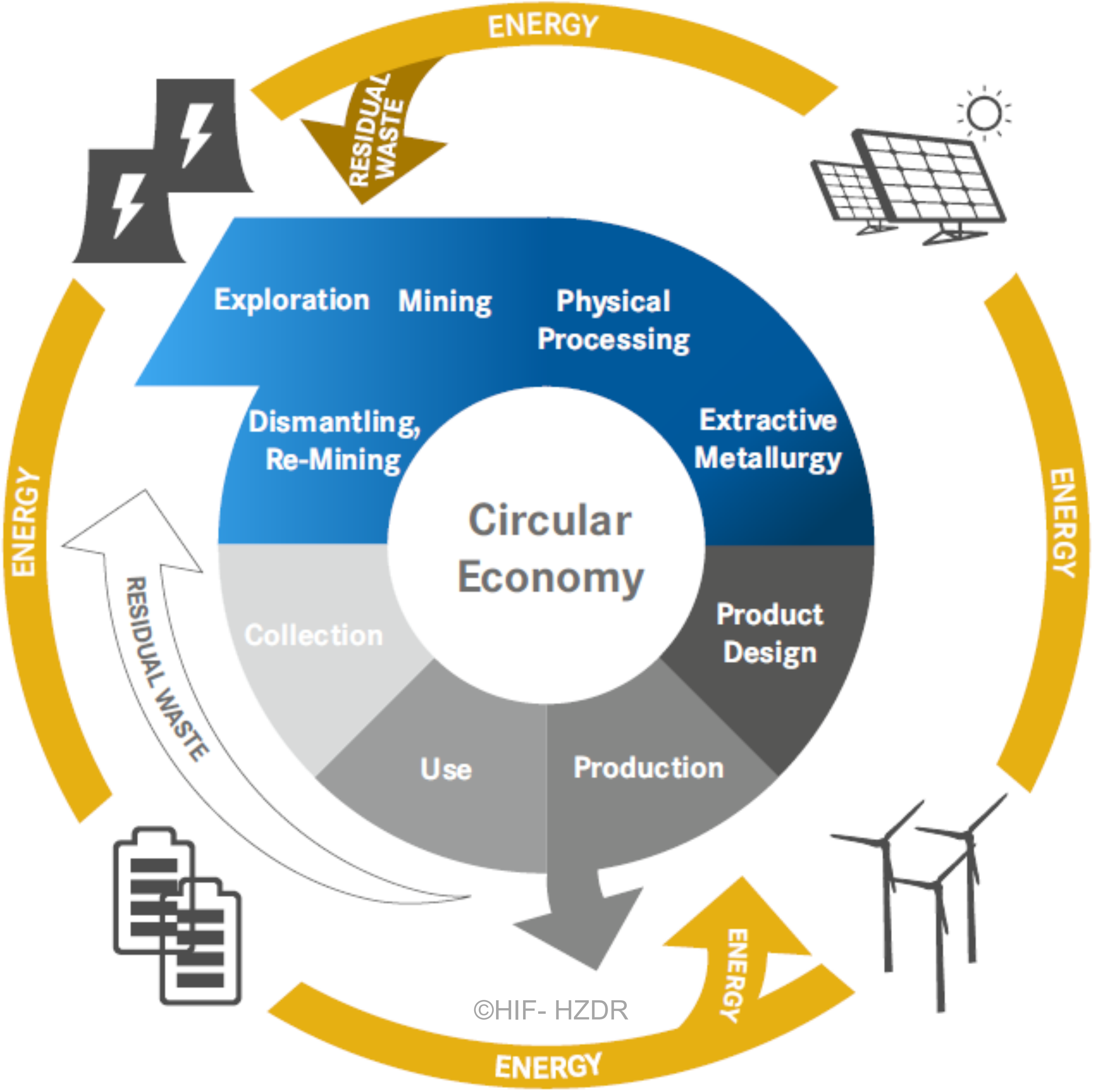
Digitalizing the Circular Economy

Markus A. Reuter

M.A. Reuter (2016): Digitalizing the Circular Economy-Circular Economy Engineering defined by the metallurgical Internet of Things- 2016 TMS EPD Distinguished Lecture Award, USA, Metallurgical Transactions B 47(6), 3194-3220 (http://link.springer.com/article/10.1007/s11663-016-0735-5).

Agenda

- Circular Economy
  - Fairphone example / flowsheet simulation + FACT
- Industrial examples
  - Using FACT Sage to design, optimize & control furnaces, as well as connected to flowsheet simulation & big data analysis
  - From my work at Ausmelt / Outotec
    - Industrial Example 1: Lead - China
    - Industrial Example 2: Copper, residues & eWaste - Japan
- Digitalizing the Circular Economy
  - Fairphone example concluded using FACT detail (if available!)


ENERGY
RESIDUAL WASTE
Exploration
Mining
Physical Processing
Dismantling, Re-Mining
Extractive Metallurgy
Circular Economy
Collection
Product Design
Use
Production
RESIDUAL WASTE
ENERGY
ENERGY
ENERGY
ENERGY
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Some personal past history…

Applied Technology

The Intelligent Supervisory Control of Submerged-Arc Furnaces

Markus A. Reuter, Carla Pretorius, Chloë West, Peter Dixon, and Morné Oosthuizen

INTRODUCTION

In spite of the many advances in the process control of submerged-arc furnaces, a certain degree of human input is still required. Such input by the operator and the metallurgist is largely done by an innate "feel" for the process, although there are some modern methodologies available such as artificial intelligence techniques[1,2] that could assist in these activities. In a constantly changing market where profit margins are tight, it is imperative that furnaces run as optimally as possible. This can arguably be done better in a computerized environment.

This article discusses the intelligent supervisory control of submerged-arc furnaces. Various aspects of such a system are illustrated, relating the metallurgical and electrical parameters to the control loops of the furnace.

50 JOM • December 1996

InTouch™) provides all of the standard features of such state-of-the-art packages, including graphical interfaces, data logging, historical trending, and SQL features; intelligent multiple symptom alarming (e.g., through the command language); statistical process control; on-line documentation; the checking of trends and setting of corresponding alarms; and the monitoring of furnace pressures, temperatures, and instrument readings for failure.

In addition to the basic SCADA software customized for an application, various modular *Windows* utilities could also be accessed from SCADA's user-interfaces. These model-based utilities provide the user with tools with which various furnace modes of operation can be simulated, hence, providing very useful operator guidance. Among these tools are:

- *Characteristic Curves.* This on-line networked electrical model of a furnace models and displays the electrical side of furnace operation in real time. This is a very useful tool to demonstrate the control of a furnace as well as to create expert

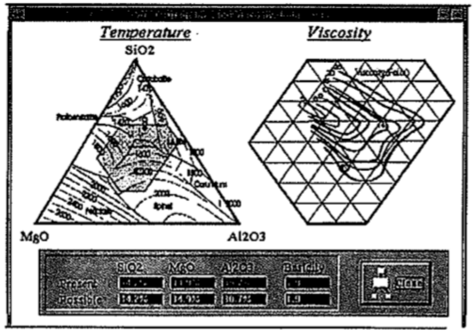
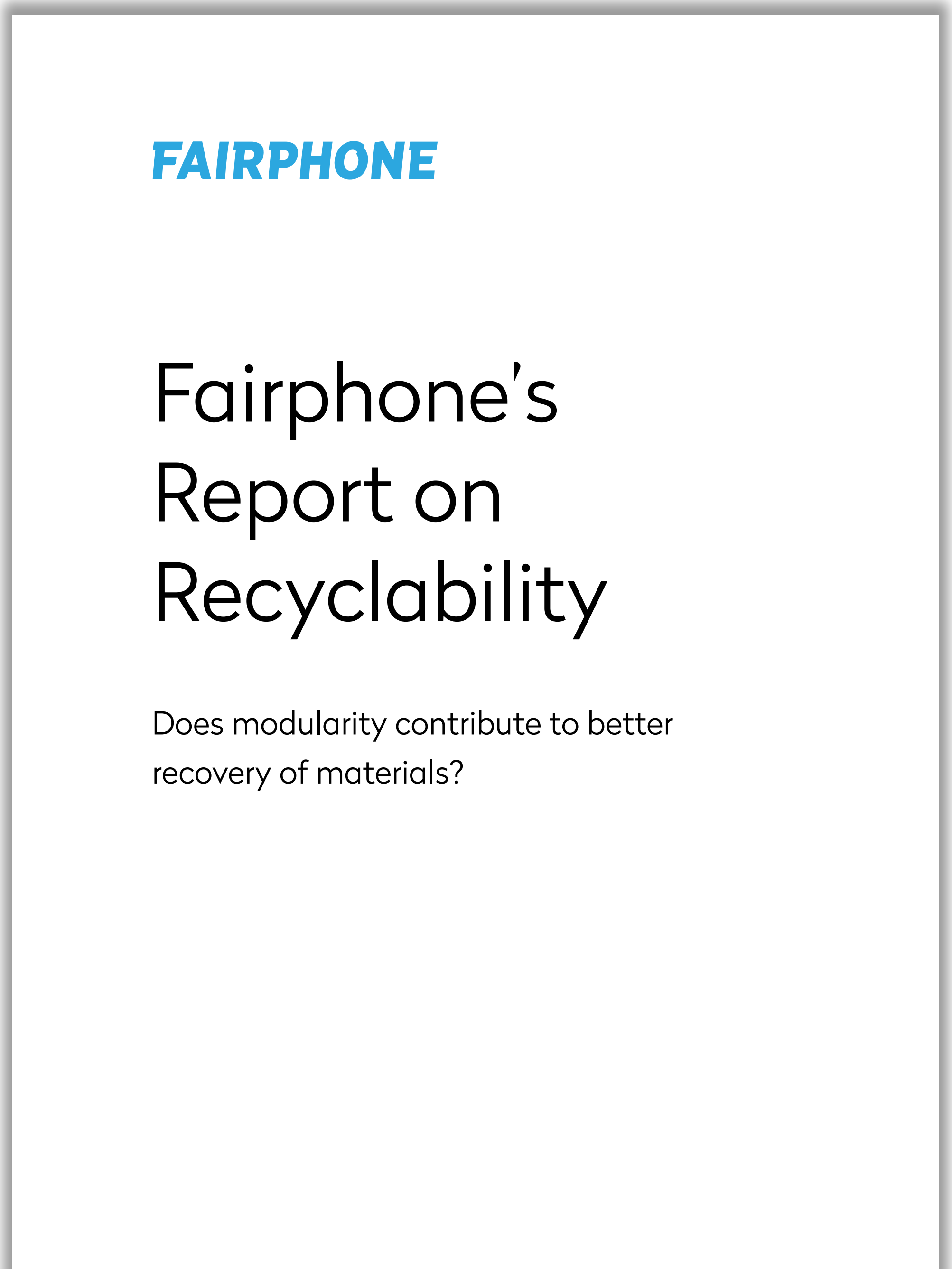


Figure 3. An on-line phase diagram accessed through the database.

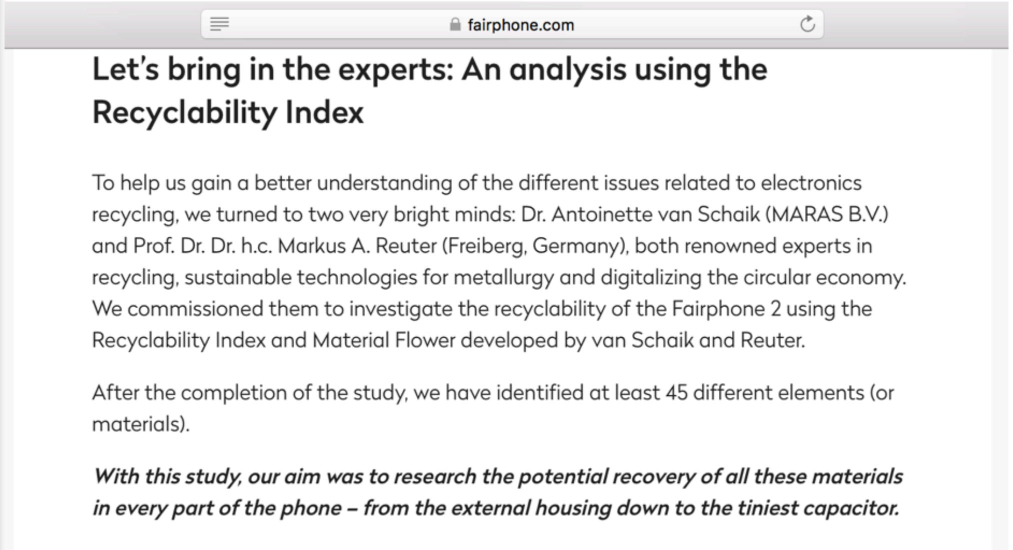


FAIRPHONE

Fairphone's Report on Recyclability

Does modularity contribute to better recovery of materials?

https://www.fairphone.com/en/2017/02/27/recyclable-fairphone-2/



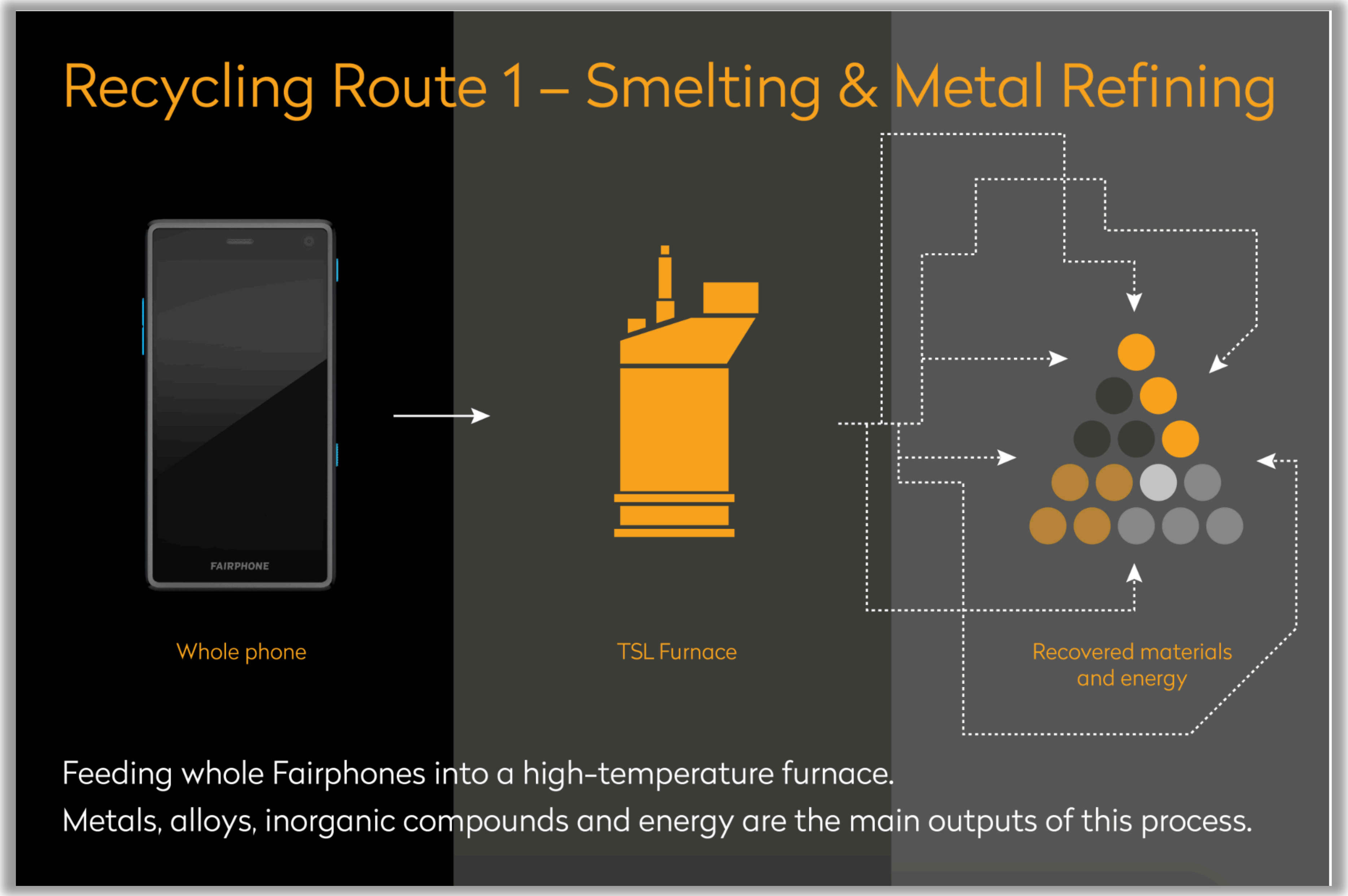
Let's bring in the experts: An analysis using the Recyclability Index

To help us gain a better understanding of the different issues related to electronics recycling, we turned to two very bright minds: Dr. Antoinette van Schaik (MARAS B.V.) and Prof. Dr. Dr. h.c. Markus A. Reuter (Freiberg, Germany), both renowned experts in recycling, sustainable technologies for metallurgy and digitalizing the circular economy. We commissioned them to investigate the recyclability of the Fairphone 2 using the Recyclability Index and Material Flower developed by van Schaik and Reuter.

After the completion of the study, we have identified at least 45 different elements (or materials).

With this study, our aim was to research the potential recovery of all these materials in every part of the phone – from the external housing down to the tiniest capacitor.

Fairphone Recyclability: Recycling Flow Sheet



Recycling Route 1 – Smelting & Metal Refining

Whole phone

TSL Furnace

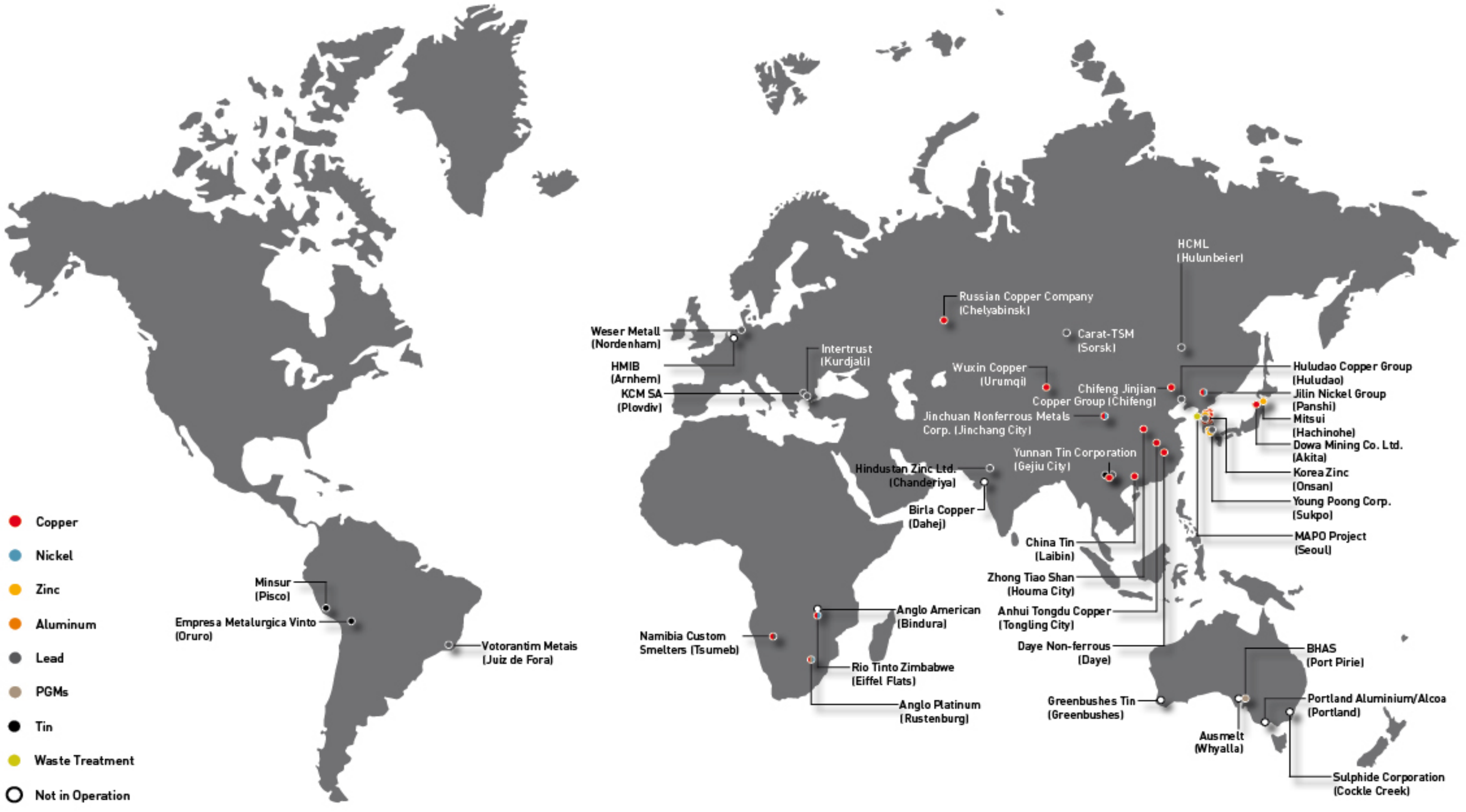
Recovered materials
and energy

Feeding whole Fairphones into a high-temperature furnace.

