COMMITTEE FOR EUROPEAN
CONSTRUCTION EQUIPMENT

POSITION PAPER

The role of construction equipment in decarbonising Europe

APRIL 2021

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Introduction

The construction equipment sector in Europe counts around 1,200 companies that employ about 300,000 people directly and indirectly. Their annual revenues amount to € 40 billion. Construction equipment manufacturing is an integral part of Europe's engineering industries with a positive trade balance and overall global competitiveness.

The sector's durable and innovative machinery are working tools to help build houses, offices, factories, roads, railways and bridges that serve citizens across the globe. Indeed, while vehicles transport people or goods from A to B, construction machinery is used for many different tasks. These tasks are performed in a professional environment. Equipment is sold in business-to-business transactions as elements of the overall productivity gains in the construction/infrastructure projects. In addition, certain construction machinery are used by other industries, such as mining and quarrying, waste management, forestry and farming, and can be essential tools in responding to natural disasters.

Another exceptional feature of the construction machinery industry is its heterogeneity, a distinguishing factor from on-road transport. Indeed, construction machinery fleets usually comprise of hundreds of highly-customised models manufactured in small volumes by several medium-sized companies specialised on certain machinery for a specific jobsite.

Sustainability and the Green Deal in construction activities

Following the Paris Agreement[1] on 11th December 2019, the European Commission presented the European Green Deal[2], a long term strategy to establish Europe as the world's first climate neutral continent. This goal will be achieved by reducing net greenhouse gas (GHG) emissions to zero by 2050, with intermediate milestones leading up to that. For the construction sector, the largest contributor to GHG emissions is CO_2.

Within the European Green Deal, buildings are singled out as a key element in terms of challenges and opportunities. It is estimated that through its life-cycle the built environment accounts for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU. With energy-inefficient buildings in Europe and building renovation rate of 1% per year, the EU aims at tackling the issue by launching a Renovation Wave targeting the EU housing stock.

Estimating that 80% of today's buildings will still be in use in 2050[3], it seems clear that the most relevant sustainability gain lies in the carbon footprint and energy consumption of buildings in their lifetime.

However, there are also many opportunities for decarbonisation in construction activity. These include: project design, materials selected, organisation and operation of the construction site as well as the machinery used.

[1] https://unfccc.int/sites/default/files/english_paris_agreement.pdf
[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[3] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

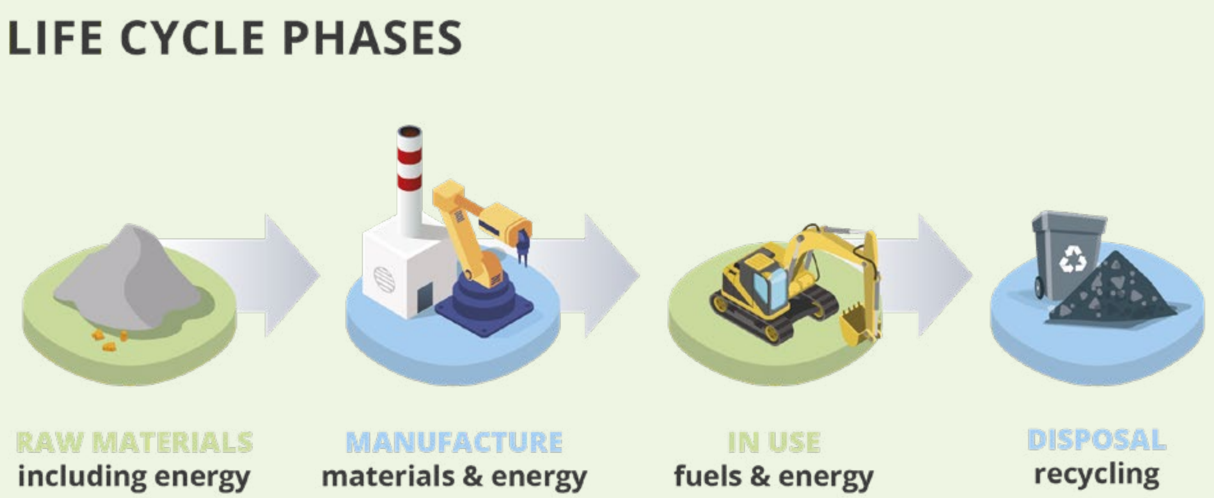
The contribution of construction equipment

The CO_2 emissions from using the machinery is only a fraction of the overall CO_2 emissions from the construction activity. Indeed, it is estimated that construction equipment contributes to only 0.5%[4] of the total greenhouse gas emissions in the EU-27.

CECE supports the objectives of the European Green Deal and the decarbonisation of Europe by 2050. Indeed, pushing for ever more sustainable development and growth has become a global task and major challenge for the years to come. Boasting an impressive track record in achieving energy efficiency gains in the past 50 years, the construction machinery industries continue to be committed to decarbonisation.

Indeed, European construction machinery manufacturers are in a leading position in the development of machinery using low or net-zero CO_2 energy carriers. Fuel is one of the highest input costs our sector faces and therefore there is constant pressure on machinery manufacturers to achieve efficiency improvements which result in a reduction in fuel consumption and consequent reduction in CO_2 emissions.

