AZTERLAN

MEMBER OF BASQUE RESEARCH
& TECHNOLOGY ALLIANCE

RE·THINKING METALLURGY

re·THINKING
Sustainability of Metallic Alloys

WORKSHOP on Sustainable Materials organized by EMIRI-AMI2030
DONOSTI 21ST NOVEMBER 2023

- Private Research Centre focused on metallurgy and manufacturing technologies of metallic components (since 1974)
- Great expertise in foundry, forging, stamping technologies.
- Avantgarde equipment and facilities.
- Members of the BRTA-Basque Research and Technology Alliance, gathering 17 R&D organizations acting in different fields.
- International networking and collaborations

Compliance with INTERNATIONAL STANDARDS and customer homologations

- Testing Laboratories EN ISO/IEC 17025
- National Aerospace and Defense Contractors Accreditation Program
- R&D activities UNE166002

ilac-MRA · ENAC ENSAYO ISO 17025 Nº59 / LE069 · Nadcap Administered by PRI ACCREDITED · UNE 166.002 I+D+i BUREAU VERITAS Certification · AIRBUS · SIKORSKY A LOCKHEED MARTIN COMPANY · BOEING · RENAULT

OUTSTANDING FACILITIES

- Pilot plant with liquid and solid alloys processing capabilities.
- Heat treatment and cryogenic facilities.
- Laboratories for testing materials properties (destructive and non-destructive)
- Simulation and modelling capacities of materials and processes.
- Metallic powder atomization and EHLA projecting capabilities.
- Sand mold injecting and printing capabilities.
- Machining workshop.

FIELDS OF ACTIVITY

MATERIALS: Design and development of ferrous and non-ferrous metallic materials, solidification analysis and phase transformations.

INTELLIGENT MANUFACTURING TECHNOLOGIES: Predictive Control Systems, traceability of process variables, monitoring and artificial intelligence in real time.

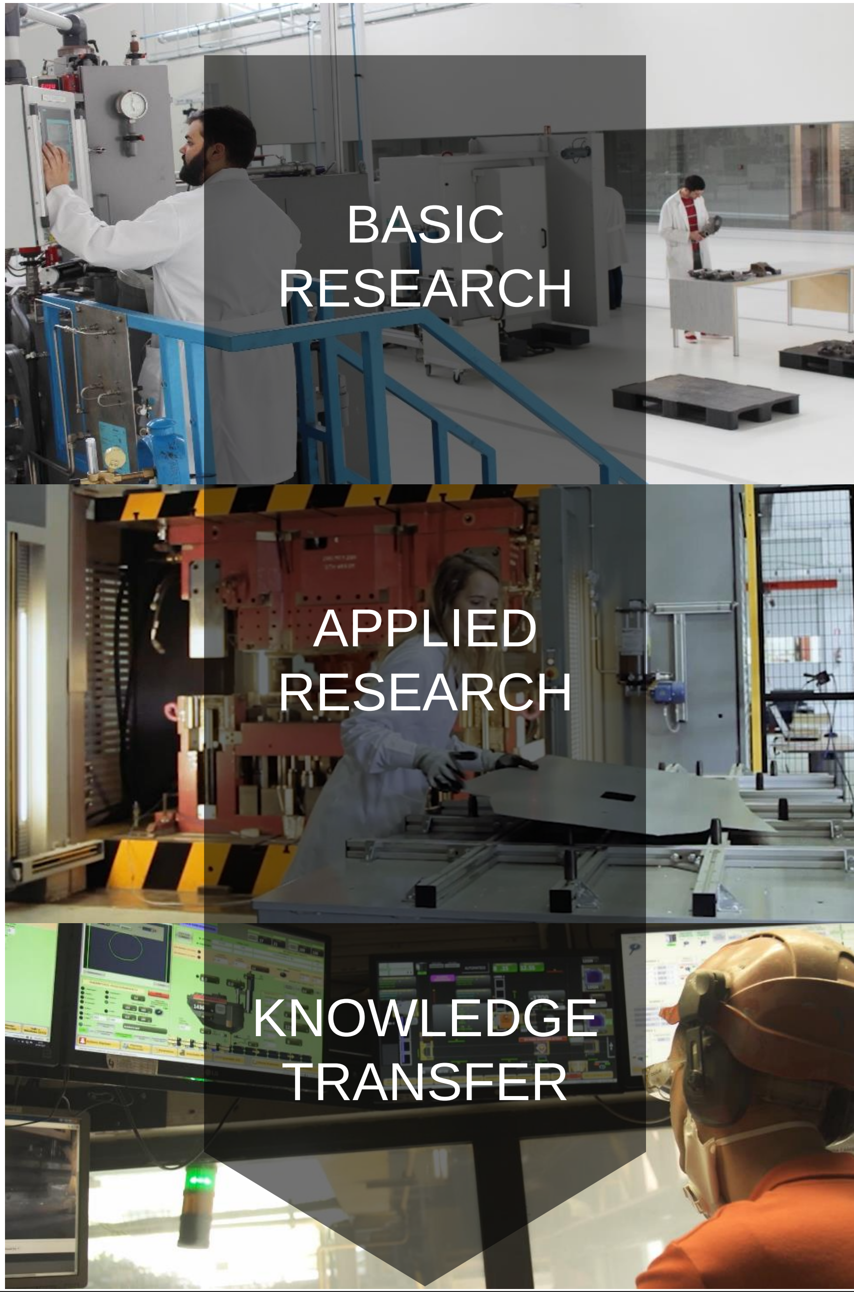
MANUFACTURING PROCESSES: Foundry technologies for ferrous and non-ferrous metallic materials (Gravity, High and low pressure die casting, etc.), transformation into solid and semi-solid state (stamping, forging), heat treatment, process development, defective reduction, etc.

SUSTAINABILITY AND ENERGY: Management and recovery of industrial waste, sustainable processes, air pollution, energy efficiency.

OTHER RELATED AREAS: Corrosion, surface technologies, fracture mechanics.

- 1 new Metal alloy
- 1 new Metal Processing Technology

} patented per year



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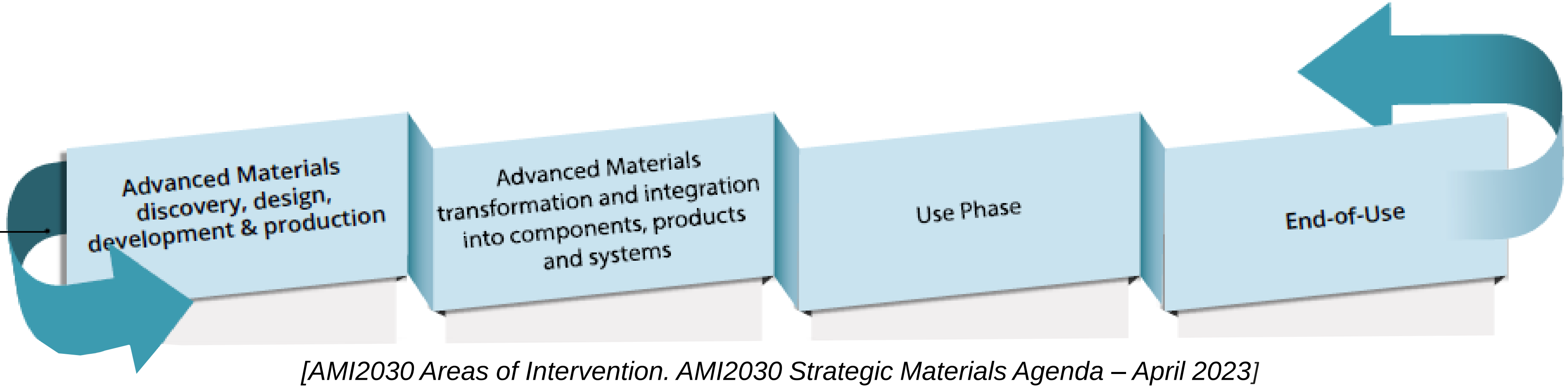
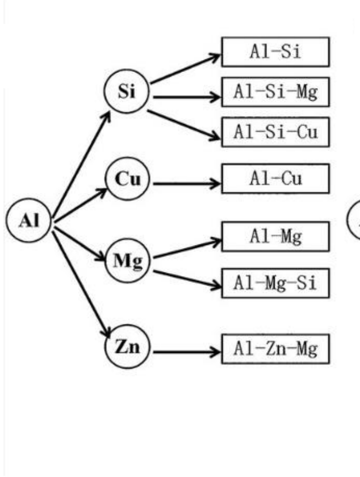
The main segments of the advanced materials circular value chain



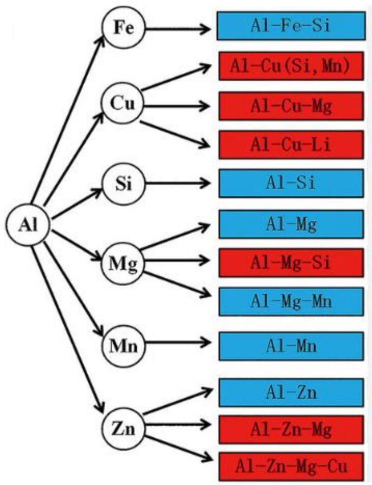
[AMI2030 Areas of Intervention. AMI2030 Strategic Materials Agenda – April 2023]

Advanced Metallic Materials ➡ Complex materials (very different chemical composition).