Metals, alloys, inorganic compounds and energy are the main outputs of this process.

Technology / System Design & Simulation

Outotec Ausmelt
TSL Plants (65)

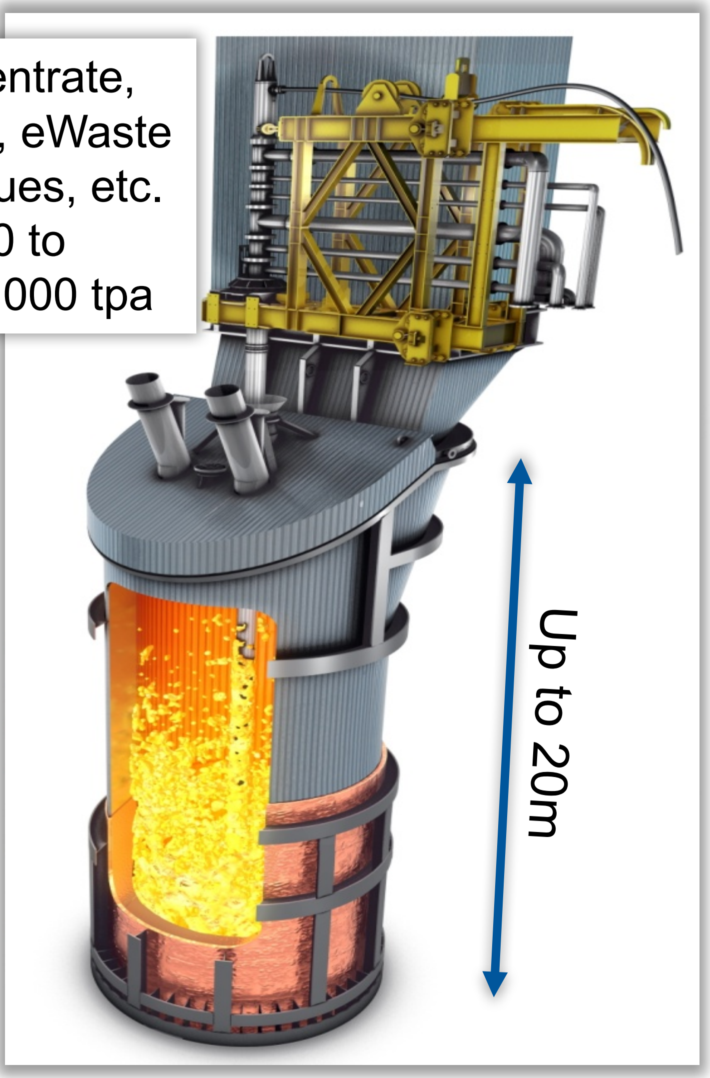


www.outotec.com

Technology / System Design & Simulation

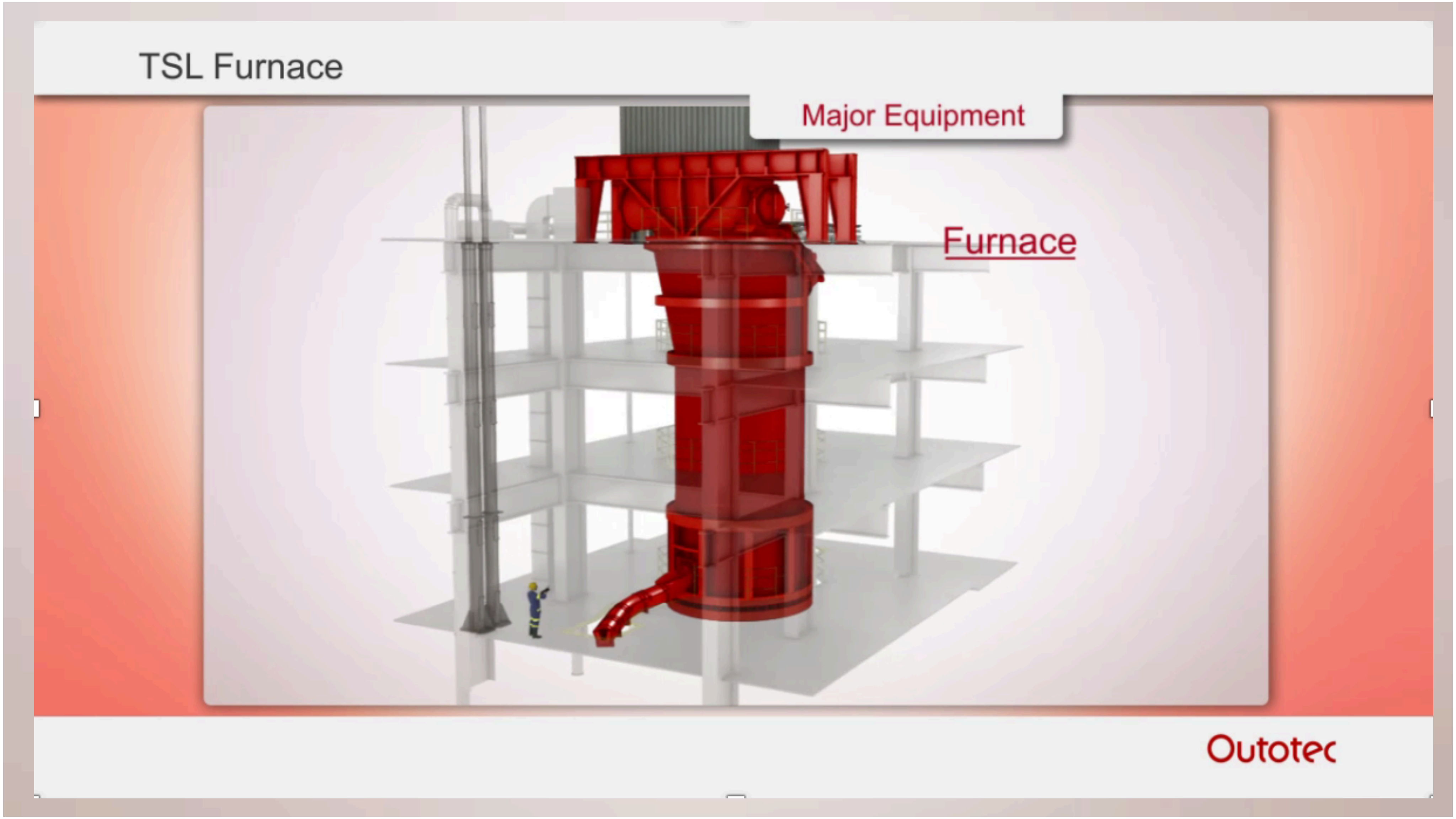
Outotec Ausmelt
TSL Plants (65)

Concentrate,
Scrap, eWaste
Residues, etc.
10,000 to
1,500,000 tpa



www.outotec.com

Technology / System Design & Simulation (Video)



www.outotec.com

Industrial apps:Cu, Zn, Pb, Ni, Residues, eWaste

Dowa (Japan): PCBAs, Cu, residues

Boliden Rönnskår (Sweden): Kaldo for eWaste

Recylex (Germany): Lead Battery, Pb residues

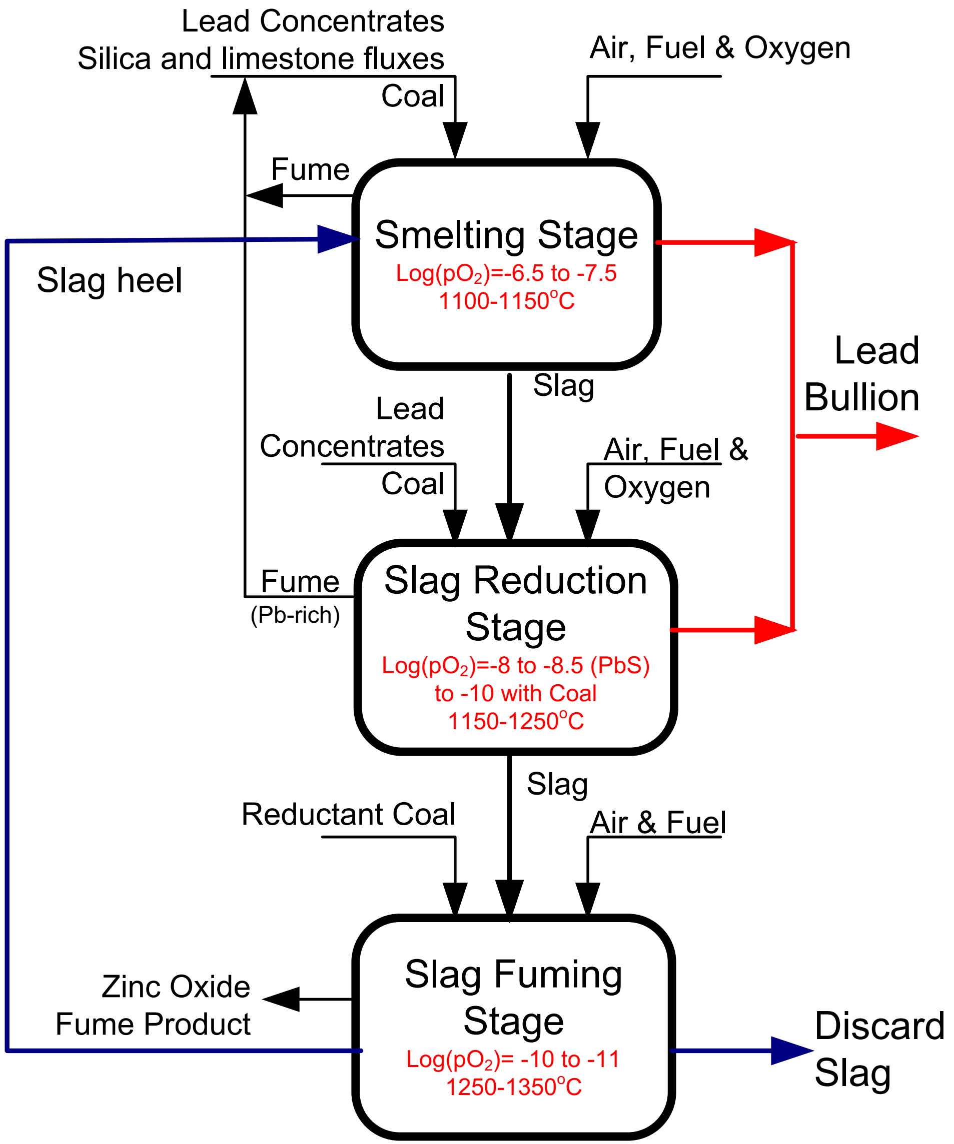
JCC Guixi (China): Cu scrap, internal material (slags) , residues

GRM – Danyang Smelter (S. Korea): Cu scrap, residues etc.

Young Poong Corporation (S. Korea): Pb/Zn

1, 2 or 3 Stage Lead Smelting in a TSL

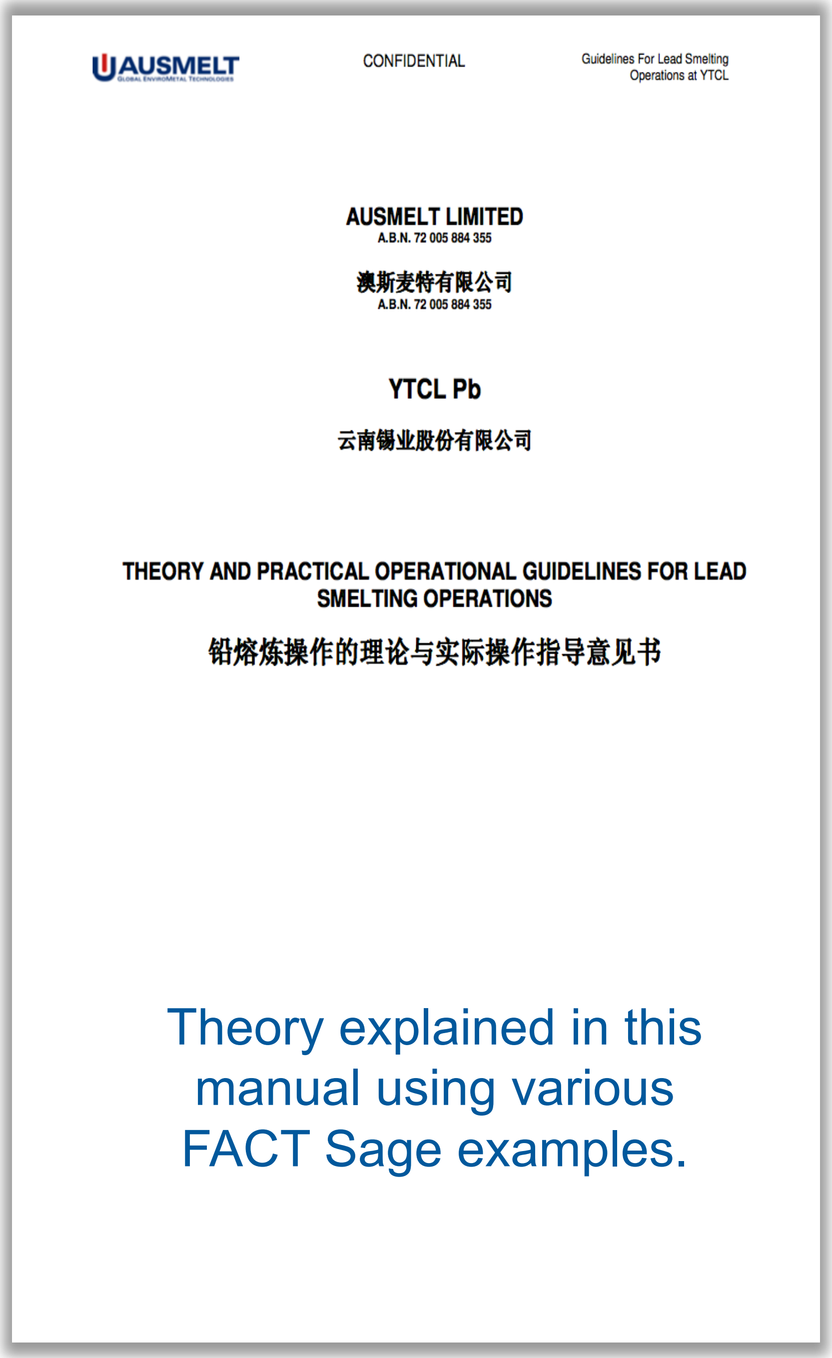
Australia, Bulgaria, China, Germany, India, S. Korea



YTCL Lead Smelter, China

- Design capacity
  - 190,000 t/y lead concentrates
  - 100,000 t/y refined lead
  - 160 t/y silver
  - 86,000 t/y sulphuric acid

