



Energilagring

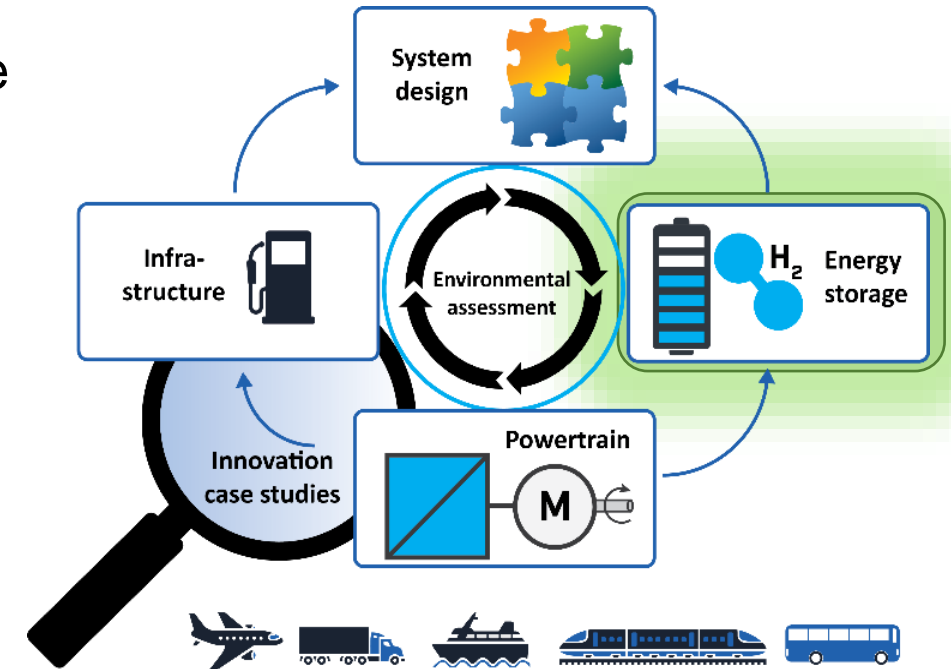
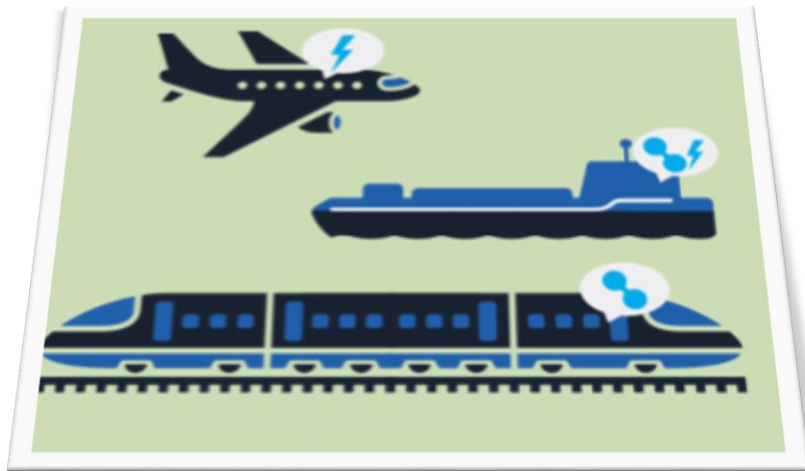
Åsmund Ervik & Petter Nekså
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Energy storage for heavy duty transport

Heavy duty transport requires large scale energy storage

Batteries and hydrogen will both be necessary

Different transport modes have different requirements



Energy storage for heavy duty transport

- Full electrification for zero emission operation
 - Not feasible for heaviest duty transport - e.g. Viking Energy ship: ~150 MWh energy consumption per day (LNG)
- Hybridization of drivetrains for reducing fuel consumption
- Hydrogen-based propulsion systems for zero emission operation



Electric power conversion technology will be important for reducing emissions

Energy storage - compressed, liquid or other H₂-carrier?

Fuel cell and battery – integration, ageing prospects?

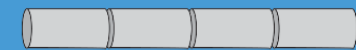
Able to reach necessary energy and power density?



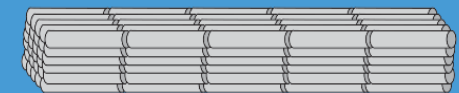
Relative volume requirements



Diesel fuel 1



LH₂ fuel ~ 3-5



GH₂ fuel (450 bar) ~ 20

1 MWe Fuel cell system



?

1.2 MWe ICE generator





Liquid hydrogen: scaling-up is feasible

LNG

1959: 5 500 m³



Image source: shippingtandy.com

1964: 28 300 m³



1973: 87 600 m³



Image source: ship-photo-roster.com

2018: 182 000 m³



Image source: Kawasaki Kisen Kaisha

LH₂

2020: 1 250 m³ = 3000 MWh



Mid-term: 9 000 m³



Image source: Moss Maritime

Long-term: 160 000 m³



Image source: Kawasaki Heavy Industries



Research challenges

- Hydrogen storage technology:
 - Tradeoffs for different hydrogen carriers - compressed H₂ has low energy density, liquid H₂ requires advanced tank insulation to ensure acceptable boil-off rate and dormancy, alternative carriers need further study and development (e.g. N₂O from ammonia?)
- Safety of hydrogen use:
 - strong efforts already, collaboration w/ Sandia (HyRAM), SH2IFT, PRESLHY, SVV, ++
- Hybrid hydrogen/battery solutions:
 - Balance-of-plant, significant potential for synergies e.g. with respect to heat integration
- Battery and fuel cell use in heavy duty and marine/cold environment
 - Ageing prospects of these components in the ZETA context

