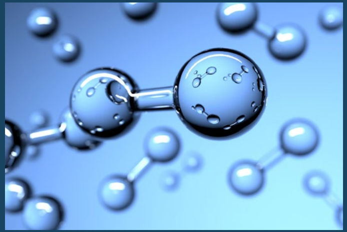
Hydrogen as a fuel in heavy duty transport: a scientific perspective

12 November 2025

Maria Grahn

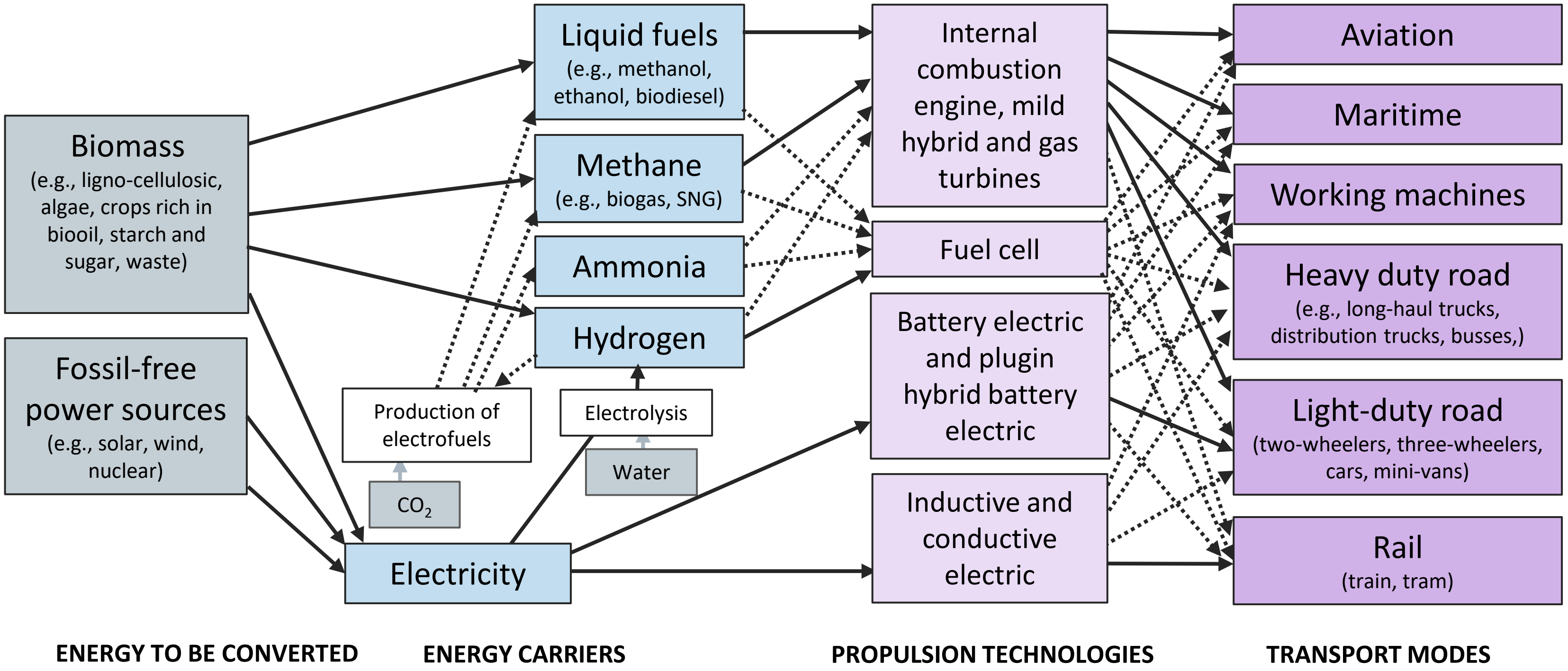
Associate Professor in Energy Systems Analysis

Chalmers University of Technology, Dept Mechanics and Maritime Sciences

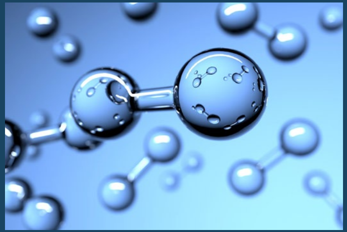


Various types of fuels and vehicle technology options

which are differently well suited for the different transport modes, where the dashed arrows indicate pathways that currently are more complex, less mature or less used.



Brynolf S, Grahn M (2024). Liquid fuels: Flexibility with low environmental impact. News and Views. Nature Energy 9, 1179–1180. https://doi.org/10.1038/s41560-024-01637-0.



