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+ RECYCALYSE -

H2020-NMBP-ST-IND-2019
LC-NMBP-29-2019
Materials for non-battery based energy storage (RIA)

RECYCALYSE: New sustainable and recyclable catalytic materials for proton exchange membrane electrolysers

D8.4: Report on circularity assessments: Final results and conclusions

Date: 31-07-2023

This document is part of the RECYCALYSE project 861960 corresponding to D8.4 lead by DTI.

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Project acronym	RECYCALYSE	Start / Duration	1 April (36 months)
Topic	LC-NMBP-29-2019 Materials for non-battery based energy storage	Call identifier	861960
Type of Action	RIA	Coordinator	DANISH TECHNOLOGICAL INSTITUT (DTI)
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13 June 2023	0.1	Morten Kokborg	First draft
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Contents

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1. Executive summary

Part of the focus of the RECYCALYSE project is to increase the circularity of the proposed PEMEC solution. The Material Circularity Indicator, MCI, and the included Linear Flow Index, LFI, are used to indicate the circularity of the PEMEC solution developed through the various WPs of the RECYCALYSE project.

The MCI calculation focus only on the mass of materials without consideration of resource scarcity (e.g. identical focus on iron and platinum). The calculations in RECYCALYSE are performed only with the metals within the membrane electrode assembly (MEA), focusing on the critical raw materials (CRMs), e.g. iridium, ruthenium etc., and excluding the metals such as stainless steel.

Stainless steel is used in much higher quantities for piping and instrumentation and would dominate the circularity calculations. This would fail to address the purpose of the RECYCALYSE project which is to improve the handling of the CRMs.

Information is collected from the other WPs and a calculation is performed on the CRM consumption, and CRM being lost out of a circular system, due to washing out, due to not being collected as residual waste or due to being lost in the recycling process. As an update from D8.3 information is available on material washed out during operation; material which is assumed lost in all scenarios.

Several basic scenarios are evaluated:

- ‘RECYCALYSE’ scenario with virgin CRM as input, CRM production waste is not collected, and final product is collected for CRM recycling after use.
- ‘Recycled content’ where the collected CRM material after use is recycled and used to provide recycled content in the input material stream.
- ‘Residual collection’ where all CRM production waste is collected, recycled, and used to provide recycled content of the input CRM material stream.
- ‘Increased Utility” scenario where the current density of the catalytic stack is increased compared to industry average.
- ‘Combined scenario’ where the ‘Recycled Content’ and ‘Increased Utility’ scenarios are combined.

The circularity calculations yield the results below and indicated in Figure 1:

- The Linear Flow Index (LFI) indicates if material behave linearly (virgin input and lost as output waste). The default RECYCALYSE scenario has the value of 0.41, and possibly going down to 0.32 for the ‘Combined’ Scenario.
- The MCI value in general varies between 0.1 and 1 (with 1 being best). The default RECYCALYSE scenario ends up with an MCI value of 0.41 which could be increased up to 0.77 with the ‘Combined’ scenario.

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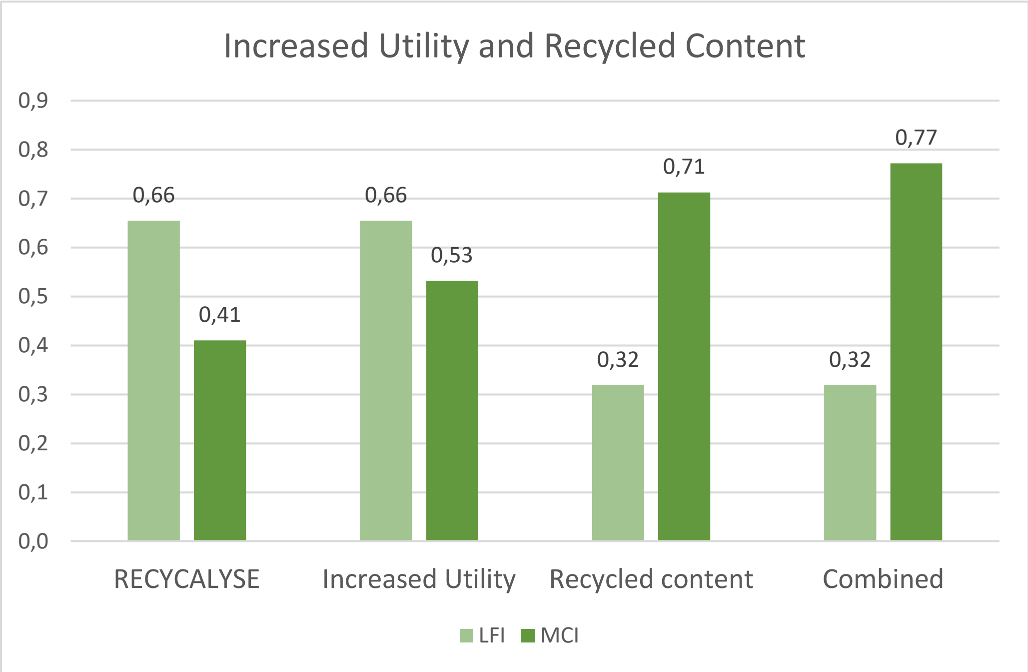

Figure 1: LFI and MCI results

The MCI values are cross compared with other indicators as price increase, supply risk and resource scarcity. This brings forward the metals of iridium, ruthenium and platinum as having the combination of the lowest circularity and the higher risk for price, supply risk and resource scarcity.

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2. Definitions and abbreviations

CRM: Critical Raw Materials, defined by high economic importance for the EU and a high supply risk.

FU: Functional Unit is a measure of a product's use.

Ir: The metal **Iridium**

L/L_{av}: Lifetime/Lifetime of an average market product. A measure of lifetime of a product.

LFI: Linear Flow Index: The part of the material flow that comes from virgin materials and ends up in landfill.

MCI: Material Circularity Indicator: A score between 0 and 1 assessing the linearity of material flows, and how long and intensely a product is used compared to similar industry average.

MEA: Membrane Electrolysis Assembly is the primary part of a fuel cell responsible for producing hydrogen via inducing an electrochemical reaction.

PEMEC: Proton Exchange Membrane Electrolyser: A device which uses a solid polymer electrolyte to carry out electrolysis of water, via conduction of protons, separation of gases, and insulation of electrodes.

Pt: The metal **Platinum**

Ru: The metal **Ruthenium**

Sb: The metal **Antimony**

Sn: The metal **Tin**

Ti: The metal **Titanium**

U/U_{av}: Utility/Utility of an average market product. A measure of functional units delivered.

WP: Work Package: The different work packages in the RECYCALYSE project.

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3. Goal and scope

The goal of the final circularity assessment is to expand the scenarios and indicators covered in the screening process in deliverable D8.3. The calculation routines are not altered and therefore not explained in this document. Hence, many of the calculation steps will only make sense using deliverable D8.3 as guidance.

As in D8.3, the calculation is performed on the Critical Raw Materials (CRMs[1]) within the MEA, characterized by being scarce and having a high impact on production. The materials are in Table 3.1 below.

If this focus is not applied, the calculations will essentially focus on the main steel-based material, as the MCI calculations only operate by weight. The stack itself weighs approx. 3 kg, and piping and instrumentation etc. brings this up to 10-20kg. Hence, a 50g CRM content constitutes less than 0.5% of an entire operative system. The circularity would therefore be calculated only on the control and system equipment and neglect the circularity of the CRMs; hence the entire purpose of the RECYCALYSE project would be ignored.

Table 3.1: CRM content of final stack

Metal	Symbol	Composition	
		g/stack	%
Tin	Sn	1.18	2.2%
Antimony	Sb	0.09	0.2%
Iridium	Ir	0.83	1.5%
Ruthenium	Ru	0.19	0.3%
Platinum	Pt	1.06	2.0%
Titanium	Ti	50.47	93.8%
Sum		53.82	100%

The established calculation routines are not altered, and the assessment will take the form of evaluation the circularity effect of scenarios and knowledge gain from the other WPs during the RECYCALYSE project, combined with additional indicators showing risk profiles of the used materials.

One point to be covered is the consequence of change in lifetime and change in the efficiency in the output compared to other marketed solutions:

- Systemic effects:
  - The effect of increased lifetime
  - The effect of increased utility

[1] As defined in EU CRM (2023). Tin is just under the classification limit for Supply Risk for the EU CRM list but is still included.

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The consequences of a researched activity during the RECYCALYSE projects was analysed for the effect on circularity indicators:

- Reactivated cells, reused components

The calculated circularity MCI indicator is suggested lined up against a set of other indicators as suggested in the background methodology used:

- Complementary indicators
    - Price variation,
    - Supply risk,
    - Material scarcity

This is considered a non-exhaustive list of complementary indicators.

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4. System setup

The current report follows the exact same calculation routines as outlined in D8.3. The calculation routines in this document is not explained in detail but can be found in D8.3.

