RECONSTRUCTING VESSEL ENERGY DEMAND FROM SPARSE PUBLIC DATA

A BEHAVIOUR-LED FRAMEWORK FOR TIME-RESOLVED ENERGY DEMAND & OPERATIONAL BEHAVIOUR IN INLAND WATERWAYS

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CONFERENCE 2026
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1. Observed Operation

Data Used –

- AIS Vessel Tracks
- River Geometry
- Current Vectors
- Operational Context

2. Physics-Informed Inference

What the model reconstructs

STW reconstruction → Hull resistance (Hull curves) → Propulsive power inference → Fuel & emissions estimation

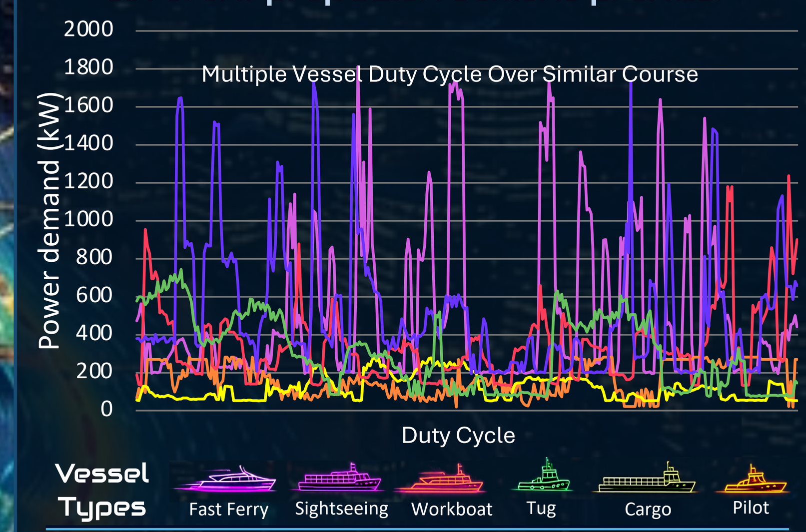
3. Revealed Energy Demand

What is quantified

- Time-resolved propulsion power
- Operational variability
- Spatial concentration
- Infrastructure implications

Operational Variability Across Vessel Types

Even over similar routes, vessel type and operational behaviour produce fundamentally different propulsion demand profiles.



Operational Modes

Energy behaviours & transient demand.

Total time spent in operational mode

Dead Slow	Slow	Transit	Service	Fast
12.7%	19.3%	19.3%	25.1%	23.5%

Operational modes over the duty cycle

Cumulative Energy Demand

Propulsion energy over the duty cycle

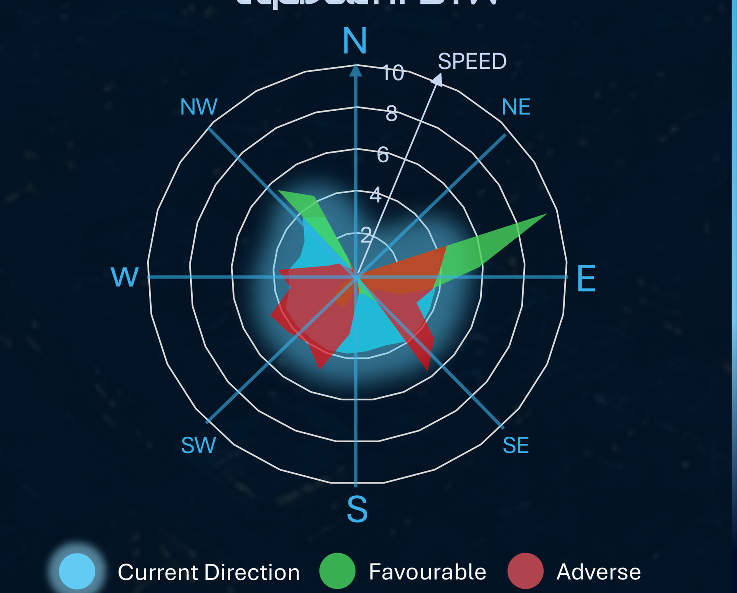
Hidden operational energy demand variabilities

From Movement to Energy

Observed vessel movement is translated into time- and location-resolved propulsion energy demand using physics-informed inference.
The analytical outputs shown represent an example vessels operational signatures reconstructed from AIS-derived behaviour.

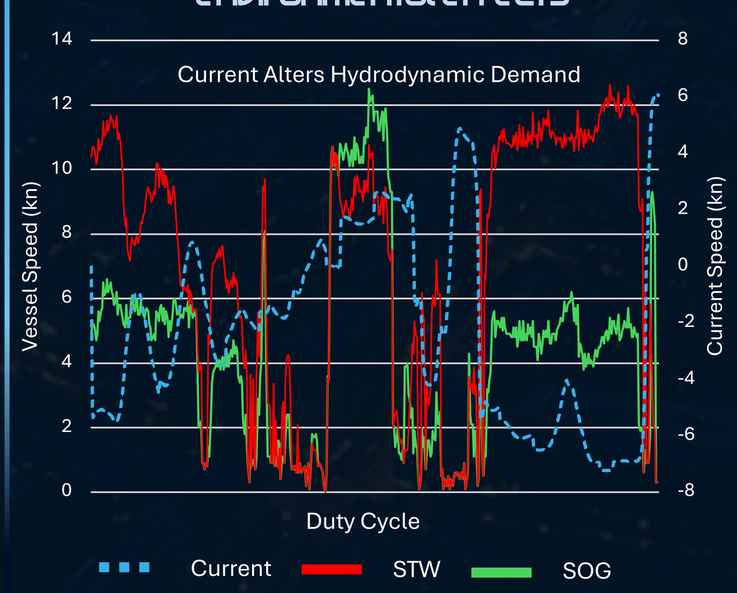
Current Interaction

Direction & magnitude drive power-equivalent STW



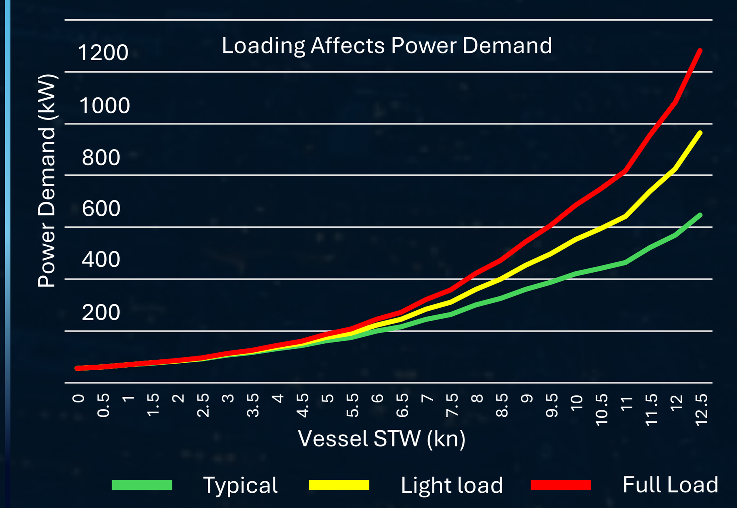
STW Reconstruction

Separating vessel motion from environmental effects



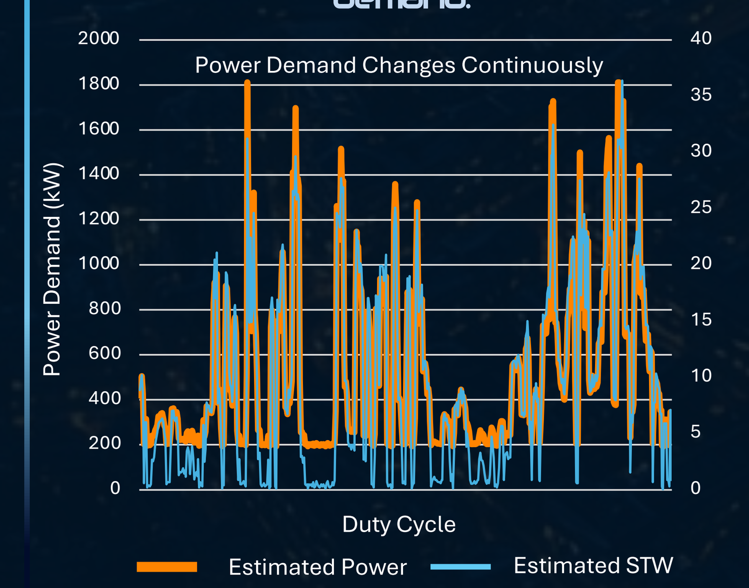
Hull Curve Mapping

Froude-scaled representative hull curves show increased demand sensitivity to loading at higher STW



Propulsive Power Inference

Timestep-resolved propulsion power demand.