Main insights from our research on hydrogen

Fayas Malik Kanchiralla, Postdoc,
fayas.kanchiralla@chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY

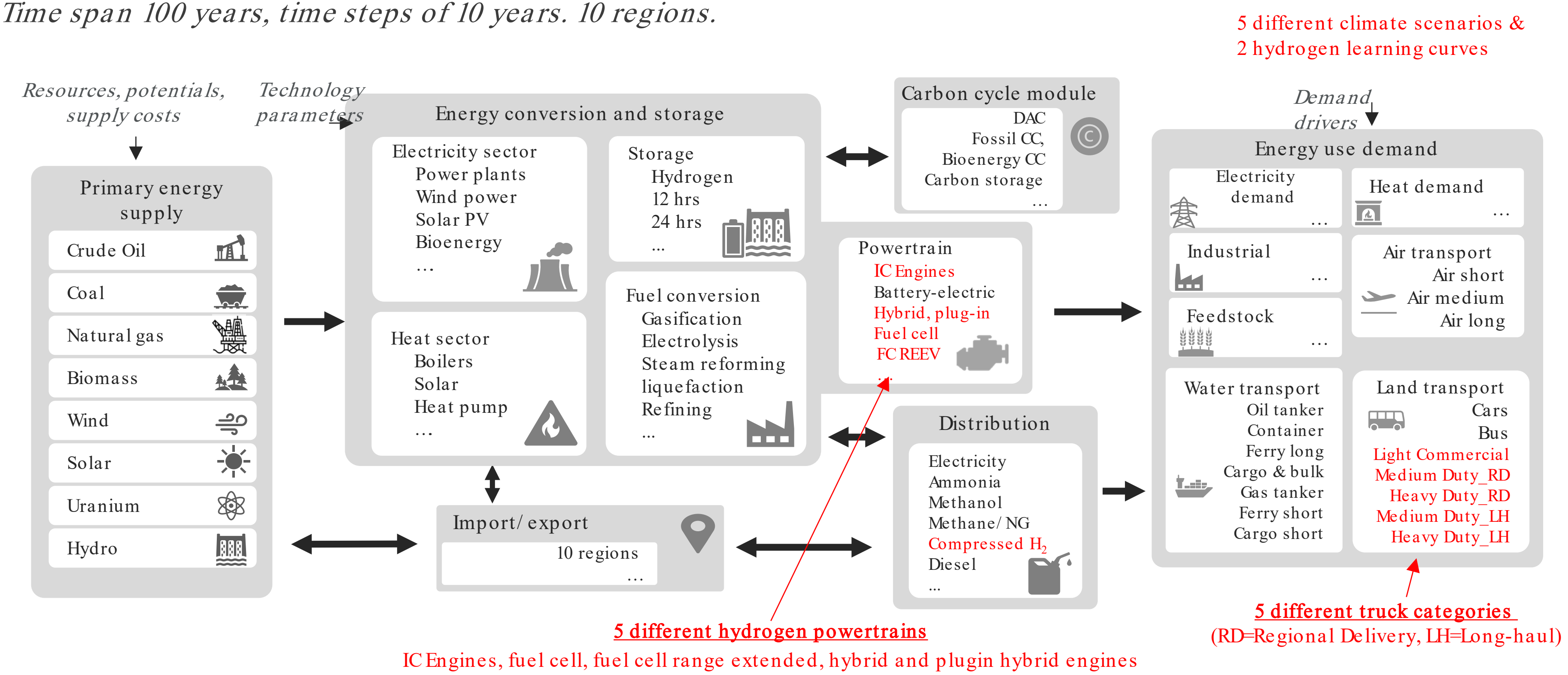
The future role of hydrogen trucks in an energy systems context

where different energy sectors compete for the same primary energy sources

Kanchiralla FM, Brynolf S, de Oliveira Laurin M, Grahn M (2026?). Decarbonization of the global road freight: results from global energy systems cost-minimizing modeling. *Manuscript in preparation*.

The global energy transition (GET) model

GET is a linearly programmed energy systems cost-minimizing model, and it generates the fuel and technology mix that meets the demand (subject to the constraints) at lowest global energy system cost. Time span 100 years, time steps of 10 years. 10 regions.

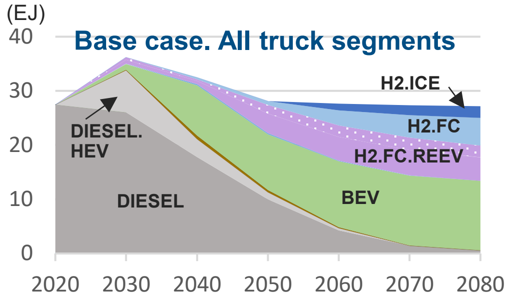


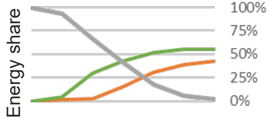
Kanchiralla FM, Brynolf S, de Oliveira Laurin M, Grahn M (2026?). Decarbonization of the global road freight: results from global energy systems cost-minimizing modeling. *Manuscript in preparation.*

Cost-effective fuel and technology choices for global truck fleets

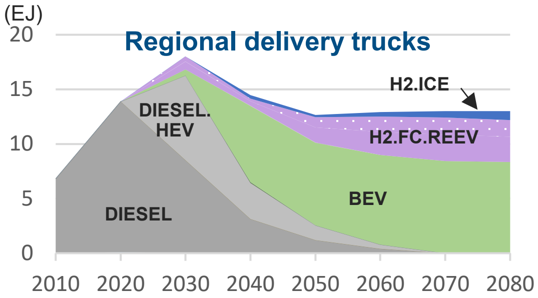
meeting 1.5 degree climate target (scenario Ambitiuos).

