Sustainability impact assessment of additive manufacturing productive processes

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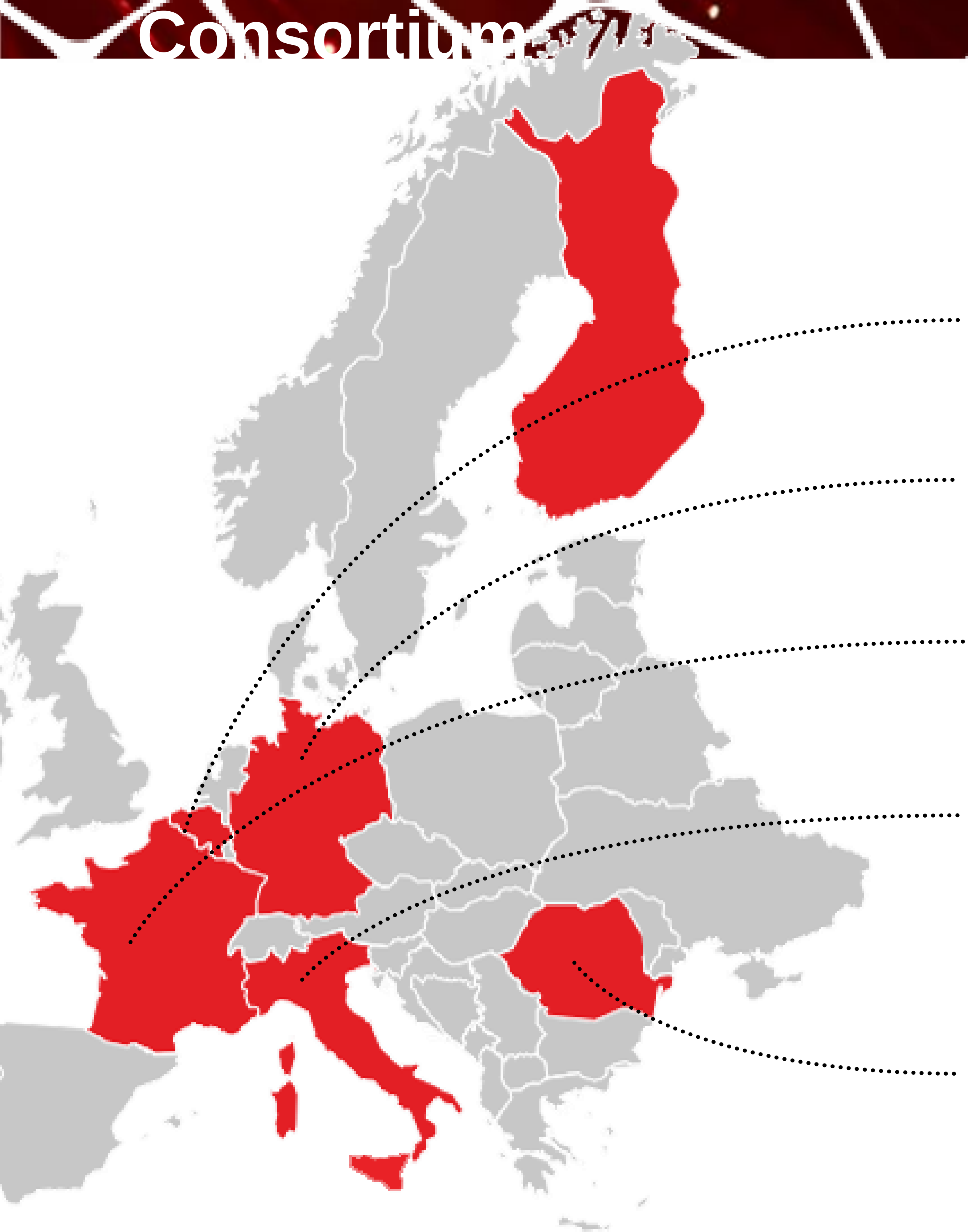
Objective

The aim of DREAM is to significantly improve the performance of laser **Powder Bed Fusion** of **titanium**, **aluminium,** and **steel** components in terms of **speed**, **costs**, **material use** and **reliability**, also using a Life Cycle approach, whilst producing work pieces with controlled and significantly **increased fatigue life**, as well with **higher strength-to-weight ratios**.

The motivation for the project is to go far beyond the state of the art in laser-based Powder Bed Fusion, by mastering of all stages of the process chain; among the numerous industrial applications, the project is focused on components for **prosthetic**, **automotive** and **moulding** applications to optimize the procedure respectively for titanium, aluminium and steel.

DREAM targets the development of a competitive supply chain to increase the productivity of laser-based Additive Manufacturing and to bring it a significant step further towards larger **scale industrial use**.

