umicore
materials for a better life

Effective Use of Ge

Final presentation

ESA Effective Use of Germanium

Contract number: 4000128156/19/NL/FE

The work presented here was supported by the European Space Agency under the Effective Use of Germanium project

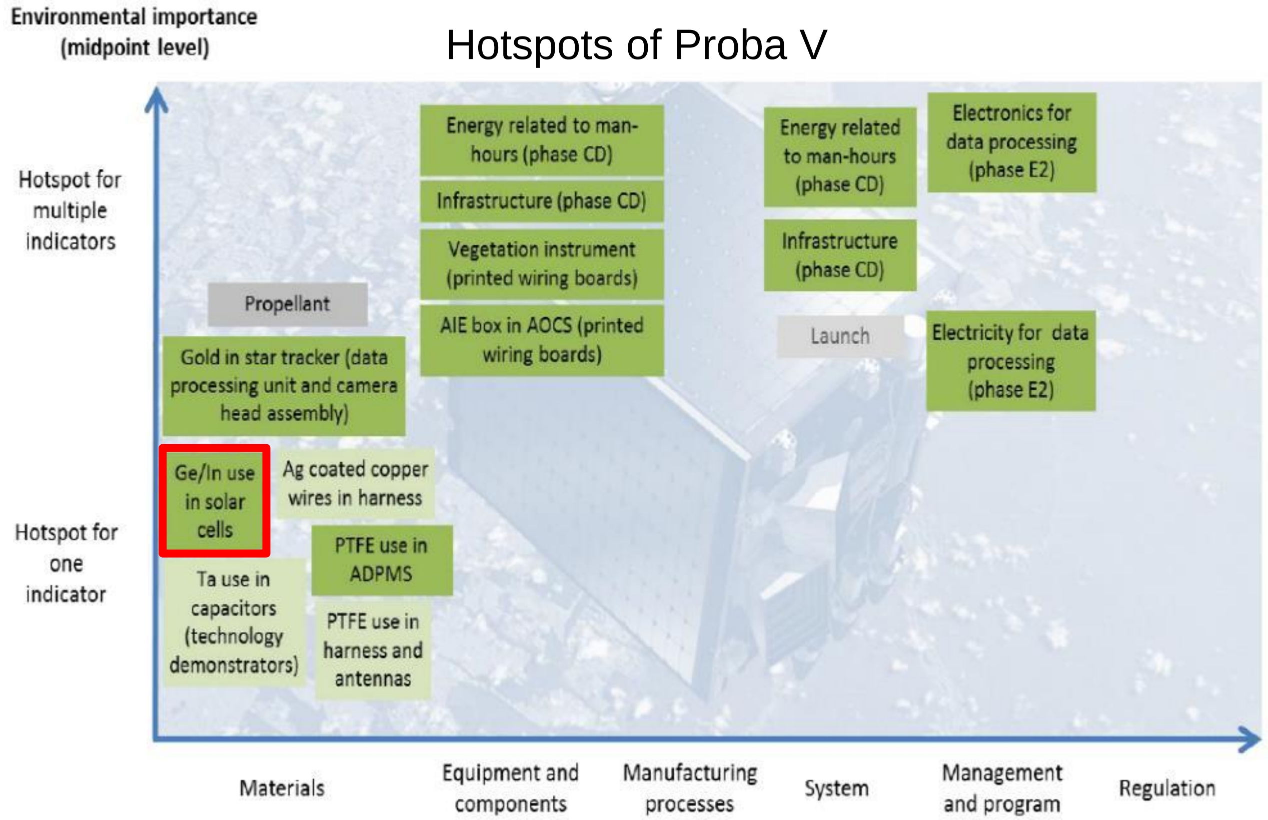
Project partners: umicore, AZUR SPACE

Key external service providers: imec, Deloitte., vito

Motivation

In previous LCA studies, Ge has been identified as one of the major environmental hotspots of ESA's space missions.