4.1 Default scenarios from D8.2

The circularity in deliverable D8.2 is calculated on a default scenario and two alternatives:

RECYCALYSE (Default in D8.2)

The default scenario uses data from the relevant WPs of the RECYCALYSE project, based on the current state of development. This includes that the end stack is collected and the recycling process developed in WP7 is applied. As an update from the screening calculation, it is found that part of the noble metals are washed out during operation and therefore not available for recycling. This is included in an updated calculation using the recovery percentages from Table 4.1 below.

Table 4.1: Washout of metals during operation

Metal	Symbol	Washout, %	Recovery, %
Tin	Sn	10%	90%
Antimony	Sb	10%	90%
Iridium	Ir	10%	90%
Ruthenium	Ru	55%	45%
Platinum	Pt	1%	99%
Titanium	Ti	0%	100%

Recycled content (Alternative 1 in D8.2)

The end stack is collected for material recycling as in the RECYCALYSE scenario. The recycled catalytic materials are delivered and used to provide recycled catalytic material as described in Task 4.4 of the RECYCALYSE project. As the default scenario, this is updated with the above information on washout during operation.

Residual collection (Alternative 2 in D8.2)

All the waste catalytic material from production of support material, anode on support, cell, and stack is collected and used to supply recycled material. The material washed out during operation is assumed lost.

The output of the calculation of the Linear Flow Index, LFI, and Material Circularity Index MCI, is given below in Figure 2. The complete calculation routine is seen in appendix 1.

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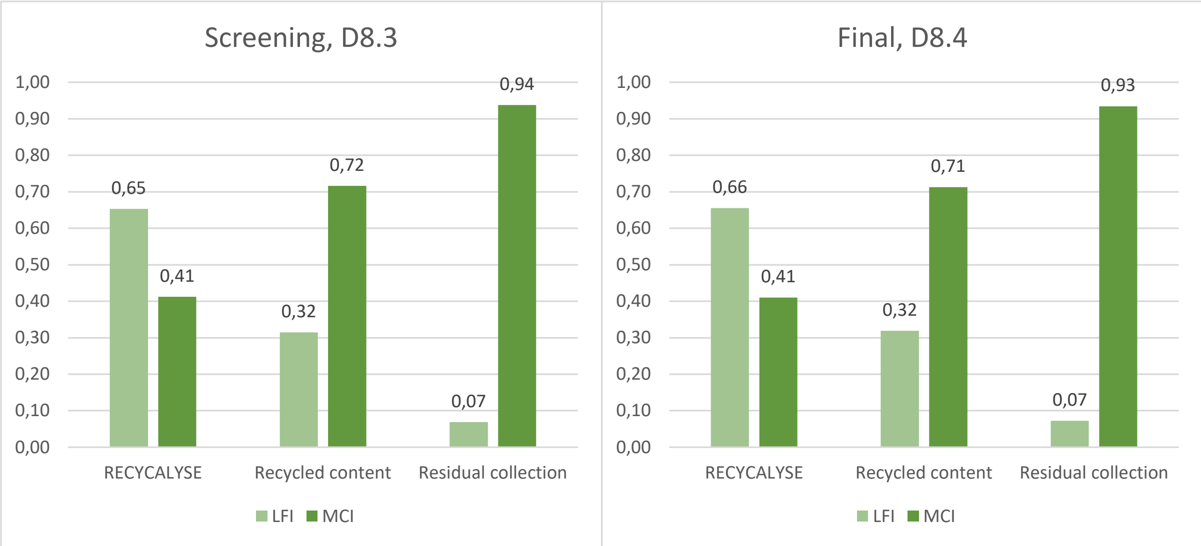

Figure 2: LFI and MCI values of all scenarios

The updated values with washout does not change the overall evaluation of circularity much, since a large part of the weight is centered in the titanium plate where the material is not washed out to any great extent. Therefore the conclusion ends up similar.

The result from a default scenario ends up with and linear flow value of LFI=0.66, indicating that 66% of the material acts in a linear fashion. This corresponds to a circularity index value of MCI=0.41. Considering that the index value primarily acts from 0.1-1 with 1 being good, this indicates that the value is quite low.

The first values can be improved as indicated by the alternative scenarios:

- Using the collected metals from the stack to provide recycling material on the input side makes the LFI value go down to 0.32 and even lower to 0.07, hereby indicating that only 7% of the material acts in a linear fashion. The remaining acts in a circular fashion.
- The MCI goes up to 0.71 and collecting all production waste maximizes the MCI at 0.93.

The remaining index up to 1 is not obtained due to losses in the recycling process, and to a minor extent washout during operation.

5. Further analyses

5.1 Utility (intensity of use and lifetime)

The material circularity indicator contains a calculation of the utility, X, using the expected lifetime and expected functional performance compared to industry average; the L and U values under D8.3, chapter 3.1.3, and the following F(X) value:

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$$X = \left(\frac{L}{L_{av}}\right) \cdot \left(\frac{U}{U_{av}}\right) \qquad F(X) = \frac{0.9}{X}$$

Lifetime

The lifetime of the final system is operated with 40-60000 hours which is comparable to industry average of a PEMEC solution (Zhao et al., 2020). Hence, no additional effect of the lifetime (L/L_{av}) value is expected compared to industry average.

Intensity of use

The 'Intensity of Use' component (U/U_{av}) represent if a product is used to its full capacity. U is the average number of functional units (or reference flow unit) obtained during the use of a product and U_{av} is the comparable industry-average product of similar type.

The current density that can be applied to an electrolysis stack is directly linked to how much hydrogen at constant voltage (and hence functional unit) that can be produced using the same stack area and hence the same materials.

According to deliverable D6.1, the stack is operated with a current density of 2,27 A/cm2. This is compared to a market based PEMEC cell (Zhao et al, 2020) which is operated at 1,8A/cm2. This leads to an 'Intensity of Use' value of

$$U/U_{av} = 2.27\text{A/cm2} \ / \ 1.8\ \text{A/cm2} = 1.26$$

X = 1.26 and F(X) = 0.9/1.26 = 0.71

The Linear Flow Index remain unchanged. but the MCI value of the default solution rises

MCI 0.41→ 0.53

5.2 Combination, recycled content and utility

A optimal calculation of the MCI value based on the actions occurring within the RECYCALYSE project is to combine the increase in current density with producing the cells with the 'Recycled content' scenario where CRMs are collected at the disposal of the outlived stack. The result is seen in Table 5.1 and Figure 3 below.

Table 5.1: Combination of Utility increase and recycled content

	LFI	MCI
'RECYCALYSE' scenario	0.66	0.41
'Increased Utility' scenario	0.66	0.53
'Recycled Content' scenario	0.32	0.71
Combined utility and recycled content	0.32	0.77

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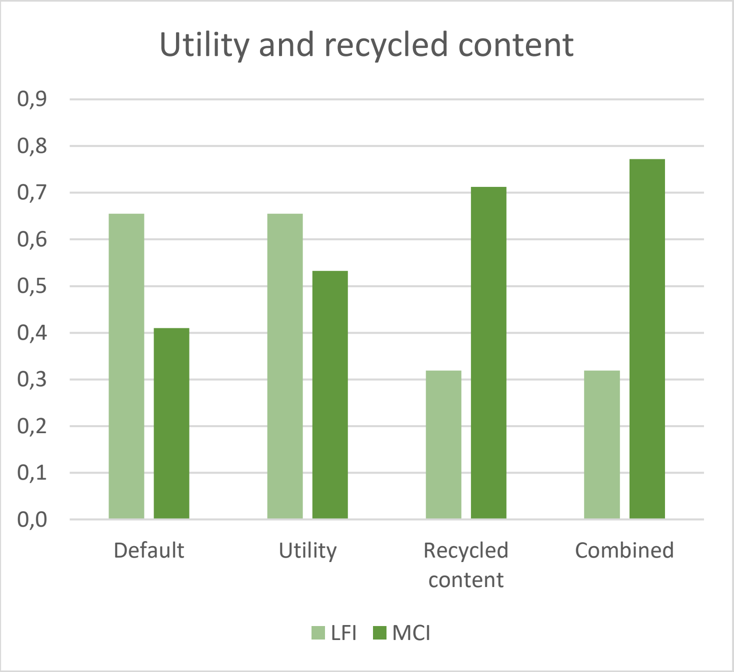

Figure 3: Utility and recycled content

Combining the utility increase with the use of recycled content brings the LFI down to 0.32 and increase the MCI value to 0.77.

5.3 Cathodic reactivation

In Task 7.2 of the RECYCALYSE project it was tested if the catalysts could be reactivated and reused as part of Task 5.5 as a reused input. There was no success from the technical point of view but the effect on the MCI value is calculated to demonstrate the circularity of this approach.

This can be calculated in the MCI circularity as the anode elements are calculated as collected for reuse (C_U) and calculated as from a reused sources (F_U) on the input side. The result is seen as only a minor increase in the circularity value (MCI 0.41→0.44). since the 50g of titanium used as part of the cathode is following the default recycling route.

If the entire stack is assumed collected for reuse and used as a reused component on the input side; then the entire stack system is calculated without material losses and without virgin input. This represents the ideal circular case, and has the outcome of the MCI value = 1.

The results are compared below in Figure 4.

