Hydrogen 4×4 Yard Tractor Pilot at Valencia Terminal Europa (VTE) – Main Results

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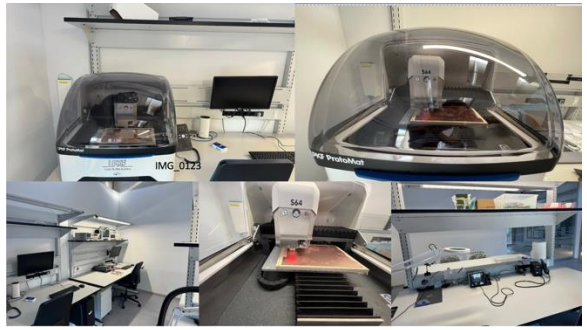
A Non-Profit Research and Innovation Consortium



Private Parts

System Integrator

COELMO
GRADED
AET
C.E.A.

ShipYard

CANTIERI DEL MEDITERRANEO

Aerospace, IT, Engineering & Consulting

PROTOM GROUP
GREEN ENERGY PLUS
SRS ENGINEERING DESIGN
TECHNOVA Scarl

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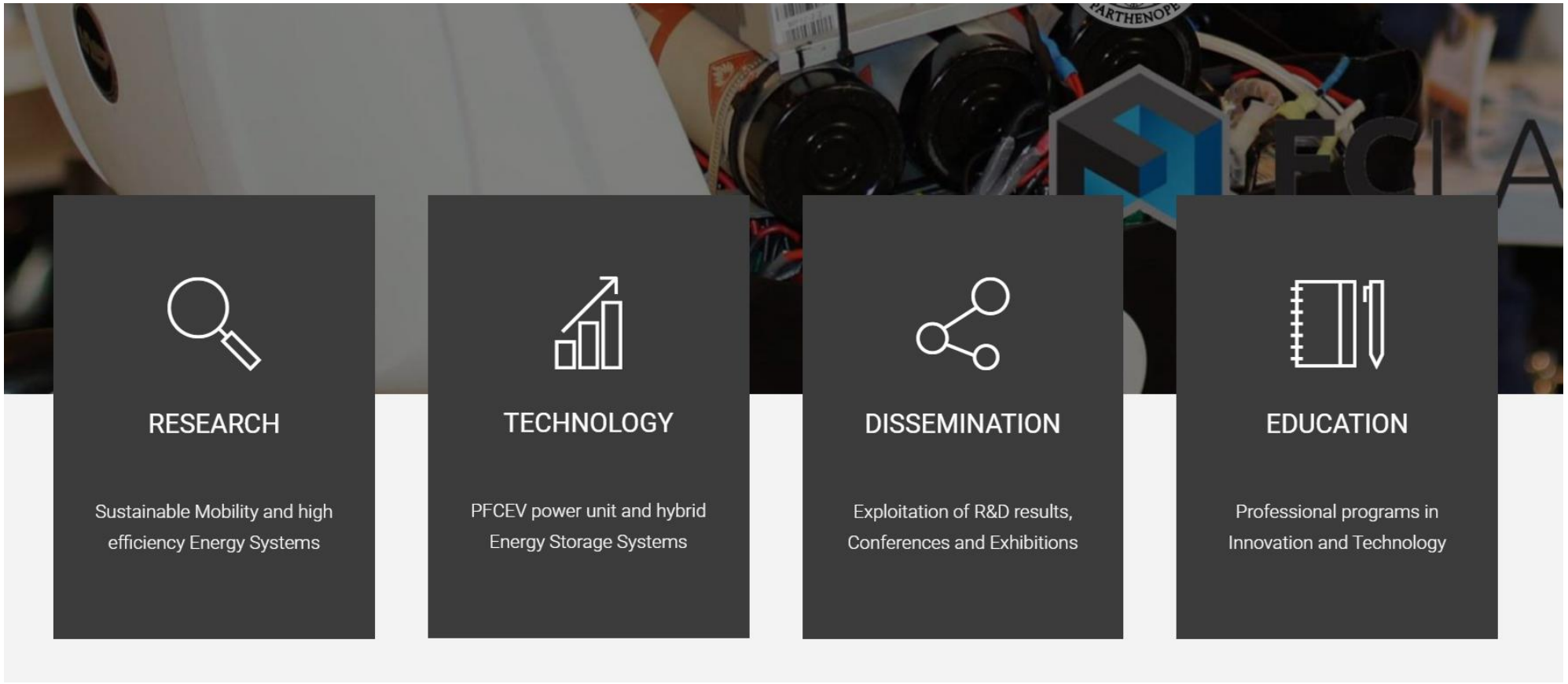
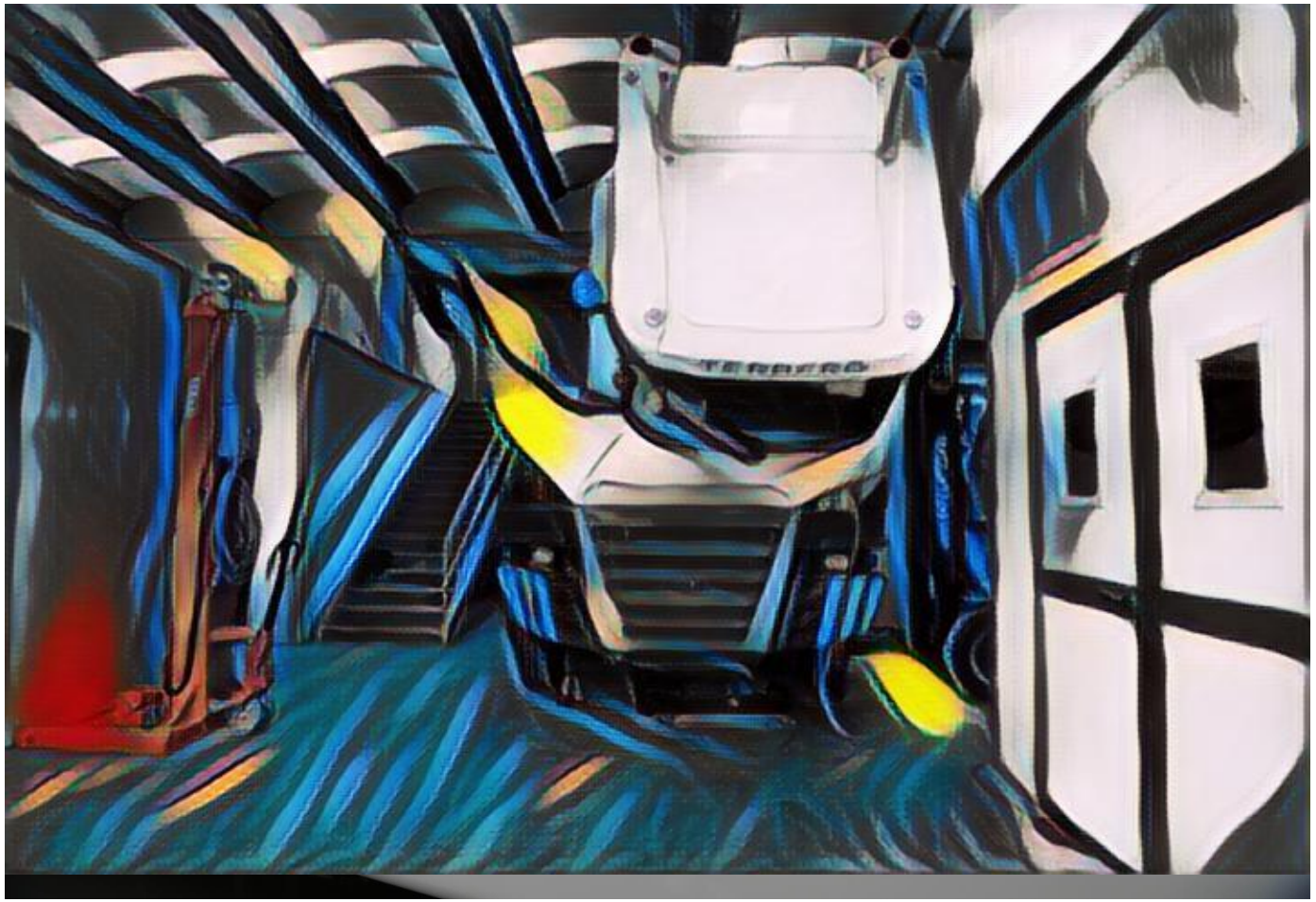
Atena Mission

ATENA develops **advanced and emerging technologies** across the energy and mobility sectors.

