SUPREME Project: Sustainable and flexible powder metallurgy processes optimization by a holistic reduction of raw material resources and energy consumption

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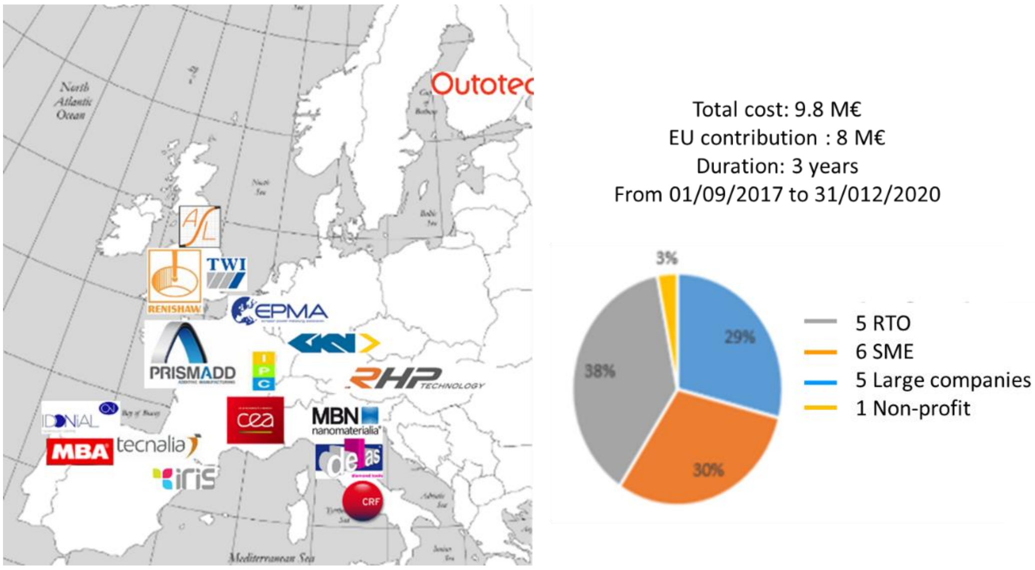
Context and overall objectives of the project

SUPREME aimed at optimising the sustainability of powder metallurgy (PM) processes throughout the value chain. This H2020-SPIRE funded project focused on a combination of fast growing industrial production routes and advanced ferrous and non-ferrous metals. By offering more integrated, flexible and sustainable processes for powder manufacturing and metallic parts fabrication, it enabled the reduction of raw material resource losses while improving energy efficiency and thus carbon dioxide emissions, into sustainable processes and towards a circular economy.

A cross-sectorial integration and optimisation has been designed between several PM processes; gas and water atomisation as well as mechanical alloying for metal powder production, additive manufacturing (AM) and near-net shape technologies for end-parts fabrication. The consortium covered the full value chain from mining to end parts applications (Figure 1). The innovations resulted from the close cooperation between RTD organizations and companies aim a transfer to the market to have significant impact on wealth and jobs creation. SUPREME addressed several key process industries: minerals, ferrous and non-ferrous metals.



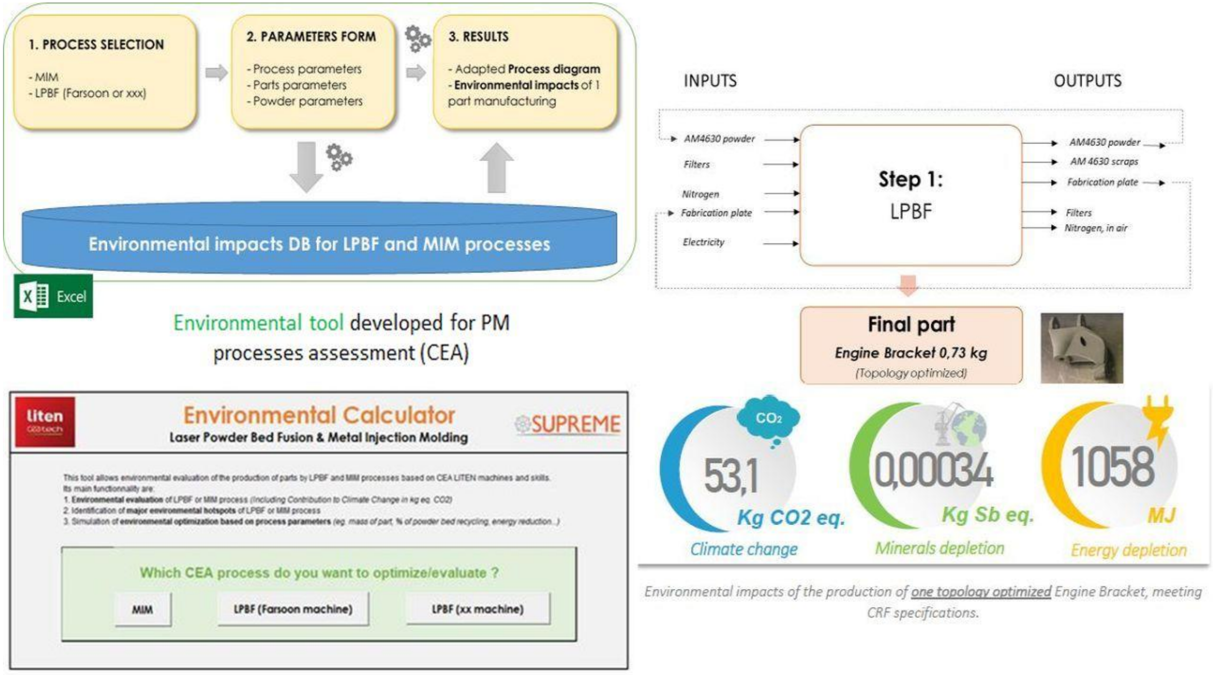
Total cost: 9.8 M€
EU contribution : 8 M€
Duration: 3 years
From 01/09/2017 to 31/012/2020