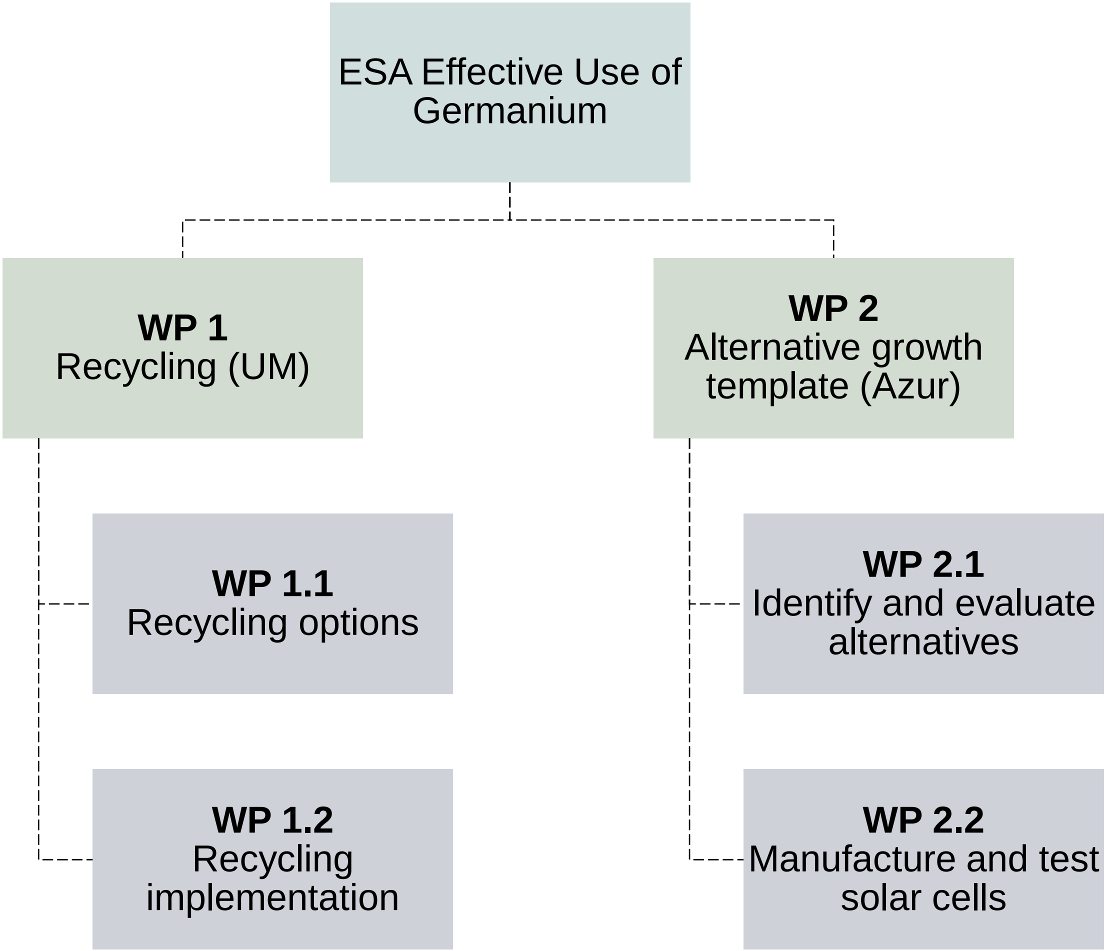
Hotspots of Proba V



Objectives

The main objectives of this activity are as follows:

- **Develop and implement a recycling process for Ge** for process steps in the wafer/solar cell productions of today’s solar cells for which this is currently not done (e.g. the thinning process of the Ge backside).
- Develop a process for manufacturing highly efficient III-V solar cells using **alternative growth templates that allow for a significant reduction of Ge**. Thereby, nowadays state-of-the-art III-V multi-junction solar cell efficiencies shall be maintained
- **A Life Cycle Assessment (LCA) of the two options** (“recycling” and “alternative growth template”) shall be performed. This shall be benchmarked against current technology and manufacturing processes.