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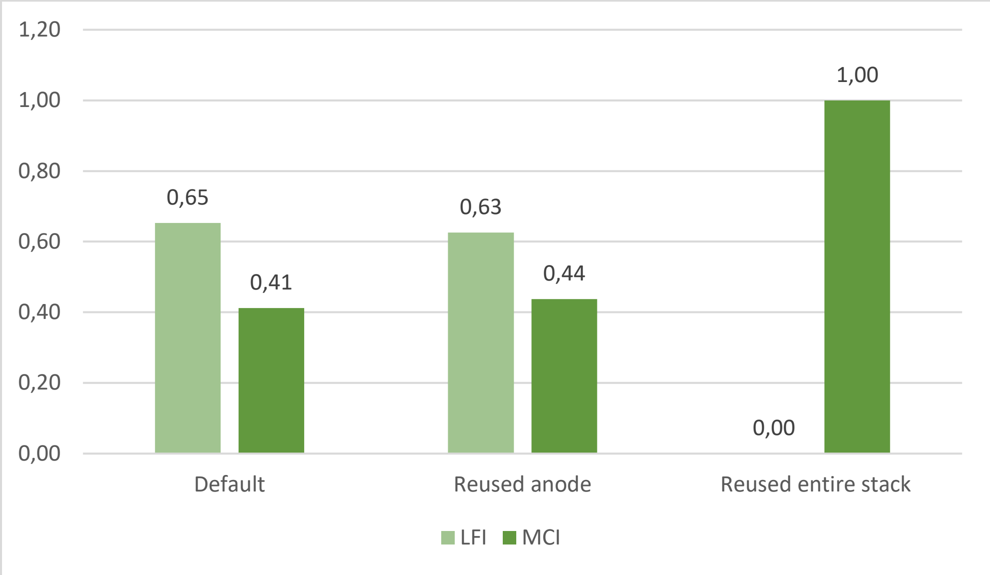

Figure 4: LFI and MCI values of reactivation scenarios

6. Supplementary indicators

As suggested in Task 8.4 the MCI values will be used with a set of suggested supplementary indicators.

6.1 Supply Risk

In the 'Study on the Critical Raw Materials for the EU' (EC, 2023) a Supply Risk factor is integrated. It is one of the two main parameters (along with Economic Importance) to measure the criticality of a raw material. The Supply Risk is calculated based on factors that measure the risk of a disruption in supply of a specific material, e.g. global supply and EU sourcing countries mixes, import reliance, supplier countries' governance performance measured by the World Governance Indicator, trade restrictions and agreements, availability and criticality of substitutes. The actual reasoning behind the calculation of the supply risk factor is not covered in this report.

The supply risk factors are listed in Table 6.1 together with the individual material calculated MCI values as calculated in Figure 9 based on the calculation methodology outlined in deliverable D8.3. The combination is depicted in Figure 5. The material of interest is the materials of ruthenium and iridium, which have the combination of the high supply risk and low circularity MCI value.

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Table 6.1: Supply Risk (SR) and MCI

Material	Supply risk (SR)	MCI
CRMs total	1.64	0.41
Sn	0.90	0.30
Sb	1.80	0.29
Ir	3.90	0.30
Ru	3.80	0.20
Pt	2.13	0.37
Ti	1.60	0.42

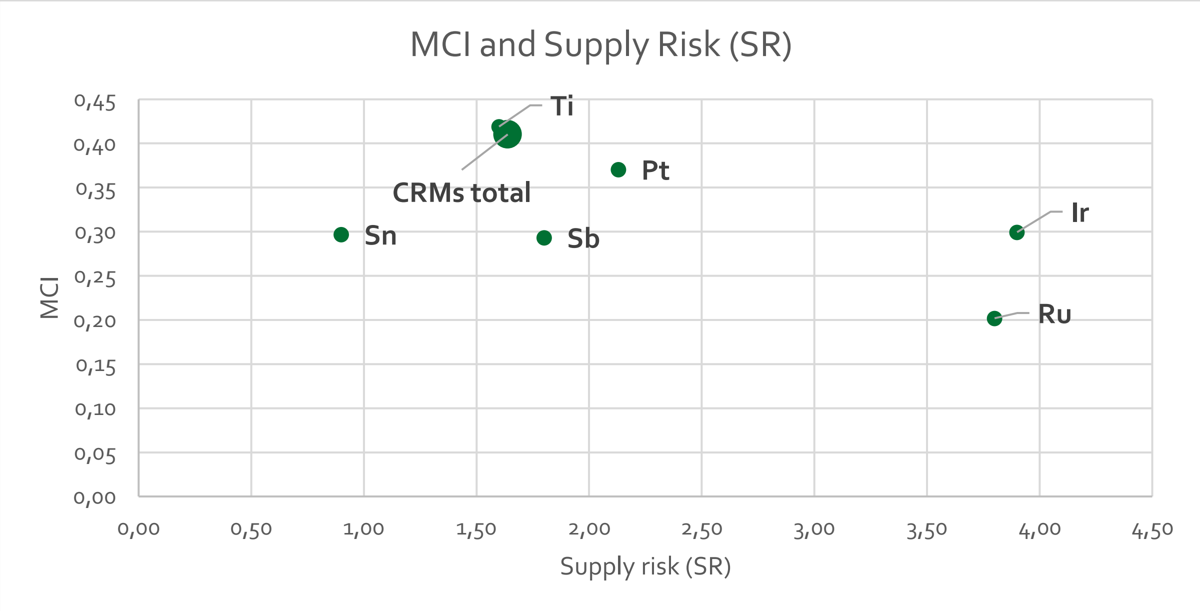

Figure 5: Supply Risk (SR) and MCI values of catalytic materials

6.2 Resource scarcity

The environmental impact of Abiotic Resource Depletion of elements (ADPe) is used in LCA calculation. It is based on the scarcity of a given resource, comparing the global annual extraction to the global reserves of that resource. The value is then indexed towards antimony, leading to the unit of kg Sb eq. (van Oers et al., 2020). The usage of ADPe values together with the MCI values from Figure 9 are seen below in Table 6.2 and Figure 6. Seen in this context, the most important material is platinum, which has a very high resource scarcity.

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Table 6.2: Resource Scarcity (ADPe) and MCI

	ADPe (kg Sb eq/kg material)	MCI
CRMs total	23	0.41
Sn	0	0.30
Sb	1	0.29
Ir	192	0.30
Ru	366	0.20
Pt	971	0.37
Ti	0.0000004	0.42

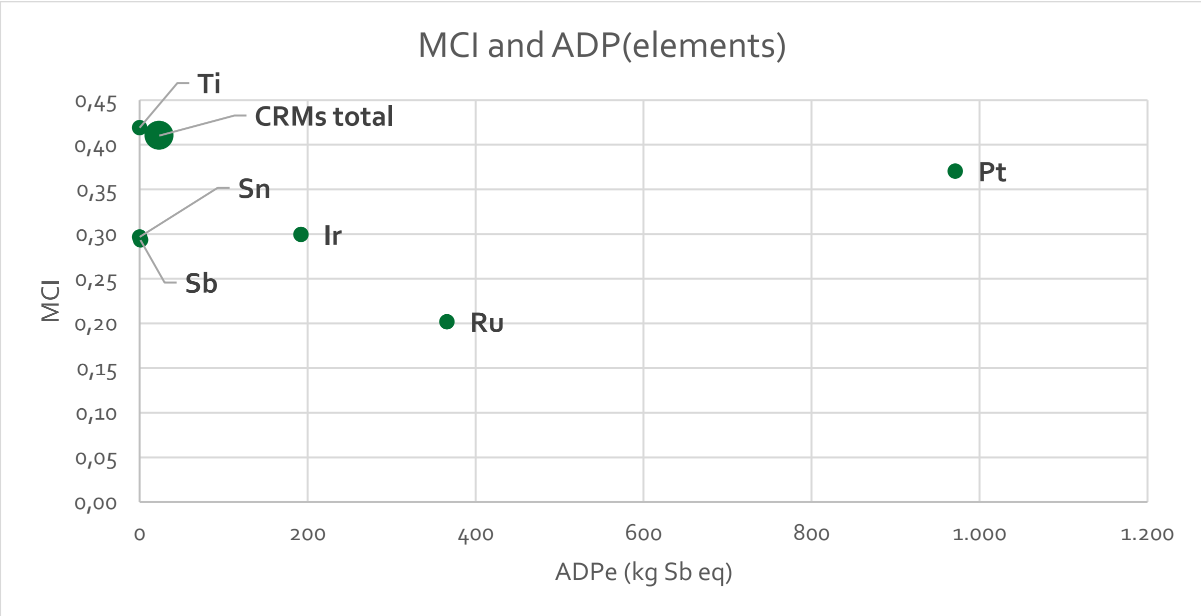

Figure 6: Abiotic Resource Depletion of elements (ADPe) and MCI values of catalytic materials

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6.3 Price variation

Price variation shown with the calculated MCI (from Figure 9) in Table 6.2 and Figure 7 below. Price variation calculated as the factor increase over a 5-year period. This is calculated via price indicators from USGS, 2023. This additional indicator puts a focus on Iridium having had the highest price increase which could indicate the highest increase in demand.