Figure 1: SUPREME consortium, budget and duration

Processes optimizations were quantified by a set of Key Performances Indicators (KPI), measured thanks to monitoring systems (IRIS) and validated by an eco-innovation methodology (CEA).

Work performed and main results achieved

Energy and material flows were quantified for 38 processes (baseline and SUPREME ones). Life cycle assessment (LCA) of these processes allowed to calculate all relevant KPIs and identify the reduction in energy, raw material resources, water, gases and CO_2 emissions (Figure 2). A map of the SUPREME PM value chain has been provided (CEA).



Environmental Calculator

Laser Powder Bed Fusion & Metal Injection Molding

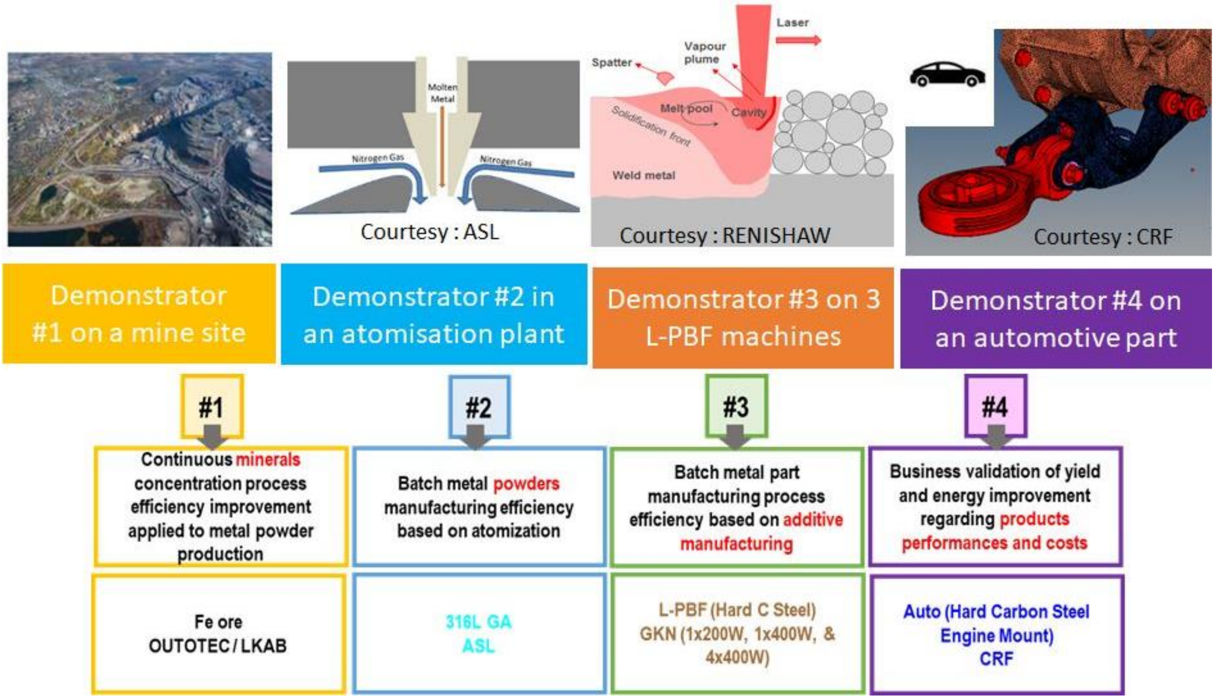
This tool allows environmental evaluation of the production of parts by LPBF and MIM processes based on CEA LITEN machines and skills.
Its main functionnality are:
1. **Environmental evaluation** of LPBF or MIM process *(Including Contribution to Climate Change in kg eq. CO2)*
2. Identification of **major environmental hotspots** of LPBF or MIM process
3. Simulation of **environmental optimization based on process parameters** *(eg. mass of part, % of powder bed recycling, energy reduction...)*

Which CEA process do you want to optimize/evaluate ?