Its mission is to push beyond the state of the art through **visionary engineering, applied research, and collaborative innovation** with universities, industries and public institutions.



Atena in H2Ports: WP4 Coordinator
Implementation of FC and H2 in Terminal Tractors



EU Clean Hydrogen JU funding

€1,100,000 approx.

ATENA, Grimaldi Group, Ballard, National Hydrogen Centre, Fundación Valenciaport

Development and deployment a 4x4 Yard Tractor equipped with a Fuel Cells and test it in Valencia Terminal Europa (Grimaldi Group). It involves three tasks:

- Design, assemble and pilot a 4x4 Hydrogen Tractor
- Demonstration site: Valencia Terminal Europa in Valnecia, Spain

Atena @ H2Ports

WP4 Staff & Acknowlegments

Grimaldi LogiPort

Grimaldi - VTE

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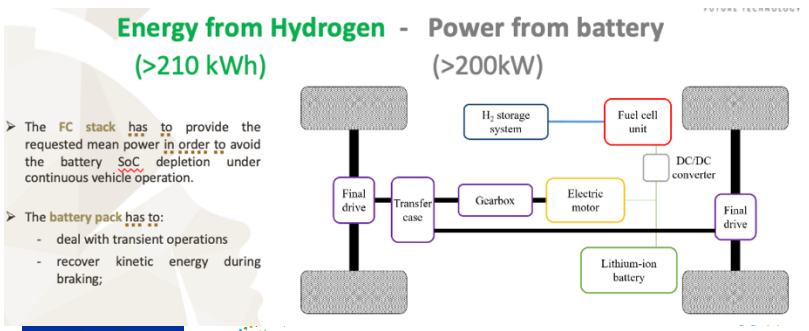
WP4 Task Activities

Implementation of FC and Hydrogen in a Yard Tractor

ATENA FUTURE TECHNOLOGY

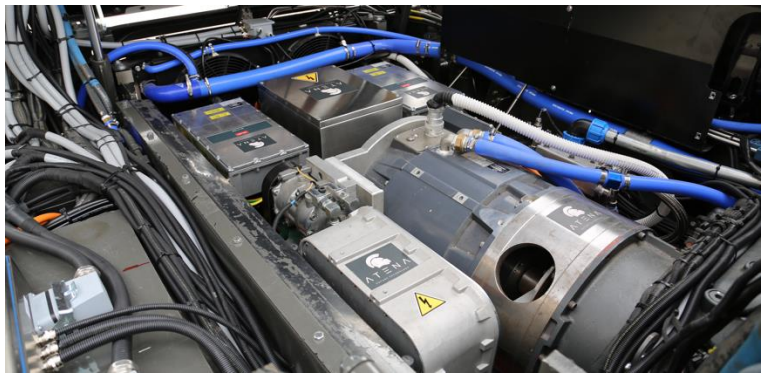
T4.1 DESIGN

Vehicle baseline analysis and power requirements
FC–battery hybrid architecture definition
Electric driveline and auxiliaries design
Cooling, H_2 storage, braking and control systems
Performance modelling, diagnostics, and optimization



T4.2 ASSEMBLING

Powertrain conversion (thermal → electric)
Fuel cell module, compressor, cooling, battery pack, H_2 tanks installation
Piping, wiring, driver interface
Steady-state and dynamic testing
Vehicle validation and O&M reporting



T4.3 PILOTING

Acceptance and safety procedures
Training of operators
Operational piloting in Valencia
Emission reduction assessment, LCA and business case

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H2 PORTS

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4x4 Yard Truck – RoRo Port Operations

Tug Masters operate inside the RoRo vessel, climbing steep ramps and requiring high torque and 4-wheel drive traction for continuous, demanding operation

Operational Scenario:

- Vessel loading capacity: 500 trailers
- Loading/unloading time: 12 hours
- Tug Masters per vessel: 4 – 10
- Two decks per vessel for simultaneous operations

Port Traffic Conditions:

- Typically 2 or more vessels in port
- Up to 26 Tug Masters operating at the same time

Benefits of H_2 Tug Masters:

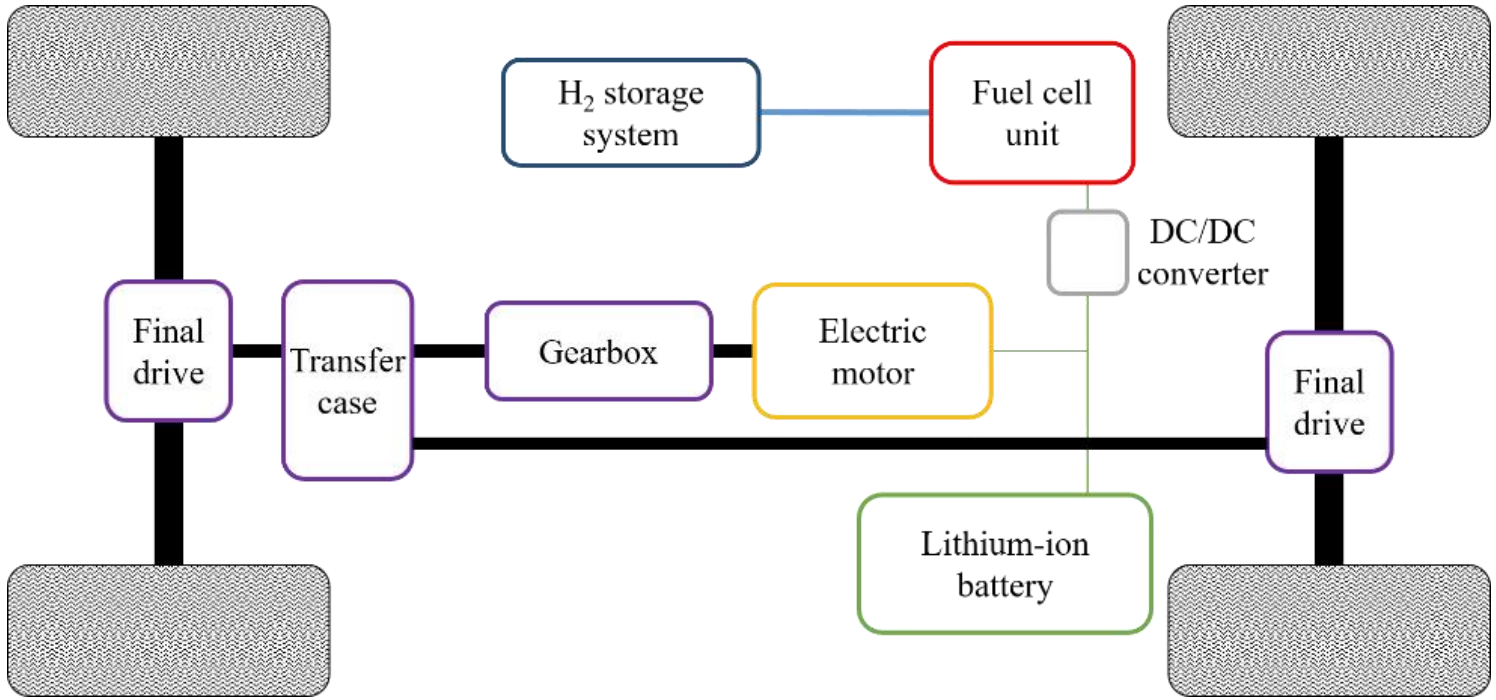
- Up to 200 tons of diesel saved per vessel per year
- Lower emissions, reduced noise and improved air quality

Atena Hybrid Power Unit Concept

Energy from Hydrogen - Power from battery

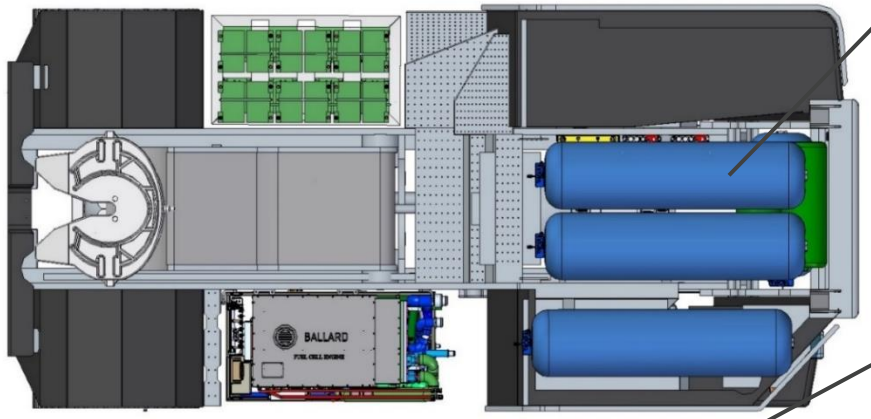
(>210 kWh) (>200kW)

- The **FC stack** provides the average power and ensuring SoC stability during continuous operation
- The **battery pack:**
  - Manages transient load and peak power
  - Supports regenerative breaking
  - Stabilizes vehicle dynamic on ramps



4x4 RoRo Tractor

Zero Emission 4x4 RoRo Tractor Main Specs.