ESA Effective Use of Germanium
WP 1
Recycling (UM)
WP 2
Alternative growth template (Azur)
WP 1.1
Recycling options
WP 1.2
Recycling implementation
WP 2.1
Identify and evaluate alternatives
WP 2.2
Manufacture and test solar cells

WP1: Recycling

Importance of germanium recycling

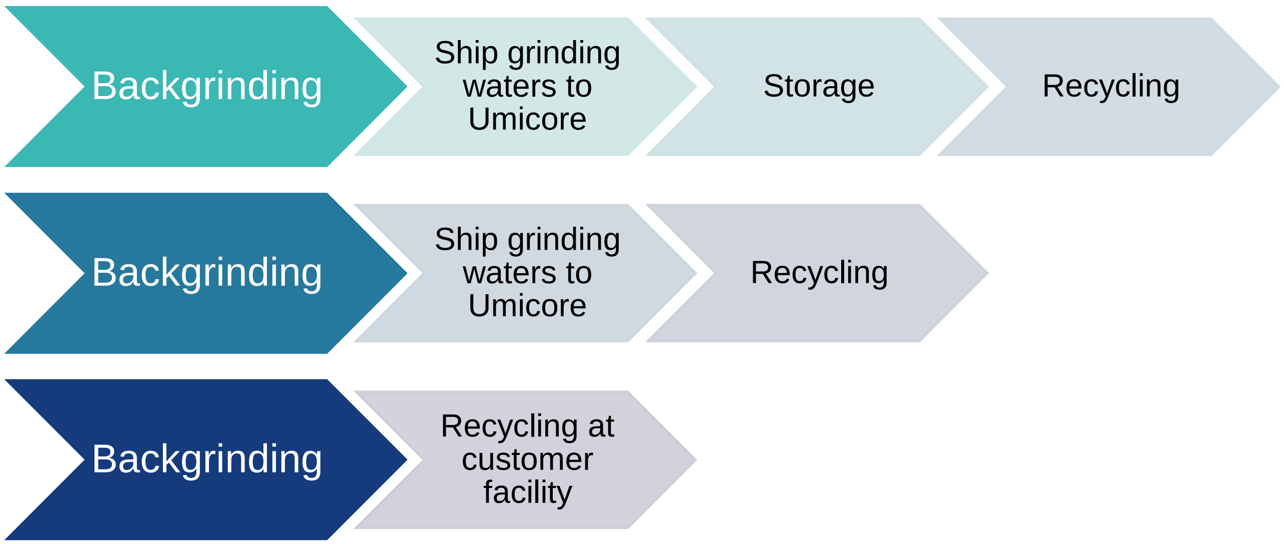
CO_2 impact lower for entire production line

Germanium is included in list of EU's Critical Raw Materials (CRM)

Win-win for customer & Umicore
➔ insusceptible to germanium price fluctuations
➔ lower end-product price

Recycling Ge from backgrinding of customers

Early tests have shown that recycling will need to occur at the customer



0 % Ge recovered (dissolved in water)

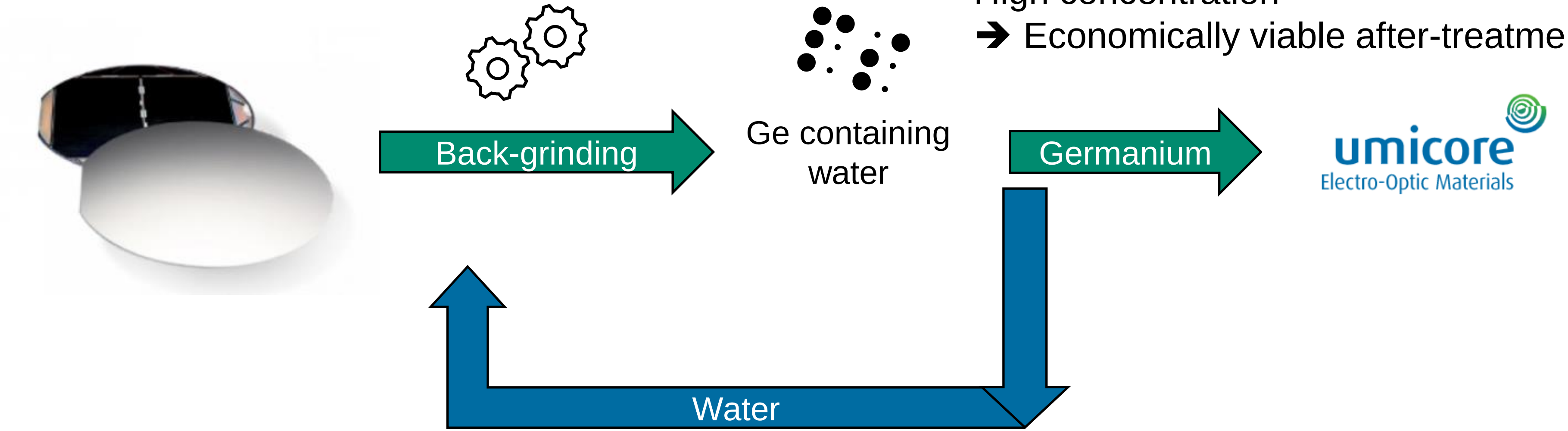
30 % Ge recovered (dissolved in water)

