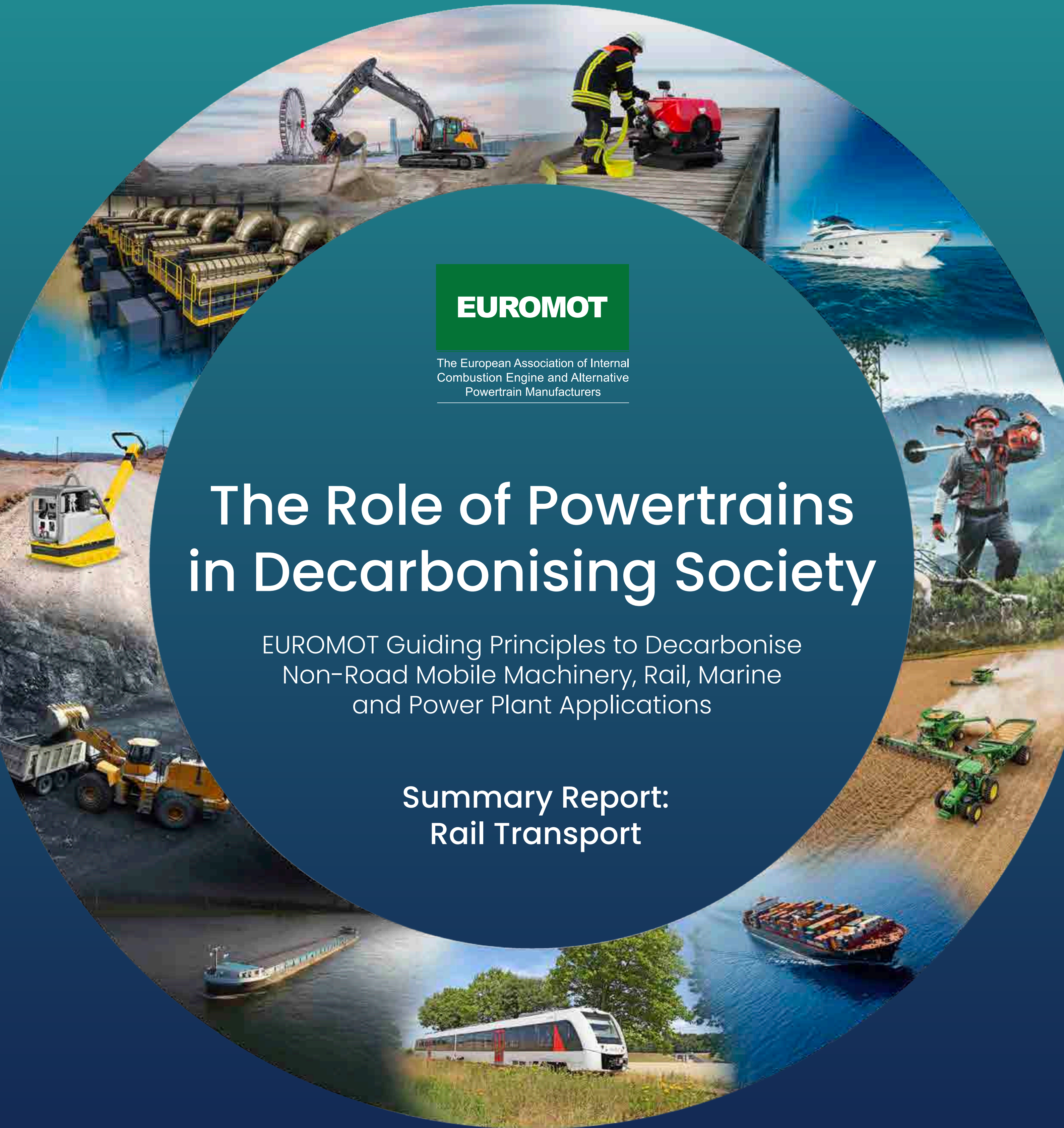

EUROMOT

The European Association of Internal Combustion Engine and Alternative Powertrain Manufacturers

The Role of Powertrains in Decarbonising Society

EUROMOT Guiding Principles to Decarbonise Non-Road Mobile Machinery, Rail, Marine and Power Plant Applications