To understand the potential of decarbonisation offered by modern machinery, it is important to move from a solely machine-focussed approach to a more holistic view. Historically, the majority of CO_2 emissions for construction machinery came from the operational phase. However, in future with the introduction of new technologies, this might not be the case.



For a complete understanding of the CO_2 emissions from a machine, it is necessary to consider the whole life cycle of construction machinery. This means how the machine is designed including the selection of the energy carrier and how it is produced, used and disposed. This is called a full Life Cycle Analysis (LCA) and generates a Carbon Footprint (CF).

Aside from the production and the end of life disposal of the machine itself, the complexity of this holistic approach can be understood as four interdependent pillars: machine efficiency, process efficiency, operation efficiency, and alternative energy sources. Each has its own related costs and efficiency potential, while all the pillars deliver their full potential only when taken in conjunction with the others. By consequence, it is critical to evaluate the decarbonisation as a whole and not to separately evaluate the decarbonisation from each individual pillar.

[4] https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases-7/assessment
2007 Technical Review of the NRMM Directive 1997/68/EC as amended by Directives 2002/88/EC and 2004/26/EC

Figure 1: Interdependent pillars to decarbonisation

Machine efficiency (1st pillar) relates to the integration of optimised components into the machinery.

Process efficiency (2nd pillar) is achieved by an optimal workflow of the tasks on the jobsite. It includes the choice of the most suitable machine or the combination of connected machines.

Operation efficiency (3rd pillar) relies on trained operators and/or autonomous systems for an intelligent and productive use of the machine. Effective management and smooth teamwork require skilled workforce, a fundamental factor for this pillar to achieve its full potential.

The 4th pillar introduces the use of alternative energy sources such as bio- or synthetic fuels, electricity, hydrogen, ammonia etc. all of which would need to be produced by low or net-zero CO_2 processes. These deliver energy, while contributing less net CO_2. This is further explained in the next section of this document.

Process and operation efficiency may be positively impacted by the ever increasing digitalisation of construction machinery. Indeed, state-of-the-art construction machines have reached high levels of intelligence in areas like automation, precision application and connectivity. Thanks to the use of advanced technologies like GPS, smart sensors and actuators, these machines are able to achieve ever higher levels of accuracy in the working process. The integration of more and more intelligent machines with precise technologies results in:

- optimised machine operations and machine use such as reduced working hours, combining operations and limiting the number of tasks;
- making better use of the in-service machine fleet thanks to connectivity between vehicles and coordination within the construction site;
- improvement of the planning of different operations to be carried out during the process.

Energy carriers offering low or net-zero CO_2 solutions

The energy carrier is the substance or device that stores energy in a form that is readily converted for use in many activities by society. Energy may come from the sun, either momentarily as incident heat and light, or as stored energy from past photosynthesis in the form of coal, oil and natural gas (methane). It may also come from harnessing the winds, waves or tides, or be released by nuclear reaction.

In construction activity 'mechanical' energy is required to move earth, raw and finished materials - excavating, crushing, screening, moving, lifting, compressing etc. Construction machinery converts stored energy (stored chemical energy in fuels or stored electrical energy in batteries) into mechanical energy. The energy converters are predominantly motors - either internal combustion engines (ICE) or electrical.

We can classify the existing and potential energy carriers for the construction machinery sector as:

- Hydrocarbon fuels - that are divided on:
  - Conventional fossil fuels *(e.g. diesel, petrol, methane)*
  - Bio and synthetic fuels *(e.g. biodiesel, ethanol, paraffinic fuels, biomethane, methanol)*
- Non-hydrocarbon fuels *(e.g. hydrogen and ammonia)*
- Electricity *(e.g. stored in batteries or provided via an external cable)*

Note that, when comparing energy carriers, their contribution for decarbonisation should be assessed on the basis of a full LCA (e.g considering production, distribution and storage).

