PowerCylinder project – an overview

Introduction

In heavy-duty mechanical applications, hydraulic systems play a vital role by converting mechanical energy into hydraulic energy, creating high-power density and compactness.

These systems are crucial in various sectors, including construction and demolition, where significant forces require high pressure. Piston pumps, one of the most important components of hydraulic systems, help machinery perform tasks requiring high force and precision.

However, current hydraulic systems are plagued by inefficiencies, environmental concerns and safety issues, which is where the LIFE-PowerCylinder project comes into play.

LIFE- PowerCylinder aims to enhance hydraulic systems used in demolition machinery, improve efficiency and lower emissions, and align with the European Union's Waste Framework Directive 75/442/EEC, a central piece of legislation governing waste management and recycling. By adopting innovative technologies in hydraulic systems, the project seeks to contribute to a more sustainable, efficient and environmentally responsible future for the construction and demolition industries.

Project background: challenges in hydraulics systems

Hydraulic systems are common in industries that demand high-force operations, particularly in construction, mining, agriculture and demolition.

These systems, which include piston pumps and hydraulic cylinders, can generate large amounts of power in a compact form. Hydraulic pumps are especially important because they enable machinery to function under high pressures and flow rates, which is essential in heavy-duty machinery such as excavators, loaders, and cranes. In fact, the global market for piston pumps is projected to continue to grow due to rising demand across these sectors.

However, despite their widespread use, hydraulic systems have several significant challenges. The buildings and construction sector accounts for over a third of global energy consumption and nearly 39% of energy and process related CO_2 emissions (International Energy Agency, 2019).

In addition, hydraulic machinery often operates in harsh environments and faces high stress over long operational hours. Thus, various failures often occur, leading to efficiency decline, pressure fluctuation, unexpected machine breakdowns, and even worse, severe accidents. Hydraulic systems also use large amounts of harmful, not environment friendly hydraulic fluids. Although sealing technologies have advanced considerably over the past 30 years, the development of hydraulic system operating pressures and response times repeatedly leads to leakage. According to hydraulic hose manufacturer Gates, it is estimated that 370 million litres of oil leak from hydraulic equipment every year. For comparison, one litre is capable of polluting one million litres of water.

Current hydraulic cylinders are bulky and inefficient. Traditional systems also face the issue of energy waste, as full power is not always required for every operation.

State-of-the-art solutions incorporate external pressure amplifiers, adding system complexity, boosting cost and increasing energy consumption.

Therefore, hydraulic systems require a high reliability and condition monitoring approach. In this scenario, hydraulic cylinders play a key role in satisfying the demand for technological upgrades and compliance with environmental standards to optimise machine and resource efficiency without sacrificing performance or profitability.

To address these challenges, the LIFEPowerCylinder project has partnered with Mantovanibenne S.r.l. (manufacturer of demolition attachments) and Idraulica Sighinolfi Albano S.r.l. (manufacturer of hydraulic cylinders).

Idraulica Sighinolfi Albano S.r.l. developed the first hydraulic PowerCylinder (PC), which integrates an internal pressure amplifier, the cartridge booster (CB), into the hydraulic cylinder. This novel cylinder offers several benefits:

- ✓ increasing efficiency, resulting in less fuel consumption of machines
- ✓ lowering CO_2 emissions, reducing weight due to smaller cylinder design
- ✓ geared towards raw material reduction (steel)
- ✓ less demand for harmful substances (hydraulic oil).

Avoiding high-pressure connections and external hoses mitigates the risk of external oil leakage and the danger of hose breaking/ exploding, reducing the probability of work accidents significantly.

With the integration of the PC into demolition attachments from the enduser Mantovanibenne (MBI), this project will show the potential of this new technology.