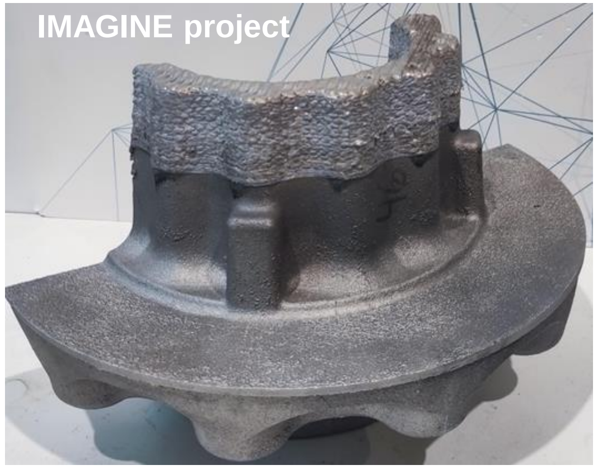
Integration into components, products and systems ➡ Complex mixed products and systems.



Casting Aluminium alloy families

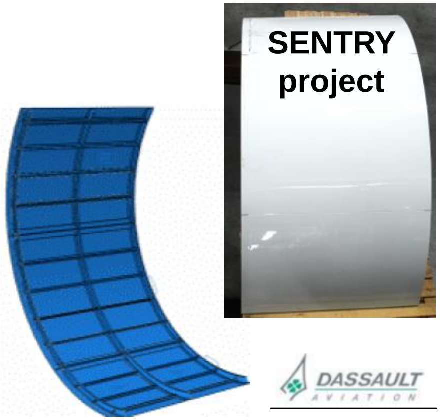


Wrought Aluminium alloy families

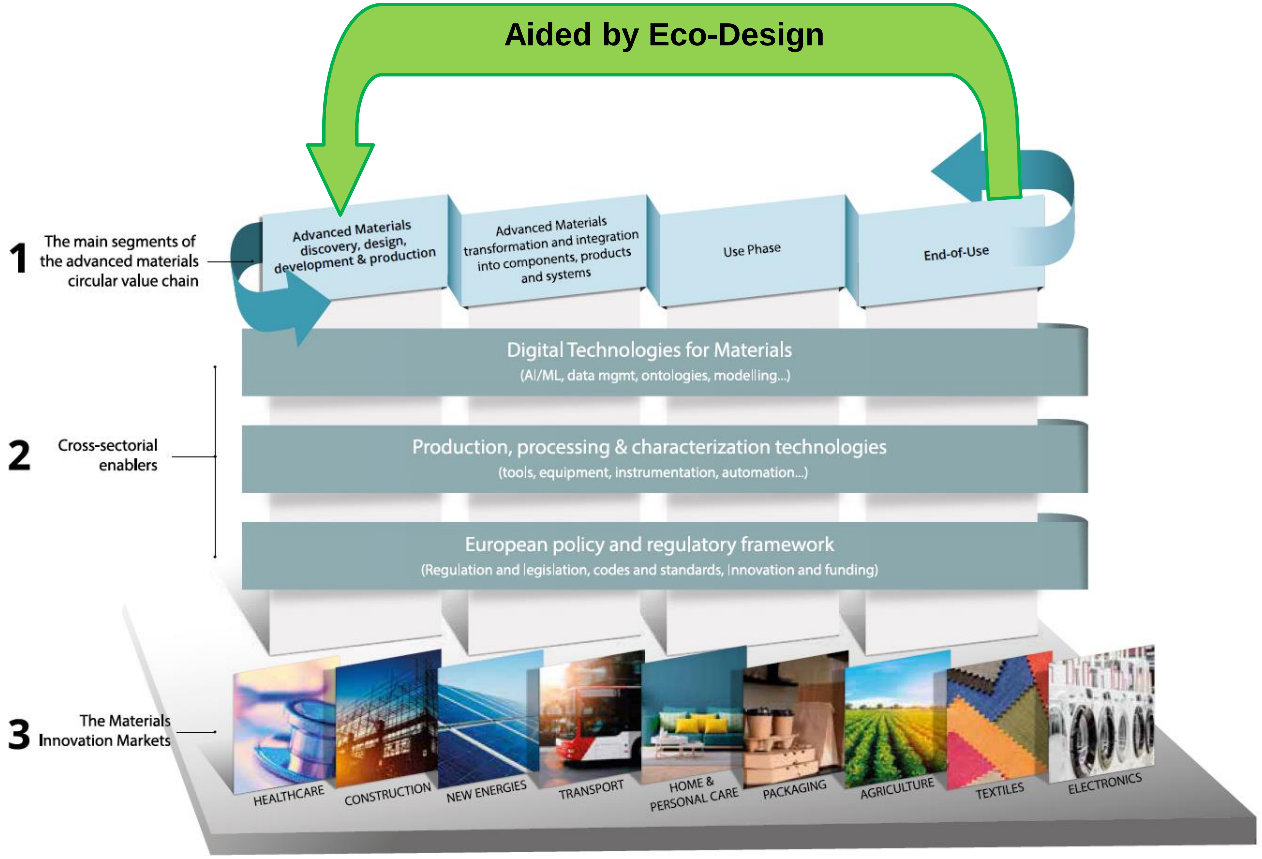


Hybrid components (casting + aditive).
[Madarieta et al. Dyna 2023]

BiW of multitude of different materials weld each other *[Andersson et. Al. 2016]*



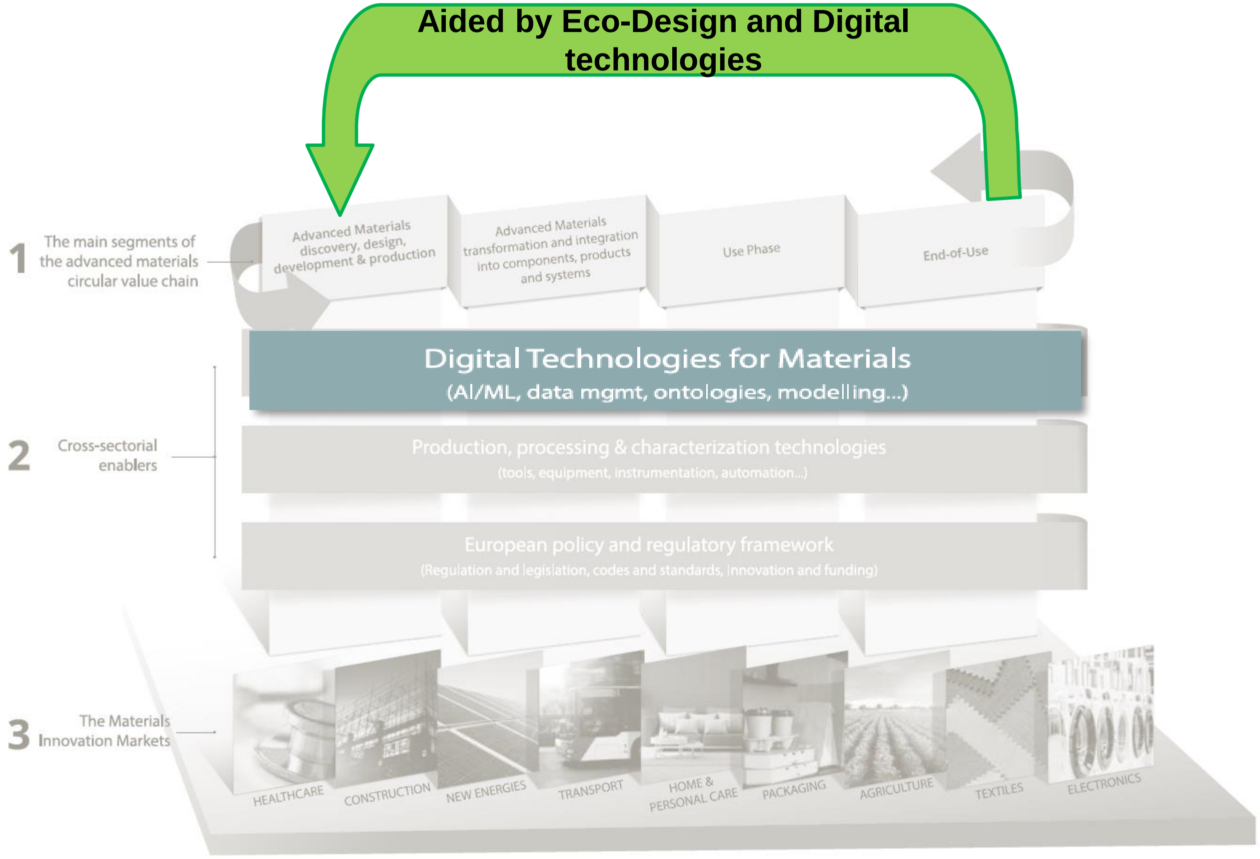
Al aeroestructure of different materials
[Arnaiz et. Al. 2016]



AMI2030 Areas of Intervention. [AMI2030 Strategic Materials Agenda – April 2023]

KEY ASPECTS for SUSTAINABLE RECYCLING to avoid the easy downcycling of advanced metals:

- **Eco-Design** of products/systems:
  - Study the **chemical compatibility** of the alloys to avoid poisoning of high-grade alloys.
  - Design and development of recycled friendly-alloys (**more-scrap tolerant** alloys).
  - Use **easy disassembly system** for non-compatible products (modular or standardised joining).



