Green Metallurgy
innovation

2010 - 2013

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Layman's Report

Industrial pilot project for lean integrated process cycle for eco-sustainable production of high performing magnesium components

An European Project co-financed by :

Green Metallurgy
innovation

Green Metallurgy project's goal is to demonstrate the possibility of industrializing an innovative single-step manufacturing process with substantially reduced CO_2 footprint capable to fabricate lighter structural components for various industry sector, mainly addressing weight saving targets of automakers. It aims to look forward with capability of producing large-size and complex shapes made of new generation of high-performing light-materials

The support provided by the **Politecnico di Milano**, the **Centro Nacional Investigaciones Metalurgica** and **Buhler Group** has allowed the execution of this innovative project co-financed by the European Community

Contents

1 Context and background 5

3 The GREEN METALLURGY project 7

3.1 The objectives 7

3.2 The process scheme 8

4 The outcomes 9

4.1 The High-Strength Lightweight Magnesium 9

4.2 The Low Impact Magnesium Alloys from Recycling 10

4.3 The environmental impact assessment: basic assumption 11

4.4 The specific LCA model for magnesium alloys 12

4.5 The results: the lowest carbon footprint for Eco-Mg Green Metallurgy route 13

5 Conclusions: future challenges 15

1 Context and background

The GREEN Metallurgy project was conceived in the context of the EU policy which stated the need of dealing with the global warming and clean metal production. Its aim is to transform Europe into a high energy-efficient and low greenhouse gas (GHG) emitting economy.

It was calculated that, increasing the usage of new generation of magnesium based materials (up to 180kg) onboard an Internal Combustion Engine road average size vehicle, thus manufacturing such lighter components by use of high-efficient technology, it is possible to reduce the CO2 emission closely to 15-20%, as compared with conventional (with melting steps) routes for the manufacturing Mg based materials

The Project Roadmap started in September 2010 to conclude in August 2013 and explored the capability of introducing a disruptive technology for the production of recycled and low environmental impact low magnesium metal for the transport sector.

With a density of 1.81 g/cm3 compared to 7.87 g/cm3 for steel, magnesium offers highest potential for weight reductions of structural components in the automotive industry and transport in general (hence reduced fuel consumption). Main barrier in terms of low mechanical resistance of conventional magnesium as well as high environmental impact in conventional magnesium metallurgy production have to be faced since they are current main drawbacks that prevent widening of magnesium component production.

- **Reduce CO2 emissions in production stage**
- **Increase mechanical resistance of magnesium alloys to compete with aluminum and steel**
- **Make magnesium alloys affordable for automotive industry**
- **Make magnesium material fully recycle**
- **Reduce energy content in production phase**

2 **The idea:** magnesium produced by solid powders and chips

The Life+ **GREEN METALLURGY** project has main its basis on the production in both high strength magnesium material produced from nanostructured solid powders and low impact magnesium alloys from recycled chips, both materials produced avoiding any conventional melting step really impacting on environment (*see Figure 1)*

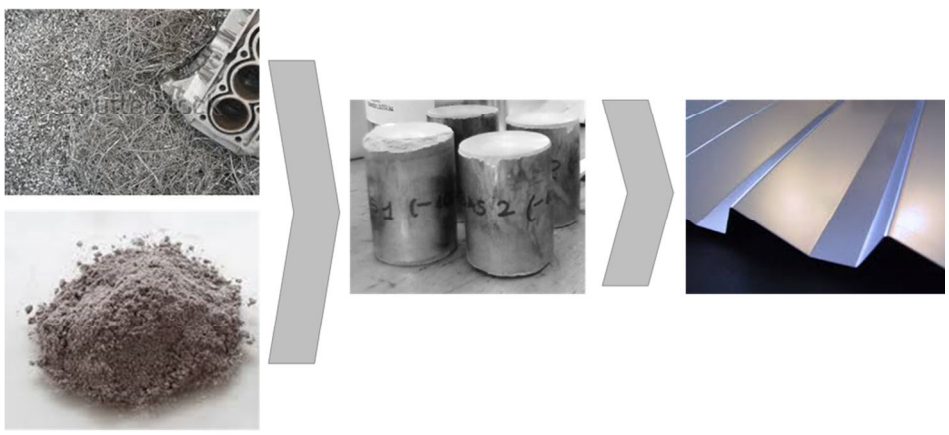
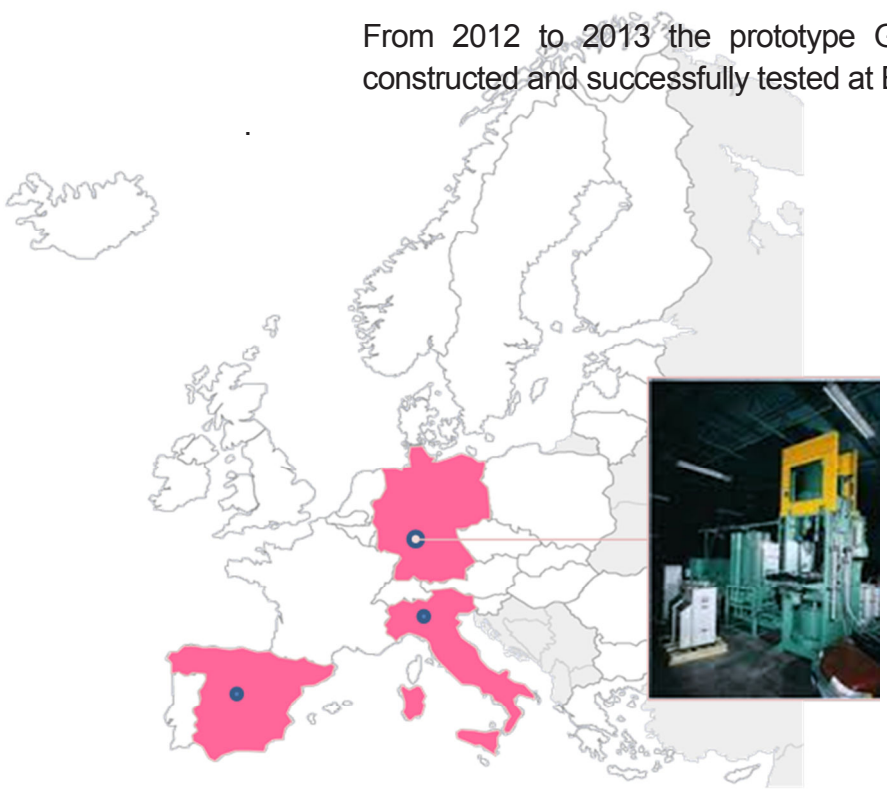


