"Alternative Railway Electrification in Norway"

FCH 2 JU & S2R JU: Hydrogen Train Workshop

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Outline

- Norway – an early market for 0-emission transport
- Alternatives to Electrification with Over-Head Lines (OHL)
- Approach and Methodology for the freight train study
- Results for the selected Nordland line, sensitivity
- Summary/Conclusions

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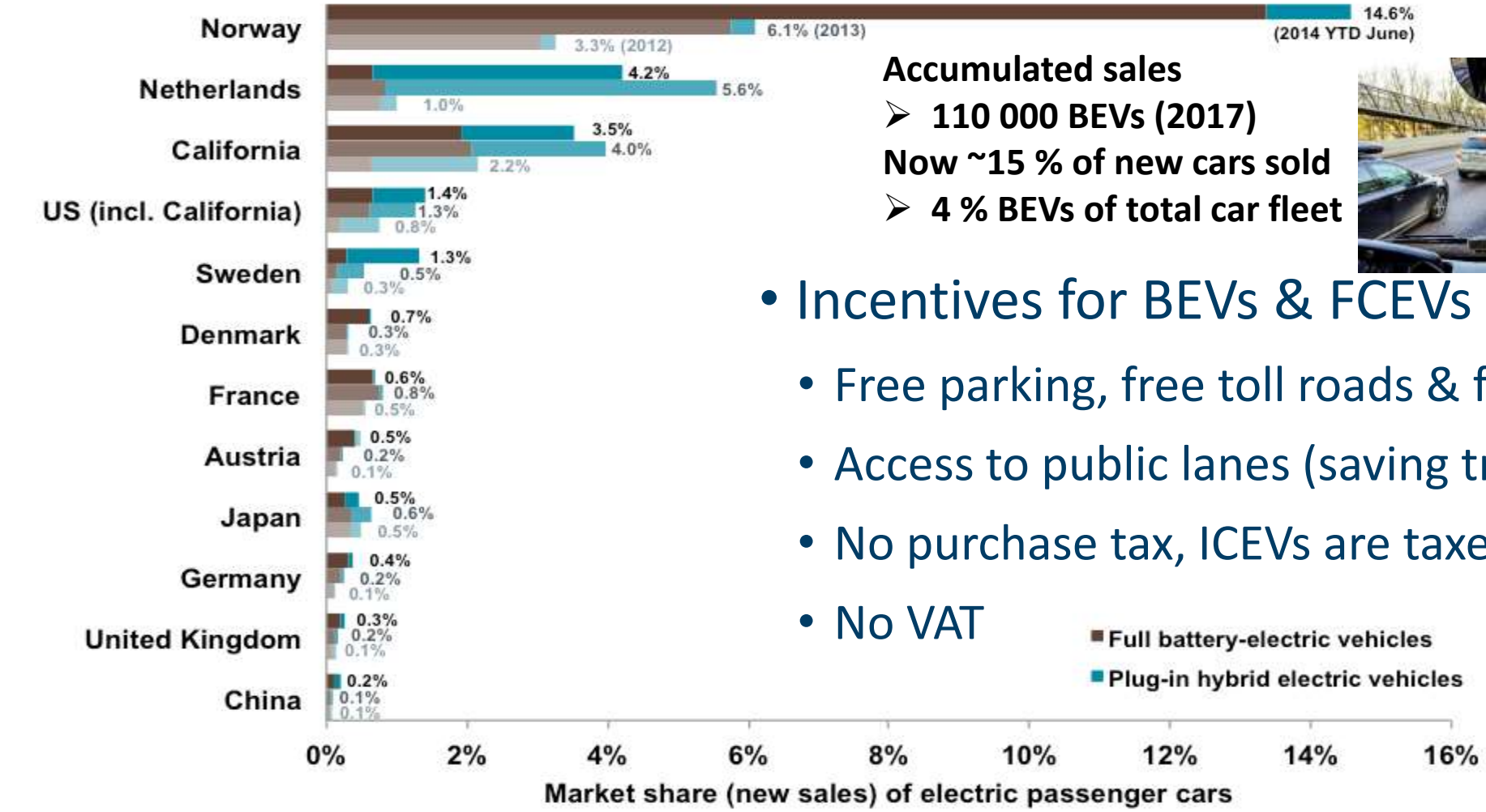
Norway, an Early Market for BEVs