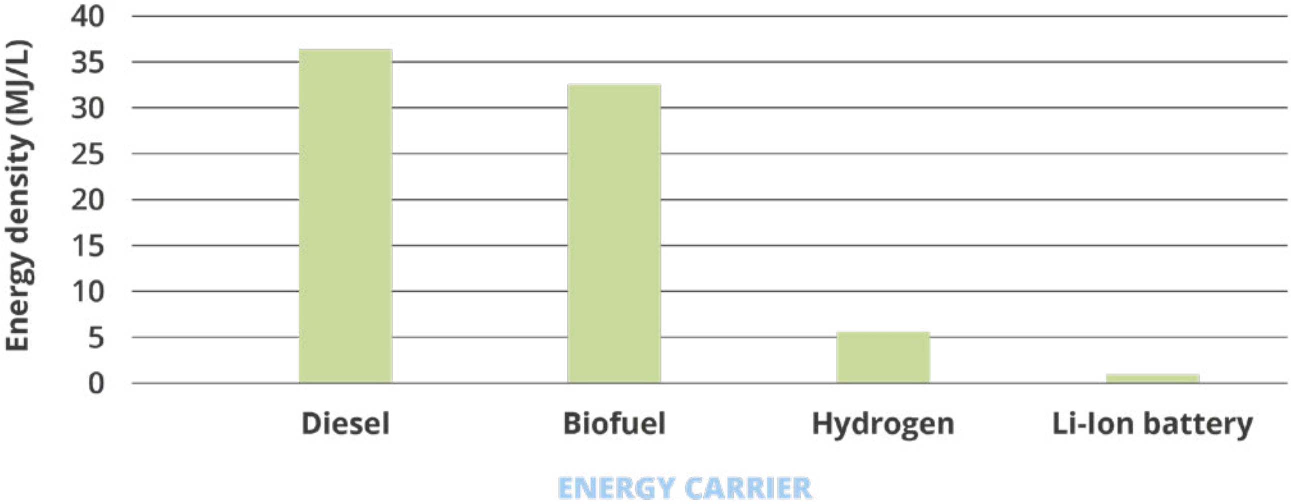
An important measure of an energy carrier for mobile machinery is its energy density - both by volume and by mass - as this factor is critical for design and usage feasibility and the dimension of the storage system. As the energy density reduces, the size of the energy storage on the machine must increase to enable the machine to retain the same ability to work, or alternatively, the duration of use of the machine must decrease.

The Carbon Footprint (CF) of the energy carriers depends on their provenance (origin of the material, extraction, processing, storage, distribution, etc.) and each of these carriers can vary from net-zero to very high net carbon emissions.

For the energy carriers listed above, possible production pathways are:

- Electricity: low or net-zero CO_2 energy origin such as solar, wind and water.
- Hydrogen can be produced via water hydrolysis using low or net-zero energy or hydrocarbons with carbon capture[5] and ammonia can be produced from this hydrogen.
- Bio and synthetic fuels: produced from waste biomaterial or by synthesis using low or net-zero CO_2 electricity.

Figure 2: Energy density by energy carrier



Hydrogen at 700 bar pressure 5.6 MJ/L (K Moller, sciencedirect)
Lithium ion battery pack average density of 1.54 MJ/ L(J Quinn et al, Journal of Electrochemical Sciences vol. 165 no. 14)

[5] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A hydrogen strategy for a climate-neutral europe

Technologies that have the potential to deliver low or net-zero CO_2 machinery by 2050

There is potential to release carbon dioxide during the different phases of the life of a construction machine:

- At manufacture, including raw materials;
- During use;
- Upon disposal at end of life.

These phases all have to be included in a full LCA of the carbon emissions of a machine. If only one phase is taken into consideration, there is a risk that a chosen technology will move the carbon output to one of the other phases.

Considering the amount of energy used in order to perform the intended function during the life of the machine, the choice of energy carrier plays a key role for decarbonisation. The technologies that exist with the potential to deliver net-zero carbon emissions are:

1. **Internal Combustion Engine** (ICE) using synthetic or bio-fuels;
2. **Fuel Cell**, using hydrogen, plus battery and electric motor;
3. **Battery** plus electric motor;
4. **Off-board power supply** plus electric motor

These technologies can be combined into hybrid solutions. For example, powertrain technologies combining ICEs (point 1) and batteries (plus electric motors – point 3) may represent an opportunity to optimize both machine efficiency and work cycles. This can deliver net-zero carbon solutions when using synthetic or biofuels and can provide advantages compared with using each technology in isolation.

The table below shows the energy carriers, technologies and some of the challenges to deliver these technologies to the market.

Table 1: Technologies and challenges for energy carriers

ENERGY CARRIERS	PATHWAY TO ZERO	TECHNOLOGIES	CHALLENGES
 ELECTRICITY	Renewable (solar, wind, water, etc)	• Battery plus electric motor • Off-board power supply plus electric motor	• Battery size, cost, raw materials, manufacturing and recycling. • Changing availability and time • Connection to supply grid
 HYDROGEN & AMMONIA	Water hydrolysis using renewable energy from hydrocarbons with carbon capture	• Fuel cell plus electric motor • Internal combustion engine	• Supply infrastructure • High pressure on board storage • Cost and availability
 BIO & SYNTHETIC FUELS	• Waste biomaterial • Synthesis using renewable electricity	Internal combustion engine	• Efficiency of synthetic fuel production • Material availability for biofuels

Some of the challenges of technologies delivering zero emissions are:

Electricity

Battery size: The energy density of available batteries is much lower than hydrocarbon fuels.

For example, a current Li-on battery has twenty times lower energy density. This means for a construction machine (e.g a 20 tonnes excavator) that currently has a 500 litres fuel tank for the same operating capability, it would need 10m³ of space for an equivalent Lit-on battery which is not available and therefore the battery must be smaller and be recharged frequently.
This generally limits feasibility to smaller machines.

Charging availability and time: Construction equipment is often used in undeveloped areas, where electricity supply is not available. In order to run powerful machine directly or rapidly recharge batteries, high power electrical distribution and recharging infrastructure is needed. This issue is amplified by the fact that machines often work simultaneously in combination with each other, so will likely need to be recharged simultaneously at the end of the working day to be available to work together again during the next shift. The time required to recharge batteries also effects uptime therefore operational efficiency.