Consortium



be WARRANT

eos
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ADLER ORTHO FRANCE

POLY-SHAPE
additive manufacturing

Ferrari

R.B. s.r.l.

INSTM

Transilvania University of Brasov

MIND.4D
one step beyond

Goal and scope definition

Life cycle assessment (ISO 14040/44):

Medium size prosthetic titanium component

- Studied system: Additive manufacturing productive process using Ti6Al4V powder
- Functional unit: 20 femoral stems
- System boundaries: ‘from cradle to grave’
- Data quality: primary data and literature sources
- Calculation software: SimaPro 8.5.2
- Database: EcoInvent v.3.4
- Impact assessment method: modified** IMPACT 2002+
- LCI model: attributional with substitution

*DREAM Communication kit, http://www.dream-euproject.eu/wp-content/uploads/2018/06/dream_poster_90x60_highMOD_01_06_2018low-min.pdf
**Ferrari et al., 2015, Cappucci et al., 2018, Ferrari et al., 2019

Project Business Case: system boundaries

Medium size prosthetic titanium component

*

From cradle to grave

Production phase

**

- Ti6Al4V powder produced by gas atomization (GA)
- Ti6Al4V powder produced by plasma atomization (PA)

Use phase

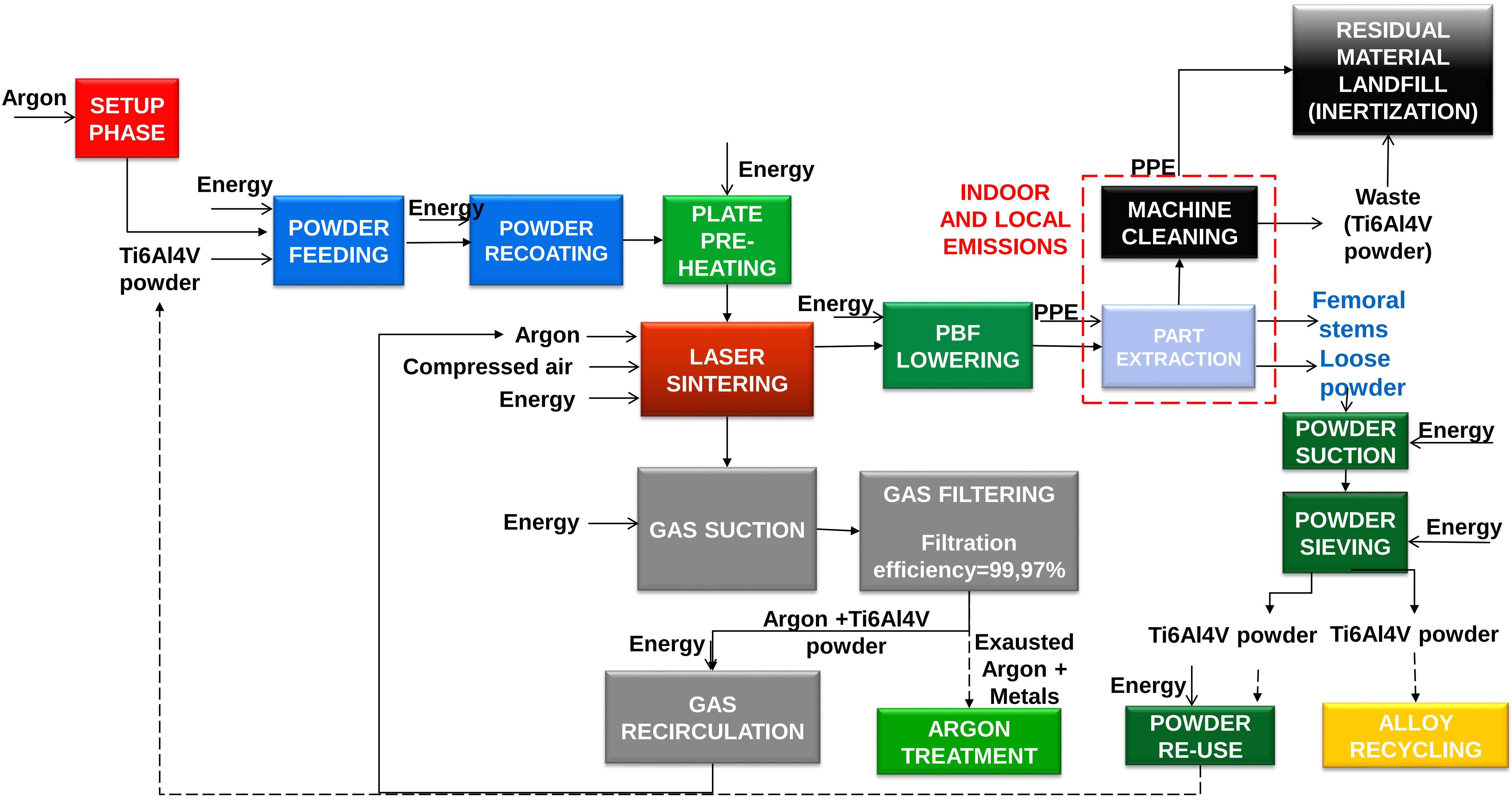
- Stem's implantation
- Medical examinations
- Stem's removal