Figure 1: Scheme of concept process step: (1) raw materials in form of powders or chips are cold compacted in precursor billet (2) for final hot extrusion (3) of profiles, plates, bars.

After an intensive period from 2010 to early 2012 of preliminary studies at laboratories of CENIM in Madrid, and Department of Mechanics at Politecnico di Milano, the optimal scheme layout of the pilot plant was finally approved.

From 2012 to 2013 the prototype Green Metallurgy pilot plant was designed, constructed and successfully tested at Buhler Group facility in Viernheim, Germany.



The GREEN Metallurgy pilot plant was set in the premise of Buhler Group, Viernheim, Germany.

3 The GREEN METALLURGY project

Project title: Industrial pilot project for lean integrated process cycle for eco-sustainable production of high performing magnesium components
Project acronym: GREEN METALLURGY
Countries: Italy, Spain, Germany
Start date: 01/09/2010 End date: 31/08/2013
Total project budget: 2.059.867 € EC contribution requested: 1.009.358 €

Project team based at **Politecnico di Milano, Milano** with specific scientific references on metallurgy and metallurgical processes

Project team based at research institute **CENIM, Madrid** with specific scientific references on nanostructured magnesium alloys

Project team based at Buhler Group, Viernheim, Germany with specific industrial references on metallurgy production machinery

3.1 The objectives

- Develop an innovative production process suitable to produce superlight components that are more elaborated and larger than the ones produced by current Mg working plants and technologies available.
- Develop innovative manufacturing plant can be much more environmental friendly and sustainable than standard processes employed today.
- Achieve excellent mechanical properties (YS>350 MPa, elongation > 20%) for the market adoption and concrete environmental benefit up to 60% reduction energy consumption over manufacturing line and the 100% reduction of greenhouses gases.

3.2 The process scheme

The GREEN Metallurgy pilot plant has the main purposes to process both nanostructured based **high performance Mg-Zn(Y) magnesium alloys** (also called, Basic Alloy System, BAS) and a **fully-recyclable Eco-Magnesium alloys** (also called, Alternative Alloy System, AAS) applying the same process route (Fig.2) which addresses environmental and competitiveness issues.