Accumulated sales

- **110 000 BEVs (2017)**

Now ~15 % of new cars sold

- **4 % BEVs of total car fleet**

- Incentives for BEVs & FCEVs in Norway:
  - Free parking, free toll roads & ferries (fjords)
  - Access to public lanes (saving travel time)
  - No purchase tax, ICEVs are taxed 50-100 %
  - No VAT

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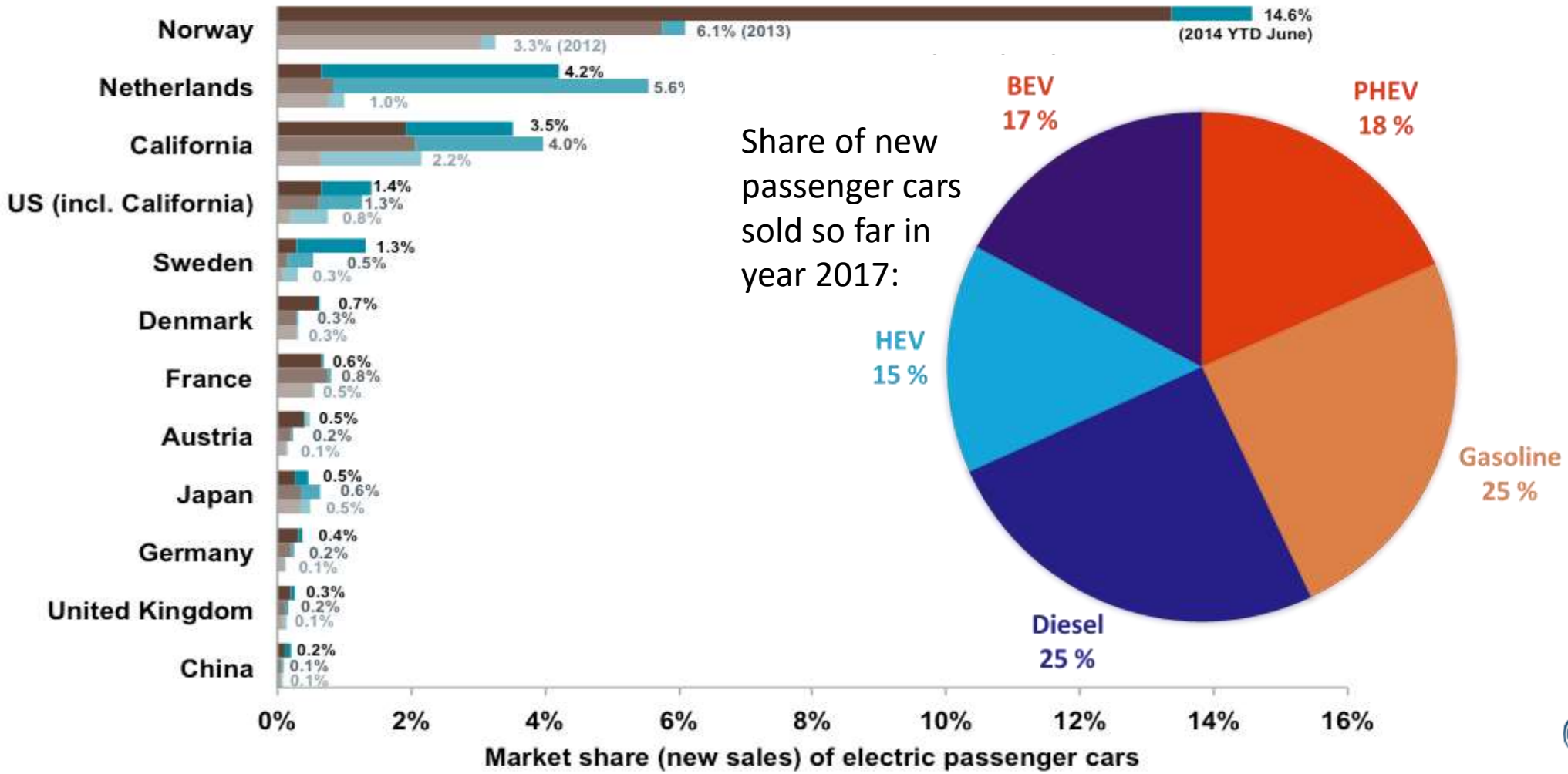
Norway, an Early Market for BEVs



