REPORT

Recycling and recovery assessment of the Fairphone 3 (FP3) based on a modular approach to recycling

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MARAS
Material Recycling and Sustainability

Colophon

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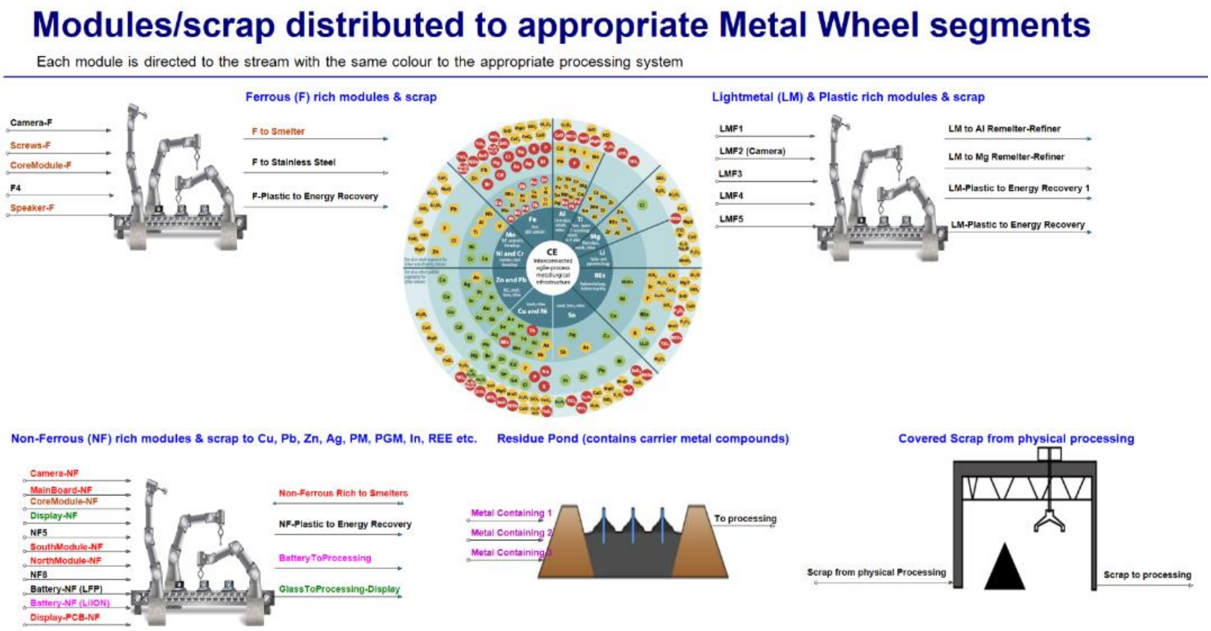
EXECUTIVE SUMMARY

This report describes the recycling assessment of the Fairphone 3 (FP3).

The calculation of the overall recycling rate of the FP3, as well as of its composing materials, elements and compounds is of importance to evaluate the performance of the FP in terms of Circular Economy. The previous recycling study on the FP2 clearly revealed that the modular design of the FP not only allows for repairability, but at the same time contributes to achieving higher recycling rates, when applying a modular approach to recycling. This approach implies that the different modules of the FP are separated and processed within the most suitable industrial (metallurgical) processing infrastructures. In this study it is assessed if the modular design of the FP3, combined with this modular approach to recycling, results in higher recycling rates than the preceding FP2 model. In addition to the previous study, it has been evaluated if dismantling of parts from the FP3 modules can contribute to even higher improvement of recyclability. By doing this, most optimal dismantling strategies can be evaluated.



The figure above is a visual summary of the simulation-based approach used to determine the recycling rate of the FP3. It shows that each module and additionally dismantled part(s) of the FP are processed in a segment of the Metal Wheel for optimal recovery of materials and energy, where each segment in the Metal Wheel is representing a full metallurgical recycling infrastructure for the processing of the different (base and associated) metals.

The flowsheet used for this simulation-based approach is based on industrial economically viable processing. It contains over 220 unit operations for the ca. 1000 materials and compounds in the

Fairphone and produced by the flowsheet as well as over 1000 streams for all phases including molten, aqueous, dust, slimes, slags etc.. The most suitable Best Available Technique (BAT) processing routes for the recycling of the of the FP3 provide the basis for the business cases as required by Fairphone.

The main conclusions from this study are:

- The recycling rate of FP3 lies between 50 % and 60% for all 3 cases, therefore significantly higher than for FP 2 due to improved design (for recycling)
- These values are valid for creating quality alloys, compounds, materials etc. that can be applied again directly in Fairphone 3 – thus true Circular Economy.
- The improved recycling performance of the FP3 is a result of (i) improved design in which the modules are more clean. The major difference between the FP2 and the FP3 lies in the possibility to recover both glass and a part of the plastics. Also do the cleaner modules in the FP3 allow for a better recovery of some metals (e.g. Fe and alloying elements); (ii) the specific processing and expansion of the recycling flowsheet corresponding to the cleaner modules as present in the FP3 has increased the recovery; (iii) better and detailed data on the FP3 facilitate a better insight into the composition of the modules and parts and a optimised organisation of the recycling by sending the modules and parts to the most suitable and optimal recycling (metallurgical) infrastructure. The know-how of Fairphone B.V. combined with a clear communication and data detail on the options to dismantle certain parts make a more specific and separate processing of these parts and contained materials possible resulting in optimised recycling.
- Although the total recycling rates of the FP3 do not differ much for the different cases, the individual material or element recycling rates are different. This makes clear that there is no one best recycling route when considering the recycling rates of the individual elements, and that recycling rates per element and material are different for each case (recycling route). Comparing individual material recycling rates is crucial when selecting the most optimal recycling option and will differ depending of the materials or elements defined as critical to recover.
- Complex combinations of materials and compounds may limit the recycling rate for future designs, especially if the definition of Circular Economy is rigorously followed, i.e. materials, alloys, compounds, functional material combinations etc. in Fairphone 3 must be recycled so that their quality is of sufficient level to return to Fairphone 3.
- Including the full compositions of materials and their functional connections permits the evaluation of the true recovery of materials and energy hence allowing the evaluation of the effect of changed product design: physics-based Design for Recycling.
- Additional dismantling of parts containing materials of interest or incompatible materials in recycling can increase the recyclability of specific materials when being based on in depth recycling know-how as provided by the models. This is illustrated by the case for the dismantling of ferrous containing parts, which significantly increased the recycling rate of Fe with 20% to 60% depending on the recycling infrastructure applied. Additional dismantling of ferrous parts allows at the same time the remainder of these dismantled modules to be processed for optimal

recovery of other elements such as Au. The additional dismantling of plastic results in higher recycling rates as a consequence of design improvements.

- Business cases have been defined by listing the BATs for industrial (and hence economic viable) recycling processing routes and hence plants to be applied to derive the most optimal treatment for the different modules as well as replaceable and dismantlable parts of the FP3.

Definitions

Recycling for Circular Economy:	Recycling of a product within the circular economy implies creating the same material quality after recycling so that it can be applied in the same product.
Compound:	Material defined in its stoichiometric chemical composition, i.e. aluminium as Al, Al_2O_3, etc.
Dismantling:	Includes disassembly and implies taking the Fairphone 3 apart into its modules as well as understanding if the modules can be further selectively disassembled into smaller parts that can be channelled into the correct processing.
Energy recovery:	Plastic compounds are used as an energy source as well as for feedstock recycling e.g. using C and H as reductants.
Feed composition:	The simulation model requires a full description of the compounds as input to the model, which must add up to 100% in weight.
Flowsheet:	A logical sequence of reactors that convert the input into among others high quality materials, compounds, alloys, metals, building materials, energy as well as residues and intermediates that can be ponded or used in further processes. These flowsheets are industrially realistic and economically viable for different processing routes.
Flows:	All the flows of materials, solution, mixture, phases, gases, dust (among others) are quantified in terms of enthalpy and entropy (kWh/h) values in addition to the mass flows (both total mass flows and mass flows per compound) in kg/h or tonnes/h.
Module:	The major modules of the Fairphone.
Parts:	Specific parts on the modules that can possibly be removed and sent to more dedicated processing.
Plastic compounds:	Full composition of all organic molecules of C, H, O, N, Br, Cl, metals atoms etc. in addition to fillers within the plastic. These are complex functional materials that are difficult to recycle to produce the same quality as for the original plastic compound.
Product data:	This is the complete composition of the product, thus all compounds, functional materials, alloys, plastics etc. and their spatial position on the modules. This means aluminium in Al, an alloy of aluminium, Al_2O_3 as an oxidized/anodized layer on the aluminium, or a filler etc.
Reactor:	A unit in which the input of material is converted to a product, energy, off gas, solution or similar.
Recycling rate:	Within the circular economy paradigm this means producing the same quality material, alloy, metal, or compound that can be used within the Fairphone 3. The recycling rate of each element thus implies the recycling into high quality products.

Simulation: Predicting the flows of all compounds and phases throughout the complete flowsheet.

Metal Wheel: Depicting the paths of recycling of materials into different processing infrastructures (see the figure above in the "Executive Summary").

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1. INTRODUCTION AND PROJECT GOALS

Following up on the recyclability study of the Fairphone 2 (FP2) completed in 2016, a recyclability assessment has been performed also on the FP3 by the application of recycling flowsheet simulation modelling. This is a continuation and deepening of the previous study. The recycling performance of the FP3 has been assessed in order to determine the recycling rates, which can be achieved by application of Best Available Techniques (BAT) in metallurgical recycling processing as well as to determine the improvement in recyclability of the FP3 in comparison to the FP2.

Recycling in the context of the circular economy is understood to produce the same quality of materials so that they can function at the same quality in the same product again. The recycling rates of a product and its composing materials and compounds are determined by:

- the design, structure, materials and compounds used in a product or module,
- their functional connections and full composition of each (multi-) material, as well as,
- the recycling route(s) and combination of processes, which are applied to recycle the complete product and/or different modules or parts.

The previous study on the FP2 clearly showed, based on the assessment of 3 different recycling routes, that the selection of recycling routes, i.e. the recycling flowsheet configuration or in other words the metallurgical infrastructure architecture for processing the product, has a direct effect on the overall recycling rate. At the same time, the different recycling routes result in different recycling rates for the different materials and compounds present in the product, modules or parts.

To understand, illustrate and assess the influence of recycling route configuration, i.e. the combination of different processing routes and options within the recycling processes available, 3 different case studies have been performed in this study for the FP3. The recycling flowsheet architecture designed for the processing of the FP as captured in the models was applied to define different recycling configurations (2 cases). This means, that in each case, modules of the FP3 were fed into different and most suitable metallurgical processing routes for recycling (this configuration will differ for each of the cases) , to estimate the recyclability of the FP3 and to define the most optimal processing architecture. The third case addresses additional dismantling of selected parts from the FP modules and the most optimal configuration of processes.

Based on the performed assessment, business cases can be defined, by generating insight on the BAT industrial (and hence economic viable) recycling processing routes and hence plants to be applied to derive the most optimal treatment for the different modules as well as replaceable and dismantlable parts of the FP3.