End-of-life

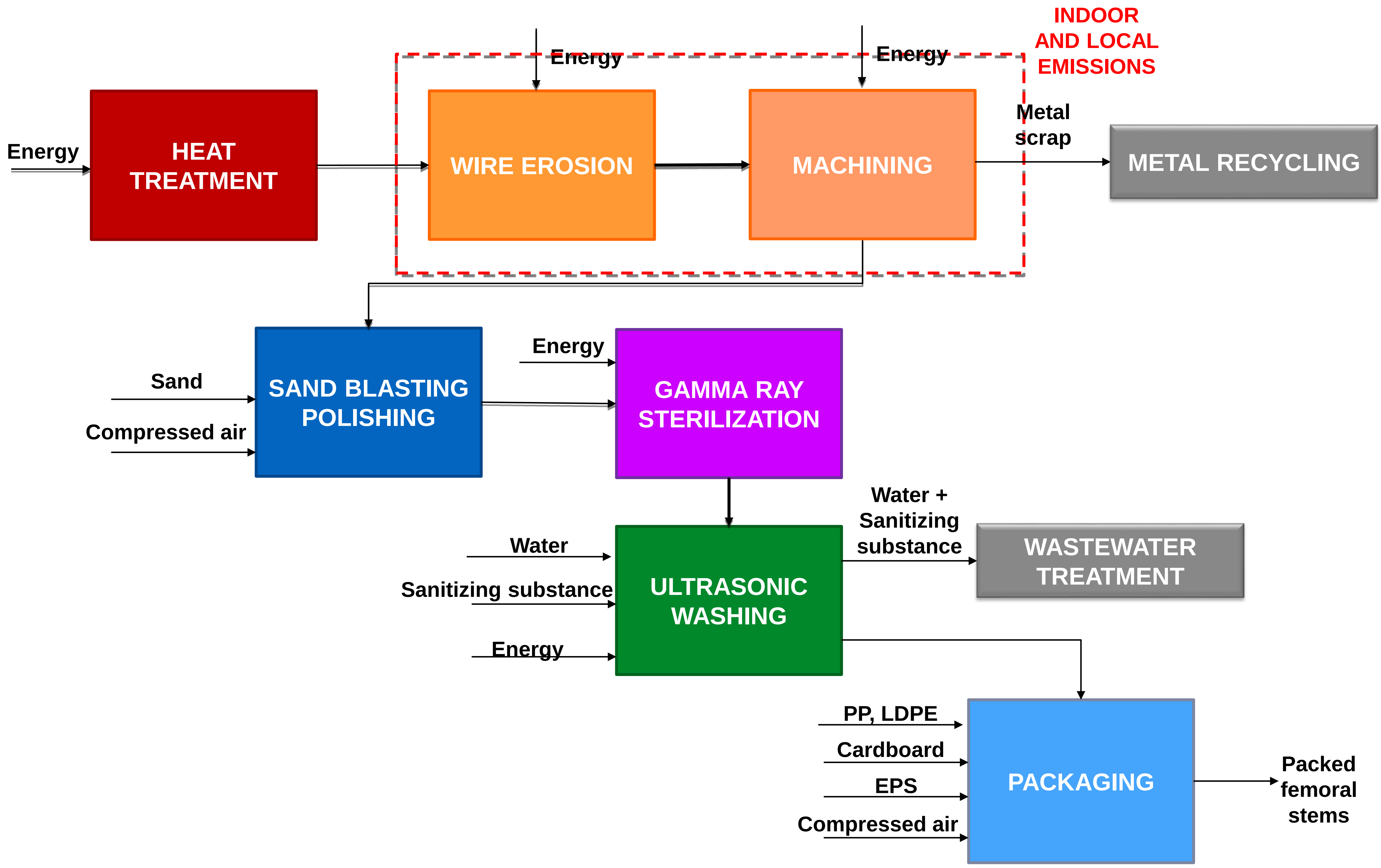
- Sterilization***

*DREAM Communication kit, http://www.dream-euproject.eu/wp-content/uploads/2018/06/dream_poster_90x60_highMOD_01_06_2018low-min.pdf
**https://www.eos.info/eos-m290
***Dr. Susanna Stea, Rizzoli Orthopaedic Institute, Bologna, Italy