Unlike for road vehicles, it is not practical to take the machine to a vehicle recharging facility but instead the electricity must be provided at the jobsite where the machine is working. The feasibility of providing electricity at the jobsite will depend upon a number of factors including whether the machine will operate in the same jobsite for long periods.

Other issues include:

Critical raw materials (e.g. cobalt, lithium) are needed for batteries manufacturing. The availability of those raw materials may be limited by the expansion of battery use for other purpose such as light duty road transport.

Manufacturing – the CF can be significant and needs to be taken into account in any analysis[6],[7].

Recycling of advanced batteries requires sorting and discharge of cells and specialised extraction of the hazardous chemical components[8].

Hydrogen

Supply infrastructure: High volume, low cost net-zero carbon hydrogen is not currently available. Therefore, considerable production capacity needs to be installed and distribution networks need to be developed.

Low or net-zero carbon hydrogen can be produced by electrolysis which requires large quantity of low or net-zero CO_2 electricity or by steam reformation of hydrocarbons and carbon capture and storage. These processes need industrialisation development to be cost-effective and some energy will be lost at each energy transformation.

Unlike for road vehicles, it is not practical to take the machine to a vehicle recharging facility but instead the hydrogen must be provided at the jobsite where the machine is working.

Storage: Typically gaseous hydrogen tanks operate at 350-700 bar requiring additional safety measures and around eight times the storage volume for the same amount as stored energy as diesel. Alternatively, storing hydrogen as liquid is possible, in this case hydrogen tanks occupy four times the volume of a diesel tank for a certain amount of stored energy, however the main challenge is the low temperature required (around -253 C). Refuelling can be achieved in similar time to filling a diesel tank.

Ammonia

The issues related to liquid ammonia in terms of production and supply infrastructure are similar to those of hydrogen. The storage challenges are somewhat reduced compared with hydrogen because only three times the volume of a diesel tank is required for the same stored energy and the pressure requirement is about 10 bar, but a major challenge is its toxicity. This may limit opportunities for the use of ammonia in construction equipment.

Bio & synthetic fuels

Biofuels – To be sustainable, production would need to come from the use of biomass wastes and residues and/or cultivation of specific energy crops.

Synthetic fuels use large quantities of low or net-zero CO_2 electricity in their production and require carbon capture to be zero carbon. These processes need industrialisation development to be cost-effective.

Both bio and synthetic fuels offer the opportunity to decarbonise the existing in-use fleet as well as provide larger reductions in new machines as internal combustion engine technology continues to advance. This has the benefit of being achievable using existing fuel storage and fuel distribution infrastructure and therefore can be deployed rapidly.

[6] Directive 2006/66/EC and EU Commission proposal for a new EU Battery Regulation COM(2020) 798/3
[7] Analysis of the climate impact of lithium-ion batteries and how to measure it- Hans Eric Melin
[8] Directive 2006/66/EC and EU Commission proposal for a new EU Battery Regulation COM(2020) 798/3

Technology selection for construction machine applications and uses

The selection of which technologies are practical to implement is determined not only by the machinery type but also by the characteristics of the operating site and the purpose for which the machinery is used.

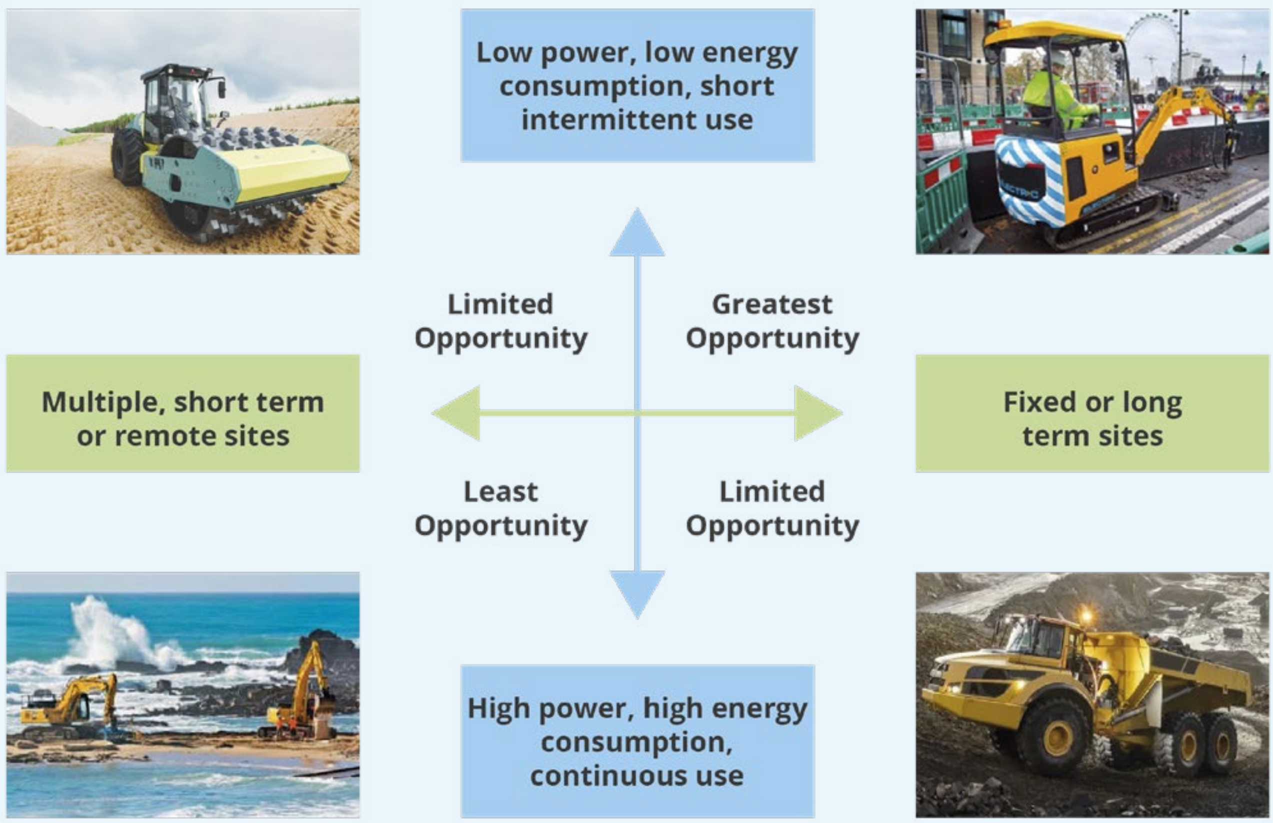
The most suitable technology that is capable of achieving net-zero carbon emissions will depend on the following criteria:

- The **use** of the machine: intermittent or continuous operation
- The **energy consumption** per hour/shift/day
- The **location** of the site: remote without installed energy carrier infrastructure or developed with installed energy carrier infrastructure

All three criteria must be considered to select the appropriate technology.

Focusing on battery electric and hydrogen energy carriers, the image below shows how use, energy consumption and location determine the suitability for construction activities.

Figure 3: Opportunity for battery electric and hydrogen energy carriers



Note: All applications and uses can be decarbonised with bio or synthetic fuels

Note:

Fixed Site: *A permanent work location employing machines for an extended period of time (years).*

Long term site: *A temporary work location where machines are deployed for an extended period of time (months) before moving to a different site.*

Short term site: *A temporary work location at which a machine spends a short period of time (hours or days) before moving to the next work location.*

Multiple sites: *A number of work locations to which a machine could be deployed & between which the machine may be moved back and forth after a period of time (hours or days).*

Remote sites: *A site a long distance from existing utility and transport infrastructure.*

Taking into account those constraints in the use of the electricity and hydrogen carriers it is necessary to consider the broader range of net-zero carbon energy carriers for use in construction activities. For example:

- A high energy consumption, continuous operation task in a remote area requires a high-density energy carrier, that can be efficiently delivered to the site. In this case the solution could be the use of an internal combustion engine with net-zero carbon high density fuel.
- A low energy consumption, intermittent operation task in an urban location could be best served by a battery electric machine using net-zero carbon generated electricity.
- A high energy consumption, continuous operation task on a confined site might need a internal combustion engine and net-zero carbon high density fuel on a remote location, but could use direct electric if the site was located close to a grid substation.
- A high or low energy consumption, continuous or intermittent operation task in multiple, short term or remote sites may still require an internal combustion engine with net-zero carbon high density fuel.

Taking a broader perspective, the following table 2 summarises, for a range of technologies the energy carrier and potential applications together with the advantages and challenges that influence the choice of construction equipment. For certain applications, especially those in-between the cases described above, hybrid solutions (e.g. ICE + battery electric) might represent an effective way to best compromise advantages and challenges of each single technology.

Table 2 : Technologies and suitable applications

TECHNOLOGY	LOW OR NET-ZERO CARBON ENERGY CARRIER	POTENTIAL APPLICATIONS	ADVANTAGES	CHALLENGES
Internal Combustion Engine (ICE)	Bio & synthetic liquid fuels	All with liquid fuels ICE	• Can be used in existing machine designs. • Drop-in fuels can be used for in-use machine fleet	• Limited supply and high cost of energy carrier • Eliminating remaining air quality emissions(1) at point of use
	Bio & synthetic gaseous fuels	All with ICE (conversion required for a liquid fuelled ICE)	• Can be used in existing machine designs. • Drop-in fuels can be used for in-use gaseous fuelled machine fleet	
	• Low or net-zero CO_2 • Hydrogen	Continuous use, larger machines used on fixed or long-term sites	• Fast refuelling • Continue use of ICE technology	• Cost of hydrogen • Hydrogen availability & distribution • Size and shape of tank • Site Safety measures
Off-board electric (cable or catenary + motor)	Electricity	Static/infrequently moved machines or those on a repetitive route, used on fixed or long-term sites	• Efficient use of energy • Low noise level • Zero air quality emissions at point of use	• Needs to be continuously connected • Significant operational restrictions
Battery Electric (battery+ motor)	Electricity	Low power demand, low energy consumption, short intermittent use e.g. smaller urban machines	• Efficient use of energy • Low noise level • Zero air quality emissions at point of use	• Cost of batteries • Charging time • Access to charging points • Battery size vs running time
ICE – Electric Hybrid (ICE, either cable, catenary or battery, and motor)	Bio & synthetic fuels & Electricity	Where necessary to operate the machine without the electricity supply	Greater operational flexibility compared to either ICE, battery electric or off-board electric alone	• Certain elements of the individual technology challenges remain depending on the configuration and application. • Space to fit both technologies on the machine
Fuel Cell – Electric (fuel cell, battery and motor)	Low or net-zero CO_2 hydrogen	Continuous use, larger machines used on fixed or long-term sites	• Fast refuelling • Low noise level • Zero air quality emissions at point of use	• Cost of fuel cell • Cost of hydrogen • Hydrogen availability & distribution • Size and shape of tank • Site Safety measure