Table 6.3: Price increase and MCI

	5 year price factor increase	MCI
CRMs total	1.09	0.41
Sn	1.68	0.30
Sb	1.65	0.29
Ir	3.63	0.30
Ru	2.45	0.20
Pt	1.11	0.37
Ti	1.03	0.42

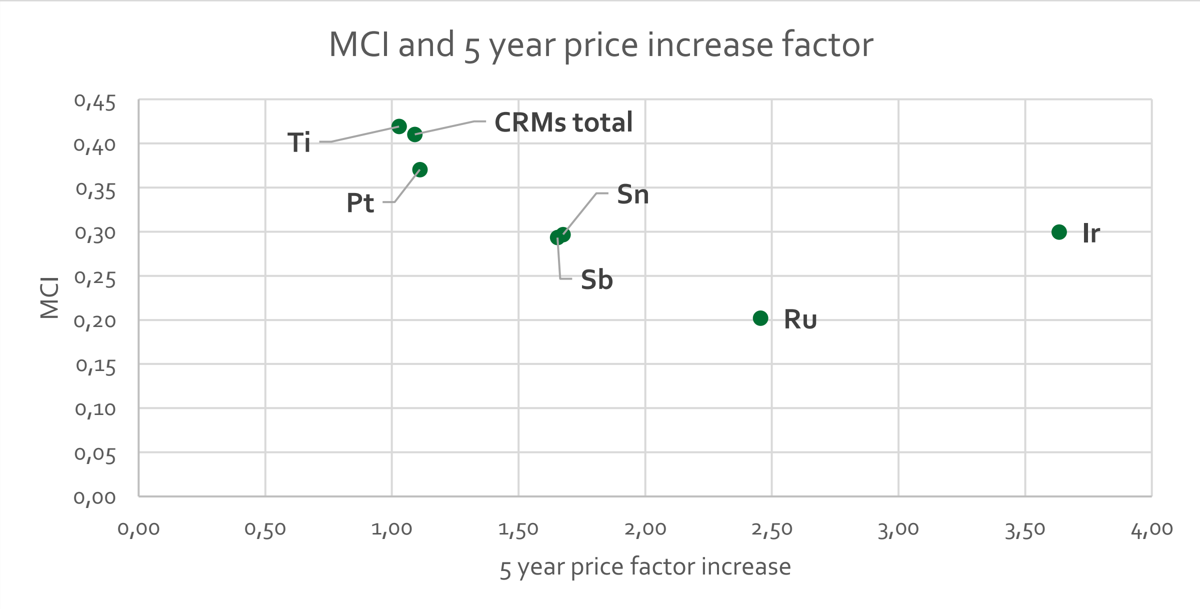

Figure 7: Price increase and MCI values of catalytic materials

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7. Discussion and conclusion

The maximum circularity would be reached if the cells could be reactivated. However, this proved during technical testing to not be possible but can only remain as a possible future option.

Combining the utility increase obtained by the increase in current density with the use of recycled content collected at the stack disposal brings together a current optimal value. Here the LFI value is 0.32 indicating that 32% of the material behave in a linear fashion. The MCI indicator value is increased to 0.77. This is indicated in Figure 8 below.

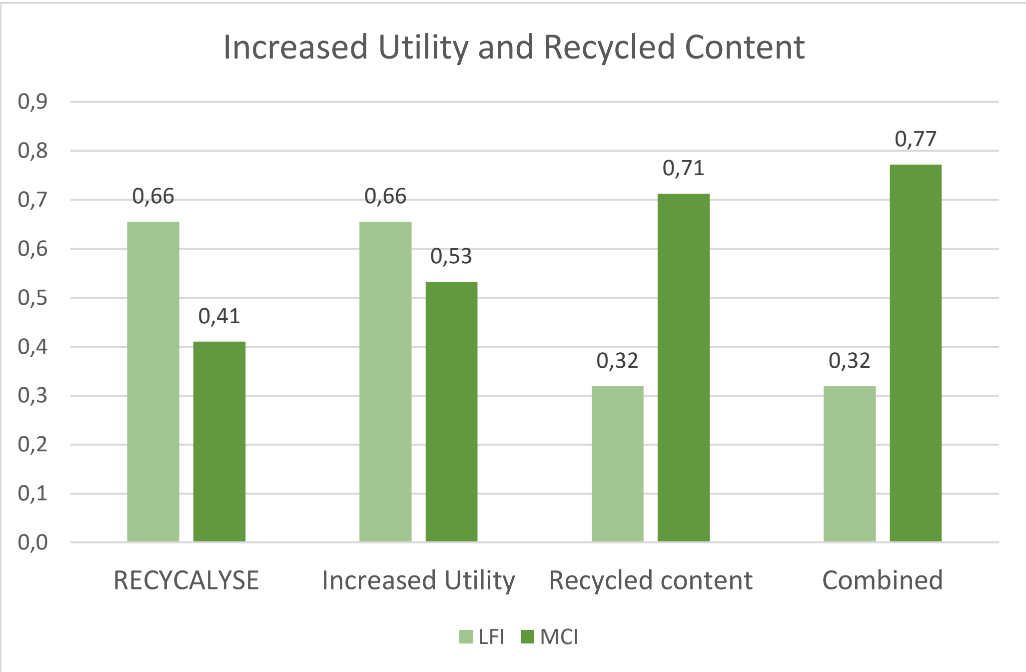

Figure 8: Utility and recycled content

Comparing the MCI value to additional indicators bring forward the metals of iridium, ruthenium and platinum as having the combination of the lowest circularity and the higher risk for price, supply risk and resource scarcity.

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8. References

Ellen MacArthur Foundation (2019). “Circularity Indicators, An Approach to Measuring Circularity Methodology”

Zhao et al . (20250). Guangling Zhao, Mikkel Rykær Kraglund, Henrik Lund Frandsen, Anders Christian Wulff, Søren Højgaard Jensen, Ming Chen, Christopher R. Graves. ”Life cycle assessment of H2O electrolysis technologies”

EU CRM (2023). "European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report

van Oers, L., Guinée, J., Heijungs, R. (2020). The International Journal of Life Cycle Assessment (2020) 25:294–308

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9. Appendix 1. Calculation results

Total calculations

Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	19,69	1,24	0,10	0,79	0,26	0,64	16,66	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
- Unrecoverable waste	W	21,53	1,27	0,10	0,83	0,27	0,66	18,40	g
- LFI		0,66	0,78	0,79	0,78	0,89	0,70	0,65	
Utility									
- Lifetime	L	10	10	10	10	10	10	10	
- Lifetime, average	L_{av}	10	10	10	10	10	10	10	
- Use int	U	10	10	10	10	10	10	10	
- Use int, average	U_{av}	10	10	10	10	10	10	10	
- Utility	X	1	1	1	1	1	1	1	
- Function F	F(X)	0,90	0,90	0,90	0,90	0,90	0,90	0,90	
MCI									
- Material Circularity Indicat	MCI	0,41	0,30	0,29	0,30	0,20	0,37	0,42	

WP3, support

Metal	Sn	Sb	
Process calculations			
Input material	2,30	0,18	g
Yield	**95%**	**95%**	%
Output material	2,19	0,17	g
Material loss	0,12	0,009	g
Weights			
- delta mass	0,12	0,01	g
Non-virgin input			
- from recycled sources	0%	0%	
- from reused sources	0%	0%	
Collection			
- for recycling	0%	0%	
- for reuse	0%	0%	
Efficiency in recycling			
- feedstock recycling	94%	92%	
- recycling after use	94%	92%	
Calculated losses			
- initial loss, not collected	0,12	0,01	g
- loss in feedstock recyc	0,00	0,00	g
- loss in waste recyc	0,00	0,00	g
LFI (Lineal Flow index) calculations			
- Virgin input	0,12	0,01	g
- Unrecoverable waste	0,12	0,01	g
- LFI			
Utility			
- Lifetime			
- Lifetime, average			
- Use int			
- Use int, average			
- Utility			
- Function F			
MCI			
- Material Circularity Indicat			

WP4, anode on support

Metal	Sn	Sb	Ir	Ru	
Process calculations					
Input material	2,19	0,17	1,54	0,35	g
Yield	**90%**	**90%**	**90%**	**90%**	%
Output material	1,97	0,15	1,39	0,31	g
Material loss	0,22	0,02	0,15	0,03	g
Weights					
- delta mass	0,22	0,02	0,15	0,03	g
Non-virgin input					
- from recycled sources	0%	0%	0%	0%	
- from reused sources	0%	0%	0%	0%	
Collection					
- for recycling	0%	0%	0%	0%	
- for reuse	0%	0%	0%	0%	
Efficiency in recycling					
- feedstock recycling	94%	92%	90%	93%	
- recycling after use	94%	92%	90%	93%	
Calculated losses					
- initial loss, not collected	0,22	0,02	0,15	0,03	g
- loss in feedstock recyc	0,00	0,00	0,00	0,00	g
- loss in waste recyc	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations					
- Virgin input	0,22	0,02	0,15	0,03	g
- Unrecoverable waste	0,22	0,02	0,15	0,03	g
- LFI					
Utility					
- Lifetime					
- Lifetime, average					
- Use int					
- Use int, average					
- Utility					
- Function F					
MCI					
- Material Circularity Indicat					