Energy, Fuel & Emissions

Total energy, fuel and emissions can be inferred for total duty cycle – Example

Total Energy
2,604 kWh

Total Fuel
660 litres

Total CO_2 Emissions
1.77 tonnes

Why it Matters

- Enables right-sized and right-placed infrastructure and storage
- Supports integration of renewable energy from any source
- Reveals operational bottlenecks & energy demand hotspots
- Improves accuracy of planning & transition strategies

Validated analytical pathway from sparse publicly available data and model specific physics libraries to inferred energy demand.

What's Revealed

THERE IS NO STEADY STATE IN REAL OPERATIONS

ONLY CONTINUOSLY CHANGING ENERGY DEMANDS.

AIS DATA	VESSELS MODELED	TIME RESOLUTION	SPATIAL COVERAGE
1.5 + million positions analysed	25 + and growing	26-32 s timesteps	Thames and expanding

SCAN TO LEARN MORE

LinkedIn | Website | Paper

Clean Maritime Assembly 2026

Durham University, Teaching & Learning Centre, South Road, Durham, DH1 3LS

24-25 June 2026, 08:30-17:00

Ulster University

Numerical study of LH2 release and dispersion from the bottom of a 56 m³ vertical storage tank in a port area: hazard distances based on flammability and frostbite

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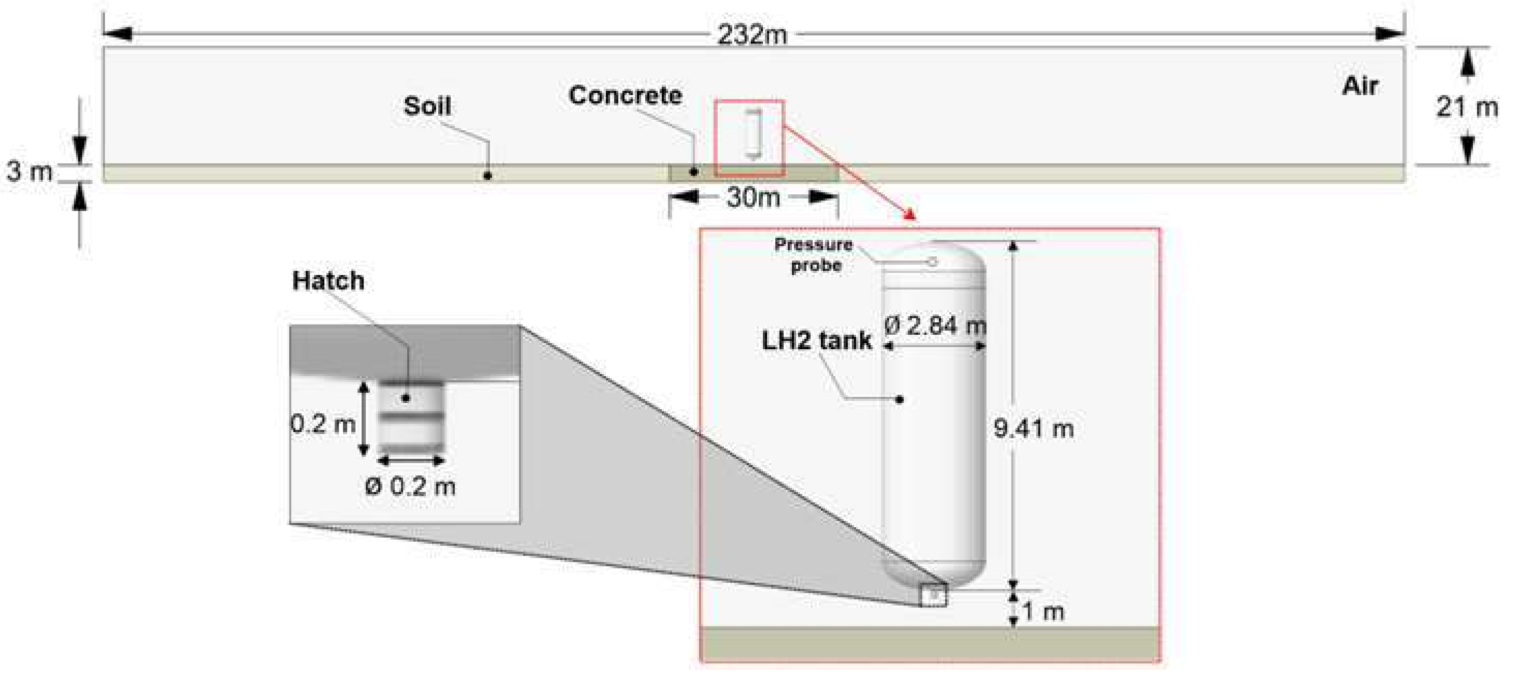
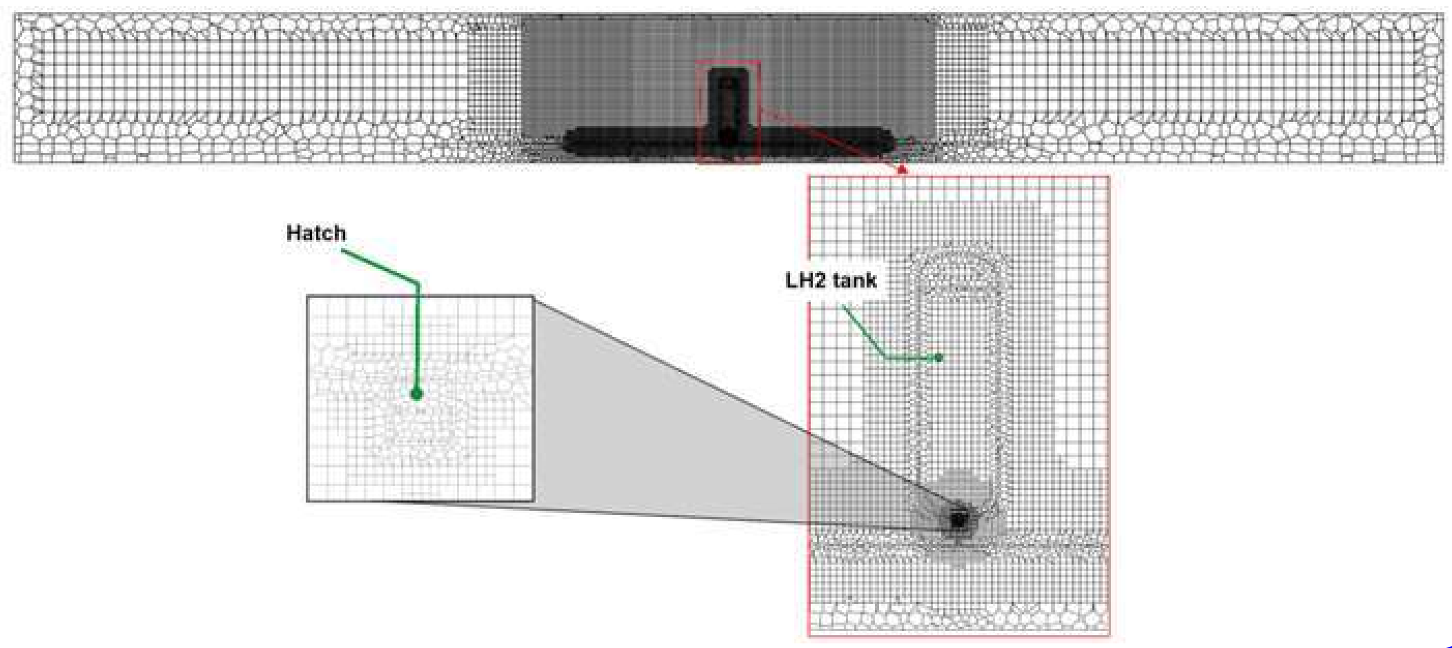
Introduction

- The aim of this study is to understand the physical phenomena governing hazard distances defined by flammability and frostbite for the scenario of LH2 release and dispersion from the bottom of a large-scale LH2 storage tank in a port area.
- A multiphase, multicomponent, 3D transient CFD model was developed to investigate this scenario and demonstrate the use of CFD as a contemporary tool for hydrogen safety engineering in maritime applications.
- The industrial importance of this study lies in estimating hazard distances associated with a large-scale loss of containment in a port area, which is costly and dangerous to determine experimentally.