Summary Report: Rail Transport

March 2026

The Role of Powertrains in Decarbonising Society

EUROMOT Guiding Principles to Decarbonise Rail Transport

This document is one of a portfolio of decarbonisation reports produced by EUROMOT, which are:

1. EUROMOT Guiding Principles
2. Executive Summary
3. Full Report
4. Sector-specific Summary Reports:
   - Non-road Mobile Machinery
   - Forestry, Lawn and Utility Machines
   - Marine Inland Waterways Transport
   - Marine Seagoing
   - Marine Recreational Craft
   - Rail Transport
   - Stationary Power Plants

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About EUROMOT

EUROMOT, the European Association of Internal Combustion Engine and Alternative Powertrain Manufacturers, represents the key manufacturers of internal combustion engines and alternative powertrains installed in Construction, Agriculture and Industrial; Forestry, Lawn and Utility; Marine; Rail; and Stationary power plant applications that are operating in Europe and globally.

Founded in 1991, we provide a recognised hub of expertise for businesses, authorities, regulators, and public stakeholders worldwide. In partnership with major sector associations and institutions, it is our mission to advocate better regulation, and to foster innovation that supports our sustainability and industry objectives.

Delivering reliable power for society at high energy conversion efficiency with low emissions remains a key objective of EUROMOT member companies. EUROMOT asserts internal combustion engines and alternative powertrains are a key enabler to address decarbonisation across multiple industry sectors. This can be achieved by continuing to advance the development of flexible highly efficient energy conversion systems capable of operating on various low and net zero greenhouse gas emissions energy carriers.

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EUROMOT Guiding Principles to Decarbonise Rail Transport

The sector encompasses trains varying from high speed main line passenger units and heavy freight carriers to smaller branch line trains as well as shunting and maintenance locomotives.

Core Principles:

Technology neutrality:

- Facilitate a diversified energy mix and do not be tempted to force a single technology.
- Base overall GHG reduction objectives in each industry sector on Life Cycle Analysis (LCA) considering different end uses and do not focus solely on emissions at point of use.

Predictable global approach:

- Align activities and levels of ambition at international level recognising internal combustion engines, alternative powertrains and the applications in which they are installed are developed for global markets.

Recognition of the needs of end users:

- Ensure the continued ability to deliver dependable power to perform the intended task wherever it is needed.
- Ensure the availability of new low or net zero greenhouse gas (GHG) energy carriers at competitive costs.
- Facilitate the availability and use of low and net zero GHG energy carriers suitable for existing in-use products.

Key Factors that Determine Decarbonisation Pathways

Europe's Rail Transport network is already widely electrified with electric trains comprising 54% of the network and 80% of passenger kilometres travelled. The remaining part of the network is uneconomical to electrify and alternative decarbonisation pathways are required.

Trains running on non-electric routes or across a mix of electric and non-electric lines are currently diesel powered. Low carbon and renewable fuels, and bi-mode powertrains with the versatility to run on electric and non-electric tracks could help decarbonise this format of rail network.

Alternative solutions for Rail must fulfil the requirement for interoperability, cost efficiency, range, reliability, and safety across a mixture of track types, trains and diverse use cases from shunting to freight transport.

Passenger and freight trains have power units of **1 MW to 20 MW**. Shunters and maintenance units from 200kW to 1 MW.

Trains can run for **short periods** on branch lines, whilst intercity passenger and freight journeys can last **many hours or even days**.

Alternative propulsion systems must be of a **size and weight** that enables a train **to perform** the journeys for which it is intended.

High speed passenger trains can consume up to **100 MWh per day.**

Trains run through **urban, rural and remote undeveloped areas**.

Electrified tracks have electricity delivered via a **catenary system**. Other trains have to carry sufficient fuel or energy for a full journey. **Refuelling times** may be important for timetable efficiency.

Evaluation of these low emissions technologies also needs to factor in other key criteria including:

Cost-competitiveness to drive market penetration ane ensure rail transport is competitive with road and air.

Availability of the required energy carrier **production, distribution, and storage** networks across all operating environments.

Powertrain Technologies

The powertrain technologies, that are available to support decarbonisation and their attributes, are shown here.

