Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes - REVaMP

H2020-NMBP-ST-IND-2018-2020 / H2020-NMBP-SPIRE-2019

Grant agreement no. 869882

Start Date: January 1st, 2020

Duration: 48 months

Project Type: Innovation Action

Material flow analysis created and data provided for all use cases

Due Date: September 30th, 2021

Submission Date: October 7th, 2021

Work Package: **WP 2 – Modelling of operational input conditions and process performance**

Lead Beneficiary: **RWTH AACHEN**

Authors:

Partner	Name
BFI	Bernd Kleimt
SIDENOR I+D	Leixuri Fernandez
SIDENOR	Inigo Unamuno
EURECAT	Manel da Silva López
GRUPAL ART	Mar Ruiz, Yolanda Soler, Francesc Peregrín, Marc Pericas
RWTH AACHEN	Felix Kaiser, Tim Reichel, Thomas Echterhof
EXIDE	Nuria Jimeno, Javier Elso

Dissemination level

PU public ☒

CO Confidential, only for members of the consortium (incl. the Commission Services) ☐

Table of Contents

1. About REVaMP

The main objective of the project "Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes" (REVaMP) is to develop, adapt and apply novel retrofitting technologies to cope with the increasing variability and to ensure an efficient use of the feedstock in terms of materials and energy.

For this purpose, existing metal production plants shall be retrofitted with appropriate sensors for scrap analysis and furnace operation. Furthermore, the selection of the optimal feedstock in terms of material and energy efficiency shall be improved by application of appropriate process control and decision support tools. Also, a solid scrap preheating system operated with waste derived fuel shall increase the energy efficiency of the melting processes. To monitor and control the process behaviour in an optimal way, model-based software tools will be developed and applied.

The retrofitting solutions will be exemplarily demonstrated within three different use cases from the metal making industry, namely electric and oxygen steelmaking, aluminium refining and lead recycling. The performance of the different technologies will be assessed, and the benefits will be evaluated in terms of economic and ecological effects, as well as cross-sectorial applicability in other process industries.

2. Introduction and Summary

This deliverable D 2.5, “Material flow analysis created and data provided for all use cases”, is included in the work package WP 2 “Modelling of operational input conditions and process performance” of the project.

Within this task, a Material Flow Analysis (MFA) for the three use cases of steelmaking, aluminium production and lead production shall be created. This consists of the steps illustrated in Figure 1:

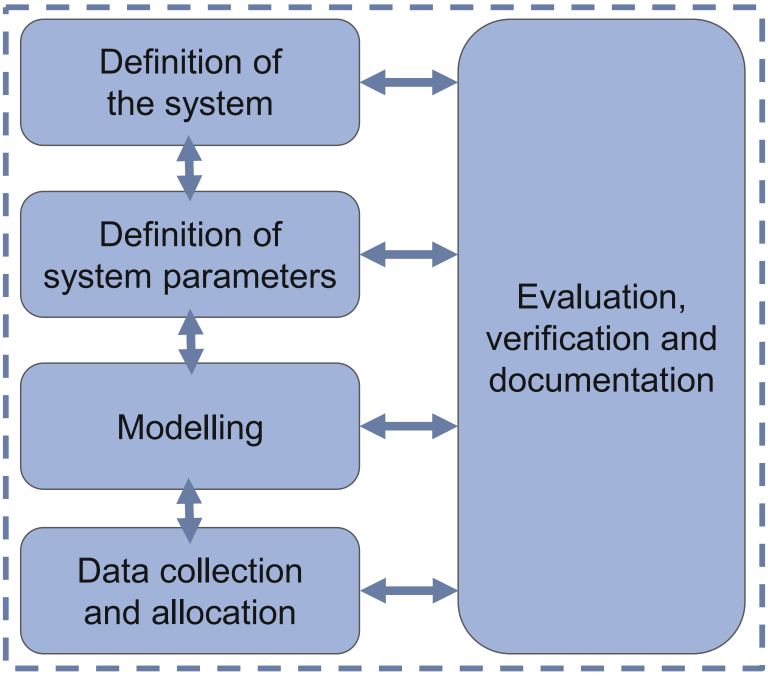

Figure 1 – Phases in the creation of an MFA in this project

First, the system that should be analysed must be defined with its system boundaries and essential parameters. Here, the purpose for which the MFA is to be performed must already be taken into account. Then, with the help of the defined parameters and system boundaries, a model is created within a software. In this project, the software Umberto LCA+ is used for this purpose. Subsequently, the parameters of the model must be filled with numerical values. If the process of a specific plant is to be analysed, as it is in this project, it is essential that the numerical values used match the common practice of that plant.

During the creation of the model, it should be continuously evaluated and reviewed. In the case of reference to a real plant, experts for the particular process should also be involved.

3. Material flow analysis

Based on the results of task 1.3, which included the definition of scope and goal for the subsequent material flow and life cycle analysis, the three models are built to create three material flow models depicting all relevant input and output flows for the most import process steps. For additional information on the production processes, please refer to the report on Deliverable 1.4, specifically the flowcharts, which were created in collaboration with the industrial partners.

In order to create the MFA models within the Umberto LCA+ software, multiple assumptions about the origin of certain quantities are necessary. For example, an electricity mix has to be assumed in order to calculate the environmental impact of the electrical energy used. The same applies to all other input flows, where a source type has to be defined in order to be able to calculate all impact indicators later on. In addition, all input and output flows must be referenced to one ton of the final product so that the calculation can be made in the software.

These assumptions are made in collaboration with the industrial partners to make the models as applicable to the real industrial plants as possible. The models then serve as a baseline, to which the later state of the plant, after the retrofitting solutions have been implemented, are compared. Therefore, the assumptions and frameworks should be chosen completely equal for both states of the model. This way, the assumptions influence the absolute values of the results, but not the overall conclusions drawn from them.

Note: Since this deliverable report is public, no numerical values for the process parameters of the industrial partners have been included.

3.1. Material flow analysis: steel use case

In this use case, the electric steelmaking process from recycled steel scrap is analysed. The analysed use case resembles the usual process carried out by Sidenor at their plant located in Spain. The model focuses solely on the process step taking place at the Electric Arc Furnace and before that.

Definition of the system & Definition of system parameters

The product system under investigation is a process step during the production of steel via the electric steelmaking route: the melting process in an Electric Arc Furnace. The analysis covers all processes from the natural and secondary resources down to the creation of liquid steel. Due to the applied cradle-to-gate approach, all processes of the process route after the Electric Arc Furnace are not considered.

The flowchart below shows all analysed processes and their input and output flows. These flowcharts with the defining system parameters were created in close collaboration with the industrial partner Sidenor.