Environmental impacts of the production of one topology optimized Engine Bracket, meeting CRF specifications.

Figure 2: Environmental tool developed for Powder Metallurgy Processes and Environmental impacts of the production of one topology optimized Engine Bracket

10 use-cases representing 20 production routes were studied: a gang saw blade tool for cutting stones (Dellas; Metal Injection Moulding MIM); a motor bracket for aeronautics (WAA; Laser Powder Bed Fusion, L-PBF); 2 medical implants and 2 medical tools (MBA; L-PBF, MIM and Metal Fused Filament Fabrication M-FFF); 2 automotive engine brackets (GKN: L-PBF and RHP: Plasma Metal Deposition, PMD); and mould inserts for injection moulds (IPC; L-PBF). Four demonstrators (Figure 3) were monitored in detail: (i) iron ore grinding (Outotec), (ii) gas atomization (ASL), (iii) 3D metal printing (GKN) of automotive bracket (CRF) with 3 different L-PBF machines and one PMD machine (Figure 4).



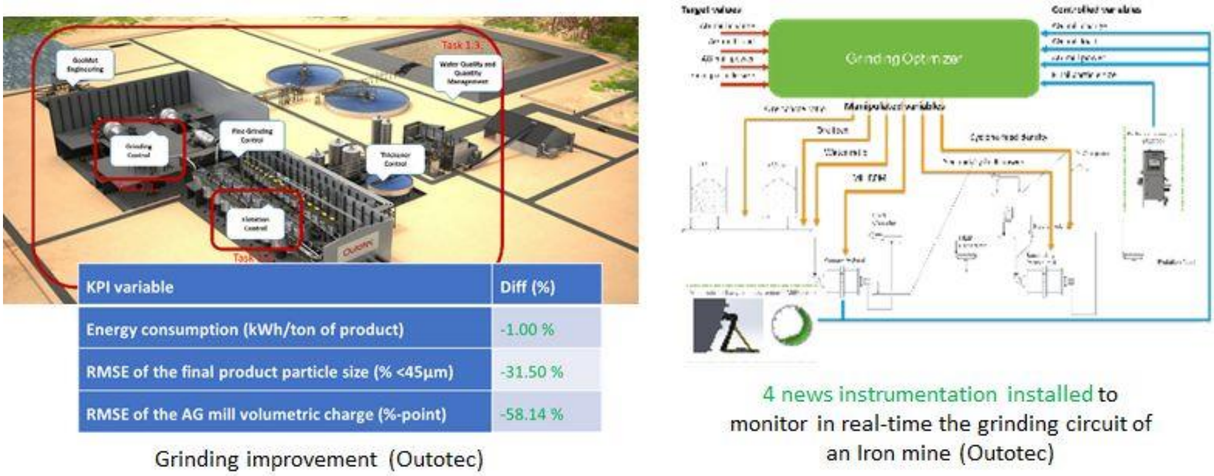
Demonstrator #1 on a mine site	Demonstrator #2 in an atomisation plant	Demonstrator #3 on 3 L-PBF machines	Demonstrator #4 on an automotive part
#1	#2	#3	#4
Continuous minerals concentration process efficiency improvement applied to metal powder production	Batch metal powders manufacturing efficiency based on atomization	Batch metal part manufacturing process efficiency based on additive manufacturing	Business validation of yield and energy improvement regarding products performances and costs
Fe ore OUTOTEC / LKAB	316L GA ASL	L-PBF (Hard C Steel) GKN (1x200W, 1x400W, & 4x400W)	Auto (Hard Carbon Steel Engine Mount) CRF

Figure 3: Demonstrators selected along the Powder Metallurgy Value Chain

38% or 34% decrease in weight of automotive bracket thanks to topological optimization and L-PBF or PMD processes with same fatigue properties as cast bracket (GKN, RHP & CRF)

Figure 4: Automotive brackets developed in the project during their test on a fatigue bench at CRF

Regarding mineral processing (Figure 5), significant improvements were reached without compromising the production rate or end-product quality: 1.2% reduction of grinding energy consumption (2400 kWh reduction annually for an average plant), 89% reduction of water consumption, 9.9 kt reduction of CO_2 emissions per year for 3 concentrator plants. A huge potential for further energy savings around the world is expected.