90 % Ge recovered (bench top setup)

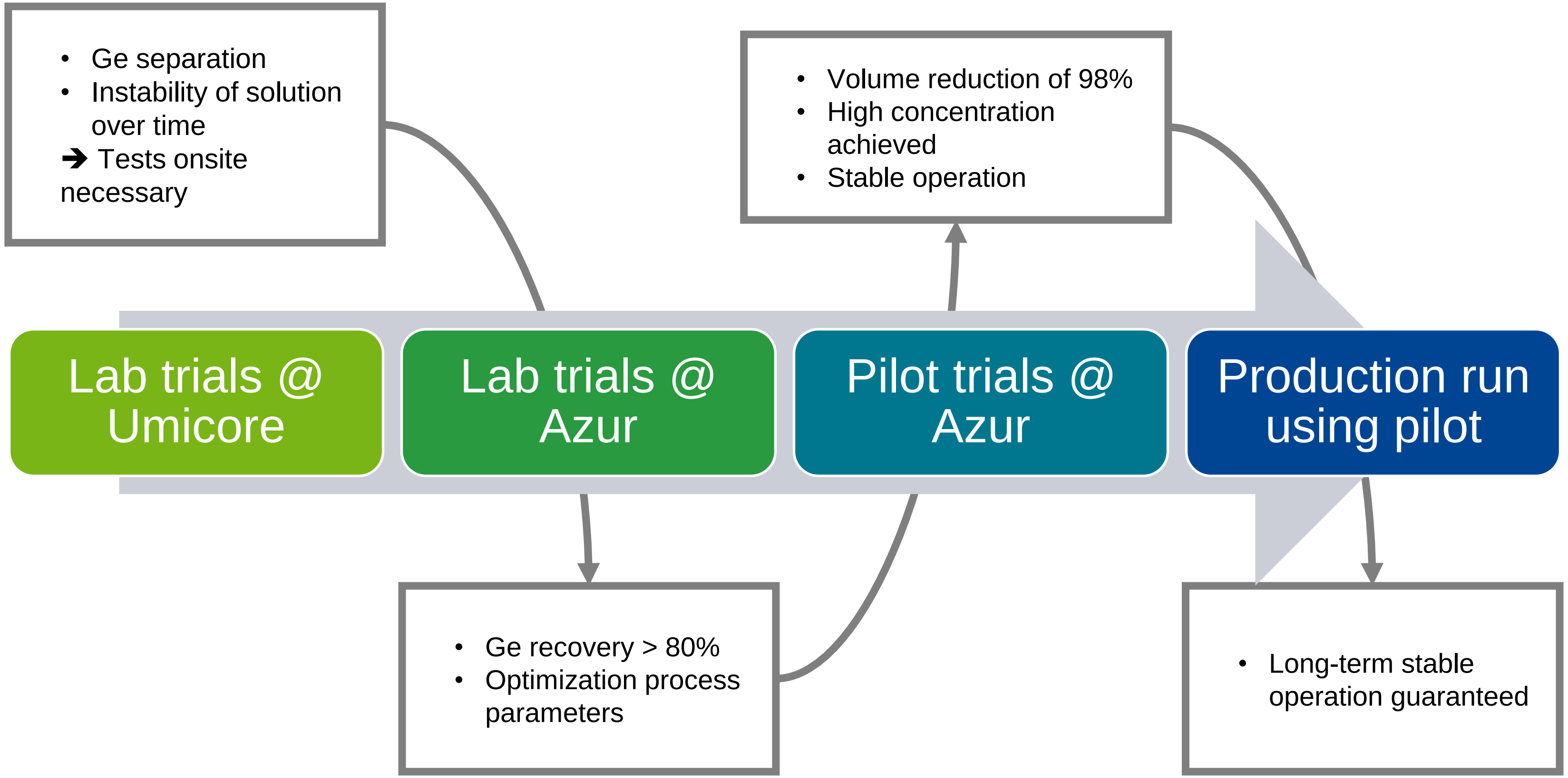
Recycling flowsheet

Objectives:

- Min. yield of 80%
- High concentration
  ➔ Economically viable after-treatment

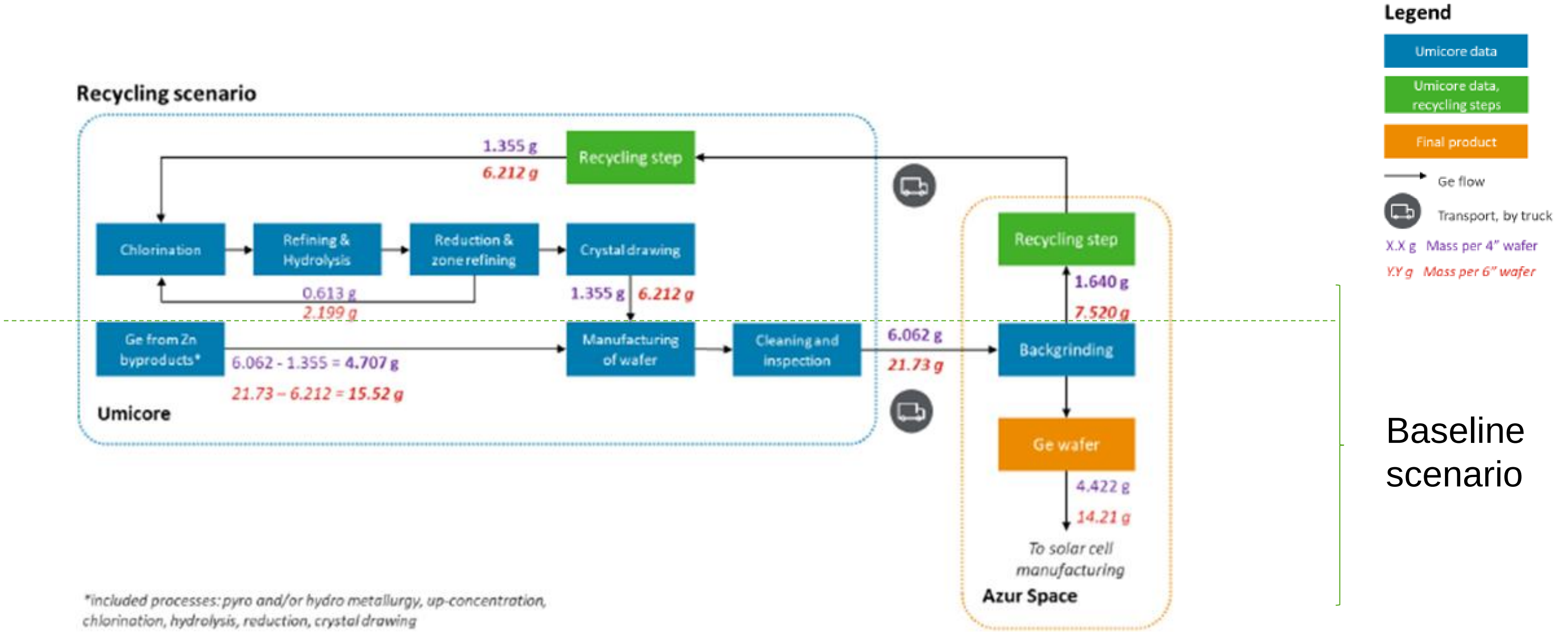


Summary of experimental work



Life Cycle Analysis

Scope of the study



Functional unit = Manufacturing of one output 4/6 inch germanium wafer with back-grinding

Progress of the study

Iteration 1

Outcome: relative low climate change impact results compared to previous studies

➔ Include Umicore's process data for primary Ge route

Iteration 2

Outcome: wafer manufacturing + cleaning & inspection processes relatively small contribution