Internal combustion engines

Efficiency
Highly operationally efficient as the most compact powertrain technology with readily available, energy-dense fuel sources and fast refuelling times.

Up to 55% energy conversion efficiency.

Emissions
Potential for decarbonisation when using reduced carbon, low carbon, and renewable fuels (including non carbon fuels such as hydrogen and ammonia). Lower embedded GHG emissions* than fuel cells or electric powertrain technologies.

Technological maturity
Proven technology across all industrial applications and use cases.

Security, cost, and availability
Secure, domestic supply chains and readily available material sources except some precious materials used in aftertreatment.

The technologies may be combined to improve system attributes - Hybrids

*"Embedded GHG emissions" refer to the greenhouse gas emissions associated with the production, transportation, and disposal of a product or material, but not necessarily emitted during its use.

Hydrogen fuel cells with batteries and electric motors

Efficiency
Similar refuelling times to ICEs but hydrogen tanks need 4-8x onboard storage space of diesel tanks. Can achieve up to 60% energy conversion efficiency for some applications (efficiencies may reduce with use).

Emissions
Zero air quality or GHG emissions at the point of use. Moderate embedded GHG emissions, usually higher than ICEs and lower than battery electric.

Technological maturity
Technology already in use in non-road applications including cars and forklift trucks, but still in development for Rail Transport.

Security, cost, and availability
Supply chain costs and risks around some components. Fuel cell systems for dynamic applications require a hybrid configuration with batteries.

Electric Motors - Continuous electric supply or with battery storage

Efficiency
The highest energy conversion efficiency technology giving **75-90% efficiency.**

The overall operational efficiency can be reduced by downtime due to charging, and the extra storage space needed for large onboard batteries.

Emissions
Zero GHG emissions at the point of use. Usually higher embedded GHG emissions than ICEs or fuel cells.

Technological maturity
Proven technology across some industrial applications.

Security, cost, and availability
Supply chain security risks, high costs and projected shortages for raw materials and components in batteries and motors.

Energy Carriers

Energy carriers are predominantly fuels or electricity. Their carbon intensity depends on their provenance.

Fuels

Fossil fuels

Derived from ancient organic matter, fossil fuels like coal, oil, and natural gas are burned for energy. Their combustion releases greenhouse gases, contributing to global warming. Unlike renewable fuels, fossil fuels are finite and environmentally impactful.

Reduced carbon fuels

Fuels where the carbon footprint (CF) is lower than the fossil fuels they replace, for example natural gas replacing diesel/fuel oil; B20 biodiesel; E50 gasoline.

Low carbon fuels

Fuels where the CF is >70% lower than their fossil equivalent.

Non carbon fuels

Fuels that do not contain carbon such as hydrogen and ammonia (not necessarily renewable).