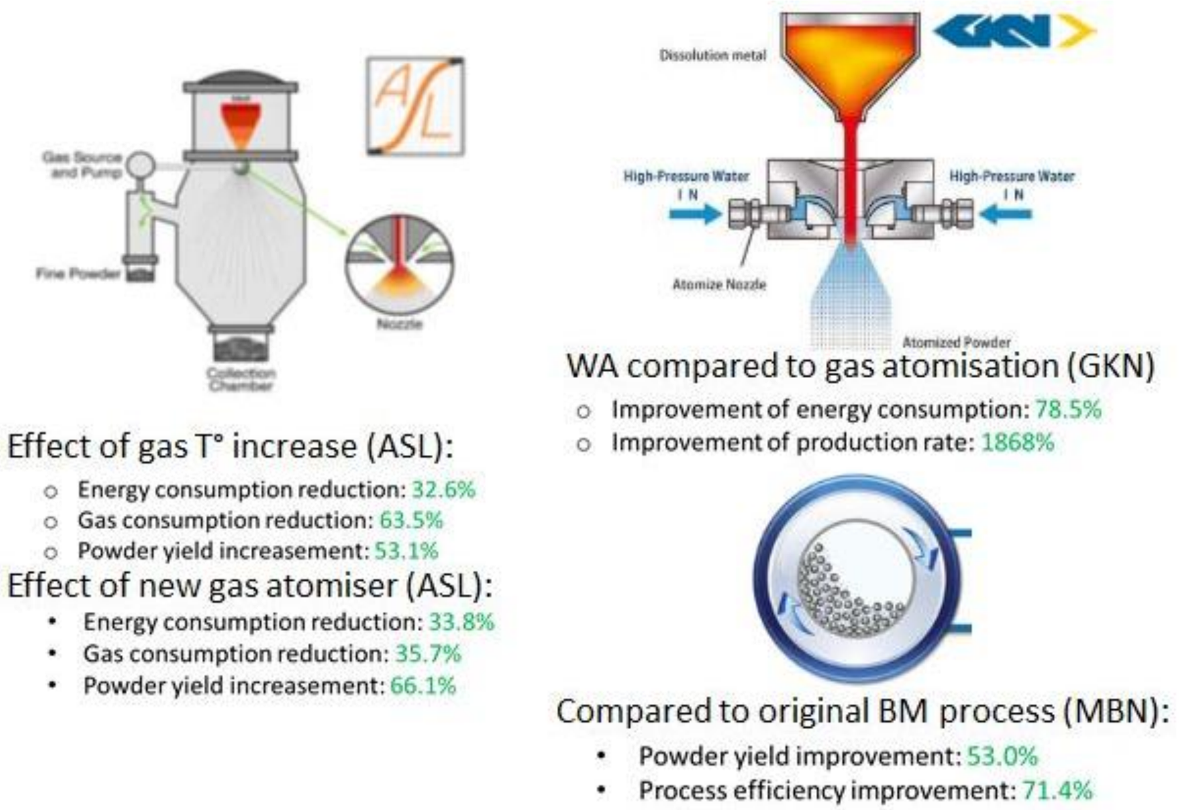
KPI variable	Diff (%)
Energy consumption (kWh/ton of product)	-1.00 %
RMSE of the final product particle size (% <45µm)	-31.50 %
RMSE of the AG mill volumetric charge (%-point)	-58.14 %

Grinding improvement (Outotec)

4 news instrumentation installed to monitor in real-time the grinding circuit of an Iron mine (Outotec)

Figure 5: Results obtained at the Mineral Ore Processing step and Global View of the Grinding Circuit with new sensors

Regarding powder production, KPIs were quantified for gas atomization (GA), water atomization (WA) and high energy ball milling (HEBM) (Figure 6). To produce GA AM + MIM powder by using SUPREME atomizer, the resulting energy & gas consumption, powder yield and production rate could be improved by 33.8 %, 35.7 %, 66.1 % and 90.5 %, respectively. A 62% reduction of energy consumption based on the use of WA powder instead of GA powder was obtained. To produce MIM powder by using optimized HEBM process, the powder yield, production rate and CO_2 emissions could be improved by 53%, 71% and 32%, respectively.