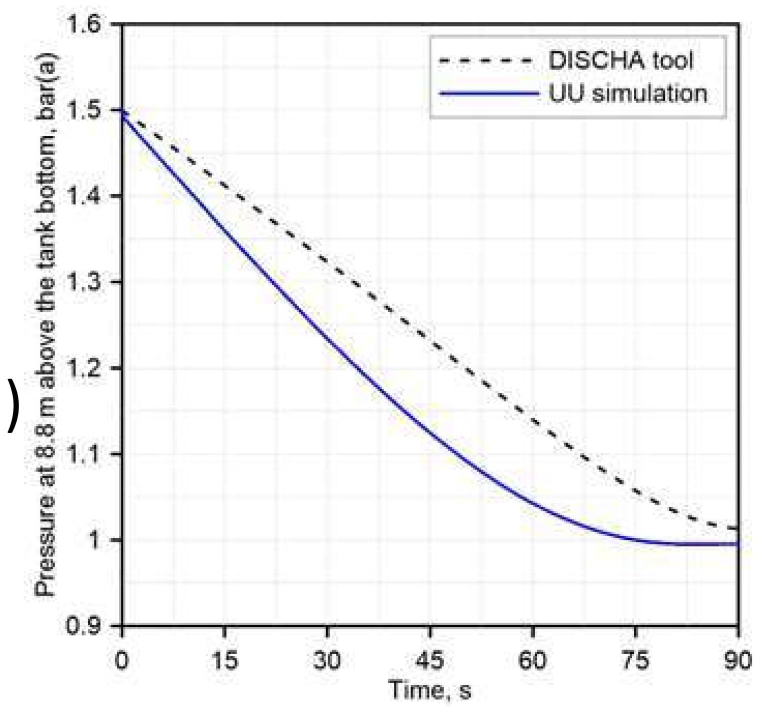
Numerical details

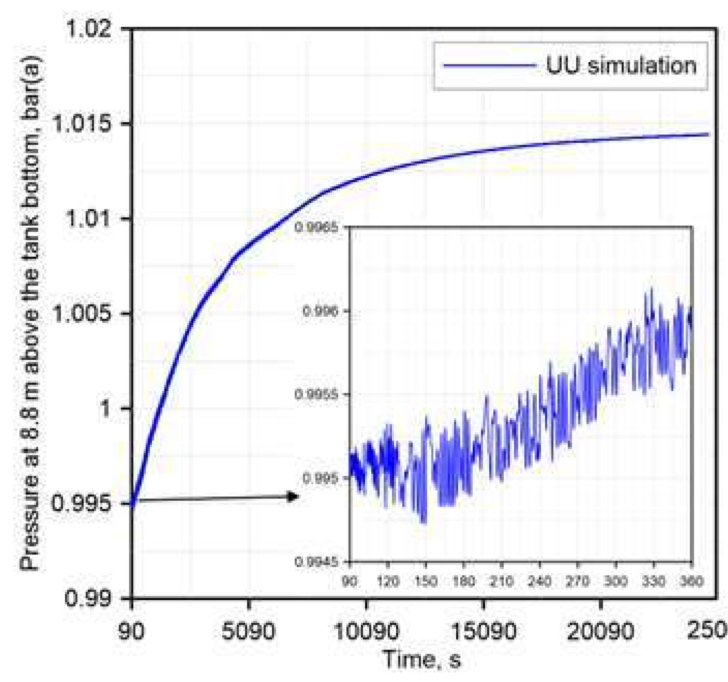
- A pressure-based implicit solver was employed to solve the governing equations, with the PISO algorithm applied for pressure–velocity coupling.
- The multiphase model utilised an implicit formulation for the volume fraction, incorporating the “dispersed interface” option to model interactions between the liquid and vapour phases.
- This model accounts for the condensation of air components, and Lee's evaporation–condensation model was employed.

Simulation results (1/2)

Blowdown simulation results

- DISCHA is an integral engineering tool for hydrogen discharge analysis.
- The CFD model predicted an LH2 release duration of 6.8 hours.
- The DISCHA reduced tool is applicable only for the first 90 s (a limitation).
- The CFD model captures long-term release behaviour that cannot be represented by reduced-order models.

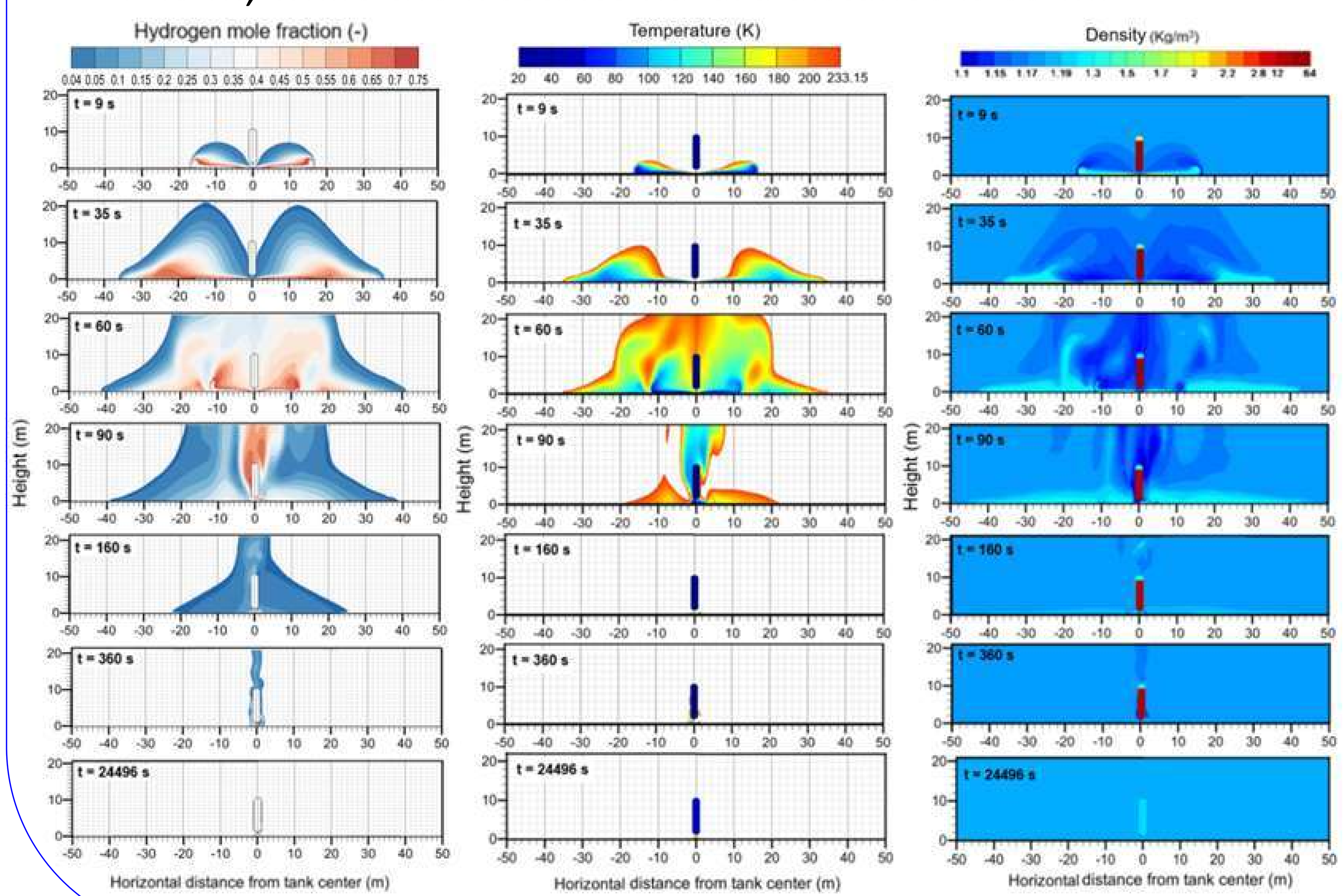




Simulation results (2/2)