The electric energy input combines the input necessary for the scrapyard operations and for smelting operation. Compared with the flowchart from WP1, it was decided to leave out alloying materials, as these are part of the ladle metallurgy and not the actual Electric Arc Furnace process. The off-gas was also simplified to the dust and CO_2 emissions. These substances are in most cases among the most relevant mass flows of the off-gas, also regarding impact assessment in later stages of the LCA. Therefore, this choice was also made in this regard.

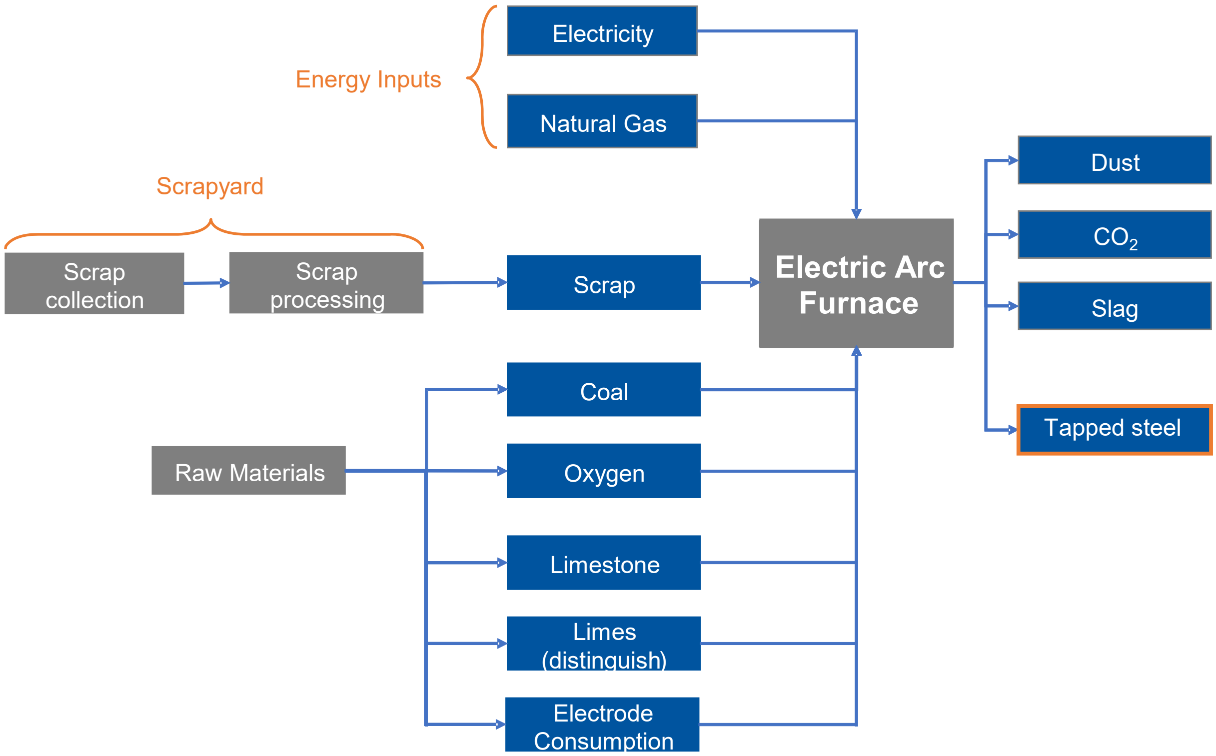

Figure 2 – Flowchart of the steel production through an Electric Arc Furnace

Modelling & Data collection and allocation

Based on the flowchart, the input and output parameters have been filled out with data according to Sidenor's usual production process. The final list of all parameters and their corresponding values are implemented in the model but not shown here due to the report being public.

For the creation of the model in the software Umberto LCA+, the origin of the raw materials and energy inputs also has to be defined. This can have a big influence on the impact assessment result later on, so a transparent definition is really important. The selection of the supplying electricity mix is particularly noteworthy here, since large amounts of energy are required for the process under consideration and the production of electric power in many countries still largely relies on fossil fuels.

The oxygen used in the Electric Arc Furnace is produced on site. Therefore, a cryogenic air separation unit using electric energy for oxygen production is implemented in the model from the ecoinvent database. Algeria was chosen as the country of origin for the natural gas due to its geographical proximity. All other raw materials are modelled to be sourced from an international market, available in the ecoinvent database. For the electrode consumption, a mean value from the ecoinvent database is chosen.

	Process modules	Parameter	Value	Unit
Input	Electric Arc Furnace (and scrapyard)	Electric energy	XXX	kWh/t_{Steel}
		Natural gas	XXX	Nm^3/t_{Steel}
		Scrap	XXX	t/t_{Steel}
		Coal	XXX	kg/t_{Steel}
		Oxygen	XXX	Nm^3/t_{Steel}
		Limestone	XXX	kg/t_{Steel}
		Limes (injected)	XXX	kg/t_{Steel}
		Electrode consumption	XXX	kg/t_{Steel}
Output	Electric Arc Furnace (and scrapyard)	Tapped steel	XXX	t/t_{Steel}
		Slag	XXX	kg/t_{Steel}
		Dust	XXX	kg/t_{Steel}
		CO_2	XXX	kg/t_{Steel}

Figure 3 – Parameter list and numerical values for the steel use case MFA

Regarding electric energy, Sidenor has detailed data on the electricity production mix of their supplier, which is shown below. In order to make the MFA model less generic and more accurate for this specific case, this electricity mix was implemented as the source of all electric energy. The main difference of this electricity mix to the general Spanish electricity mix is, that Sidenor's mix shows a larger percentage of nuclear power production and less renewables. The other figures are roughly the same. For the modelling aspect, some assumptions were necessary in order to implement the specific electricity mix. The facilities of the individual types of electricity generation were assumed to correspond as closely as possible to the current Spanish status. The nuclear portion is covered entirely by pressure water reactors. The hydropower share is provided by reservoir hydroelectric plants. The share of renewables is supplied entirely by wind energy. And the fossil-fuelled power generation types are completely powered by natural gas.

Regarding the current scrap mix, Sidenor also has detailed data on their currently used compositions. This data is currently not included in the model. It is expected that the solutions implemented in this project will have an effect on the average scrap composition. However, this change in scrap composition would not be visible on its own in the results within the MFA and the impact assessment that will take place later. Instead, the resulting changes in other operating parameters (energy demand, necessary raw material quantities...) will be registered, which in turn will have an influence on the results.