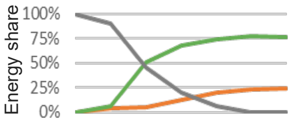
CHALMERS
UNIVERSITY OF TECHNOLOGY



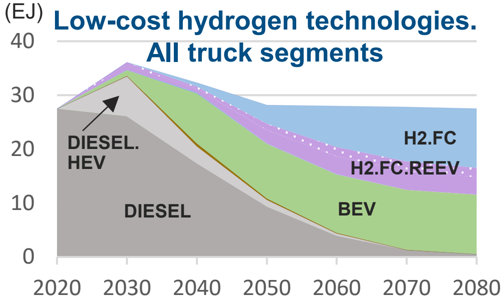


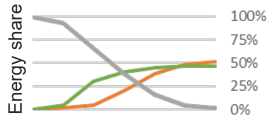
By 2080 almost 50% BEV and 50% H2



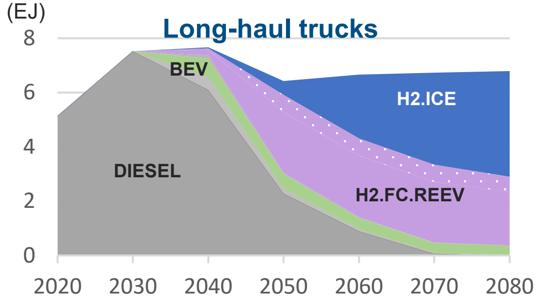


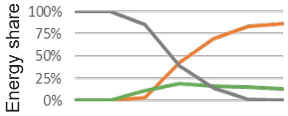
By 2080 75% BEV and 25% H2





By 2080 slightly more than 50% H2 (rest is BEV)





By 2080 25% BEV and 75% H2

- **Hydrogen** has a role to play in the global truck fleet along with **batteries** especially for long- hauls, when meeting ambitious climate targets.
- **Cost** of hydrogen **technologies** important for fuel cell adoption
- The model shows a larger share of battery electric trucks for trucks segment having shorter driving distances.
- **Hydrogen** first and foremost a cost-effective solution for **long-haul trucks.**

Diesel
Hydrogen
Electricity

Acronyms used: H2= hydrogen, ICE=internal combustion engines, FC=fuel cell, REEV=range extension, BEV=battery electric vehicle, EJ=10^{18} Joule

Kanchiralla FM, Brynolf S, de Oliveira Laurin M, Grahn M (2026?). Decarbonization of the global road freight: results from global energy systems cost-minimizing modeling. *Manuscript in preparation*.

Jorge Velandia Vargas.
jorge.velandia@chalmers.se

CellPress
OPEN ACCESS

iScience

Article

Vehicle-oriented and Sweden-framed life cycle assessment: Hydrogen for long-haul trucks

Jorge Enrique Velandia Vargas,[1,4,*] Selma Brynolf,[1] Maria Grahn,[1] Felipe Rodriguez,[2] and David Blekhman[3]
[1]Chalmers University of technology, Gothenburg, Sweden
[2]Colorado State University, Fort Collins, CO, USA
[3]California State University, Los Angeles, CA, USA
[4]Lead contact
*Correspondence: jevelandiav@unal.edu.co
https://doi.org/10.1016/j.isci.2025.113607

SUMMARY

Hydrogen trucks are an alternative for decarbonizing the long-haul segment. However, the environmental footprint benefits depend on how hydrogen is produced, transported, and used but also in truck characteristics. We conduct life cycle assessment to quantify the impacts per ton-km. For centralized production, we included electrolysis and steam reforming cases, with dedicated transportation pathways but also included production onsite. We evaluated fuel cells and combustion engines and included supply chain hydrogen leakages. We found that global warming potential (GWP) of different truck versions varies up to 50tCO$_2$eq per vehicle. Additionally, electrolysis powered by the Swedish grid appears more competitive than blue hydrogen, for most cases evaluated. For high hydrogen leakage scenarios (~30%), GWP of green hydrogen, per ton-km, increases 2-fold. The low payload of tanker ships transporting hydrogen nullifies the benefits of importing green hydrogen. Truck manufacturing industries and low-carbon electricity enhance the potential for hydrogen to decarbonize the segment in Sweden.