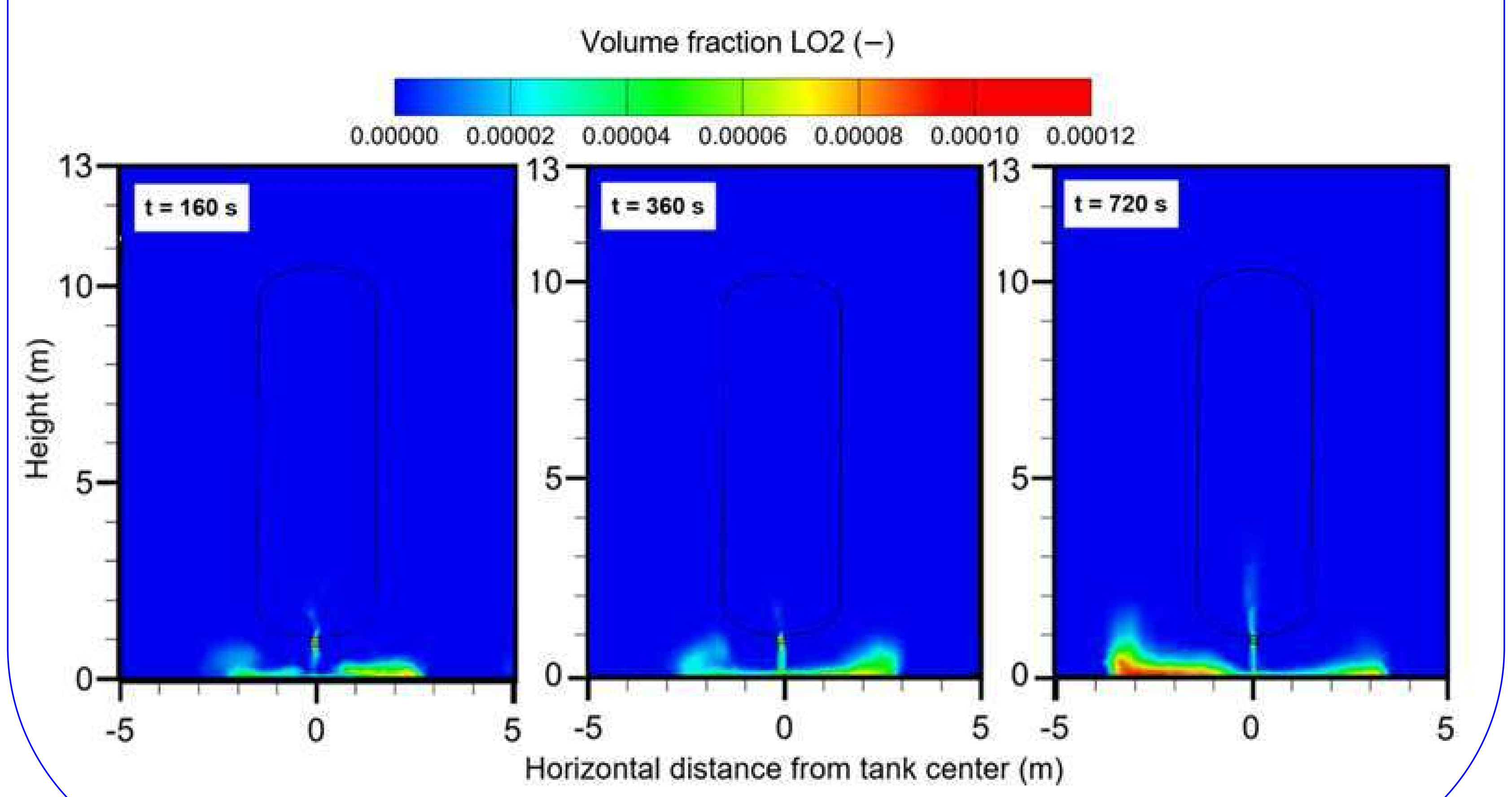
Evolution of hazard distances

- The horizontal span of the flammable hydrogen-air cloud is 41.5 m, while the frostbite hazard distance is 39 m.



Discovery of the “bubbling” phenomenon

- Oxygen condenses in the hatch and at the bottom of the tank. This is a result of the “bubbling” phenomenon.
- Bubbling and ingress of air into large LH2 storage, identified in UU simulation, pose an increased explosion risk.



Conclusions

- Reduced models cannot capture this long release time and the revealed bubbling phenomenon.
- The Hazard distance based on flammability (41.5 m) is larger than that based on frostbite (39 m).
- The bubbling phenomenon begins when the pressure inside the tank drops from the initial value to atmospheric pressure.

Acknowledgments

- This research has received funding from the Clean Hydrogen Partnership. ELVHYS and DelHyVEHR projects are supported by the Clean Hydrogen Partnership (CHP) and its members. Also, this research has received funding from the Engineering and Physical Sciences Research Council (EPSRC) of the UK through the Tier 2 Northern Ireland High-Performance Computing facility. The study is supported by the UK Department for Transport, as part of the UK Shipping Office for Reducing Emissions (UK SHORE) Programme, and the EPSRC (UK National Clean Maritime Research Hub, Grant EP/Y024605/1).

Towards Sustainable Port Infrastructure: A Life Cycle Perspective on EV-Charging-Integrated HVAC Systems

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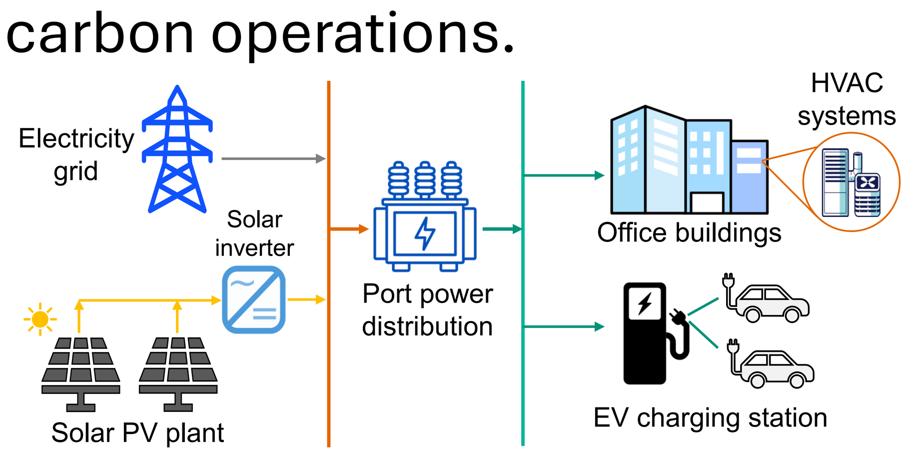
Objectives

- Assess the environmental impacts of integrated HVAC, EV charging, and solar energy systems
- Compare grid-powered and solar-powered energy supply options using life cycle assessment
- Identify key environmental hotspots and influencing factors across the system life cycle
- Evaluate the potential of renewable energy integration to support port decarbonisation

Port of Sines

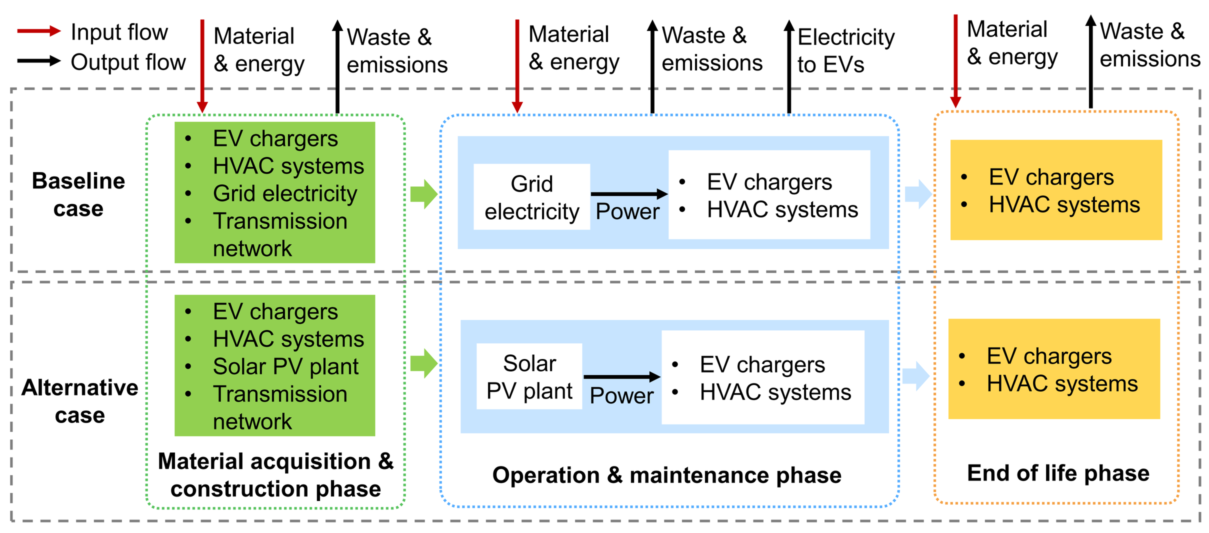
A major logistics and energy hub on the Atlantic coast of Portugal. The port is exploring innovative pathways towards sustainable maritime infrastructure and low-carbon operations.