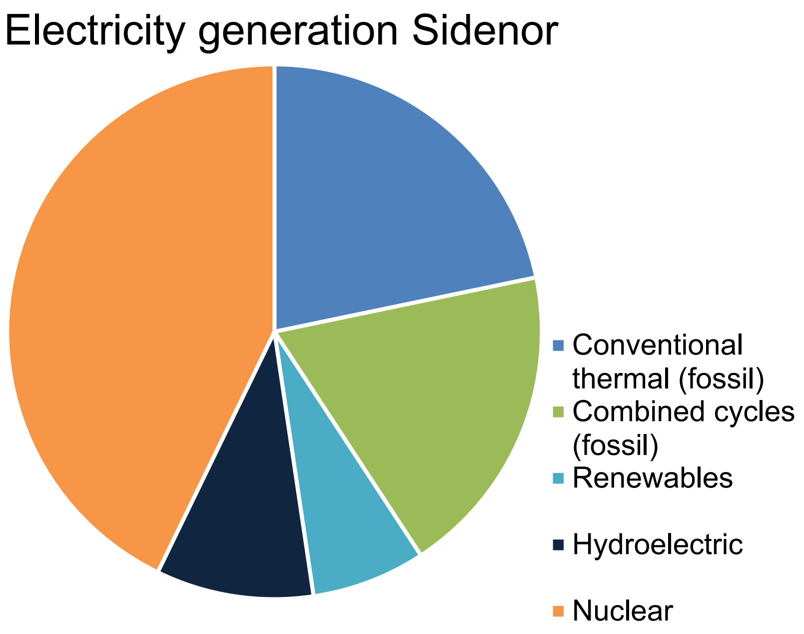

Figure 4 – Specific electricity mix for Sidenor

Evaluation, verification and documentation

The model has been created in close collaboration with the industrial partner. The parameters considered were selected in close consultation, and the associated numerical values were taken directly from the usual production practice. The model was also closely discussed and evaluated.

Shown below in Figure 5 is the MFA model for the steel use case in the software Umberto LCA+. Also shown is the software's internal Sankey diagram, which illustrates all material flows. The diagram shows that both the scrap and the electrical energy represent the largest material flows. For additional information, the influence of the individual material flows on the determination of the global warming potential is shown in Figure 6. From this, the same conclusions can be drawn. In addition to the scrap used, the electrical energy input is most relevant for the overall GWP result.

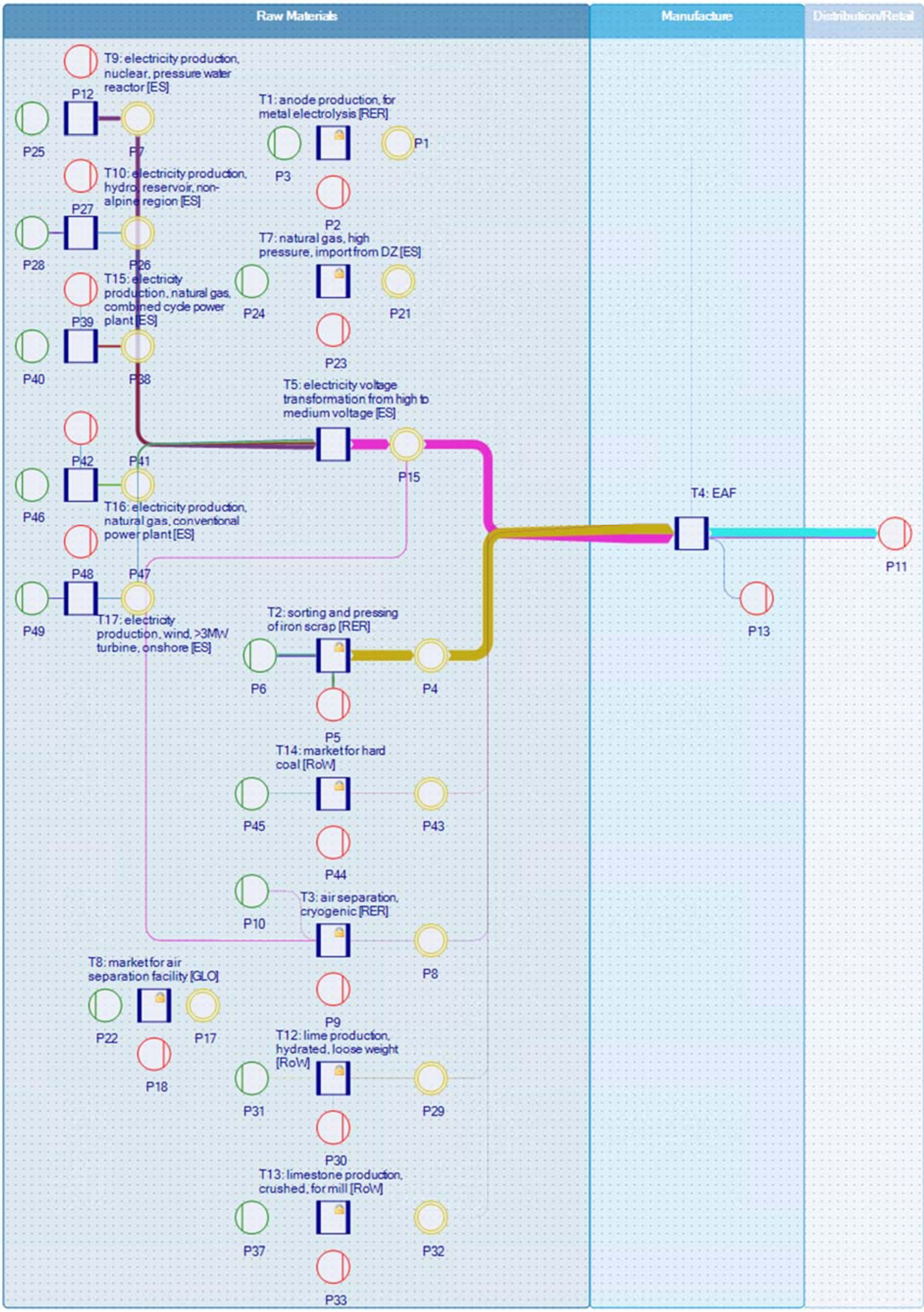

Figure 5 – MFA model for the steel use case and Sankey Diagram showing all materials flows