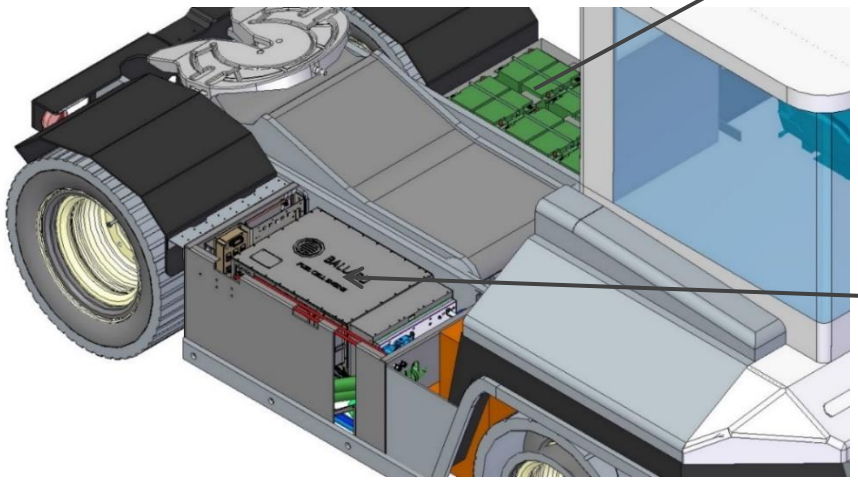


LUXFER G-Stor™ H2 – carbon composite Type 3 cylinders
Hydrogen storage system: CH2 @ 350 bar

Overall H2 capacity	12.67 kg
Total Weight	273.7 kg
Total water volume	525 L

Danfoss EM-PMI375-T800
Synchronous Reluctance assisted Permanent Magnet (SRPM)

Peak Torque	1200 Nm
Nominal Efficiency	96 %
Weight	210 kg

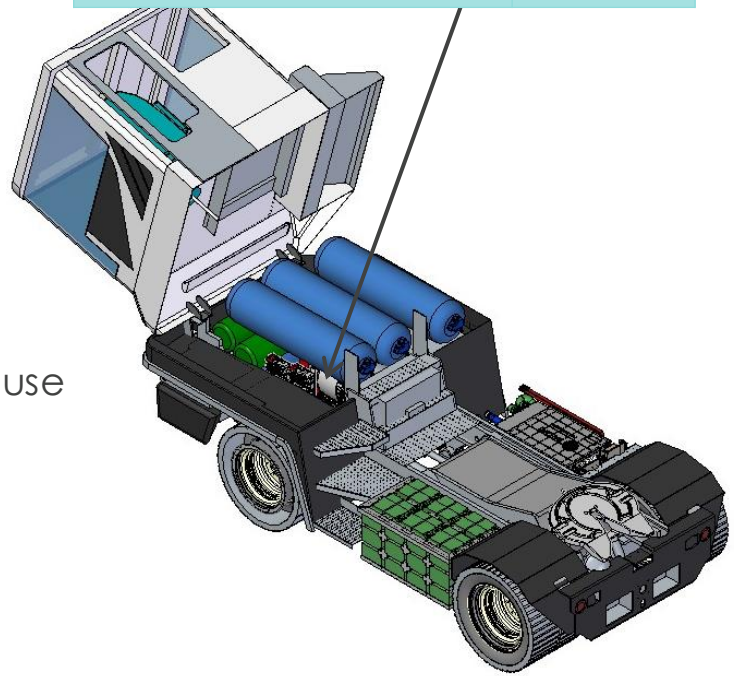


LITHION P40-24 POWER MODULE
Lithium Iron Phosphate chemistry platform.

Nominal voltage	25.6 V
Nominal capacity	40 Ah
N. of modules	24
Nominal energy capacity	25 kWh

BALLARD FCmove™ HD70
Heavy duty fuel cell power module for use in zero-emission motive applications.

Nominal power range	8 –72 kW
Max efficiency	57 %



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RoRo Tractor Assembling

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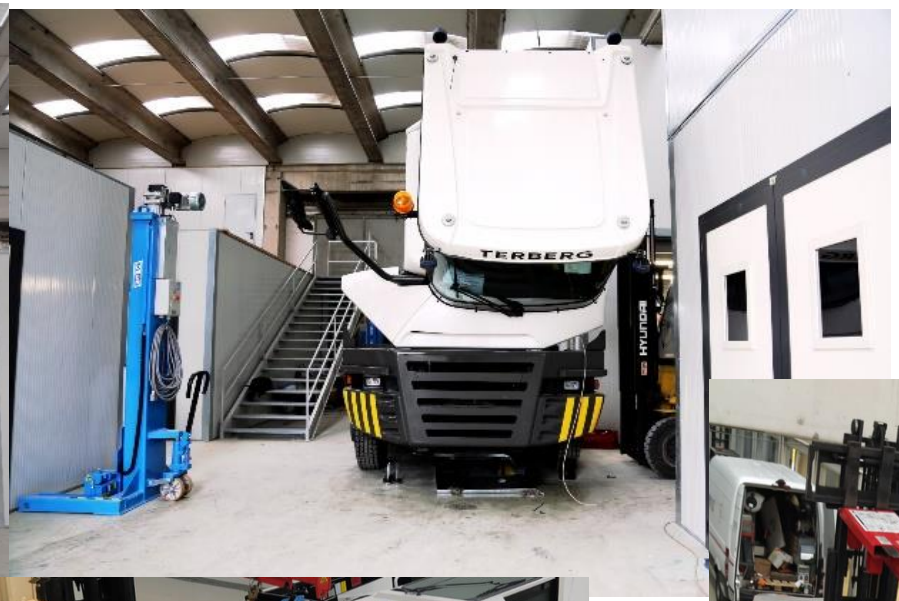