Consistent with the methodology applied in the previous study, the assessment and underlying calculations have been performed by the application of rigorous and physics-based process simulation models. These models include the complex interlinkages of functional materials in the modules as well as all chemical transformation processes in the reactors in the system model in versatile flowsheet simulation modules. This approach permits the rigorous evaluation of the recyclability of a product within the circular economy.

The process simulation model has been developed in the industrial software platform HSC Chemistry Sim® 10 (www.mogroup.com), providing a professional and industrial platform for process simulation tools and recycling as well as environmental impact calculations.

The previous work showed that a modular approach to recycling by separating FP2 modules by dismantling and processing them in the most suitable (industrial available) metallurgical and plastic and energy recovery processes (*'Route 2' in the FP2 study*) is the most optimal (and novel) approach to recover a wide(r) range of materials and elements from their complex functional connections (see Figure 1). This is contrasted relative to the traditional shredding-based recycling approach or processing the entire FP2 into (base metal) smelting furnace. For this reason, this most optimal modular recycling approach (Route 2) has been applied as the basis of all three cases of the recycling assessment of FP3 and its results and recommendations.

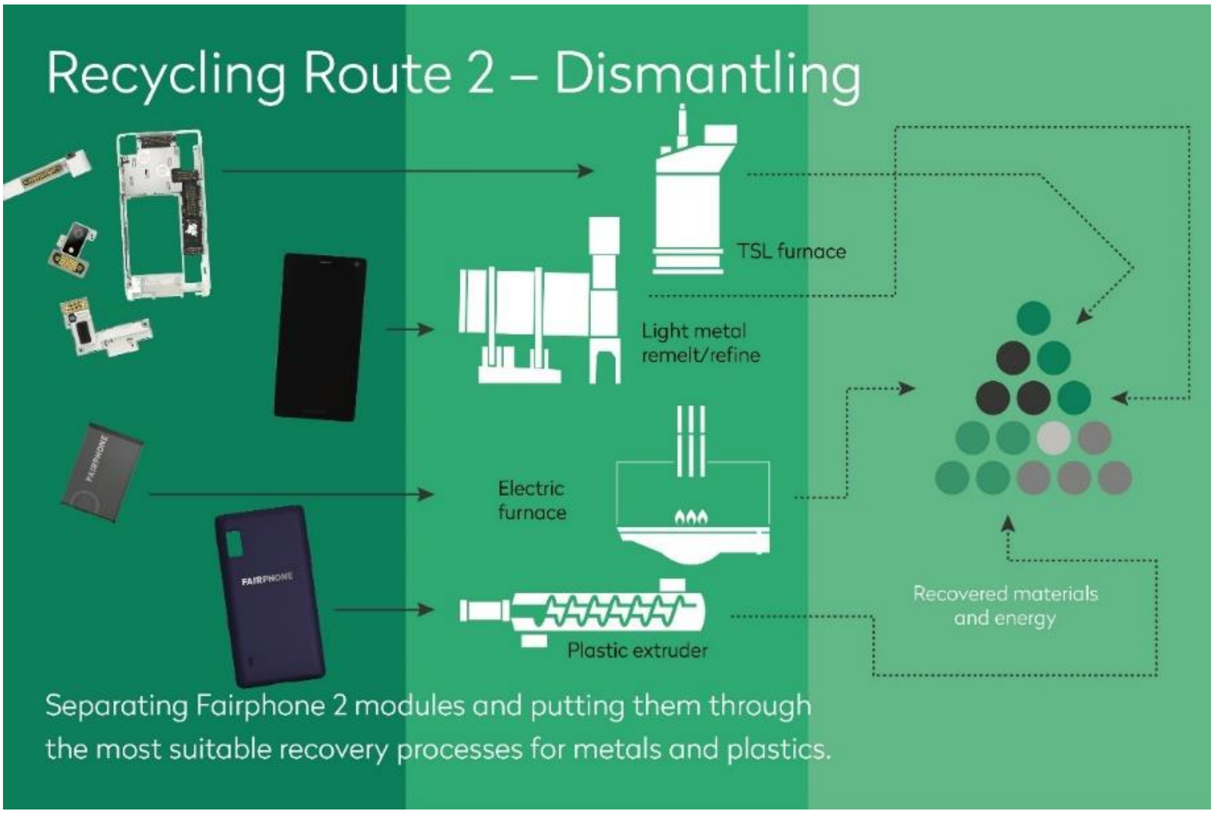


Figure 1 Recycling Route 2 of the FP2 recycling assessment study (2016) provides the basis for the recycling assessment of the FP3 (recycling based on dismantling of the FP modules and putting them through the most suitable recovery processes for metals and plastics) as this proved to be the most efficient recycling option for the FP

2. Methodology and process of recycling assessment based on a modular approach to recycling (Route 2 in study on FP2)

2.1 Data analysis on FP3 data, completion of data, identification, and correction of errors in data and transformation to data format suitable for simulation

Successful accomplishment of recycling assessment on a rigorous simulation basis requires detailed product data of the product and its modules for which the recycling assessment is being performed, i.e. in this case for the FP3 and its modules. In other words, the complete "mineralogy" of the product must be available as is usual when simulating and optimizing metallurgical processes and flowsheets. The previous study showed that Fairphone B.V. is very well capable of collecting and providing this very detailed information, being an outstanding example for the industry on how product functional material data for recycling assessment should be defined and made available for studies and to consumers.

The detailed FP3 product compositional data provides the input to the recycling process simulation models in order to calculate the recycling performance of the FP3. Compositional data, as delivered by Fairphone B.V., needs data analysis and processing in order to prepare and structure this in a format, from which the input to the recycling simulation models can be defined. This means the full compositional information of all materials must be available, as well as their distribution on the modules. These data as provided by Fairphone B.V. have been analysed and processed by MARAS in order to define the input data for the recycling assessment per module of the FP3, involving the following activities:

- Data have been analysed on completeness, consistency, unclarities and possible errors in data (e.g. gold data and its functional connection to other materials, metals and alloys) – mass and compositional data have been verified i.e. all compounds e.g. Al, Al_2O_3 etc.
- All data have been transferred from material descriptions, names and/or CAS numbers to stoichiometric chemical formulas. This has been done based on a very extensive consultation of material and compositional databases.
- Data description and chemical formulas of organic compounds have been added to the data file in terms of composition, this is important as this determines the enthalpy and entropy of the compounds.
- Identified data inconsistencies or errors have been communicated to FP and have been corrected.
- Data (gaps) have been completed where required and if at all possible.
- Updated, new and adjusted data have been processed and included.
- Full mass and compositional analyses in terms of chemical formulas have been defined and derived for each of the different modules in the FP3. Excluded are confidential material and compound data. This provides the input data in a format suitable to recycling and recovery rate calculations using a process simulation platform.

2.2 Identification of list of non/low recovered materials in FP2 and elements defined as critical by Fairphone B.V.

Due to complex functional material connections in the product and modules, materials which are incompatible in recycling (as visualised by the Metal Wheel) are combined and might end up during recycling in processing routes in which not all of them can be recovered. This results in materials ending up in slags, speiss, flue dusts etc. from which it is often not possible to (economically) recover them. Based on the results of the assessment of recyclability of the FP2, the non- or only limited recoverable materials have been identified and listed. To this list, additional elements as defined as critical by Fairphone B.V., have been added as a focus to be recovered into high-quality final compounds and materials. This selection was done in close consultation with Fairphone B.V.. The material recoveries of the listed elements can be compared to the recoveries that can be achieved for the FP3. On this basis improvement or changes with respect to material and therefore elemental recoveries resulting from the design improvements for recycling of the FP3 versus that of the FP2 can be assessed.

It is important to realize that in the recycling assessment, the recyclability of all materials and compounds that are present in the FP3 are determined. As part of this assessment, the recycling rates of the identified non/low recovered materials in traditional (non-modular) recycling can hence be compared to their recycling in the improved FP3 design and as a consequence of defined disassembly strategies. This allows a scan based on focus materials and low or non-recovered materials/elements to identify improvements and pinpoint further needs for Design for Recycling or adapted recycling approaches.

Table 1 The element recoveries into valuable material products of non/low recovered materials for traditional i.e. non-modular, recycling approach (captured by 'Routes 1 and 3' in study on FP2). The second column adds elements on Fairphone's focus material list (not necessarily low in recovery).

Elements	**Selection criteria**	**Recycling [%] in FP2 Route 1 (processing entire FP2 in base metal smelting furnace)**	**Recycling [%] in FP2 Route 2 (modular recycling of FP2)**	**Recycling [%] in FP2 Route 3 (Shredding based recycling of FP2)**
Al	Low recovery in FP2	0-10	10-20	0-10
As	Low recovery in FP2	30-40	30-40	30-40
Au	FP focus material list	90-100	90-100	90-100
B	Low recovery in FP2	0-10	0-10	0-10
Ba	Low recovery in FP2	0-10	0-10	0-10
Be	Low recovery in FP2	0-10	0-10	30-40
Bi	Low recovery in FP2	0-10	0-10	0-10
C	Low recovery in FP2	0-10	0-10	0-10
Ca	Low recovery in FP2	0-10	0-10	0-10
Co	FP focus material list	90-100	80-90	80-90
Cu	FP focus material list	90-100	90-100	90-100
Cr	Low recovery in FP2	0-10	0-10	0-10

Dy/REE	Low recovery in FP2 & FP focus material list	0-10	0-10	0-10
Fe	Low recovery in FP2	0-10	0-10	70-80
Ga	FP focus material list	90-100	90-100	80-90
In	FP focus material list	90-100	90-100	80-90
Li	Low recovery in FP2	0-10	0-10	0-10
Mg	Low recovery in FP2	0-10	80-90	90-100
Mn	Low recovery in FP2	0-10	0-10	30-40
Nd/REE	Low recovery in FP2	0-10	0-10	0-10
Ni	FP focus material list	90-100	90-100	80-90
Pr	Low recovery in FP2	0-10	0-10	0-10
Sb	Low recovery in FP2	60-70	60-70	60-70
Si	Low recovery in FP2	0-10	0-10	0-10
Sn	Low recovery in FP2 & FP focus material list	90-100	80-90	60-70
Sr	Low recovery in FP2	0-10	0-10	0-10
Ta	Low recovery in FP2 & FP focus material list	0-10	0-10	0-10
Ti	Low recovery in FP2	0-10	0-10	0-10
W	Low recovery in FP2 & FP focus material list	0-10	0-10	0-10

2.3 Process of recycling assessment of FP3

Recycling route 2 of the FP2 study made very clear that the modular design of the FP for repairability allows for a better recyclability of materials and compounds present in the phone since modularity allows for a better 'separation', i.e. by (automated or manual) dismantling and selection of recyclates, modules or parts for subsequent focussed metallurgical and other final treatment processing.

Based on the results of the FP2 study, the (study on) FP3 focussed further on the possibilities of modular design (for recycling). Based on the modular recycling of the FP, in which the different modules and their composition have been assessed by MARAS in terms of material content and combinations, modules are directed to the most suitable metal and plastic processing routes available as reflected by the Metal Wheel. Most suitable routes imply the recycling processing infrastructure in which the compounds of the module are most optimally recycled with a minimum of losses and emissions. This will differ per module, due to its specific material composition as defined in the design. For some modules, different options in processing might be considered, depending on which of the materials is preferred to recycle from the module's material content.