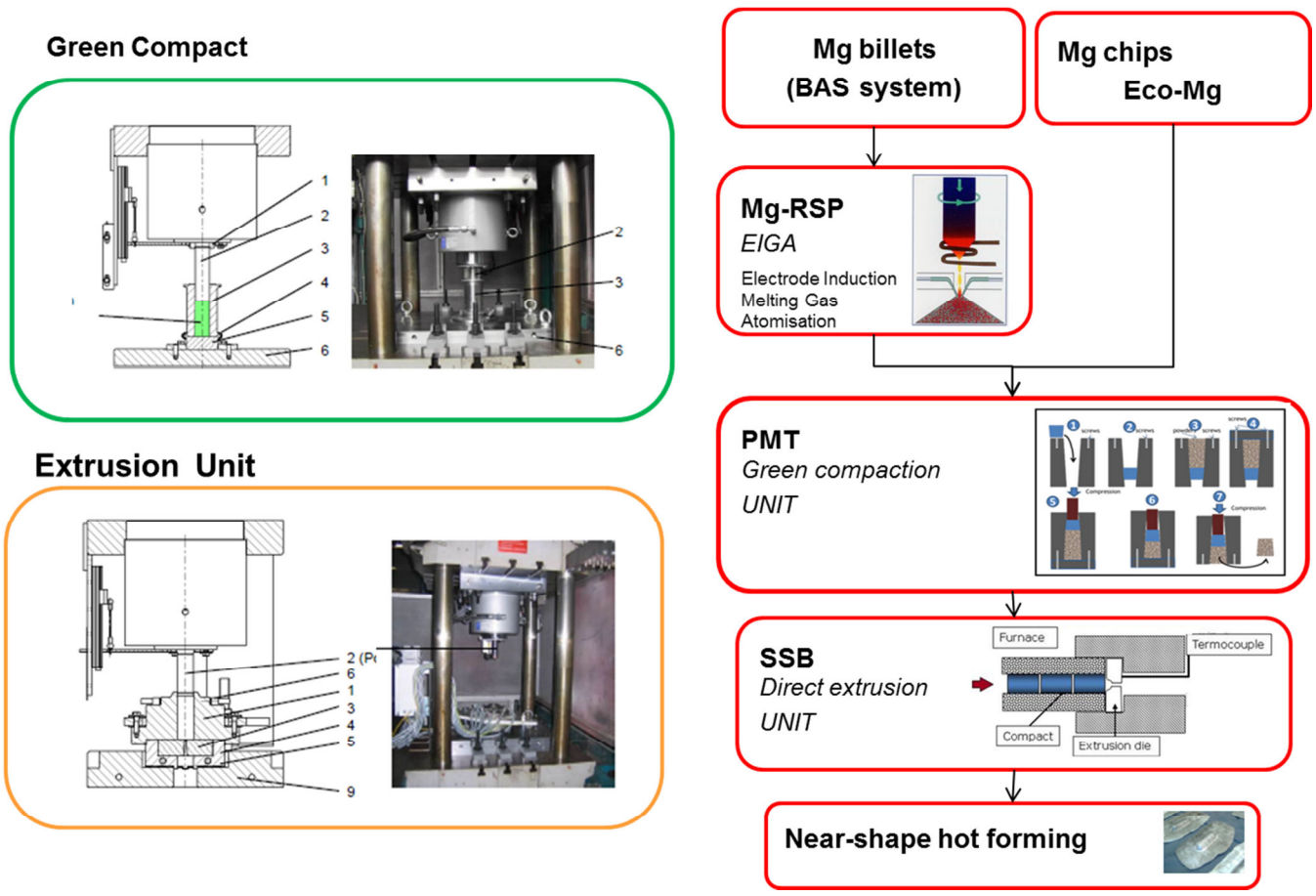


Figure 2: Diagram of the Green Metallurgy pilot plant

The Basic Alloy System (BAS) is a Mg alloy systems based on chemical compositions developed at CEN; these material are Mg-Y-Zn base systems, capable of reaching the highest mechanical properties experimented with to date for Mg-based alloys.

The Alternative Alloy System (AAS) is a commercial Eco-Magnesium AZ31 base alloy, namely a commercial Mg alloy system modified by the addition of a specific amount of CaO. The Eco-Mg series was recently developed by the Korean Institute of Industrial Technology (KITECH). It is spreading rapidly as it does not require the protective use of highly-environmental impacting gases as the presence of CaO provides a protective cover during the melting phase.

4 The outcomes

4.1 The High-Strength Lightweight Magnesium

The nanostructured powder of Mg-Y-Zn (Fig.3) have been cold pre-compacted in for of billets (Fig.4) and finally hot extruded in three section shape bars (Fig.5).

The mechanical tests conducted have revealed mechanical properties aligned with aluminum alloys commonly used in automotive, but with 30% less weight since lower density of magnesium against aluminum.

Material	YS (MPa)	UTS (MPa)	E%
HP nano Mg-Y-Zn	412	432	14

Table 1: Test results obtained for HP Mg-Y-ZN alloy

Figure 3 – Nanostructured powders

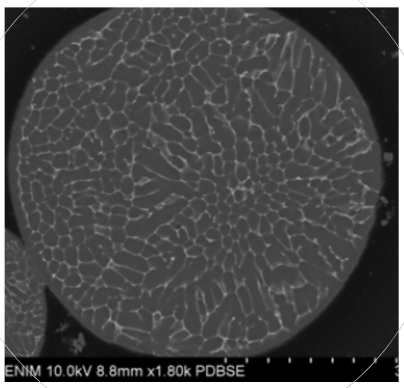
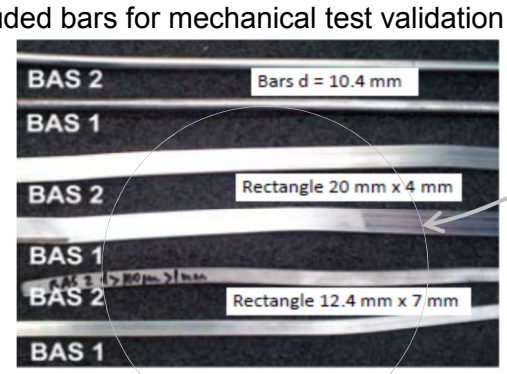