Norway's engagement and ambitions

- Main focus on Transport due to renewable based stationary sector
- Share of new vehicles sold by 2025 which shall be 0-emission (el/H_2):
  - *100% of passenger cars*
  - *100 % of light duty vans*
  - *50 % of heavy duty vans*
- Parliament decision: A hydrogen refuelling infrastructure shall be established, but some delay in implementation
- New funding instruments for H_2 in ships and heavy duty vehicles
- Discussions on the use of H_2 as fuel for trains in the Transport Ministry

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GHG emissions (transport) & H_2 demos

Passenger vehicles, 5,6 mill tonnes

CO_2

Vans and heavy duty vehicles 4,4 mill tonnes

CO_2

Domestic maritime and fishing, 3.7 mill tonnes

Other mobile sources 2.3 mill tonnes

Domestic air traffic 1,3 million tonnes

Motor bikes and scooters 0,1 million tonnes

Railroads 0,05 million tonnes

Statens vegvesen
Norwegian Public Roads Administration

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Norwegian Railway Network

- Røros and Solør lines (381 km, 94 km)
  - Catenary (=OHL) officially proposed
  - "Backup" for Dovre line
- Rauma line (111 km)
  - Scenic line for tourists
  - OHL not desirable
- Nordland line, 731 km
  - Southern part to be electrified (130 km) due to higher population density, compatibility Sweden
- Politicians (traditionally): "*Please electrify everything*"
- Rail Administration asked SINTEF for other alternatives

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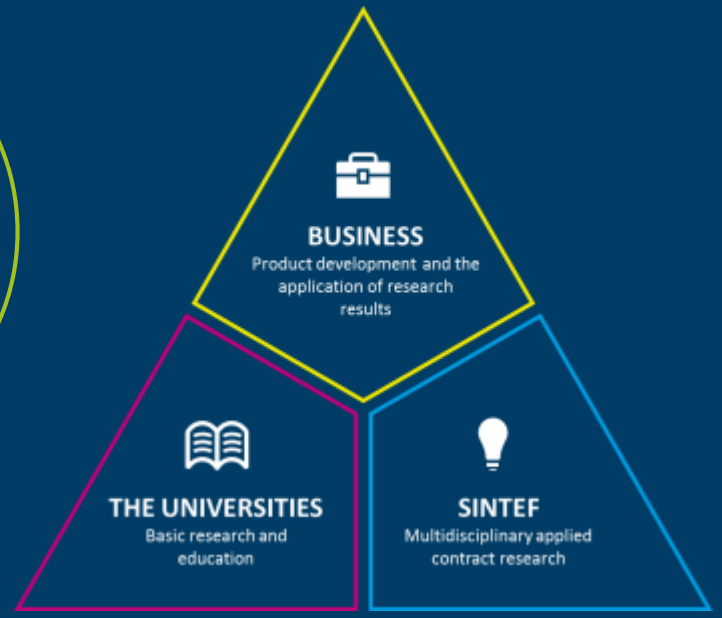
SINTEF - Scandinavia's largest independent research organization

2000
Employees

70
Nationalities

3800
Customers



NOK 3,2 billion
Revenues

NOK 500 MILL
International sales

Key player in low & 0-emission transport both in R&D and implementation:

- experience within combustion-, battery- as well as H_2 and FC-technologies

- interdisciplinary competence: technology, economy & social science

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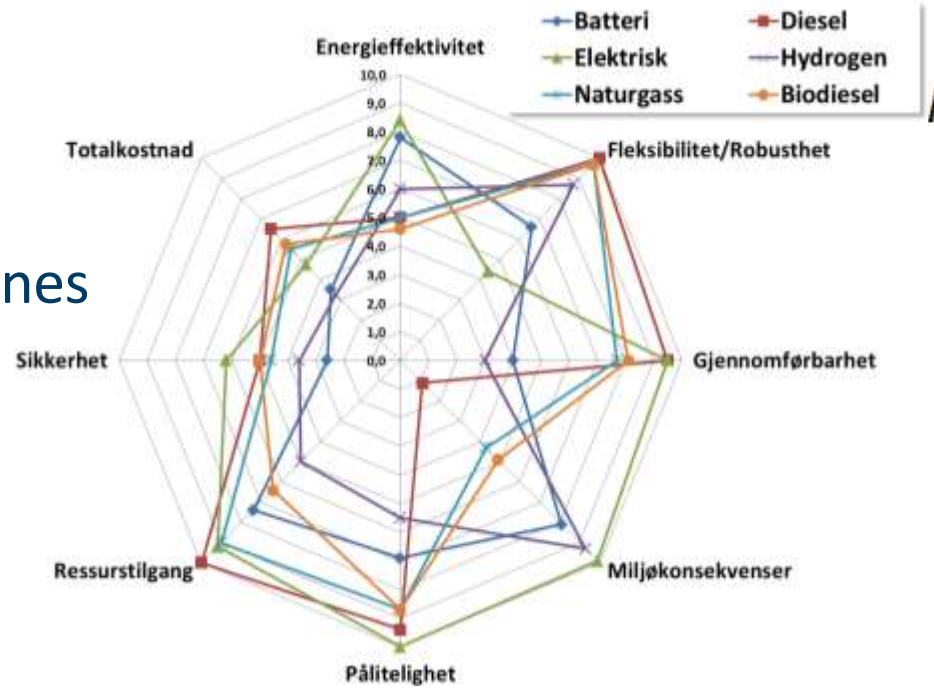
Approach and Methodology

- Study carried out in close collaboration w/Norwegian Rail Administration (JBV)
- Involvement of experts in relevant areas/disciplines (from JBV and SINTEF)
- SINTEF established a new Methodology for this study
  - *a technology neutral framework for assessment of the selected alternative drivetrains/fuels and*
  - *a transparent and consensus based process to reach recommendations for future investments*
- Study carried out in two phases and three workshops were arranged:
  - *Phase 1) selection of evaluation criteria/weighting, sensitivity, assumptions, consistency → screening*
  - *Phase 2) detailed assessment for identification of Future Proof* solutions for rail propulsion → 2050*

Approach and Methodology (cont.)

- **Alternatives considered:**
  - Biofuels
  - Natural gas
  - Hydrogen
  - Batteries
  - Diesel
  - Over-Head Lines
  - Hybrids

- **Preliminary results from screening exercise (Phase 1)**



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Approach and Methodology (cont.)

- **Alternatives considered:**
  - Biofuels
  - Natural gas
  - Hydrogen
  - Batteries
  - Diesel
  - Over-Head Lines
  - Hybrids

- **Evaluation criteria (Phase 2)**
  - Economy
  - Flexibility & Robustness
  - Technology readiness
  - Regulatory framework
  - Environment (CO_2/local)

- **Approach**
  - Assumptions from reliable sources
  - Using agreed set of evaluation criteria
  - Learning curves, performance, cost
  - Allowing *Future Proof* solutions only

  e.g., compatibility w/EU's emission targets
  - Using *"fuzzy logic"* algorithm to sum up Boolean and continuous scores

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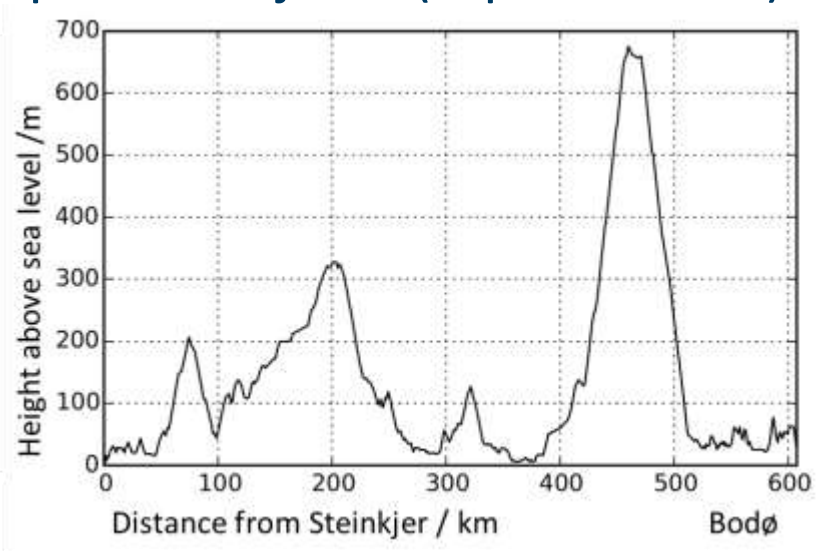
The Nordland line