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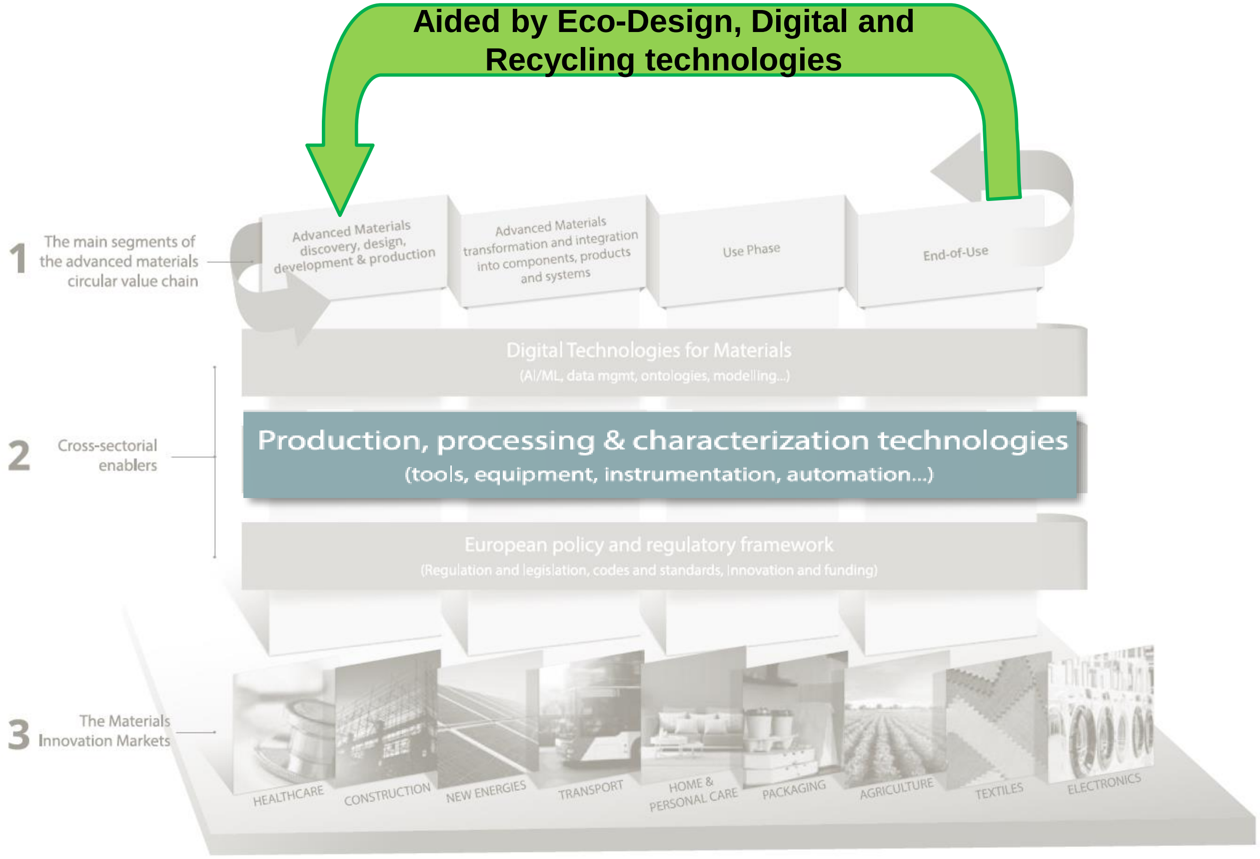
  - Develop software **compatibility tools**.
  - Introduce **Digital Passport** to facilitate identification and separation by alloy grade.



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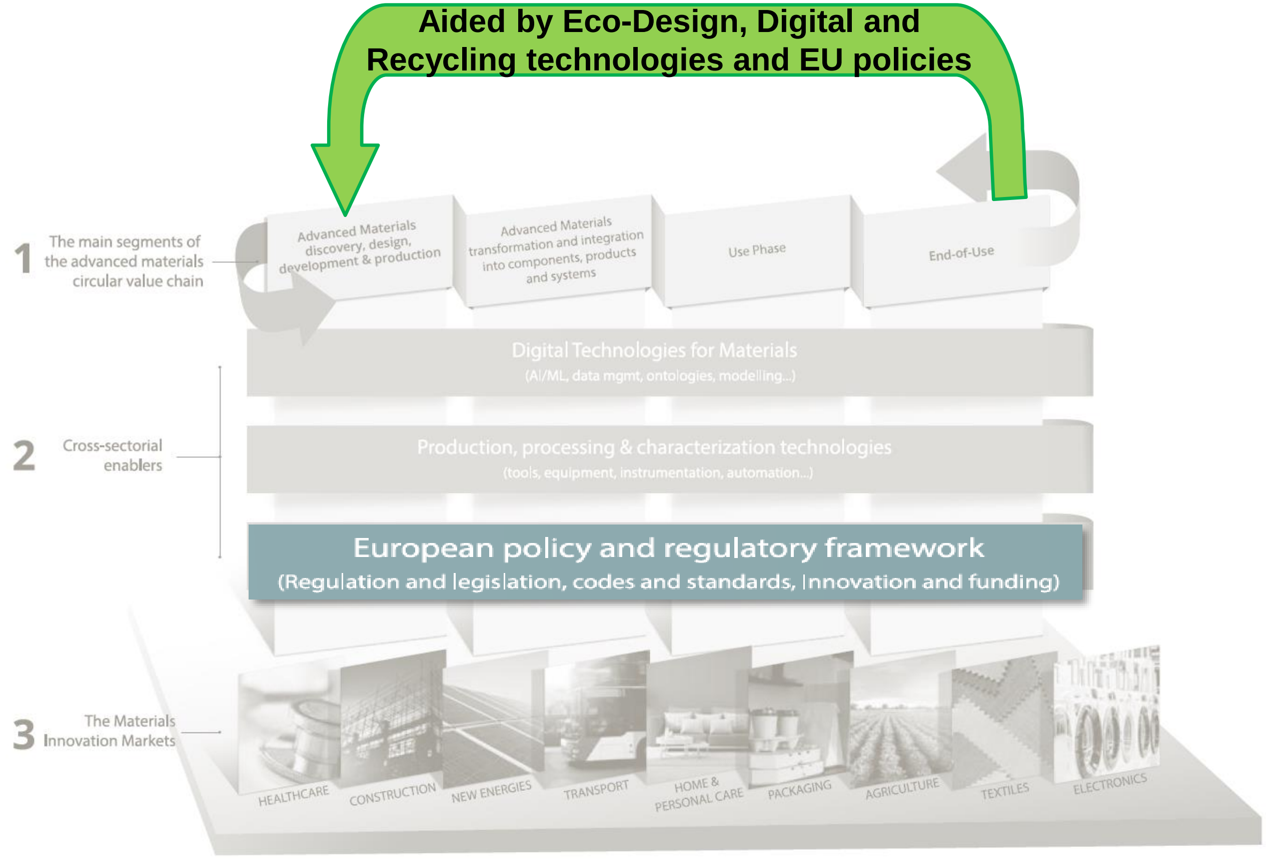
- **Guidelines for End-of-Life** recycling of metallic products/systems for
  - **“UP-grade RECYCLING”**.
  - Promote **valorisation of alloying elements** of domestic scrap.