State-of-the-art

- Today's use of hydrogen within the transport sector is limited, dominated by compressed gaseous storage onboard small vehicles.
- There are large energy demands in many applications, such as many maritime vessels, requiring novel technological concepts.
- Knowledge from use of hydrogen available from other fields (e.g. aerospace).
- Many of these are areas where Norway has a large home market and an export oriented vendor industry.
- First concepts are being developed today
- Need to get on the ship before it leaves the quay



LH₂ fuelled super-yacht



State-of-the-art

- Sophisticated modeling can be performed from the systems to the component level – multiple scales
- Novel concepts for hydrogen storage and end-use can be evaluated in this context
- Models are based on physical theories and experimental data

Reducing the exergy destruction in the cryogenic heat exchangers of hydrogen liquefaction processes

Øivind Wilhelm Geir Skaugen

* SINTEF Energy Res
* NTNU, Department

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Analysis of Natural Gas Engine De-Loading on LNG Fuelled Vessels

Joseph DiRenzo^{a,*}, Petter Nekså^b, Kjell Kolsaker^a

Time Efficient Solution of Phase Equilibria in Dynamic and Distributed Systems with Differential Algebraic Equation Solvers

Øivind Wilhelmsen^{*,†,‡}, Geir Skaugen[†], Morten Hammer[†], Per Eilif Wahl[†], and John Christian Morud[§]

[†]SINTEF Energy Research, N-7465 Trondheim, Norway

[‡]Department of Chemistry, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

[§]SINTEF Materials and Chemistry, N-7465 Trondheim, Norway

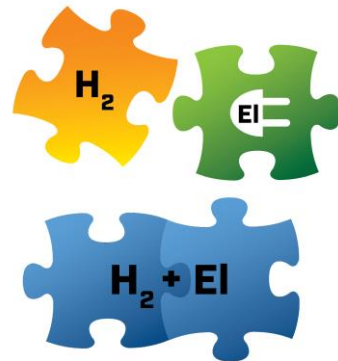
Supporting Information

ABSTRACT: Solution of phase equilibria with flash calculations is central in many processes. During the integrating of the conservation equations in these systems, flash calculations are traditionally solved in inner loops at each integration step. Some of these systems can be solved more efficiently using modern DAE solvers, where the differential equations and the algebraic equations describing the phase equilibrium are solved simultaneously. In this paper we present a framework, called the Thermodynamic Differential Algebraic Equation (TDAE) method, which handles most two-phase flash variants. The phase boundary is tracked, enabling a robust solution also with phase changes. The time consumption of the TDAE method has been compared to the traditional approach in several examples implemented in both Fortran and Matlab. In some cases, the TDAE method is more than 800 times faster, and in other cases the traditional methodology should be used. We will give insight into how and when DAE solvers can be used to speed up phase equilibrium calculations.



Potential contributions and innovations

- Modelling frameworks for fuel handling using accurate fluid- and thermodynamics
 - Boil-off rates in tanks and transfer lines, use of waste heat/cold, dynamic responses, etc.
- Concept evaluation for different hydrogen carriers
 - Compressed hydrogen (CH₂), Liquid hydrogen (LH₂), Gelled liquid hydrogen, Ammonia (NH₃) and Liquid organic H₂ carriers
- Component and system evaluation/development for selected hydrogen carriers
 - Storage tanks, fuel transfer lines, compressors/pumps, engine supply systems
- Large capacity fuel cell concepts for alternative fuels
 - Recirculation systems modelling, cooling and heat integration systems
- Battery and fuel cell integration in heavy duty transport
 - Ageing prospects, hybrid systems and synergies with hydrogen power
- Norwegian industry is very well suited to supply fuel and concepts utilizing different hydrogen carriers, thus enabling large value creation.





Alignment with European R&D strategy

R& I: Horizon Europe & Clean Hydrogen for Europe

PILLAR H2 PRODUCTION	PILLAR H2 DISTRIBUTION	PILLAR H2 END USES
SO1: LOW CARBON H2 PRODUCTION 1. Electrolysis 2. Other modes of production	SO3: H2 STORED & DELIVERED AT LOW COST 4. Large scale storage 5. H2 in the gas grid 6. Transport & storage in liquid carriers 7. Transport by road, ships, etc 8. Key techno for distribution	SO5: TRANSPORT VEHICLES <u>Priorities</u> 10. Technology building blocks 11. Truck and large vans (HD) 12. Maritime (Ships & Port) <u>Other new applications</u> 13. Aviation 14. Train 15. Coach
SO2: INTEGRATION OF RENEWABLES 3. Role of electrolysis	SO4: REFUELING INFRASTRUCTURE 9. HRS for multiple applications	SO6: H2 FOR HEAT AND POWER (in building and industry) 16. H2 Stationary FC 17. H2 Burners and turbines (also gas grid cf. distribution pillar)