- 3 stage batch process
  - Smelting, slag reduction, zinc fuming



CONFIDENTIAL

Guidelines For Lead Smelting
Operations at YTCL

AUSMELT LIMITED
A.B.N. 72 005 884 355

澳斯麦特有限公司
A.B.N. 72 005 884 355

YTCL Pb

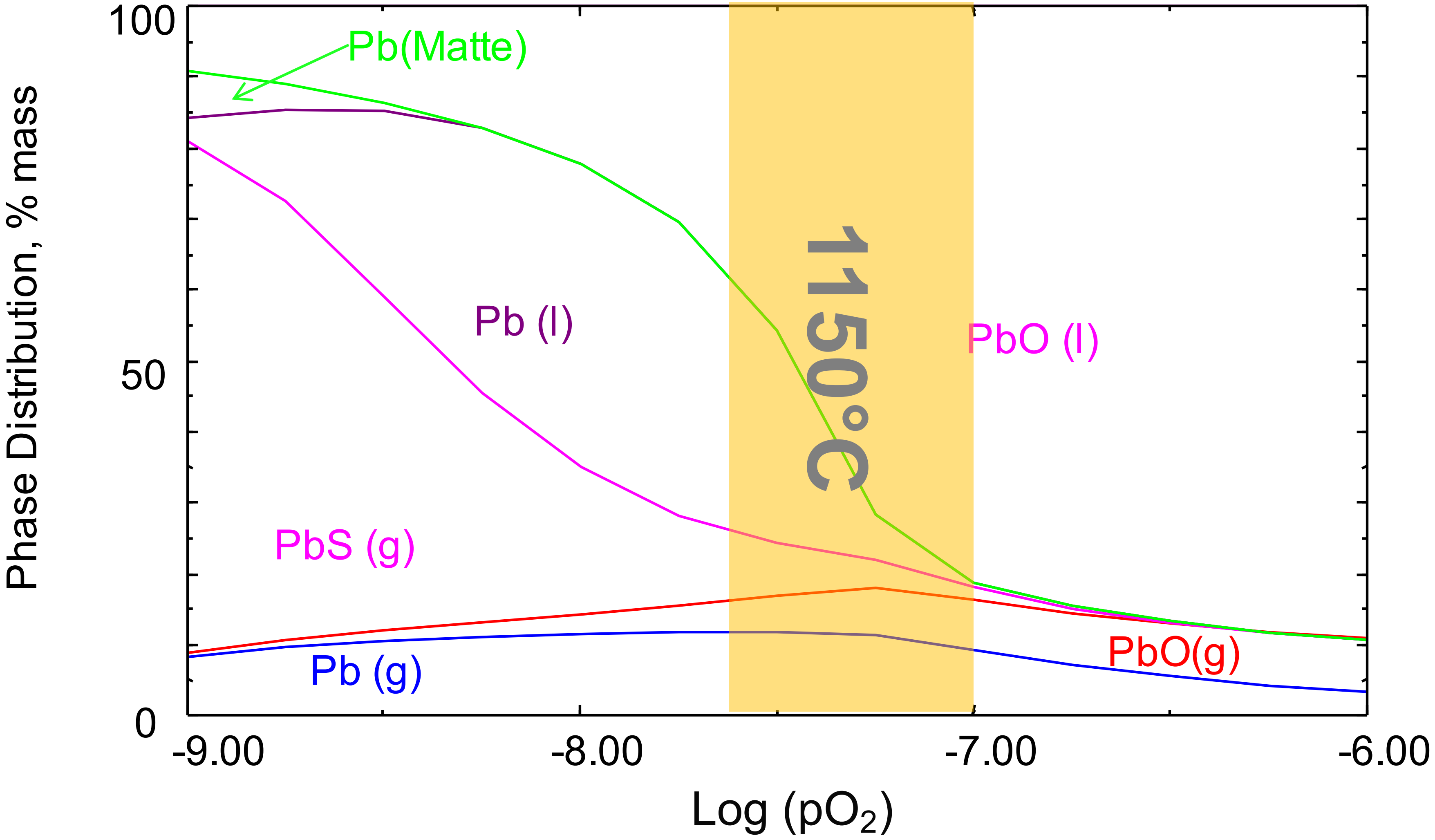
云南锡业股份有限公司

THEORY AND PRACTICAL OPERATIONAL GUIDELINES FOR LEAD SMELTING OPERATIONS

铅熔炼操作的理论与实际操作指导意见书

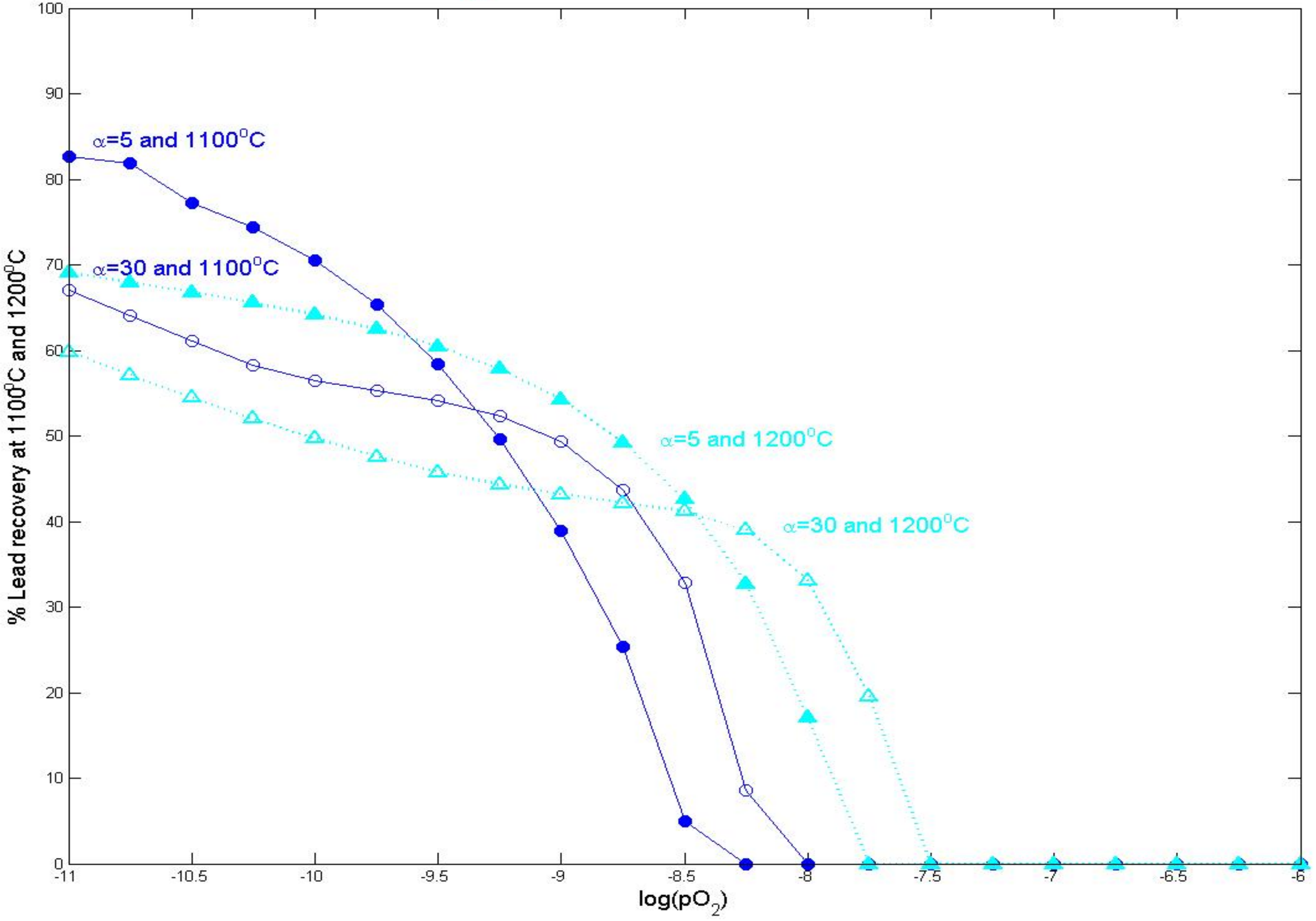
Theory explained in this manual using various FACT Sage examples.

Smelting phase distributions (function of feed & calibrated for operating conditions in TSL)



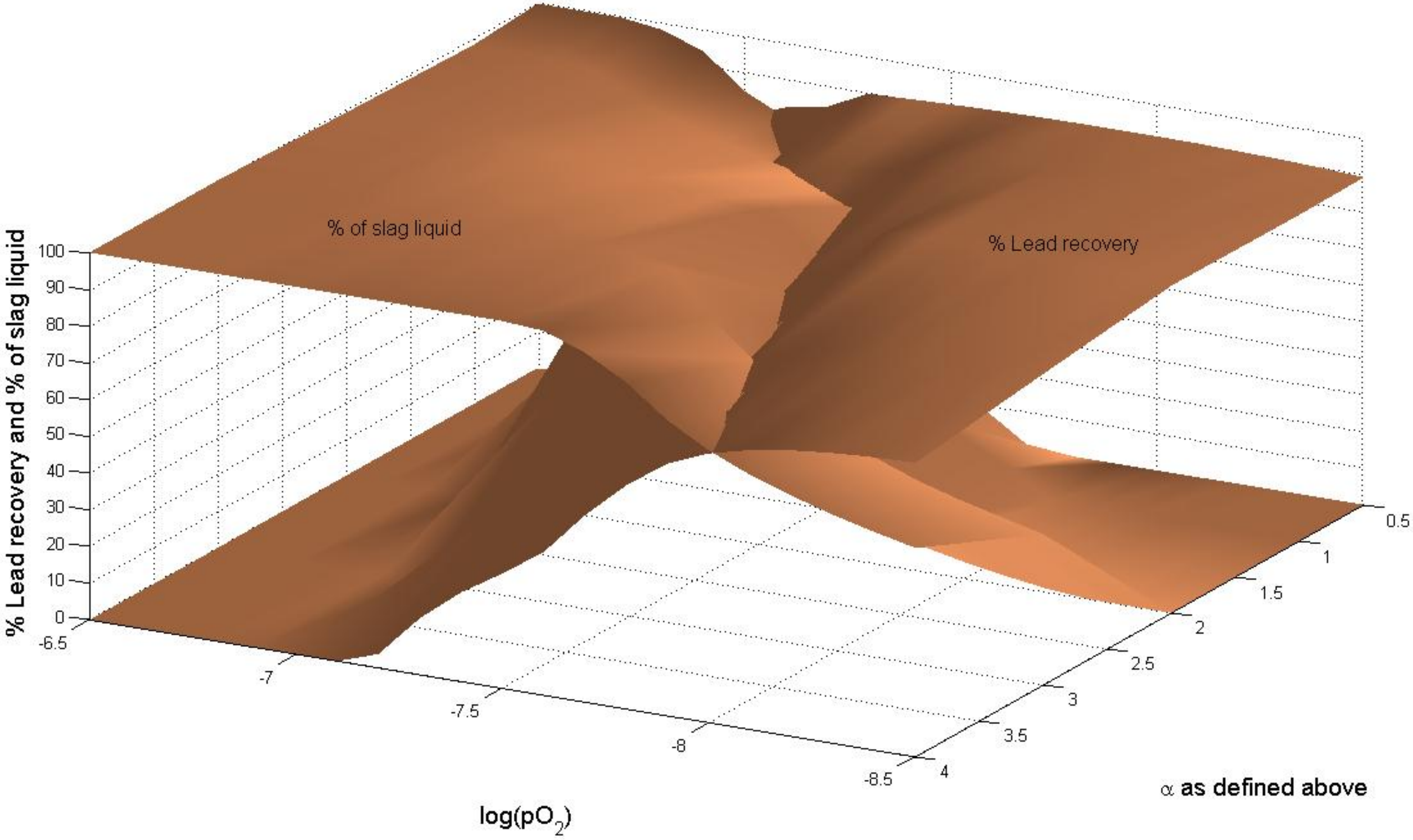
Controlling the furnace operation

A FeO+ B PbO+ C SiO_2+ D CaO .... at 1100°C and 1200°C



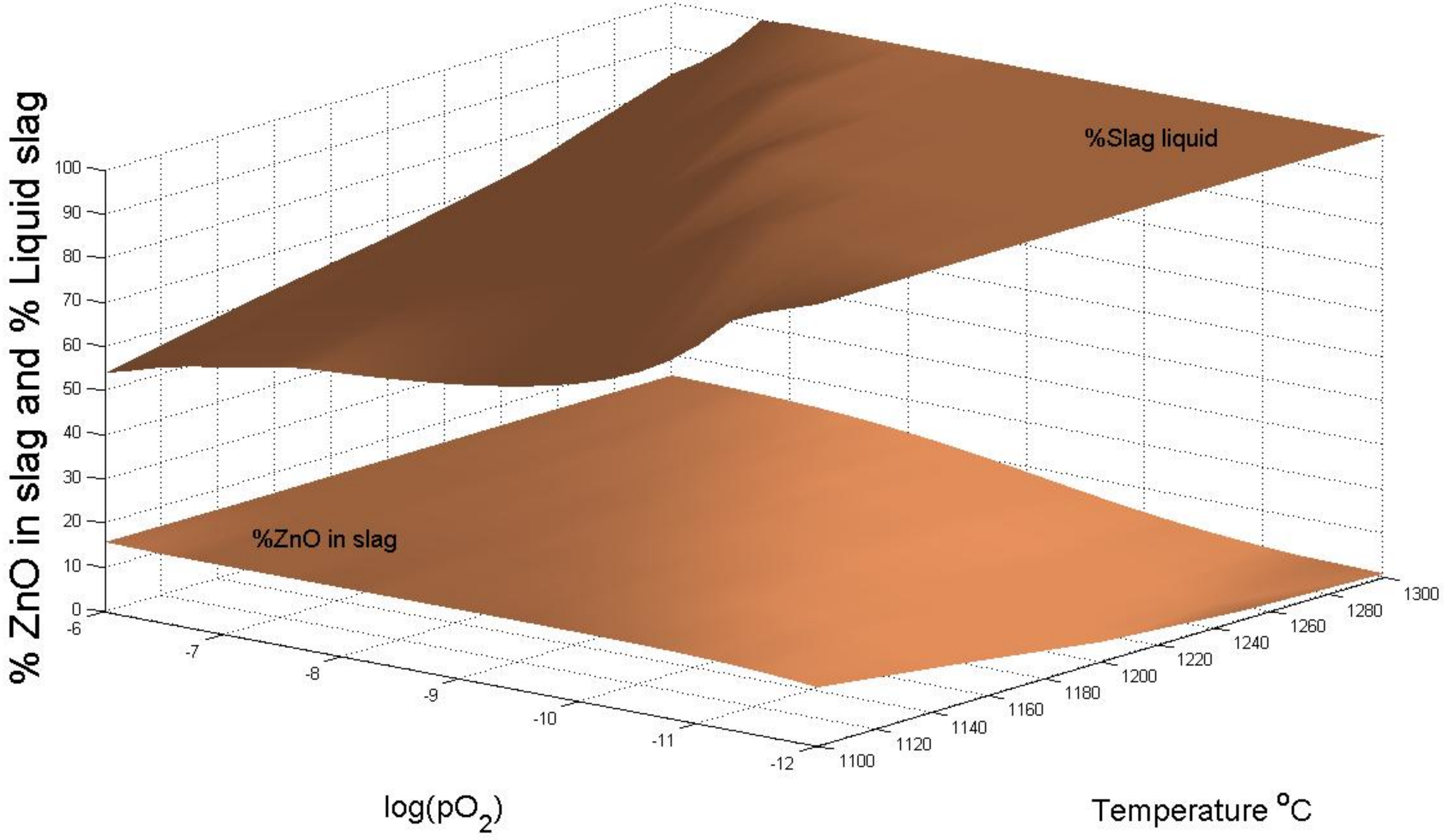
Various feed parameters: TSL smelting & reduction stage (generalized figure)

A Pb+ B PbO+ C $PbSO_4$+ D $CaO+\alpha(1.2Fe+SiO_2)$ at 1100°C



Slag fuming stage (generalized figure)

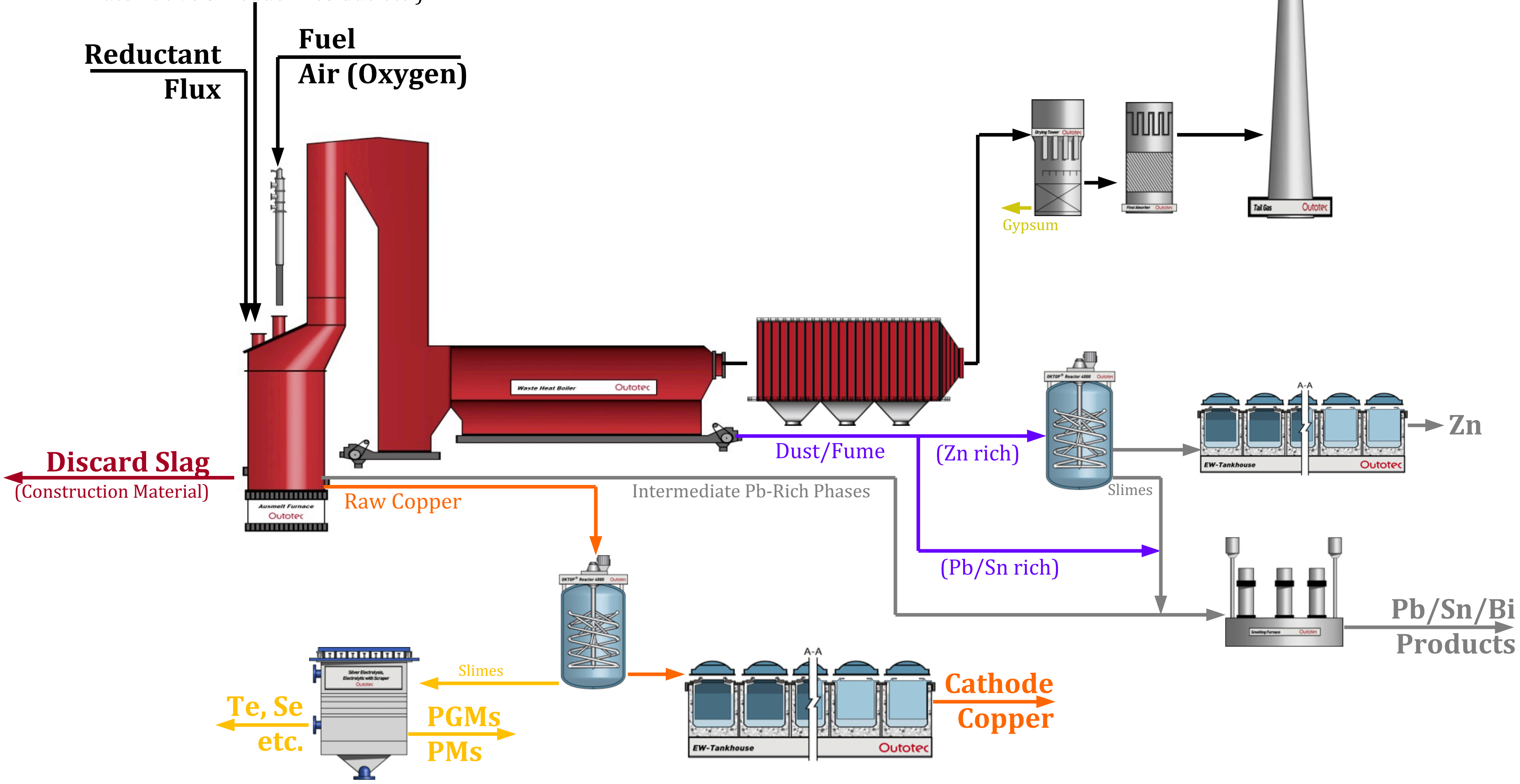
A FeO+ B ZnO+ C SiO_2+DCaO+EAl_2O_3+ ….. at 1100°C to 1300°C



DOWA Holdings, Japan

http://www.dowa.co.jp

DOWA: Copper scrap and eWaste smelting



Secondary Feeds
(low grade Cu, circuit boards,
metal containing residues (Pb/Zn),
Automative Shredder Residue etc.)

Reductant
Flux

Fuel
Air (Oxygen)

Discard Slag
(Construction Material)

Raw Copper

Intermediate Pb-Rich Phases

Dust/Fume

(Zn rich)

(Pb/Sn rich)

Gypsum

Slimes

Zn

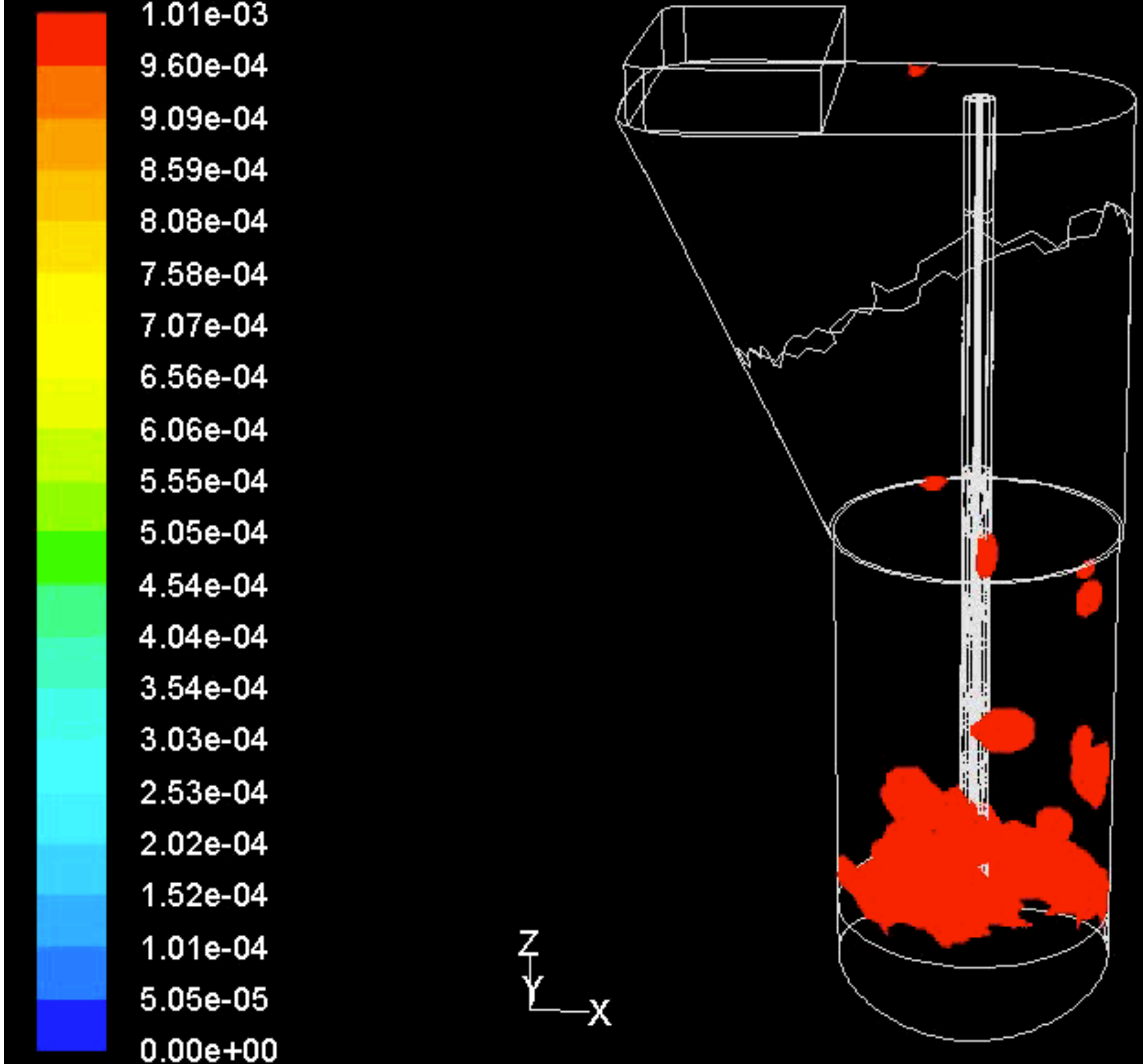
Pb/Sn/Bi Products

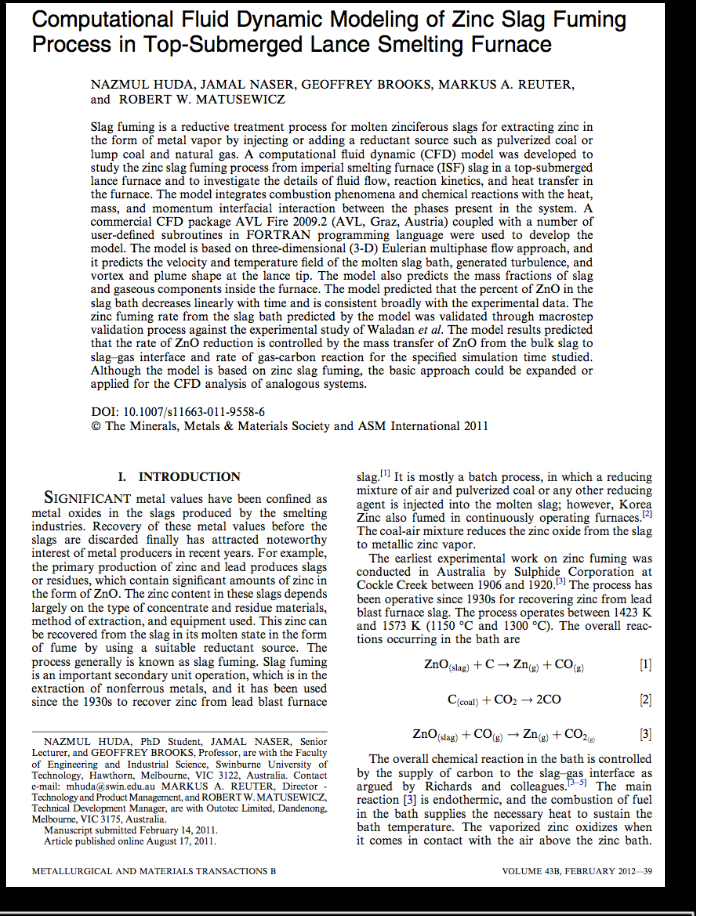
Slimes

Cathode Copper

Te, Se etc.