INTRODUCTION

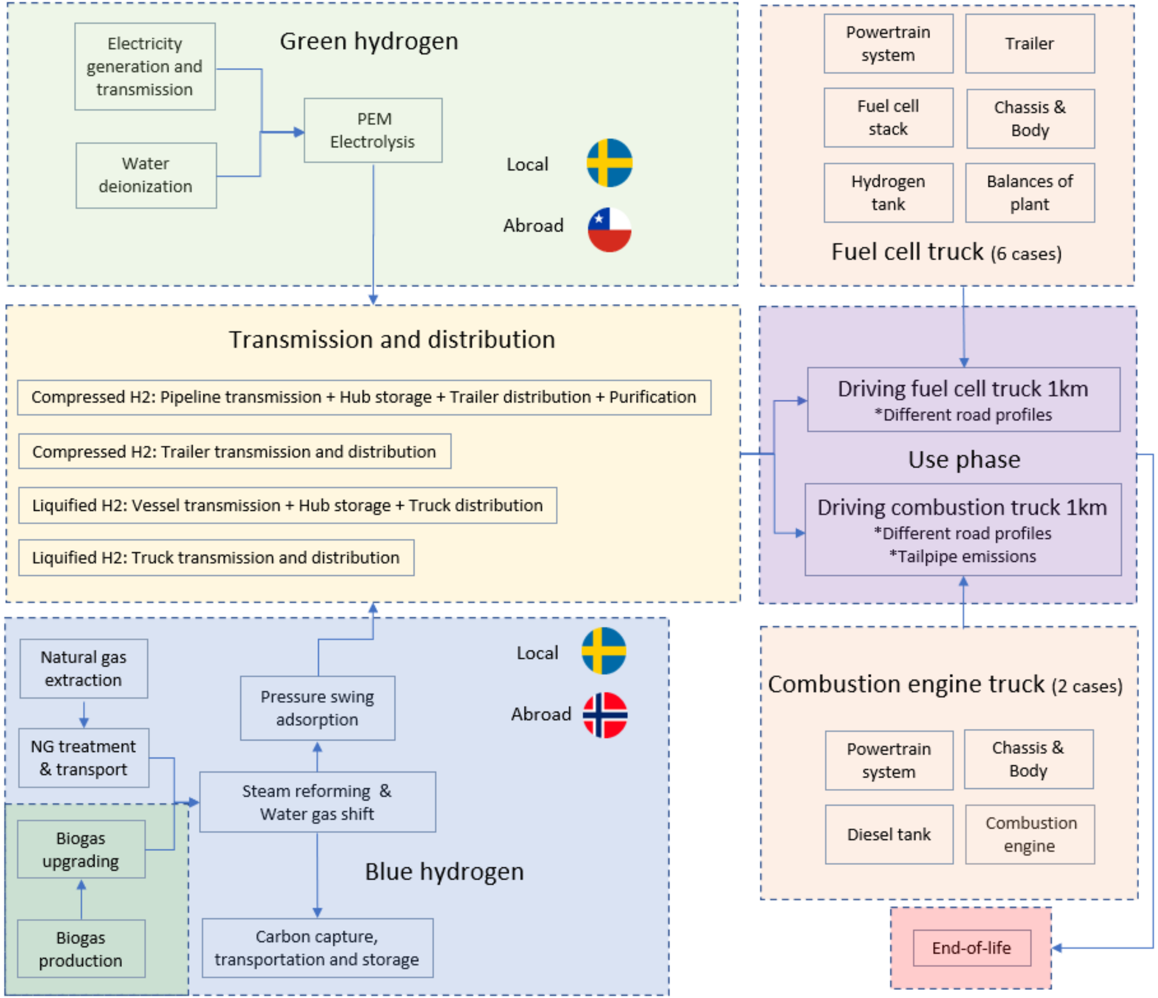
...bal warming below 2°C, a substantial decarboniza-... is necessary.[1] Globally, transport ... oil demand,[2] while the ... responds to

2050.[5,16] The hydrogen roadmap for Europe aims to deploy 45,000 HDVs, referring to buses and trucks, by 2030,[17] which is nearly half the current market.[18]
Although FC technologies for LDVs have been, for years, in development by nearly every major automotive manufacturer, investments on the HDVs segment only started to gain momentum recently[19]; by the end of 2022, there were around 20 fuel cell

Comparing carbon footprint from using hydrogen in trucks?

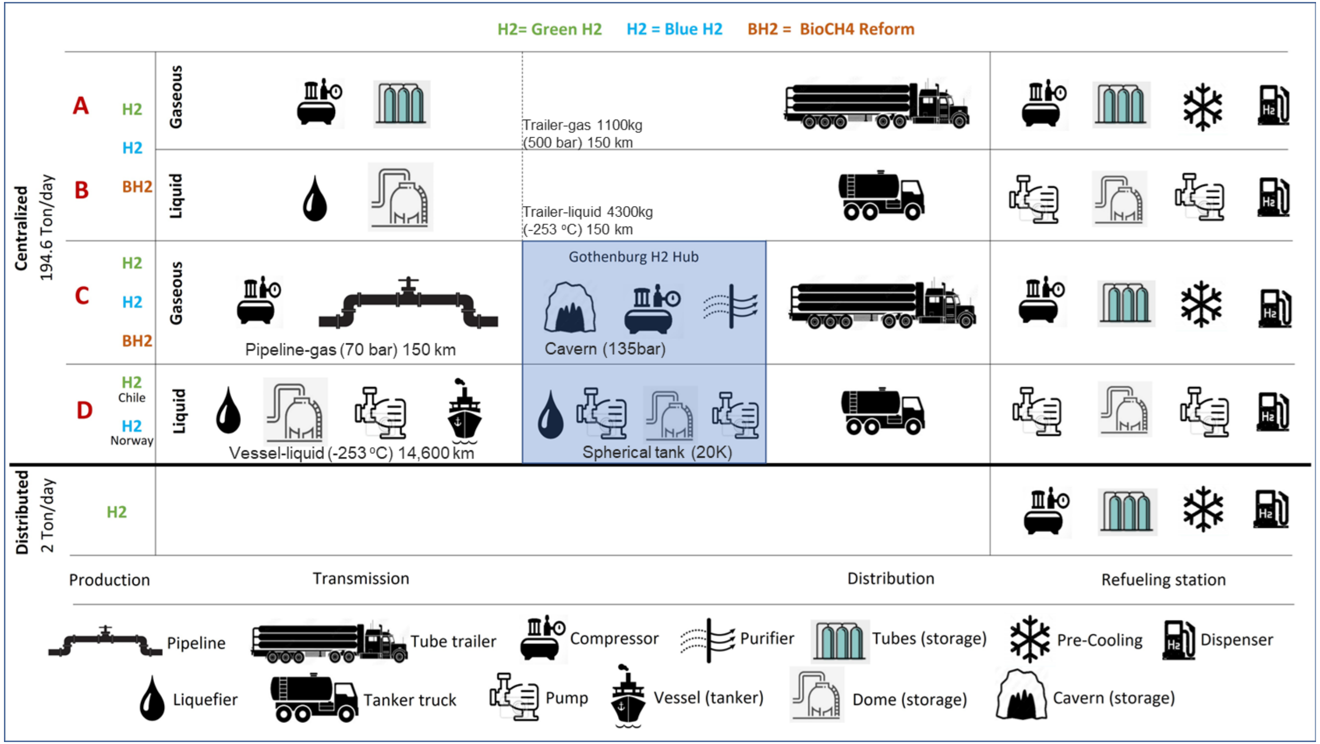
Velandia Vargas, J.E., Brynolf, S., Grahn, M., Rodriguez, F., Blekhman, D. (2025). Vehicle-oriented and Sweden-framed life cycle assessment: Hydrogen for long-haul trucks, *iScience* 28(10), 113607, doi: https://doi.org/10.1016/j.isci.2025.113607.