To allow for the assessment and optimization of the industrial feasibility of the metallurgical recycling processing options, all modules and hence all materials and compounds present in the FP3 (including but not limited to the list of selected elements/materials of interest as discussed above) have been included in the recycling assessment. In this assessment, the materials, which proved to be not (or limited) recoverable and the materials defined as critical are part of an entire range of materials and compounds which are addressed in the recycling assessment. Including all materials, elements and compounds in recycling assessment is crucial, as material combinations are affecting the mutual recovery rates in processing. We therefore follow the Product Centric approach (addressing all materials and compounds in a product and not just a selection of elements) as defined by Reuter and Van Schaik (Reuter and Van Schaik, 2013). The materials listed can be given special focus where required, e.g. when selecting the most optimal or most suitable recycling route(s) for processing the different modules of the FP3.

To be able to address and understand the balance between dismantling and metallurgical and plastics processing as well as energy recovery, a complete particle and thermochemistry-based flowsheet simulation model was developed as depicted by Figure 2 for FP2 and was expanded to the expansive flowsheets depicted in Figure 3 and Figure 6 as well as the linked figures in the Appendix. All compositional data of the FP3 and its composing modules is integrated into the simulation models. HSC Chemistry Sim 10 calculation modules automatically utilize extensive thermochemical databases, which contains enthalpy (H), entropy (S) and heat capacity (C) data for all materials and compounds included, allowing not only recycling rate calculations, but at the same time environmental analysis including exergy assessment. This quantifies therefore also each stream not only in kg/h units but also in MJ/h or kW. This is rather important to analyse the true losses also in terms of thermodynamics of all materials i.e. in terms of exergetic dissipation or losses in line with the second law of thermodynamics. Frankly, this is the only correct way to fully understand the circular economy of products and their recyclability. Mass-based approaches such as material flow analysis do not include thermodynamics and therefore give erroneous results.

2.4 Flowsheet development for recycling assessment of FP3 and support of business cases

The processing flowsheet, including all (industrial) available processing routes for the recycling of the FP3, provides the basis for the calculation of the recycling rates. This processing flowsheet has been updated and extensively elaborated in comparison to the study on the FP2, investigating and including best suitable technologies for the processing of the FP3 design with a focus on the identified materials, elements and modules. The flowsheets as summarized in the Appendix covers the complete metallurgical (and other final treatment) recycling processing infrastructures present in industry for the processing and recovery of all materials and compounds of the FP3. Figure 3 is the cover disassembly sheet of the model that directs the modules into the different sections of the complete flowsheet to maximize recovery into the highest quality products.

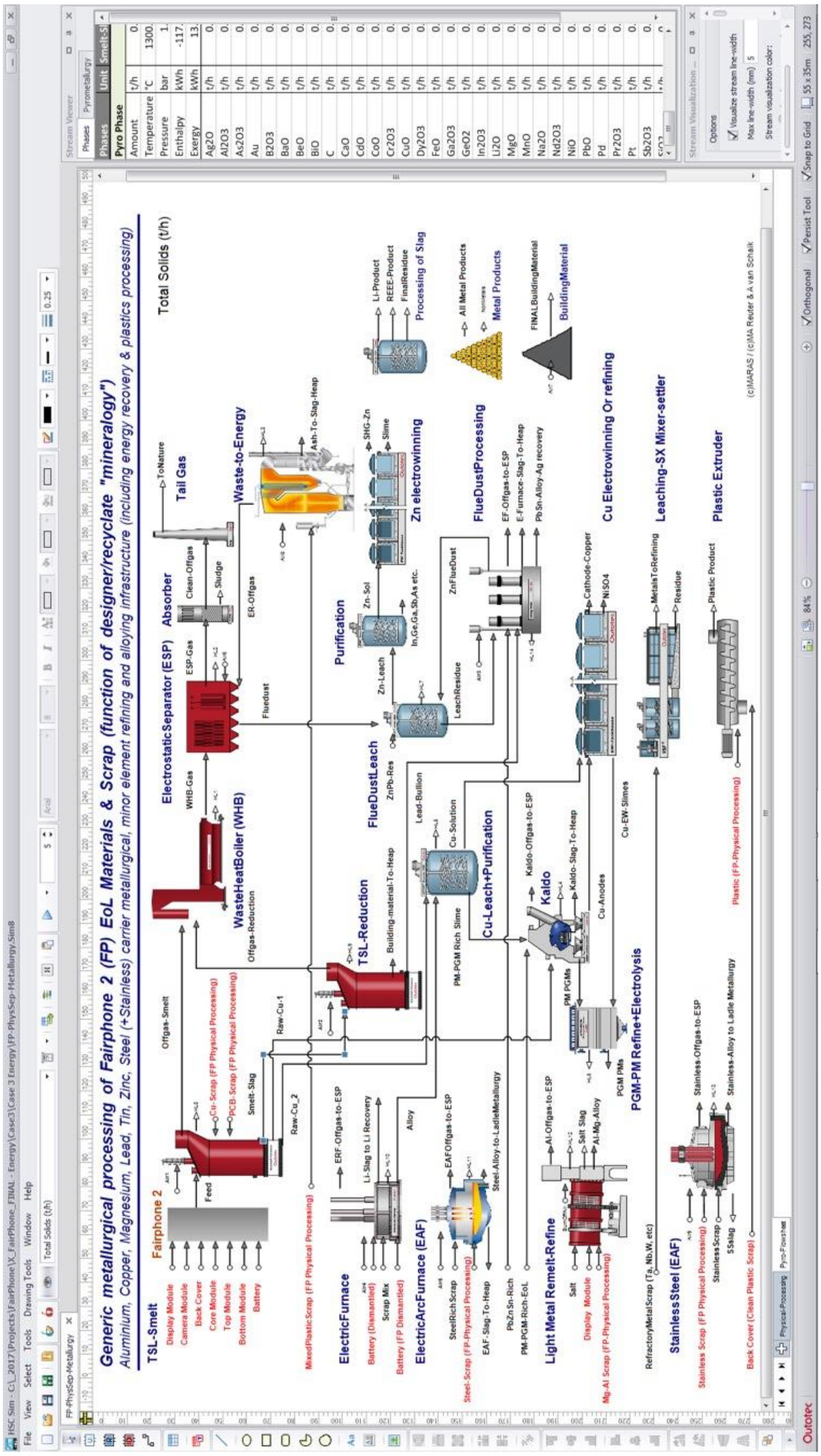


Figure 2 The metallurgical, energy and plastics processing flowsheet for FP2 as industrially available to process the multitude of metals, alloys, functional materials and plastics in an end-of-life product. It covers steel, stainless steel, copper, lead, tin zinc, aluminium and magnesium as carrier metal metallurgical infrastructure as well as plastics recycling and energy recovery. This simulation model as depicted here served as the basis for the FP2 recyclability analysis, and was expanded considerably for FP3 as the appendix reveals by detailing the different processing flowsheets underlying this figure.

The different modules of the FP3 and additional disassembled parts from the modules are directed into the recycling flowsheet simulation model following the segments in the Metal Wheel (as displayed in the 'Feeds' sheet of Figure 3). The Metal Wheel depicts the basic metallurgical infrastructure in the centre band, that makes the recovery of elements in each segment possible due to the refining and alloying infrastructure and compatible chemistry and material physics. Each module is directed to the most appropriate metal wheel segment, which is covered in the simulation models by the complete flowsheets and range of reactors composing the different (metallurgical) processing infrastructures.

The recycling assessment does not only provide recycling rates for the total FP3 and its modules' materials and compounds, but also provides insight and knowhow on the industrially BAT for the metallurgical recycling processing options. This supports the business cases as required by FP. To accomplish this, the recycling and processing flowsheets have been extensively updated and expanded in this study in order to facilitate this and reflect state of the art industrial processing options for recycling. These are depicted in the Appendix, each flowsheet is connected appropriately.

The performed recycling assessment cases provide the basis to define business cases. The assessment cases generate insight on the Best Available Technique (BAT) industrial (and hence economic viable) recycling processing routes and hence plants to be applied to derive the most optimal treatment for the different cases and objectives of recycling (either focussing on optimal total recovery or optimal recovery of specific elements) for the different modules and (replaceable and dismantlable) parts of the FP3.

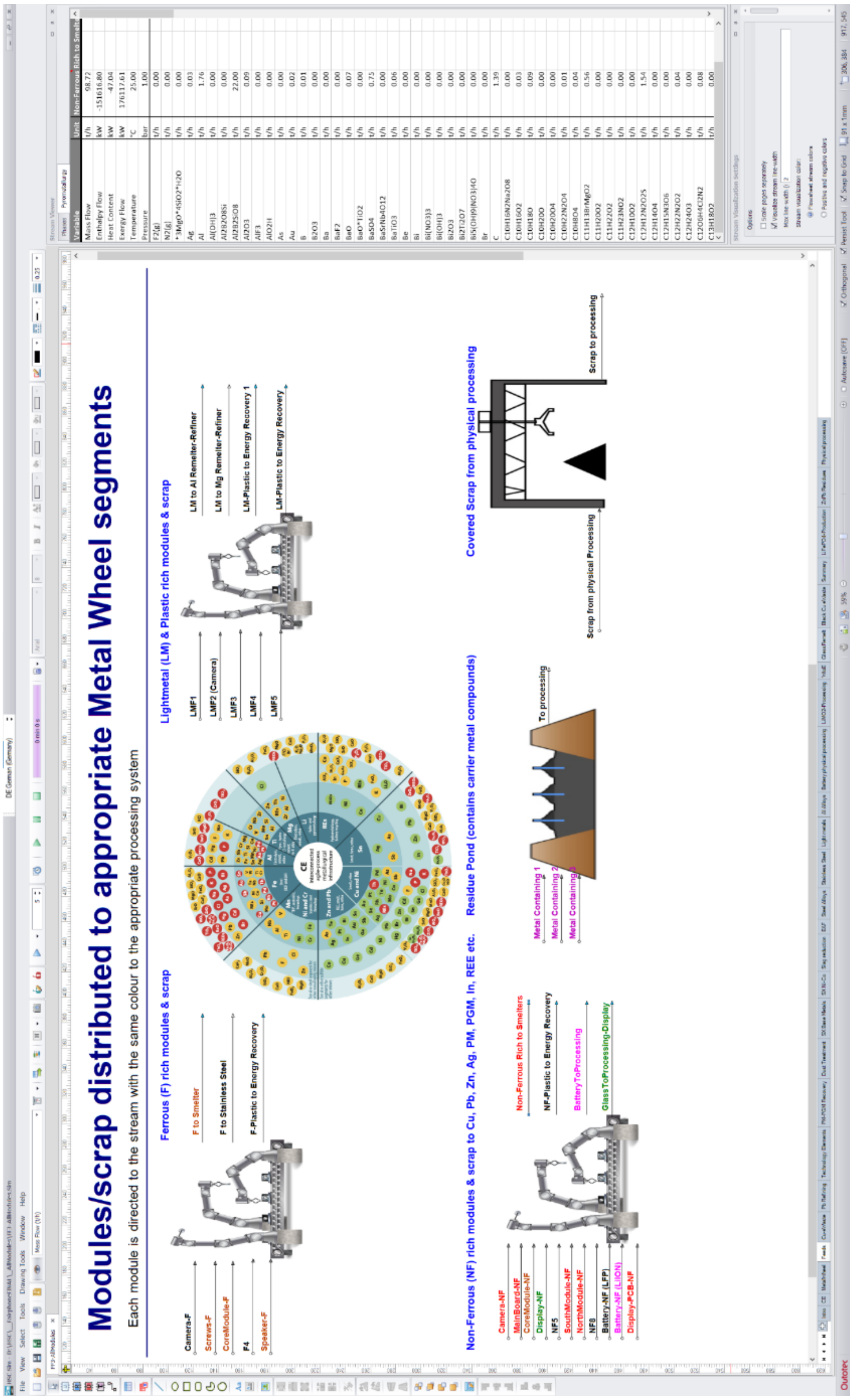


Figure 3 In the FP3 process model, the "Feeds" sheet is of importance as it shows in which metallurgical processing infrastructure (according to the segments of the Metal Wheel in the middle) the modules (indicated as inputs e.g. Camera – F (in which F implies ferrous), Camera - NF (non-ferrous), LM (Camera) (LM=Light Metal), Main Board – NF) are processed.