➔ Include Umicore's process data for manufacturing + cleaning & inspection

Iteration 3

Outcome: updated LCI

		4" wafer		6" wafer	
Inputs and outputs	Units	Baseline	Recycling	Baseline	Recycling
Primary germanium	kg	6.74E-03	5.38E-03	2.41E-02	1.79E-02
Electricity	kWh	6.76E+00	8.89E+00	2.27E+01	3.00E+01
Natural gas	MJ	4.78E+00	4.06E+00	1.51E+01	1.18E+01
Coal	MJ	1.77E+01	1.37E+01	6.34E+01	4.53E+01
Other energy	MJ	1.29E+00	1.01E+00	4.64E+00	3.31E+00
Compressed air	Nm3	6.19E+00	6.51E+00	2.22E+01	2.22E+01
Steam	kg	1.62E-01	2.55E-01	5.82E-01	8.79E-01
Water	kg	3.20E+02	3.17E+02	1.15E+03	1.13E+03
Chemicals and consumables	kg	3.36E+00	3.45E+00	1.14E+01	1.11E+01
Wastewater	kg	2.33E+02	3.40E+02	8.37E+02	1.22E+03

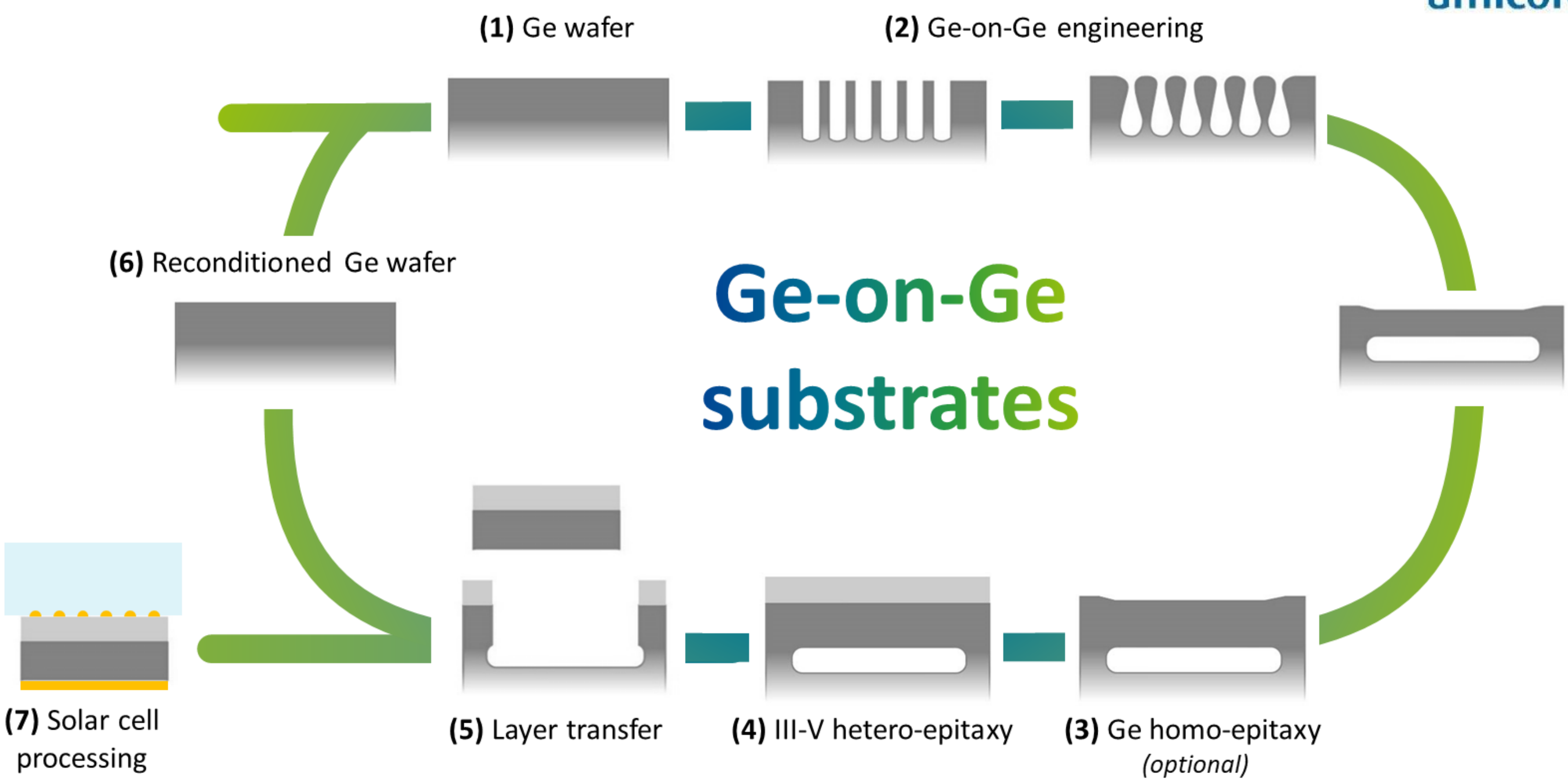
Results third iteration

Impact category/environmental indicator	Units	4" wafer	% difference with baseline	6" wafer	% difference with baseline
Climate change	kg CO_2 eq.	1.03E+01	-9%	2.28E+01	-16%
Primary energy consumption	MJ	2.16E+02	-4%	4.20E+02	-10%