WP5, cell

Metal	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations							
Input material	1,97	0,15	1,39	0,31	1,69	67,13	g
Yield	**60%**	**60%**	**60%**	**60%**	**62,7%**	**75,2%**	%
Output material	1,18	0,09	0,83	0,19	1,06	50,47	g
Material loss	0,79	0,06	0,55	0,12	0,63	16,66	g
Weights							
- delta mass	0,79	0,06	0,55	0,12	0,63	16,66	g
Non-virgin input							
- from recycled sources	0%	0%	0%	0%	0%	0%	
- from reused sources	0%	0%	0%	0%	0%	0%	
Collection							
- for recycling	0%	0%	0%	0%	0%	0%	
- for reuse	0%	0%	0%	0%	0%	0%	
Efficiency in recycling							
- feedstock recycling	94%	92%	90%	93%	96%	93%	
- recycling after use	94%	92%	90%	93%	96%	93%	
Calculated losses							
- initial loss, not collected	0,79	0,06	0,55	0,12	0,63	16,66	g
- loss in feedstock recyc	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	0,00	0,00	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations							
- Virgin input	0,79	0,06	0,55	0,12	0,63	16,66	g
- Unrecoverable waste	0,79	0,06	0,55	0,12	0,63	16,66	g
- LFI							
Utility							
- Lifetime							
- Lifetime, average							
- Use int							
- Use int, average							
- Utility							
- Function F							
MCI							
- Material Circularity Indicat							

WP5, final stack

Metal	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations							
Input material	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%
Output material	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss	0,00	0,00	0,00	0,00	0,00	0,00	g
Weights							
- delta mass	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input							
- from recycled sources	0%	0%	0%	0%	0%	0%	
- from reused sources	0%	0%	0%	0%	0%	0%	
Collection							
- for recycling	**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
- for reuse	0%	0%	0%	0%	0%	0%	
Efficiency in recycling							
- feedstock recycling	94%	92%	90%	93%	96%	93%	
- recycling after use	**94%**	**92%**	**90%**	**93%**	**96%**	**93%**	
Calculated losses							
- initial loss, not collected	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations							
- Virgin input	1,18	0,09	0,83	0,19	1,06	50,47	g
- Unrecoverable waste	0,149	0,01	0,12	0,11	0,03	1,74	g
- LFI							
Utility							
- Lifetime							
- Lifetime, average							
- Use int							
- Use int, average							
- Utility							
- Function F							
MCI							
- Material Circularity Indicat							

Figure 9: RECYCALYSE (Default) scenario. Calculation of MCI and LFI values

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Metal		Total calculations: Sum	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	19,69	1,24	0,10	0,79	0,26	0,64	16,66	g
- loss in feedstock recyc	W_F	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
- loss in waste recyc	W_C	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	23,36	1,30	0,10	0,87	0,27	0,68	20,14	g
- Unrecoverable waste	W	23,36	1,30	0,10	0,87	0,27	0,68	20,14	g
- LFI		0,32	0,57	0,57	0,56	0,77	0,40	0,30	
Utility									
- Lifetime	L	50	50	50	50	50	50	50	
- Lifetime, average	L_{av}	50	50	50	50	50	50	50	
- Use int	U	1	1	1	1	1	1	1	
- Use int, average	U_{av}	1	1	1	1	1	1	1	
- Utility	X	1	1	1	1	1	1	1	
- Function F	F(X)	0,90	0,90	0,90	0,90	0,90	0,90	0,90	
MCI									
- Material Circularity Indicat	MCI	0,71	0,49	0,48	0,49	0,30	0,64	0,73	

Metal	WP3, support: Sn	Sb		WP4, anode on support: Sn	Sb	Ir	Ru	
Process calculations								
Input material	2,30	0,18	g	2,19	0,17	1,54	0,35	g
Yield	**95%**	**95%**	%	**90%**	**90%**	**90%**	**90%**	%
Output material	2,19	0,17	g	1,97	0,15	1,39	0,31	g
Material loss	0,12	0,009	g	0,22	0,02	0,15	0,03	g
Weights								
- delta mass	0,12	0,01	g	0,22	0,02	0,15	0,03	g
Non-virgin input								
- from recycled sources	**43%**	**43%**		**43%**	**43%**	**44%**	**23%**	
- from reused sources	0%	0%		0%	0%	0%	0%	
Collection								
- for recycling	0%	0%		0%	0%	0%	0%	
- for reuse	0%	0%		0%	0%	0%	0%	
Efficiency in recycling								
- feedstock recycling	94%	92%		94%	92%	90%	93%	
- recycling after use	94%	92%		94%	92%	90%	93%	
Calculated losses								
- initial loss, not collected	0,12	0,01	g	0,22	0,02	0,15	0,03	g
- loss in feedstock recyc	0,00	0,00	g	0,01	0,00	0,01	0,00	g
- loss in waste recyc	0,00	0,00	g	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations								
- Virgin input	0,07	0,01	g	0,12	0,01	0,09	0,03	g
- Unrecoverable waste	0,12	0,01	g	0,22	0,02	0,16	0,04	g
- LFI								
Utility								
- Lifetime	**Material collection per WP**							
- Lifetime, average	0,00	0,00		0,00	0,00	0,00	0,00	
- Use int								
- Use int, average								
- Utility								
- Function F								
MCI								
- Material Circularity Indicat								

Metal	WP5, cell: Sn	Sb	Ir	Ru	Pt	Ti		WP5, final stack: Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations														
Input material	1,97	0,15	1,39	0,31	1,69	67,13	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield	**60%**	**60%**	**60%**	**60%**	**62,7%**	**75,2%**	%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%
Output material	1,18	0,09	0,83	0,19	1,06	50,47	g	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss	0,79	0,06	0,55	0,12	0,63	16,66	g	0,00	0,00	0,00	0,00	0,00	0,00	g
Weights														
- delta mass	0,79	0,06	0,55	0,12	0,63	16,66	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input														
- from recycled sources	**43%**	**43%**	**44%**	**23%**	**60%**	**70%**		**43%**	**43%**	**44%**	**23%**	**60%**	**70%**	
- from reused sources	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Collection														
- for recycling	0%	0%	0%	0%	0%	0%		**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
- for reuse	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Efficiency in recycling														
- feedstock recycling	94%	92%	90%	93%	96%	93%		94%	92%	90%	93%	96%	93%	
- recycling after use	94%	92%	90%	93%	96%	93%		**94%**	**92%**	**90%**	**93%**	**96%**	**93%**	
Calculated losses														
- initial loss, not collected	0,79	0,06	0,55	0,12	0,63	16,66	g	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	0,02	0,00	0,03	0,00	0,01	0,86	g	0,03	0,00	0,04	0,00	0,02	2,62	g
- loss in waste recyc	0,00	0,00	0,00	0,00	0,00	0,00	g	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations														
- Virgin input	0,45	0,03	0,31	0,10	0,25	5,00	g	0,67	0,05	0,47	0,15	0,43	15,14	g
- Unrecoverable waste	0,80	0,06	0,57	0,13	0,64	17,09	g	0,17	0,01	0,14	0,11	0,04	3,05	g
- LFI														
Utility														
- Lifetime														
- Lifetime, average	0,00	0,00	0,00	0,00	0,00	0,00		1,00	0,08	0,67	0,08	1,01	46,99	
- Use int				**Totals collected**				1,00	0,08	0,67	0,08	1,01	46,99	
- Use int, average				**Total mass**				2,30	0,18	1,54	0,35	1,69	67,13	
- Utility				**Recycled content**				43%	43%	44%	23%	60%	70%	
- Function F														
MCI														
- Material Circularity Indicat														

Figure 10: Recycled content (Alternative 1). Calculation of MCI and LFI values

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RECYCALYSE -

Total calculations

Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	0,32	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	5,00	0,13	0,01	0,14	0,02	0,06	4,63	g
- loss in waste recyc	W_C	5,00	0,13	0,01	0,14	0,02	0,06	4,63	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	5,32	0,25	0,02	0,23	0,12	0,07	4,63	g
- Unrecoverable waste	W	5,32	0,25	0,02	0,23	0,12	0,07	4,63	g
- LFI		0,07	0,11	0,13	0,15	0,35	0,04	0,07	
Utility									
- Lifetime	L	10	10	10	10	10	10	10	
- Lifetime, average	L_{av}	10	10	10	10	10	10	10	
- Use int	U	10	10	10	10	10	10	10	
- Use int, average	U_{av}	10	10	10	10	10	10	10	
- Utility	X	1	1	1	1	1	1	1	
- Function F	F(X)	0,90	0,90	0,90	0,90	0,90	0,90	0,90	
MCI									
- Material Circularity Indicat	MCI	0,93	0,90	0,89	0,87	0,69	0,96	0,94	