2.5 Assessment of recycling performance of additional dismantling activities (including instructions on intensity of dismantling)

The recycling of the FP3 based on its modular structure is being assessed by the application of the recycling flowsheet simulation model cover 'feeds' sheets of Figure 3, Figure 6 and processing flowsheets in the Appendix detailing the cover flowsheet. As additional dismantling of selected parts within the modules is considered as a possibility to increase the recyclability of specific materials of the FP3, options for additional dismantling were defined in consultation with FP. These were then compared to the recycling assessment cases in which different recycling options for the recycling of the different modules were assessed, without considering additional dismantling of specific parts. The effect of the selected additional dismantling activities provided the detail for a third case. In this manner, the effect of additional dismantling and feedback on the intensity of dismantling can be determined. This would be simulation-based design for recycling.

2.6 Definition of cases for the recycling assessment of the FP3

As the recycling routes and combinations of processes, which are applied to recycle the different modules or parts of the FP3 are of direct effect on the recycling rate of the product, case 1 and 2 have been defined to assess the recycling of the modules of the FP3 in different recycling infrastructures and evaluate the results thereof to provide recommendation on the most optimal recycling route to be followed for the FP3 modules. The options for additional dismantling in view of recycling performance improvement are evaluated in a third case. The cases are summarised below. In the next chapter, more detail on the cases is provided when discussing the results.

Case 1 : Recycling flowsheet configuration 1

- Main board, camera module, north and south module and dismantled display module PCB processed in the Cu route
- Speaker module, screws and core module processed in steel processing
- Battery processed in dedicated battery recycling plant
- Display module (ex PCB) processed in glass recycling

Case 2 : Recycling flowsheet configuration 2

- Core module processed in Cu route instead of in steel processing route
- Rest of recycling flowsheet configuration as in case 1

Case 3: Additional dismantling activities – Ferrous parts dismantling case

- Ferrous parts isolated from different modules, speaker module and screws processed in steel processing
- Remaining modules after dismantling of ferrous parts are processed according to recycling flowsheet configuration of case 2

3. RESULTS OF RECYCLING ASSESSMENT

This chapter will present and discuss the results of the recycling assessment as performed on the basis of the process and methodology as described in the previous Chapter.

Figure 3 shows a screen capture of (and a section of) the "Feeds" pane of the simulation model. In the right-hand table a small excerpt of the input compositional (and material combinational) data is shown as included in the models. This sheet directs all flows of the modules to the correct and most suitable (i.e. with the highest recovery and lowest amount of losses/emissions) metallurgical processing infrastructure. As pointed out, the data of the FP3 and its modules provided by FP and analysed and processed by MARAS, have been integrated as input into the simulation models. This has been done by including the required detailed description of materials in terms of needs to functionally describe metallurgical processing using a process simulator.

The HSC Sim simulation model as applied for the assessment of the FP3 has 221 reactors, 970 streams, ca. 50 elements and close to 1000 compounds being processed. It is a globally unique model to analyse design changes and improvements in complete detail. The model has therefore been enhanced considerably relative to the FP2 study and can be helpful to estimate the effects of design for recyclability of future FP products.

3.1 Recycling assessment results– different recycling flowsheet architectures for processing of the FP3 modules (cases 1 and 2)

The different cases and corresponding results are listed below. The results are in summary discussed based on the overall recycling rate of the FP3 as well as on the Fe and Au recycling rates. The recycling rates of all other materials and compounds that are recovered into the various high quality materials, compounds, alloys etc. of the FP3 are included and provided by the Material Recycling Flower for each different case. This allows for transparent visualization of the individual materials/element recycling/recoveries and a comparison between the performance and differences between the various cases. Although all elements and materials present in the FP3 are included in the assessment, it has been chosen to visualise in this report only the recycling rates for the identified non/low recovered materials for traditional i.e. non-modular, recycling approach and the elements on Fairphone's focus material list (listed in Table 1 and 3).

Case 1

Description of processing of modules in the metallurgical recycling flowsheet architecture (see Figure 3 and Appendix):

- Main board, camera module, north and south module and dismantled display module PCB processed in the Cu route (see Figure 6, which gives an overview of the processing in terms of reduction and oxidative processing, as well as cleaning of the slag to create a building material quality product)

- Speaker module, screws and core module processed in steel processing (see Appendix)
- Battery processed in dedicated battery recycling plant (see Appendix)
- Display module (ex PCB) processed in glass recycling (see Appendix)

The flowsheets of all processing routes as included in the recycling simulation model, giving the detailed processing infrastructures of all recycling routes as included in the model and presented in Figure 3, and also summarized in the Appendix of this report.

Summary of results of FP3 recycling for case 1

The following recycling rates are achieved within case 1 (presented for Au and Fe recovery - see Table 3 and Material Recycling Flowers for recycling rates of all materials/elements):

- Overall recycling rate 46.4%
- Au recycling rate 71.2%
- Fe recycling rate 62.8%

The recycling rates of the selected elements from Table 1 for Case 1 are depicted by the Material Recycling Flower in Figure 4.

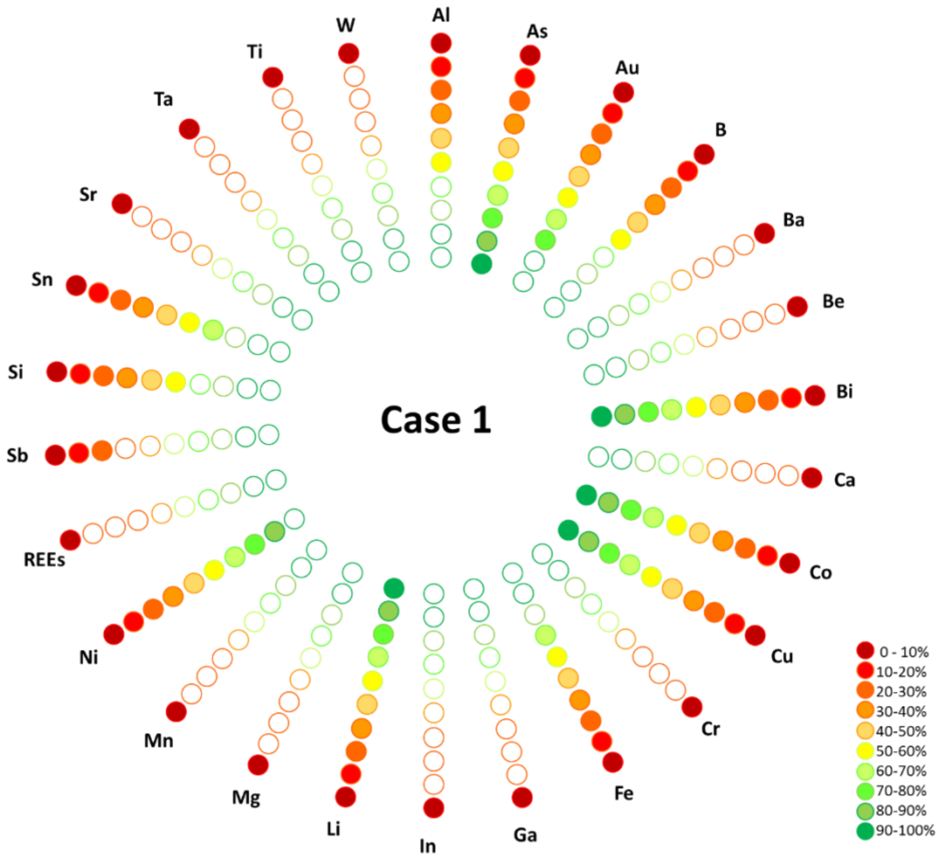


Figure 4 Material Recycling Flower showing recycling rates for the selected elements from Table 1 for Case 1

Case 2 : As case 1 but with entire core module processed in Cu route instead of in steel processing route

In order to show the effect of different processing options/routes on the recycling rate, a second case is added in which the core module (without any dismantling of ferrous containing parts) is sent to the Cu route due to the presence of Cu, Au, Ag and other metals which can be recovered in this route.

Description of processing of modules / recycling flowsheet architecture as depicted by Figure 7:

- Main board, camera module, north and south module, dismantled display module PCB part and core module processed in Cu route (Figure 6)
- Speaker module, screws processed in steel processing
- Battery processed in dedicated battery recycling plant
- Display module (ex PCB) processed in glass recycling

Summary of results of FP3 recycling for case 2

The following recycling rates are achieved within case 2 (presented for Au and Fe recovery - see Table 3 and Material Recycling Flower for recycling rates of all materials/elements):

- Overall recycling rate 44.9%
- Au recycling rate 94.3%
- Fe recycling rate 22.9%

The recycling rates of the selected elements from Table 1 for Case 2 are depicted by the Material Recycling Flower in Figure 5.

This route shows a significant decrease in Fe recovery due to Fe being lost to the slag in the Cu route.