PGMs PMs





Computational Fluid Dynamic Modeling of Zinc Slag Fuming Process in Top-Submerged Lance Smelting Furnace

NAZMUL HUDA, JAMAL NASER, GEOFFREY BROOKS, MARKUS A. REUTER, and ROBERT W. MATUSEWICZ

Slag fuming is a reductive treatment process for molten zinciferous slags for extracting zinc in the form of metal vapor by injecting or adding a reductant source such as pulverized coal or lump coal and natural gas. A computational fluid dynamic (CFD) model was developed to study the zinc slag fuming process from imperial smelting furnace (ISF) slag in a top-submerged lance furnace and to investigate the details of fluid flow, reaction kinetics, and heat transfer in the furnace. The model integrates combustion phenomena and chemical reactions with the heat, mass, and momentum interfacial interaction between the phases present in the system. A commercial CFD package AVL Fire 2009.2 (AVL, Graz, Austria) coupled with a number of user-defined subroutines in FORTRAN programming language were used to develop the model. The model is based on three-dimensional (3-D) Eulerian multiphase flow approach, and it predicts the velocity and temperature field of the molten slag bath, generated turbulence, and vortex and plume shape at the lance tip. The model also predicts the mass fractions of slag and gaseous components inside the furnace. The model predicted that the percent of ZnO in the slag bath decreases linearly with time and is consistent broadly with the experimental data. The zinc fuming rate from the slag bath predicted by the model was validated through macrostep validation process against the experimental study of Waladan *et al*. The model results predicted that the rate of ZnO reduction is controlled by the mass transfer of ZnO from the bulk slag to slag–gas interface and rate of gas-carbon reaction for the specified simulation time studied. Although the model is based on zinc slag fuming, the basic approach could be expanded or applied for the CFD analysis of analogous systems.

DOI: 10.1007/s11663-011-9558-6
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I. INTRODUCTION

SIGNIFICANT metal values have been confined as metal oxides in the slags produced by the smelting industries. Recovery of these metal values before the slags are discarded finally has attracted noteworthy interest of metal producers in recent years. For example, the primary production of zinc and lead produces slags or residues, which contain significant amounts of zinc in the form of ZnO. The zinc content in these slags depends largely on the type of concentrate and residue materials, method of extraction, and equipment used. This zinc can be recovered from the slag in its molten state in the form of fume by using a suitable reductant source. The process generally is known as slag fuming. Slag fuming is an important secondary unit operation, which is in the extraction of nonferrous metals, and it has been used since the 1930s to recover zinc from lead blast furnace slag.[1] It is mostly a batch process, in which a reducing mixture of air and pulverized coal or any other reducing agent is injected into the molten slag; however, Korea Zinc also fumed in continuously operating furnaces.[2] The coal-air mixture reduces the zinc oxide from the slag to metallic zinc vapor.

The earliest experimental work on zinc fuming was conducted in Australia by Sulphide Corporation at Cockle Creek between 1906 and 1920.[3] The process has been operative since 1930s for recovering zinc from lead blast furnace slag. The process operates between 1423 K and 1573 K (1150 °C and 1300 °C). The overall reactions occurring in the bath are

$$\mathrm{ZnO_{(slag)}} + \mathrm{C} \rightarrow \mathrm{Zn_{(g)}} + \mathrm{CO_{(g)}} \qquad [1]$$

$$\mathrm{C_{(coal)}} + \mathrm{CO_2} \rightarrow 2\mathrm{CO} \qquad [2]$$

$$\mathrm{ZnO_{(slag)}} + \mathrm{CO_{(g)}} \rightarrow \mathrm{Zn_{(g)}} + \mathrm{CO_{2_{(g)}}} \qquad [3]$$

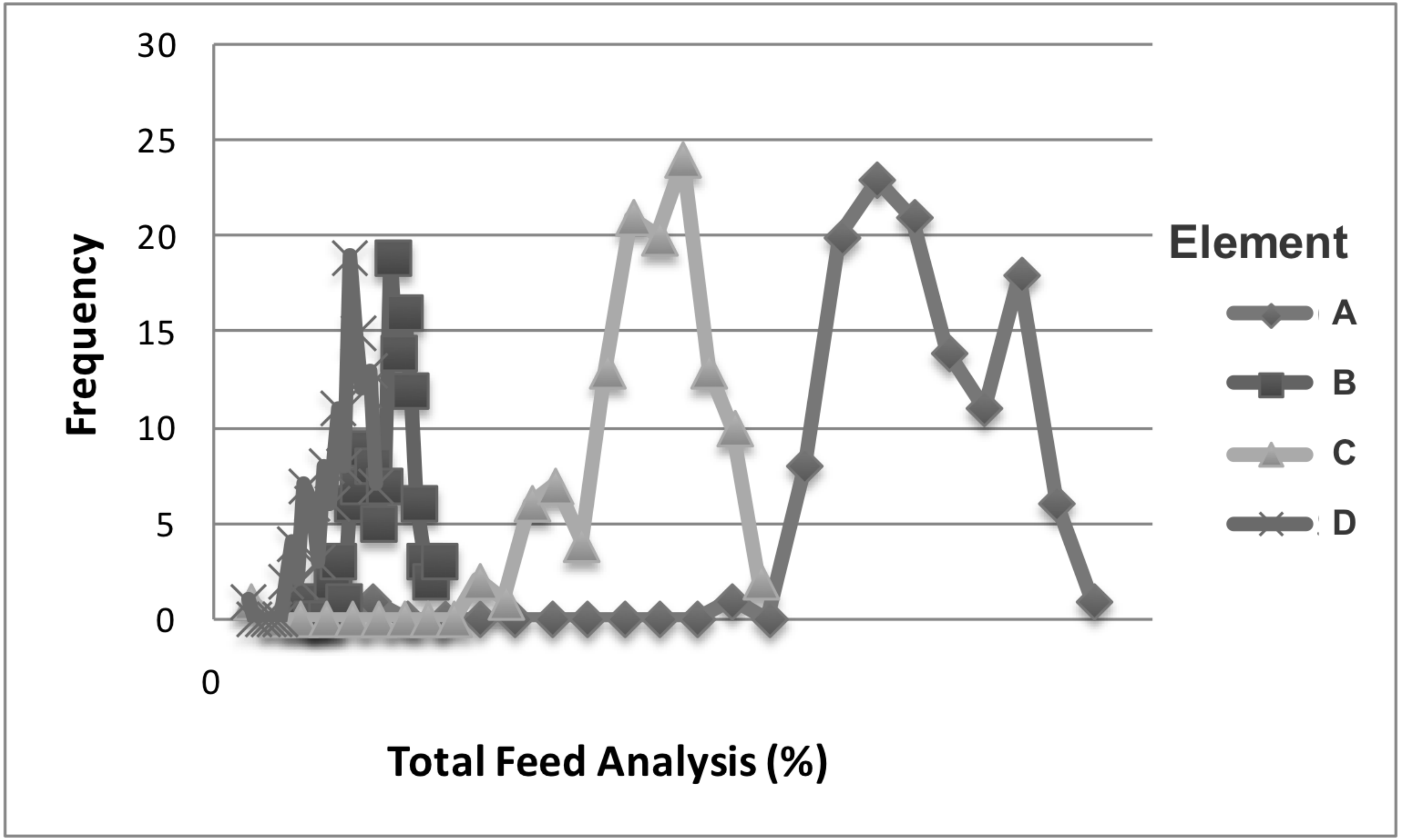
The overall chemical reaction in the bath is controlled by the supply of carbon to the slag–gas interface as argued by Richards and colleagues.[3–5] The main reaction [3] is endothermic, and the combustion of fuel in the bath supplies the necessary heat to sustain the bath temperature. The vaporized zinc oxidizes when it comes in contact with the air above the zinc bath.

NAZMUL HUDA, PhD Student, JAMAL NASER, Senior Lecturer, and GEOFFREY BROOKS, Professor, are with the Faculty of Engineering and Industrial Science, Swinburne University of Technology, Hawthorn, Melbourne, VIC 3122, Australia. Contact e-mail: mhuda@swin.edu.au MARKUS A. REUTER, Director - Technology and Product Management, and ROBERT W. MATUSEWICZ, Technical Development Manager, are with Outotec Limited, Dandenong, Melbourne, VIC 3175, Australia.

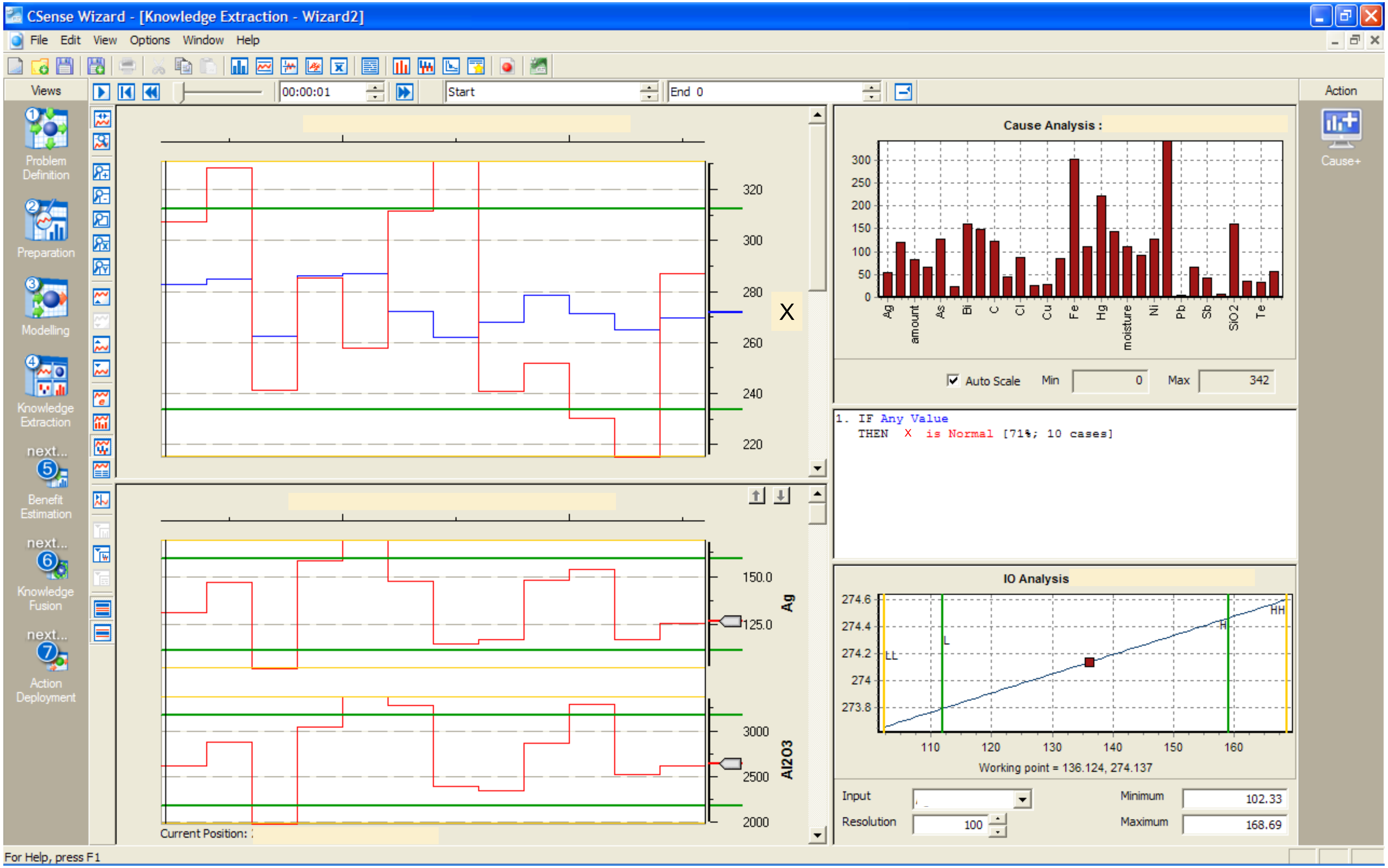
Manuscript submitted February 14, 2011.
Article published online August 17, 2011.

Various Outotec patents developed from this knowledge

Generalized data showing typical feed complexity & variation – care must be taken when simulating!



Big data analysis: Understanding operating points, distributions of data, standard deviations, etc.



CSense Wizard - [Knowledge Extraction - Wizard2]

00:00:01

Start

End 0

☑ Auto Scale

Min 0

Max 342

```
1. IF Any Value
   THEN  X  is Normal [71%; 10 cases]
```

Working point = 136.124, 274.137

Input

Resolution 100

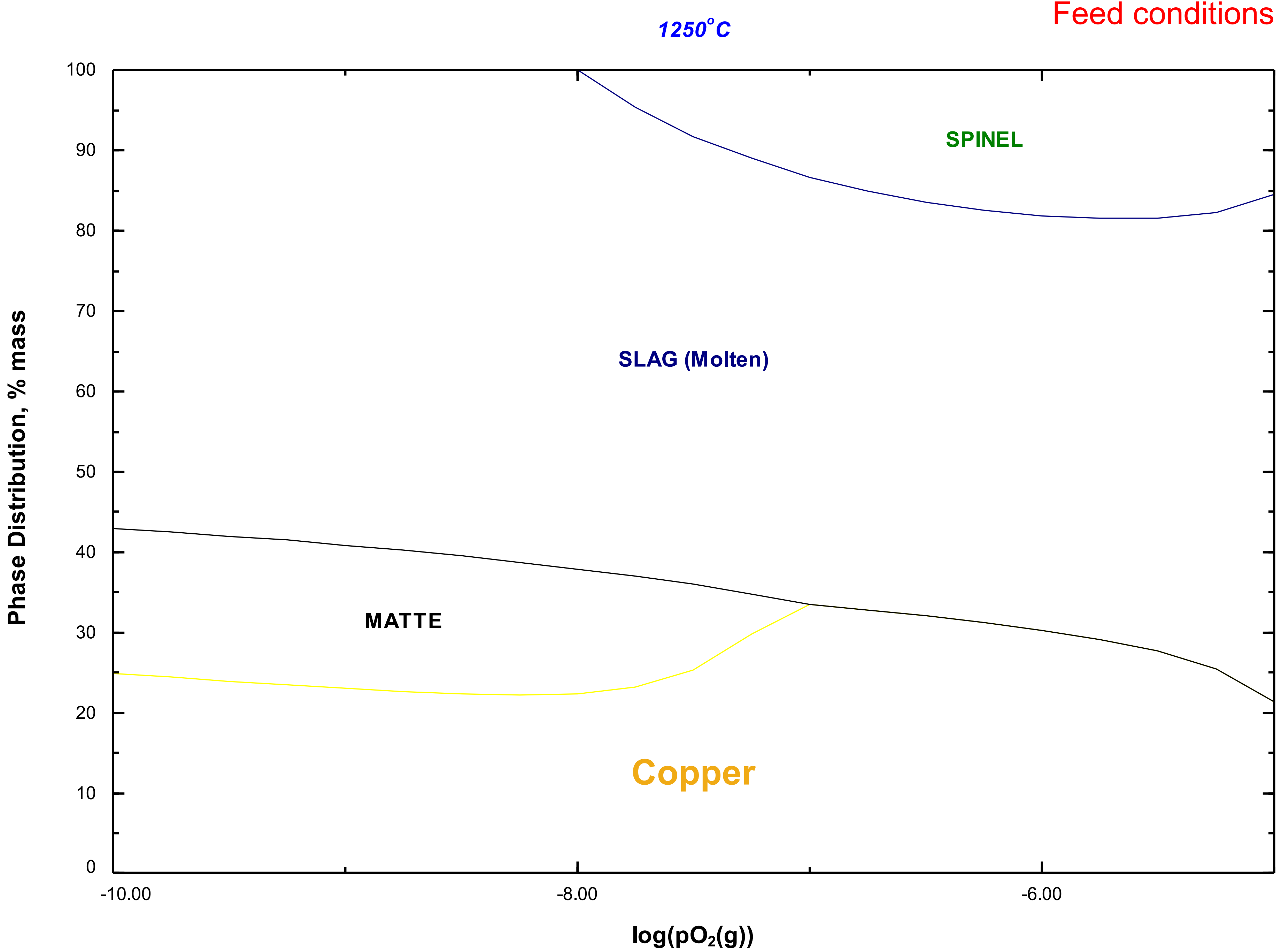
Minimum 102.33

Maximum 168.69

Current Position:

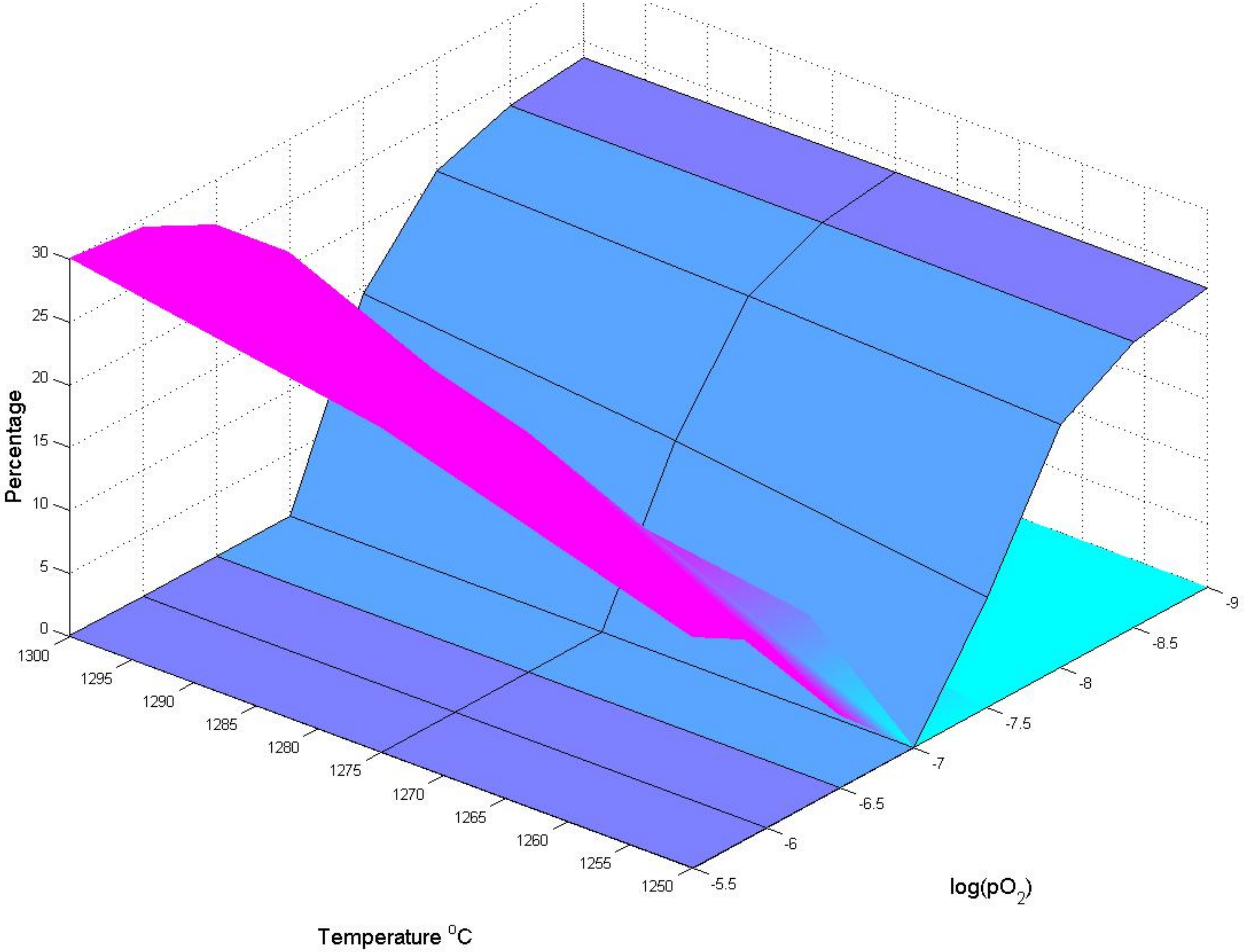
For Help, press F1

A t **Cu +** B t **Pb +** C t **Zn +** D t **Fe + ...** TSL Operating & Feed conditions



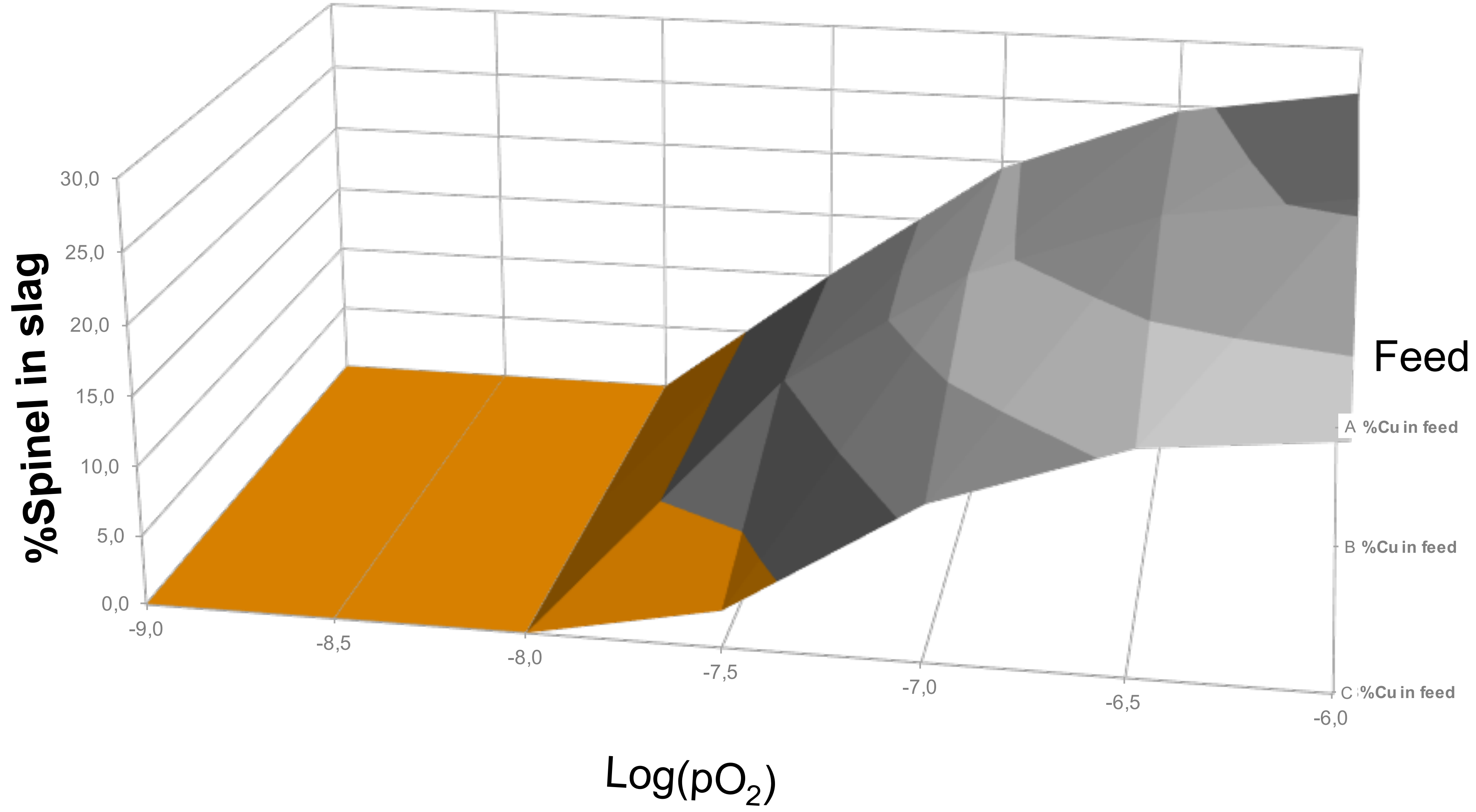
Spinel (left) and Matte (right) mass %

Calculation in FACT Sage for a specific feed recipe, slag chemistry, flow conditions etc.



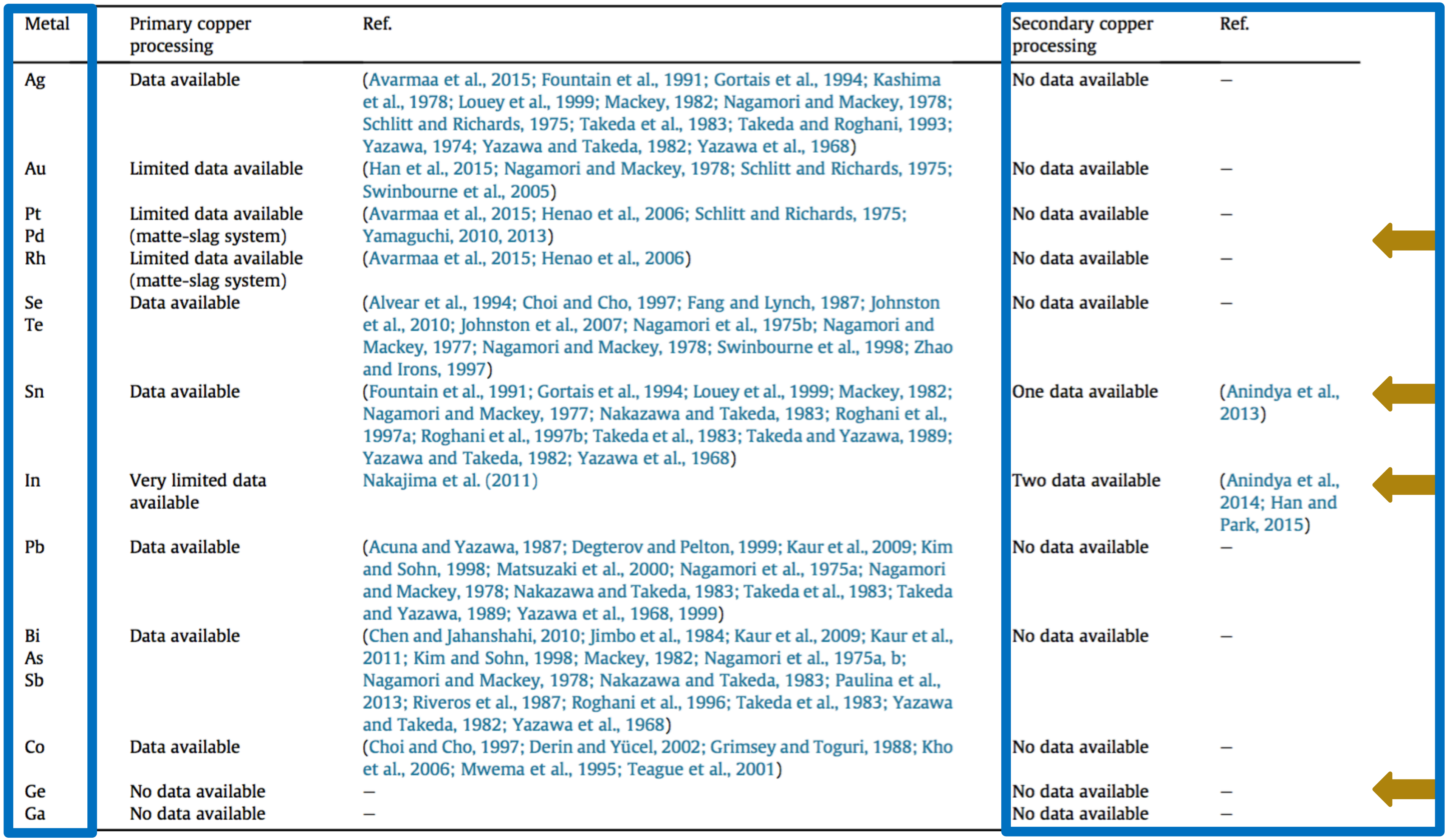
Spinel as a function of feed

Calculation in FACT Sage for a specific temperature, slag chemistry, flow conditions etc.



Developing thermodynamic data

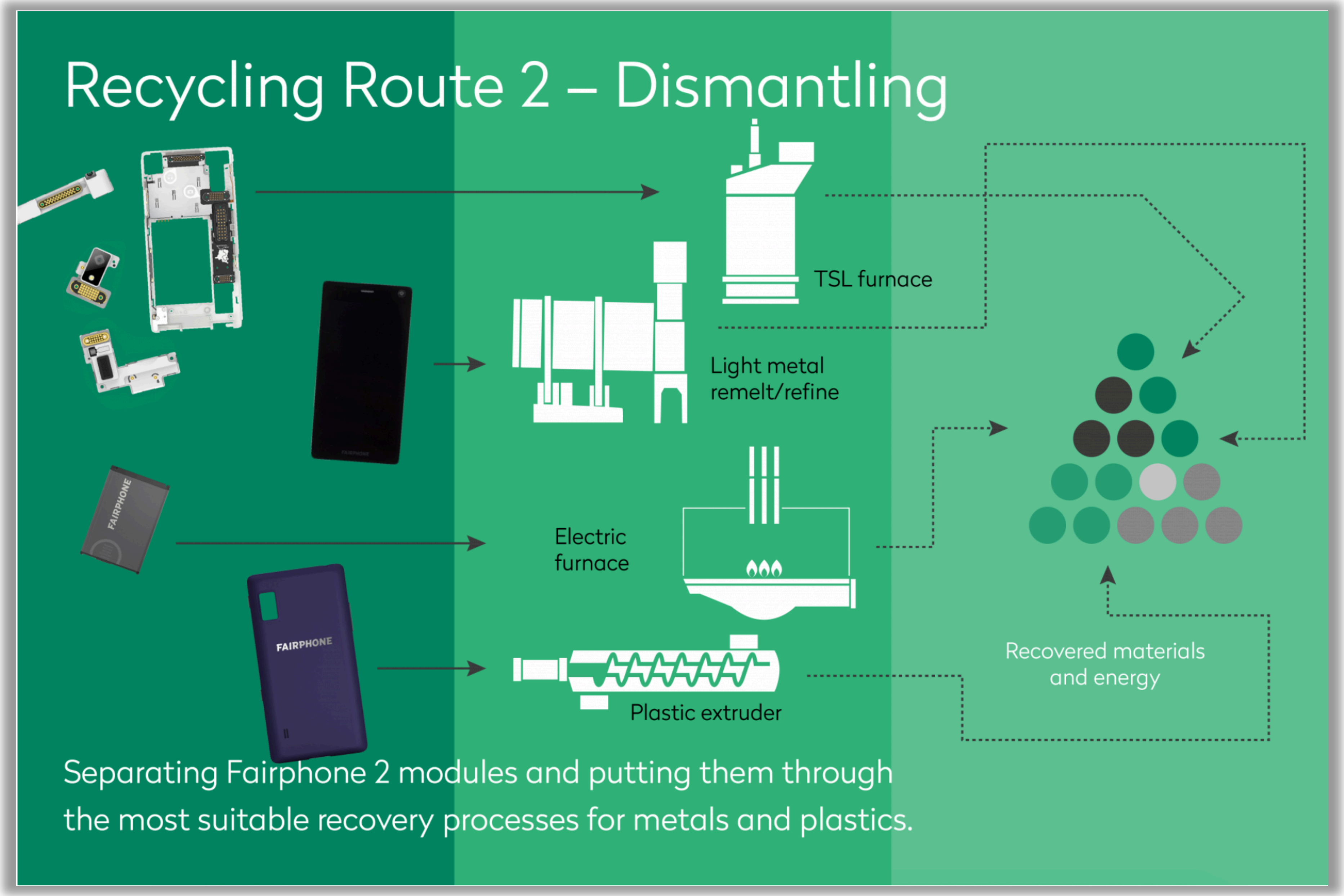
Completed to date In, Sn, Ge, Pd, Ta (brief summary below)



Metal	Primary copper processing	Ref.	Secondary copper processing	Ref.
Ag	Data available	(Avarmaa et al., 2015; Fountain et al., 1991; Gortais et al., 1994; Kashima et al., 1978; Louey et al., 1999; Mackey, 1982; Nagamori and Mackey, 1978; Schlitt and Richards, 1975; Takeda et al., 1983; Takeda and Roghani, 1993; Yazawa, 1974; Yazawa and Takeda, 1982; Yazawa et al., 1968)	No data available	–
Au	Limited data available	(Han et al., 2015; Nagamori and Mackey, 1978; Schlitt and Richards, 1975; Swinbourne et al., 2005)	No data available	–
Pt Pd	Limited data available (matte-slag system)	(Avarmaa et al., 2015; Henao et al., 2006; Schlitt and Richards, 1975; Yamaguchi, 2010, 2013)	No data available	–
Rh	Limited data available (matte-slag system)	(Avarmaa et al., 2015; Henao et al., 2006)	No data available	–
Se Te	Data available	(Alvear et al., 1994; Choi and Cho, 1997; Fang and Lynch, 1987; Johnston et al., 2010; Johnston et al., 2007; Nagamori et al., 1975b; Nagamori and Mackey, 1977; Nagamori and Mackey, 1978; Swinbourne et al., 1998; Zhao and Irons, 1997)	No data available	–
Sn	Data available	(Fountain et al., 1991; Gortais et al., 1994; Louey et al., 1999; Mackey, 1982; Nagamori and Mackey, 1977; Nakazawa and Takeda, 1983; Roghani et al., 1997a; Roghani et al., 1997b; Takeda et al., 1983; Takeda and Yazawa, 1989; Yazawa and Takeda, 1982; Yazawa et al., 1968)	One data available	(Anindya et al., 2013)
In	Very limited data available	Nakajima et al. (2011)	Two data available	(Anindya et al., 2014; Han and Park, 2015)
Pb	Data available	(Acuna and Yazawa, 1987; Degterov and Pelton, 1999; Kaur et al., 2009; Kim and Sohn, 1998; Matsuzaki et al., 2000; Nagamori et al., 1975a; Nagamori and Mackey, 1978; Nakazawa and Takeda, 1983; Takeda et al., 1983; Takeda and Yazawa, 1989; Yazawa et al., 1968, 1999)	No data available	–
Bi As Sb	Data available	(Chen and Jahanshahi, 2010; Jimbo et al., 1984; Kaur et al., 2009; Kaur et al., 2011; Kim and Sohn, 1998; Mackey, 1982; Nagamori et al., 1975a, b; Nagamori and Mackey, 1978; Nakazawa and Takeda, 1983; Paulina et al., 2013; Riveros et al., 1987; Roghani et al., 1996; Takeda et al., 1983; Yazawa and Takeda, 1982; Yazawa et al., 1968)	No data available	–
Co	Data available	(Choi and Cho, 1997; Derin and Yücel, 2002; Grimsey and Toguri, 1988; Kho et al., 2006; Mwema et al., 1995; Teague et al., 2001)	No data available	–
Ge	No data available	–	No data available	–
Ga	No data available	–	No data available	–

M.A.H. Shuva, M.A. Rhamdhani, G. Brooks, S. Masood, M.A. Reuter (2016) Thermodynamics data of valuable elements relevant to e-waste processing through primary and secondary copper production - a review, J. Cleaner Production, 131, 795-809..

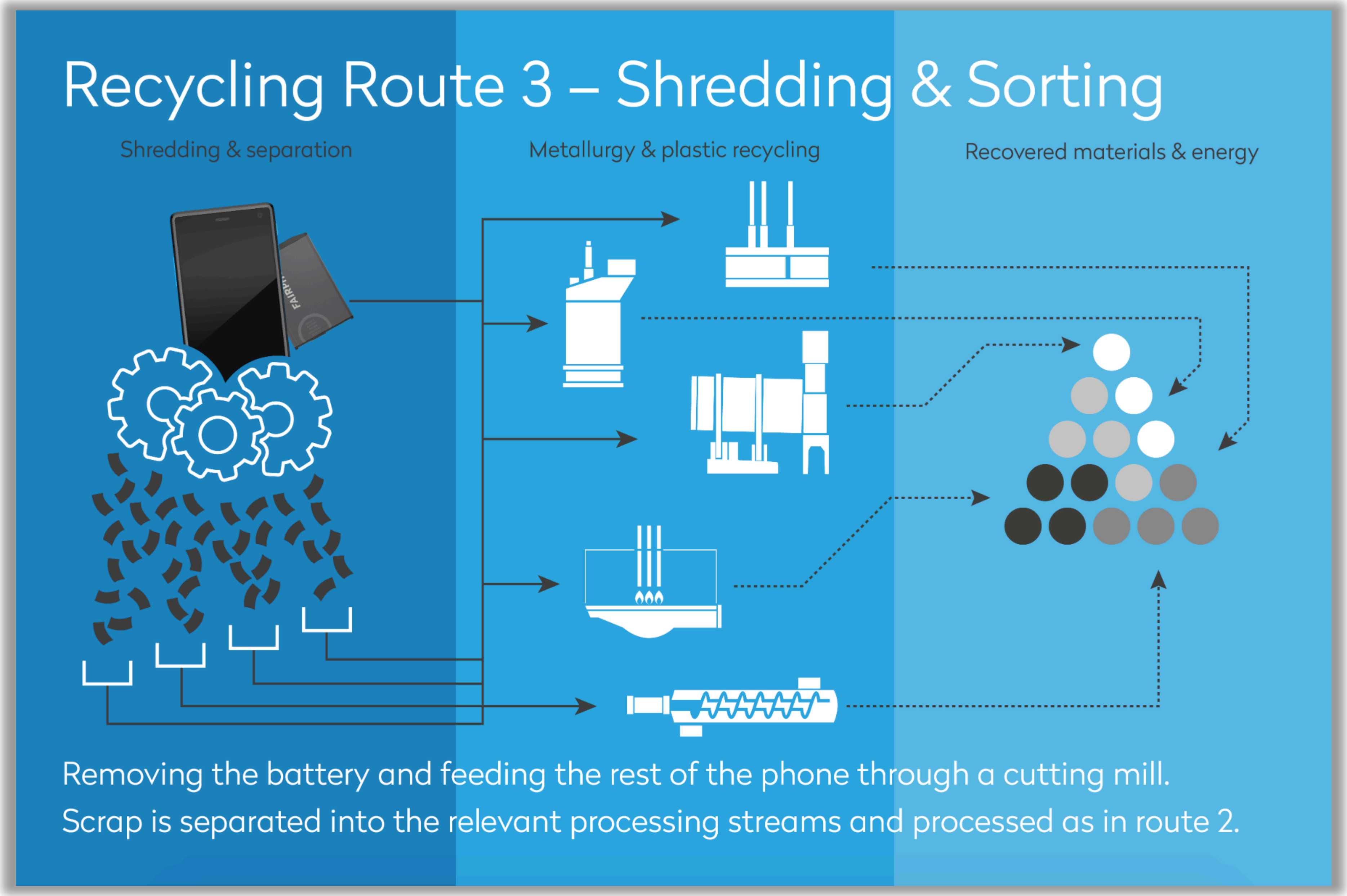
Fairphone Recyclability: Recycling Flow Sheet



Recycling Route 2 – Dismantling

Separating Fairphone 2 modules and putting them through the most suitable recovery processes for metals and plastics.