Figure 4 – Precompacted billet of Mg-Y-Zn

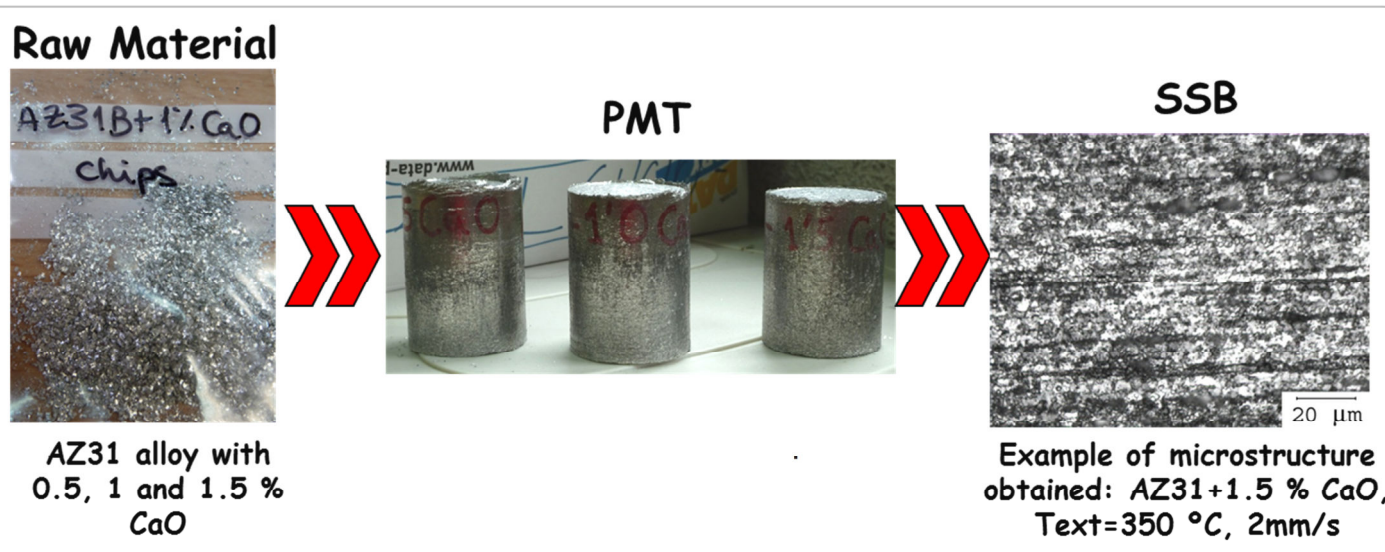
Figure 5 – Hot extruded bars for mechanical test validation



4.2 The Low Impact Magnesium Alloys from Recycling

The Eco-Magnesium chips route processes recycled chips as raw material instead of powders to produce hot extruded bars in the same equipment machine.

- ✓ Korean Institute of Technology (KITECH), recently developed an environmentally friend magnesium alloy system called Eco-Magnesium®
- ✓ Based on commercial chemical compositions (i.e. AZ91D, AZ31, AM60, etc.) but with the addition of CaO.
- ✓ CaO causes achieve a dramatic increase in oxidation resistance in the melt phase and avoid protective greenhouse gases, as SF6 usually employed in magnesium casting industry.



Eco-Recycled chips

KITECH provided raw materials in form of machined chips of a cheaper commercial Eco-Magnesium alloy, a AZ31 series. .

Mechanical properties

(Average values on test samples from extruded bars)