Figure 1: Hydraulic cartridge pressure amplifier integrated into a demolition attachment, developed under the LIFE PowerCylinder project

Objectives of the LIFE-PowerCylinder project

The LIFE-PowerCylinder project has clear and ambitious objectives designed to meet the EU's environmental goals while simultaneously addressing the inefficiencies of traditional hydraulic systems. The key objectives of the project include:

- Optimising system design for efficiency
  The project aims to design and manufacture advanced hydraulic cylinders with CB, improving efficiency by ensuring the force needed is only applied when required, much like an automatic gearshift. This leads to faster and more effective machinery operation.
- Integration into demolition machinery
  The PC technology will be integrated into various demolition tool excavator attachments, such as crushers, rotating pulverisers and fixed pulverisers. By developing six prototypes in two sizes each, the project aims to demonstrate the adaptability of the technology and that the smaller tool is equal in performance to the larger one.
- Real world testing
  The six prototypes underwent extensive testing under controlled conditions at an artificial test site as well as on real demolition sites. The test was conducted over 300 hours to assess its performance, efficiency and environmental impact.

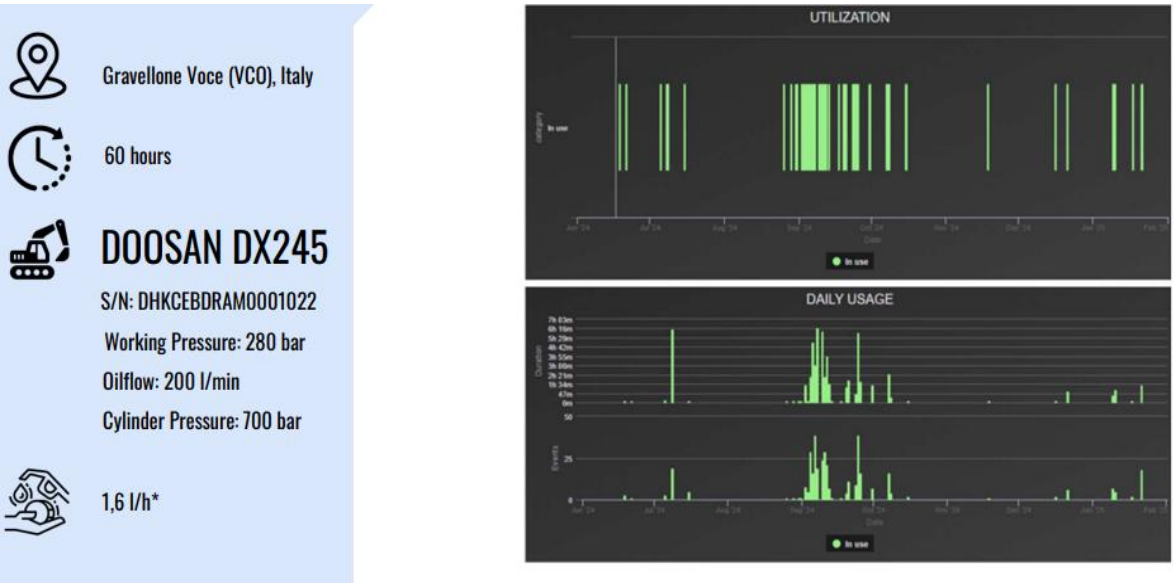

Fig.2 example of field test data

- Environmental impact monitoring
  Monitoring key environmental and health parameters such as fuel consumption, noise, dust and safety has been critical to understanding the impact of the PCs.
- Safety and health benefits
  Increasing operational safety for workers is a priority, which will be addressed by reducing high-pressure parts and eliminating external amplification components. The pressure amplification is confined inside the cylinder.
- Contribution to EU climate targets
  The LIFE-PowerCylinder project is designed to help meet the EU's climate action targets and align with the European Green Deal and EU health, safety and environmental protection directives.

Technical, economic and environmental results

- Faster and stronger hydraulic cylinders

  The CBs will act like automatic gearshifts, providing up to 50% faster operation and generating 37% more force than conventional cylinders of the same weight. This leads to improved efficiency and reduced operational time.

- Easier installation

  Unlike external amplification systems, the PC can be integrated more easily into existing machinery without additional components or complications

- Energy efficiency

  The new PowerCylinders reduce overall energy consumption by 15–20%, as they only apply maximum force when needed. This reduction in energy use directly leads to lower fuel consumption and decreased CO2 emissions.