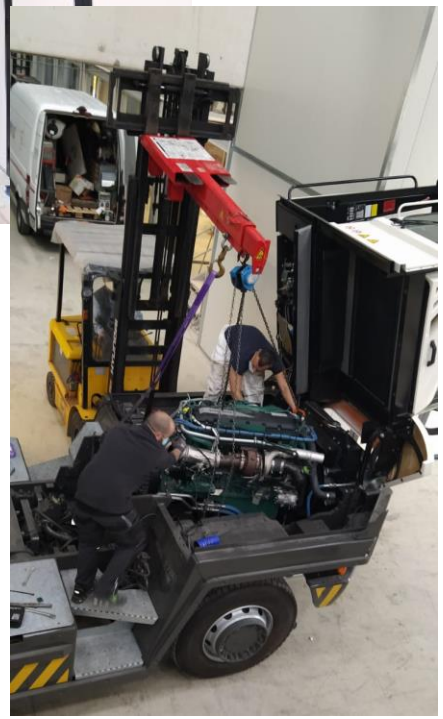

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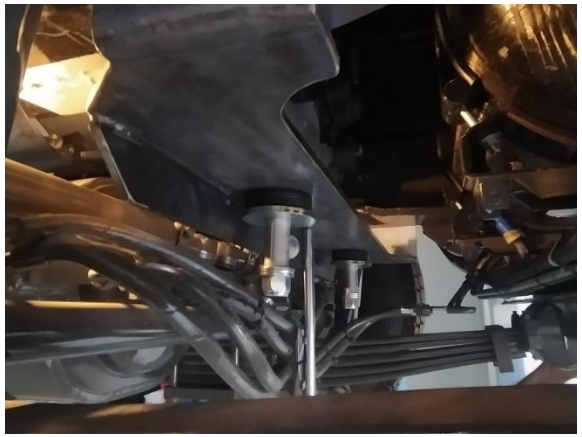
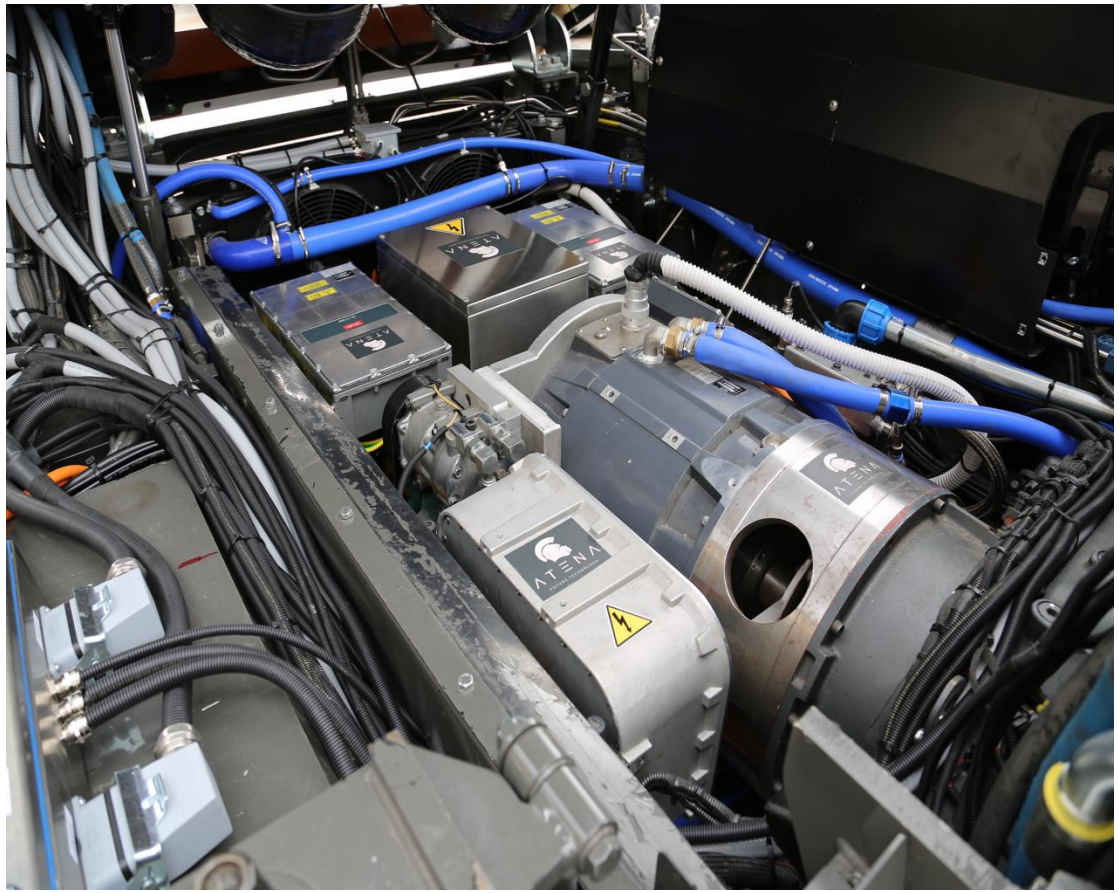
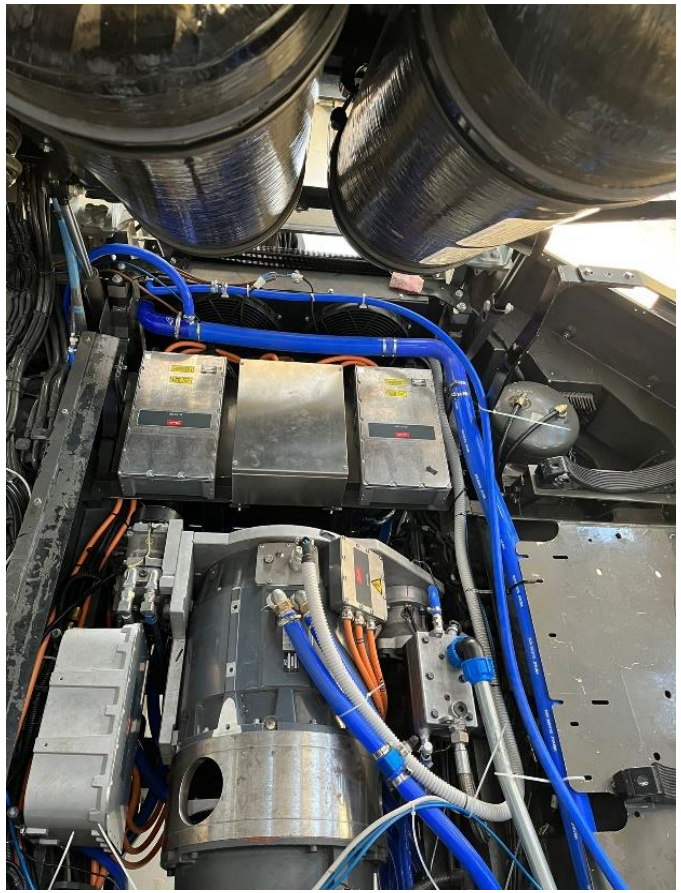
RoRo Tractor Power Unit Assembled







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4x4 Hydrogen Tractor Performance @Valencia

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Operation at Grimaldi Terminal Europa in Valencia

Engine speed [rpm]

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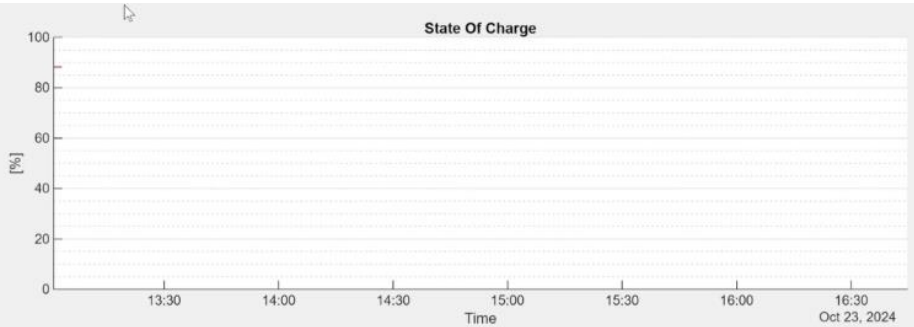
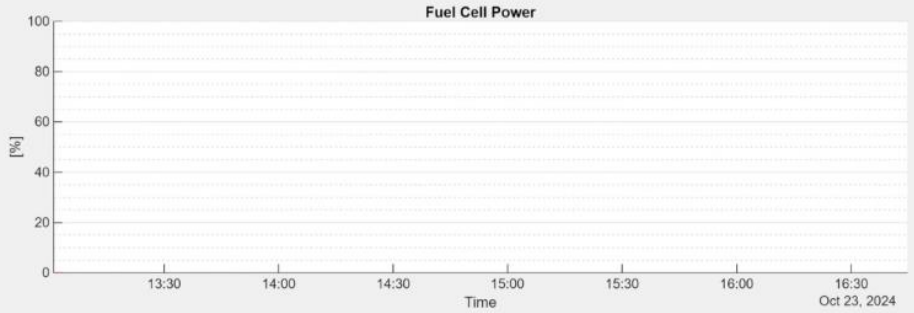
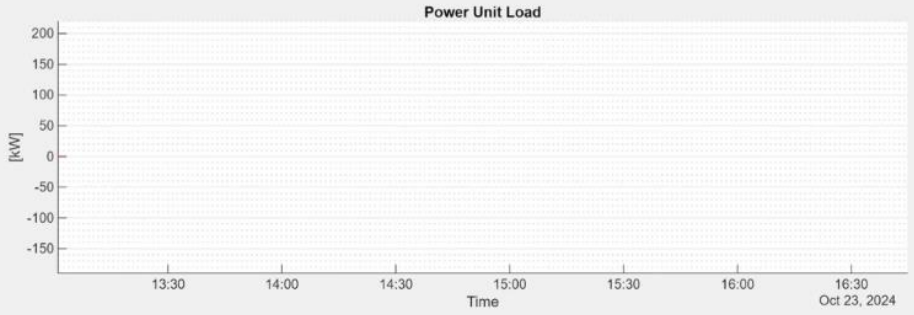
Vehicle speed [km/h]