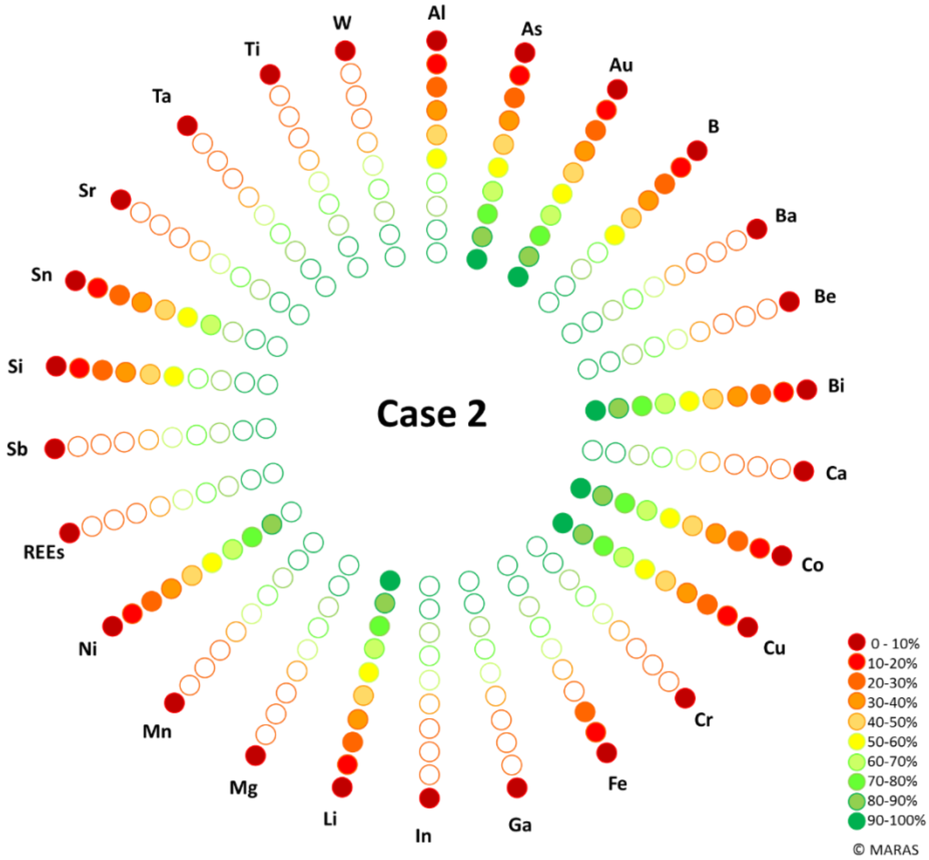


Figure 5 Material Recycling Flower showing recycling rates for the selected elements from Table 1 for Case 2

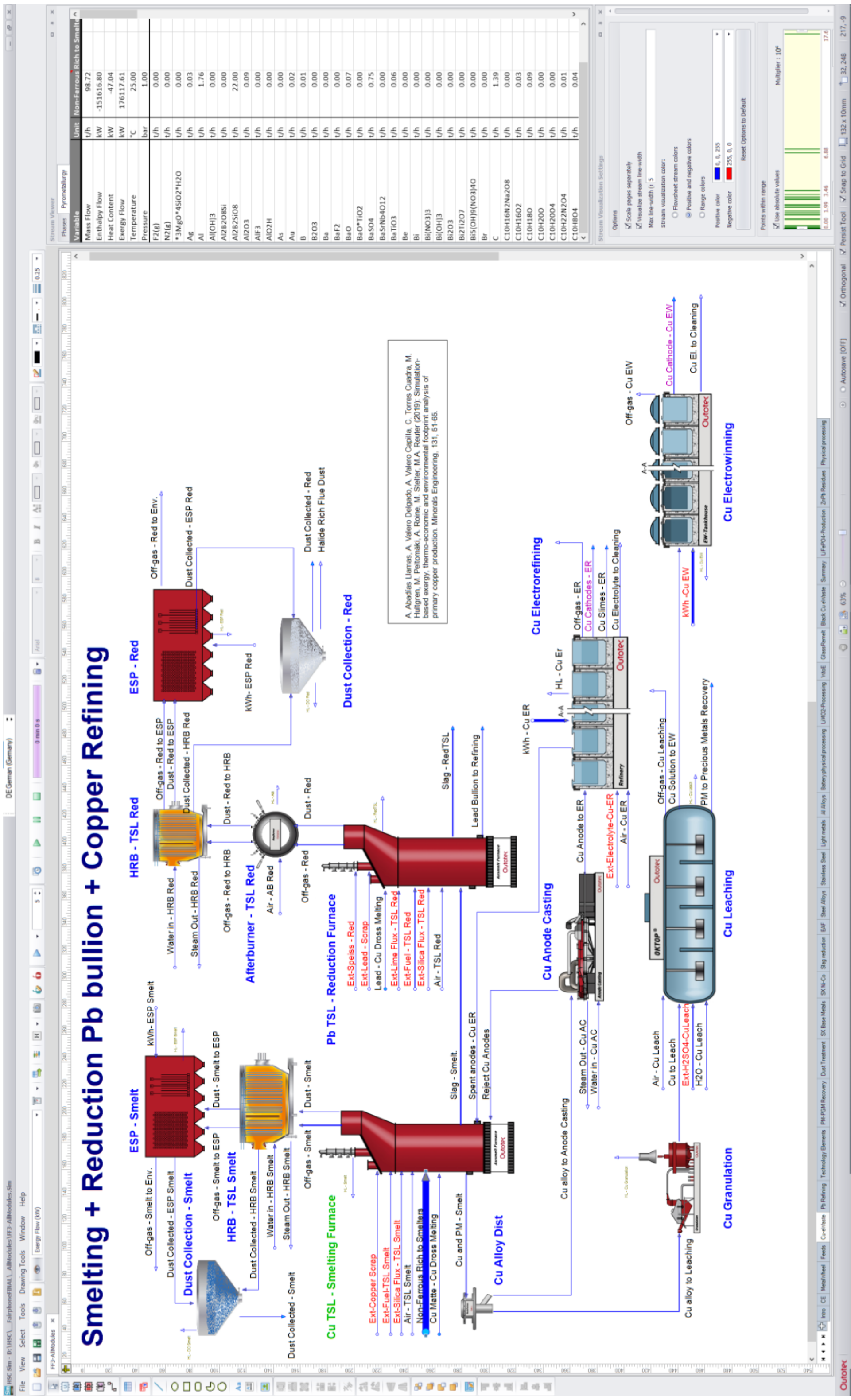


Figure 6 'Cu route' – Smelting (Cu TSL (Top Submerged Lance) – smelting furnace), reduction of Pb bullion (Pb TSL – reduction furnace) and Cu refining. The TSL reactor can also be a proxy for a TBRC (Top Blown Rotary Convertor) type reactor, the metallurgy is determined by the partial oxygen pressure and temperature in the reactor. Also shown is the oxidative leach of raw copper and subsequent electrowinning of the copper

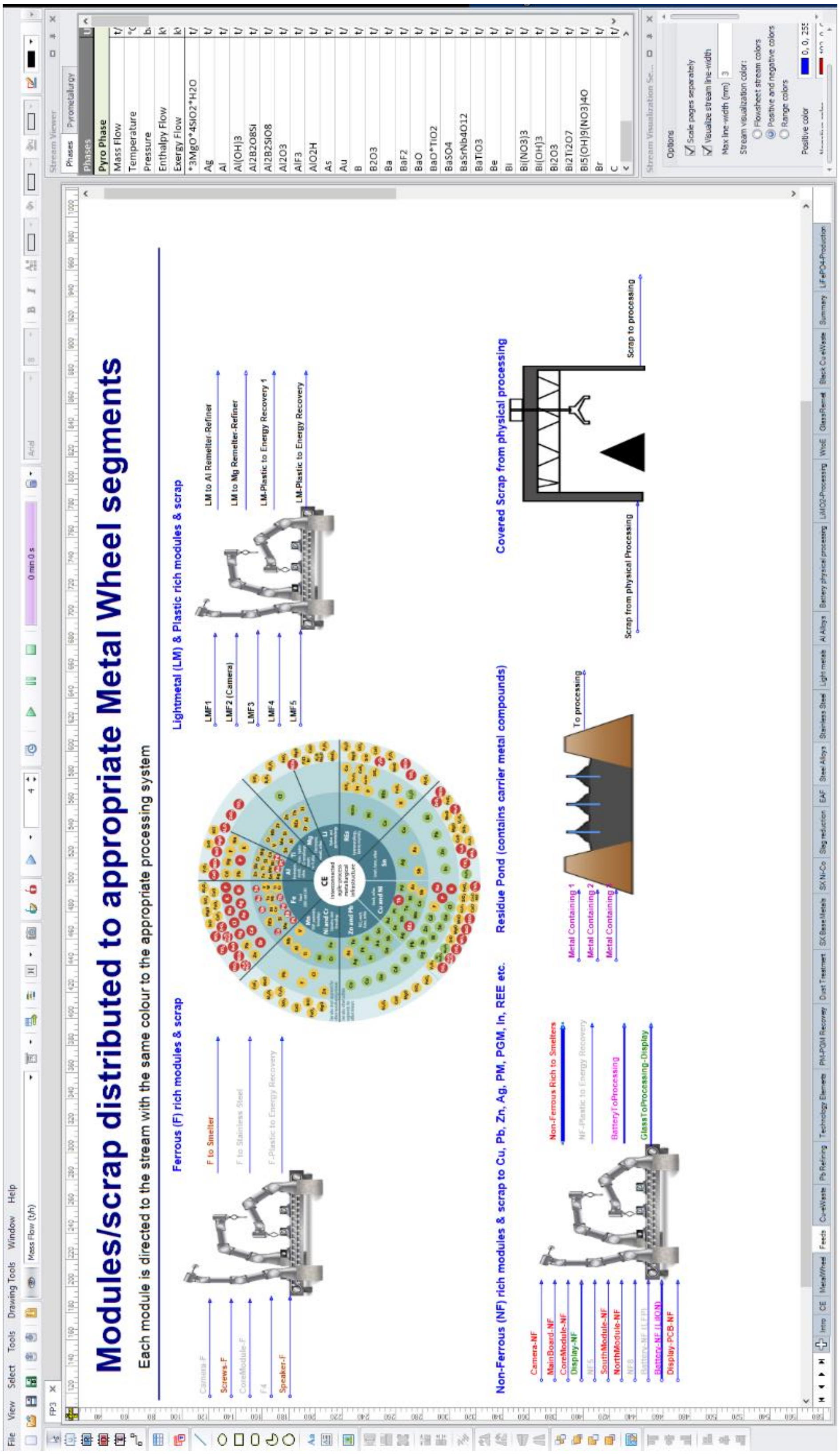


Figure 7 Feed sheet and processing routes for case 2 (difference with case 1 is that the core module is processed in the Cu route) as can be seen bottom left (compare to Figure 3 top left)

3.2 Recycling assessment results on additional dismantling activities (case 3)

As additional dismantling (increasing dismantling depth) might be an option to increase the recycling rate of the FP3 and/or particular materials and compounds of interest. This has been investigated (after discussing the additional assembly options with Fairphone B.V.) by assessing the additional dismantling of Fe containing parts in the FP3.

Based on the results of the assessment of cases 1 and 2, the recovery of Fe versus Au (and other precious metals contained in the core module) turns out to be conflicting due to their combination in the same module/part and their need for a different processing route to recover them. Both Fe and Au have been listed in Table 1 as critical and focus of this project. The Fe recovery remains even for case 1, in which the Fe containing core module is sent to the steel processing route, not very high (62.%). This indicates options for improvement. FP has indicated that additional dismantling of Fe containing parts might be an option, as these parts can relatively easily be traced in the product. Therefore, additional dismantling of Fe containing parts has been defined as a possible case for assessing the possibilities and effects of extra dismantling on recycling performance. FP has provided the part numbers for which additional dismantling with a focus on the ferrous content would be possible.

This section presents and discusses the recycling results for the case where ferrous containing parts (according to the part numbers as provided by FP) are isolated/dismantled from the various modules.

The following is included in this assessment:

- The dismantled ferrous containing parts have been processed in the steel processing flowsheet.
- The effects of the additional dismantling of ferrous parts on the most suitable routes for the remainder of the dismantled modules have also been included in the assessment. The additional dismantling of ferrous containing parts has as a result that other iron rich parts such as the core module, which was initially processed in the steel flow due to the high ferrous content, can now be sent to the Cu processing and refining route (Figure 6). This increases then the recovery of the contained gold which goes lost in the steel route as it nicely dissolves in steel. This also includes a high Fe recovery (and related alloying elements such as Ni, Co, etc.).
- It has been observed from the results in cases 1 and 2 that the Au-rich parts end up in the Cu processing route as well (see Figure 6). There is no reason to dismantle them, as they are processed in the most suitable route in this manner.