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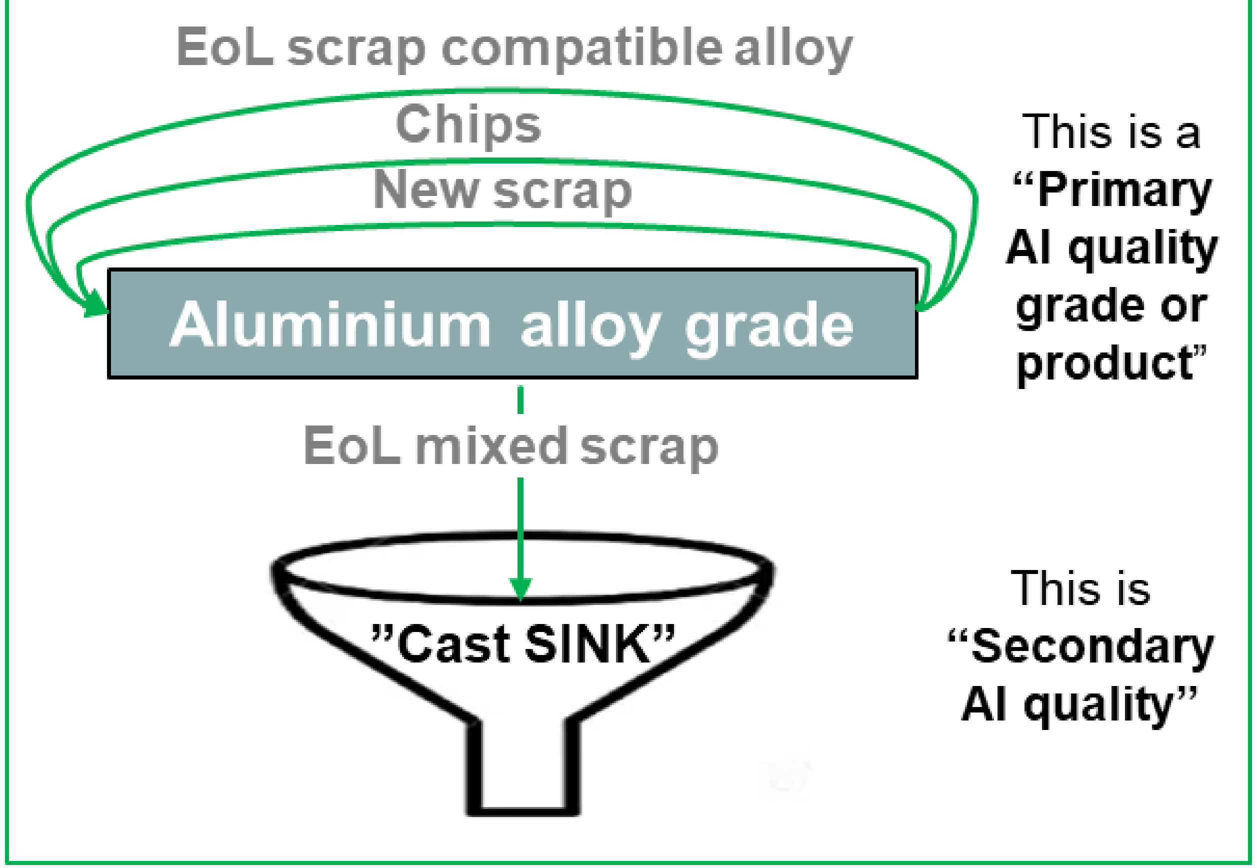
  - Promote **valorisation of alloying elements** of domestic scrap.

- **EU policy and regulatory framework**
  - **Limit scrap exportation**
  - Stimulate **circular economy/product**
  - Stimulate **collaboration along the value chain**

Example of Recyclability loops of Aluminium (Al)

Aluminium is ENDLESS RECYCLABLE to produce the SAME PRODUCT with the SAME HIGH QUALITY



New scrap is generated during the manufacturing or fabrication process of metal products (e.g. up to 90 % of aircraft sheets returns for close-loop recycling).

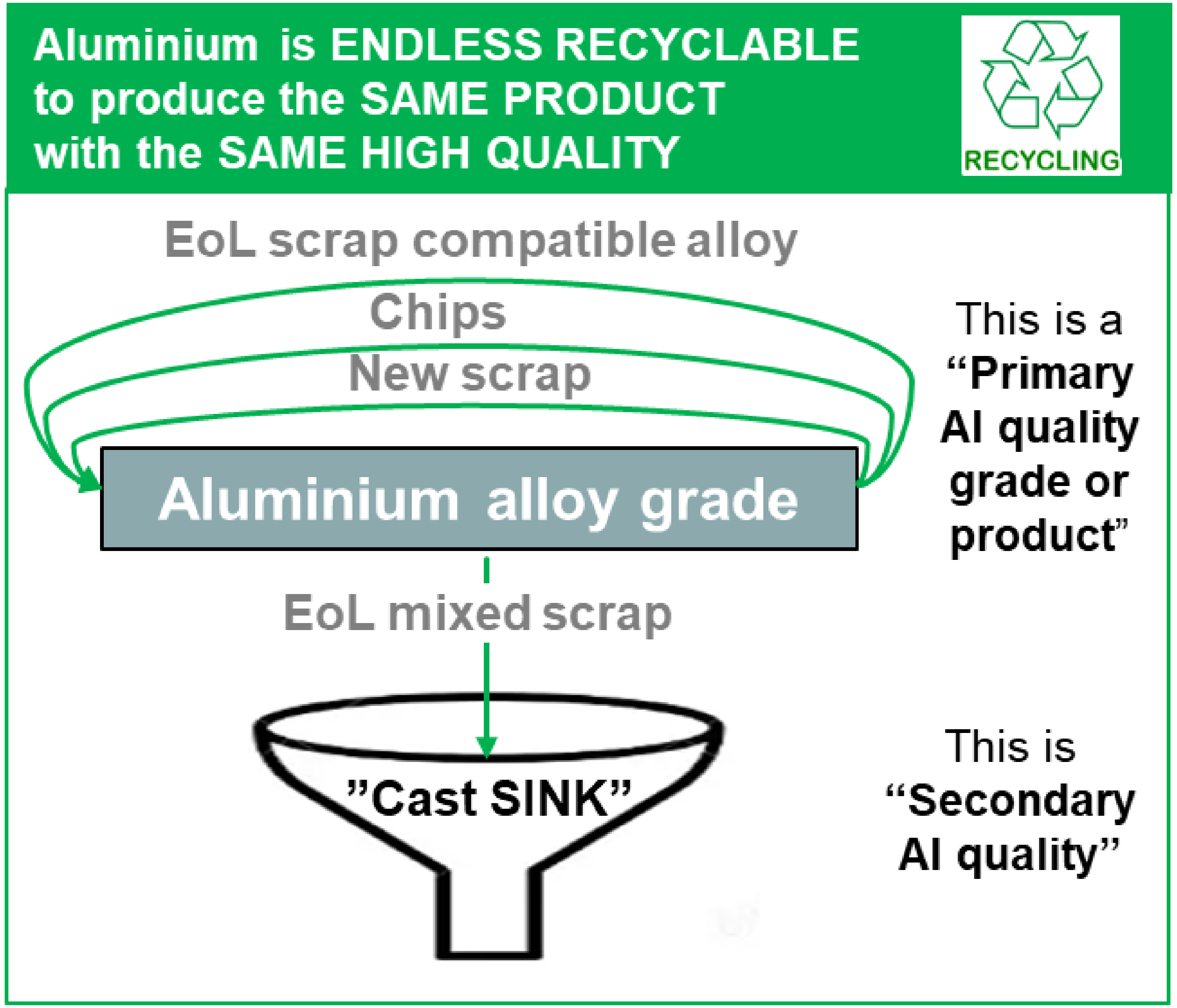
EoL scrap from products that have reached the end of useful life (currently, Al EoL usually goes to "cast sink")

Recycling Al vs primary production allows saving:
- up to **95 % energy**
- **96 % CO_2 emissions**
- 8 t of **bauxite**, 6300 L of **oil**, and 7.6 m3 of **landfill space** are saving per each 1 ton of Al recycled

By 2050, **50 % of EU demand for Al could be supplied by recycling Al** (if specific conditions met). This will not be possible if EU continues **exporting 1 million tonnes** of Al scrap per year (mainly to Asia).

[EAA, 2022, Circular Al action plan | A strategy for achieving aluminium's full potential for circular economy by 2030]

Example of Recyclability loops of Aluminium (Al)