Renewable fuels

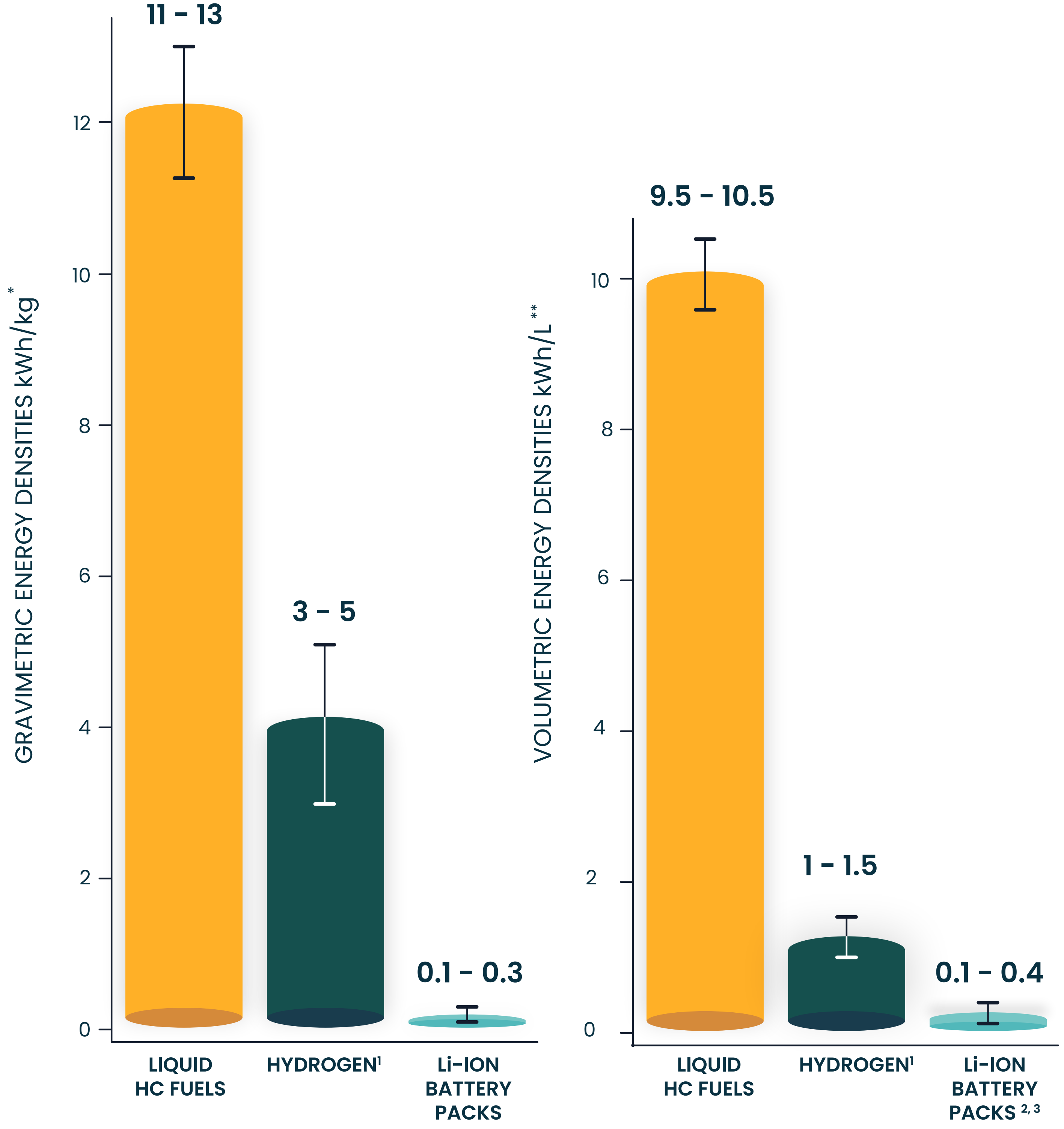
Fuels of biological or non-biological origin where the stored energy comes from renewable sources; either solar energy via photosynthesis or from renewable electricity. The EU Renewable Energy Directives (REDs) require the Carbon Footprint (CF) of renewable fuels to be >70% lower than their fossil equivalent.

Electricity

Generated from

- Fossil Fuels: coal, oil
- Natural Gas (RCF)
- Low cabon fuels
- Renewable fuels
- Non carbon fuels
- Renewable energy: solar, wind, hydro

Comparing energy densities for compressed hydrogen, liquid hydrocarbon (HC) fuels and lithium-ion (li-ion) batteries.