Life cycle assessment

Goal and scope definition

- Functional unit: operation of the energy systems for **30 years**
- Product system: the energy systems and infrastructure in the port
- System boundaries:



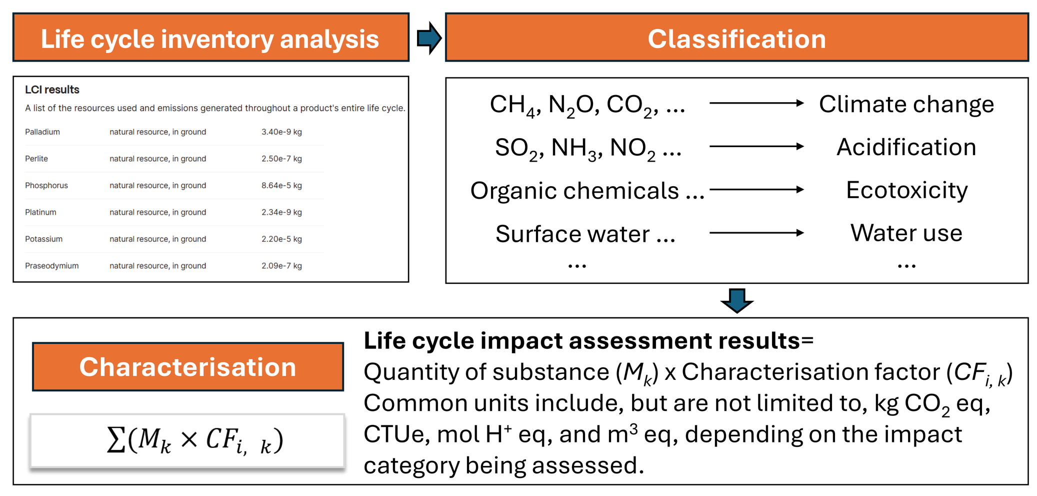
Life cycle inventory

- The energy and materials input
- Products and emissions output

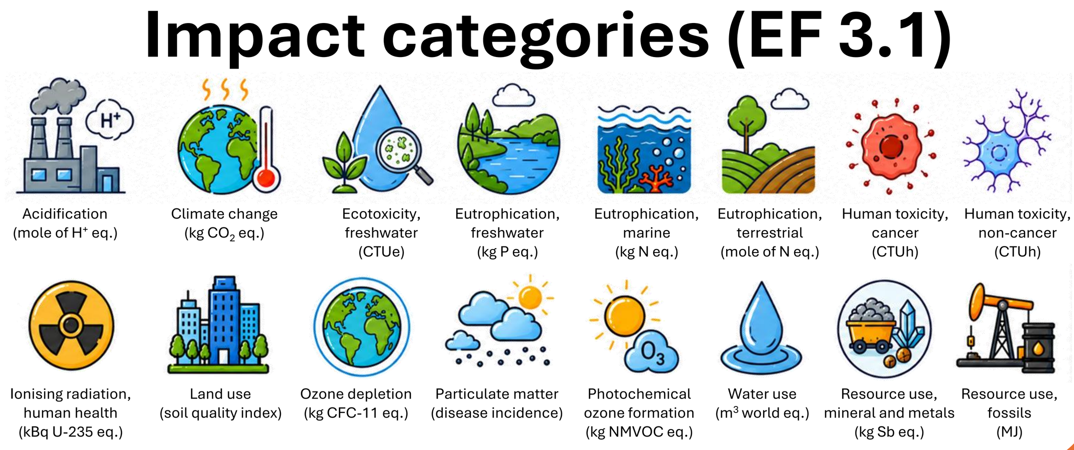
Inputs for making air conditioners in the office building (total weight: 8321.5 kg)

Flow	Quantity	Amount	Unit
Aluminium	Mass	5.17E+02	kg
Copper	Mass	1.41E+03	kg
Iron	Mass	5.93E+02	kg
Stainless steel	Mass	1.22E+02	kg
Steel	Mass	2.92E+03	kg
High-density polyethylene (HDPE)	Mass	5.83E+00	kg
Polypropylene (PP)	Mass	6.82E+01	kg
Polystyrene (PS)	Mass	5.45E+02	kg
Expanded polystyrene (EPS)	Mass	3.25E+01	kg
High impact polystyrene (HiPS)	Mass	1.35E+03	kg
Polyvinyl chloride (PVC)	Mass	3.36E+02	kg
Polyamide (PA-6)	Mass	1.06E+02	kg
Polybutylene terephthalate (PBT)	Mass	4.99E+01	kg
Acrylonitrile butadiene styrene (ABS)	Mass	1.75E+01	kg
Lacquer	Mass	7.16E+01	kg
Rubber	Mass	1.41E+01	kg
Refrigerant	Mass	1.61E+02	kg
Manufacturing electricity	Energy	1.64E+05	MJ

Life cycle impact assessment



Impact categories (EF 3.1)



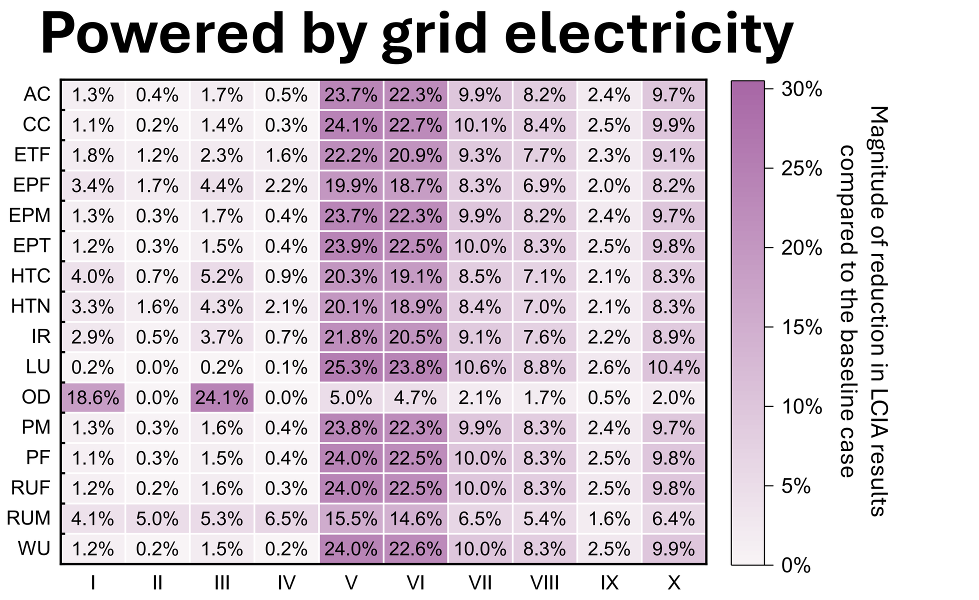
Sensitivity analysis

- Key parameters varied by ±10% to ±30%
- Assessed impacts on LCIA results
- Based on stakeholder interest