Production phase (EOS M290)



Post-production processes



Calculation method: modified IMPACT 2002+

IMPACT 2002+ modified method covers more impact categories than other methods and includes more substances, but the following additions and modifications have been implemented in order to describe the system considered in a more representative manner:

•**Land use** has been estimated by considering basic indicators of both land occupation and transformation. In the present study Transformation, to industrial area have been introduced (Pini M. et al., 2017)

•**Mineral extraction** has been characterized in consideration of some additional resources such as silver, gravel, sand, lithium, bromine and, in particular, Water, groundwater consumption, derived from the category Minerals of Eco-indicator 99 with the same characterisation factors (Goedkoop & Spriensma, 2001)

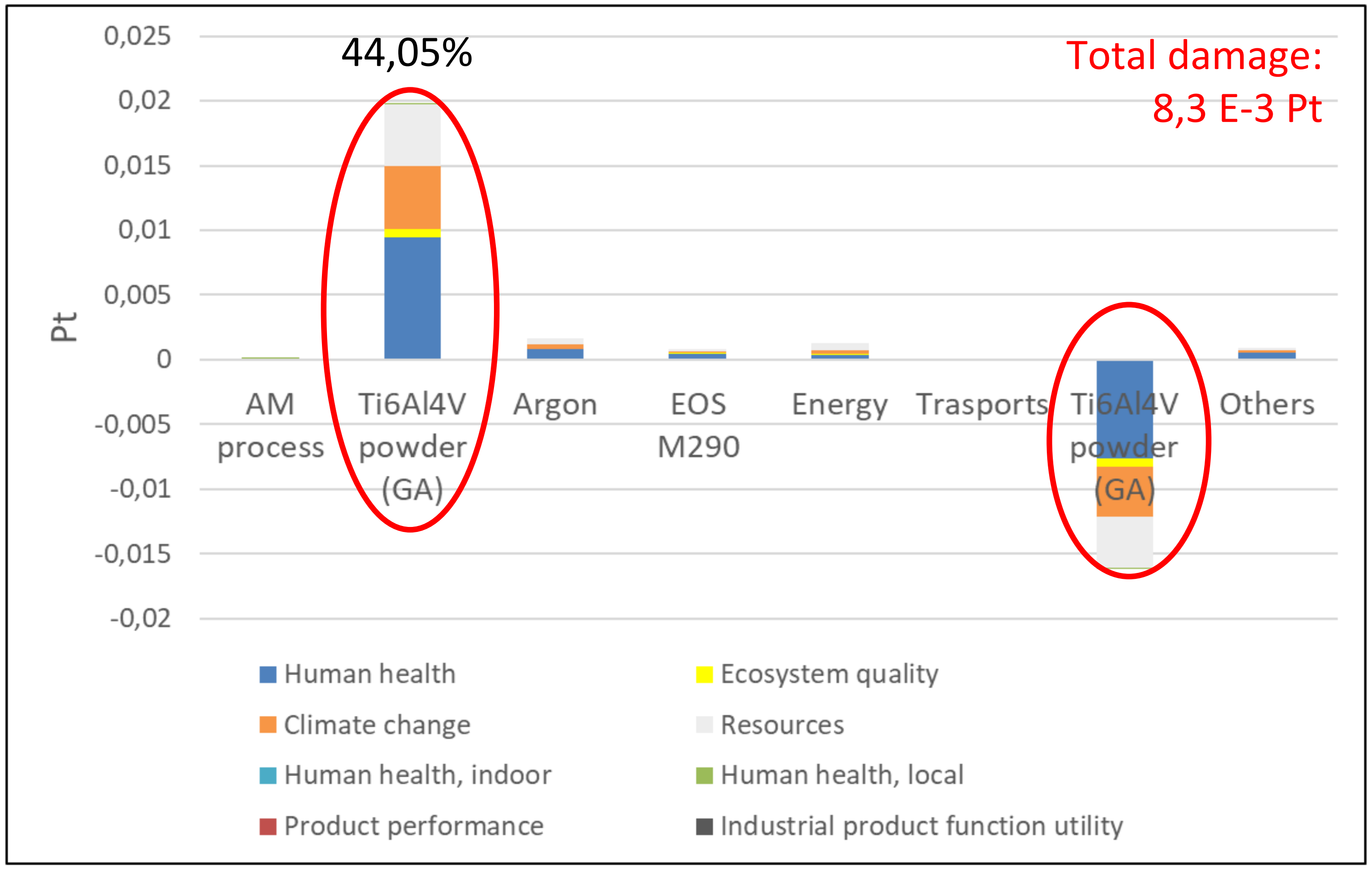
•In the category **Carcinogens** the substance Particulates, < 2,5 mm has been added. The characterization factor of Ecoindicator 99 method has been considered for the category Carcinogens and then divided by the damage assessment factor of IMPACT 2002+ method: 9,78E-6 DALY/kg/2,8E-6DALY/kgC2H3Cl= 3,492857143 kgC2H3Cl/kg (Neri et al., 2010).