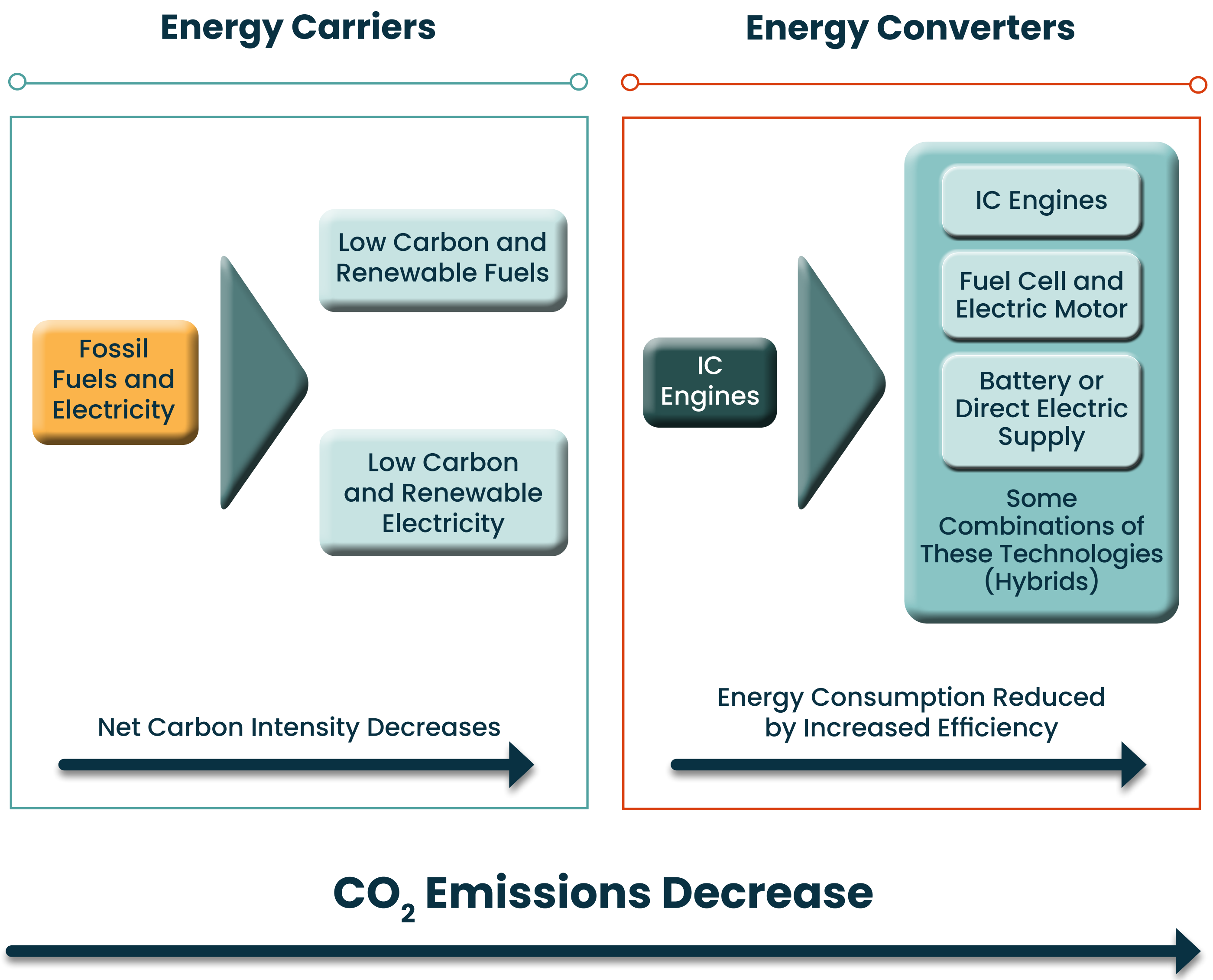
*Energy carriers with lower gravimetric energy density are heavier, which affects their feasibility for applications where weight is at a premium.

**Energy carriers with lower volumetric energy density need more onboard storage space, affecting their use in applications where space is at a premium.

[1]Compressed to 700 bar including the tank.
[2]STIHL. (2023). AP 300 S Battery.
[3]Husqvarna. (2025). Akku B330X.

Decarbonisation Journey

How sector decarbonisation will result by combining efficient energy converters with an increasing panel of low carbon and renewable energy.



Use Case Examples

The following section presents a selection of examples that demonstrate the fundamental principles of decarbonisation.

These examples are not exhaustive, and do not represent the only pathways to decarbonisation for each type of machine.

Each of these machines may require different powertrain technologies offering pathways to decarbonisation for different use cases.

The energy consumption numbers in the following examples include the efficiency of the ICE, i.e. they are comparable to the output of the electric motor of electric machines.

Important Criteria for Assessing Decarbonisation Pathways

Key Criteria*	Use Case Evaluation		
Energy use	Low	Is a large amount of energy used for the example task?	High
Work intensity	Low	Is the average power the machine is working at a high percentage of its maximum output power?	High
Type of use	Sporadic	Is the machine running for a high proportion of the task duration, or for a small portion?	Continuous
Availability of electricity on site	Available	Is electricity at a usable voltage and power available at the site of use of the machine?	Not available
Predictability of deployment	Pre-planned	Can the task be planned well in advance, or is it required to act urgently depending on circumstances?	Un-planned
Location of site	Adjacent to infrastructure	Is the machine being used in an area with infrastructure and service availability or any area without these?	Remote from infrastructure
Time on site	Extended	Is the time a machine is on site short i.e. days or weeks, or long i.e. months or years?	Short
Required machine mobility	Low	Does the machine used for the task move around the site (>100 m) or does it stay in one position?	High
Minimise refuelling/ recharging	Infrequent	Is it important to complete task without significant downtime for refuelling/recharging	Fast

*Terms used to explain the use case evaluations found in the following examples.