WP3, support

Metal	Sn	Sb	
Input material	2,30	0,18	g
Yield	**95%**	**95%**	%
Output material	2,19	0,17	g
Material loss	0,12	0,009	g
- delta mass	0,12	0,01	g
- from recycled sources	**89%**	**87%**	
- from reused sources	0%	0%	
- for recycling	**100%**	**100%**	
- for reuse	0%	0%	
- feedstock recycling	94%	92%	
- recycling after use	94%	92%	
- initial loss, not collected	0,00	0,00	g
- loss in feedstock recyc	0,01	0,00	g
- loss in waste recyc	0,01	0,00	g
- Virgin input	0,01	0,00	g
- Unrecoverable waste	0,01	0,00	g
- Lifetime	**Material collection per WP**		
- Lifetime, average	0,11	0,01	

WP4, anode on support

Metal	Sn	Sb	Ir	Ru	
Input material	2,19	0,17	1,54	0,35	g
Yield	**90%**	**90%**	**90%**	**90%**	%
Output material	1,97	0,15	1,39	0,31	g
Material loss	0,22	0,02	0,15	0,03	g
- delta mass	0,22	0,02	0,15	0,03	g
- from recycled sources	**89%**	**87%**	**85%**	**65%**	
- from reused sources	0%	0%	0%	0%	
- for recycling	**100%**	**100%**	**100%**	**100%**	
- for reuse	0%	0%	0%	0%	
- feedstock recycling	94%	92%	90%	93%	
- recycling after use	94%	92%	90%	93%	
- initial loss, not collected	0,00	0,00	0,00	0,00	g
- loss in feedstock recyc	0,01	0,00	0,01	0,00	g
- loss in waste recyc	0,01	0,00	0,02	0,00	g
- Virgin input	0,02	0,00	0,02	0,01	g
- Unrecoverable waste	0,01	0,00	0,01	0,00	g
- Lifetime, average	0,21	0,02	0,14	0,03	

WP5, cell

Metal	Sn	Sb	Ir	Ru	Pt	Ti	
Input material	1,97	0,15	1,39	0,31	1,69	67,13	g
Yield	**60%**	**60%**	**60%**	**60%**	**62,7%**	**75,2%**	%
Output material	1,18	0,09	0,83	0,19	1,06	50,47	g
Material loss	0,79	0,06	0,55	0,12	0,63	16,66	g
- delta mass	0,79	0,06	0,55	0,12	0,63	16,66	g
- from recycled sources	89%	87%	85%	65%	96%	93%	
- from reused sources	0%	0%	0%	0%	0%	0%	
- for recycling	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
- for reuse	0%	0%	0%	0%	0%	0%	
- feedstock recycling	94%	92%	90%	93%	96%	93%	
- recycling after use	94%	92%	90%	93%	96%	93%	
- initial loss, not collected	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in feedstock recyc	0,04	0,00	0,05	0,01	0,02	1,15	g
- loss in waste recyc	0,05	0,00	0,05	0,01	0,02	1,15	g
- Virgin input	0,08	0,01	0,08	0,04	0,03	1,15	g
- Unrecoverable waste	0,05	0,00	0,05	0,01	0,02	1,15	g
- Lifetime, average	0,74	0,06	0,50	0,12	0,61	15,51	
- Use int				**Totals collected**			
- Use int, average				**Total mass**			
- Utility				**Recycled content**			

WP5, final stack

Metal	Sn	Sb	Ir	Ru	Pt	Ti	
Input material	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%
Output material	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss	0,00	0,00	0,00	0,00	0,00	0,00	g
- delta mass	1,18	0,09	0,83	0,19	1,06	50,47	g
- from recycled sources	89%	87%	85%	65%	96%	93%	
- from reused sources	0%	0%	0%	0%	0%	0%	
- for recycling	**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
- for reuse	0%	0%	0%	0%	0%	0%	
- feedstock recycling	94%	92%	90%	93%	96%	93%	
- recycling after use	**94%**	**92%**	**90%**	**93%**	**96%**	**93%**	
- initial loss, not collected	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	0,07	0,01	0,08	0,01	0,04	3,48	g
- loss in waste recyc	0,06	0,01	0,07	0,01	0,04	3,48	g
- Virgin input	0,13	0,01	0,12	0,07	0,05	3,48	g
- Unrecoverable waste	0,18	0,02	0,16	0,11	0,05	3,48	g
- Lifetime, average	1,00	0,08	0,67	0,08	1,01	46,99	
- Use int (Totals collected)	2,05	0,16	1,31	0,23	1,62	62,50	
- Use int, average (Total mass)	2,30	0,18	1,54	0,35	1,69	67,13	
- Utility (Recycled content)	89%	87%	85%	65%	96%	93%	

Figure 11: Residual collection (Alternative 2). Calculation of MCI and LFI values

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Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
		Total calculations							
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	19,69	1,24	0,10	0,79	0,26	0,64	16,66	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
- Unrecoverable waste	W	21,53	1,27	0,10	0,83	0,27	0,66	18,40	g
- LFI		0,66	0,78	0,79	0,78	0,89	0,70	0,65	
Utility									
- Lifetime	L	50	50	50	50	50	50	50	
- Lifetime, average	L_{av}	50	50	50	50	50	50	50	
- Use int	U	2,27	2,27	2,27	2,27	2,27	2,27	2,27	
- Use int, average	U_{av}	1,8	1,8	1,8	1,8	1,8	1,8	1,8	
- Utility	X	1,261	1,26	1,26	1,26	1,26	1,26	1,26	
- Function F	F(X)	0,71	0,71	0,71	0,71	0,71	0,71	0,71	
MCI									
- Material Circularity Indicat	MCI	0,53	0,44	0,44	0,44	0,37	0,50	0,54	

Metal		WP3, support			WP4, anode on support				
		Sn	Sb		Sn	Sb	Ir	Ru	
Process calculations									
Input material		2,30	0,18	g	2,19	0,17	1,54	0,35	g
Yield		**95%**	**95%**	%	**90%**	**90%**	**90%**	**90%**	%
Output material		2,19	0,17	g	1,97	0,15	1,39	0,31	g
Material loss		0,12	0,009	g	0,22	0,02	0,15	0,03	g
Weights									
- delta mass	M	0,12	0,01	g	0,22	0,02	0,15	0,03	g
Non-virgin input									
- from recycled sources	F_R	0%	0%		0%	0%	0%	0%	
- from reused sources	F_U	0%	0%		0%	0%	0%	0%	
Collection									
- for recycling	C_R	0%	0%		0%	0%	0%	0%	
- for reuse	C_U	0%	0%		0%	0%	0%	0%	
Efficiency in recycling									
- feedstock recycling	E_F	94%	92%		94%	92%	90%	93%	
- recycling after use	E_C	94%	92%		94%	92%	90%	93%	
Calculated losses									
- initial loss, not collected	W_0	0,12	0,01	g	0,22	0,02	0,15	0,03	g
- loss in feedstock recyc	W_F	0,00	0,00	g	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	g	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	0,12	0,01	g	0,22	0,02	0,15	0,03	g
- Unrecoverable waste	W	0,12	0,01	g	0,22	0,02	0,15	0,03	g

Metal		WP5, cell							WP5, final stack						
		Sn	Sb	Ir	Ru	Pt	Ti		Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations															
Input material		1,97	0,15	1,39	0,31	1,69	67,13	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield		**60%**	**60%**	**60%**	**60%**	**62,7%**	**75,2%**	%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%
Output material		1,18	0,09	0,83	0,19	1,06	50,47	g	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss		0,79	0,06	0,55	0,12	0,63	16,66	g	0,00	0,00	0,00	0,00	0,00	0,00	g
Weights															
- delta mass	M	0,79	0,06	0,55	0,12	0,63	16,66	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input															
- from recycled sources	F_R	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
- from reused sources	F_U	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Collection															
- for recycling	C_R	0%	0%	0%	0%	0%	0%		**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
- for reuse	C_U	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Efficiency in recycling															
- feedstock recycling	E_F	94%	92%	90%	93%	96%	93%		94%	92%	90%	93%	96%	93%	
- recycling after use	E_C	94%	92%	90%	93%	96%	93%		**94%**	**92%**	**90%**	**93%**	**96%**	**93%**	
Calculated losses															
- initial loss, not collected	W_0	0,79	0,06	0,55	0,12	0,63	16,66	g	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	g	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,00	0,00	g	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations															
- Virgin input	V	0,79	0,06	0,55	0,12	0,63	16,66	g	1,18	0,09	0,83	0,19	1,06	50,47	g
- Unrecoverable waste	W	0,79	0,06	0,55	0,12	0,63	16,66	g	0,149	0,01	0,12	0,11	0,03	1,74	g