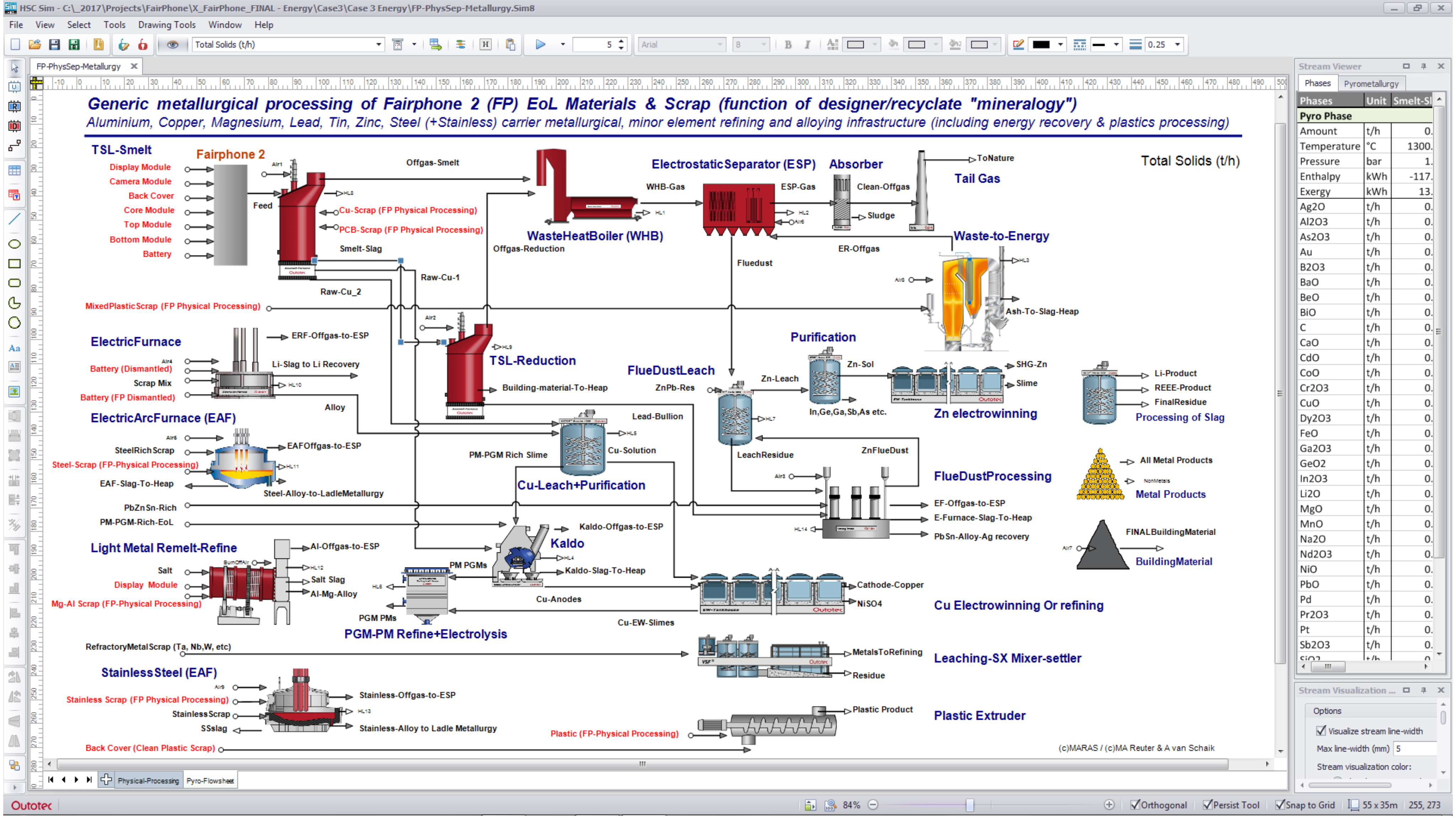
Fairphone Recyclability: Recycling Flow Sheet



Recycling Route 3 – Shredding & Sorting

Removing the battery and feeding the rest of the phone through a cutting mill.
Scrap is separated into the relevant processing streams and processed as in route 2.

Metallurgical flowsheet to capture as many metals & materials: FACT provides some detail



HSC Sim - C:_2017\Projects\FairPhone\X_FairPhone_FINAL - Energy\Case3\Case 3 Energy\FP-PhysSep-Metallurgy.Sim8

Generic metallurgical processing of Fairphone 2 (FP) EoL Materials & Scrap (function of designer/recyclate "mineralogy")

Aluminium, Copper, Magnesium, Lead, Tin, Zinc, Steel (+Stainless) carrier metallurgical, minor element refining and alloying infrastructure (including energy recovery & plastics processing)

(c)MARAS / (c)MA Reuter & A van Schaik

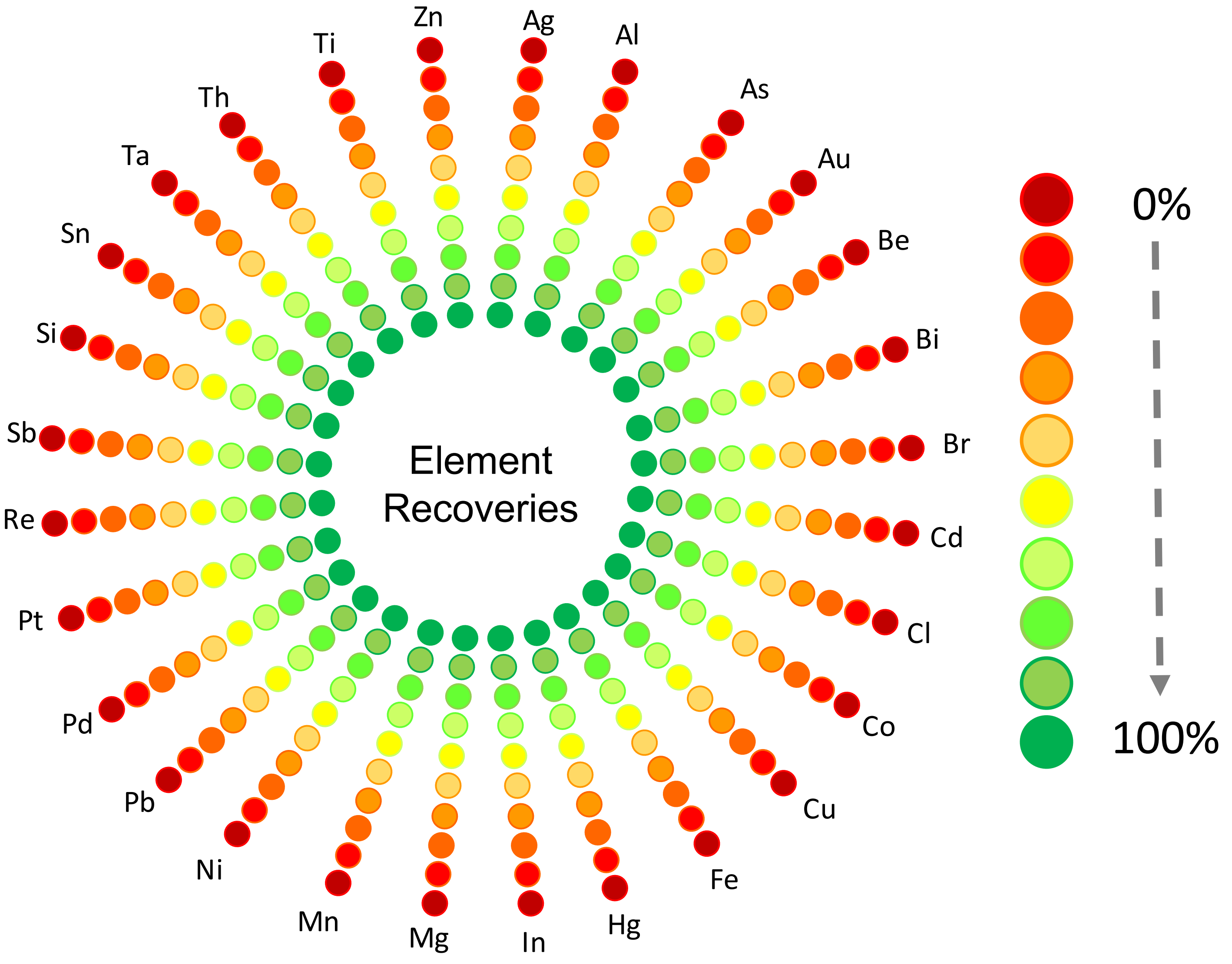
Phases	Unit	Smelt-Sl
Pyro Phase		
Amount	t/h	0.
Temperature	°C	1300.
Pressure	bar	1.
Enthalpy	kWh	-117.
Exergy	kWh	13.
Ag2O	t/h	0.
Al2O3	t/h	0.
As2O3	t/h	0.
Au	t/h	0.
B2O3	t/h	0.
BaO	t/h	0.
BeO	t/h	0.
BiO	t/h	0.
C	t/h	0.
CaO	t/h	0.
CdO	t/h	0.
CoO	t/h	0.
Cr2O3	t/h	0.
CuO	t/h	0.
Dy2O3	t/h	0.
FeO	t/h	0.
Ga2O3	t/h	0.
GeO2	t/h	0.
In2O3	t/h	0.
Li2O	t/h	0.
MgO	t/h	0.
MnO	t/h	0.
Na2O	t/h	0.
Nd2O3	t/h	0.
NiO	t/h	0.
PbO	t/h	0.
Pd	t/h	0.
Pr2O3	t/h	0.
Pt	t/h	0.
Sb2O3	t/h	0.

☑ Visualize stream line-width

Max line-width (mm) 5

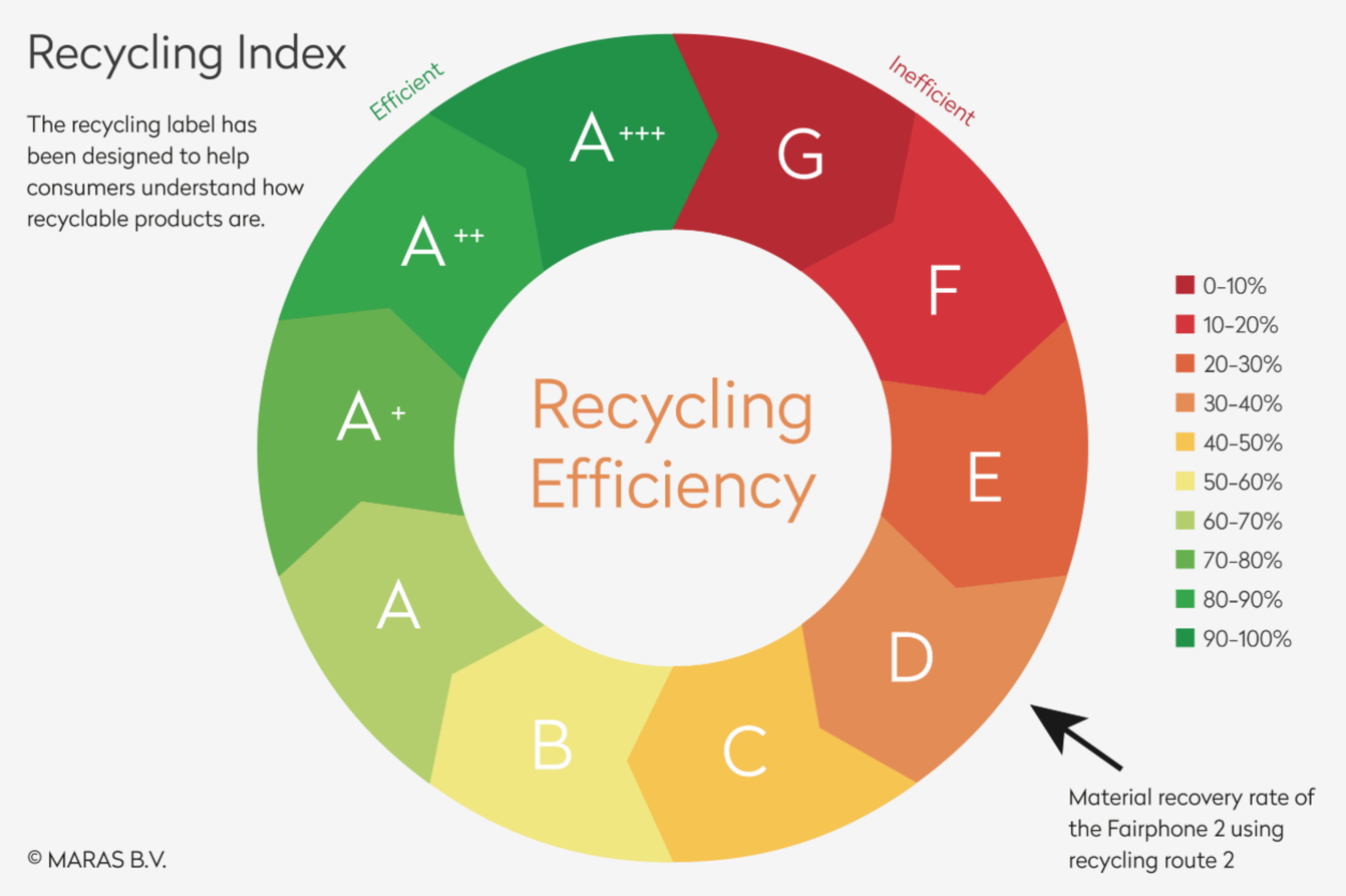
Stream visualization color:

Recovery of all materials (expressed as element) from a product



A. van Schaik, M.A. Reuter (2016): RECYCLING INDICES VISUALIZING THE PERFORMANCE OF THE CIRCULAR ECONOMY, World of Metallurgy – ERZMETALL, 69(4), 201-216.

Fairphone Recyclability: The Result



The recycling label has been designed to help consumers understand how recyclable products are.

Material recovery rate of the Fairphone 2 using recycling route 2

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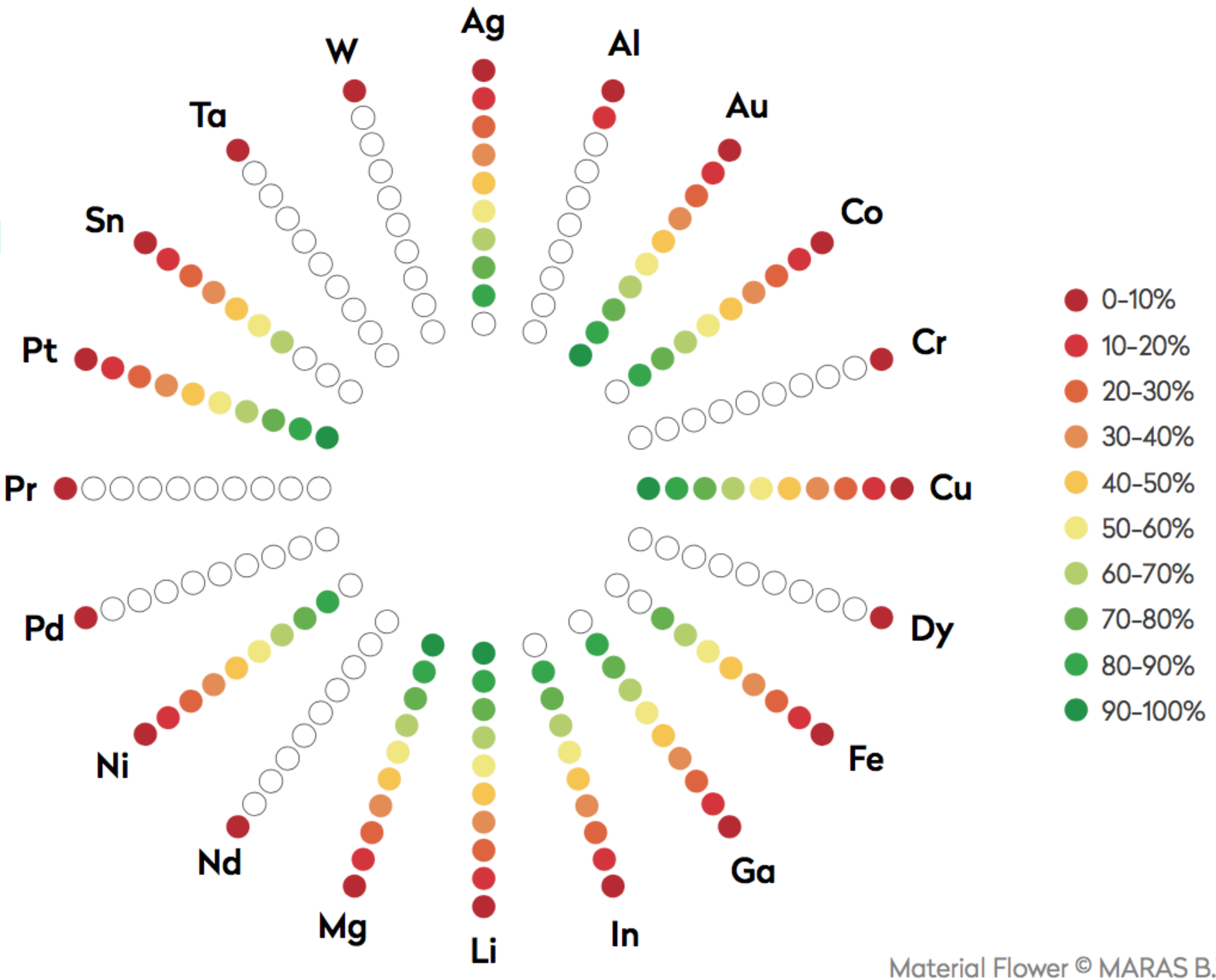
A. van Schaik, M.A. Reuter (2016): RECYCLING INDICES VISUALIZING THE PERFORMANCE OF THE CIRCULAR ECONOMY, World of Metallurgy – ERZMETALL, 69(4), 201-216.