System boundaries



Velandia Vargas, J.E., Brynolf, S., Grahn, M., Rodriguez, F., Blekhman, D. (2025). Vehicle-oriented and Sweden-framed life cycle assessment: Hydrogen for long-haul trucks, *iScience* 28(10), 113607

Assessed distribution options



A: Trailer-gas 1100 kg (500 bar) 150 km

B: Trailer-liquid 4300 kg (-253°C) 150 km

C: Pipeline-gas (70 bar) 150 km

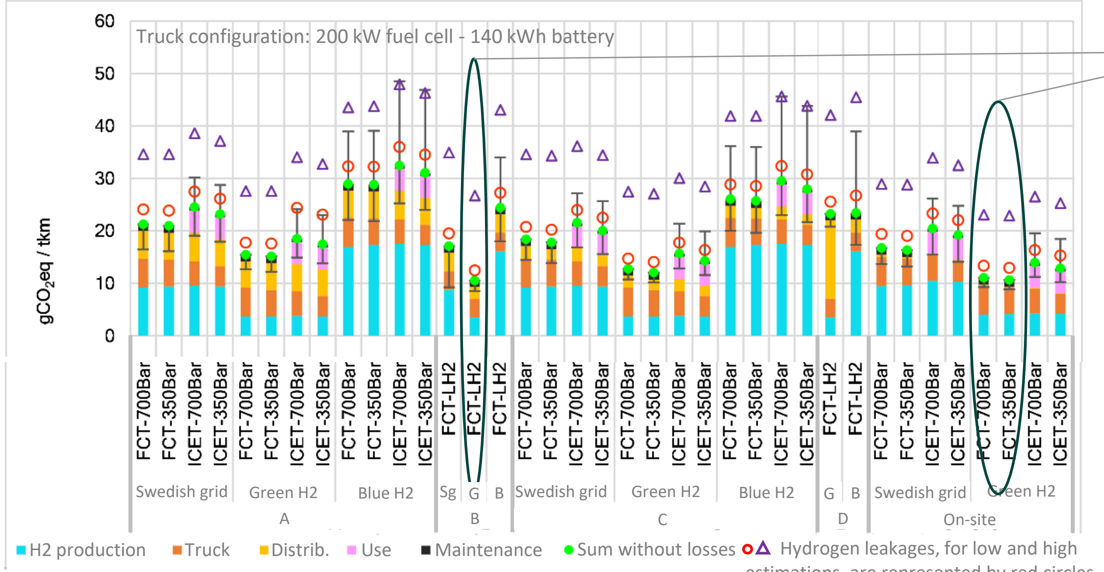
D: Vessel run on biodiesel (-253°C) 14,600 km

Onsite production: No distribution.

Velandia Vargas, J.E., Brynolf, S., Grahn, M., Rodriguez, F., Blekhman, D. (2025). Vehicle-oriented and Sweden-framed life cycle assessment: Hydrogen for long-haul trucks, *iScience* 28(10), 113607

Total LCA carbon footprint per tkm of a fully loaded 40-ton truck run on hydrogen

comparison of multiple hydrogen production and distribution pathways, combined with different types of fuel cell and combustion engine hydrogen trucks.