Figure 12: Utility and lifetime calculations. Calculation of MCI and LFI values

Horizon 2020 European Union Funding for Research & Innovation

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		Total calculations							
Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	73,19	2,30	0,18	1,54	0,35	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	19,69	1,24	0,10	0,79	0,26	0,64	16,66	g
- loss in feedstock recyc	W_F	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
- loss in waste recyc	W_C	3,67	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	23,36	1,30	0,10	0,87	0,27	0,68	20,14	g
- Unrecoverable waste	W	23,36	1,30	0,10	0,87	0,27	0,68	20,14	g
- LFI		0,32	0,57	0,57	0,56	0,77	0,40	0,30	
Utility									
- Lifetime	L	50	50	50	50	50	50	50	
- Lifetime, average	L_{av}	50	50	50	50	50	50	50	
- Use int	U	2,27	2,27	2,27	2,27	2,27	2,27	2,27	
- Use int, average	U_{av}	1,8	1,8	1,8	1,8	1,8	1,8	1,8	
- Utility	X	1,26	1,26	1,26	1,26	1,26	1,26	1,26	
- Function F	F(X)	0,71	0,71	0,71	0,71	0,71	0,71	0,71	
MCI									
- Material Circularity Indicat	MCI	0,77	0,60	0,59	0,60	0,45	0,71	0,79	

		WP3, support			WP4, anode on support				
Metal		Sn	Sb		Sn	Sb	Ir	Ru	
Process calculations									
Input material		2,30	0,18	g	2,19	0,17	1,54	0,35	g
Yield		**95%**	**95%**	%	**90%**	**90%**	**90%**	**90%**	%
Output material		2,19	0,17	g	1,97	0,15	1,39	0,31	g
Material loss		0,12	0,009	g	0,22	0,02	0,15	0,03	g
Weights									
- delta mass	M	0,12	0,01	g	0,22	0,02	0,15	0,03	g
Non-virgin input									
- from recycled sources	F_R	**43%**	**43%**		**43%**	**43%**	**44%**	**23%**	
- from reused sources	F_U	0%	0%		0%	0%	0%	0%	
Collection									
- for recycling	C_R	0%	0%		0%	0%	0%	0%	
- for reuse	C_U	0%	0%		0%	0%	0%	0%	
Efficiency in recycling									
- feedstock recycling	E_F	94%	92%		94%	92%	90%	93%	
- recycling after use	E_C	94%	92%		94%	92%	90%	93%	
Calculated losses									
- initial loss, not collected	W_0	0,12	0,01	g	0,22	0,02	0,15	0,03	g
- loss in feedstock recyc	W_F	0,00	0,00	g	0,01	0,00	0,01	0,00	g
- loss in waste recyc	W_C	0,00	0,00	g	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	0,07	0,01	g	0,12	0,01	0,09	0,03	g
- Unrecoverable waste	W	0,12	0,01	g	0,22	0,02	0,16	0,04	g
- LFI									
Utility									
- Lifetime	L	**Material collection per WP**							
- Lifetime, average	L_{av}	0,00	0,00		0,00	0,00	0,00	0,00	
- Use int	U								
- Use int, average	U_{av}								
- Utility	X								
- Function F	F(X)								
MCI									
- Material Circularity Indicat	MCI								

		WP5, cell							WP5, final stack						
Metal		Sn	Sb	Ir	Ru	Pt	Ti		Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations															
Input material		1,97	0,15	1,39	0,31	1,69	67,13	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield		**60%**	**60%**	**60%**	**60%**	**62,7%**	**75,2%**	**%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**%**
Output material		1,18	0,09	0,83	0,19	1,06	50,47	g	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss		0,79	0,06	0,55	0,12	0,63	16,66	g	0,00	0,00	0,00	0,00	0,00	0,00	g
Weights															
- delta mass	M	0,79	0,06	0,55	0,12	0,63	16,66	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input															
- from recycled sources	F_R	**43%**	**43%**	**44%**	**23%**	**60%**	**70%**		**43%**	**43%**	**44%**	**23%**	**60%**	**70%**	
- from reused sources	F_U	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Collection															
- for recycling	C_R	0%	0%	0%	0%	0%	0%		**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
- for reuse	C_U	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
Efficiency in recycling															
- feedstock recycling	E_F	94%	92%	90%	93%	96%	93%		94%	92%	90%	93%	96%	93%	
- recycling after use	E_C	94%	92%	90%	93%	96%	93%		**94%**	**92%**	**90%**	**93%**	**96%**	**93%**	
Calculated losses															
- initial loss, not collected	W_0	0,79	0,06	0,55	0,12	0,63	16,66	g	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	0,02	0,00	0,03	0,00	0,01	0,86	g	0,03	0,00	0,04	0,00	0,02	2,62	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,00	0,00	g	0,06	0,01	0,07	0,01	0,04	3,48	g
LFI (Lineal Flow index) calculations															
- Virgin input	V	0,45	0,03	0,31	0,10	0,25	5,00	g	0,67	0,05	0,47	0,15	0,43	15,14	g
- Unrecoverable waste	W	0,80	0,06	0,57	0,13	0,64	17,09	g	0,17	0,01	0,14	0,11	0,04	3,05	g
- LFI															
Utility															
- Lifetime	L														
- Lifetime, average	L_{av}	0,00	0,00	0,00	0,00	0,00	0,00		1,00	0,08	0,67	0,08	1,01	46,99	
- Use int	U				**Totals collected**				1,00	0,08	0,67	0,08	1,01	46,99	
- Use int, average	U_{av}				**Total mass**				2,30	0,18	1,54	0,35	1,69	67,13	
- Utility	X				**Recycled content**				43%	43%	44%	23%	60%	70%	
- Function F	F(X)														
MCI															
- Material Circularity Indicat	MCI														

Figure 13: Combination, recycled content and utility. Calculation of MCI and LFI values

Horizon 2020
European Union Funding
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		Total calculations							
Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	71,11	1,18	0,09	0,83	0,19	1,69	67,13	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	17,62	0,12	0,01	0,08	0,10	0,64	16,66	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	3,52	0,00	0,00	0,00	0,00	0,04	3,48	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	68,82	0,00	0,00	0,00	0,00	1,69	67,13	g
- Unrecoverable waste	W	19,38	0,12	0,01	0,08	0,10	0,66	18,40	g
- LFI		0,63	0,05	0,05	0,05	0,28	0,70	0,65	
Utility									
- Lifetime	L	10	10	10	10	10	10	10	
- Lifetime, average	L_{av}	10	10	10	10	10	10	10	
- Use int	U	10	10	10	10	10	10	10	
- Use int, average	U_{av}	10	10	10	10	10	10	10	
- Utility	X	1	1	1	1	1	1	1	
- Function F	F(X)	0,90	0,90	0,90	0,90	0,90	0,90	0,90	
MCI									
- Material Circularity Indicat	MCI	0,43	0,96	0,96	0,96	0,75	0,37	0,42	

		WP3, support						
Metal		Sn	Sb					
Process calculations								
Input material		1,18	0,09					g
Yield		**100%**	**100%**					%
Output material		1,18	0,09					g
Material loss		0,00	0,000					g
Weights								
- delta mass	M	0,00	0,00					g
Non-virgin input								
- from recycled sources	F_R	0%	0%					
- from reused sources	F_U	**100%**	**100%**					
Collection								
- for recycling	C_R	0%	0%					
- for reuse	C_U	0%	0%					
Efficiency in recycling								
- feedstock recycling	E_F	94%	92%					
- recycling after use	E_C	94%	92%					
Calculated losses								
- initial loss, not collected	W_0	0,00	0,00					g
- loss in feedstock recyc	W_F	0,00	0,00					g
- loss in waste recyc	W_C	0,00	0,00					g
LFI (Lineal Flow index) calculations								
- Virgin input	V	0,00	0,00					g
- Unrecoverable waste	W	0,00	0,00					g
- LFI								
Utility								
- Lifetime	L							
- Lifetime, average	L_{av}							
- Use int	U							
- Use int, average	U_{av}							
- Utility	X							
- Function F	F(X)							
MCI								
- Material Circularity Indicat	MCI							

		WP4, anode on support						
Metal		Sn	Sb	Ir	Ru			
Process calculations								
Input material		1,18	0,09	0,83	0,19			g
Yield		**100%**	**100%**	**100%**	**100%**			%
Output material		1,18	0,09	0,83	0,19			g
Material loss		0,00	0,00	0,00	0,00			g
Weights								
- delta mass	M	0,00	0,00	0,00	0,00			g
Non-virgin input								
- from recycled sources	F_R	0%	0%	0%	0%			
- from reused sources	F_U	**100%**	**100%**	**100%**	**100%**			
Collection								
- for recycling	C_R	0%	0%	0%	0%			
- for reuse	C_U	0%	0%	0%	0%			
Efficiency in recycling								
- feedstock recycling	E_F	94%	92%	90%	93%			
- recycling after use	E_C	94%	92%	90%	93%			
Calculated losses								
- initial loss, not collected	W_0	0,00	0,00	0,00	0,00			g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00			g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00			g
LFI (Lineal Flow index) calculations								
- Virgin input	V	0,00	0,00	0,00	0,00			g
- Unrecoverable waste	W	0,00	0,00	0,00	0,00			g
- LFI								
Utility								
- Lifetime	L							
- Lifetime, average	L_{av}							
- Use int	U							
- Use int, average	U_{av}							
- Utility	X							
- Function F	F(X)							
MCI								
- Material Circularity Indicat	MCI							