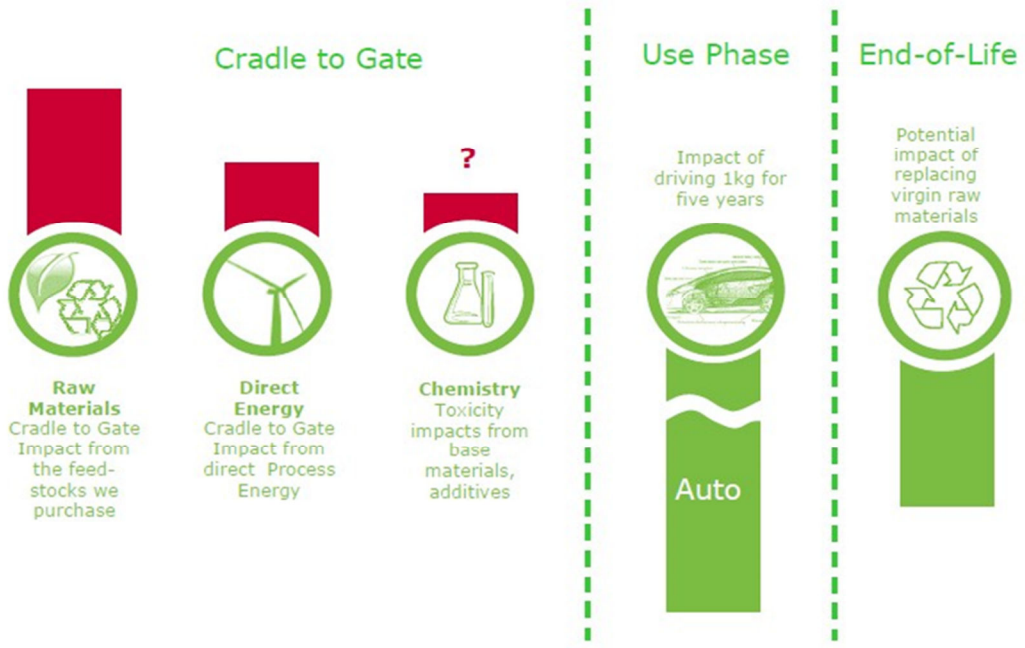
UTS: 370 MPa
YS: 320 MPa
E%: 12%

4.3 The **environmental** impact assessment: basic assumption

The European Automobile Manufacturers' Association (ACEA) basic scenario stated the ICE is expected to continue to be the dominant technology Today the main scope of automakers is to make ICE retain similar performance while cutting CO2 emissions by coupling **lightweight designs.**

Overall pollution emissions, namely the carbon footprint, in automotive sector powered by fossil fuels has to be assessed considering total life cycle of lightweight product. From the “dirty” stage that considers the carbon footprint of the production phase (e.g. emissions for extraction of raw materials, energy sources used for transformation, etc.)

The LCA assessment scheme in automotive sector[2] fossil-fuel fueled



Reducing fossil-fuel consumption by weight-saving + benefits of recycle of materials

4.4 The specific **LCA model** for magnesium alloys

The LCA model for the magnesium alloys should take into account the “dirty” phase of magnesium raw material production and second manufacturing stages.

It is shown in Fig.6 the effect of increasing of emissions produced in the manufacturing phase, since it has direct impact on break-even point for net reduction of emissions in comparison with the basic case, for example similar component made of conventional heavier material.