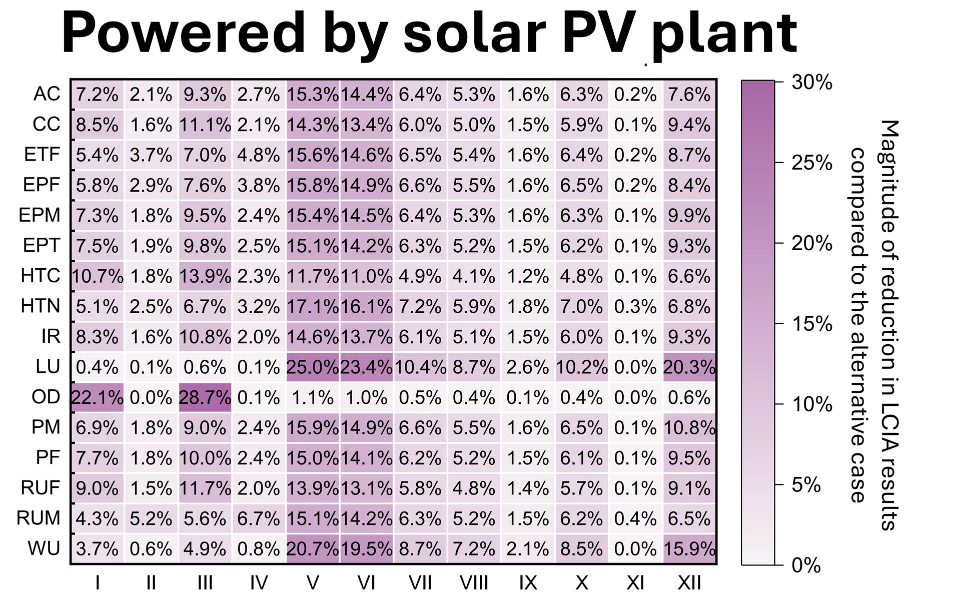
Key parameter	Component	Influence phase	Baseline value
System lifespan	HVAC systems	Manufacturing	15 years
	EV chargers	Manufacturing	15 years
System weight	HVAC systems	Manufacturing	8589.3 kg
	EV chargers	Manufacturing	55 kg each
Rated output power	Solar PV plant	Manufacturing	250 kW
Heating set point temperature	HVAC systems	Operation	18°C
Cooling set point temperature	HVAC systems	Operation	25°C
Daily heating duration	HVAC systems	Operation	10 hours
Daily cooling duration	HVAC systems	Operation	8 hours
SOC of EVs upon arrival for charging	EV chargers	Operation	0.2
Weekly charging frequency of one EV	EV chargers	Operation	3 times
Solar irradiance	Solar PV plant	Operation	1000 W/m^2

Impact reduction potentials with different strategies

Powered by grid electricity



Powered by solar PV plant

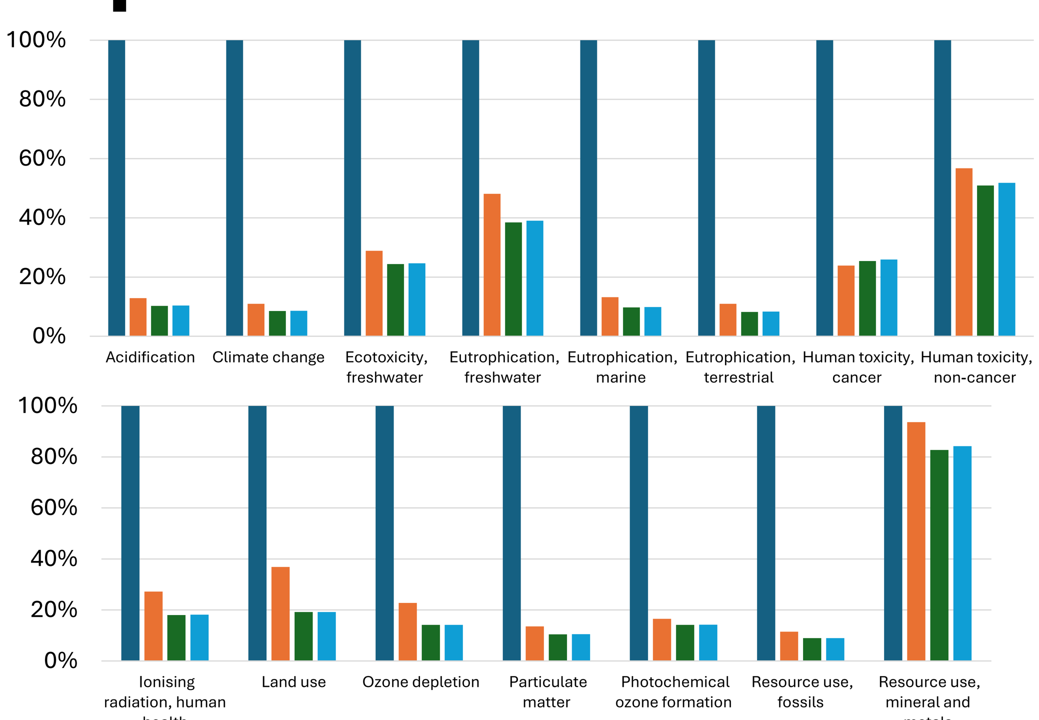


Impact categories
AC: Acidification; CC: Climate Change; ETF: Ecotoxicity, Freshwater; EPF: Eutrophication, Freshwater; EPM: Eutrophication, Marine; EPT: Eutrophication, Terrestrial; HTC: Human Toxicity, Cancer; HTN: Human Toxicity, Non-cancer; IR: Ionising Radiation, Human Health; LU: Land Use; OD: Ozone Depletion; PM: Particulate Matter; PF: Photochemical Ozone Formation, Human Health; RUF: Resource Use, Fossils; RUM: Resource Use, Mineral and Metals; WU: Water Use

Strategies for reducing environmental impacts
I: Extending system lifespan (HVAC systems); II: Extending system lifespan (EV chargers); III: Reducing system weight (HVAC systems); IV: Reducing system weight (EV chargers); V: Reducing set point temperature for heating; VI: Increasing set point temperature for cooling; VII: Reducing heating duration per day; VIII: Reducing cooling duration per day; IX: Increasing SOC; X: Reducing charging frequency per week; XI: Increasing rated output power of solar PV plant; XII: Increasing solar irradiance

Future energy plan for port

- Electricity is powered by grid
- Electricity is powered by onsite solar PV plant
- Future energy plan 1: 6.5 MW solar PV and 12.5 MW onshore wind
- Future energy plan 2: 10 MW solar PV and 25 MW onshore wind



Refrigerants management

Process	GWP 100 (kg CO_2 equivalent)
Production of refrigerant	5385
Reclamation of used refrigerant	583
Disposing used refrigerant in incineration	1298
Venting refrigerant	491436

✓Reclaimed refrigerants reduced GWP100 by **5.8%**
✓Direct venting generated the highest emissions
✓Recovery and reuse refrigerants support low-carbon HVAC systems

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FROM VALIDATED CONCEPT → PRE-COMMERCIAL HARDWARE → FUNDED NEXT STEP

TOWARDS GREENER SHIPPING: FEASIBILITY OF METHANOL REFORMING, CO_2 CAPTURE AND PORT-SIDE CO_2 UTILISATION FOR UK MARITIME CORRIDORS

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Scan to Connect on in

THE MATURITY LADDER — EACH RUNG MOVES THE WORK ONE STEP CLOSER TO DEPLOYMENT →

1. **PROVEN** — Works thermodynamically
2. **VIABLE** — Pays under the right conditions
3. **REAL** — Built & trialed at Larne
4. **NEXT BOTTLENECK** — PSA is the weak link
5. **FUNDED SOLUTION** — Membranes · CMRH Wave 3
6. **IMPACT** — Route to green corridors

THE CASE — *why it matters*

1 The Challenge & Why Methanol

2.89% of global CO_2 emission ~1.1 Gt/yr from shipping

>18 Mt UK shipping CO_2/yr — ~5% of national GHG

IMO TARGETS
- 2024 — Baseline · EU ETS live
- 2030 — −40% carbon intensity
- 2050 — Net Zero