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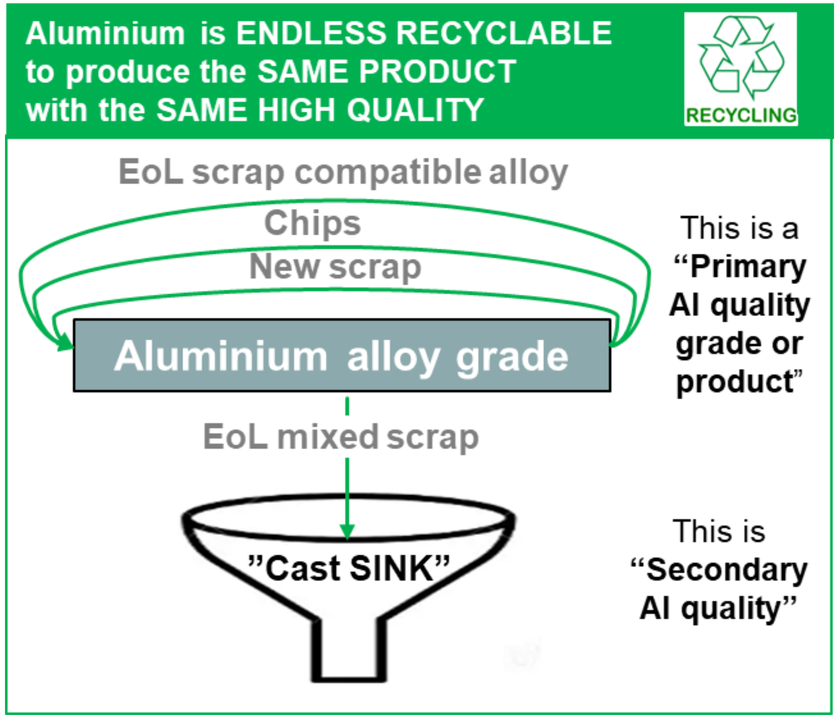
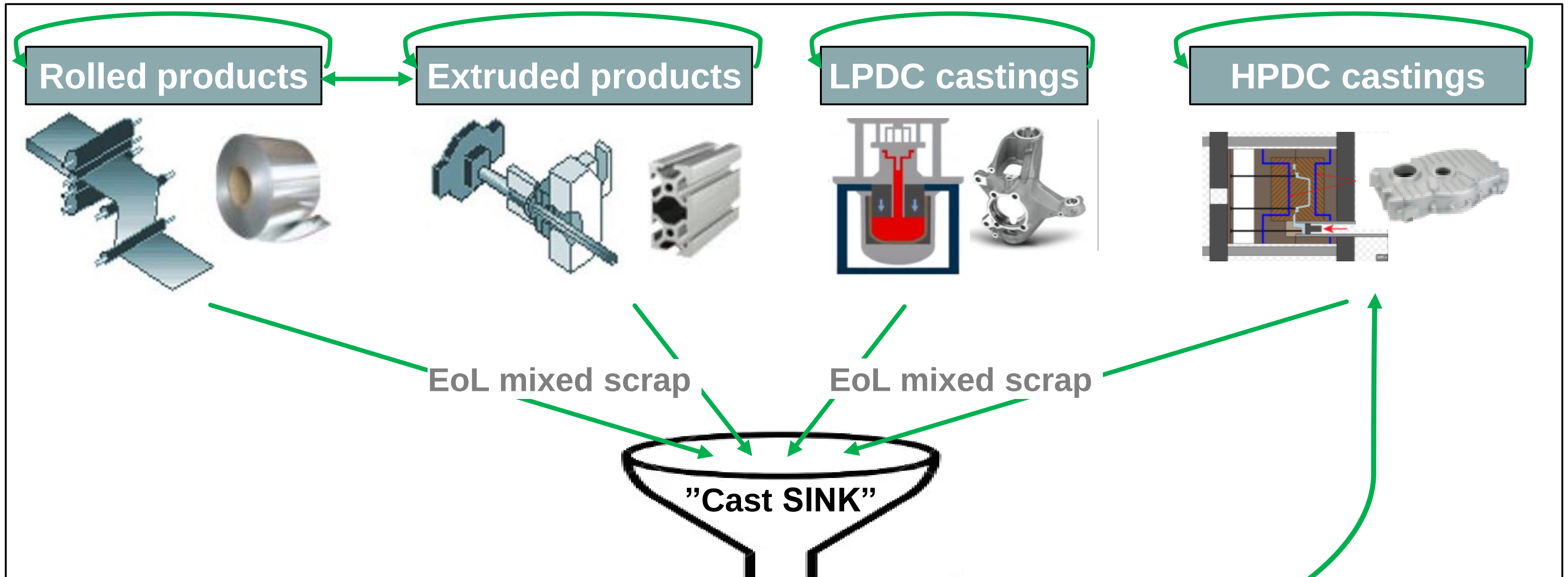
EoL scrap from products that have reached the end of useful life (currently, Al EoL usually goes to "cast sink")

Close-loop of high performance alloys is CRITICAL.
For example, **Al-Li aircraft alloys**:
- Al-Li are high performance alloys ~ 3-4% lighter alloys (good candidates for new aircraft such as A380).
- Expensive alloying (Li, Ag and Zr) and complex manufacturing process (high reactivity of Li)

What happens is they are downcycled in "cast sink"?
- **Al** and **Cu** content will be mostly **recovered**
- **Ag** and **Zr** alloying will be lost as **impurities**
- **Li** will fade forming a high amount **"sponge dross"**

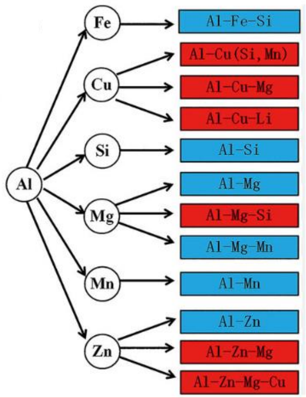
Example of Recyclability loops of Aluminium (Al)





[Figure modified from a scheme of EAA, 2022, Circular Aluminium action plan | A strategy for achieving aluminium's full potential for circular economy by 2030]

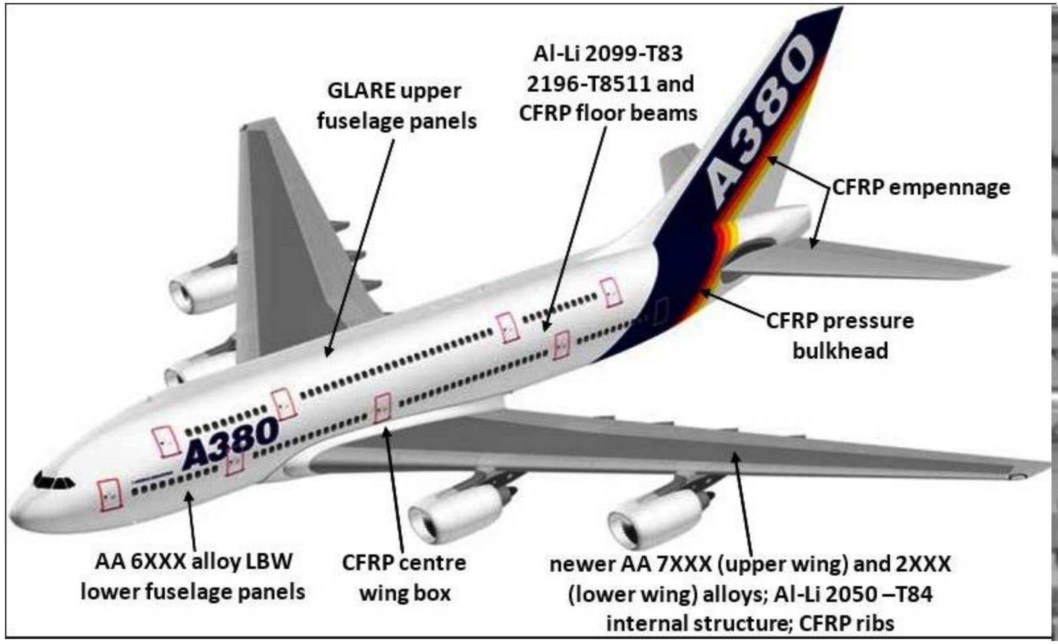
Wrought Aluminium alloy families

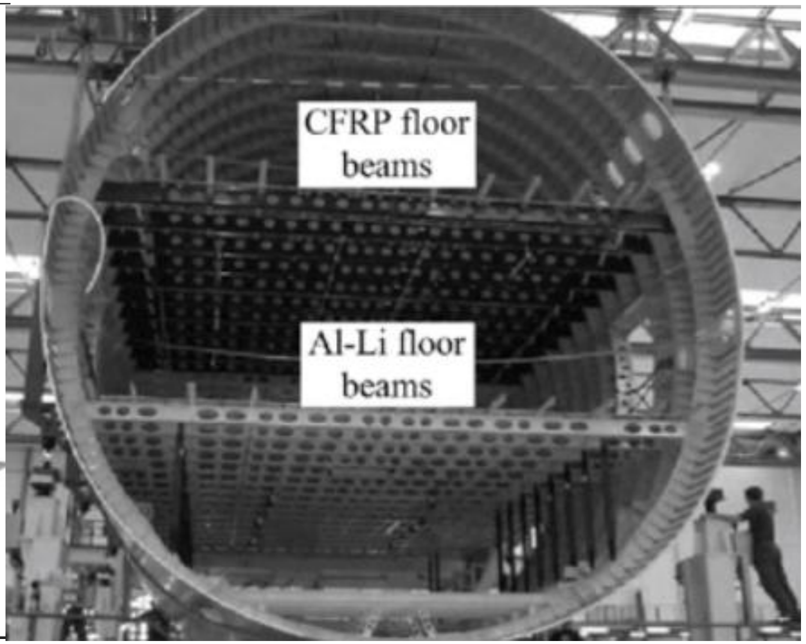


Once the Al scrap is mixed and goes to the "Cast SINK" **alloying elements** of each alloy type **becomes impurities**

Even one of the most expensive Al alloys (such as Al-Li alloys) could become a very low-quality scrap

Several Al-Li aircraft structures are present in new Airbus A380 aircraft.