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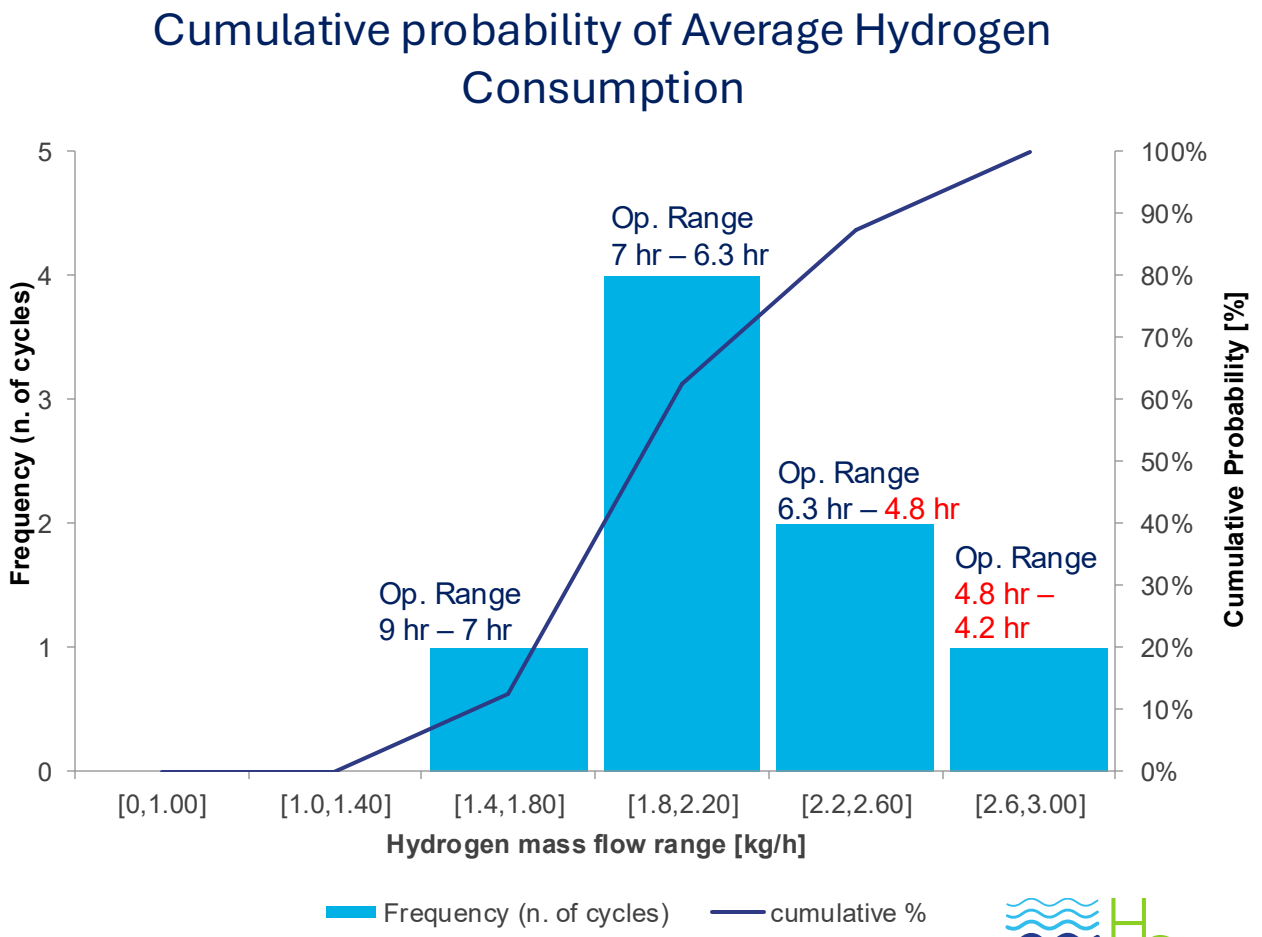
HyTruck Piloting – Main Operational Results

From About 672 Working Hours

Site	Max power [kW]	Mean power [kW]	Total energy [kWh]	Average Fuel Rate [kg/h]	Max fuel cell power [kW]	Mean fuel cell power [kW]	KER [%]
Valencia Roll-Off	181.2	35.5	35.2	2.1	43.4	39.2	18%
Valencia Roll-Off	179.8	36.3	55.4	2.2	43.6	40.5	17%
Valencia Roll-On	179	46.7	56.2	2.8	55.3	49.7	11%
Valencia Roll-On	181.2	44.5	120.8	2.6	72.0	47.1	11%
Salerno Roll-On	201.4	25.7	132.6	1.6	36.9	29.0	14%
Salerno Roll-On	201.1	33.8	209.2	2.0	40.6	37.7	11%
Salerno Roll-On	201.6	39.0	139.2	2.3	72.0	42.7	11%



Observed operational ranges vary from **9 hours down to 4.2 hours**, depending on ramp load, trailer mass and duty cycle severity.

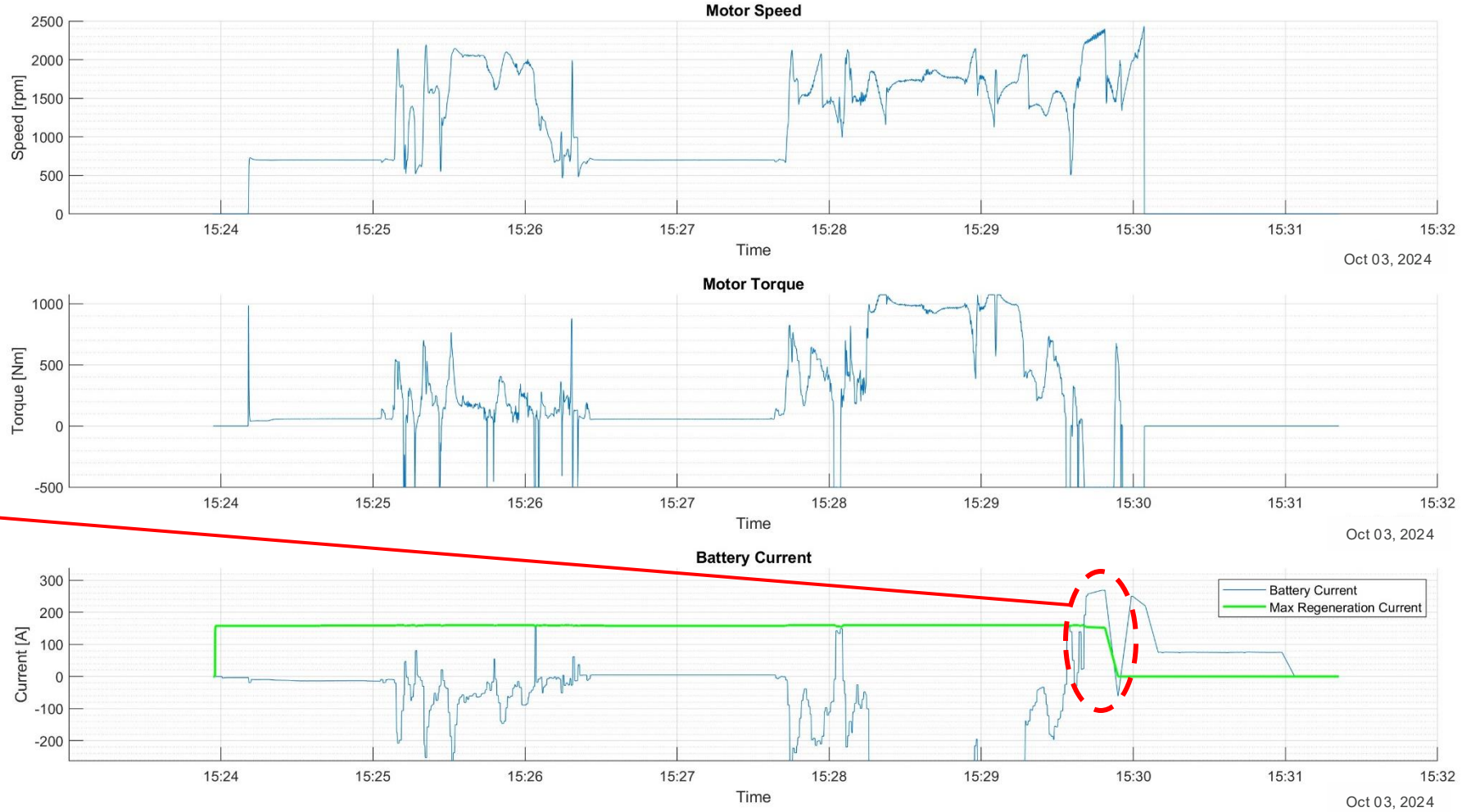
Battery & BMS KER Limitation

Battery & BMS – Regenerative Braking Limitations

High regenerative currents triggered BMS limits during long ramp descents

When current exceeded maximum allowable values, regenerative braking was temporarily disabled