Effect of gas T° increase (ASL):

- ○ Energy consumption reduction: 32.6%
- ○ Gas consumption reduction: 63.5%
- ○ Powder yield increasement: 53.1%

Effect of new gas atomiser (ASL):

- Energy consumption reduction: 33.8%
- Gas consumption reduction: 35.7%
- Powder yield increasement: 66.1%

WA compared to gas atomisation (GKN)

- ○ Improvement of energy consumption: 78.5%
- ○ Improvement of production rate: 1868%

Compared to original BM process (MBN):

- Powder yield improvement: 53.0%
- Process efficiency improvement: 71.4%

Figure 6: Improvements for Key Process Indicators of the three powder production processes studied in SUPREME

SUPREME helped ASL to identify the main energy losses (Figure 7), thus acting directly in the factory to save >15% of energy consumption. This directly affects the production price of the AM and MIM powders. GKN-Hoeganaes has gained knowledge on usage of low-cost WA ferrous alloys powders for several processes. MBN is the first material producer able to offer high quality and added value Fe-based powder to the diamond tool market.

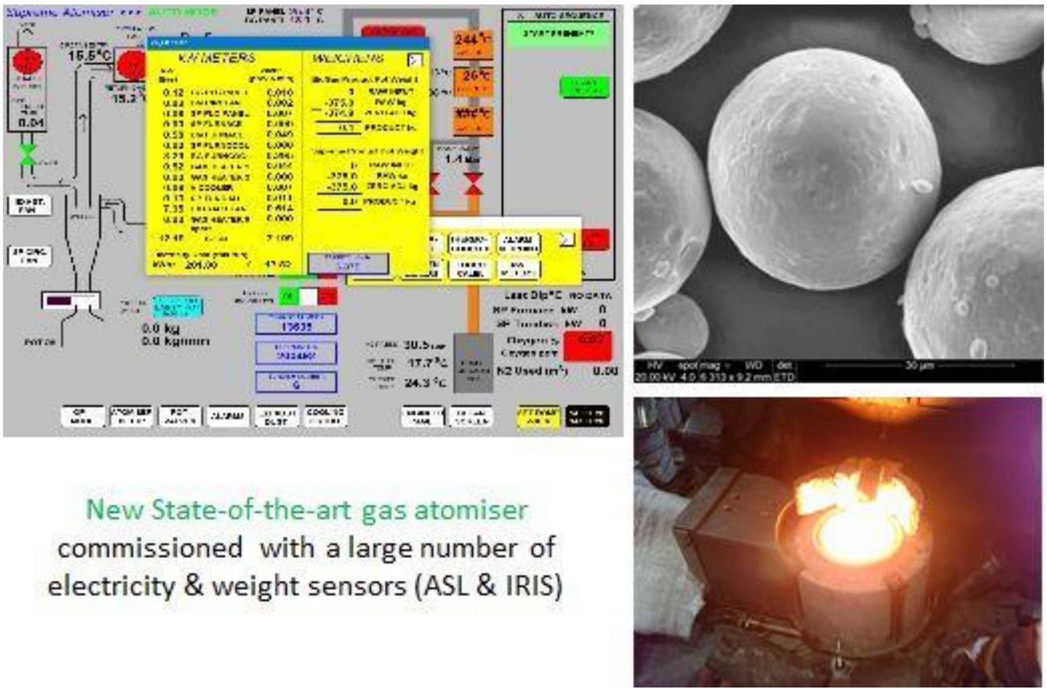
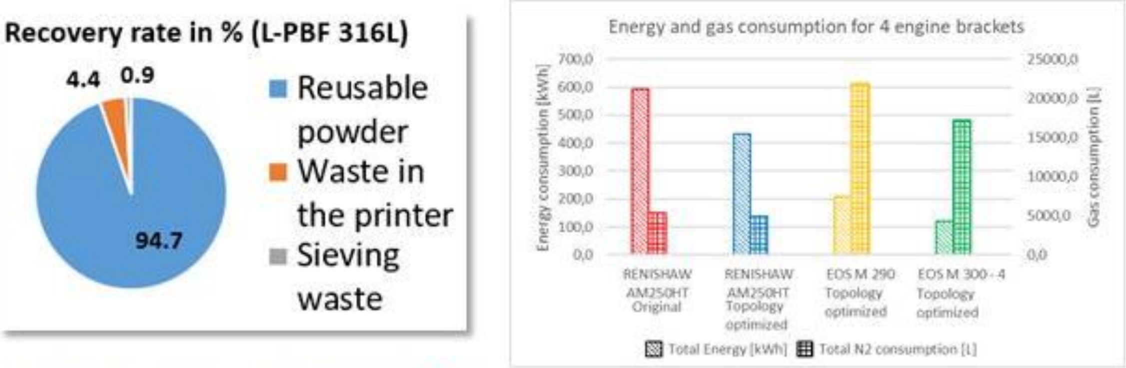