Recycling Route 3:

Recovery rate by metal

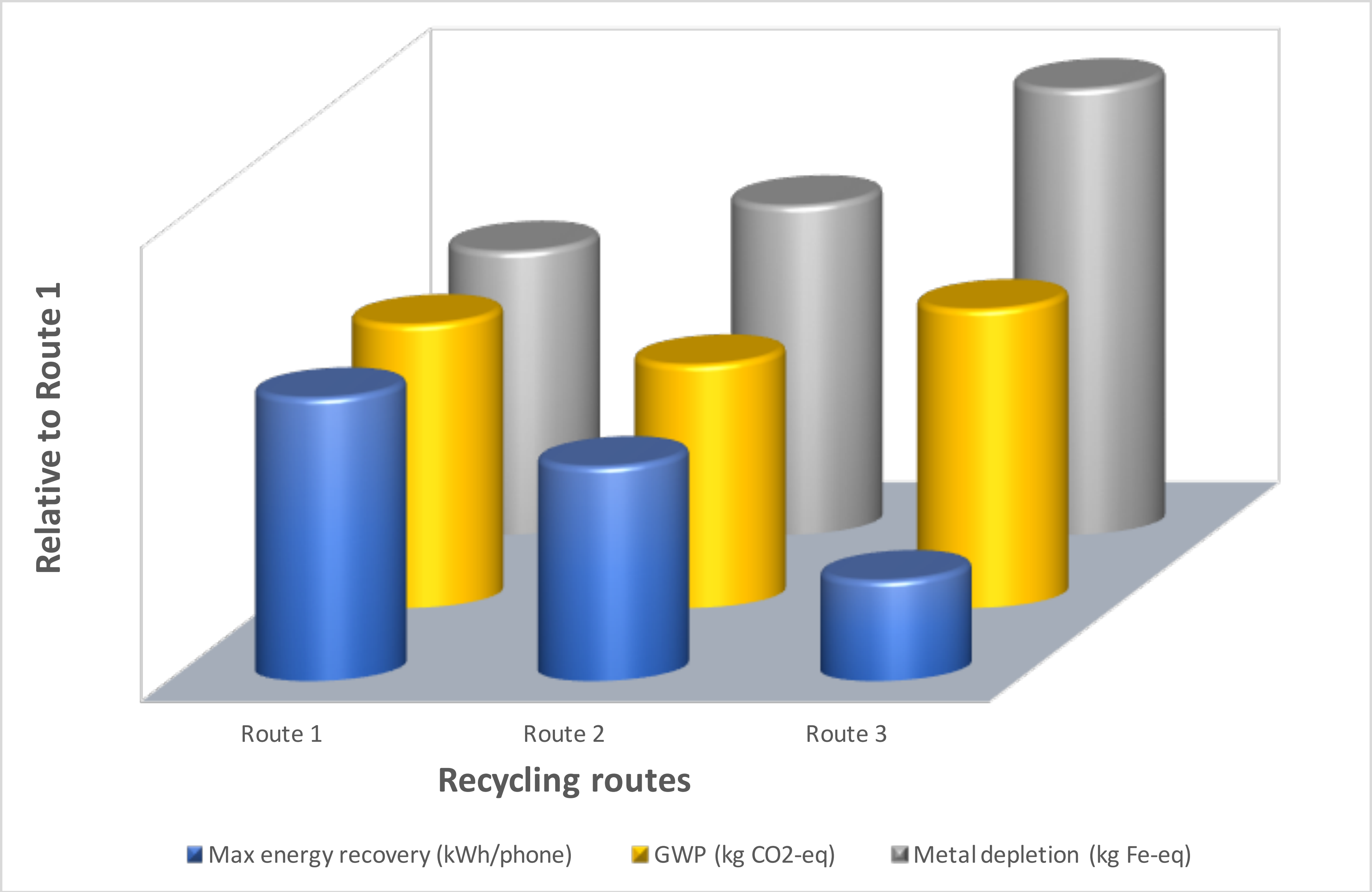


Material Flower © MARAS B.V.

Materials Flower for Recycling developed by Van Schaik and Reuter.

A. van Schaik, M.A. Reuter (2016): RECYCLING INDICES VISUALIZING THE PERFORMANCE OF THE CIRCULAR ECONOMY, World of Metallurgy – ERZMETALL, 69(4), 201-216.

Footprint (GWP, Metal depletion, Energy recovery)

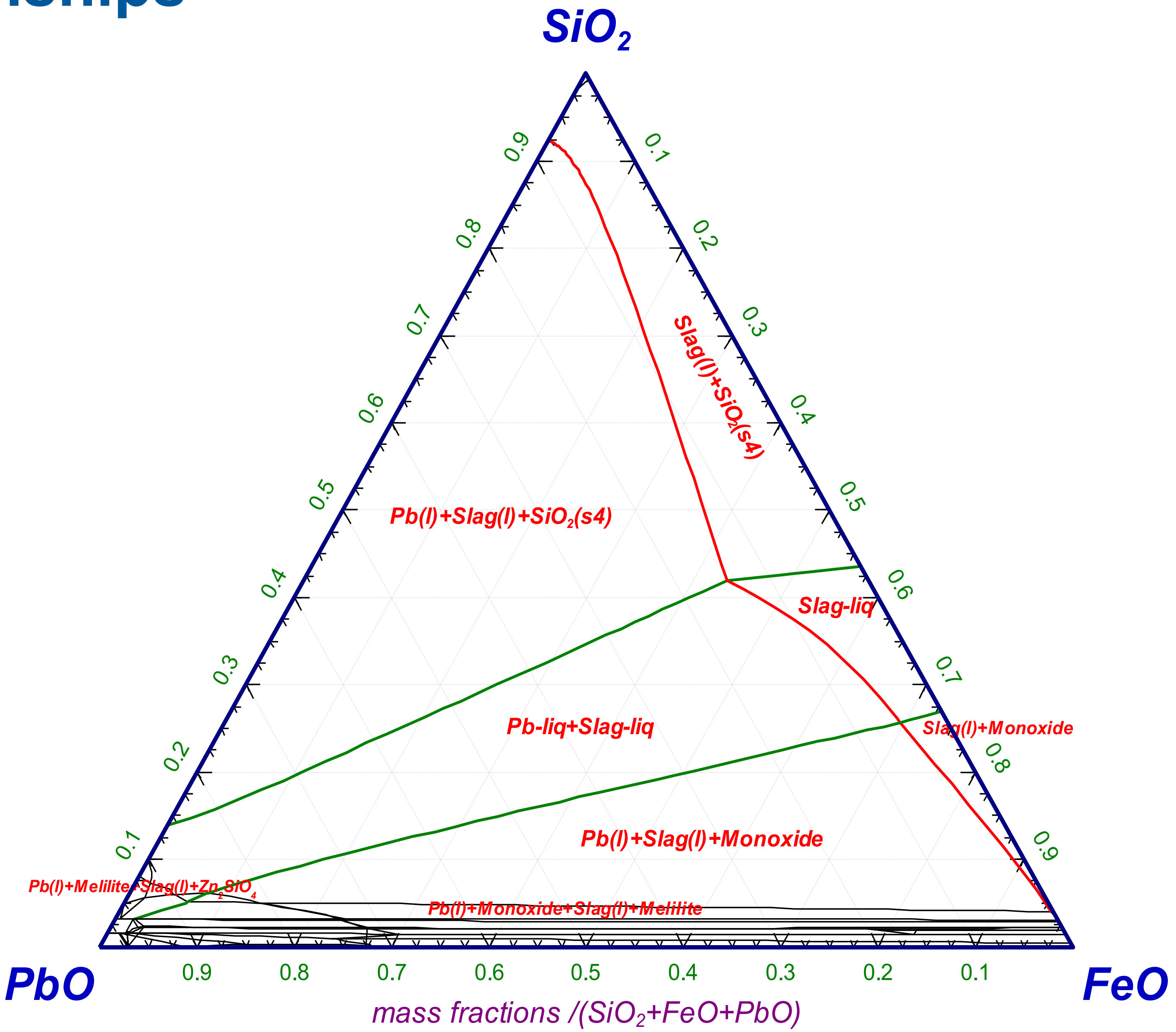


Additional sheets

Phase Relationships

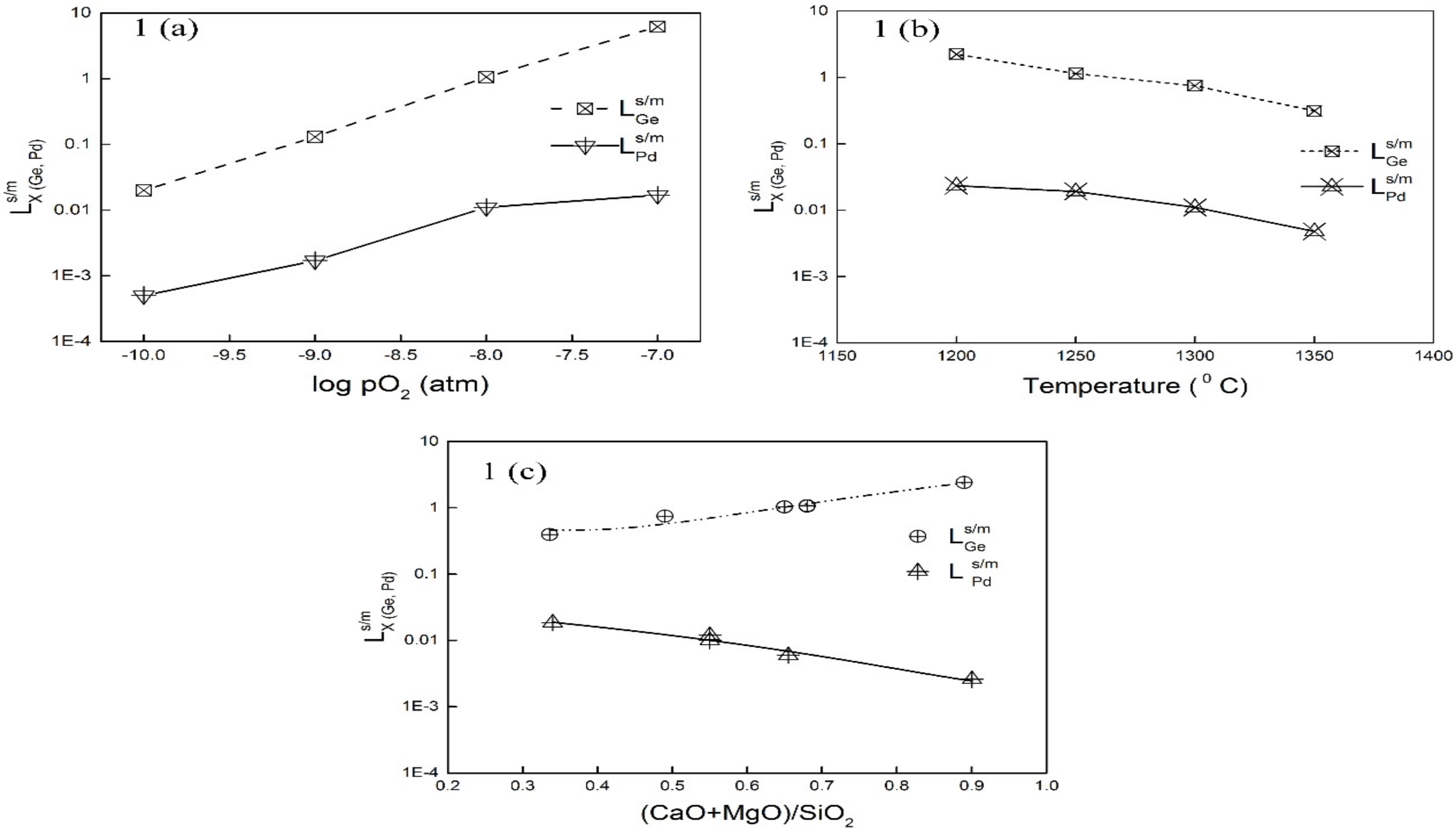
SiO_2 - FeO - PbO - ZnO - CaO - O_2

CCCC °C, $p(O_2) = 10^{-a}$ atm, mass ZnO/Z = X ,
mass CaO/Z = Y , Z=(SiO_2+FeO+PbO)



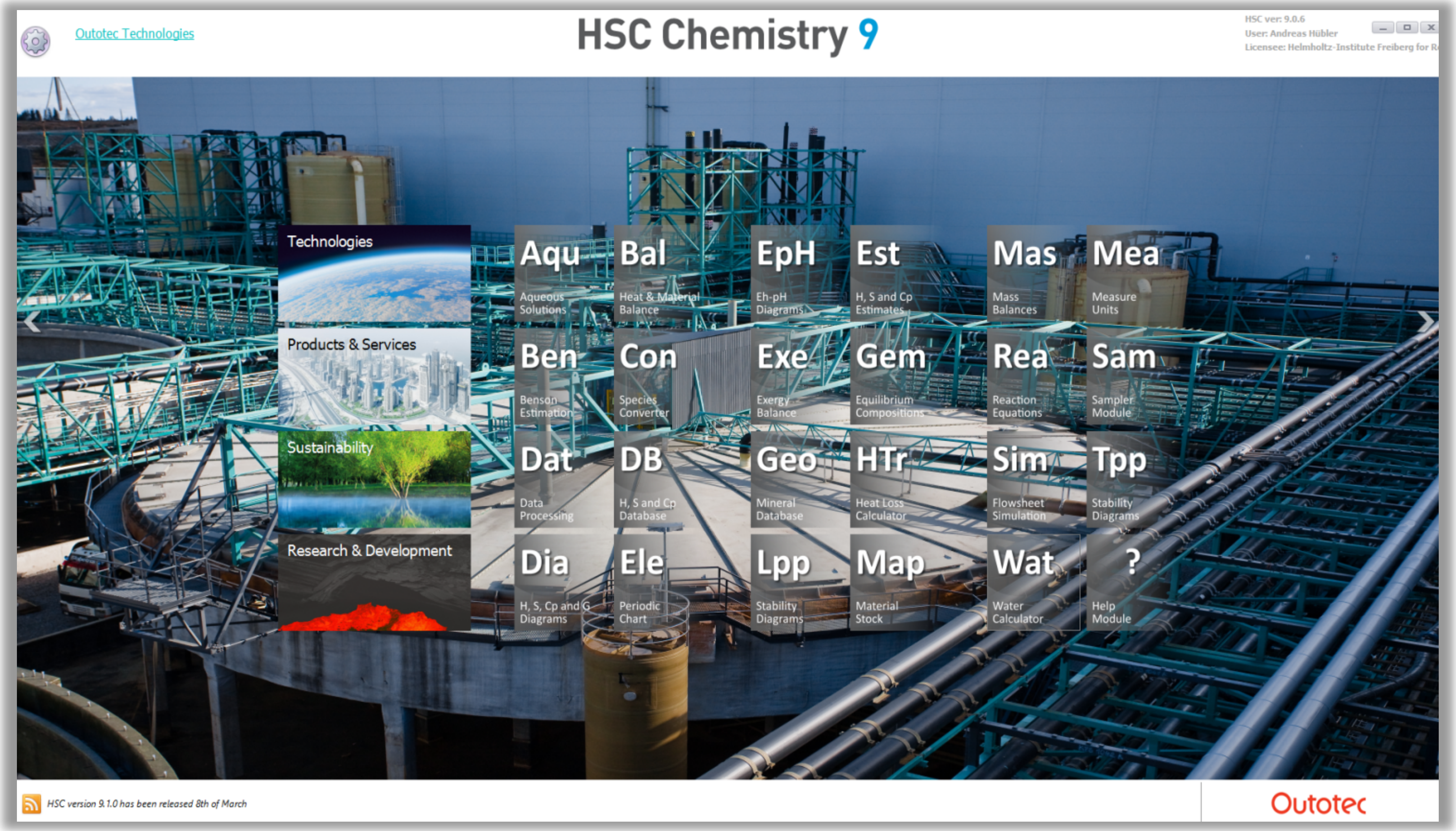
Developing thermodynamic data

Completed to date In, Sn, Ge, Pd, Ta (brief summary below)



M.A.H. Shuva, M.A. Rhamdhani, G. Brooks, S. Masood, M.A. Reuter (2016) Thermodynamics data of valuable elements relevant to e-waste processing through primary and secondary copper production - a review, J. Cleaner Production, 131, 795-809..

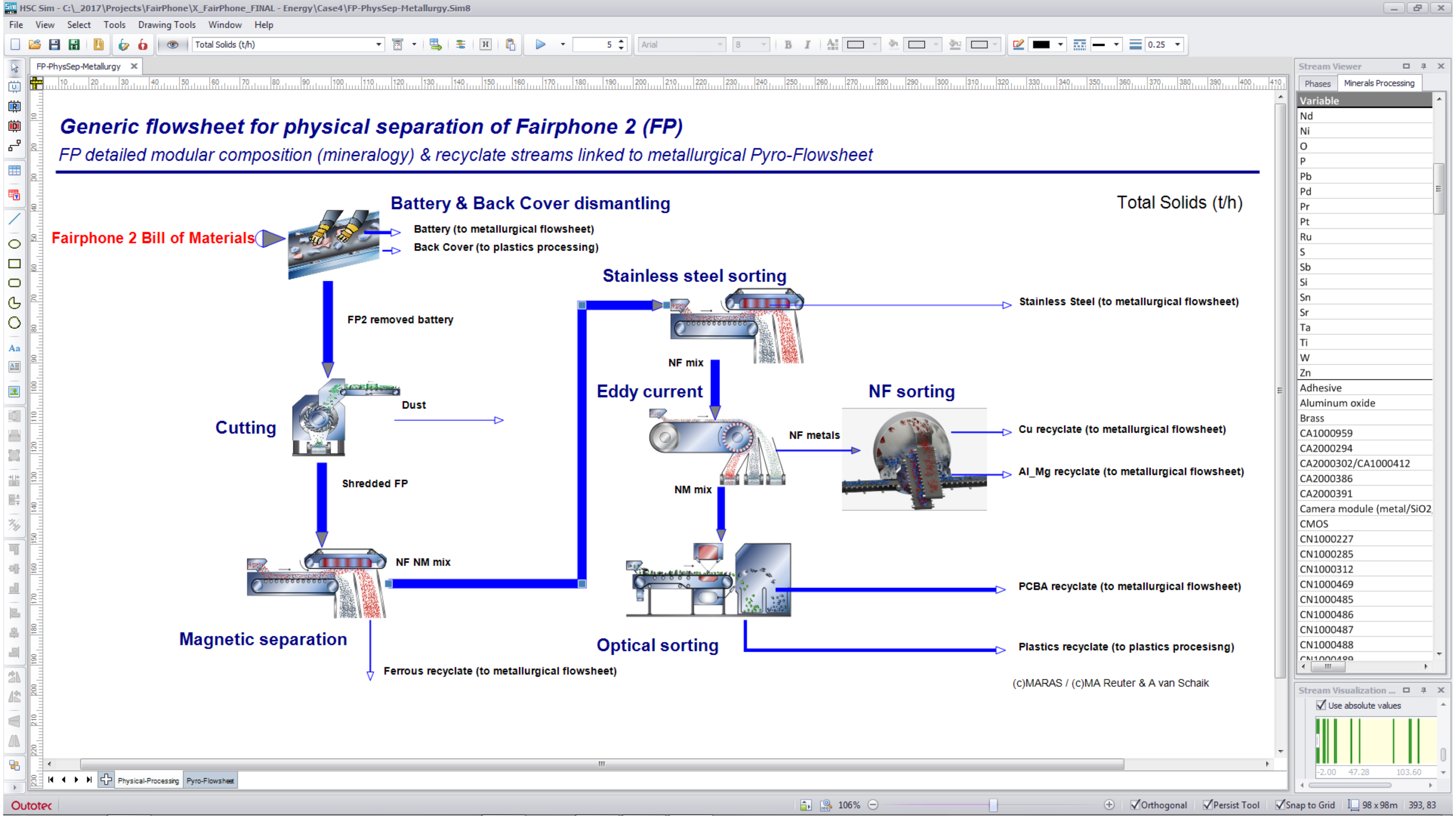
Industrial process design, simulation & control



HSC ver: 9.0.6
User: Andreas Hübler
Licensee: Helmholtz-Institute Freiberg for R

HSC version 9.1.0 has been released 8th of March

Simulation permits digitalization of the Circular Economy system



HSC Sim - C:_2017\Projects\FairPhone\X_FairPhone_FINAL - Energy\Case4\FP-PhysSep-Metallurgy.Sim8

Generic flowsheet for physical separation of Fairphone 2 (FP)

FP detailed modular composition (mineralogy) & recyclate streams linked to metallurgical Pyro-Flowsheet