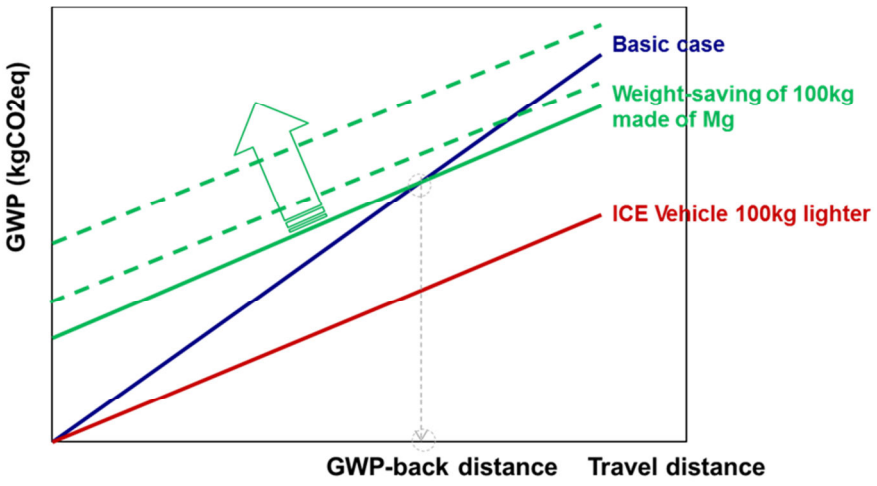
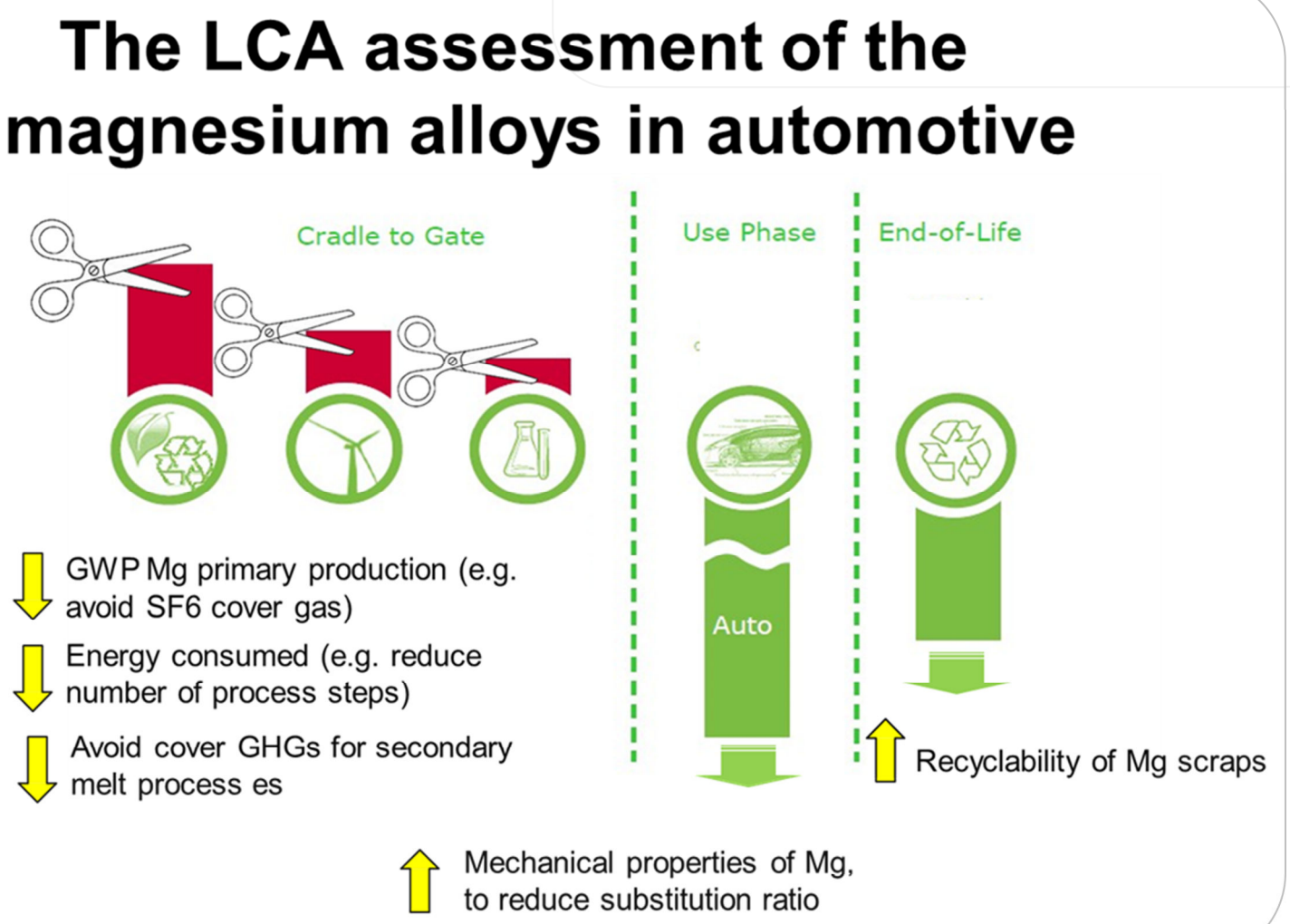
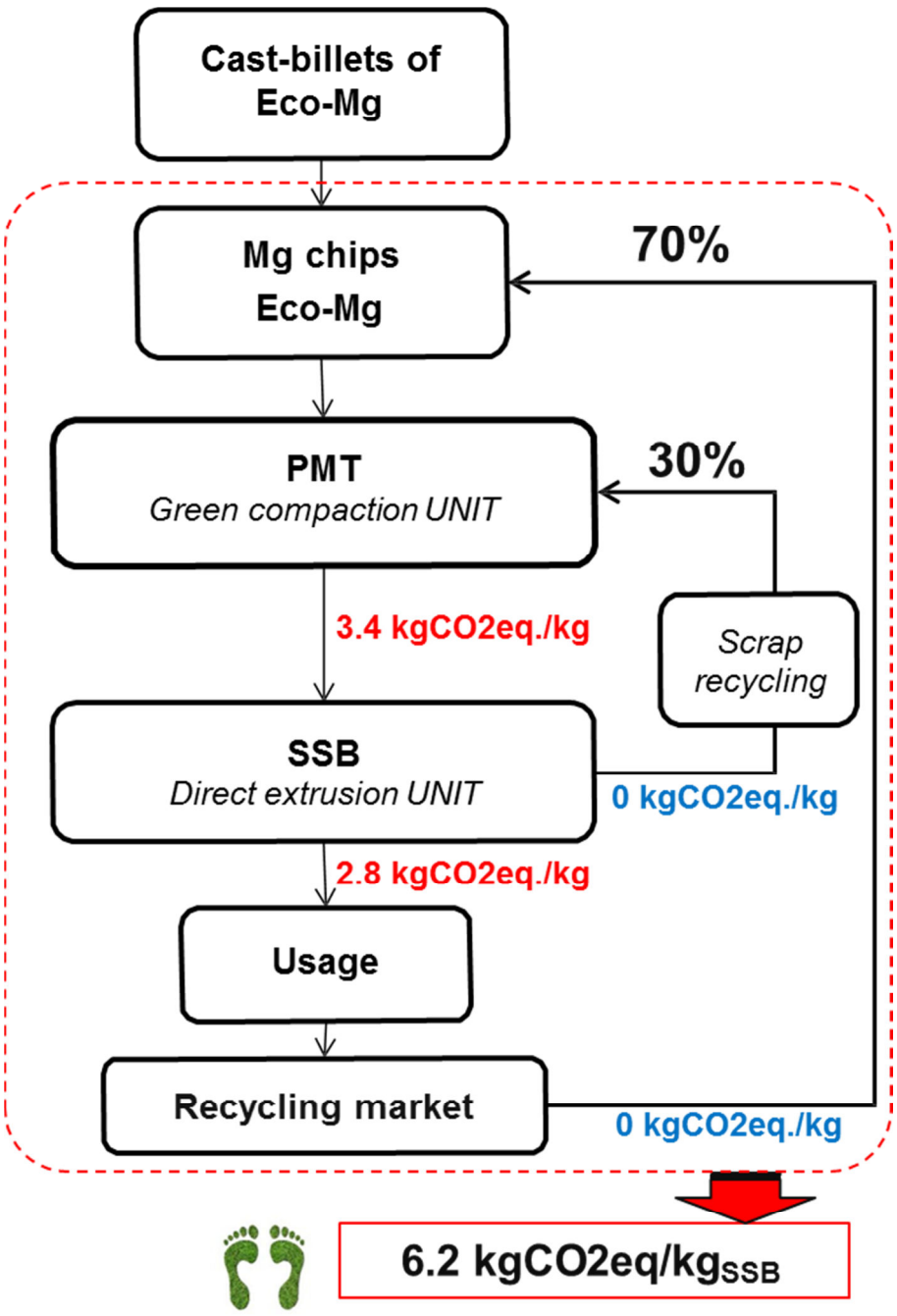