- Single-track line, 3000 train movements/a
- Passing loops: 600 meters
- Vossloh Euro 4000 locomotives (6)
  - Diesel-electric, 400 kN, 3.15 MW
- 19 ‰ slope at Saltfjellet (top at ~700m)
  - Freight trains at 40 km/h (up-hill)



Freight train at Trondheim

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The Nordland line

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- Passing loops: 600 meters
- Vossloh Euro 4000 locomotives (6)
  - Diesel-electric, 400 kN, 3.15 MW
- 19 ‰ slope at Saltfjellet (top at 700m)
  - Freight trains at 40 km/h (up-hill)
- Crosses the polar circle (66°33’46.7” N)
- Strong winds (few or no trees)
- Potential for ice formation on infrastructure

Freight train at Saltfjellet

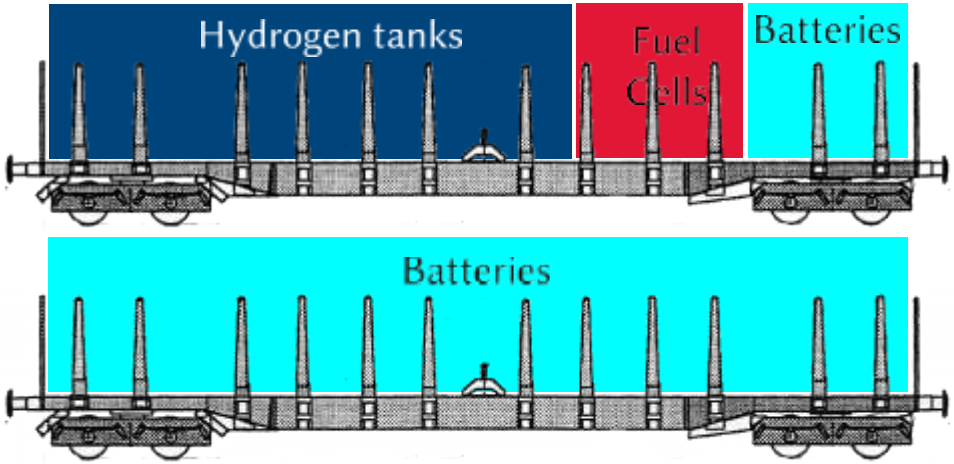
Current options

Characteristic features (general)	Diesel	OHL
Extra infrastructure	None	Large
Energy cost	High	Low
Pollution	Local & Global	None Direct
Tractive effort	High	Low
Power	Low	High
Suitability with respect to	**Nordland Line**	
Traffic volume	Low	High
Population	Sparse	Dense
Inclination	High	Low
Speed	Low	High

Alternatives

- Biodiesel
  - "Quick fix"
  - Less global, same local pollution
- Batteries
  - Heavy and cumbersome
  - 1 battery wagon: 5.7 MWh
  - 3 wagons for Nordland line
  - Option to charge midway
    - » At station
    - » With short catenary

- Hydrogen
  - 1 "H_2 wagon": 18 MWh
  - Require hydrogen refuelling station
  - Fuel cells system: ~ 15 t for 5.6 MW
  - Hybridisation with batteries