Case 3: Additional dismantling activities – Ferrous parts dismantling case

Description of processing of modules / recycling flowsheet architecture as reflected by Figure 9:

- Main board, core module, display module PCB part all excluding the disassembled ferrous containing parts, camera module, north and south module processed in Cu route (including Au rich parts)

- Ferrous parts isolated from different modules, speaker module and screws processed in steel processing
- Battery processed in dedicated battery recycling plant
- Display module (ex PCB) processed in glass recycling

Summary results of FP3 recycling for case 3

The following recycling rates are achieved within case 3 (presented for Au and Fe recovery - see attachment/table for recycling rates of all materials/elements):

- Overall recycling rate 45.9%
- Au recycling rate 94.8%
- Fe recycling rate 82.9%

The recycling rates of the selected elements from Table 1 for Case 3 are depicted by the Material Recycling Flower in Figure 8.

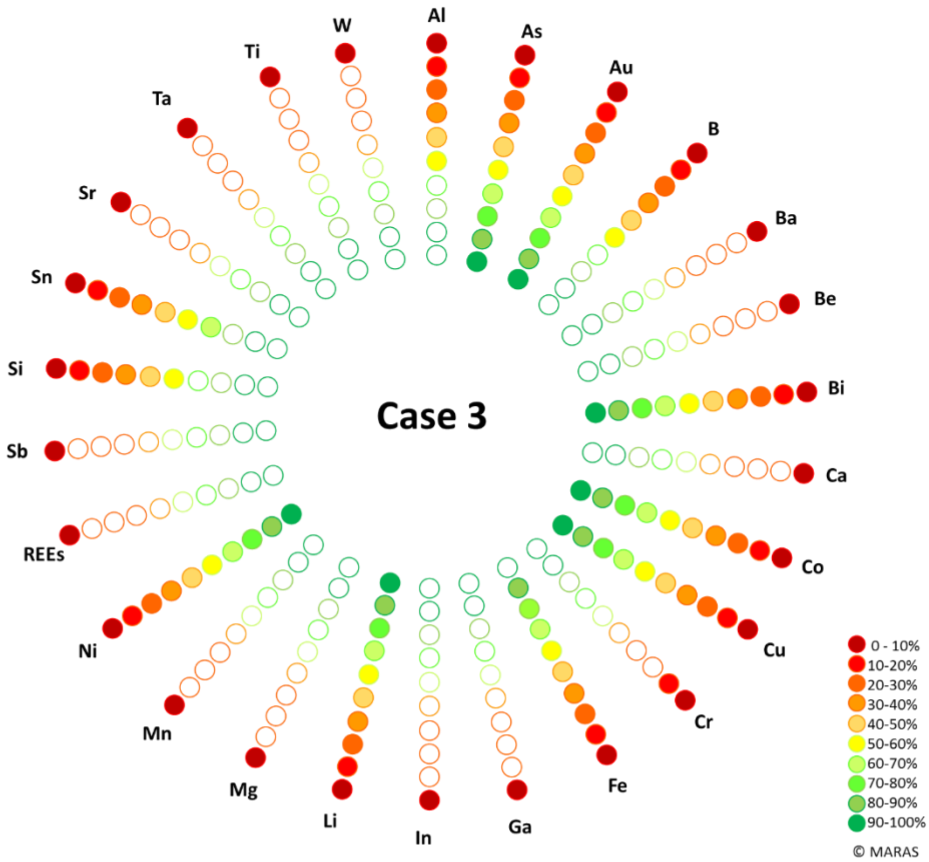


Figure 8 Material Recycling Flower showing recycling rates for the selected elements from Table 1 for Case 3

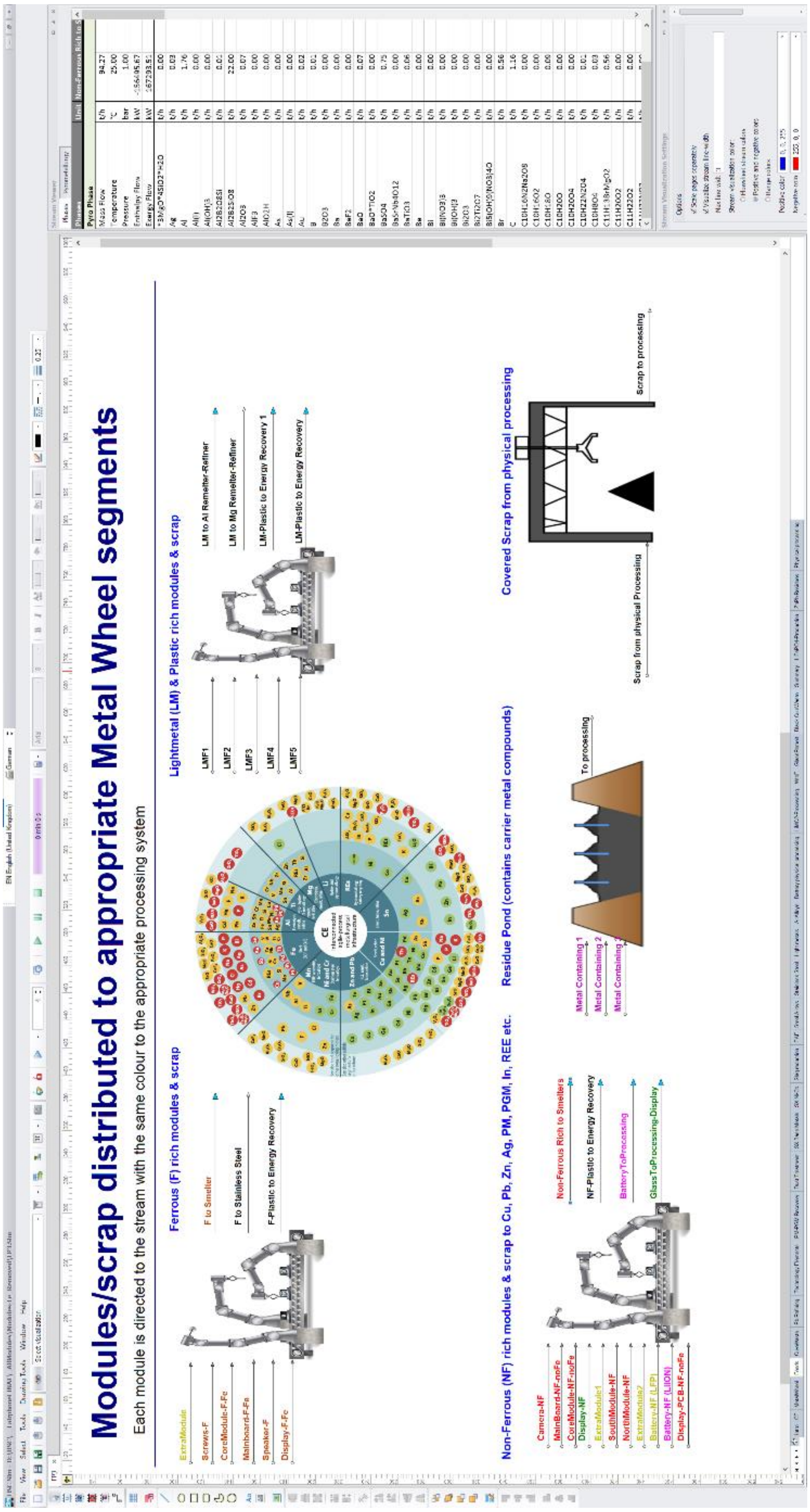


Figure 9 Feed sheet and processing routes/flowsheets case 3 – additional dismantling and suitable processing of Fe containing parts (see top left which is different to both Figure 3 and Figure 7)

3.3 Recycling rate assessment including recycling of plastic and organic compounds

In the above assessments, the recycling rate of the FP3 and its functional materials and compounds have been assessed, without yet considering the possible recovery of organic elements (including plastics) as present in the FP3 in order to clearly visualize the material recycling rates, which can be achieved for the various metals, elements and materials.

The design of the FP3 contains a significant amount of plastic and organic compounds in the parts and modules, present either as 'physical' plastics in the design as well as organic compounds in the various modules and materials. To fully consider all recycling options, the recycling options of plastic and organic compounds as present in the FP3 have been added to the assessment. This is in line with the assessment as performed for the FP2.

Due to the improved design, plastic recycling is added to the assessment by including efficiency of physical sorting and separation for plastic recycling (where applicable to the recycling of organics present as 'physical' plastics in the design which can be liberated, removed or sorted from the FP3). This addition in the assessment addresses in fact also another disassembly cases, in which additional dismantling of plastic containing parts and removal of e.g. steel/ferrous screws etc was considered.

It must be noted that depending on the application of the plastics, these are often functionally linked to other materials (e.g. containing fillers, coatings, etc.) from which they can be separated only with difficulty, whereas the additives of the plastics often limit their material recycling as this will lower the quality of the final recycled material produced from the recyclate. The non-plastic organics in the FP are part of compounds and combinations in complex parts of the FP and therefore non-recyclable in terms of material recycling as from these generally no high-quality materials can be produced after recycling. Therefore, the use of organic materials in the smelting process(es) both as reductant as well as energy carrier in the process, replacing the addition of (part) of the primary resources is usual industrial practice to the process in order to achieve the required thermodynamic and operation conditions for processing. It often also makes no sense to recycle such complex mixtures into plastics again as often the same material quality cannot be achieved (this can make sense for a plastic-rich or purely plastic module in which the plastic can easily be fully liberated/separated from other materials).

The total recycling rates for the 3 cases provide the basis for the comparison of the recycling performance of the FP3 compared to the recycling of the FP2. A comparison of the recycling rates of the materials, elements and compounds present in the FP3 with those of the FP2 details this further.

The overall recycling performance of the FP3, including the recycling of plastic and organic compounds for the different cases is found to be:

- Case 1 54.8%

- Case 2 54.0%
- Case 3 53.6%

These results reveal the increase in recycling rate to the FP2. This is increase is not only a consequence of including the energy and feedstock recycling of plastics and organics of the FP3 (making them comparable as this was also included in the assessment of the FP2), but also arises due to the fact that improved design of the FP3 allows for additional dismantling of some plastic containing parts. These could now be recovered as plastics in physical recycling, whereas the metal parts (ferrous) removed from the plastics, were also recovered in suitable processing. This case in fact also illustrates the benefit of selective additional disassembly.

Fairphone B.V. clearly communicated for the FP3 on the options to disassemble certain plastic parts. Combined with the availability of detailed data on the composition and weights of these parts, plastic and other material content (e.g. steel screws/bolts) of which the latter could be removed from the plastic parts, this allows for better options for disassembly and recycling of plastics in the FP3 in comparison to the FP2.