•In the category **Respiratory inorganics** the following types of paticulates have been added: Particulates >10 mm; Particulates, diesel soot; Particulates, fine mineral fibers; Particulates, SPM; Particulates, unspecified with characterization factor= 0,157142857kg PM2.5 eq/kg and Particulates, > 2.5 mm, and < 10 mm with a characterization factor of 0,535714286 kg PM2.5 eq/kg **(**Neri et al., 2015).

•**Human health, indoor and Human health, local**: the substance Argon indoor has been introduced in the category **Non-carcinogens, indoor**, by calculating its damage factor **(**Cappucci et al., 2018); the substance Metals, unspecified indoor and Metals, unspecified, local have been introduced, namely in the category **Carcinogens, indoor** and **Carcinogens, local (**Ferrari et al., 2019).

Damage analysis

Life cycle impact assessment*: 1 femoral stem production phase (AM-GA powder)



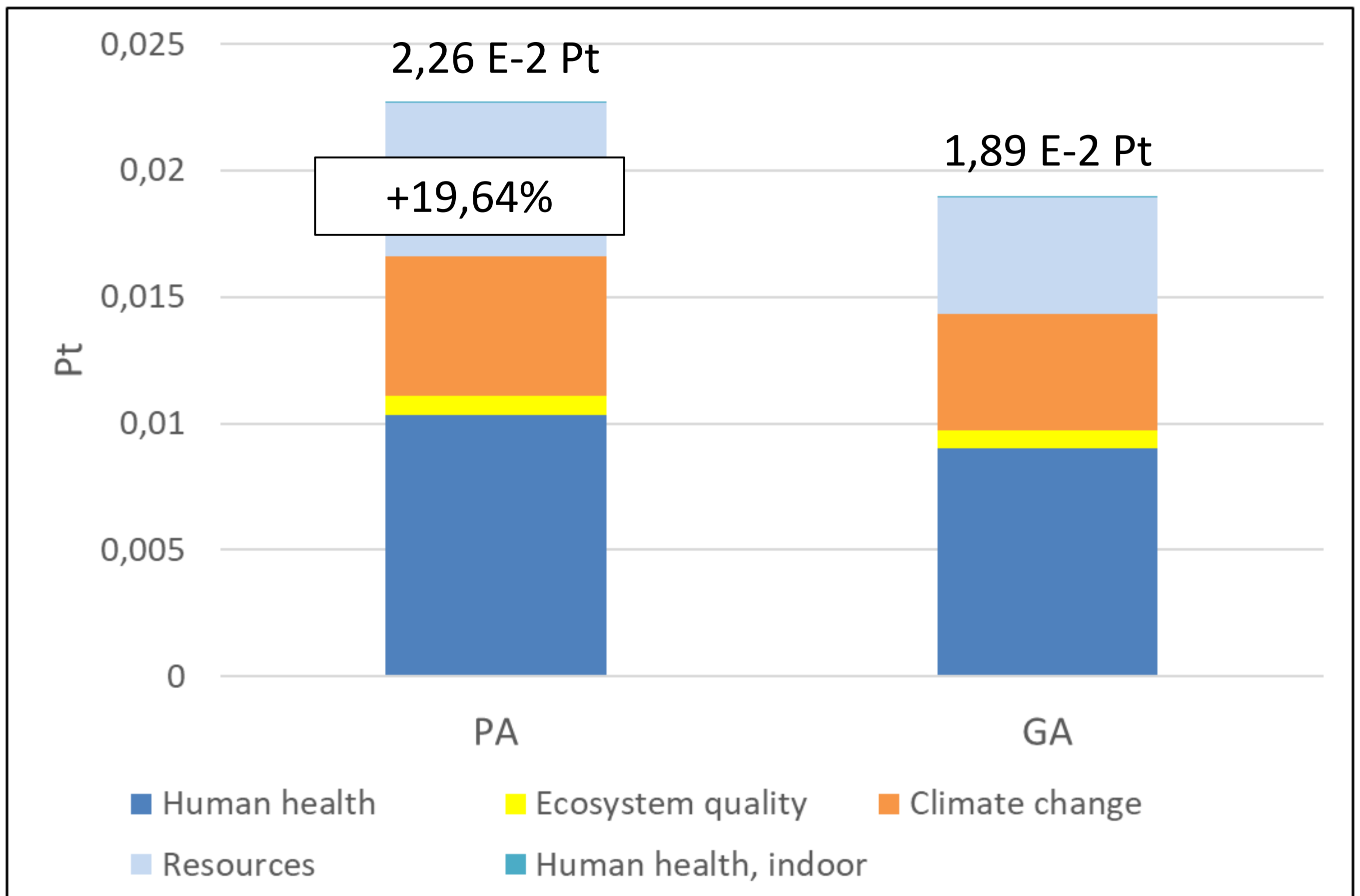
Damage category	Contribution %	Substance
Human health	**47,94**	***Particulates, <2,5 micron***
Resources	**25,58**	***Coal, hard***
Climate change	23,47	*Carbon dioxide, fossil*
Ecosystem quality	3,94	*Aluminium*
Human health, local	0,15	*Metals, unspecified, local*
Human health, indoor	6,03E-5	*Argon, indoor*