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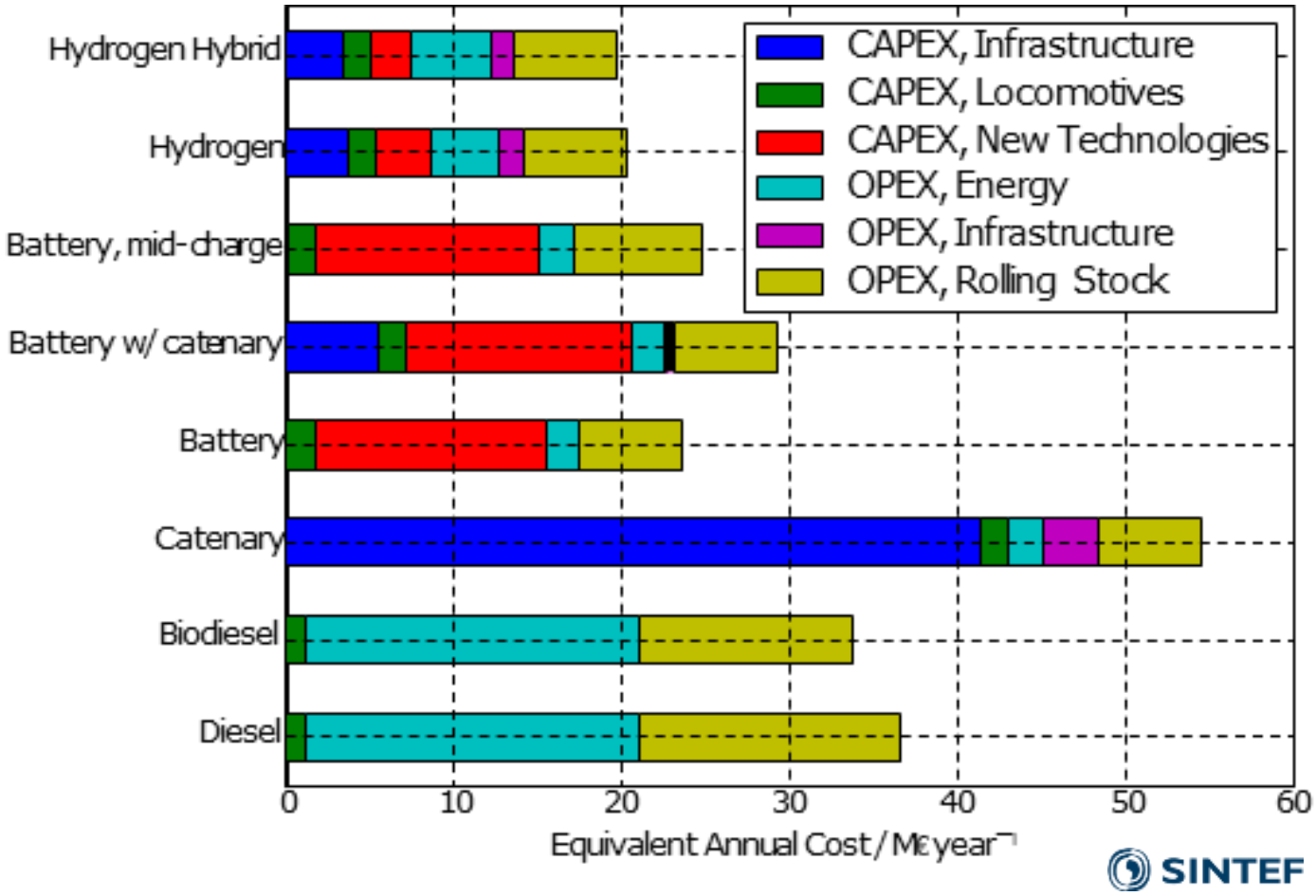