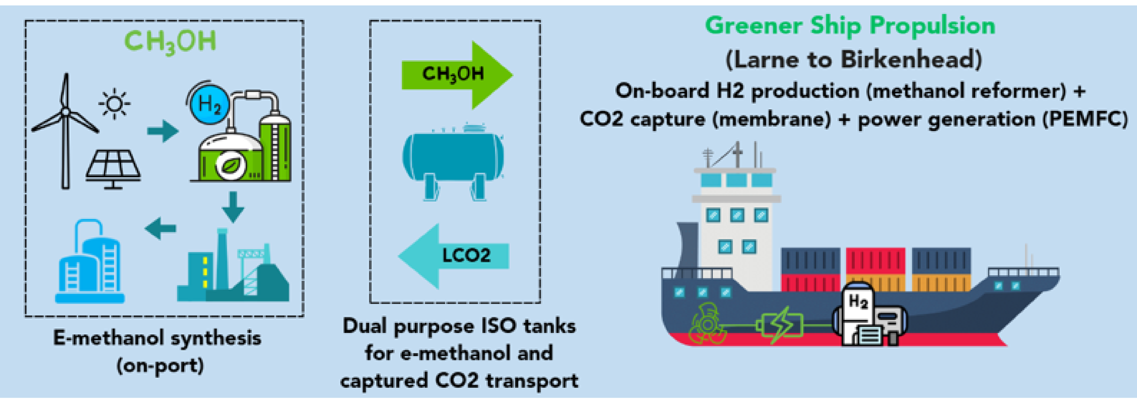
Policy push: EU-ETS, 2024 (\$100/t_{CO_2}) and FuelEU Maritime-2025 (\$2,400/t_{HFO}) strengthen the economic case for low-carbon fuels by penalising fossil marine fuels and rewarding lower-GHG alternatives

- ❑ Why methanol — liquid at ambient conditions, growing bunkering, engine + fuel-cell compatible, safer than ammonia/LNG; 60-90% well-to-wake GHG cut from renewable routes
- ❑ The catch — methanol-fueled vessels still emit substantial CO_2, so onboard capture is essential for net zero

FIG 1: Regulatory drivers & emissions context

2 The Closed-Carbon-Loop Concept

The NI/GB Clean Maritime Corridor (CMDC-4) proposes a zero-emission closed loop for Ro-Ro ferries, Larne (NI) ↔ Liverpool (UK):



1. Green H_2 — 140 MW PEM electrolyser at Ballylumford on wind power
2. Onboard reforming + PEMFC — steam reformed 245°C, 12 atm → H_2 propulsion
3. e-Methanol (port) — CO_2 hydrogenation 210°C, 75 atm → 49,500 t/yr
4. CO_2 capture & return — liquefied via cold methanol (−80°C), dual-use ISO tanks → >95% cut

CATALYTIC HYDROGENATION REACTION

$3H_2 + CO_2 \leftrightarrow CH_3OH + H_2O$; $\Delta H^o = -1.58\ MJ/kg_{CH3OH}$

FIG 2 · Port + on-board closed carbon loop

3 Reference Voyages

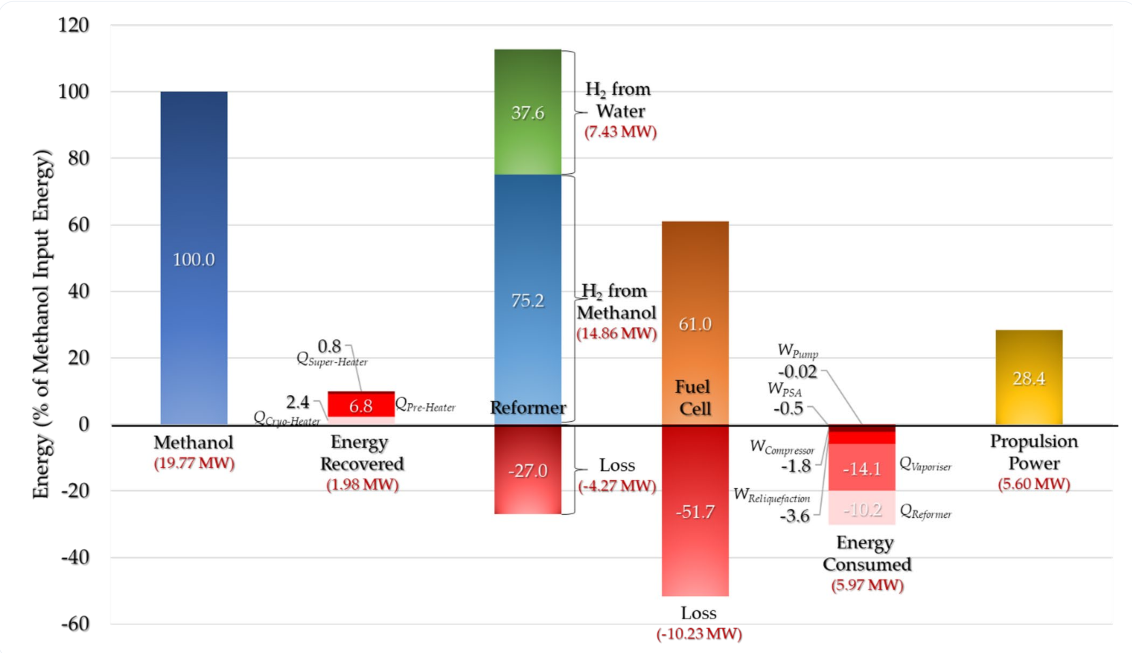
Parameters (Per round trip)	Larne-Liverpool	Immingham-Esbjerg
BASE CASE (FOSSIL FUEL-HFO/MGO)		
Power required	5.6 MW	6.4 MW
HFO/MGO	37 t, 40m³, 3 tanks	86 t, 93m³, 5 tanks
CO_2 emissions (2.7t_{CO2}/t_{HFO})	100 t	233 t
PROPOSED ALTERNATE-FUEL CASE (e-METHANOL)		
Methanol required	86 t, 95m³, 5 tanks	196 t, 216m³, 11 tanks
CO_2 captured (on-board)	115 t, 125m³, 7 tanks	263 t, 286 m3, 15 tanks
H_2 (for Methanol synthesis)	17 tonnes	37 tonnes
Water (for H_2 production)	46 tonnes	100 tonnes
Energy required (Renewable)	30-40MW	70-80 MW
CO_2 reduction	>95%	>95%

FIG 3 · Two reference ferry corridors, modelled from real operating data

THE EVIDENCE — *completed work*

4 Thermodynamic Feasibility — COMPLETED

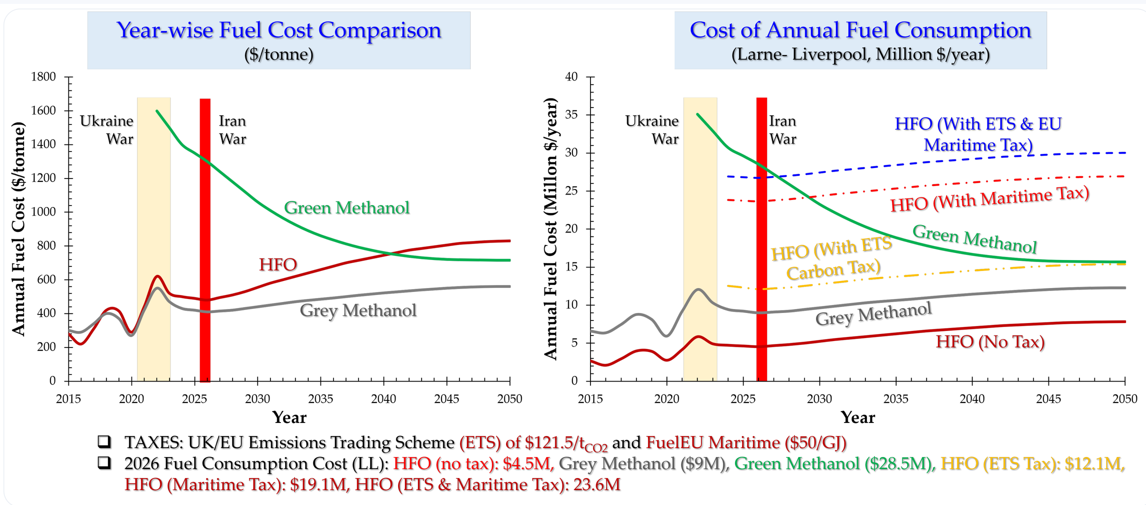
86%	54.1%	28.4%	22.2%
Reformer	PEMFC	Ship	End-to-End



- ❑ Net propulsion = 28.36% of methanol input (5.6 MW, Larne–Liverpool); ~10% recovered from reformate waste heat
- ❑ 50% of CO_2 liquefied via cold-methanol heat exchange (−22 °C) ; remainder by onboard re-liquefier (COP 2)
- ❑ Dual-use ISO tanks — emptied methanol tanks reused for CO_2 → carbon circularity onboard.