- Increased speed and reduced CO_2 emissions

  The technology enables tools to complete the same tasks more quickly and allows, also, smaller excavators to perform the same job, leading to a reduction of 5,5 tons of CO_2 during the demonstration phase.

Cylinder type	Operating time (h)	CO2 emissions (ton)	NOx emissions (kg)	fuel consumed (L)
Standard cylinder	330	20.31	30.32	7579
SmartCylinder	300	14.82	22.12	5530

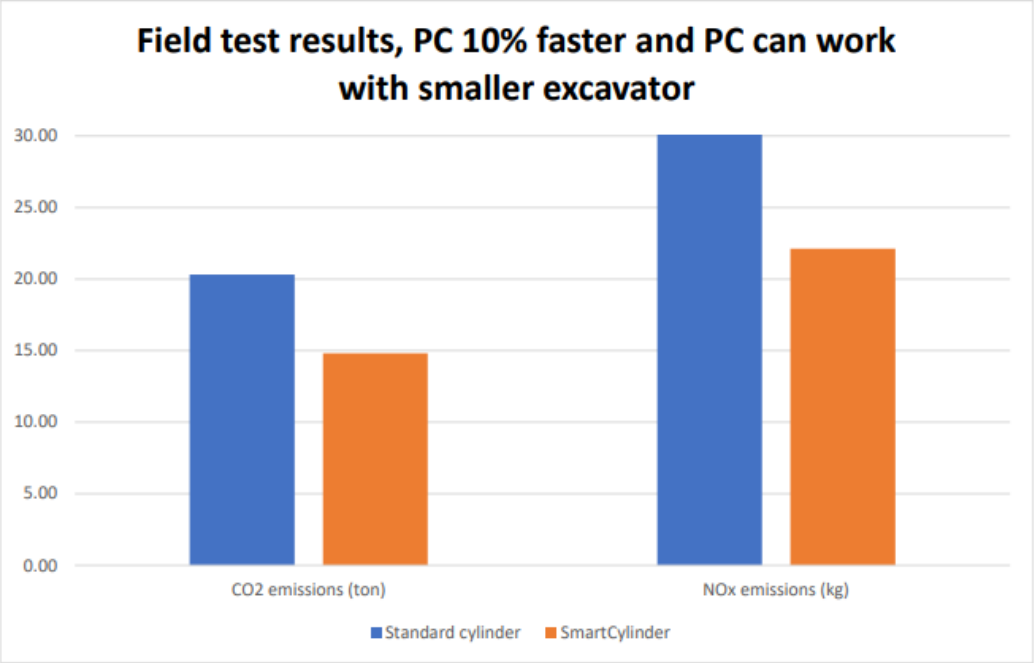

Fig.4 Field test data results, same job assuming PowerCylinder 10% faster and some attachments can work with smaller excavators

- <u>LCA (Life Cycle Assessment)</u>

  We decided to make an LCA analysis of the PowerCylinder, it is the calculation of the environmental impact. This study was submitted to the third part independent critical review and it is in compliance with ISO 14040 and ISO 14044. The LCA type is from cradle to grave, so the entire life cycle is considered.