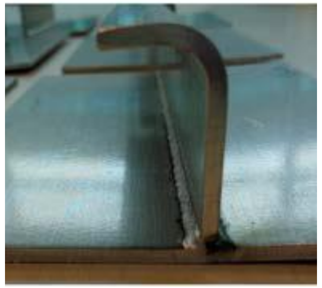
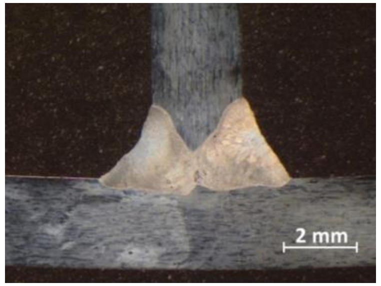


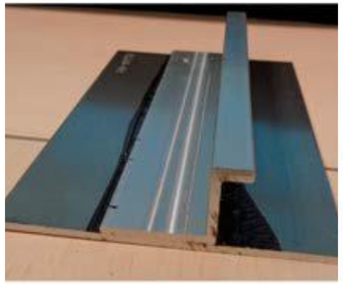
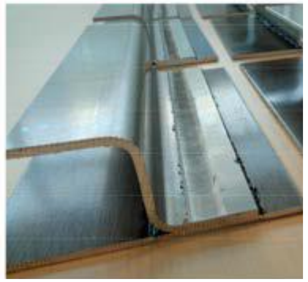
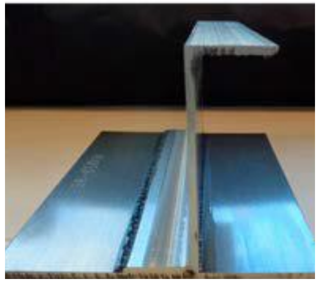
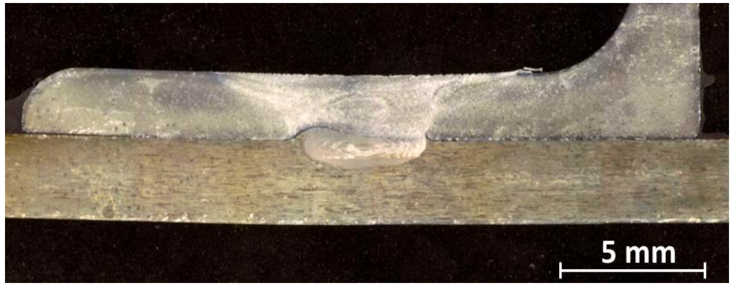
ReINTEGRA project investigated **EoL of 10 integral welded Al-Li coupons:**

- **4 LBW** (Laser Beam welded) coupons using 4 different Fillers wires
- **6 FSW** (Friction Stir Welded) coupons, joining 4 different Al-Li stringers and 2 different Al-Li sheets.

Clean Sky 2 ReINTEGRA

GA No. 886609 — H2020-CS2-CFP10-2019-01

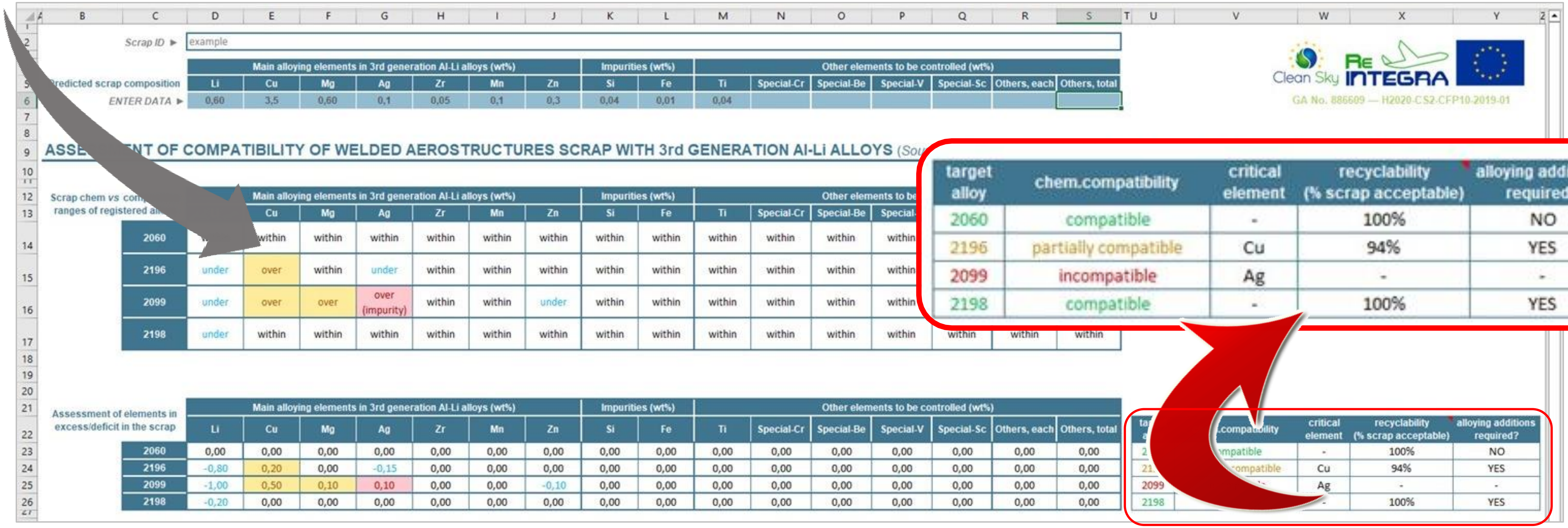





[Fernández et al. Crystals 2023]

ReINTEGRA project (www.reintegra.eu)

- **9 of 10 mixed LBW and FSW Al-Li aeroestructures are compatible for close-loop recycling** to manufacture aircraft Al-Li alloys.
- **The high-Si filler wire** of one LBW combination **poison EoL recycled** AL-Li alloy. Based in the compatibility software tool developed in the Project **the separation of the weld seam is necessary**.

Assessment of compatibility of remelted scrap with the 4 base Al-Li alloys: **ReINTEGRA Scrap Recyclability Tool**



	Main alloying elements in 3rd generation Al-Li alloys (wt%)							Impurities (wt%)		Other elements to be controlled (wt%)						
Predicted scrap composition	Li	Cu	Mg	Ag	Zr	Mn	Zn	Si	Fe	Ti	Special-Cr	Special-Be	Special-V	Special-Sc	Others, each	Others, total
ENTER DATA ►	0,60	3,5	0,60	0,1	0,05	0,1	0,3	0,04	0,01	0,04						

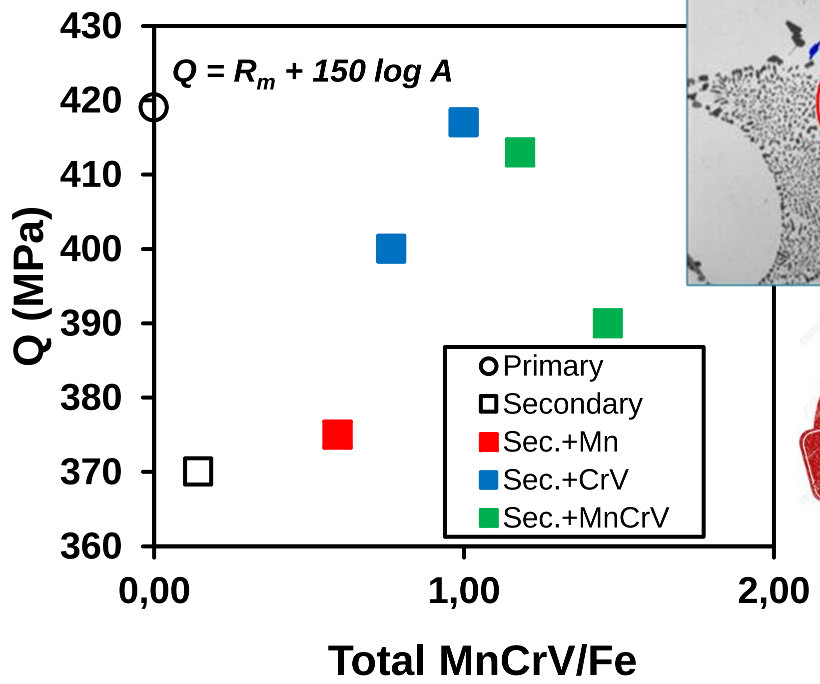
Scrap chem vs com... ranges of registered al...	Li	Cu	Mg	Ag	Zr	Mn	Zn	Si	Fe	Ti	Special-Cr	Special-Be	Special-V
2060		within	within	within	within	within	within	within	within	within	within	within	within
2196	under	over	within	under	within	within	within	within	within	within	within	within	within
2099	under	over	over	over (impurity)	within	within	under	within	within	within	within	within	within
2198	under	within	within	within	within	within	within	within	within	within	within	within	within

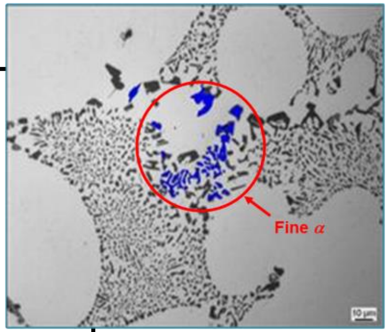
target alloy	chem.compatibility	critical element	recyclability (% scrap acceptable)	alloying additions required?
2060	compatible	-	100%	NO
2196	partially compatible	Cu	94%	YES
2099	incompatible	Ag	-	-
2198	compatible	-	100%	YES

Assessment of elements in excess/deficit in the scrap	Li	Cu	Mg	Ag	Zr	Mn	Zn	Si	Fe	Ti	Special-Cr	Special-Be	Special-V	Special-Sc	Others, each	Others, total
2060	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2196	-0,80	0,20	0,00	-0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2099	-1,00	0,50	0,10	0,10	0,00	0,00	-0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2198	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Substitution of Primary alloy AlSi7Mg alloy with 0.11 %Fe for LPDC (Low Pressure Die casting): steering knuckles, wheels, etc.