		WP5, cell						
Metal		Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations								
Input material		1,18	0,09	0,83	0,19	1,69	67,13	g
Yield		**100%**	**100%**	**100%**	**100%**	**62,7%**	**75,2%**	**%**
Output material		1,18	0,09	0,83	0,19	1,06	50,47	g
Material loss		0,00	0,00	0,00	0,00	0,63	16,66	g
Weights								
- delta mass	M	0,00	0,00	0,00	0,00	0,63	16,66	g
Non-virgin input								
- from recycled sources	F_R	0%	0%	0%	0%	0%	0%	
- from reused sources	F_U	**100%**	**100%**	**100%**	**100%**	0%	0%	
Collection								
- for recycling	C_R	0%	0%	0%	0%	0%	0%	
- for reuse	C_U	0%	0%	0%	0%	0%	0%	
Efficiency in recycling								
- feedstock recycling	E_F	94%	92%	90%	93%	96%	93%	
- recycling after use	E_C	94%	92%	90%	93%	96%	93%	
Calculated losses								
- initial loss, not collected	W_0	0,00	0,00	0,00	0,00	0,63	16,66	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations								
- Virgin input	V	0,00	0,00	0,00	0,00	0,63	16,66	g
- Unrecoverable waste	W	0,00	0,00	0,00	0,00	0,63	16,66	g
- LFI								
Utility								
- Lifetime	L							
- Lifetime, average	L_{av}							
- Use int	U							
- Use int, average	U_{av}							
- Utility	X							
- Function F	F(X)							
MCI								
- Material Circularity Indicat	MCI							

		WP5, final stack						
Metal		Sn	Sb	Ir	Ru	Pt	Ti	
Process calculations								
Input material		1,18	0,09	0,83	0,19	1,06	50,47	g
Yield		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**%**
Output material		**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss		0,00	0,00	0,00	0,00	0,00	0,00	g
Weights								
- delta mass	M	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input								
- from recycled sources	F_R	0%	0%	0%	0%	0%	0%	
- from reused sources	F_U	**100%**	**100%**	**100%**	**100%**	0%	0%	
Collection								
- for recycling	C_R	0%	0%	0%	0%	**99%**	**100%**	
- for reuse	C_U	**90%**	**90%**	**90%**	**45%**	0%	0%	
Efficiency in recycling								
- feedstock recycling	E_F	94%	92%	90%	93%	96%	93%	
- recycling after use	E_C	94%	92%	90%	93%	**96%**	**93%**	
Calculated losses								
- initial loss, not collected	W_0	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,04	3,48	g
LFI (Lineal Flow index) calculations								
- Virgin input	V	0,00	0,00	0,00	0,00	1,06	50,47	g
- Unrecoverable waste	W	0,118	0,01	0,08	0,10	0,03	1,74	g
- LFI								
Utility								
- Lifetime	L							
- Lifetime, average	L_{av}							
- Use int	U							
- Use int, average	U_{av}							
- Utility	X							
- Function F	F(X)							
MCI								
- Material Circularity Indicat	MCI							

Figure 14: Reactivation of anode. Calculation of MCI and LFI values

Horizon 2020 European Union Funding for Research & Innovation

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Metal		Sum	Sn	Sb	Ir	Ru	Pt	Ti	
		Total calculations							
Process calculations									
Input material									
Yield									
Output material									
Material loss									
Weights									
- delta mass	M	53,82	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input									
- from recycled sources	F_R								
- from reused sources	F_U								
Collection									
- for recycling	C_R								
- for reuse	C_U								
Efficiency in recycling									
- feedstock recycling	E_F								
- recycling after use	E_C								
Calculated losses									
- initial loss, not collected	W_0	0,32	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations									
- Virgin input	V	0,00	0,00	0,00	0,00	0,00	0,00	0,00	g
- Unrecoverable waste	W	0,32	0,12	0,01	0,08	0,10	0,01	0,00	g
- LFI		0,00	0,05	0,05	0,05	0,28	0,01	0,00	
Utility									
- Lifetime	L	10	10	10	10	10	10	10	
- Lifetime, average	L_{av}	10	10	10	10	10	10	10	
- Use int	U	10	10	10	10	10	10	10	
- Use int, average	U_{av}	10	10	10	10	10	10	10	
- Utility	X	1	1	1	1	1	1	1	
- Function F	F(X)	0,90	0,90	0,90	0,90	0,90	0,90	0,90	
MCI									
- Material Circularity Indicato	MCI	1,00	0,96	0,96	0,96	0,75	1,00	1,00	

Metal		WP3, support Sn	WP3 Sb						WP4, anode on support Sn	WP4 Sb	WP4 Ir	WP4 Ru			
Process calculations															
Input material		1,18	0,09					g	1,18	0,09	0,83	0,19			g
Yield		**100%**	**100%**					%	**100%**	**100%**	**100%**	**100%**			%
Output material		1,18	0,09					g	1,18	0,09	0,83	0,19			g
Material loss		0,00	0,000					g	0,00	0,00	0,00	0,00			g
Weights															
- delta mass	M	0,00	0,00					g	0,00	0,00	0,00	0,00			g
Non-virgin input															
- from recycled sources	F_R	0%	0%						0%	0%	0%	0%			
- from reused sources	F_U	**100%**	**100%**						**100%**	**100%**	**100%**	**100%**			
Collection															
- for recycling	C_R	0%	0%						0%	0%	0%	0%			
- for reuse	C_U	0%	0%						0%	0%	0%	0%			
Efficiency in recycling															
- feedstock recycling	E_F	94%	92%						94%	92%	90%	93%			
- recycling after use	E_C	94%	92%						94%	92%	90%	93%			
Calculated losses															
- initial loss, not collected	W_0	0,00	0,00					g	0,00	0,00	0,00	0,00			g
- loss in feedstock recyc	W_F	0,00	0,00					g	0,00	0,00	0,00	0,00			g
- loss in waste recyc	W_C	0,00	0,00					g	0,00	0,00	0,00	0,00			g
LFI (Lineal Flow index) calculations															
- Virgin input	V	0,00	0,00					g	0,00	0,00	0,00	0,00			g
- Unrecoverable waste	W	0,00	0,00					g	0,00	0,00	0,00	0,00			g
- LFI															
Utility															
- Lifetime	L														
- Lifetime, average	L_{av}														
- Use int	U														
- Use int, average	U_{av}														
- Utility	X														
- Function F	F(X)														
MCI															
- Material Circularity Indicato	MCI														

Metal		WP5, cell Sn	WP5 cell Sb	WP5 cell Ir	WP5 cell Ru	WP5 cell Pt	WP5 cell Ti		WP5, final stack Sn	Final stack Sb	Final stack Ir	Final stack Ru	Final stack Pt	Final stack Ti	
Process calculations															
Input material		1,18	0,09	0,83	0,19	1,06	50,47	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Yield		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	%
Output material		1,18	0,09	0,83	0,19	1,06	50,47	g	**1,18**	**0,09**	**0,83**	**0,19**	**1,06**	**50,47**	g
Material loss		0,00	0,00	0,00	0,00	0,00	0,00	g	0,00	0,00	0,00	0,00	0,00	0,00	g
Weights															
- delta mass	M	0,00	0,00	0,00	0,00	0,00	0,00	g	1,18	0,09	0,83	0,19	1,06	50,47	g
Non-virgin input															
- from recycled sources	F_R	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
- from reused sources	F_U	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
Collection															
- for recycling	C_R	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	
- for reuse	C_U	0%	0%	0%	0%	0%	0%		**90%**	**90%**	**90%**	**45%**	**99%**	**100%**	
Efficiency in recycling															
- feedstock recycling	E_F	94%	92%	90%	93%	96%	93%		94%	92%	90%	93%	96%	93%	
- recycling after use	E_C	94%	92%	90%	93%	96%	93%		94%	92%	90%	93%	96%	93%	
Calculated losses															
- initial loss, not collected	W_0	0,00	0,00	0,00	0,00	0,00	0,00	g	0,12	0,01	0,08	0,10	0,01	0,00	g
- loss in feedstock recyc	W_F	0,00	0,00	0,00	0,00	0,00	0,00	g	0,00	0,00	0,00	0,00	0,00	0,00	g
- loss in waste recyc	W_C	0,00	0,00	0,00	0,00	0,00	0,00	g	0,00	0,00	0,00	0,00	0,00	0,00	g
LFI (Lineal Flow index) calculations															
- Virgin input	V	0,00	0,00	0,00	0,00	0,00	0,00	g	0,00	0,00	0,00	0,00	0,00	0,00	g
- Unrecoverable waste	W	0,00	0,00	0,00	0,00	0,00	0,00	g	0,118	0,01	0,08	0,10	0,01	0,00	g
- LFI															
Utility															
- Lifetime	L														
- Lifetime, average	L_{av}														
- Use int	U														
- Use int, average	U_{av}														
- Utility	X														
- Function F	F(X)														
MCI															
- Material Circularity Indicato	MCI														

Figure 15: Reactivation of cell. Calculation of MCI and LFI values

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