A: Trailer-gas 1100 kg (500 bar) 150 km
B: Trailer-liquid 4300 kg (-253oC) 150 km
C: Pipeline-gas (70 bar) 150 km
D: Vessel run on biodiesel (-253oC) 14,600 km

- Apart from the bio-based options with CCS, **lowest** carbon footprint can be seen for:
  1. Scenario B where hydrogen is large-scale produced in central plants, and powered by green electricity, then liquefied and distributed by trailers for 150 km and used in fuel cell trucks having a stainless steel tank for liquid hydrogen,
  2. Scenario "onsite" where hydrogen is produced from green electricity, at the refueling station, and used in fuel cell trucks having a 350 bar storage tank,
  3. the same as (2) but a 700 bar storage tank.
- **Highest** carbon footprint is seen from all options assessing blue hydrogen. Slightly higher for the combustion engines (ICET) compared to fuel cells (FCT).
- All options are **below carbon footprint of fossil diesel** (55-150 gCO_{2eq}/tkm).

Velandia Vargas, J.E., Brynolf, S., Grahn, M., Rodriguez, F., Blekhman, D. (2025). Vehicle-oriented and Sweden-framed life cycle assessment: Hydrogen for long-haul trucks, *iScience* 28(10), 113607

Joel Löfving PhD student,
joel.lofving@chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY

Where in Europe may the demand for future hydrogen refuelling stations for trucks appear?

Löfving J, Brynolf S, Grahn M (2025). Geospatial distribution of hydrogen demand and refueling infrastructure for long-haul trucks in Europe, *International Journal of Hydrogen Energy 128*: 544-558.

International Journal of Hydrogen Energy 128 (2025) 544–558

Contents lists available at ScienceDirect

International Journal of Hydrogen Energy

journal homepage: www.elsevier.com/locate/he

ELSEVIER

Check for updates

Geospatial distribution of hydrogen demand and refueling infrastructure for long-haul trucks in Europe

Joel Löfving [a,b,*], Selma Brynolf [a,b], Maria Grahn [a,b]

[a] Chalmers University of Technology, TechForH2 Excellence Center, Hörsalsvägen 7A, 412 96, Gothenburg, Sweden
[b] Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Hörsalsvägen 7A, 412 96, Gothenburg, Sweden

ARTICLE INFO

Keywords:
Hydrogen demand
Heavy duty
Topography
Geography
AFIR
GIS
EU policy

ABSTRACT

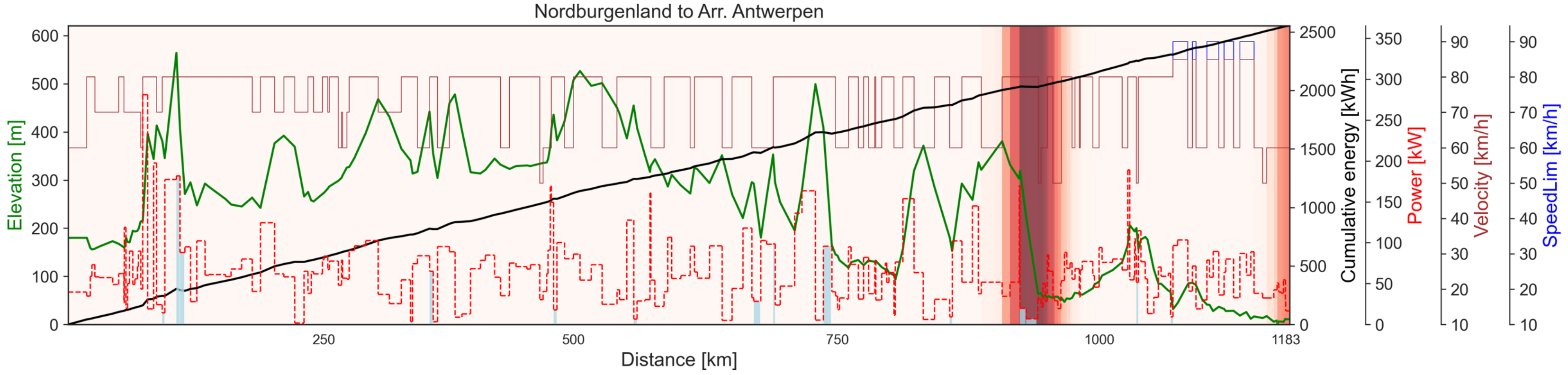
Using hydrogen as a fuel is one option to reduce impact on climate and environment from heavy-duty road transportation. However, the deployment of a hydrogen refueling network is a major bottleneck. To facilitate this development, it is crucial to better understand appropriate location and sizing of hydrogen refueling stations (HRS). We present a bottom-up, geographically detailed model for simulating energy demand from long-haul hydrogen trucks and determining locations and sizes of HRSs, across all of Europe under different scenarios in 2050. The model, called SVENG, calculates weighted energy demand for network links, considering specific local conditions on each link along the route. These are used by a search algorithm for distributing demand along individual routes and simulate HRS locations and sizes. The model scales linearly, supporting large networks; for this study using 0.6 million rows of origin-destination cargo flow data on a network of 17,000 nodes. We show that the model's novel functionality for calculating dynamic vehicle power requirements has a large impact on the distribution of fuel demand and required refueling infrastructure. Results are compared to the Alternative Fuels Infrastructure Regulation (AFIR) for 2030, showing that this legislation might require more HRS than necessary even in 2050 in some countries, unless vehicle sales increase rapidly. Other countries may need to deploy more capacity by 2050 even at lower rates of adoption.