New optimized secondary Al alloy (0.3 %Fe with Mn+Cr up to 0.3%)
with the same **high mechanical properties and quality index (Q)** than primary alloy.





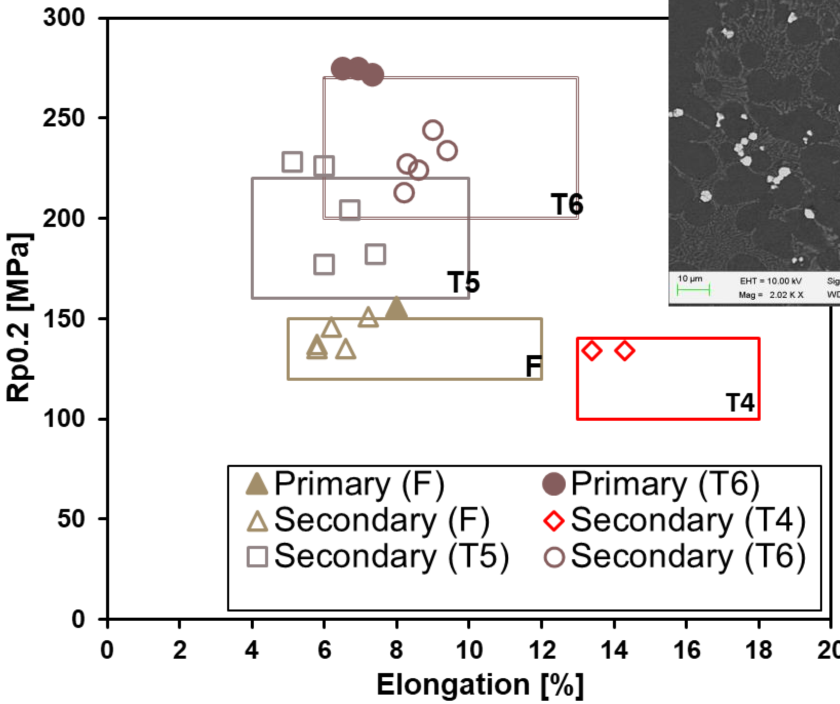
EP2471967A1

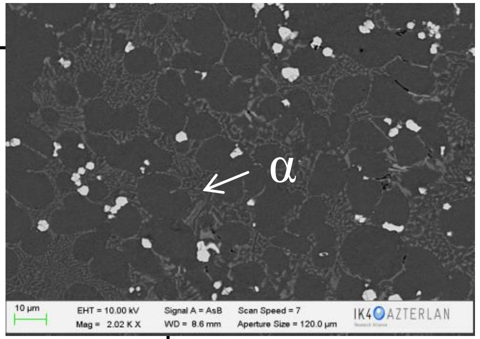
This optimum addition transform the β-iron compounds into α-iron compounds (less harmful)

[Niklas et al. Aluminium 2000 congress, Milano 2013]

Substitution of Primary alloy with 0.17 %Fe and 0.68 %Mn for VPDC (Vacuum assisted High Pressure Die casting): structural thin components

New optimized secondary Al alloy (0.6 %Fe, 0.42 % Mn)
with the same **high mechanical properties** and advantageous **lower Die sticking than primary alloy.**





Rectangles indicate the mechanical property range of the primary AlSi10MnMg alloy (commercial alloy)

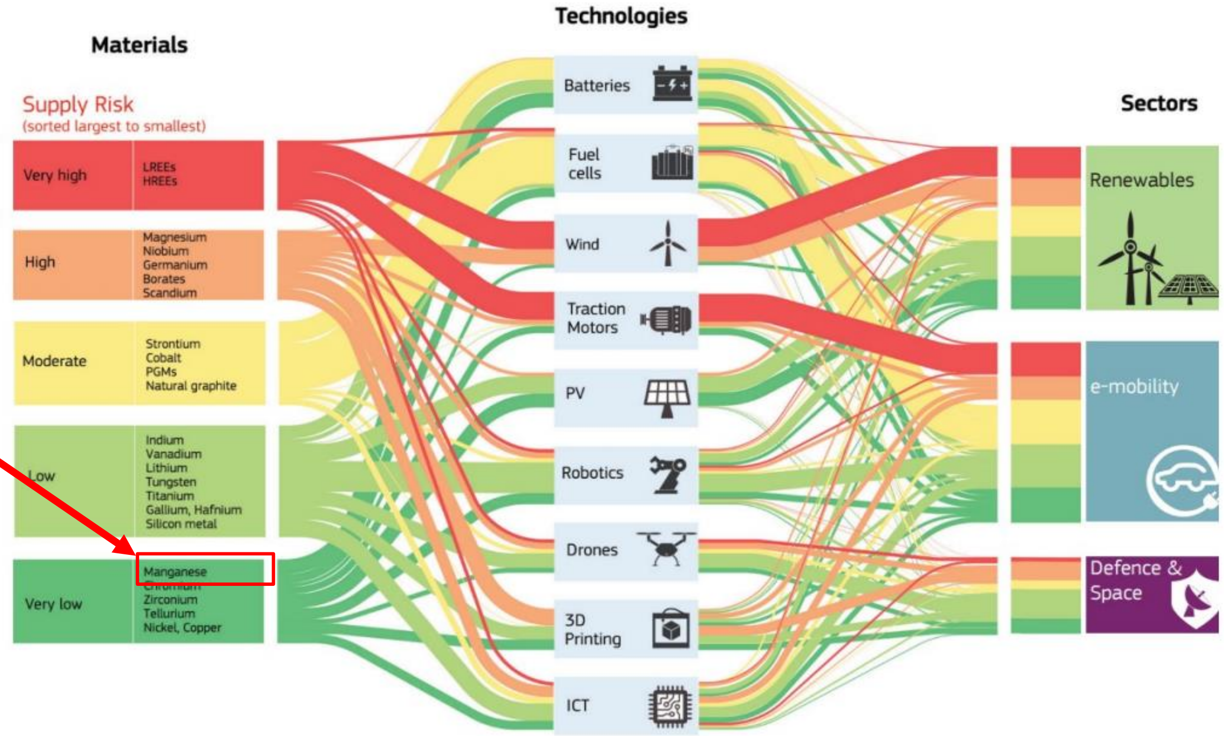
[Niklas et al. Key Eng. 2016 / Soundcast project (www.soundcastporject.eu]

5.1. Introduction. Oportunities of new sustainable steels

Manganese and aluminum are alloying elements with significant advantages compared with other alloying elements in terms of **availability, recycling possibilities** and in use performance.

- **Manganese** is **present in all steels** and as alloying element can be **incorporated in any alloy grade without contaminating it.**
- Depending on its content in the alloy and its combination with other chemical elements like aluminum, present **additional hardening mechanisms** different to the more traditional phase transformation: like **TWIP** (Twining Induced Plasticity), **TRIP** (Transformed Induced Plasticity) and **precipitation hardening.**
- **None of them** is considered as a **supply risk chemical element** that could compromise its further use in different sectors.

Manganese is a non-supply risk material present in all technologies and sectors.