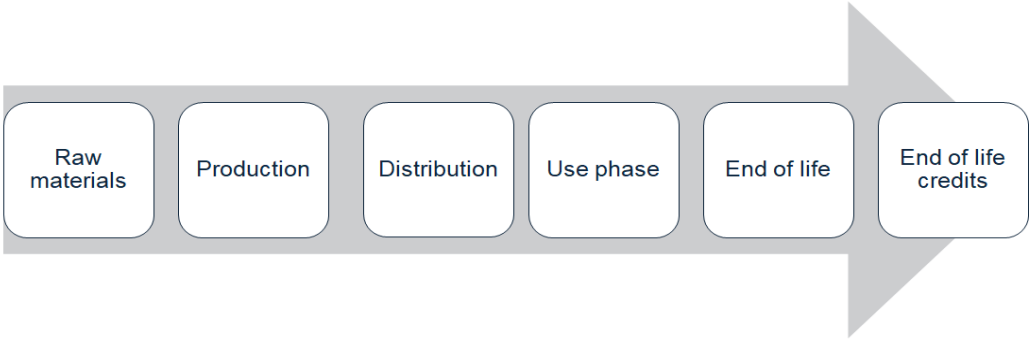

Fig.5 phases included in the LCA analysis

The most important result is that the use phase is, by far, the most impactful one on the whole life cycle. Only this phase is responsible to the 99,7% of the total emissions. For this reason, when using PowerCylinders, instead of standard ones, emissions are reduced.

Indicators	Total	Raw materials	Production	Distribution	Use phase	End of life	End of life-credits
EF 3.1 Acidification [Mole of H+ eq.]	8,25E+03	0,05%	0,01%	0,00%	99,95%	0,00%	-0,01%
EF 3.1 Climate Change - total [kg CO2 eq.]	7,27E+05	0,21%	0,09%	0,00%	99,74%	0,00%	-0,04%
EF 3.1 Climate Change, biogenic [kg CO2 eq.]	2,00E+03	0,02%	0,06%	0,00%	99,91%	0,01%	0,00%
EF 3.1 Climate Change, fossil [kg CO2 eq.]	7,13E+05	0,21%	0,10%	0,00%	99,73%	0,00%	-0,04%
EF 3.1 Climate Change, land use and land use change [kg CO2 eq.]	1,19E+04	0,00%	0,00%	0,00%	99,99%	0,00%	0,00%
EF 3.1 Ecotoxicity, freshwater - total [CTUe]	6,82E+06	0,04%	0,03%	0,00%	99,93%	0,00%	0,00%
EF 3.1 Ecotoxicity, freshwater inorganics [CTUe]	6,75E+06	0,04%	0,03%	0,00%	99,93%	0,00%	0,00%
EF 3.1 Ecotoxicity, freshwater organics [CTUe]	6,11E+04	0,04%	0,03%	0,00%	99,94%	0,00%	-0,01%
EF 3.1 Eutrophication, freshwater [kg P eq.]	3,06E+00	0,02%	1,22%	0,00%	98,76%	0,00%	0,00%
EF 3.1 Eutrophication, marine [kg N eq.]	4,19E+03	0,02%	0,01%	0,00%	99,98%	0,00%	0,00%
EF 3.1 Eutrophication, terrestrial [Mole of N eq.]	4,61E+04	0,02%	0,01%	0,00%	99,98%	0,00%	0,00%
EF 3.1 Human toxicity, cancer - total [CTUh]	1,37E-04	0,18%	0,26%	0,00%	99,61%	0,00%	-0,06%
EF 3.1 Human toxicity, cancer inorganics [CTUh]	1,33E-04	0,07%	0,20%	0,00%	99,71%	0,00%	0,02%
EF 3.1 Human toxicity, cancer organics [CTUh]	4,02E-06	4,03%	2,10%	0,00%	96,64%	0,03%	-2,80%
EF 3.1 Human toxicity, non-cancer - total [CTUh]	6,13E-03	0,11%	0,07%	0,00%	99,82%	0,00%	-0,01%
EF 3.1 Human toxicity, non-cancer inorganics [CTUh]	5,98E-03	0,11%	0,07%	0,00%	99,82%	0,00%	-0,01%
EF 3.1 Human toxicity, non-cancer organics [CTUh]	1,44E-04	0,09%	0,08%	0,00%	99,86%	0,00%	-0,02%
EF 3.1 Ionising radiation, human health [kBq U235 eq.]	1,73E+03	2,02%	1,84%	0,00%	96,24%	0,03%	-0,13%
EF 3.1 Land Use [Pt]	4,59E+06	0,04%	0,15%	0,00%	99,81%	0,00%	0,00%
EF 3.1 Ozone depletion [kg CFC-11 eq.]	5,89E-07	0,75%	87,12%	0,00%	12,13%	0,02%	-0,02%
EF 3.1 Particulate matter [Disease incidences]	9,97E-02	0,30%	0,01%	0,00%	99,72%	0,00%	-0,03%
EF 3.1 Photochemical ozone formation, human health [kg NMVOC eq.]	1,17E+04	0,02%	0,01%	0,00%	99,98%	0,00%	0,00%
EF 3.1 Resource use, fossils [MJ]	9,27E+06	0,17%	0,11%	0,00%	99,75%	0,00%	-0,04%
EF 3.1 Resource use, mineral and metals [kg Sb eq.]	8,29E-02	6,86%	20,56%	0,00%	72,74%	0,00%	-0,17%
EF 3.1 Water use [m^3 world equiv.]	1,26E+04	15,93%	0,69%	0,00%	83,90%	0,02%	-0,54%