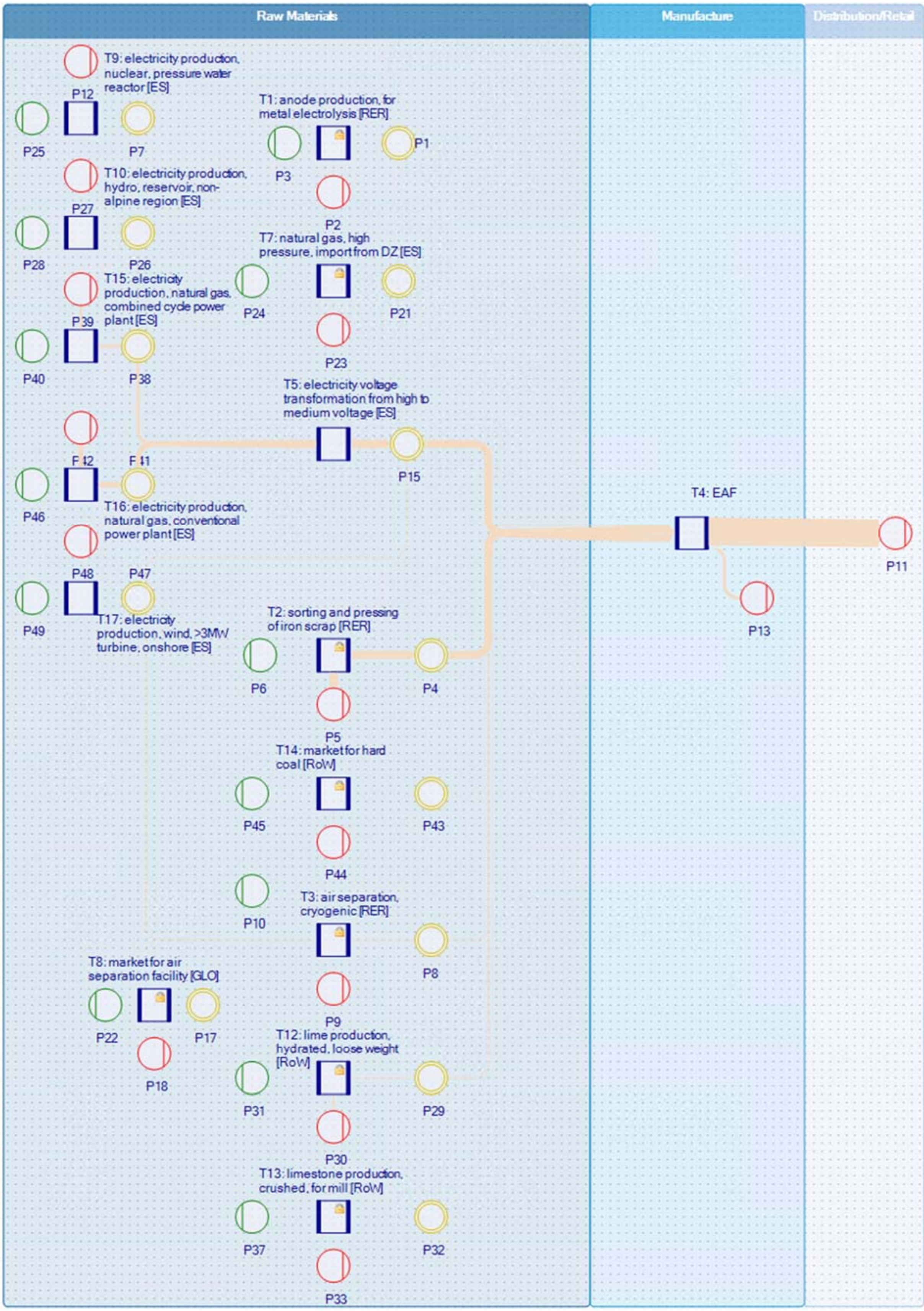

Figure 6 – MFA model for the steel use case and Sankey Diagram showing GWP calculation

3.2. Material flow analysis: aluminium use case

The material flow model shown below analyses the process of secondary aluminium production using aluminium scrap. The analysed use case corresponds to the usual process carried out by Grupal Art at their plant located in Spain. The model focuses on the process step taking place at the furnace up until the casting of the ingots. All previous process steps are included as well.

Definition of the system & Definition of system parameters

The product system under review comprises the following processes: creation of a bed of liquid aluminium, screening of the aluminium chips, filling up of the furnace, refilling of the furnace. The analysis also covers all processes from the natural resources down to the creation of liquid aluminium alloys. Due to the applied cradle-to-gate approach, all processes after the melting furnace are not considered.

The flowchart below shows all analysed processes and their regarding input and output flows. These flowcharts with the defining system parameters were created in close collaboration with the industrial partner. It is important to point out, that the electric energy is not only used for the dross removal step, but rather represents an overall figure also used for various other equipment.

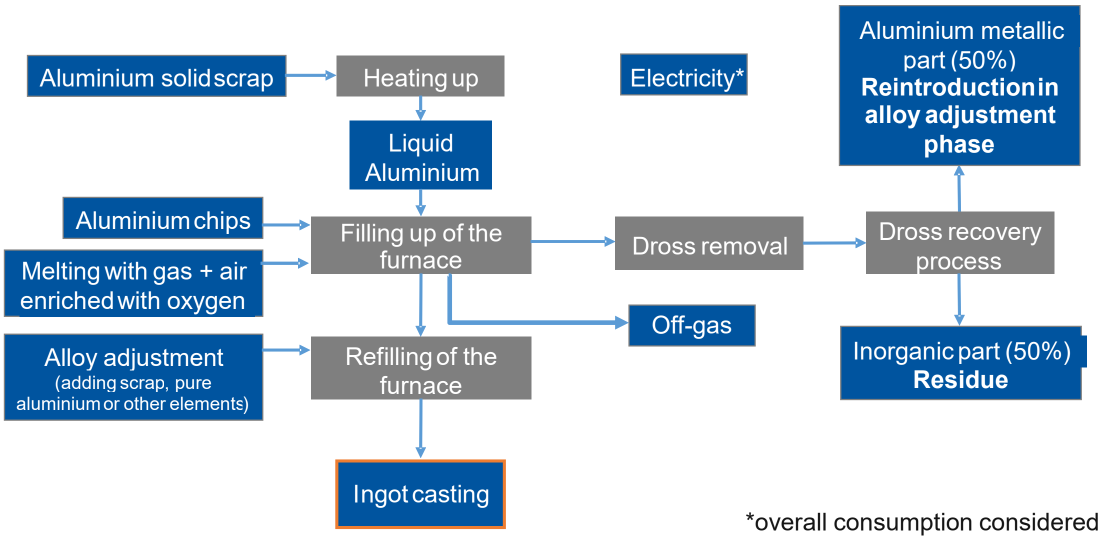

Figure 7 – Flowchart of the aluminium recycling process

Modelling & Data collection and allocation

The values for the created parameter list have been provided by Grupal Art to closely represent their process. The final list of all parameters and their corresponding values is shown below.