(1): When using Internal Combustion Engines, care must be taken to minimise pollutants that are created during combustion. Latest technologies enable these to be reduced to insignificant levels.

Low or net-zero CO_2 enablers

Technologies exist that enable construction machinery to produce zero, or near zero CO_2 emissions though barriers remain to practical implementation. To enable the deployment of these technologies it is necessary to:

- **Produce low or net-zero CO_2 bio and synthetic fuels** in sufficient quantities for construction equipment use. This is relevant for ongoing use in high energy consumption/continuous operation on remote sites but can also play a significant role in the decarbonisation strategy of existing machinery fleets.
- **Produce hydrogen with low or net-zero CO_2 footprint** in sufficient quantities and install effective distribution network.
- Install sufficient **low or net-zero CO_2 electrical generating capacity** and high power distribution network to support charging of electric battery and the powering of direct electric machines.

To ensure a rapid deployment of low or net-zero CO_2 machines, these enablers need to be industrialised to give cost-effective solutions for construction activities.

Long-term commitment to deliver these enablers is necessary for manufacturers and end-users to invest in net-zero carbon construction machinery.

The path to market for any producer of low or net-zero CO_2 machines can be broadly divided into three phases, namely prototype pilot projects, productionisation and series production.

During the prototype pilot phase, which could last from 2 to 10 years, a small number of machines may be produced to evaluate the use of a given technology for a specific machine type. That phase can begin when the technology becomes feasible for the size, type and intended use of the machine, though may not lead to significant market penetration due to the small number of machines involved.

Productionisation is the process of adapting the technology, once demonstrated as technically feasible, ready for the machines to be produced in series on the production line, rather than as special one-offs. That phase can begin when there is confidence that the required energy carrier is widely available for the size, type and intended use of the machine and there is high confidence in the future potential sales of the machine. This phase may take a further 2 to 5 years.

The series production phase will normally only commence when there is broad distribution of the required energy carrier for the size, type and intended use of the machine, both the machine and energy carrier are available at a competitive cost to the end-user, and, most crucially, the machine is attractive to end-users for purchase i.e. there is market demand for the machine.

The three phases are illustrated graphically below.