3.4 Discussion of results and comparison of 3 recycling cases

3.4.1 Discussion of overall results of the recycling assessment of the FP3

Table 2 shows a comparison of the overall recycling rates for the 3 cases including and excluding the recovery of C (derived from the plastics and organics recycling assessment) during processing, and the recycling rates of Au and Fe. The latter have been selected to show in summary the results. Due to the focus of the dismantling case on removal of ferrous containing parts and Au recycling being implicitly included, the recycling rates of Au and Fe are therefore illustrative for the differences between the assessed recycling processing routes.

Table 2 Summary of results of 3 recycling assessment cases (RR= Recycling Rate)

	Case 1	**Case 2**	**Case 3**
Overall RR excl. plastic and organic compounds recovery	Highest overall RR 46.4%	Lowest overall RR 44.9%	2nd best overall RR 45.9%
Overall RR incl. plastic and organic compounds recovery	Highest overall RR 54.8%	Lowest overall RR 54.0%	2nd best overall RR 53.6%
Au recycling rate	Lowest Au RR 71.2%	High Au RR 94.3%	Highest Au RR 94.8%
Fe recycling rate	Medium (but still low) Fe RR 62.8%	Lowest Fe RR 22.9%	Highest Fe RR 82.9%

The results reveal that, although the overall recycling rate for the 3 different cases do not differ much, the recoveries of Au and Fe for the 3 recycling options as assessed show significant differences. The different cases make clear that there is no one best recycling route when considering the recycling rates of the individual elements, and that recycling rates per element and material are different for each case (recycling route)! Each case will give a different result.

Note that this also implies that fixing recycling rates for elements/materials (e.g. as input to the End of Life - Life Cycle Assessment) is not representing industry recycling reality. Depending on the recycling case or flowsheet configuration, rates for certain elements will be high(er), while as a consequence, others will be lower. This will also vary.

Recycling of complex products is a trade-off between bulk and minor element recycling, where often the one material will (to a more or lesser extent) be 'sacrificed' for the recovery of the other. This is not always reflected by the overall recycling rates due to the lower weight of precious (scarce, critical) elements present. Overall recycling rates can be presented by the Recycling Index of a product (see Figure 11). Therefore, the Material Flowers as developed by MARAS (see Figures 4, 5 and 8) serve very well as a tool in this discussion and help to make the choice for a certain recycling route, not only driven by weight based considerations, but addressing the recycling of materials and elements, which are of interest to recycle or defined as critical and therefore require focus in selecting the most optimal recycling options. Comparing individual material recycling rates is crucial in this discussion.

The best case for the FP3 is, based on the assessed cases above when just looking at Fe and Au (and overall recycling rate), case 3 with a high Au recovery as well as a high Fe recovery. However, other elements of interest/focus (e.g. based on close communication with FP) as presented in the Material Recycling Flowers for the 3 different cases in Figures 4, 5 and 8, can change this picture and preference (see also Figure 10, which summarises these results in one graph).

3.4.2 Discussion of recycling rates of individual materials/elements as identified to be non (low) recoverable in the FP2 or defined critical by FP

The Material Recycling Flowers of Figure 4, 5 and 8 as well as Table 3 provide a comparison and assessment of the recycling of the list of selected materials, which have been identified to be either non/low recovered elements in the recycling of the FP2 or defined critical by FP. This Table and Figures provide detailed insight into the recycling rates for these elements as achievable for the FP2 compared to the rates that can be achieved in the recycling of the FP3. In addition, this table provides an explanation for each of the elements while discussing the details of the achieved recycling rates and the limits thereof.

The results of the recycling assessment as summarized in Table 3 and the explanation in this Table on achieved recycling rates and limits thereof, in combination with the developed flowsheets providing processing options for the range of materials and compounds of the FP3, provide the basis for identification of additional dismantling options. In combination with the detailed data structure, in which the materials and compounds as well as their combination in the different modules can be traced, the results of the recycling assessment as presented here could also be applied as the input for Design for Recycling (within the limits of product's functional specifications) as it pinpoints the losses of materials and compounds and motivates the causes for this.

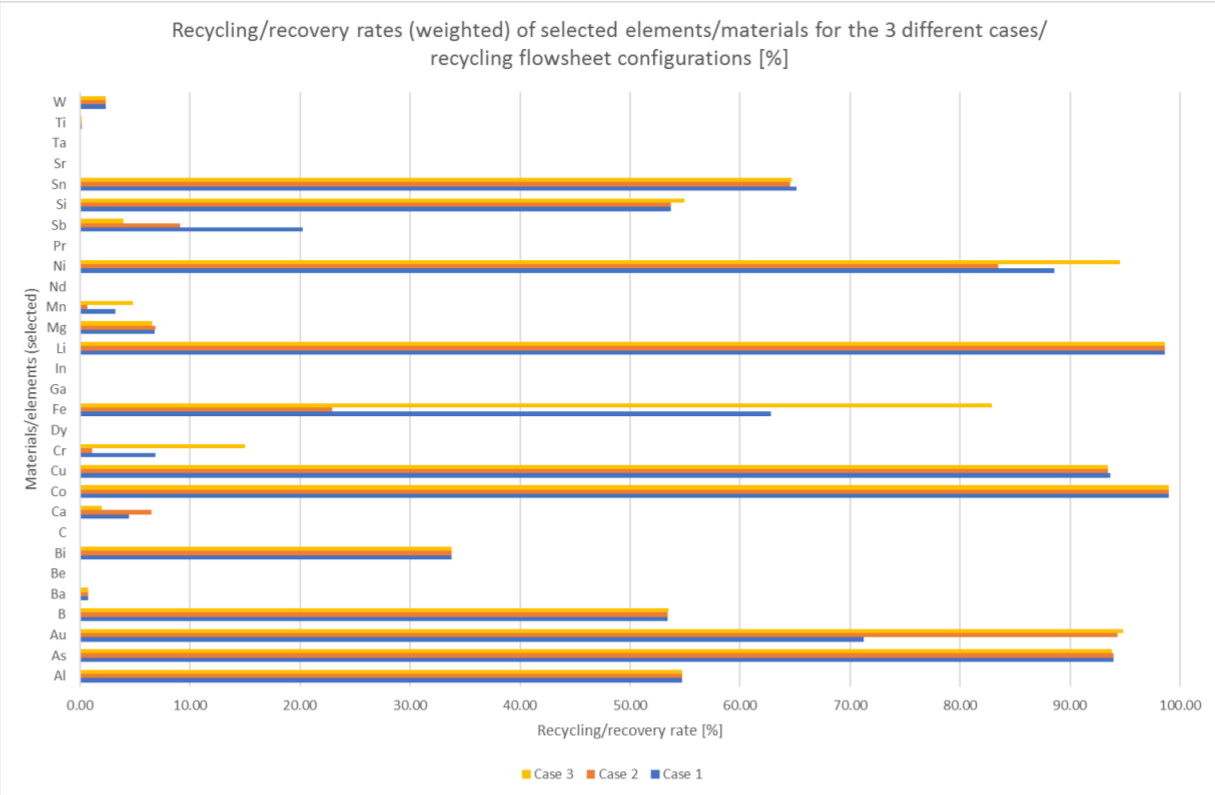


Figure 10 Recycling rates (weighted) of selected elements for the 3 different cases.

**Note that the recycling of C has not been included in this graph.*

*** Recycling rate of C as a proxy for plastics and organics which was estimated to be 28% of the plastic phases of the part of the plastic compounds going to metallurgical processing for the 3 cases ranges between 13-15%. It is also assuming that the plastics of the cover and core (as indicated by FP) can be removed for plastic recycling (for which a recycling rate of 80% is chosen to include losses during physical processing)*

Table 3 Recycling rates for identified materials/elements for 3 different recycling assessment cases including explanation and discussion of recycling results and limits

List of selected elements based on RA FP2	List of elements selected from FP criteria	Case 1 RR FP3 [%]	Case 2 RR FP3 [%]	Case 3 RR FP3 [%]	Explanation of RR for the listed elements for the different cases: Refer to the provided flowsheets (which cover over 220 unit operations for the ca. 1000 materials and was designed to represent economically viable routes) for the background to these numbers.
Al		55	55	55	Of which 19% as Al from battery and rest Al in glass Al-Si-B-O compound. So, this is not a high aluminium recovery as most is an oxide compound.
As		94	94	94	Captured as speiss for further processing
	Au	71	94	95	Partially lost to steel due to processing core module in steel route in case 1. This is above 94% if core module is processed in the base metal processing as simulated in case 2. Also, the additional dismantling of Fe in case 3 allows this module to go to base metal processing, without compromising the recovery of Fe. This shows how important the design choices are combined with well thought through additional dismantling which channel modules into the appropriate processing flowsheet.
B		53	53	53	Via glass, lost through slag.
Ba		1	1	1	In intermediate material, that can only be recovered economically presently to a low extent.
Be		0	0	0	Goes to intermediate streams in a compound mix that is uneconomic to further process at the moment.
Bi		34	34	34	Recovered during lead refining but is also present in some intermediate material and could be further processed
C		0	0	0	Carbon for reduction/energy recovery not accounted for in this table for cases 1 to 3, but of extreme importance for the energy efficient processing of all the modules. Thus, carbon is used as chemical for processing i.e reductant also to create CO and CO_2 which is an energy carrier. Recycling rate of C as a proxy for plastics and organics which was estimated to be 28% of the plastic phases of the part of the plastic compounds going to metallurgical processing for the 3 cases ranges between 13-15%. It is also assuming that the plastics of the cover and core (as indicated by FP) can be removed for plastic recycling (for which a recycling rate of 80% is chosen to include losses during physical processing) (see Recycling results including recycling of C i.e. plastics, Figure 11).
Ca		4	6	2	Recovered during refining of e.g. lead and similar refining steps.
	Co	99	99	99	Via ferroalloy e.g. FeCoNi etc. in an electric furnace and can then be further recovered through refining or as alloying elements in steel and stainless steel.
	Cu	94	93	93	Recovered through Cu (TSL) route
Cr		7	1	15	Into stainless steel as alloying element.
Dy	REE	0	0	0	Lost to slag and uneconomic to recover.
Fe		63	23	83	This depends on which modules go to steel processing and if not, the Fe is lost in the slag of non-ferrous processing (core module to Cu route in case 2). In case 3, the Fe is dismantled from different modules and directed to steel processing, resulting in more optimal recovery.

	Ga	0	0	0	Remains in intermediate material, to uneconomic to recover in the quantities present.
	In	0	0	0	In the present sheets the glass from display is recovered but the indium and other coating materials end in a mixed intermediate stream that in the flowsheets are not processed further due to economics.
Li		99	99	99	Recovered as Li3PO4 or Li2CO3, this shows if dedicated economically viable battery grade materials can be produced then the recovery rate increases. In the materials recovered in the flowsheet, all a present in intermediate materials that cannot be economically processed. As the model provides the complete composition of the streams, this type of assessment can now be made.
Mg		7	7	7	Only in recovery processing during refining, rest lost to slags, but if the slag is clean, it can find a use then as part of building materials together with Si, Fe, Ca, Al etc. as oxide compounds. Also please see Metal Wheel.
Mn		3	1	5	Mostly to slag but also to steel as alloying element.
Nd		0	0	0	To intermediate material that is presently uneconomic to process.
	Ni	89	83	95	E.g. 25% (weighted) as Ni through Cu route, 41% (weighted) through battery rec and 22% (weighted) in steel alloy for case 1
Pr		0	0	0	To slag and uneconomic to recover.
Sb		20	9	4	Is produced as an intermediary and can be further processed e.g. from speiss
Si		54	54	55	Through glass, also as building material in slags - see Metal Wheel
Sn	Sn	65	65	65	Is recovered as intermediate and then further processed e.g. to PbSn alloys in an economic manner.
Sr		0	0	0	To intermediate material that is presently uneconomic to process.
Ta	Ta	0	0	0	To intermediate material that is presently uneconomic to process.
Ti		0	0	0	To intermediate material that is presently uneconomic to process.
W	W	2	2	2	To intermediate material that is presently uneconomic to process. Partially goes to steel as alloying element.