Concerning the aluminium recycling process at Grupal Art, the removal and reusage of the dross is a central part. Half of the dross is being disposed as inorganic residue, the other half is being reintroduced into the furnace as part of the alloy adjustment. Initially, a small batch of solid scrap is being heated in the furnace. Later, it is filled up with aluminium chips, which then form the main melting batch.

	Process modules	Parameter		Unit
Input	Heating up	Aluminium solid scrap	XXX	t/t_{Al}
		Oxygen	XXX	m^3/t_{Al}
	Filling up of the furnace	Aluminium chips	XXX	t/t_{Al}
		Natural gas	XXX	m^3/t_{Al}
		Oxygen	XXX	m^3/t_{Al}
	Dross removal	Oxygen	XXX	m^3/t_{Al}
		Electric energy	XXX	kWh/tAl
	Dross recovery process	Dross (input)	XXX	t/t_{Al}
	Refilling of the furnace	Scrap	XXX	t/t_{Al}
		Liquid Aluminium	XXX	t/t_{Al}
		Alloy elements	XXX	t/t_{Al}
		Oxygen	XXX	m^3/t_{Al}
		Recovered Metals from Dross	XXX	t/t_{Al}
Output	Heating up & Filling up of the furnace	Liquid Aluminium	XXX	t/t_{Al}
		CO_2	XXX	kg/t_{Al}
	Dross removal	Dross	XXX	t/t_{Al}
	Dross recovery process	Inorganic parts	XXX	t/t_{Al}
		Aluminium metallic parts	XXX	t/t_{Al}
	Refilling of the furnace	Aluminium (to casting)	XXX	t/t_{Al}

Figure 8 – Parameter list and numerical values for the aluminium use case MFA

The electric energy in this model is being supplied by an average Spanish electricity mix from the ecoinvent database. The natural gas is once again sourced from Algeria. The produced CO_2-amount is given by the ecoinvent database for this process and the respective input of natural gas. All other input materials are provided by an international market modelled after the ecoinvent database. The quantity of alloying materials is currently modelled as a mix of 50% silicon and 50% zinc according to mean values from the ecoinvent database.

Evaluation, verification and documentation

The aluminium use case model has also been created in close collaboration with the industrial partner Grupal Art. The parameters considered were selected in close consultation, and the associated numerical values were provided, to represent the real plant processes as accurately as possible. The model was also closely discussed and evaluated.

Shown below in Figure 9 is the MFA model for the aluminium use case in the software. Also displayed is the software's internal Sankey diagram, illustrating all material flows. It can be seen that the overall mass flows are smaller compared to the other use cases. Especially the chosen origin of the scrap has an impact on the model. For additional information, the influence of the individual material flows on the determination of the global warming potential is shown in Figure 10. Here it can be seen that the heating of the furnace with natural gas has the largest influence on the calculated GWP, followed by electrical energy use.

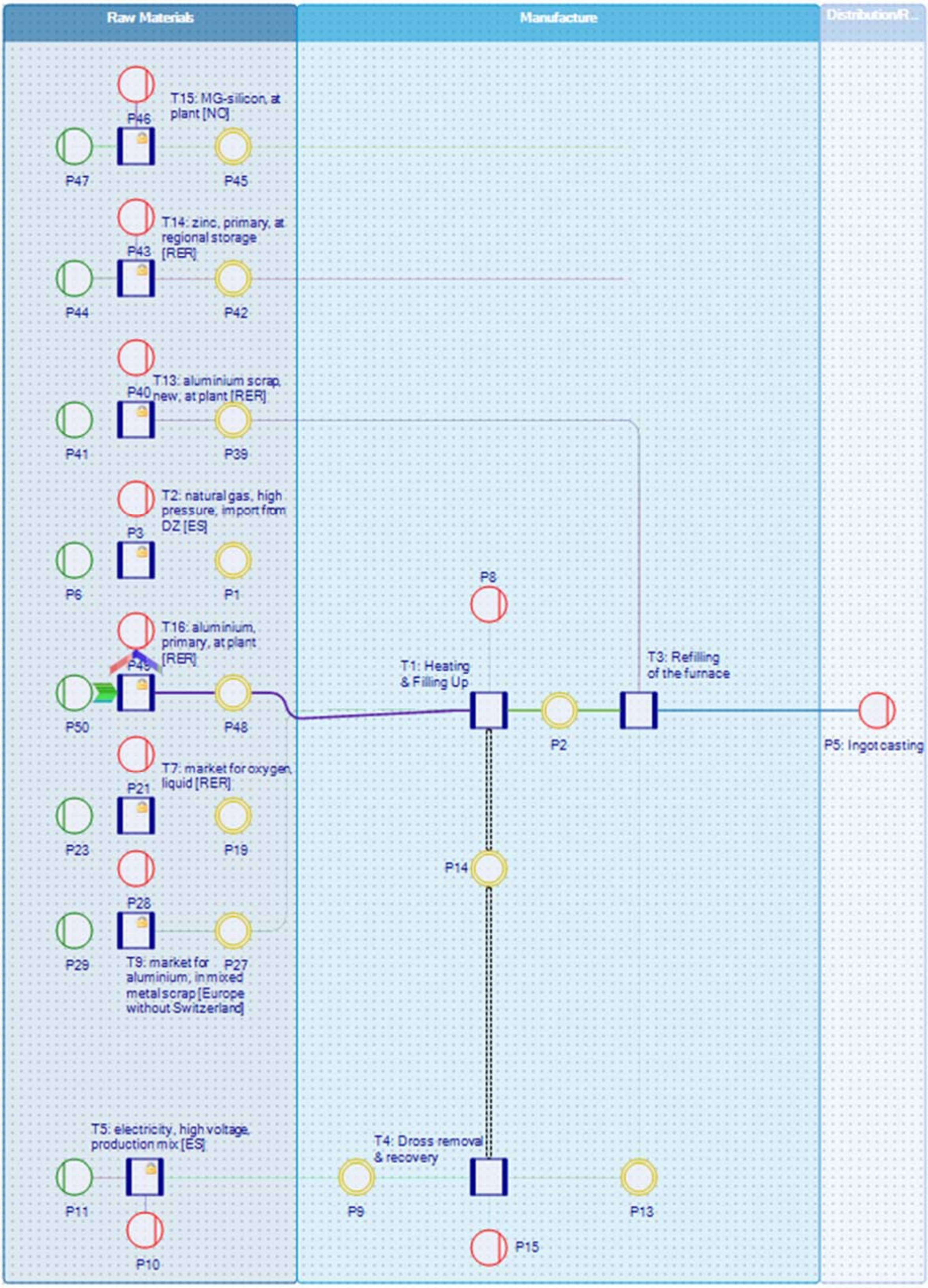

Figure 9 – MFA model for the aluminium use case and Sankey Diagram showing all materials flows