This increased hydrogen consumption and reduced energy recovery



HyTruck Piloting Main Results From About 672 Working Hours

Main Observations from On-Field Testing

- **Auxiliary power consumption** consistently above 6 kW
- **High brake air consumption** due to engine speed not dropping below 700 rpm (Gearbox minimum speed)
- **Low driveline efficiency** caused by gearbox and PTO losses
- **Low air compressor efficiency** affecting fuel consumption
- **Reduced control system reliability** due to severe ramp vibrations

HyTruck Piloting Main Results
Drivers Impressions & Feedback

Drivers love it

Consistently positive feedback from all operators

Stronger on ramps

Higher climbing speed at full load on ECO ramps.

Much quieter

Lower noise levels, more comfortable working environment

Easier to drive

Sharper, smoother handling in tight manoeuvres

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Key Lessons Learned from Piloting Failures, Mitigations and Benefits

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Failure during piloting

BMS cut KER on long ramps
- Regen current above BMS limit for >10 s
- Vehicle stopped on ECO ship ramps

Fragile in-house control boards
- Custom PCBs + loose wiring
- Bulky, hard to service, EMC-sensitive

Inefficient driveline
- E-motor coupled with 6-speed gearbox
- Mechanical auxiliaries always turning
- Limited regen & idle consumption

Mitigation / design change

Re-tuned regenerative strategy
- Limited max regen current vs speed/SoC/temp
- Shaped ramps and cut-off times to stay inside BMS envelope

Industrial ECU upgrade
- Bosch Rexroth RC27 + dedicated harness
- Sealed housing, automotive connectors, built-in diagnostics

New efficient powertrain
- Direct-drive e-motor (no gearbox)
- 800 VDC electric auxiliaries on demand
- Full regen down to standstill

Resulting benefit

Safe and stable braking
- No more BMS shutdowns
- Smoother deceleration
- **More usable regen energy** without damaging the battery

Industrial-grade controller
- Higher reliability & availability
- Fast troubleshooting via service app
- Clean wiring & EMC compliance

Better performance, less H_2
- Lower tank-to-wheel H_2 consumption
- Higher acceleration & top speed
- No “idle just to keep things running”

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Truck Performance improvement
Battery & BMS Upgrade

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BEFORE – first traction battery pack

Custom pack built from individual modules on a simple frame: suitable for initial tests but with limited power rating, regenerative braking performance, and no integrated balancing.

NOW – advanced liquid-cooled battery system

High-power automotive modules with better current specs, allowing stronger regenerative braking and providing space for an on-board unit for automatic pack balancing.

Regenerative Braking Current:
Maximum continuous: 200 A
Peak: **300 A**
(for up to 10 seconds)

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From Prototype Box To Automotive-grade ECU

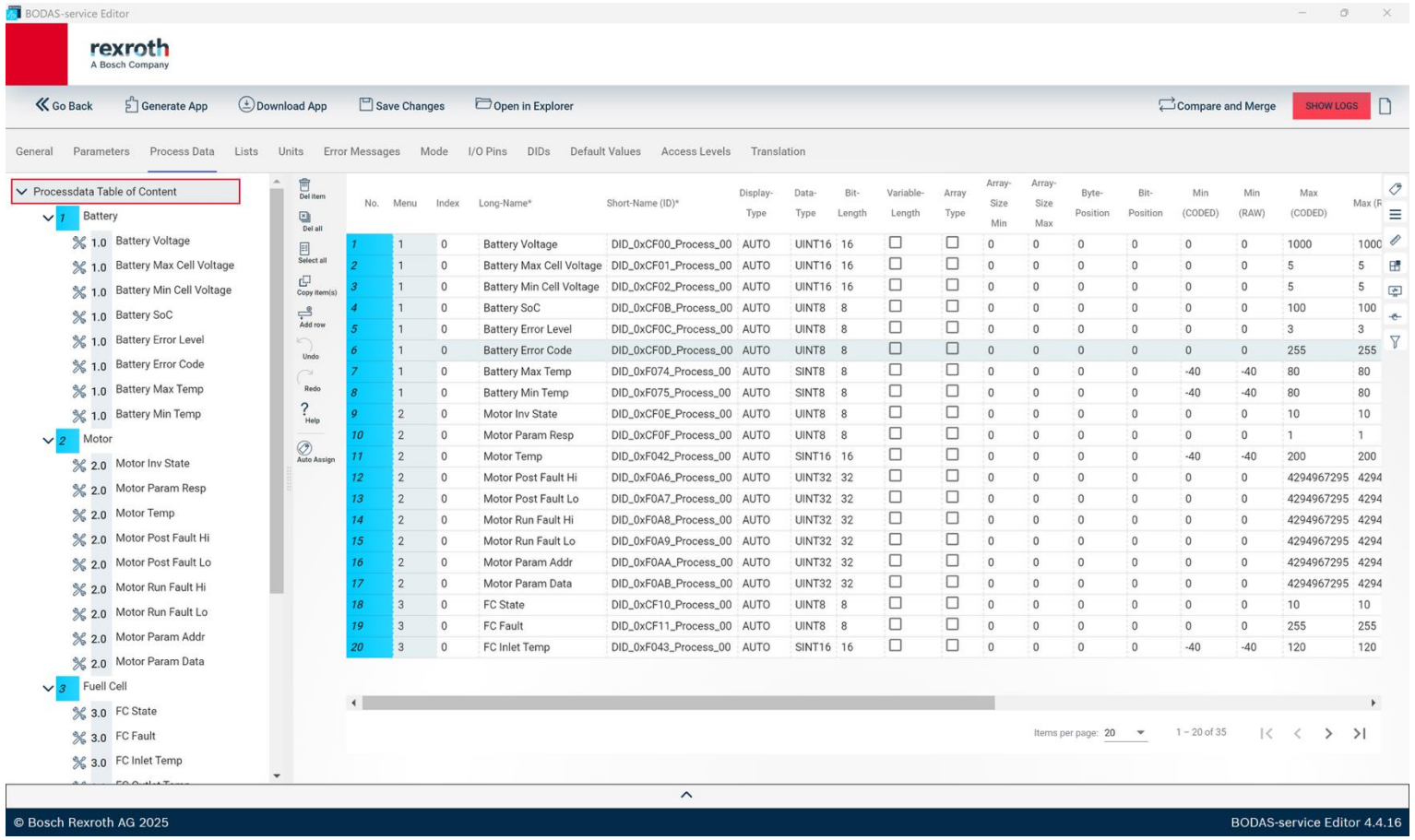
Before – in-house prototype

Early control prototype built from custom boards and loose wiring: great for quick testing, but bulky, fragile, and hard to service.

After – Bosch Rexroth RC27 ECU

Final industrial solution based on the Bosch Rexroth RC27 controller: automotive-grade hardware with integrated I/O, robust housing, sealed connectors, and built-in diagnostics. This design offers higher reliability, easier maintenance, cleaner wiring, and full compliance with safety and EMC requirements.