3.5 Small business 'cases' (i.e. advice on industrial recycling plants best suited for most optimal recycling of the FP3)

The extensive flowsheets in the simulation model reflect the range of industrially available BAT for processing the FP3. The 3 assessed cases reveal the different recycling routes as summarized by the Metal Wheel and the extensive flowsheet, suitable for the most optimal processing of the FP3 and its different modules. This provides the information for the small business cases, i.e. advice on the most suited industrial plants and processing routes for processing of the FP3.

For each of these different routes (for the different metal infrastructures and dedicated recycling routes e.g. battery) the following industry reflect the recycling processing options as assessed for optimal recycling of the FP3. These are interesting to address the business cases from a modular processing point of view for possible impact project pilots. With reference to the Metal Wheel in Figure 3 and it's segments, as this was the main focus of the project, the following will be able to process the respective parts economically together with other feeds to the respective plants at the required economy of scale without affecting the high quality of their respective metal products:

Cu/Ni/Sn/Pb/Zn Metal Wheel Segments:

- Aurubis AG (see e.g. https://www.aurubis.com/en/media/press-releases/press-releases-2021/aurubis-and-sms-to-cooperate-in-construction-of-multimetal-recycling-plant-in-georgia-us) and various in Europe e.g. Lünen, Germany (www.aurubis.com)
- Boliden in Scandinavia (www.boliden.com)
- Glencore e.g. in Canada (www.glencore.com)
- Umicore in Belgium (www.umicore.com)
- Hydrometal, Goldschmidt SA in Belgium (www.jgi-hydrometal.be)

Steel Segment (Fe/Cr/Mn etc.) :

- Tata Steel (www.tatasteel.com), Arcelor Mittal (https://corporate.arcelormittal.com) etc. if these would be interested in the low volume of high quality steel parts.

Light Metal Segments (Al/Mg) :

- Norks (www.norsk.com) and aluminium refiners that will remelt recycled aluminium to specific alloys.

For plastics and glass, the suppliers must be consulted to ensure that the quality is maintained in the recycling processes.

In the end, any closed loop circular economy processing of the FP3 (or for any product), must be able to produce the same quality materials that originally were used in the FP3. This is true circularity, which is inherently the fabric of the simulation model developed for FP2 and advanced to FP3, also then applicable for further FP models.

4. Discussion of improved recycling performance FP3 versus FP2

Using process simulation models that simulate the recycling behaviour of the materials in the FP3 in the different modules processed in the most suitable metallurgical processing route(s), the Recycling Index indicates to what extent the total product (based on the various materials) is recoverable (Van Schaik and Reuter, 2016). The potential recovery rates are based on using the current Best Available Techniques (BAT) and flowsheets (Reuter et al. 2015, Bartie et al., 2022), taking into consideration the limits of the product's design and what the laws of thermodynamics and physics allow when it comes to separating materials into usable recyclates and modules as discussed by Van Schaik and Reuter (2014). In all cases, material products are produced that have a quality so that these can return into a Fairphone.

The high-level results to compare the recycling performance of the FP2 versus the FP3 are shown in the Recycling Index depicted by Figure 8 based on the recycling assessment of the FP3 as performed in this study. This clearly reveals the truly admirable increase in recyclability of the FP3 compared to the FP2, moving from the range of 30-40% for the FP2, to 50-60% (54%).

Not only shows the total recycling performance of the FP3 a significant increase compared to the FP2, the same applies to many of the elements and materials which were low in recovery in the FP2 when comparing the recycling rates in Table 1 (FP2) with the rates for the different cases as presented in Table 3.

From the complexity the two models cannot be compared, but from an element point of view, the recoveries of FP2 and FP3 can be compared to each other to compare the result.

The major difference between the FP2 and the FP3 lies in the possibility to recover both glass and a part of the plastics. The changes and improvements in the design of the FP3 compared to the FP2 has resulted in the fact that the module containing the glass is much cleaner (i.e. not containing a high level of other materials than the one to be recovered). Some plastic containing parts could be dismantled to obtain relatively pure plastic parts, from which the plastics could be recovered. Hence, both glass and part of the plastic parts are more 'isolated' and can be recovered as materials as a consequence of design changes. As the design showed these more pure modules, the flowsheet has amongst others been expanded with glass processing and plastic recycling.

The glass was going to slag in the recycling of the FP2 and plastics were only processed for energy and feedstock recovery.

The recovery of metals is in general comparable. Tables 1 and 2, however show that some metals do show an increase in recycling rate, since the cleaner modules in the FP3 makes it possible to better recover some metals such as Fe and alloying elements to steel, rather than that these get lost in the slag of non-ferrous base metal processing.

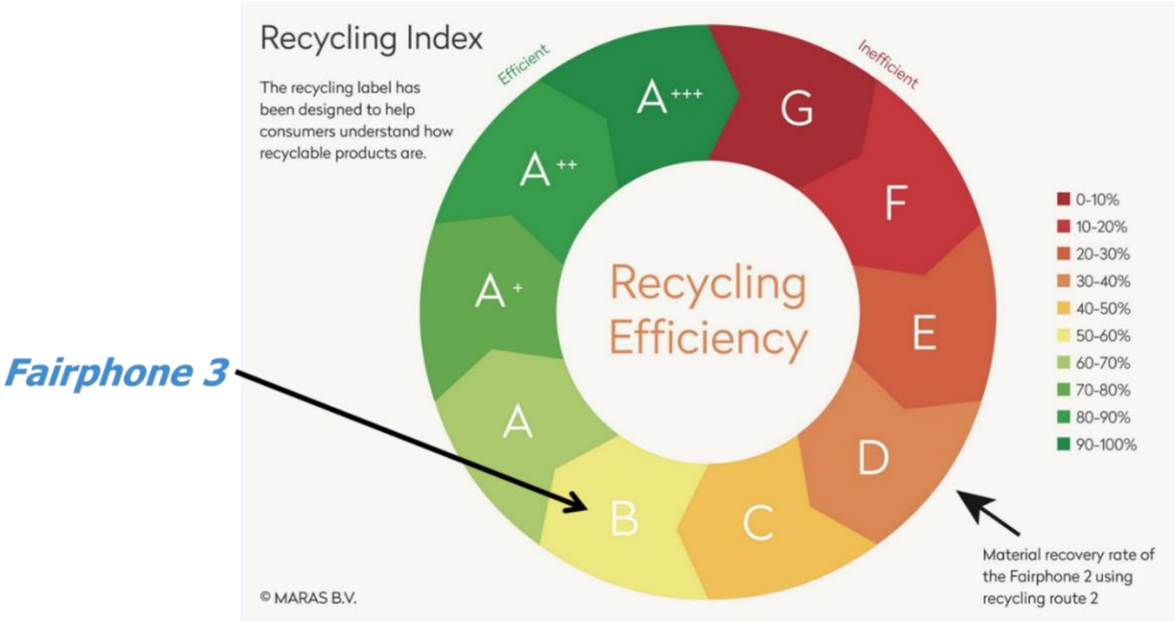
The design and specific processing has increased the recovery for the FP3. Plastics were dealt with more specifically and could be partially be recovered as plastic as the new design made this possible. A significant improvement has been realised as a consequence of the improved design of the FP3 in view of recycling.

In addition to the improvement in design, the fact that compositional data is available for the FP3 in a well structured and detailed format for the different modules and parts allows for a better insight into the composition of the modules and parts and a optimised organisation of the recycling in terms of sending the modules to the most suitable and optimal recycling (metallurgical) infrastructure. The format, detail and completeness of the product data has improved significantly from the FP2 to the FP3. The know-how of Fairphone B.V. combined with a clear communication and data detail on the options to disassemble certain parts from the different modules such as the ferrous containing and plastic parts, allows for more specific modelling of recycling based on separate processing of these parts and contained materials for more optimal recycling.

Additional dismantling as assessed in this study for the ferrous containing parts reveals that well considered dismantling of selected parts and containing materials can contribute significantly to improve the recycling rate of both the selected elements and materials as well as of the connected materials and elements in a specific module or part. This facilitates these parts and modules to be processed in the most suitable routes, leading to a higher recycling for more than just one material or element. Additional dismantling, however, will not always contribute drastically to the *overall* recycling performance in case the material and/or elements selected for additional dismantling have a low mass contribution relative to the total weight of the product. In view of Circular Economy, increasing recovery rates of individual materials, even when low in weight, is of high importance.

The additional dismantling of high Au containing parts proved not to be required for the current design and assessed recycling routes (the ones in which the parts are processed in the Cu route, i.e. case 2 and 3) as these are processed in the most suitable route in this manner. This has been carefully checked by MARAS based on the FP3 (modular) data provided by Fairphone B.V. and the assessed recycling route architectures (applying to the recycling cases 2 and 3).

To increase the recycling rate(s) of the other elements and materials that have been listed by FP to be of particular interest in view of (too) low recycling rates and therefore requiring recycling improvement, could additionally be assessed in terms of additional dismantling options to verify if this could lead to improvement of recycling performance. It should however be noted, that due to design functional specifications, combined with physical and thermodynamical limits of recycling, there will always be a limit in recycling due to the complexity of functionality of a product.



Furthermore note, that dismantling should be economically feasible, which will depend on a variety of factors (such as time). This was beyond the scope of this study and will affect the reported recycling rates.

Figure 11 Truly commendable improvement in the real recycling performance of FP3 and the improvement since 2017 from FP2.

Concluding it can be stated that the recycling performance of the FP3 has increased in comparison to that of the FP2, due to the following reasons:

Design

- The design of the FP3 has improved compared to that of the FP2 in view of recyclability, due to more segregated modules in terms of composition.
    - The cleaner modules in the FP3 makes it possible to better recover some metals, e.g. Fe and alloying elements which can now be recycled in steel metallurgical processing.
    - The major difference between the FP2 and the FP3 lies in the possibility to recover both glass and a part of the plastics due to improved and changed design.

Recycling processing and flowsheet expansion

- The improvements in design allows for a more specific processing of glass in glass processing, plastics recycling and a more optimal recycling flowsheet architecture in which modules and also disassembled parts are sent to the most optimal processing route from a recycling point of view.

Data and product (dismantlability) knowledge

- The compositional data is available for the FP3 in a well structured and detailed format for the different modules and parts and is more complete (better than of the FP2). This allows for a better insight into the composition of the modules and parts and a optimised organisation of the recycling in terms of sending the modules to the most suitable and optimal recycling (metallurgical) infrastructure.

- The know-how of Fairphone B.V. combined with a clear communication and data detail on the options to disassemble certain parts from the different modules enables specific and separate processing of these parts and contained materials for more optimal recycling.

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