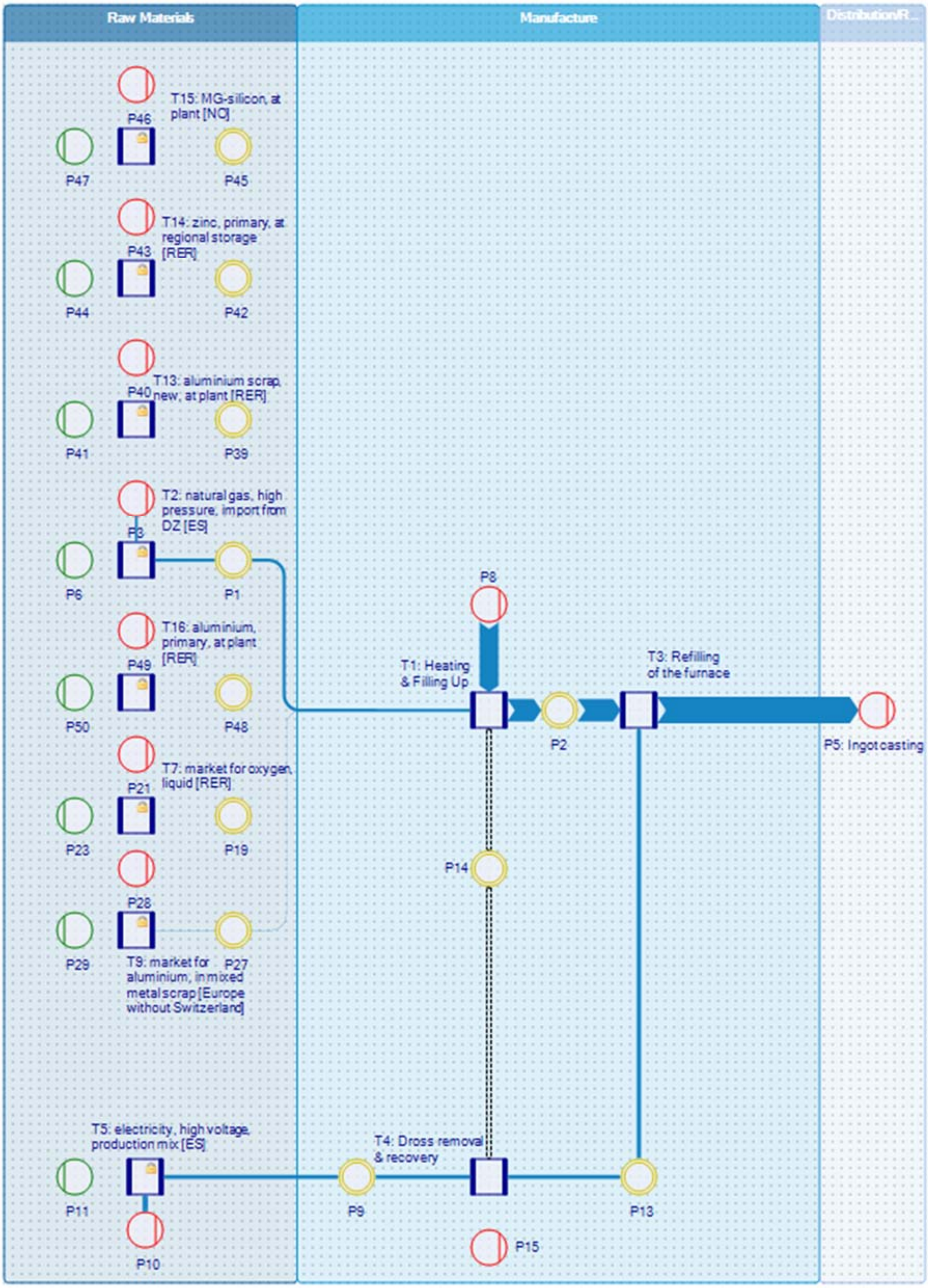

Figure 10 – MFA model for the aluminium use case and Sankey Diagram showing GWP calculation

3.3. Material flow analysis: lead use case

The material flow model presented below analyses the process of lead production by recycling of lead acid batteries. The analysed use case matches the usual process carried out by Exide in their plant in Spain. The model focuses on the process step at the furnace up to the casting of the ingots. All previous process steps, including the preparation of the batteries, are also considered.

Definition of the system & Definition of system parameters

The product system under review comprises the following processes: battery breaking and separation of the components, smelting and refining. Within the furnace process all relevant materials, process, energy, fluxes and dust extraction will be considered. All upstream processes up to the preparation and delivery of the natural resources are also considered due to the cradle to gate approach. Due to this concept, all processes after the melting furnace are not part of the calculation.

The flowchart below shows all analysed processes and their regarding input and output flows. These flowcharts with the defining system parameters were created in close collaboration with the industrial partner.

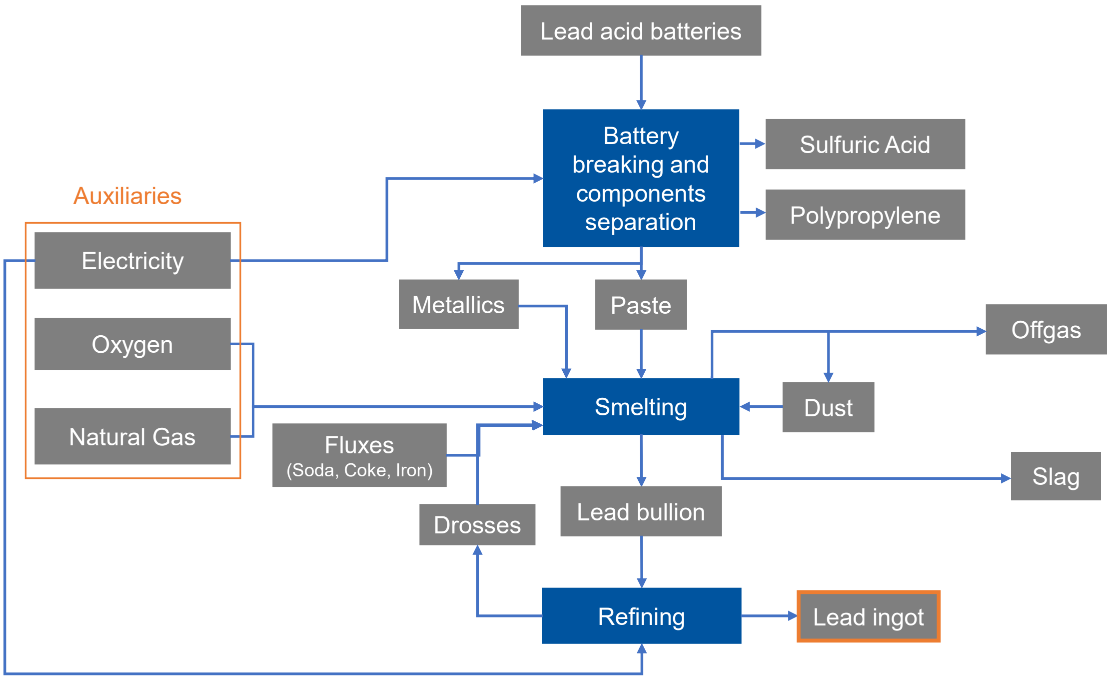

Figure 11 – Flowchart of the lead recycling process

Modelling & Data collection and allocation
Again, based on the flowchart, the following parameter list was established together with Exide. The values are based upon their usual production process.