Minerals and metals resource depletion (reserve base, corrected)	kg Sb eq.	1.32E-01	-20%	4.40E-01	-26%
Minerals and metals resource depletion (reserve base, uncorrected)	kg Sb eq.	1.05E+02	-20%	3.50E+02	-26%
Minerals and metals resource depletion (ultimate reserves)	kg Sb eq.	3.24E-03	-20%	1.08E-02	-26%
Acidification	kg SO_2 eq.	4.54E-02	-15%	1.28E-01	-22%
Marine eutrophication	kg N eq.	4.09E-03	3%	6.90E-03	8%
Freshwater ecotoxicity	CTUe	7.68E+01	9%	1.06E+02	40%

- **Recycling decreases:**
  - Climate change impact
  - Primary energy usage
  - Minerals & metals resource depletion
  - Acidification
- **Recycling increases:**
  - Marine eutrophication
  - Freshwater ecotoxicity

Due to hydrometallurgical recycling step

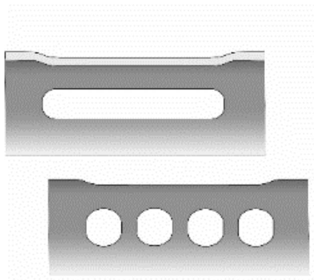
WP 2: Alternative growth template

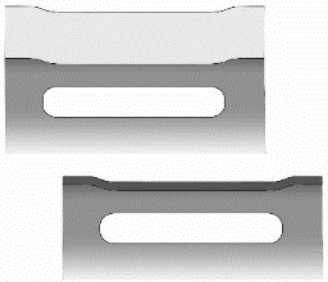

(1) Ge wafer
(2) Ge-on-Ge engineering
(6) Reconditioned Ge wafer
Ge-on-Ge substrates
(7) Solar cell processing
(5) Layer transfer
(4) III-V hetero-epitaxy
(3) Ge homo-epitaxy (optional)