Figure 4: The path to market phases

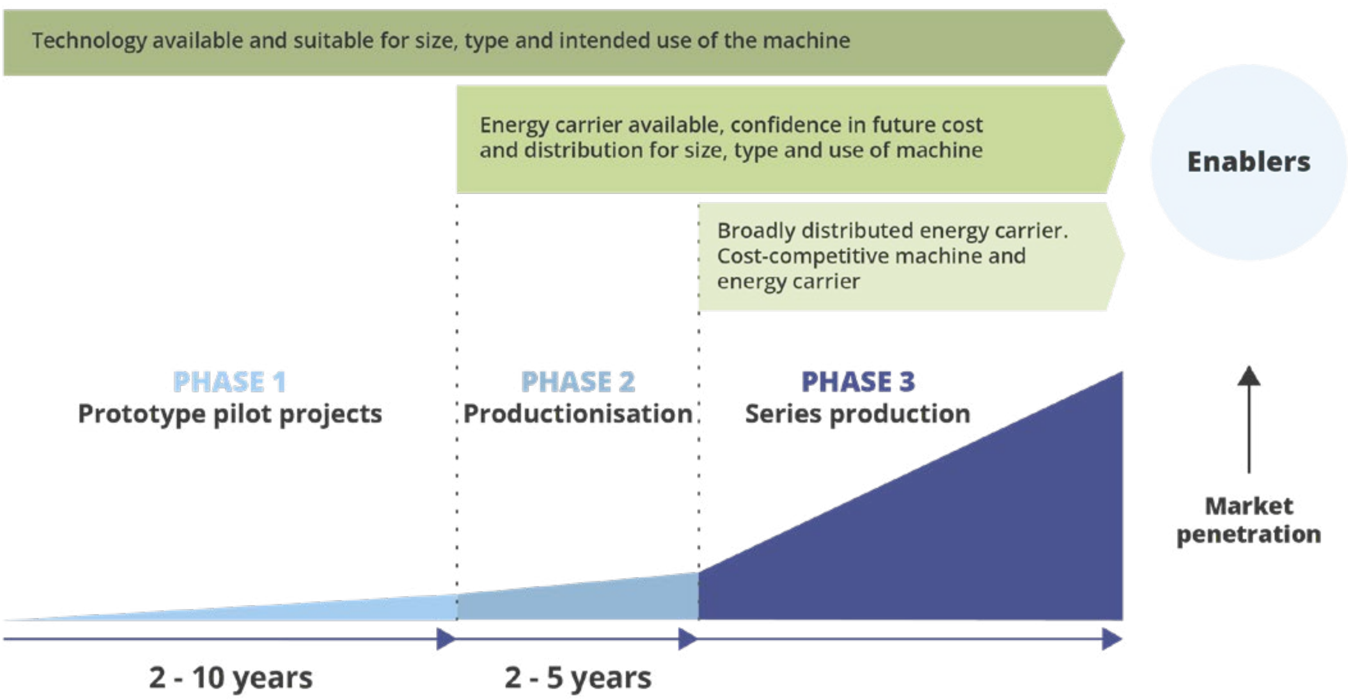
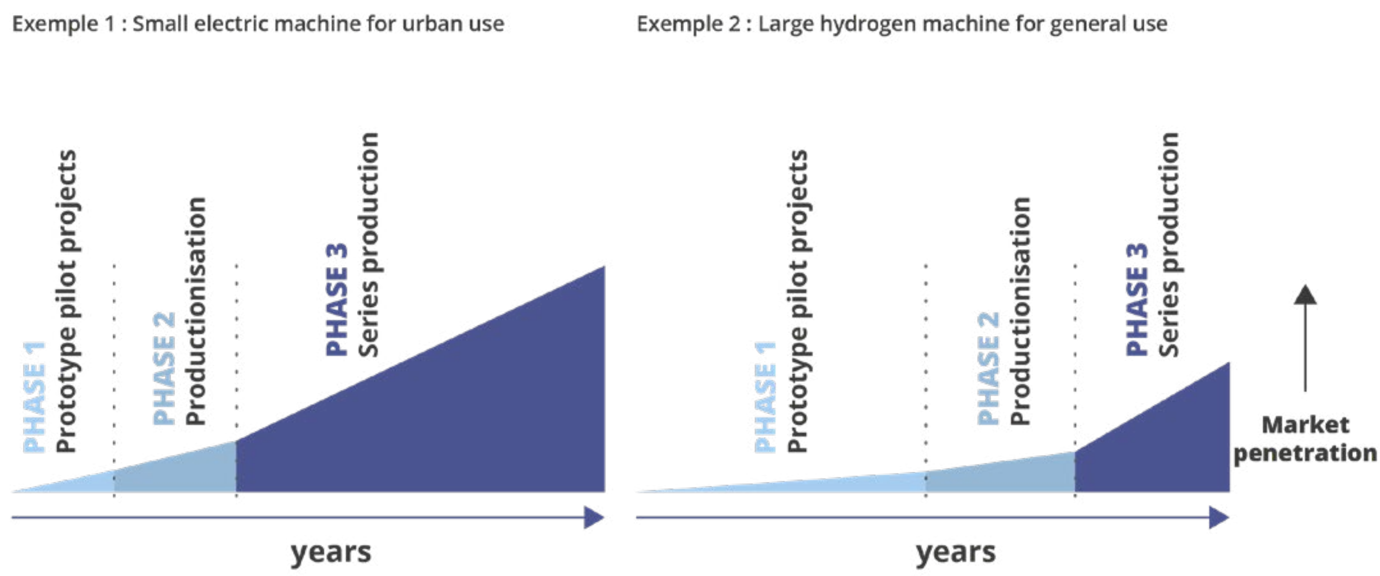