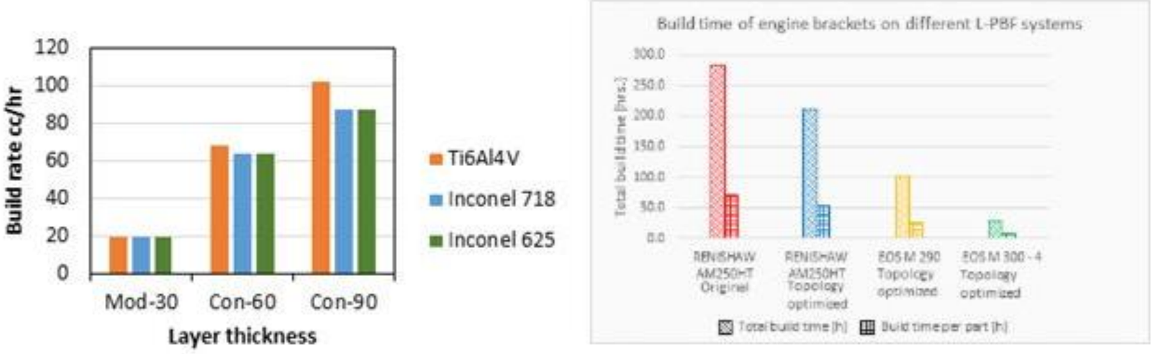
Figure 7: Screenshot of the New Gas Atomiser Interface allowing monitoring of raw materals and energy consumption ; Gas atomized powder ; New induction system for alloy melting before powder atomisation

Regarding metal AM, a dozen times re-use of L-PBF powders, without any impact on mechanical properties and with a 95% recovery rate, was shown. KPIs were quantified for L-PBF (Figure 8), PMD and Laser Metal Deposition (LMD) processes. Compared to the baseline, build time of an automotive L-PBF engine bracket was reduced by 51 % and production rate increased by 1050 %. Nitrogen consumption was reduced by 21.6% (GKN). GKN offers now to the market lightweight L-PBF topologically optimized >99% Hard Carbon Steels parts with detailed datasheets (Figure 9). LMD process optimization with HC22 superalloy (TWI) resulted in a 500% improvement of productivity and an 83% reduction in argon consumption. PMD process optimizations with WA 17-4PH steel (RHP) led to a 100% increase in the deposition rate with same mechanical performances (Figure 10). Regarding the aeronautics topologically optimized bracket (WAA), after slightly more than one year of flight, the impact cost in terms of CO_2 emissions due to the L-PBF process will be compensated by CO_2 savings in flight compared to the initial baseline part. L40 steel moulding tools (IPC) achieved a 31% reduction in material yield losses, a 14% improvement in energy efficiency, a >230% increase in production rate and a >30% reduction in CO_2 emissions after 6000 parts injected (Figure 11).



Recovery rate of L-PBF powder of ≈ 95 %
for GA 316L, GA IN625, GA L40

88 % reduction in Ar consumption in L-PBF
from RenAM250 (200W laser, 30 µm) to
RenAM 500Q (4x500W laser, 90 µm) (GKN)



93% increase in production rate in L-PBF
from RenAM250 (200W, 30 µm) to RenAM
500Q (4x500W laser, 90µm) (Renishaw)

89% reduction in build time in L-PBF from
original auto bracket on RenAM250 to
optimized bracket on EOS M300-4 (GKN)

Figure 8: Main results obtained on Laser Powder Bed Fusion process

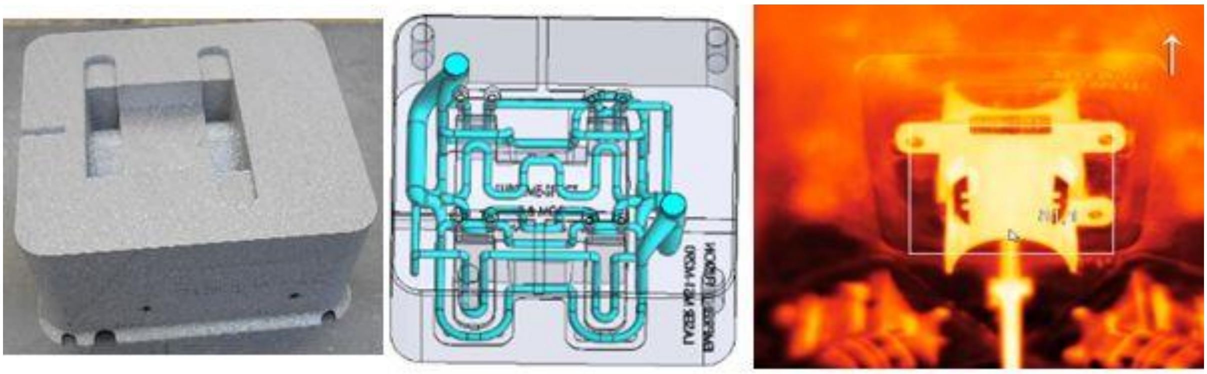
3 L-PBF machines monitored (GKN) thanks
to PATBOX systems (IRIS)