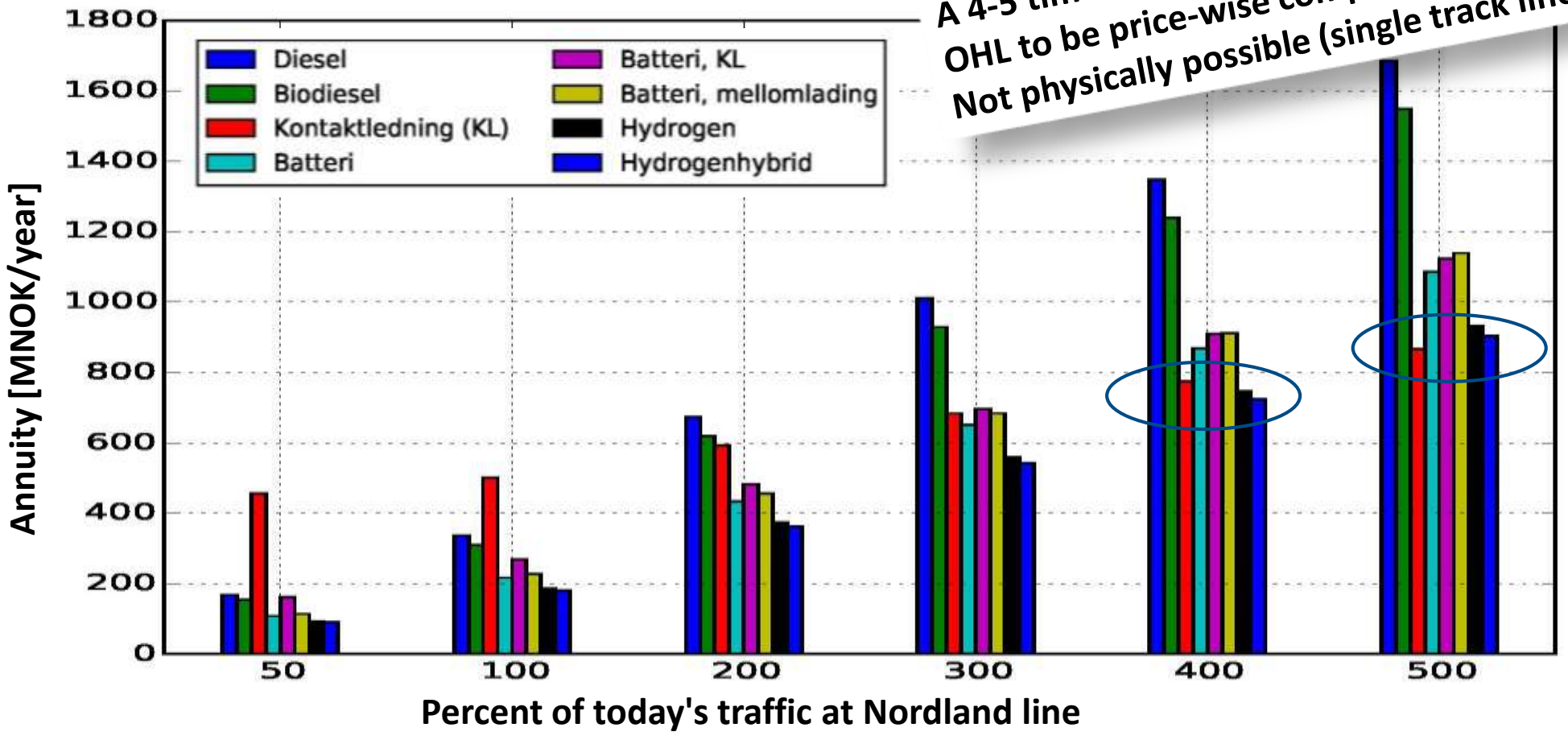
Results – Freight trains on Nordland line