Rail Transport

Example 1: Passenger Travel on Electrified Mainline Routes

Use description:

People commuting or travelling for business or leisure on mainline rail routes. There is a comprehensive network of major rail lines throughout Europe. Individual trains typically run for 16-20 hours a day.

Vehicle employed:

Electric train with direct electric supply and 32 **500 kW** electric motors (**16 MW** total). High load factor when running near maximum speed.

Decarbonisation pathways:

Progressive decarbonisation of the electricity supply.

Evaluation Criteria	Use Case Evaluation	
Energy use	Low	High
Work intensity	Low	High
Type of use	Sporadic	Continuous
Availability of electricity on site	Available	Not available
Predictability of deployment	Pre-planned	Un-planned
Minimise refuelling/ recharging	Infrequent	Fast

Rail Transport

Example 2: Freight Transport between Industrial and Commercial Centres on a non-electrified Network

Use description:

Transporting large consignments of diverse goods between industrial centres and logistics hubs using some mainline and some freight specific tracks, which are not usually electrified. Load factors are high when the train is fully laden. Train speeds are lower than passenger services and journeys take many hours (or days). A large train could consume 15 MWh of energy on a 10-hour journey.

Vehicle employed:

Train consisting of high-power locomotive(s) and multiple freight carriages. Up to **750 metres** in length and weighs circa **4,000 tonnes** in Europe. Locomotives use Internal Combustion Engines (ICE) up to circa **3,000 kW.**

Decarbonisation pathways:

As electrification of the complete track network is not regarded as economically feasible, continuing use of ICEs is expected. Decarbonisation is achieved through use of low carbon fuels, and then renewable fuels.

Evaluation Criteria	Use Case Evaluation	
Energy use	Low	High
Work intensity	Low	High
Type of use	Sporadic	Continuous
Availability of electricity on site	Available	Not available
Predictability of deployment	Pre-planned	Un-planned
Minimise refuelling/ recharging	Infrequent	Fast

Rail Transport

Example 3: Regional Passenger Travel

Use description:

People travelling for business or leisure between towns or cities using main and branch lines that are electrified in parts. Journeys are typically 1 to 3 hours and trains may be lightly or more heavily occupied.

Vehicle employed:

Railcars with electric or ICE propulsion. Bi-mode vehicles with electric motors can run on direct electricity supply via catenary, or from diesel generators when using non-electrified tracks. Such trains use multiple ICE engines of typically **300–800 kW**. Hybrid ICE/battery electric propulsion can provide efficiency benefits from recuperation and can run in pure electric mode for limited periods such as when in stations. A direct electric propulsion system, with battery backup, is feasible where non-electrified sections of track are short. The diesel generator can be replaced with a fuel cell and battery.

Decarbonisation pathways:

ICEs can run on low carbon, moving to renewable fuels. Direct electricity supply from the grid can be progressively decarbonised. Renewable hydrogen can be used with the ICE or fuel cell electric version.

Picture: 3D rendering

Evaluation Criteria	Use Case Evaluation	
Energy use	Low	High
Work intensity	Low	High
Type of use	Sporadic	Continuous
Availability of electricity on site	Available	Not available
Predictability of deployment	Pre-planned	Un-planned
Minimise refuelling/ recharging	Infrequent	Fast

Rail Transport

Example 4: Regional Freight Transport

Use description:

Transport of a variety of goods between regional distribution centres and industrial users. A mixture of electrified and non-electrified tracks is used.

Vehicle employed:

Medium-sized diesel locomotive of **1,000–2,500 kW.** Bi-Mode locomotives (ICE/Electric) can switch to electric operation on electrified lines. Lines with shorter unelectrified sections could also use (battery/direct electric) Bi-Mode systems.

