost

- Tariffs  $\approx$  energy costs for batteries
- Battery chargers cost  $\frac{2}{3}$  of HRS
- Batteries prohibitively expensive
- Fuel cell cost 300 \$/kW
- O<sub>2</sub> sale at 210 €/t covers energy & power costs for hydrogen
- If O<sub>2</sub> value >286 €/t hydrogen is best



# Way Ahead

Future studies and pilot project

## Missing data:

- Power profiles
  - Not logged
  - Cannot evaluate hybridisation
  - Smaller FC with buffer battery
  - Same hydrogen tank, HRS
- Diesel efficiency
  - Assumed 33 %, could be worse
  - Could decisively increase diesel costs
- Oxygen price for MIP
  - Strictly confidential
  - Market survey in area
- Prototype: modified A25
- Batteries (“A25B”):
  - Batteries: 800 000 €
  - Charging station: 53 000 €
  - Energy costs: 3370 €/year
- Hydrogen (“A25H”)
  - Fuel cells: 446 000 €
  - Hydrogen tanks: 35 300 €
  - Hydrogen (trucked in): 50 000 €/year
- EU project?

# Conclusions

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- Hydrogen at a significant advantage over batteries
- Diesel is still competitive, but with small margins
- Oxygen valorisation can be decisive
- Hydrogen-battery hybrid could give an even better result
- MIP interested in follow-up. *Any takers?*



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*Thank you for your attention!*



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