- Hydrogen is cheapest
- Battery very close second
- Mid-charging not attractive
- OHL most expensive



Results – Sensitivity to traffic density



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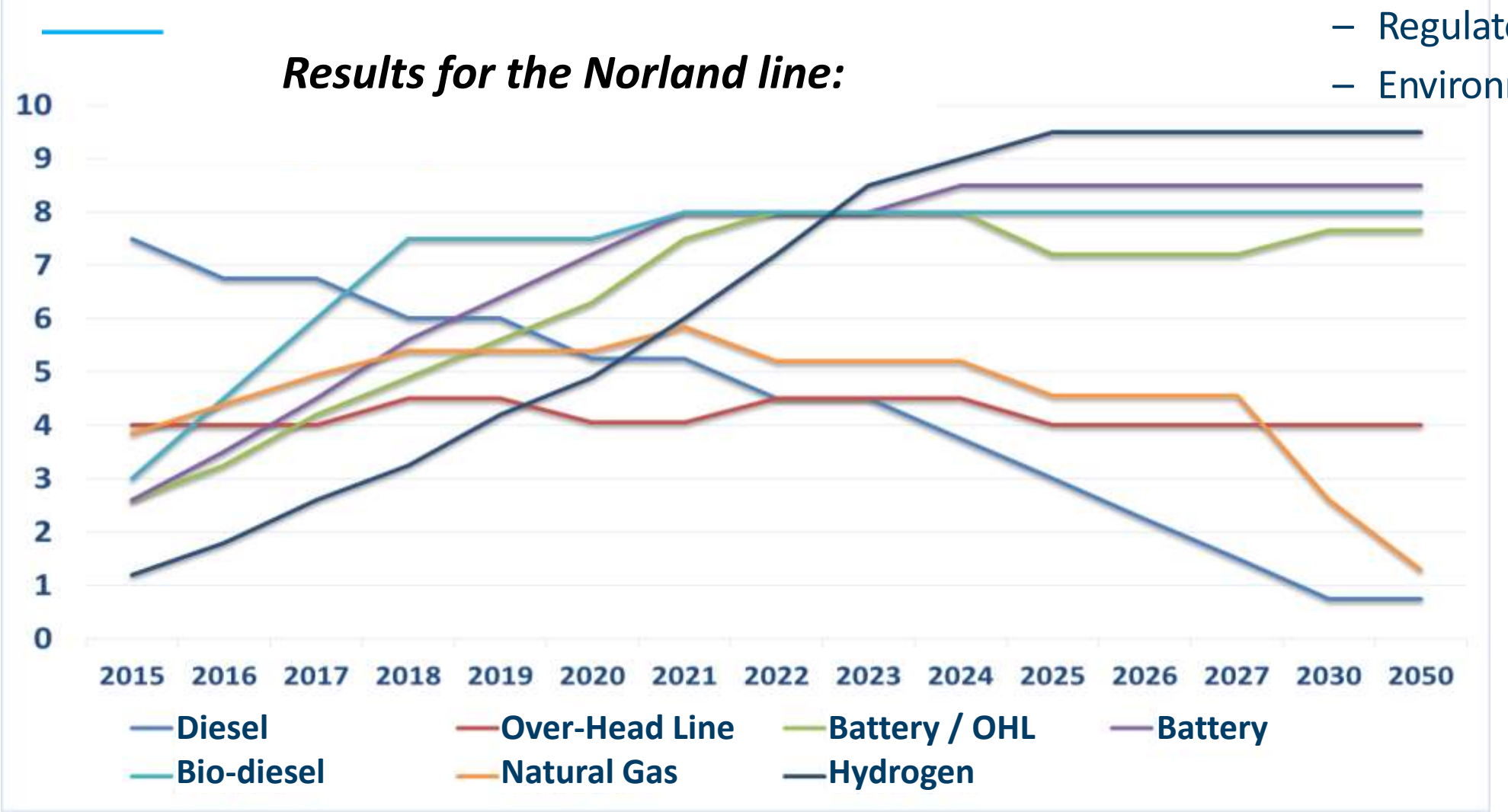
Most viable solutions towards 2050

Evaluation Criteria:

- Economy
- Flexibility & Robustness
- Technology readiness
- Regulatory framework
- Environment (CO_2/local)

Results for the Norland line:



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Summary/Conclusions

- Norway – has become an early market for 0-emission transport
  - Politicians have recently increased their ambitions → New funding instruments
- Alternatives to electrify Non-Electrified Railways (freight) have been studied
- A methodology has been established to provide recommendations → 2050
- Results for Nordland line:
  - Techno-Economical Analysis ➔ Hydrogen hybrid lowest cost, OHL will never become economically viable
- Hydrogen solution for freight trains expected < 2025 (regulatory framework)
- Norway – *could implement passenger train (Rauma line), freight trains (< 2025)*

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Full report (A27534) available online (unfortunately only in Norwegian) at SINTEF's website: www.sintef.no

The study was funded by the Norwegian Rail Administration:

Jernbaneverket

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Technology for a better society

Thank you for your attention!