Figure 6 – Scheme of LCA results for magnesium alloys onboard



4.5 The results: the lowest carbon footprint for Eco-Mg Green Metallurgy route

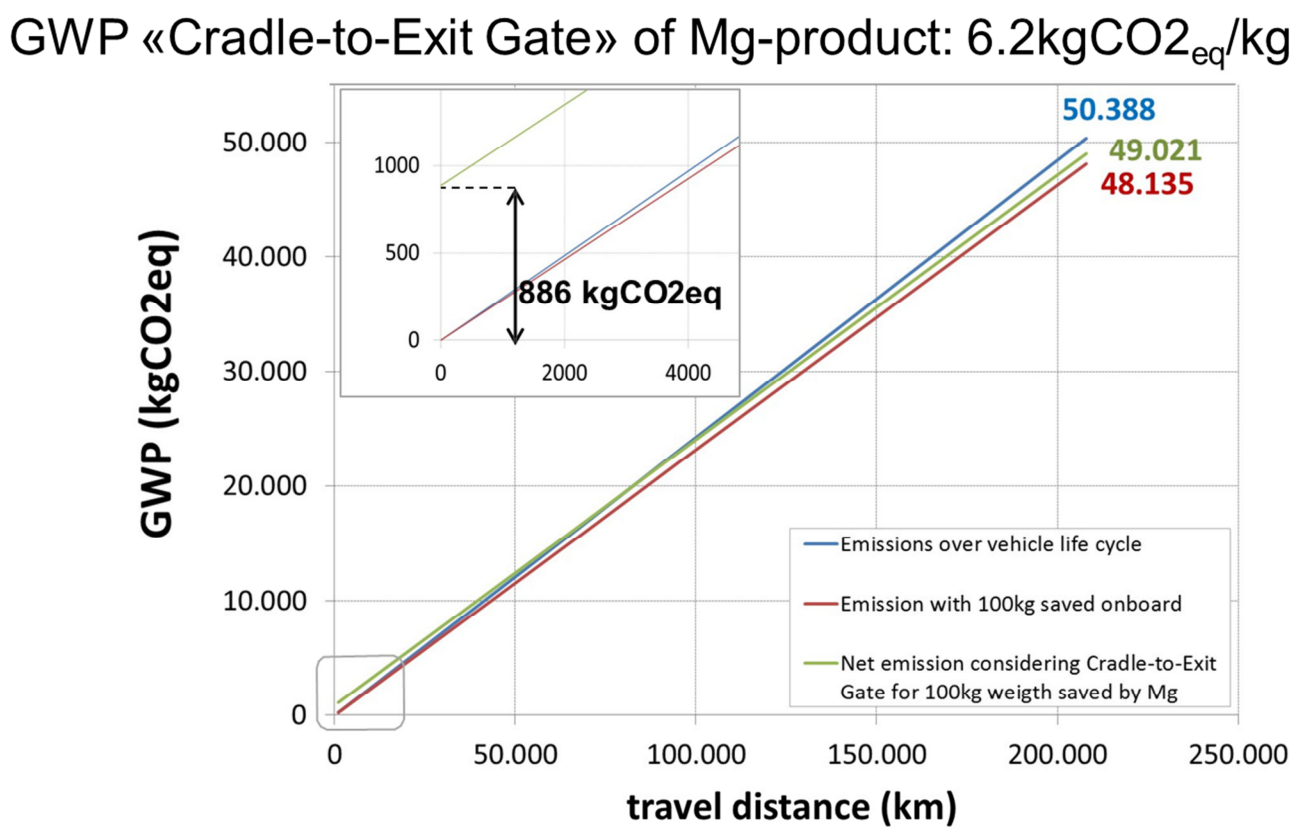


Scenario studied: Eco-Mg chips, 30% in-situ recycled chips mixed with 100% of recycled material

How much Mg is required for saving up to 100kg onboard?