1. Introduction

The EU has adopted targets requiring truck fleets to decrease their

market [15]. The uncertainty of future fuel demand distribution poses an obstacle for investors [16,17], and needs further assessments to facilitate planning of refueling infrastructure [8,18].

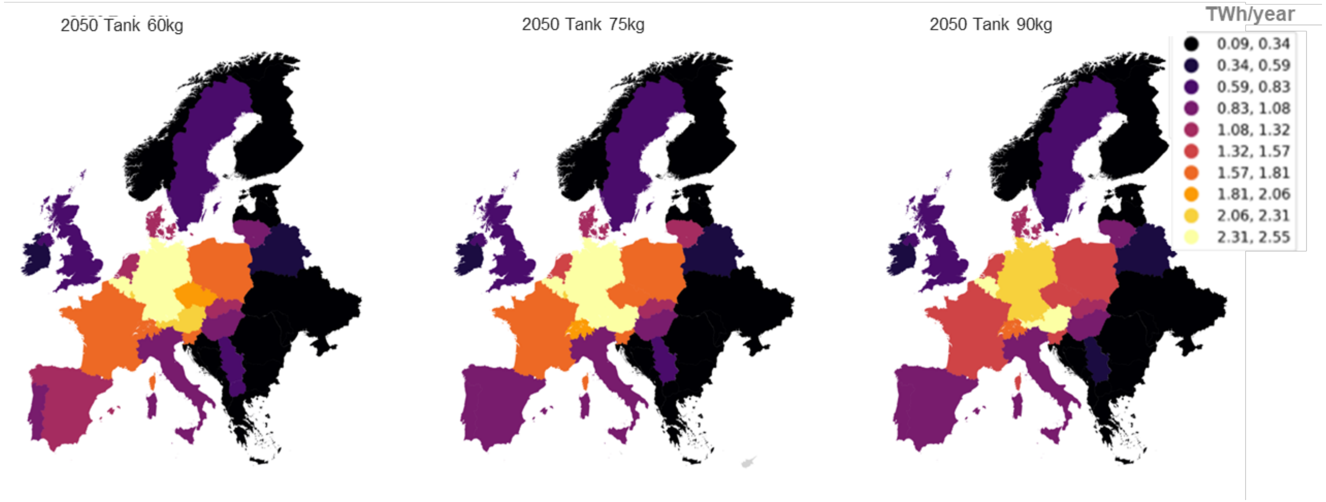
Routes for 600,000 trucks are modelled individually



- One simulated route. The x-axis represents distance driven along the route.
- Elevation (green) and velocity (brown) impacts power (red), which results in a total cumulative fuel demand (black).
- Light blue bar indicate the power needed is negative (regenerative braking).
- Refueling demand allocated to nodes along the route is depicted with vertical shaded areas. Speed limit (blue) is included to specify where the truck runs slower than the speed limit.

Löfving J, Brynolf S, Grahn M (2025). Geospatial distribution of hydrogen demand and refueling infrastructure for long-haul trucks in Europe, *International Journal of Hydrogen Energy 128*: 544-558.

Annual hydrogen demand per country for three different tank sizes, assuming 15% of the fleet of trucks are run on hydrogen



Share of routes and tkm, respectively, that can be performed without refueling on-route given the different tank sizes.

Tank size	60 kg	75 kg	90 kg
Routes	27%	40%	52%
Tkm	34%	45%	55%

Insight:
- The largest demand is shown in central Europe.
- The different tank sizes do not significantly affect the results.

Löfving J, Brynolf S, Grahn M (2025). Geospatial distribution of hydrogen demand and refueling infrastructure for long-haul trucks in Europe, *International Journal of Hydrogen Energy 128*: 544-558.

Joel Löfving PhD student,
joel.lofving@chalmers.se

Where in Europe (geographically) may the future hydrogen demand appear?

Löfving J, Brynolf S, Grahn M, Öberg S, Taljegård M (2025). Consequences of large-scale hydrogen use in Europe. *Under review at Nature Sustainability*.