From Prototype Box To Automotive-grade ECU



With the Bosch BODAS-service app we can now **monitor** the tractor like a real **industrial product**: battery, motor and fuel-cell status, active faults and logs, and maintenance parameters are all **accessible** in one place for fast **diagnostics** and service

4x4 RoRo Driveline Configuration

New Hydrogen Hybrid Powertrain

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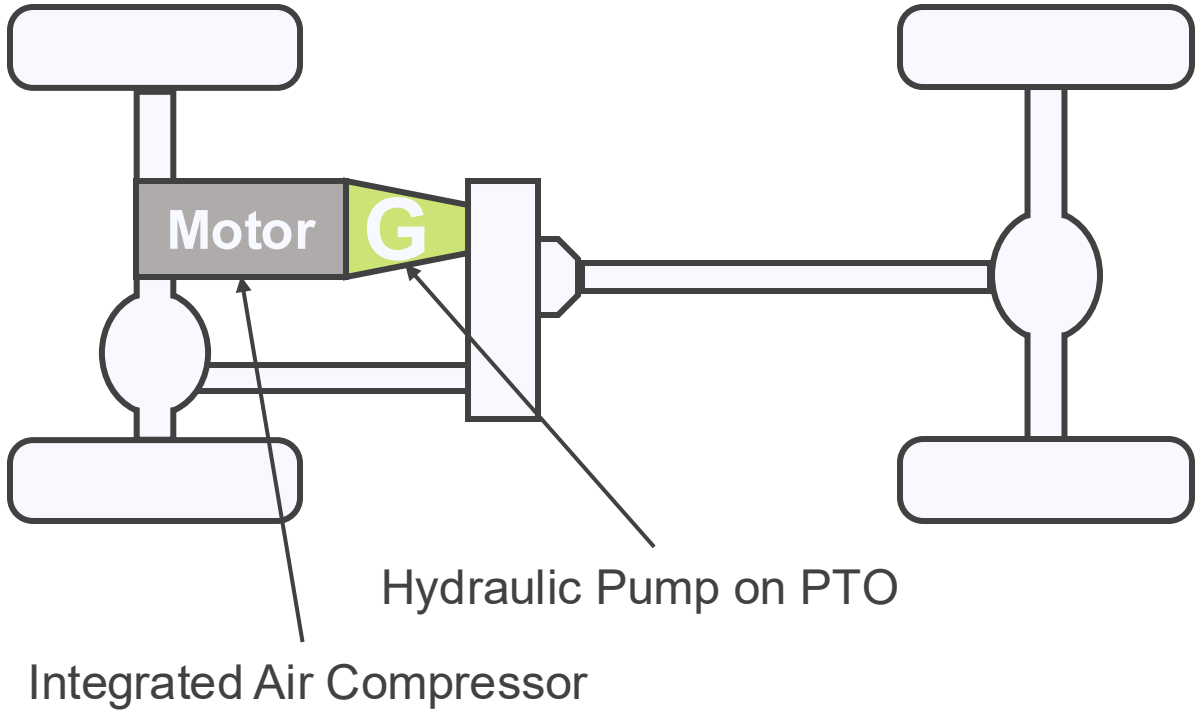
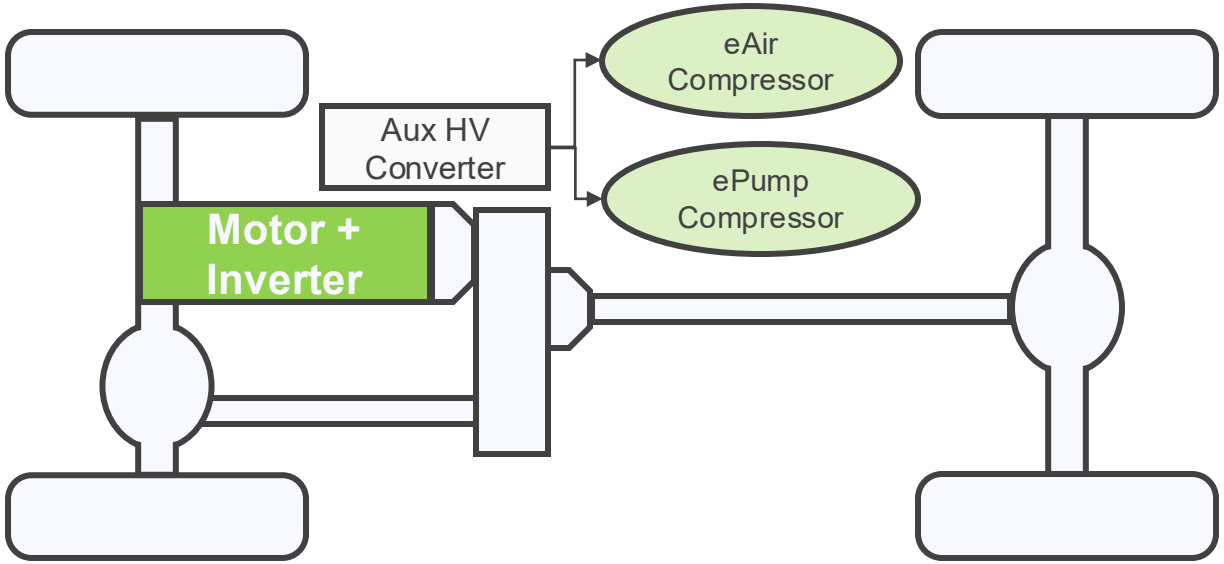
First Driveline Architecture



NEW EFFICIENT DRIVELINE ARCHITECTURE



Simplified and more efficient Powertrain Architecture:

- **NO GEARBOX REQUIRED**
- **E-driven AIR COMPRESSOR and pumps**
- **NO PTO REQUIRED FOR THE HYDRAULIC PUMP**

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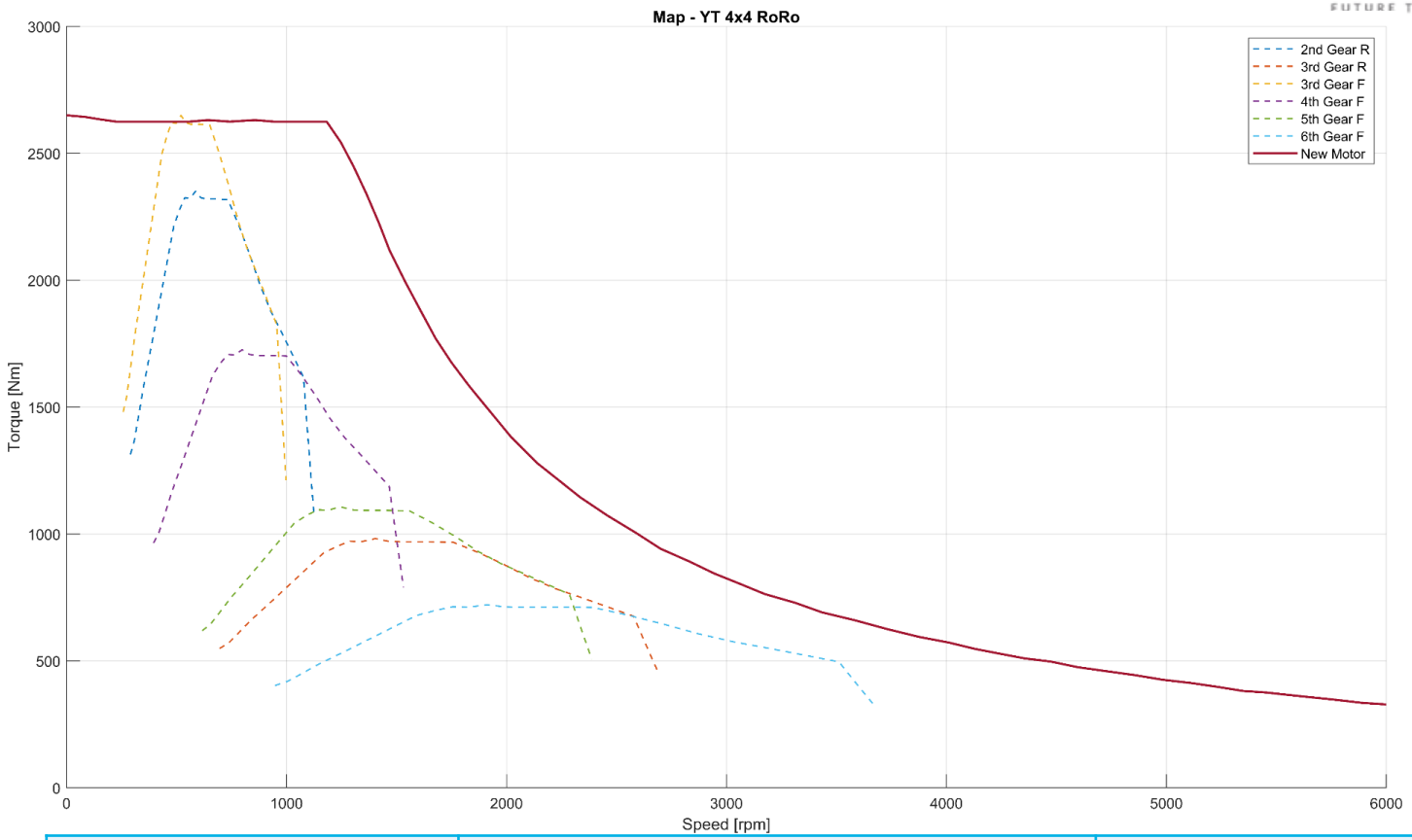
Driveline Redesign