	Process modules	Parameter		Unit
Input	Breaking and Separation	Batteries	XXX	t/t_{Lead}
		Electric energy	XXX	kWh/t_{Lead}
	Smelting	Oxygen	XXX	Nm^3/t_{Lead}
		Natural Gas	XXX	Nm^3/t_{Lead}
		Fluxes (Soda, Coke, Iron)	XXX	t/t_{Lead}
		External Raw Lead Material	XXX	t/t_{Lead}
		Internal Raw Lead Material	XXX	t/t_{Lead}
		Dross	XXX	t/t_{Lead}
		Dust	XXX	t/t_{Lead}
	Refining	Electricity	XXX	kWh/t_{Lead}
		External Lead Bullion	XXX	t/t_{Lead}
		Internal Lead Bullion	XXX	t/t_{Lead}
Output	Breaking and Separation	Sulfuric Acid	XXX	t/t_{Lead}
		Polypropylen	XXX	t/t_{Lead}
		Metallics	XXX	t/t_{Lead}
		Paste	XXX	t/t_{Lead}
	Smelting	Off-gas	XXX	Nm^3/t_{Lead}
		Dust	XXX	t/t_{Lead}
		Lead Bullion	XXX	t/t_{Lead}
		Slag	XXX	t/t_{Lead}
	Refining	Dross	XXX	t/t_{Lead}
		Lead Ingot	XXX	t/t_{Lead}

Figure 12 – Parameter list and numerical values for the lead use case MFA

Exide's lead recycling process mainly involves recycling by-products as well as supplementing them with externally sourced materials. The recovered metallics and paste from the battery breaking are supplemented with externally bought raw lead material (also in the form of metallics and paste). Roughly 2/3 of the raw lead material loaded into the smelting furnace is being bought, and therefore has to be modelled as received from a global market. The ecoinvent database is again used to model this market. The same procedure is applied for the lead bullion, where about 5 % of the bullion used in the refining step originates again from an external market. The batteries and fluxes in the model are also sourced from a similarly modelled average market.

For the origin of the natural gas once again Algeria is chosen. The electric energy is sourced from an average Spanish electricity mix taken from the ecoinvent database. The off-gas is simplified to the CO_2-component, as for the other use cases as well. This figure is obtained by taking 21,73 % of the overall produced off-gas amount, which corresponds to the amount of CO_2 in the off-gas while burning natural gas (average Algerian composition, ca 89,55 % CH_4) with oxygen. 80 % of the oxygen used in the furnace is produced on site, the rest is purchased externally. For the on-site-production, once again a cryogenic air separation unit is modelled from the ecoinvent database using electric energy.

Evaluation, verification and documentation

The lead use case model has been created in close collaboration with the industrial partner as well. All parameters considered were selected in direct consultation, and the associated numerical values were taken directly from the usual production practice. An evaluation and discussion of the model was also conducted with the industrial partner Exide.

Shown below in Figure 13 is the MFA model for the lead use case in the software Umberto LCA+. Also shown is the software's internal Sankey diagram, which illustrates all material flows. It can be seen that especially the external raw materials represent large mass flows, but electrical energy also plays a major role. For additional classification, the influence of the individual material flows on the determination of the global warming potential is shown in Figure 14. The influence of the external raw materials is visible here as well, but also the influence of the electricity-based oxygen generation.