Fig.6 LCA analysis results

- Potentially reduced material use

  The amplification ratio of the PowerCylinders (ranging from 2.0 to 2.8) allows for a reduction of the cylinder dimensions and weight. Potentially, this can lead to a reduction in material usage across the machinery
- Noise and dust reduction

  By completing tasks more efficiently, the PowerCylinder will lead to a 10% reduction in noise pollution and a 7% reduction in dust generation, both of wich improve worker safety and environmental quality.
- Improved safety

  The absense of high-pressure hoses and connections reduces the potential for mechanical failures, making the machinery safer and more reliable for workers.

Aligning with the EU's Waste Framework Directive

The LIFE-PowerCylinder project represents a major step forward in developing efficient, sustainable and safer hydraulic systems for the construction and demolition sectors.

Integrating innovative technologies, such as the CBs, into hydraulic cylinders aligns with the European Union's Waste Framework Directive 75/442/EEC, emphasizing resource efficiency, waste reduction and environmental protection.

This project also contributes to the broader goals of the European Green Deal, helping the EU achieve its climate action targets while promoting economic growth through technological innovation and job creation. The expected reduction in energy use, CO2 emissions, and material waste demonstrates how cutting-edge hydraulic technology can support the EU's efforts to move towards a circular economy, where sustainability and resource conservation are at the forefront.

The LIFE-PowerCylinder project exemplifies how industrial innovation can lead to tangible environmental and economic benefits when combined with regulatory frameworks like the EU's Waste Framework Directive. As the project progresses, it is set to transform the hydraulic systems used in demolition machinery, offering a cleaner, more efficient and safer future for the industry.

What's about the future?

Thanks to the LIFE-PowerCylinder project, we know that also demolition field can reduce its environmental impact. Let's see the improvements that PowerCylinder can bring in the demolition field in the next 5 years (using our estimation of PowerCylinders sold).