Decarbonisation pathways:

ICEs can run on low carbon, moving to renewable fuels. Direct electricity supply from the grid can be progressively decarbonised.

Evaluation Criteria	Use Case Evaluation		
Energy use	Low	(slider at mid-point)	High
Work intensity	Low	(slider at mid-point)	High
Type of use	Sporadic	(slider near right)	Continuous
Availability of electricity on site	Available	(slider at mid-point)	Not available
Predictability of deployment	Pre-planned	(slider at far left)	Un-planned
Minimise refuelling/recharging	Infrequent	(slider right of centre)	Fast

Rail Transport

Example 5: Shunting Rolling Stock in Depots and Sidings

Use description:

Moving of rolling stock in depots and sidings, travelling short distances at low speeds. High tractive effort is required. Shunters will often work in or from a designated depot, and energy consumption for each task is usually quite low. The power of smaller shunters ranges from 200-500 kW while larger ones reach up to 1,800 kW.

Vehicle employed:

25 tonne shunting locomotive.
200 kW motors and **250 kWh** battery.

Decarbonisation pathways:

Battery electric powertrains use reduced carbon electricity supply for charging. Diesel-Electric and hybrid powertrains, used for higher power and greater range, can be decarbonised by using low carbon or renewable fuels.

Evaluation Criteria	Use Case Evaluation	
Energy use	Low	High
Work intensity	Low	High
Type of use	Sporadic	Continuous
Availability of electricity on site	Available	Not available
Predictability of deployment	Pre-planned	Un-planned
Minimise refuelling/ recharging	Infrequent	Fast

Conclusion

Rail transport has made significant progress decarbonising its energy use and is already a leading transport sector in this regard. The industry has developed and implemented widespread electrification alongside low carbon fuels where ICEs are still used.

Much of the European rail network is already supplied by electricity directly through catenary structures. Some less-used lines do not warrant the high cost of electric infrastructure and require other decarbonisation solutions.

The full range of powertrain technologies is expected to be required, depending on required use patterns and the availability of low carbon and renewable energy carriers.

Recommendations

Manufacturers are developing powertrains that support decarbonisation of all the sectors of the rail network.. For successful deployment of these technologies, policy and regulation need to be technology neutral, recognising the need for the full array of decarbonisation pathways, and assessing them on life cycle basis (LCA method).

Policy also needs to enable and support the the supply of low carbon and renewable fuels. This includes the production of drop in fuels for use in existing trains.

Appendix: Definitions

Life Cycle Analysis (LCA) is a method of calculating the total CO_2e emissions from a product, including other emissions such as nitrous oxide (N_2O) and methane (CH_4), during its full lifecycle. That is throughout manufacture, use and disposal.

Well to Wheel, (or Well to Wake for marine) (WtW), or Well to X (WtX) emissions is the total (net) emissions generated when a fuel or energy carrier is created (such as when it is extracted from the ground or grown as a biological feedstock), when its energy has been converted in a machine and its end products emitted (e.g. CO_2 and water from burning a hydrocarbon fuel).

GHG Emissions CO_2 is the predominant Greenhouse Gas for this sector, but this also encompasses other GHGs such as nitrous oxide and methane, normally defined as CO_2 equivalent (CO_2e) when using the GWP100 definition (the global warming potential of a specific greenhouse gas over 100 years).

Energy Carriers are fuels and electricity (including batteries) containing stored energy that can be converted to other forms of energy which can then be used to power machines and power plants.

Energy Converters are the devices that convert energy from stored chemical energy (fuels) or electricity to mechanical energy – generally engines or motors (such as internal combustion engines, electric motors, hydrogen fuel cells combined with electric motors, hydraulic pneumatic motors, and hybrid systems).

Conversion Efficiency is the energy out of a converter divided by the energy input. For example, the mechanical energy at the flywheel, divided by the stored energy available in the fuel used.

Operational Efficiency is a measure of the work a powertrain application can do compared to a theoretical maximum or to the incumbent powertrain's performance. For example, operational efficiency is reduced if a proposed powertrain reduces the payload of a goods carrying vehicle, or if the use time available is reduced by increased refuelling times.

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Disclaimer

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