FIG 4 · End-to-end energy-flow waterfall (% of methanol input)

5 Economic Feasibility — COMPLETED



TAXES: UK/EU Emissions Trading Scheme (ETS) of \$121.5/t_{CO2} and FuelEU Maritime (\$50/GJ)
2026 Fuel Consumption Cost (LL): HFO (no tax): \$4.5M, Grey Methanol (\$9M), Green Methanol (\$28.5M), HFO (ETS Tax): \$12.1M, HFO (Maritime Tax): \$19.1M, HFO (ETS & Maritime Tax): 23.6M

- ❑ Direct-wire (bypassing grid) cuts methanol cost 26% → £502/t — the decisive lever. CAPEX is only ~2.5% of lifecycle; electricity dominates.
- ❑ 20-yr total cost: direct-wire e-methanol £352M ≈ carbon-priced HFO £387M . Newbuild essential; RFNBO double-crediting rewards early movers to 2034.
- ❑ Under EU-ETS + FuelEU, HFO rises to \$23.6M/yr vs green methanol \$28.5M/yr (2026) — and crosses over within the decade.

FIG 5 · Fuel-cost trajectory to 2050 under carbon-pricing scenarios

6 From Model to Metal — Pre-deployment Trials at Larne

- ❑ On validated feasibility, B9 Energy built a pre-commercial rig at Larne Port — 500 kW, 15 kg/h of H_2
- ❑ Modular containerized system: methanol steam reformer · PSA unit · CO_2 compressor & liquefaction · ISO-tank interface
- ❑ Demonstrated reforming, PSA CO_2 separation & H_2 in fuel cells (charging EVs) — the foundation for moving PSA → membranes

500 kW	15 kg/h	PSA	PEMFC
rig capacity	H_2 throughput	CO_2 separation	→ EV charging

Containerized & modular: reformer, PSA, CO_2 compressor/liquefaction and ISO-tank interface integrated in a single transportable unit, operated on renewable methanol at Larne Port.

FIG 6 · B9 pre-commercial rig — front view & internal reformer/PSA assembly

THE NEXT FRONTIER

7 The Gap: Need to Replace PSA

The bottleneck — CMDC-4 used PSA for onboard CO_2/H_2 separation: 15-18% electrical demand, large footprint, complexity under dynamic shipboard conditions. Rotating packed beds (RPB) shrink size but add moving parts and 22-25% penalties.

ENERGY PENALTY (% OF VESSEL POWER)

RPB	22 - 25%
PSA	10 - 12%
Membrane (target)	5 - 8%

FOOTPRINT (% Area Increase)

RPB 30-40% · PSA 50-60% · Membrane: compact

Membranes — passive, modular, no moving parts; continuous operation, rapid load response. Mature for point-source capture but never assessed for methanol-fuelled vessels . Polymeric films: 200–1000 GPU, CO_2/N_2 selectivity 20-50, 0.8-1.2 GJ/t_{CO2} vs 3-4 GJ/t_{CO2} for solvents.

8 Awarded — CMRH Wave 3 Membrane Project

Membrane-Based On-board CO_2 Capture for Methanol-Fuelled Maritime Vessels

PI: Dr Shadab Alam (ECR) · Partner B9 Energy
UK National CMRH — Wave 3 Flexible Funding · May-Oct 2026

PRE-COMBUSTION
H_2/CO_2 from reformate (20-25 vol%). Elevated T (≤200 °C), high CO_2 partial pressure — favourable separation.

POST-COMBUSTION
CO_2/N_2 from exhaust (5–12 vol%). Humid, variable-flow, near-ambient — captures residual emissions.

Benchmarking matrix: TECNALIA (CMS + Pd, pre-comb) · University of Manchester NGI (graphene-oxide / facilitated-transport, post-comb) · IICT (PVDF/PDMS composite & HFMC).

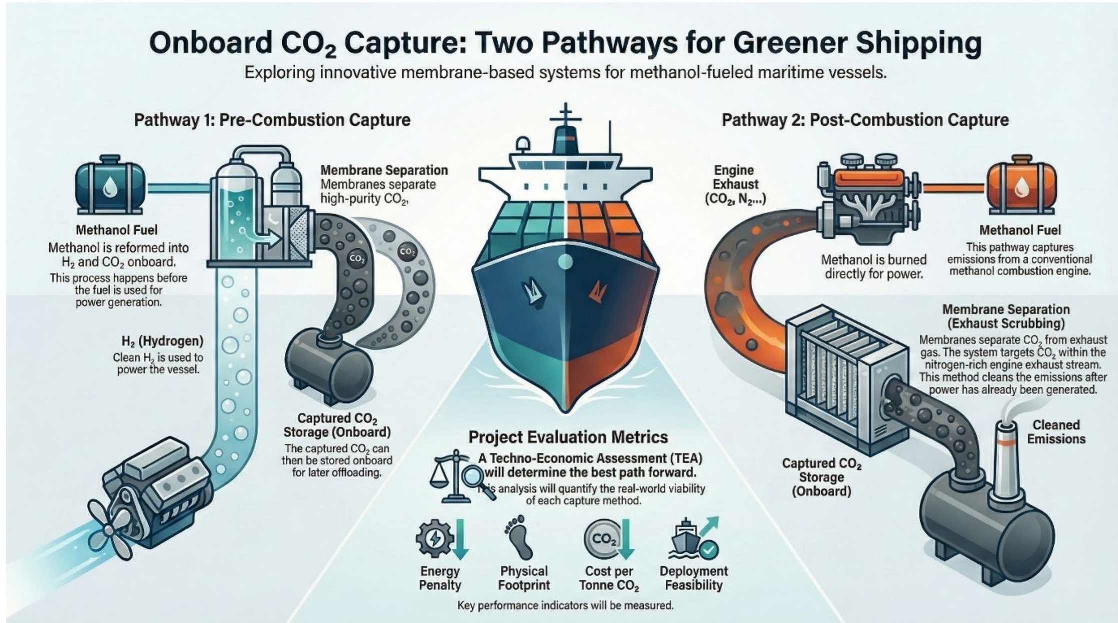


FIG 7 · Two complementary membrane capture pathways

9 Experimental & TEA Approach

Tested at the NZIIC membrane facility — Demcon Gas Separation Inspector: two automated feed lines, Coriolis permeate flow, vacuum time-lag, temp-controlled module, up to 60 bar , GC + multi-gas analysers, realistic $CO_2/H_2/CH_4$ mixtures.

MEASURED: Permeance · Selectivity · Recovery · ΔP · Temp tolerance ·Impurity sensitivity · Stability

FIG 8 · Demcon GS unit, NZIIC

Deployment-focused TEA quantifies energy penalty · footprint · mass · £/t_{CO2} — benchmarked vs PSA (CMDC-4) & RPB.

10 Envisaged Impact & Conclusions

- ✓ A complete pathway — thermodynamic feasibility → economic viability → pre-commercial hardware for methanol zero-emission corridors.
- ✓ 95% CO_2 reduction achievable; realistic 22.2% end-to-end efficiency inclusive of all penalties.
- ✓ Direct-wire renewable power makes 20-yr costs competitive with carbon-priced HFO.
- ✓ Wave 3 extends to membranes — 5-8% vs 1–12% (PSA) / 22-25% (RPB): a passive, no-moving-parts route to deployable capture.

Envisaged impact — comparative membrane-vs-PSA/RPB evidence to guide shipowner technology selection & a commercialization roadmap for early adopters (ferries, short-sea, offshore-wind vessels).
Goal: UK's first methanol-powered clean maritime corridor: a replicable blueprint for carbon-circular shipping.

GREEN SHIPPING ● RENEWABLE ENERGY ● E-FUEL (METHANOL) ● ON-BOARD CO₂ CAPTURE ● ON-PORT CO₂ UTILIZATION ● PROTON EXCHANGE MEBRANE FUEL CELL ● NET ZERO MARTIME FUTURE

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