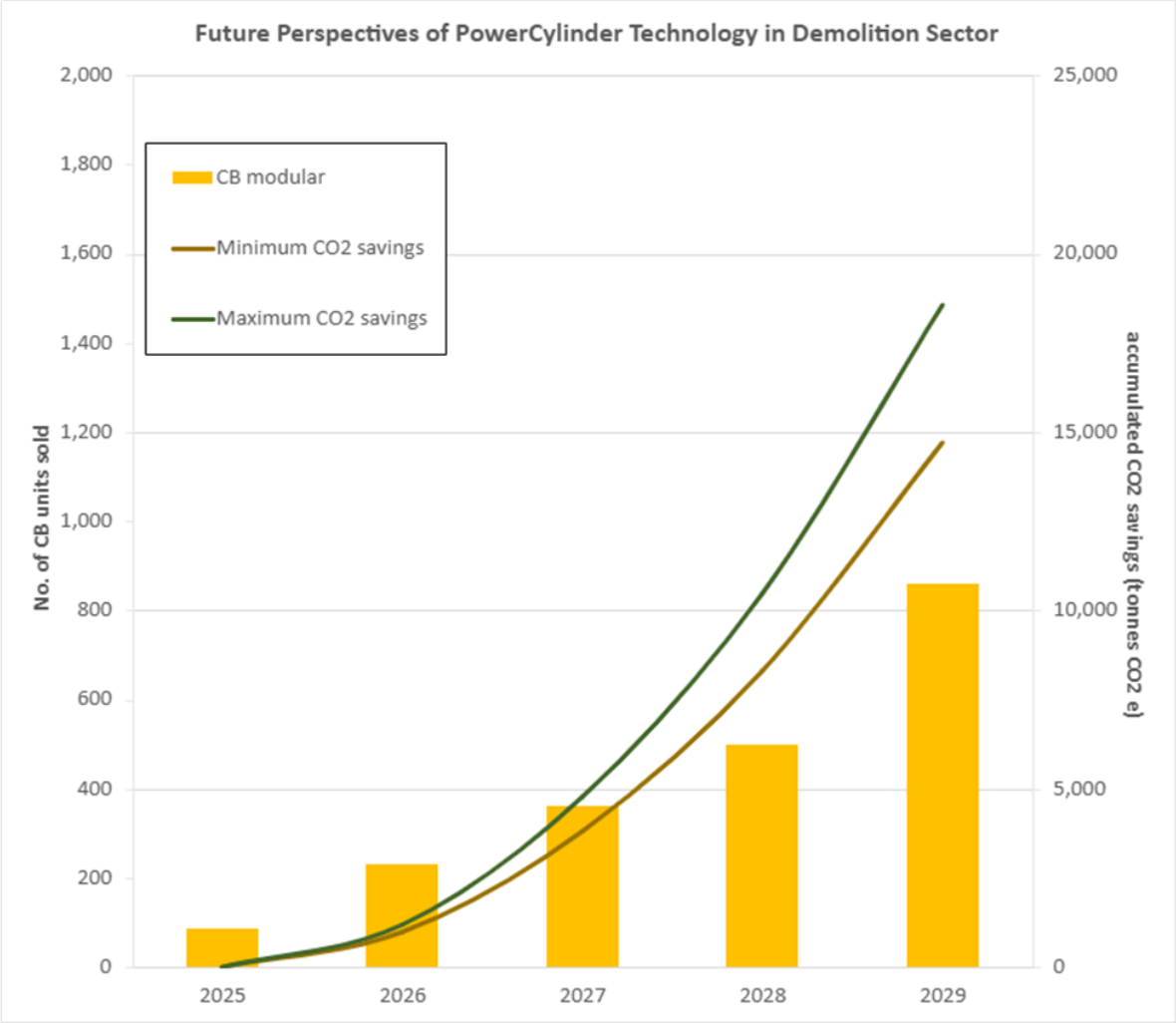

Fig.7 estimated PowerCylinder units sold and CO_2 saved. Minimum scenario assumes that PC is 10% faster than standard ones, maximum scenario assumes that PC is faster than standard ones and that some attachments with PC can work with smaller excavators.