Figure 9: One of the GKN L-PBF machine used to monitor raw materials, energy consumption and productivity

	First stage (WA powder)	Final high yield (WA powder)
Shielding gas	15 l/min	0 l/min
Powder gas	3 l/min	1.5 l/min
Deposition rate	**1.2 kg/hr**	**1.4 kg/hr**
Powder yield	85%	91%

16% increase in PMD deposition rate of WA 17-4PH and 50% decrease of powder gas consumption with the same mechanical properties as wrought alloy (RHP)

Figure 10: Main results obtained with Powder Metal Deposition process



5% increase in Energy efficiency in mold cooling thanks for L-PBF of L40 steel compared to Maraging steel (IPC)

Figure 11: L40 steel mould developed by L-PBF and during injection test

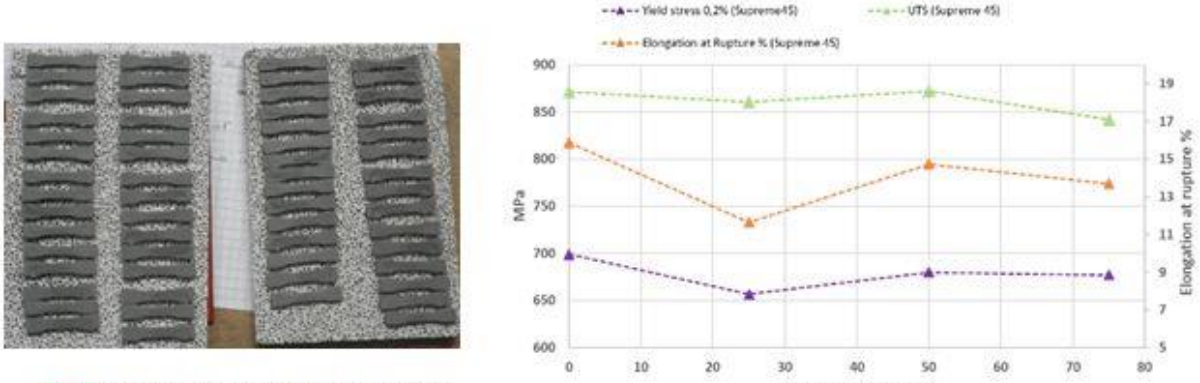
Regarding the MIM process, Fe-based raw material usage was reduced by 35% thanks to use of scrap materials (sprues) and L-PBF powder. A 100% reutilization of sprues and a reduction of the amount of rejected parts was proved (CEA & IDONIAL) (Figure 13). Good quality Co-free diamond cutting tools were obtained and the process optimisation led to fully dense parts with properties comparable to the commercial counterparts (Tecnalia). Thanks to MIM, 97% and 82% reduction in energy consumption were obtained for Fe-based medical use-cases and diamond composites, respectively. CO_2 emissions were reduced by 97% and by 83%, respectively. Compared to the current sintering process, MIM process of cutting tools (Dellas) achieved a 5% reduction in material yield losses, a 35% improvement in energy efficiency, a 25% increase in production rate and a 33% reduction in CO_2 emissions (Figure 12).

New alloy and new MIM feedstock developed for cutting tools segments (MBN, Tecnalia & DELLAS)

Good cutting performances of the MIM gang saw blades on different stones (Dellas)