*cradle to gate

Damage analysis

Life cycle impact assessment

1 kg of Ti6Al4V powder produced with GA vs PA



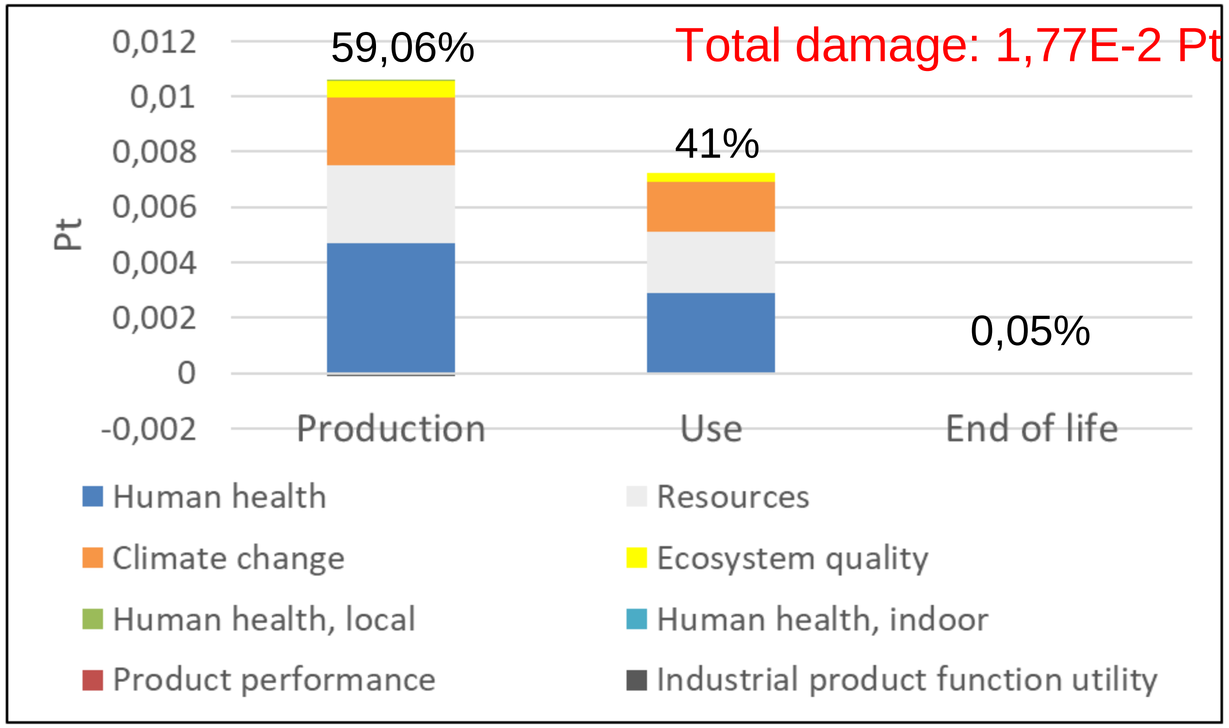
LCA analysis is conducted with GA powder

Damage category	Variation Δ %	Substance
Human health, indoor	**+2 orders**	***Argon, indoor***
Resources	**+31,56**	***Coal, hard***
Climate change	+19,24	*Carbon dioxide, fossil*
Human health	+14,45	*Particulates, <2,5 micron*
Ecosystem quality	+9,27	*Aluminium*

Damage analysis

Life cycle impact assessment - cradle to grave

- Average stem lifetime: 15 years*
- Mean age at the time of surgery: 69 years**
- Rate of deceases within 10 years of surgery: 25%**



Damage category	Contribution %	Substance
Human health	**42,77**	***Particulates, <2,5 micron***
Resources	**28,6**	***Coal, hard***
Climate change	23,88	*Carbon dioxide, fossil*
Ecosystem quality	5,18	*Occupation, forest, intensive*
Human health, local	2,83 E-5	*Metals, unspecified, local*
Human health, indoor	5,5E-5	*Argon, indoor*

*Wyatt et al., 2014.
**Wainwright et al., 2011.