New Hydrogen Hybrid Powertrain Map fully covers the original torque–speed envelope

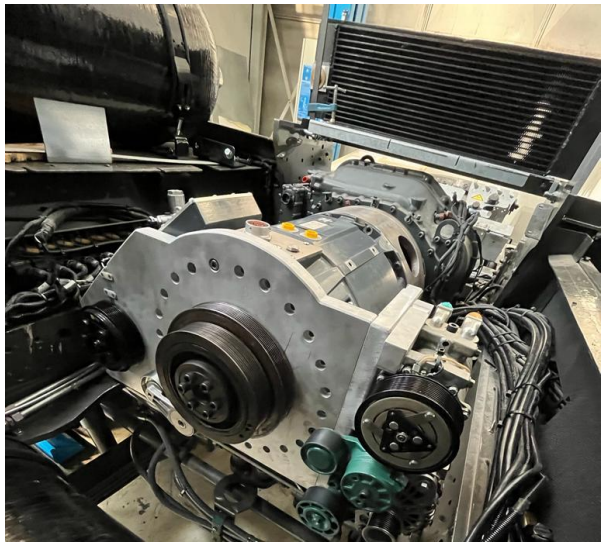
Removal of gearbox and PTO strongly reduces mechanical losses
Electrified auxiliaries operate **only when needed**, increasing overall efficiency
Hydrogen-to-wheel efficiency improved from **~43% to ~50%**
Hydrogen consumption reduced by **~30%**
Regenerative braking capability tripled

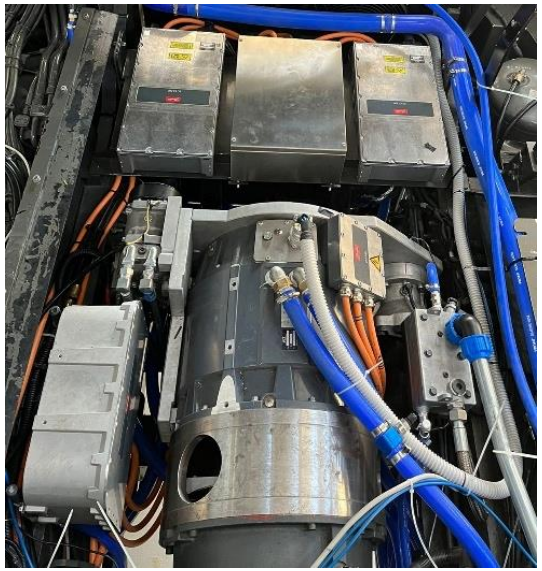


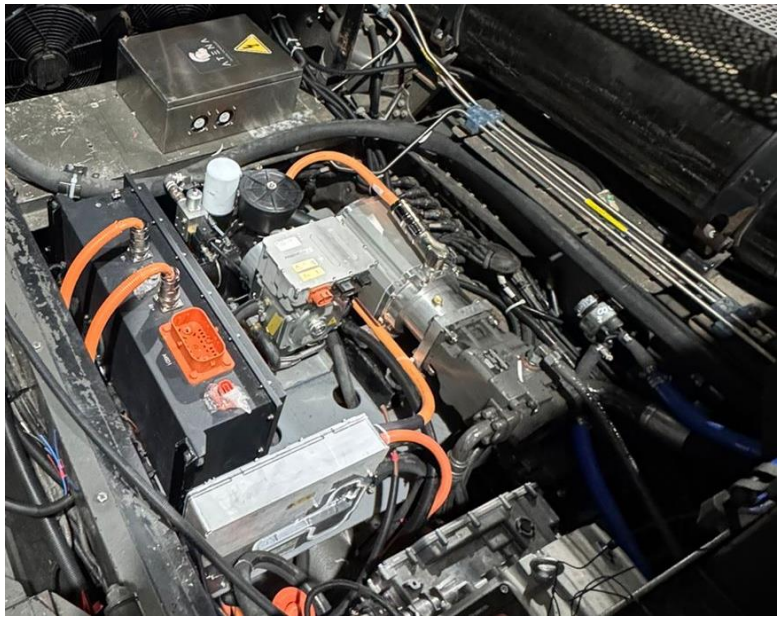
Hydrogen consumption	**≈2.09 kg H_2/h → ≈12 kg** per 6 h cycle	**≈1.4 kg H_2/h → ≈8.4 kg** per 6 h cycle

DRAMMATICAL HYDROGEN CONSUMPTION REDUCTION

Implementation of ATENA's New Efficient Driveline







Before – mechanical auxiliaries
Conventional layout with engine-driven pump, gearbox and belt-coupled two-stage compressor: auxiliaries always spinning with the motor, adding parasitic losses and limiting control of regeneration.

After – electrified auxiliaries
Electric coolant pump, no gearbox and a two-stage screw compressor driven by an e-motor: auxiliaries run only when needed, improving regenerative braking capability and enabling an estimated 5–8% reduction in overall energy/fuel consumption on typical duty cycles.

Contents

H2 PORTS

Total Cost of Ownership Analysis
4×4 Yard Truck

The goal is to assess the total cost of ownership of a 4×4 Yard Truck in port operations.

Powertrain alternatives analyzed: Diesel, Battery Electric Vehicle, Hydrogen.

Scenarios considered: Various energy sources and pricing assumptions (renewable and non-renewable).

Costs included: CAPEX (purchase and investment costs)
OPEX (fuel/energy, maintenance, insurance)

Regulatory costs: ETS2

Additional considerations: Environmental impacts of diesel emission.

Final Goal: Provide a comprehensive assessment to support cost-efficient and sustainable decision-making.

Total Cost of Ownership Assessment 4x4 Yard Truck

Parameter	Value & Unit
Average mechanical power	38 kW
Engine Max Power	185 kW
Operating hours per shift	5 h
Shifts per day	2
Annual Working Hours (tOt)	1632 h
Annual Traction Hours (trC)	1469 h
Usage Rate	90 %
ICE power consumption	10,57 l/h
BEV power consumption	29,4 kW
FCEV power consumption	1,60 kg/h

Total Cost of Ownership Over Lifetime (6yr)

Type of Vehicle	ICE		BEV**		FCEV	
CAPEX	195 k€		570 k€		340 k€	
Range	*min*	*max*	*min*	*max*	*min*	*max*
Fuel Cost	0,98 €	1,57 €	0,19 €	0,22 €	1,60 €	4,70 €
OPEX	160K€	229K€	100K€	110K€	70K€	126K€
ETS (6 yr)	28K€	28K€				
TCO	**374K€**	**414K€**	**613 K€**	**623 K€**	**342K€**	**398K€**

BEV Capex consider to use 1,5 tractor per shift

The TCO results clearly show that hydrogen-powered tractors are already a cost-competitive solution today!

ATENA New Challenge: Safe & Efficient 4x2 Port Tractor for Container Terminal

ATENA, in collaboration with DUFERCO, is developing a new 4×2 port tractor featuring the same improvements in efficiency, drivability and maintenance as the 4×4 RoRo tractor.

New focus: port safety

- ATENA's experience on the 4×4 RoRo tractor is now used to **redesign safety around the driver and the yard**.
- **Automatic brake actuation** based on front and rear **LiDAR and radar sensors**.
- Up to **14 perimeter sensors** to monitor **all blind spots**, detecting people, vehicles and obstacles around the machine.

ATENA's new hydrogen tractors will combine high-efficiency drivetrains with next-generation safety systems to enable safe and zero-emission port operations.

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Conclusions

Piloting results from H2PORTS demonstrated very good performance in zero-emission operation, and could be a valid solution for decarbonizing port operations and reduce pollutant emissions

What needs to be done to convince users to invest in hydrogen technologies?

- Move beyond a CAPEX-only perspective: upfront cost does not represent real value.
- Evaluate the full TCO (Total Cost of Ownership): stable operating costs, reduced maintenance, higher efficiency.

Hydrogen is not a future investment—it is a cost-effective choice today.

Assess competitiveness through TCO, not CAPEX.

H2 PORTS

Funded by:

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