Modelling future demand for hydrogen in Europe, 2050

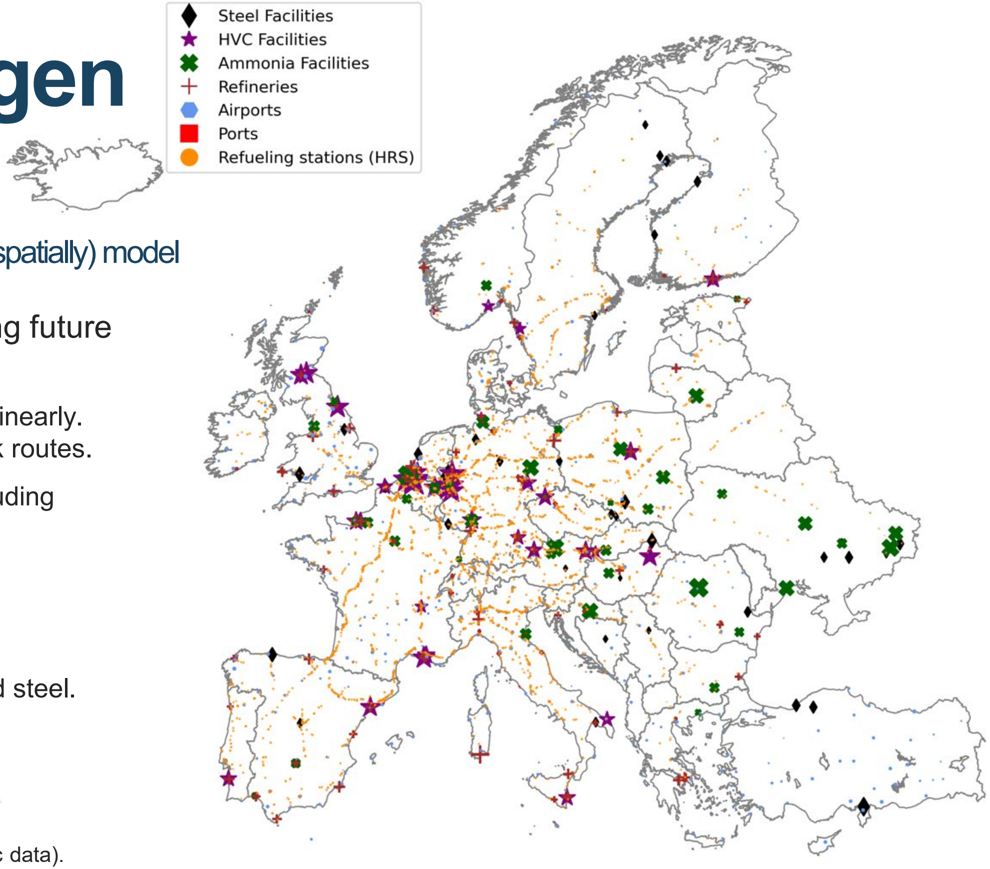
using the SVENG (Simulating Vehicle Energy Needs Geospatially) model

Python programmed GIS-oriented model, analyzing future geo-spacial hydrogen demand in Europe.

- Can handle large amounts of logistics data and scales linearly. For this study including about 0.6 million long-haul truck routes.
- Can handle a detailed road network. For this study including 17,000 nodes.
- Includes algorithms for simulating locations and sizing ofhydrogen refueling stations.
- Hydrogen demand added for ports, airports, refineries, production sites for ammonia, high-value chemicals and steel.

GIS: Geographic Information System (consists of integrated computer hardware and software that store, manage, analyze, edit, output, and visualize geographic data).

Annual demand volume indicated by node size.



Löfving J, Brynolf S, Grahn M, Öberg S, Taljegård M (2025). Consequences of large-scale hydrogen use in Europe. Under review at *Nature Sustainability*.

Summing up

General insights on future fuels, so far

- Three types of energy carriers have the potential to substantially reduce the fossil CO_2 emissions from the transportation sector:
  - Fuels including carbon atoms (biofuels and electrofuels)
  - Fuels without carbon atoms (hydrogen and ammonia)
  - Battery-electric propulsion
- It is most likely that parallel solutions will be developed, e.g.
  - There are many advantages for electric solutions in cities, both hydrogen in fuel cells and battery electric propulsion. Meeting also aspects like reduction of NOx, soot, and noise. Most likely different electric solutions in cities (delivery trucks, electric buses, cars, trams, metro etc).
  - There are several challenges for electrifying long-distance transport (especially ships and aircraft). Electrofuels may complement biofuels for these transport modes.
- Irrespective of fuel type, CO_2 emissions can be reduced by more energy efficient vehicles and measurements towards reduced transport demand.




Thanks to everyone in Team Brynolf & Grahn

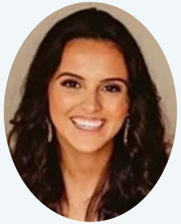
Maria Grahn, Associate professor, maria.grahn@chalmers.se

Selma Brynolf, Senior Researcher, selma.brynolf@chalmers.se

Julia Hansson, Researcher, Chalmers & IVL julia.hansson@ivl.se

Fayas Malik Kanchiralla, Postdoc, fayas.kanchiralla@chalmers.se

Yi He Postdoc, yi.he@chalmers.se



Maria deOliveira Laurin PhD student, maria.laurin@chalmers.se

Joel Löfving PhD student, joel.lofving@chalmers.se

Sunna Forslund PhD student, sunna.forslund@chalmers.se

Lina Trosvik Phd student, lina.trosvik@chalmers.se

Rasmus Parsmo, PhD student, IVL & Chalmers rasmus.parsmo@ivl.se

Jorge Velandia Vargas. (left Chalmers)

Our core research team, within the division of Transport, Energy and Environment, department of Mechanics and Maritime Sciences (M2), Chalmers University of Technology, Gothenburg, Sweden

For more info, please contact
Tomas Grönstedt
tomas.gronstedt@chalmers.se

Technologies and innovations for a future sustainable hydrogen economy,
a competence center funded by the Swedish energy agency, industrial partners, Chalmers and RISE.

CHALMERS
UNIVERSITY OF TECHNOLOGY

CHALMERS
UNIVERSITY OF TECHNOLOGY