Damage analysis

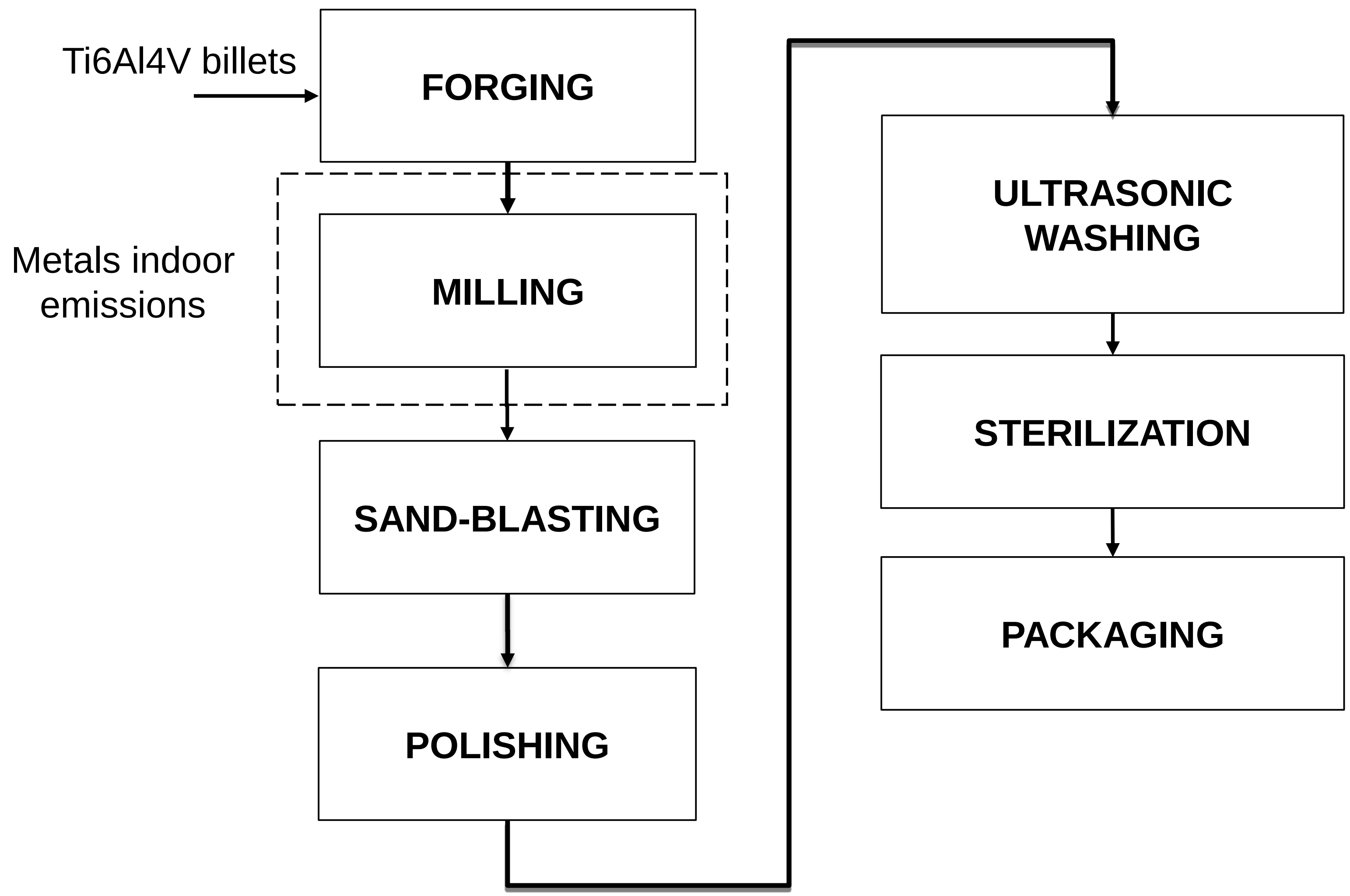
Introduction of positive aspects of AM

Impact category	Issues	Weight (CF)
Product performance	Geometry complexity	0,8
	Biocompatibility	0,8
Industrial product function utility	Medical devices	1