Features	HP Eco-Mg	Aluminum (AA7075T4)	Steel (AISI1040)
Density (kg/dm^3)	1,81	2,74	7,87
Fatigue limit (MPa)	125	160	310
Substitution ratio	2,48	1,94	1,00
Volume (dm^3)	73,2	57,2	29,5
Total weight onboard (kg)	132,4	156,6	232,2
Weigth saved (kg)	100 43,0%	76 32,5%	0 0,0%

The best practice



5 Conclusions:futurechallenges

Recycling and **reducing substitution ratio** (i.e. developing high- performance Mg alloys) appear **unique consistent strategies** to positively impact on **net GWP.**

On the other hand, **EU automakers are not generally interested in net GWP,** since they are attracted by **reduced fuel consumption** (**marketing strategy)** and **reduced emissions per km (EU Commission rules- pushed strategy:** they are worrying about possible penalties based on excess emission payments).

Recycle chips route we experienced could lead to mitigate cost of RE or Y added alloys, but difficulties in large part series components production have to be carefully addressed.

Overall drawback, **recycle industry does not exist in reality**, since the Project has employed only fresh (clean) machined chips.

Light-weighting
plugged-in fully electric will surely
be a key-factor to **extend travel distance**,
reduce technology cost per kWh and
reduce the operation costs, i.e. kWh per mile

The e-lightweight solution

Temperatures in an e- vehicle do not surpass 70°C What can Mg-fan figure out?

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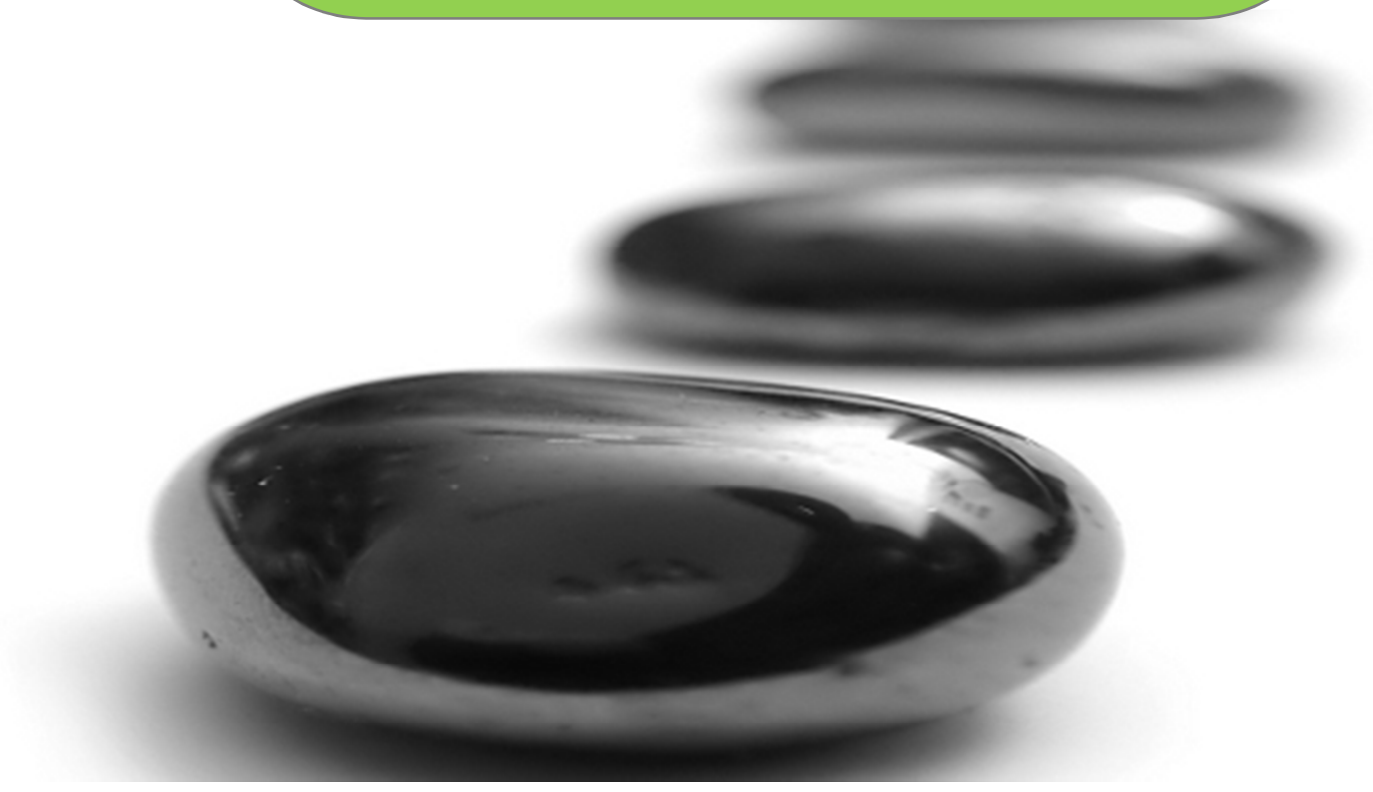
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