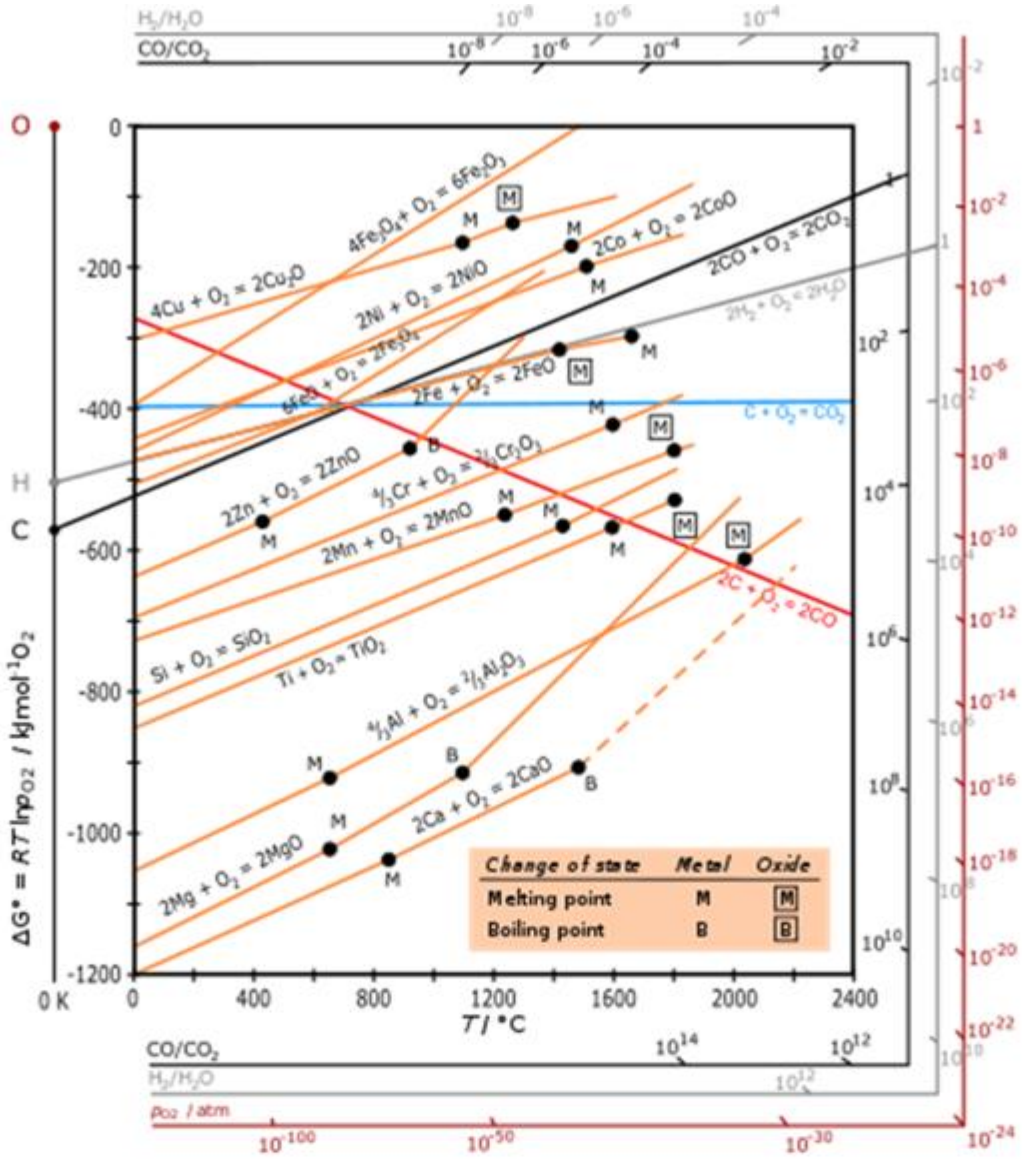


[CRMs for Strategic Technologies and Sectors – A Foresight Study,Joint Research Centre, 2020]

5.2. Introduction. Challenges of sustainable medium alloyed steels

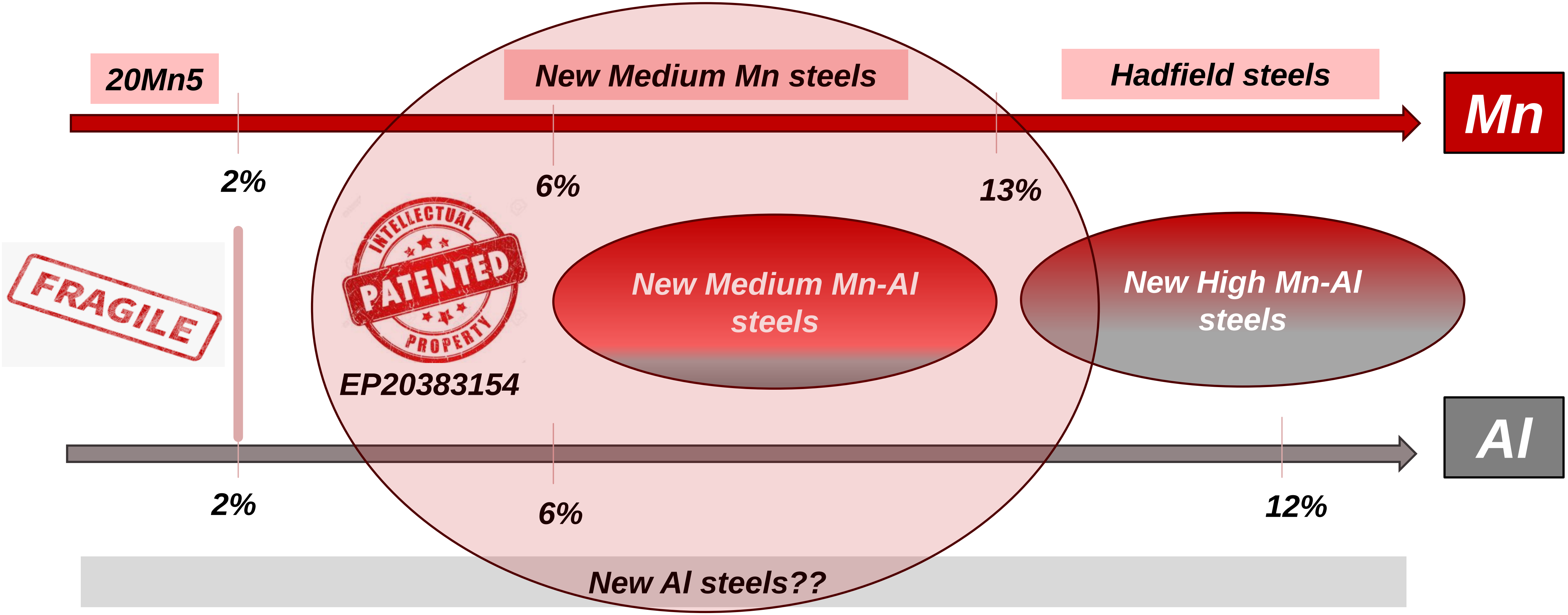
The use of a combination of manganese and aluminum as alloying elements presents significant challenges.

- **Manganese** by itself presents **initially low values of hardness and limited mechanical properties** compared with medium alloyed steels.
- **Manganese alloying quantities are higher** than any other alloying element to maintain a microstructure with a significant quantity of austenite.
- **Aluminum** has a very **high reactivity with air** conditioning the alloying process and making more complex to obtain consistent final properties.



5.3. Objectives of sustainable medium alloyed steels

- Develop new grades of Mn-Al steels linked up with a wide range of applications and thus improving **the chemical compatibility of the alloys** to avoid poisoning of high-grade alloys
- Develop **more-scrap tolerant alloys** (recycled friendly-alloys)



5.4. Results of sustainable medium alloyed steels

Finding out alternatives for the different steel families in the market

Steels families

- **Low alloyed**

- **Medium alloyed**

- **High alloyed**
  - **Tool steels**
  - **Stainless steels**

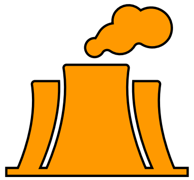
20Mn5

New Medium Mn steels

New Medium Mn-Al steels

New High Mn-Al steels

Weight (+ to −)



Manufacturing complexity (− to +)

5.4. Results of sustainable medium alloyed steels

MEDIUM Mn STEELS WITH HIGH DUCTILITY AND WEAR RESISTANCE

MEDIUM Mn-Al STEELS WITH SUPERIOR MECHANICAL PROPERTIES AND LIGHT WEIGHT

5-6% weight reduction

Density: 7.85 kg/dm^3 → **Density: 7.42 kg/dm^3**

42CrMo4 — Medium Mn-Al alloys

Manufacturing process	Heat treatment conditions	R_p (MPa)	R_m (MPa)	A_{30mm} (%)
VIM furnace	*NT*	*594*	*808*	*17.8*
Open air furnace	*QT*	*614*	*808*	*9.3*

NT: Normalized and tempered
QT: Quenched and tempered

More sensitive to oxides generation affecting ductility

Alloy	R_p (MPa)	R_m (MPa)	A_{30mm} (%)
42CrMo4 (QT)	*600*	*800-900*	*>12*

EN_10293

Gas nitriding demonstrating higher hardening potential of the alloy

Alloy type	Distance to the surface (mm) and hardness measured in $HV_{0,5}$			
	0.05	0.10	0.15	0,20
42CrMo4	711	735	662	660
Al28-A	1088	996	958	509
Al28-B	1079	1162	1012	711
Al28-C	1267	1243	1124	587

5.5. CONCLUSIONS AND NEXT STEPS IN SUSTAINABLE MEDIUM ALLOYED STEELS

New family of alloy grades integrate different **advantages** compared with traditional medium alloy grades such as:

- **Reduction of density** representing a unique opportunity to manufacture a component of the transport sector reducing its weight.
- **Simplification of heat treatment**, substituting the quenching and tempering by a normalizing and tempering process.
- Open the possibility to carry out **more efficient hardening** on the surface´s part using nitriding processes.
- Increase the use of raw materials of **less criticality** in terms of **supply risk**.

As **next steps** following considerations are made:

- **Other properties** of this alloy **have to be crosschecked** like weldability, corrosion and conformability to assure no mayor limitations appear in their future processing.
- **Addition of higher values of aluminum** balanced with manganese to continue evaluating the potential weight reduction in this family of steel grades.
- Continue with the **study of magnetic properties**, initial values show interesting **soft magnetism values** in similar range as pure iron BCC of (220 Am^2/kg).

Acknowledgments

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 886609. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union

www.reintegra.eu

This research was financially supported by European Union´s Seventh Framework Programme managed by REA – Research Executive Agency under grant agreement nº **315506** (FP7-SME-2012-1).

www.soundcastproject.eu


THANK YOU
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TACK
merci
dank je
GRAZIE
merce
sagolun
grazzi
dankeschon
diolch
AKUN
ngiyabonga
misaotra
sukriya
mauruuru
obrigado
arigato
TAKK
gracias
TAK
мерси

AZTERLAN

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Fernando Santos

fsantos@azterlan.es

Ana Fernández

afernandez@azterlan.es

ESKERRIK ASKO