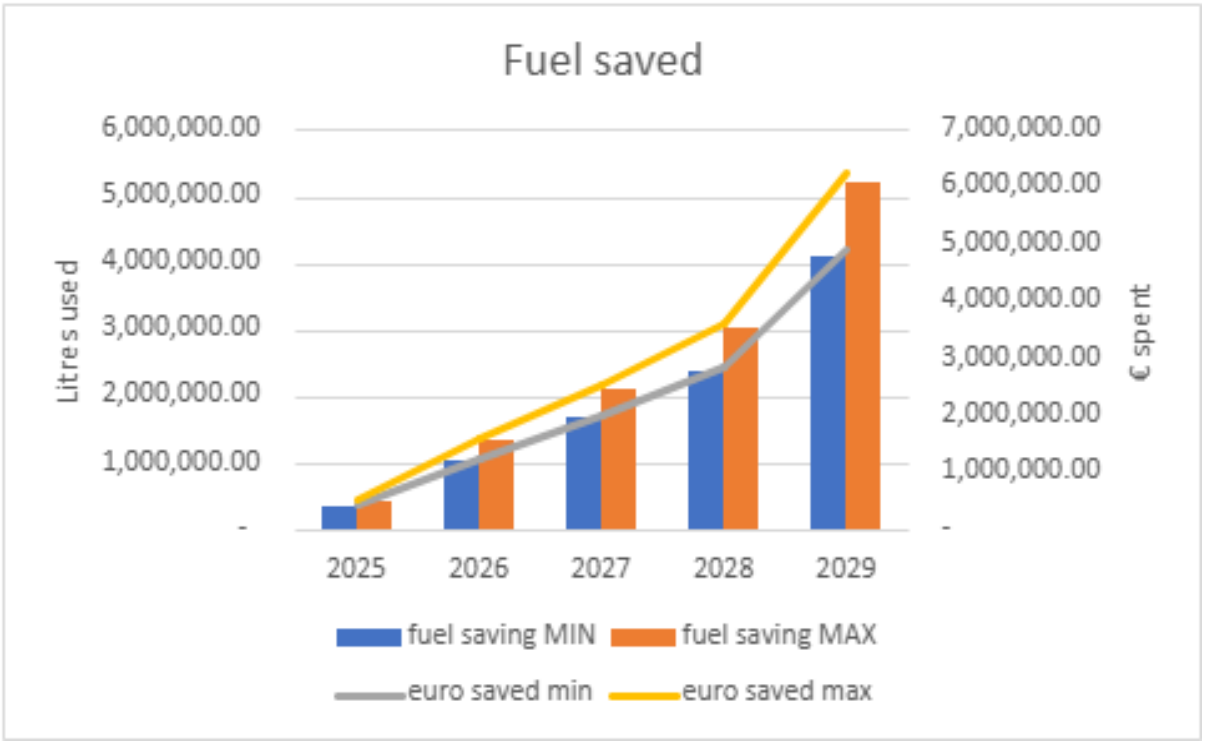

Fig.8 Fuel saved using PowerCylinders instead of standard cylinders

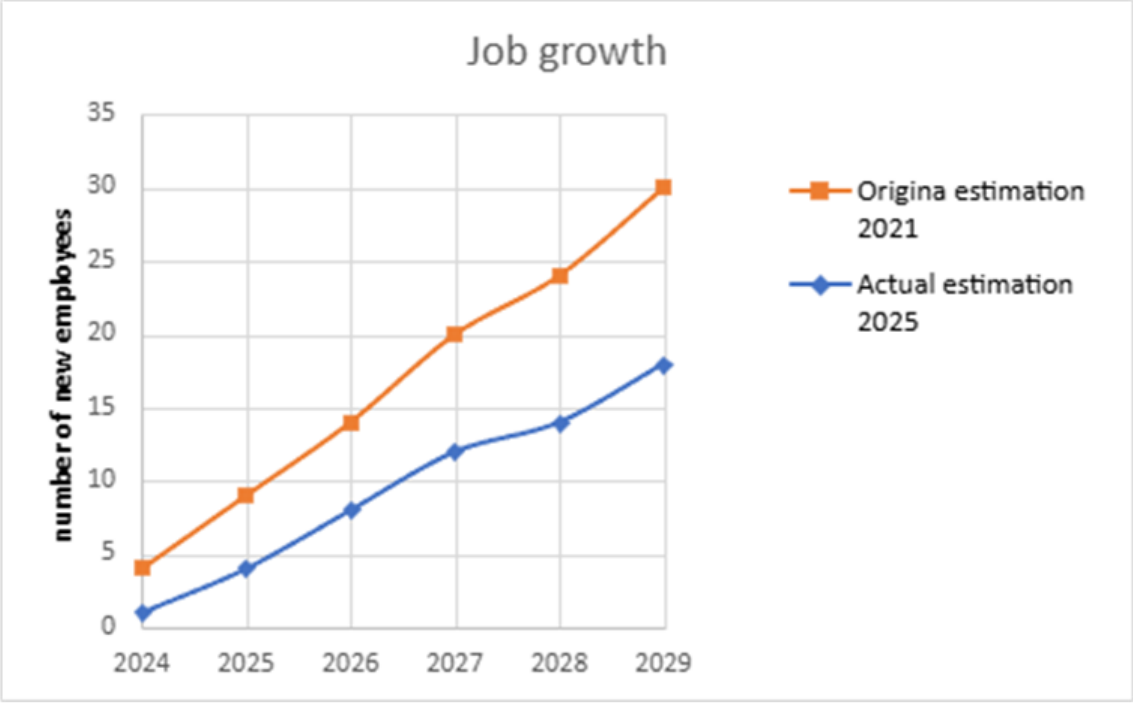

Fig.9 estimated job growth thanks to the PowerCylinder

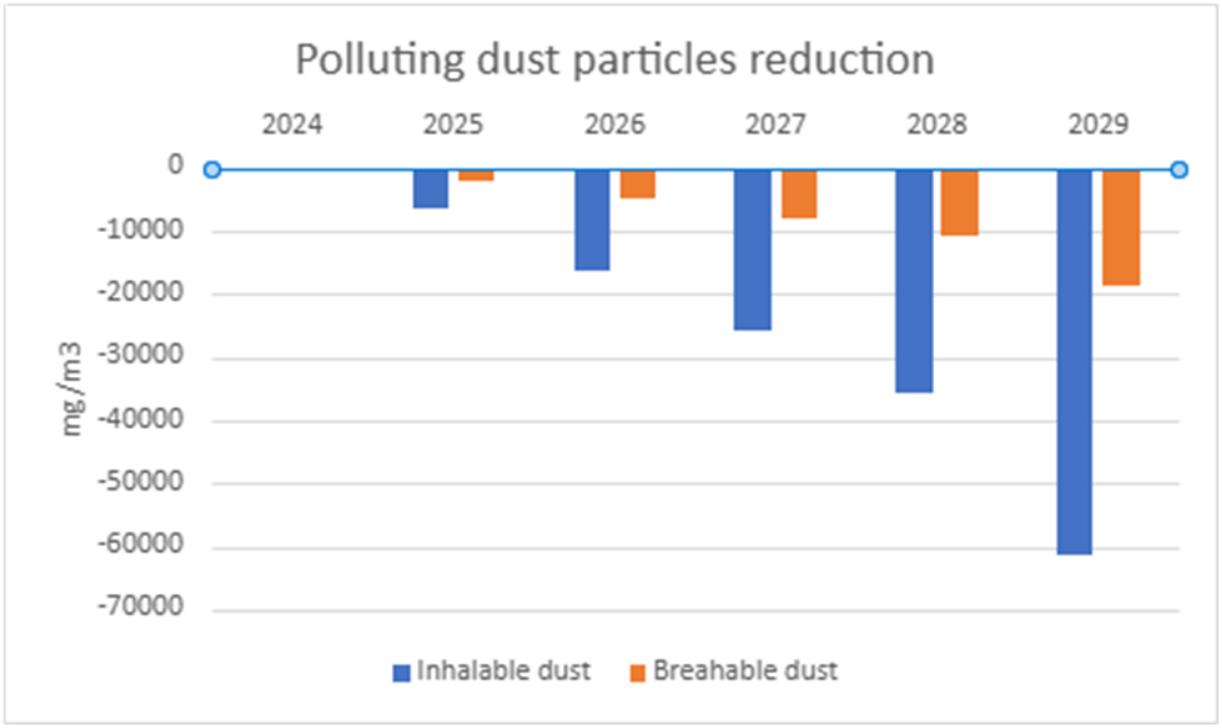

Fig.10 polluting dust particles reduction in next 5 years using PowerCylinders instead of standard cylinders

Key events

During the project, we attended various fairs and events in order to explain to people how PowerCylinder can impact their lifes.

- Ecomondo 2022

Fig.11 Idraulica Sighinolfi stand at EcomondO

- GET - GLOBAL ENERGY AND TRANSITION CONGRESS & EXHIBITION

Fig.12 Idraulica Sighinolfi stand at GET 2024

-LCA Italian association forum in Cortina d'Ampezzo 2025

Fig.13 Presentation of our scientific paper in Cortina

- Press conference in Confindustria Modena 2025

Fig.14 Press conference at Confindustria Modena