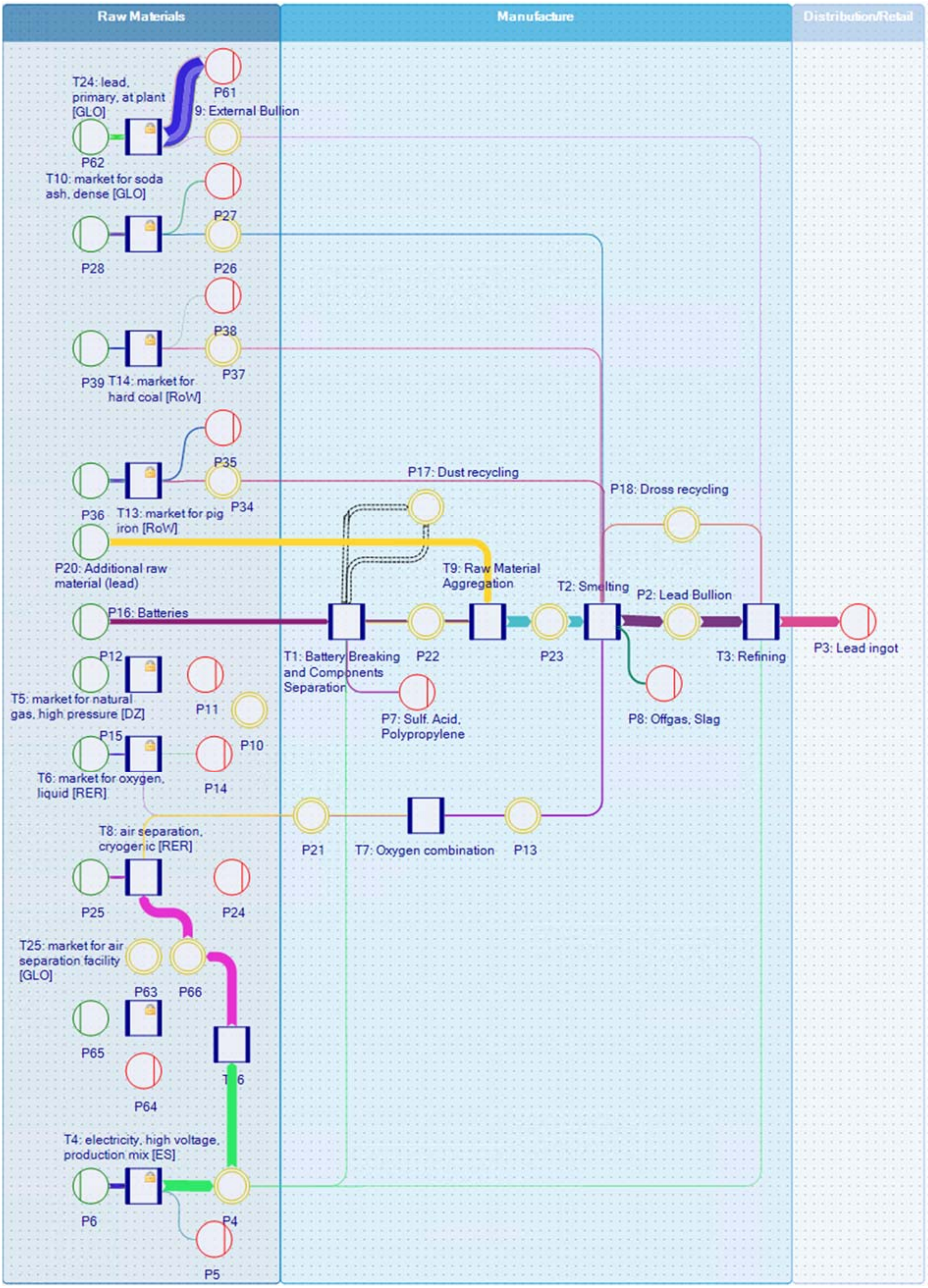

Figure 13 – MFA model for the lead use case and Sankey Diagram showing all materials flows

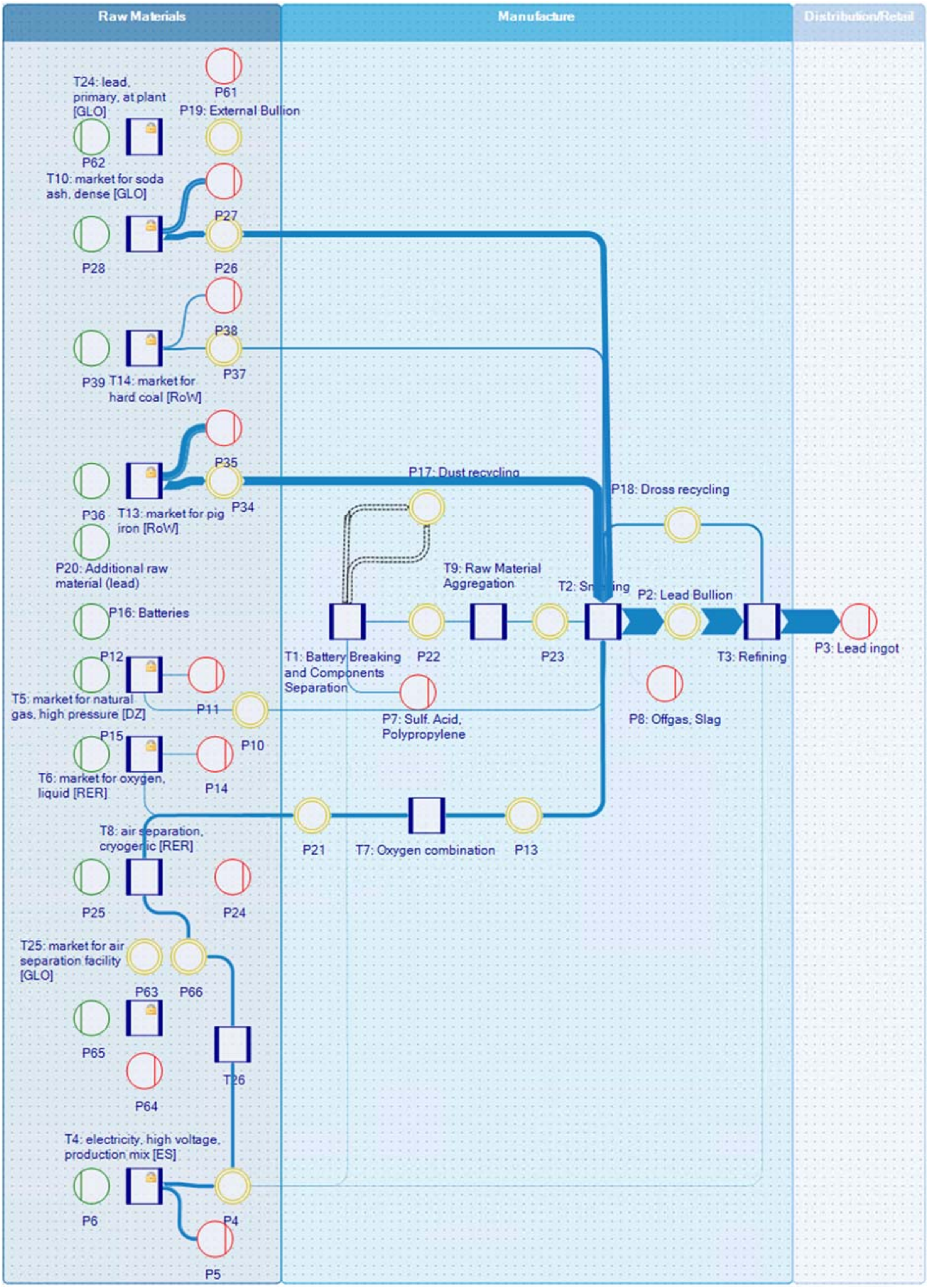

Figure 14 – MFA model for the lead use case and Sankey Diagram showing GWP calculation

4. Summary

In this work package, material flow analyses were prepared for the three use cases of the industrial partners. These will be used as a baseline in the further course of the project. The state of the processes under consideration after installation of the retrofitting solutions will also be recorded and presented as a model. The results of these secondary models can then be compared with their corresponding baseline created here. This will ensure an assessment of the impact of the new technologies according to the standard practice of Material Flow Analysis and Life Cycle Assessment.

A number of assumptions were made in preparing these analyses. These are necessary to be able to evaluate the models within the software. These assumptions are chosen identically for each secondary model of the respective use case. Thus, the assumptions influence the absolute numerical values, but not the final conclusions. This is also important to consider when interpreting the results shown here.

5. List of Abbreviations

LCA	Life Cycle Analysis / Assessment
EAF	Electric Arc Furnace
MFA	Material Flow Analysis
GWP	Global Warming Potential
BFI	VDEh Betriebsforschungsinstitut GmbH
SIDENOR	Sidenor Aceros Especiales
EURECAT	Eurecat Technology Centre
GRUPAL ART	Grupal Art SL
RWTH AACHEN	Rheinisch-Westfälische Technische Hochschule Aachen
EXIDE	Exide Technologies