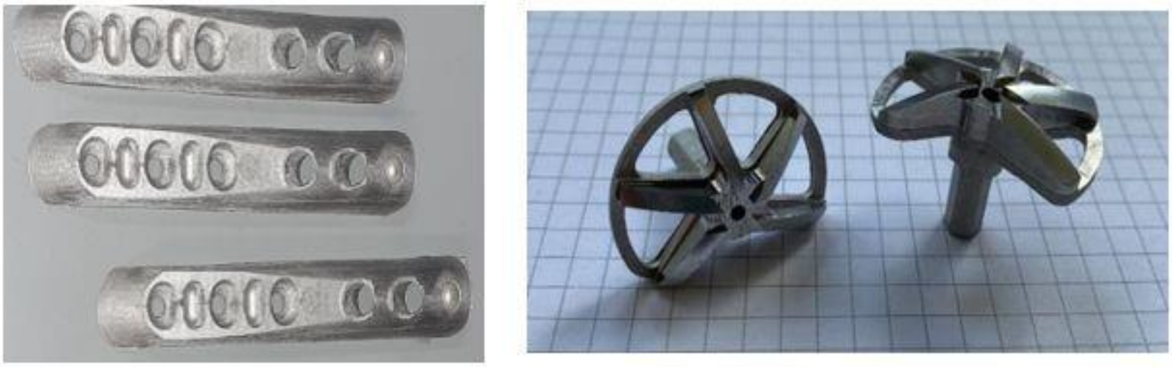
Figure 12: Diamond composite cutting segments developed by MIM process as-built and after mounting on saw blades

Regarding the medical use-cases studied (MBA) (Figure 13), the overall results are: a 36% reduction of raw material yield losses; a 72% reduction in energy consumption; a 5444% increase of production rate and a 52% reduction in CO_2 emissions compared to baseline processes.



35% reduction in scrap materials and L-PBF powder for MIM process (CEA)

100% recycling of MIM scraps for WA 17-4PH thanks to no impact on the tensile properties (CEA)

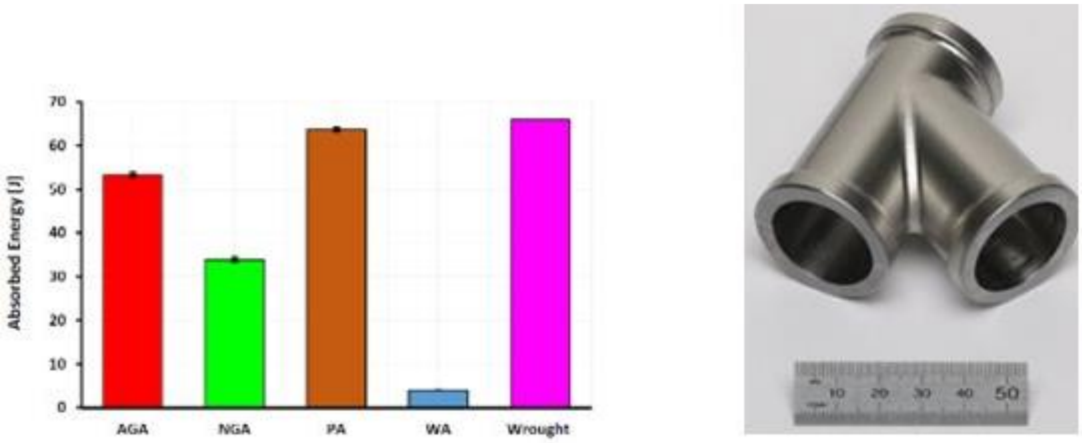


New MIM production route developed for a medical prosthesis (IDONIAL)

4 new production routes developed for a medical tool (MBA, CEA, RHP, GKN & Tecnalia)

Figure 13: Main results obained on recycling of MIM scraps and examples of medical use-cases produced by MIM

Regarding the HIP process (TWI), the sub-marine part use-case demonstrated a 75% improvement of the buy-to-fly ratio and an important energy saving (Figure 14).



50% increase on the Impact Strength of HIP Inco625 using PA powder compared to NGA powder (TWI)

75% reduction of the Buy-to-Fly ratio of Inco625 Y submarine pipe thanks to HIP compared to casting, forging and machining (TWI)

Figure 14: Main results obtained with HIP process

SUPREME was promoted through various materials (website, EPMA newsletter, 6 SUPREME Newsletters, Conferences & Exhibitions…). Three training sessions were given (EPMA Summer School 2019, PM Life AM module 2019, Experts Training workshop 2020). Many technical papers were published: most of them were presented at Euro PM 2019 and 2020, others were accepted by peer-reviewed journals.

Progress beyond the state of the art and potential impacts

SUPREME results may impact several industries (Oil & Gas, machine production, space, energy…). In addition, the monitoring experience could also tackled several other industries (food, chemistry…).

The whole European PM industry (€11.6bn turnover, 233kt of powder produced and 232kt of PM parts produced in 2019) should also be impacted. Progressively, several parts produced today by casting or machining will be produced by AM processes with optimized geometries. For example, the Ferrous Structural Parts Industry using mainly the Press and Sinter process (63% of the 2019 PM parts produced) will likely invest in more AM processes, generating significant revenues in the future (AM parts were <1% of the 2019 total PM parts produced).

Acknowledgments

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