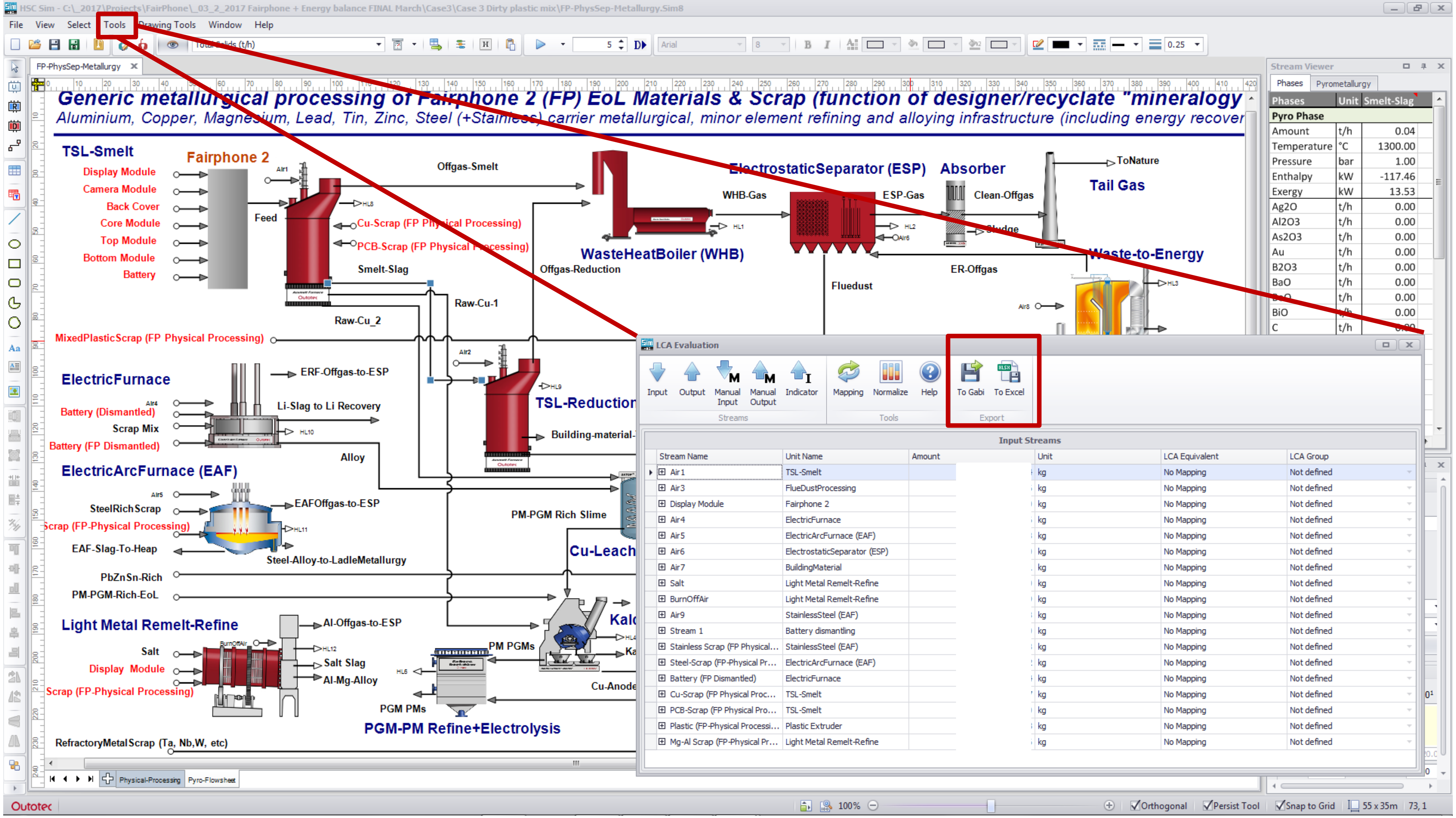
Total Solids (t/h)

(c)MARAS / (c)MA Reuter & A van Schaik

Variable
Nd
Ni
O
P
Pb
Pd
Pr
Pt
Ru
S
Sb
Si
Sn
Sr
Ta
Ti
W
Zn
Adhesive
Aluminum oxide
Brass
CA1000959
CA2000294
CA2000302/CA1000412
CA2000386
CA2000391
Camera module (metal/SiO2
CMOS
CN1000227
CN1000285
CN1000312
CN1000469
CN1000485
CN1000486
CN1000487
CN1000488

☑ Use absolute values

Environmental, Energy & Exergy Footprint: Linking HSC Sim 9 with GaBi



Input Streams

Stream Name	Unit Name	Amount	Unit	LCA Equivalent	LCA Group
Air1	TSL-Smelt		kg	No Mapping	Not defined
Air3	FlueDustProcessing		kg	No Mapping	Not defined
Display Module	Fairphone 2		kg	No Mapping	Not defined
Air4	ElectricFurnace		kg	No Mapping	Not defined
Air5	ElectricArcFurnace (EAF)		kg	No Mapping	Not defined
Air6	ElectrostaticSeparator (ESP)		kg	No Mapping	Not defined
Air7	BuildingMaterial		kg	No Mapping	Not defined
Salt	Light Metal Remelt-Refine		kg	No Mapping	Not defined
BurnOffAir	Light Metal Remelt-Refine		kg	No Mapping	Not defined
Air9	StainlessSteel (EAF)		kg	No Mapping	Not defined
Stream 1	Battery dismantling		kg	No Mapping	Not defined
Stainless Scrap (FP Physical…	StainlessSteel (EAF)		kg	No Mapping	Not defined
Steel-Scrap (FP-Physical Pr…	ElectricArcFurnace (EAF)		kg	No Mapping	Not defined
Battery (FP Dismantled)	ElectricFurnace		kg	No Mapping	Not defined
Cu-Scrap (FP Physical Proc…	TSL-Smelt		kg	No Mapping	Not defined
PCB-Scrap (FP Physical Pro…	TSL-Smelt		kg	No Mapping	Not defined
Plastic (FP-Physical Processi…	Plastic Extruder		kg	No Mapping	Not defined
Mg-Al Scrap (FP-Physical Pr…	Light Metal Remelt-Refine		kg	No Mapping	Not defined

Phases	Unit	Smelt-Slag
Pyro Phase		
Amount	t/h	0.04
Temperature	°C	1300.00
Pressure	bar	1.00
Enthalpy	kW	-117.46
Exergy	kW	13.53
Ag2O	t/h	0.00
Al2O3	t/h	0.00
As2O3	t/h	0.00
Au	t/h	0.00
B2O3	t/h	0.00
BaO	t/h	0.00
BeO	t/h	0.00
BiO	t/h	0.00
C	t/h	0.00

M.A. Reuter, A. van Schaik, J. Gediga (2015): Simulation-based design for resource efficiency of metal production and recycling systems, Cases: Copper production and recycling, eWaste (LED Lamps), Nickel pig iron, International Journal of Life Cycle Assessment, 20(5), 671-693.

arvi
Material Value Chains

WEEE Recycling Simulation Model

Created on Outotec's HSC Chemistry Software Platform

Susanna Nevalainen (Aalto U), Antti Roine (Outotec), Markus Reuter (Helmholtz-Institute)

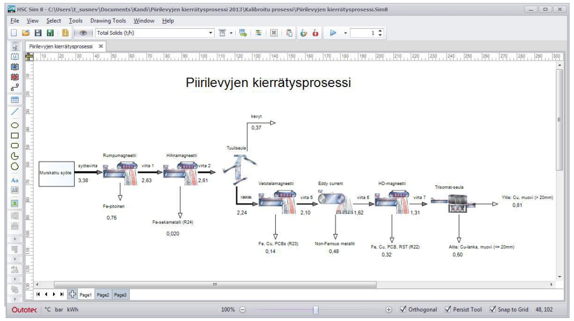
WEEE (Waste Electrical and Electronic Equipment) recycling simulation model demonstrates the possibilities of HSC Chemistry software to simulate and optimize material streams in real recycling processes, which may be used to LCA analysis.

RECYCLING SIMULATION IN HSC SIM MODULE

1) DEFINE THE FEED
Select or create materials and particles that flow through the recycling process. basic properties of material are defined when material is created.

2) SELECT RECYCLING MODELS
Select which crushers, screens and separators are used in the process.

3) DEFINE RECYCLING MODEL SETTINGS
Define used probability distribution, accuracy of



WEEE RECYCLING SIMULATION MODEL

The case study of WEEE recycling simulation model is based on the real recycling process o
Kuusakoski in 2013
model was calibrate
behavior. The process consisted of magnetic separators, eddy current separator, gravity separator and screen.

Kuusakoski, Finland

Even without calibration, it was noticed that most of the particles acted in a typical way. For example, aluminum particles mainly left the process in the eddy current separator. With a simple calibration, mass balance was also managed to match with the given data.

The WEEE recycling simulation model indicates that recycling units can be used as a good base for WEEE simulation and also for other recycling processes locally and globally. With HSC Sim, processes can be optimized efficiently without safety risks or loss of valuable materials.

Outotec www.outotec.com/HSC

RECYCLING UNIT MODELS AVAILABLE IN HSC SIM

- Feed Creator
- Crusher
- General Screen
- Gravity Separator
- Air Classifier
- Magnetic Separator
- Eddy Current Separator
- Optical Separator
- Hand Sorting
- Custom Separator
- General Separator

CLIC
Solution Architect for Global
Bioeconomy & Cleantech Opportunities

Teaching this stuff...

Summer school: Digitizing the Circular Economy

=> Applications for the 2017 summer school are closed. Keep an eye on our website for future op

PERIOD: 17-20/07/2017
LOCATION: MTC 00.12, Leuven, Belgium
COURSE LEADER: Prof. **Markus Reuter** (TUBAF)

Content

Metallurgy is a key enabler of a circular economy (CE), its digitization is the metallurgical Internet of Th
strong intrinsic recycling potentials. Process metallurgy, as a key enabler for a CE, will help much to deliv
the resource efficiency (RE) of the CE system, connecting all stakeholders via digitization. This provides w
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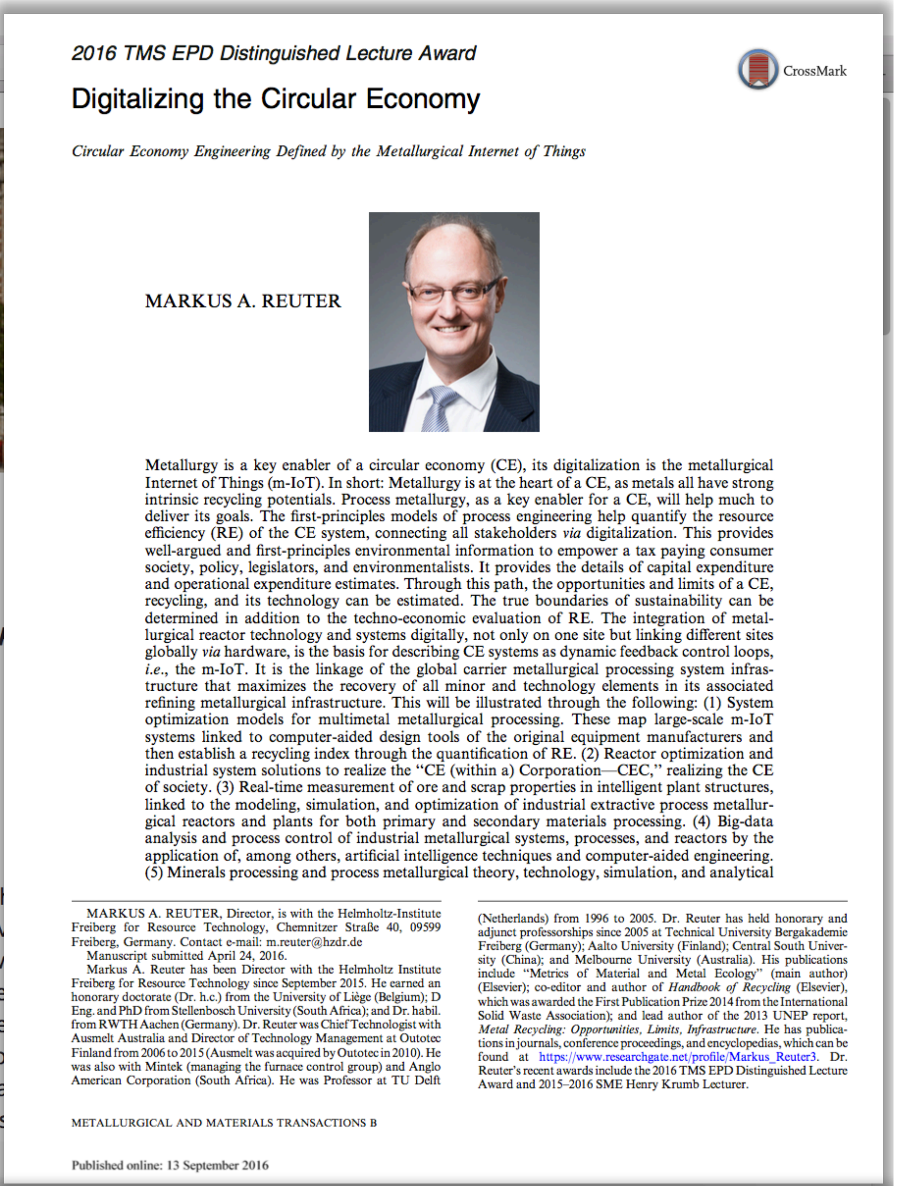

2016 TMS EPD Distinguished Lecture Award

Digitalizing the Circular Economy

Circular Economy Engineering Defined by the Metallurgical Internet of Things

MARKUS A. REUTER

Metallurgy is a key enabler of a circular economy (CE), its digitalization is the metallurgical Internet of Things (m-IoT). In short: Metallurgy is at the heart of a CE, as metals all have strong intrinsic recycling potentials. Process metallurgy, as a key enabler for a CE, will help much to deliver its goals. The first-principles models of process engineering help quantify the resource efficiency (RE) of the CE system, connecting all stakeholders *via* digitalization. This provides well-argued and first-principles environmental information to empower a tax paying consumer society, policy, legislators, and environmentalists. It provides the details of capital expenditure and operational expenditure estimates. Through this path, the opportunities and limits of a CE, recycling, and its technology can be estimated. The true boundaries of sustainability can be determined in addition to the techno-economic evaluation of RE. The integration of metallurgical reactor technology and systems digitally, not only on one site but linking different sites globally *via* hardware, is the basis for describing CE systems as dynamic feedback control loops, *i.e.*, the m-IoT. It is the linkage of the global carrier metallurgical processing system infrastructure that maximizes the recovery of all minor and technology elements in its associated refining metallurgical infrastructure. This will be illustrated through the following: (1) System optimization models for multimetal metallurgical processing. These map large-scale m-IoT systems linked to computer-aided design tools of the original equipment manufacturers and then establish a recycling index through the quantification of RE. (2) Reactor optimization and industrial system solutions to realize the "CE (within a) Corporation—CEC," realizing the CE of society. (3) Real-time measurement of ore and scrap properties in intelligent plant structures, linked to the modeling, simulation, and optimization of industrial extractive process metallurgical reactors and plants for both primary and secondary materials processing. (4) Big-data analysis and process control of industrial metallurgical systems, processes, and reactors by the application of, among others, artificial intelligence techniques and computer-aided engineering. (5) Minerals processing and process metallurgical theory, technology, simulation, and analytical

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Manuscript submitted April 24, 2016.

Markus A. Reuter has been Director with the Helmholtz Institute Freiberg for Resource Technology since September 2015. He earned an honorary doctorate (Dr. h.c.) from the University of Liège (Belgium); D Eng. and PhD from Stellenbosch University (South Africa); and Dr. habil. from RWTH Aachen (Germany). Dr. Reuter was Chief Technologist with Ausmelt Australia and Director of Technology Management at Outotec Finland from 2006 to 2015 (Ausmelt was acquired by Outotec in 2010). He was also with Mintek (managing the furnace control group) and Anglo American Corporation (South Africa). He was Professor at TU Delft (Netherlands) from 1996 to 2005. Dr. Reuter has held honorary and adjunct professorships since 2005 at Technical University Bergakademie Freiberg (Germany); Aalto University (Finland); Central South University (China); and Melbourne University (Australia). His publications include "Metrics of Material and Metal Ecology" (main author) (Elsevier); co-editor and author of *Handbook of Recycling* (Elsevier), which was awarded the First Publication Prize 2014 from the International Solid Waste Association); and lead author of the 2013 UNEP report, *Metal Recycling: Opportunities, Limits, Infrastructure*. He has publications in journals, conference proceedings, and encyclopedias, which can be found at https://www.researchgate.net/profile/Markus_Reuter3. Dr. Reuter's recent awards include the 2016 TMS EPD Distinguished Lecture Award and 2015–2016 SME Henry Krumb Lecturer.

METALLURGICAL AND MATERIALS TRANSACTIONS B

Published online: 13 September 2016

M.A. Reuter (2016): Digitalizing the Circular Economy-Circular Economy Engineering defined by the metallurgical Internet of Things- 2016 TMS EPD Distinguished Lecture Award, USA, Metallurgical Transactions B 47(6), 3194-3220 (http://link.springer.com/article/10.1007/s11663-016-0735-5).

Prof. Dr. Dr. h.c. Markus A. Reuter (PhD)

Current position:	Director, Helmholtz Institute Freiberg for Resource Technology, HIF (since 2015)
Previous Positions:	Chief Executive Technologist, Director Technology Management at Outotec (Ausmelt) Australia & Finland (2006-2015), Mintek: South Africa (1994-1996), Anglo American Corp: South Africa (1984-1985)
Professorships:	Professor & Prof Fellow Uni Melbourne, Australia (UoM) (2005 ongoing), Adj Prof at Aalto University, Finland (Aalto) (2012 ongoing), Guest Prof at Central South University, China (2012 ongoing), Prof & Emeritus at TU Delft, NL (1996-2012)
Scientific degree:	Honorary Doctorate (Dr. h.c.) Université de Liège (Belgium) (2015), D.Eng. & PhD, Uni. Stellenbosch ZA (1991 & 2006), Dr. habil., RWTH Aachen, D (1995)
Recent Research Topic:	Metallurgical Engineering, Recycling, Design for Recycling, System Engineering H-index (25 Scopus, 33 Google), >16 patents awarded in 5 patent families

- **See https://www.researchgate.net/profile/Markus_Reuter3 for various publications**
- **How recyclable is the Fairphone 2: https://www.fairphone.com/en/2017/02/27/recyclable-fairphone-2/**
- **M.A. Reuter (2016): Digitalizing the Circular Economy - Circular Economy Engineering defined by the metallurgical Internet of Things-, 2016 TMS EPD Distinguished Lecture, USA, Metallurgical Transactions B, 47(6), 3194-3220 (http://link.springer.com/article/10.1007/s11663-016-0735-5).**
- **M.A. Reuter, A. van Schaik (2016): Gold – a key enabler of a Circular Economy: In: Recycling of WEEE, Gold Ore Processing, Project Development and Operations 2nd Edition, Elsevier, Ed. M Adams, 937-956 (http://store.elsevier.com/Gold-Ore-Processing/isbn-9780444636584/).**
- **I. Rönnlund, M.A. Reuter, S. Horn, J. Aho, M. Päällysaho, L. Ylimäki, T. Pursula (2016): International Journal of Life Cycle Assessment, Part 1: Sustainability indicator framework implemented in the metallurgical industry: A comprehensive view and benchmark, 21(10), 1473-1500 & Part 2: Implementation of sustainability indicator framework in the metallurgical industry: A case study from the copper industry, 21(12), 1719-1748.**
- **A. van Schaik, M.A. Reuter (2016): Recycling indices visualizing the performance of the circular economy, World of Metallurgy – ERZMETALL, 69(4), 201-216.**
- **M.A. Reuter, A. van Schaik (2016): Strategic metal recycling: adaptive metallurgical processing infrastructure and technology are essential for a Circular Economy, RESPONSABILITÉ & ENVIRONNEMENT, AVRIL 2016, 82, 62-66.**
- **M.A. Reuter, A. van Schaik, J. Gediga (2015): Simulation-based design for resource efficiency of metal production and recycling systems, Cases: Copper production and recycling, eWaste (LED Lamps), Nickel pig iron, International Journal of Life Cycle Assessment, 20(5), 671-693.**
- **M.A. Reuter, R. Matusewicz, A. van Schaik (2015): Lead, Zinc and their Minor Elements: Enablers of a Circular Economy, World of Metallurgy – ERZMETALL 68 (3), 132-146.**
- **E. Worrell, M.A. Reuter (2014): Handbook of Recycling, Elsevier BV, Amsterdam, 595p. (ISBN 978-0-12-396459-5) (1st Prize Book Award by International Solid Waste Association http://www.iswa.org/)**
- **Lead author of the United Nations Environmental Protection (UNEP) Report (2013) “Metal Recycling: Opportunities Limits Infrastructure” http://www.resourcepanel.org/reports/metal-recycling**