Figure 5: Examples of time to market for two different machines and technologies

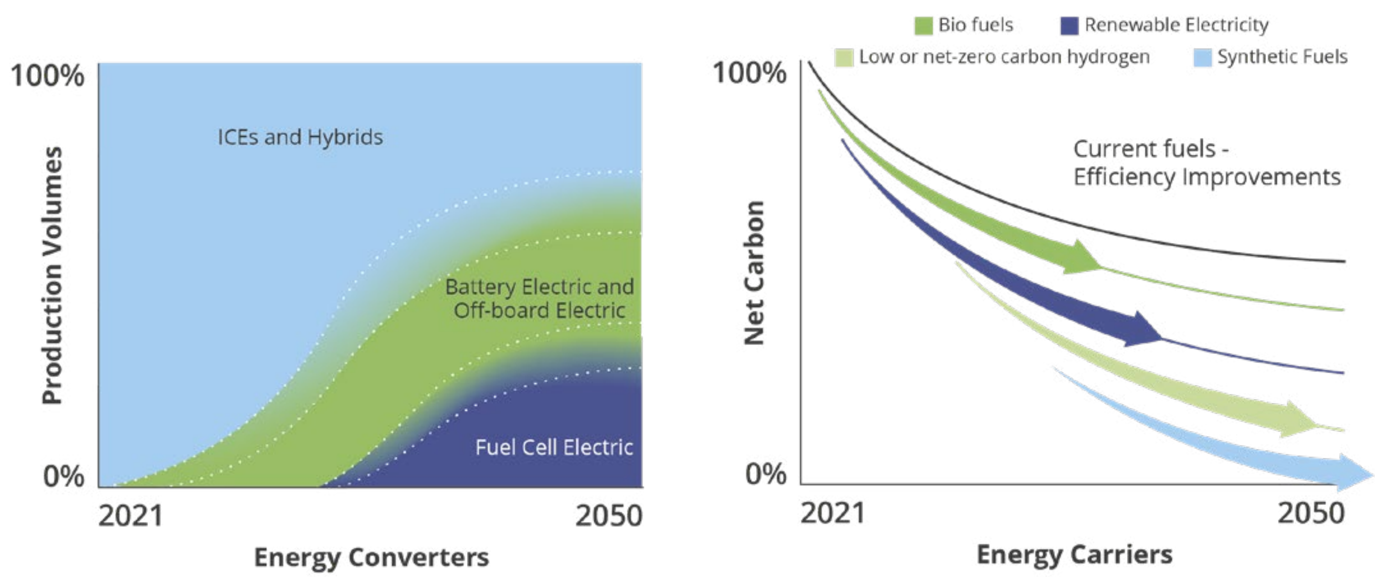


In the following figure the potential roll-out of energy carriers and converters is described.

The left part of the diagram shows the possible change in production levels of different types of energy converters (or power-trains). It shows an accelerating increase in new technologies as they become mature and the energy carriers (fuels) become available and cost competitive. The rate of increase flattens as the most suitable applications are switched.

The right part of the diagram shows the possible progressive de-carbonisation of energy carriers (fuels) as the technologies are rolled out and production capacity grows. With an increase in machine and process efficiency, net-zero can be achieved by 2050.

Figure 6: potential roll-out of energy carriers and converters



Recommendations

To ensure a positive and relevant contribution of construction machinery to the objectives of the EU Green Deal, European policy should:

Assess decarbonisation of the full life cycle inclusive of the operations involved

In line with the Circular Economy principles, it is necessary to consider manufacturing, use, remanufacturing and disposal of the machine and its energy carrier in a full Life Cycle Analysis (LCA) to properly assess the Carbon Footprint (CF). Different technologies have different potential CO_2 emissions in each of the life cycle phases of a machine.

Be developed in coordination with other regions of the world

A multilateral coordinated approach to decarbonisation should be encouraged and always preferred by the EU. Firstly because Europe's efforts to go carbon-neutral could be undermined by lack of ambition by our international partners, through the well-known phenomenon of carbon leakage and the link with global trade flows.

Secondly, global coordination is key since unilateral decarbonisation goals by the EU may create unfavourable conditions that unlevel the playing field against EU manufacturers and the whole EU economy. We believe this to be absolutely necessary for a globally competitive industry such as construction machinery.

Indeed, construction equipment is developed and used globally. Construction equipment manufacturers operate in a global market with a wide range of products; therefore, manufacturers need to maximise the volume of net-zero carbon technologies across their global manufacturing presence in order to achieve the needed economies of scale in production.

Last but not least, this is in line with article 6 of the Paris Agreement, which aims to promote an integrated, holistic and balanced approach. This will help governments in implementing their Nationally Determined Contributions[9] through voluntary international cooperation. This cooperation mechanism, if properly designed, should make it easier to achieve CO_2 reduction targets.

Ensure the availability of low or net-zero CO_2 energy carriers at acceptable costs

This should be pursued by supporting and funding innovation and development of processes to produce the energy carriers at high volume and low cost. This also requires that policy and funding decisions by the EU do not discriminate between sectors regarding availability of energy carriers for decarbonisation. The timely uptake of these low carbon or net-zero CO_2 energy carriers may require national fiscal measures and/or incentives.

Whilst on-road vehicles and non-road machines may use the same low or net-zero CO_2 energy carriers, there are different needs for the distribution of those energy carriers. On-road vehicles will generally replenish the energy carrier at the roadside facility, but for non-road machines it will be necessary to transport the energy carrier to the work site.

Incentivise fleet renewal and facilitate decarbonisation of existing machinery by making available low or net-zero CO_2 drop-in fuels.

Replacement of existing machines with new technology should be encouraged and incentivised. However, the lifespan of construction machinery can be long. Therefore, to achieve an early reduction of carbon emissions, low or net-zero CO_2 drop-in fuels need to be made available in sufficient volume and at competitive costs.

Technology independent objectives

Construction machinery sector is varied and complex requiring multiple solutions for different situations. No single technology can adequately provide decarbonisation for all situations, therefore any regulation or legislation should only target the outcome leaving the technology choice to manufacturers and end-users.

[9] Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of its long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change.

COMMITTEE FOR EUROPEAN
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contact us

+32 2 706 82 26
info@cece.eu
www.cece.eu

follow us