With the introduction of the indicators damage is reduced of **-0,5%.**

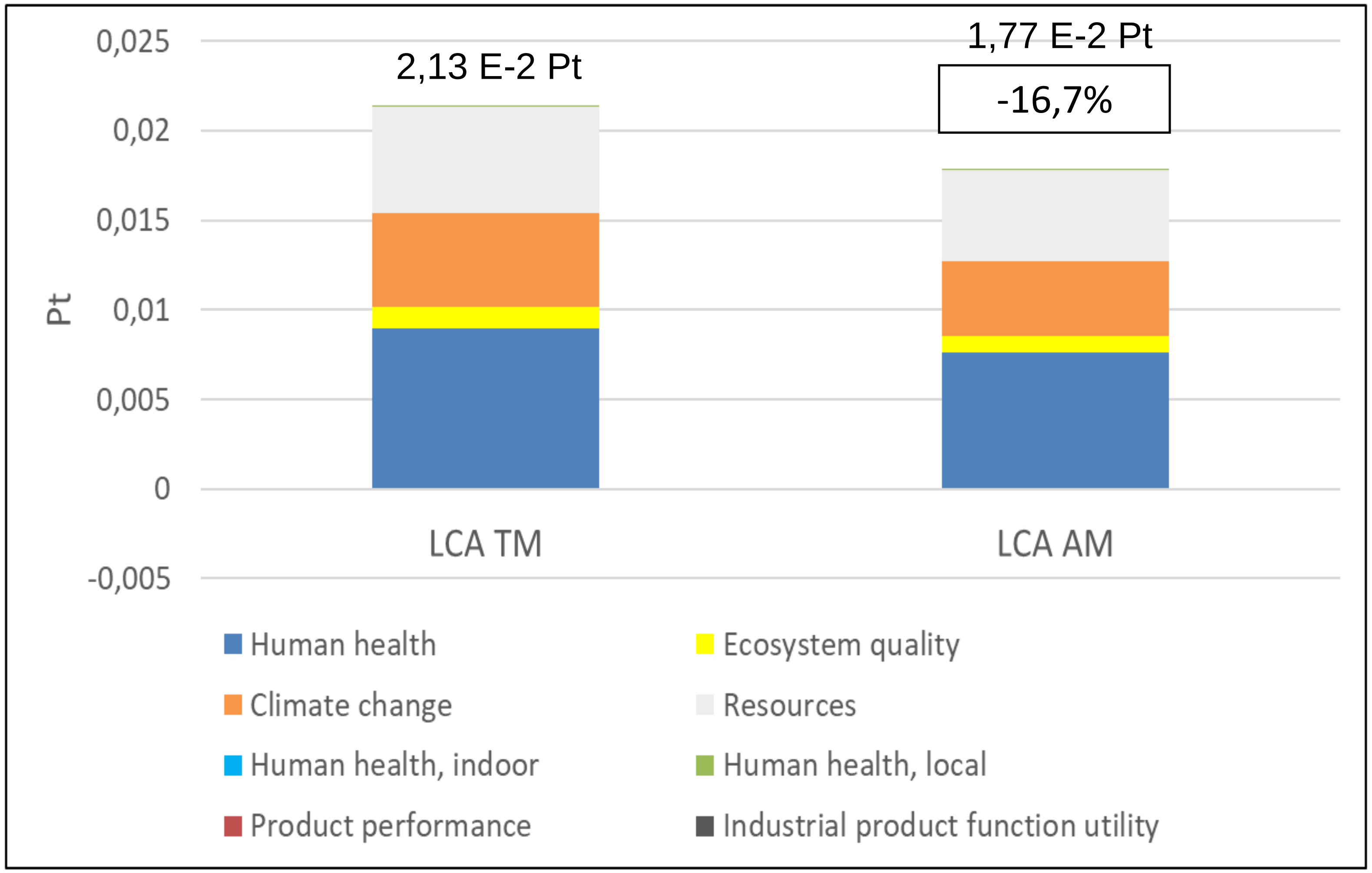
Damage analysis

Production phase TM



Damage analysis

Comparison between 1 femoral stem (TM) and (AM-GA)



Metal scrap:
- 0,45 kg (TM)
- 0,11 kg (AM)

Most significative decrease:

- **Ecosystem quality,** -25,33% (Occupation, industrial area → furnace for titanium alloy)
- **Climate change**: -19,5% (*Carbon dioxide, fossil* → heat production, for primary titanium production)

Conclusions

- A cradle to grave LCA has been performed for 20 femoral stems produced with AM and GA powder usage and, as result, the highest environmental burden is found to be the production phase, followed by use phase and end of life.
- A comparison between two different titanium alloy powder production technologies (GA and PA) is followed in order to minimize damage due to stems production phase.
- The analysis of results illustrates that the most sustainable choice for powder production is represented by Gas atomization.
- The comparison between different production technologies (TM) shows that AM is the most sustainable one thanks to the lower amount of titanium alloy used (→ lower metal scrap).
- Hint of improvement: argon reuse.

Thanks for the attention

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PHOTONICS[21] PHOTONICS PUBLIC PRIVATE PARTNERSHIP

FoF Factories of the Future Public Private Partnership

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