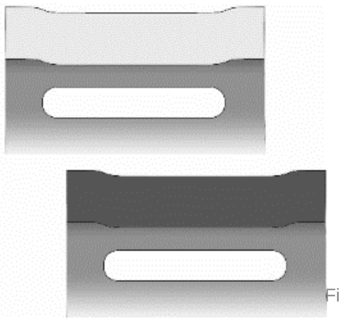
Ge-on-Ge prototype iterations

3 prototype versions

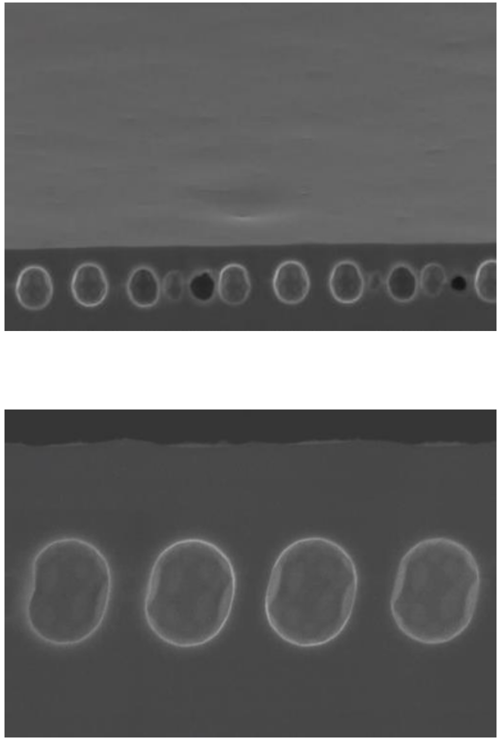
	Iteration 1 (2020)	Iteration 2 (2021)	Iteration 3 (2022)
Void layer	• Non-detachable: no collapse/flaking • Detachable: unknown collapse/flaking risk	• Reproducible • Detachable + testing against collapse/flaking	• Detachable + resilient to collapse/flaking
Restructured foil	• 1-1.5 µm thick • Non-optimised	• Optimised surface	• Optimised surface and bulk
Ge epitaxy	• Thin intrinsic (or no) Ge epitaxy	• Thick intrinsic Ge epitaxy	• Thick doped Ge epitaxy





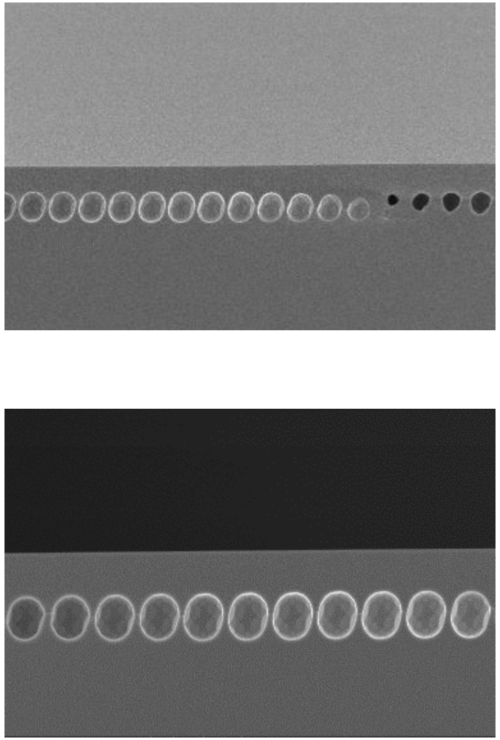


Ge-on-Ge prototype versions



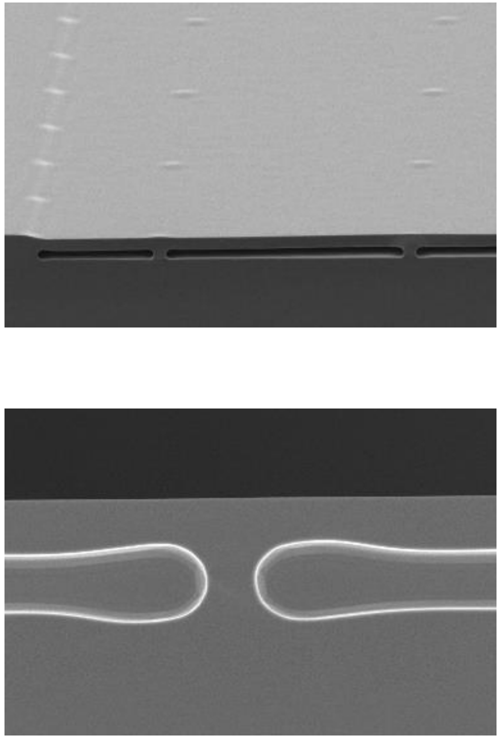
v1.0

Batch 1 and 2



v1.1

Batch 3



v2.1

Batch 4

AZUR SPACE
ENABLING TECHNOLOGIES

Effective Use of Germanium

(400012815619/NL/FE)

Ge-on-Ge substrates als alternative growth substrate for high efficiency space solar cells

Final meeting – 9th February 2022

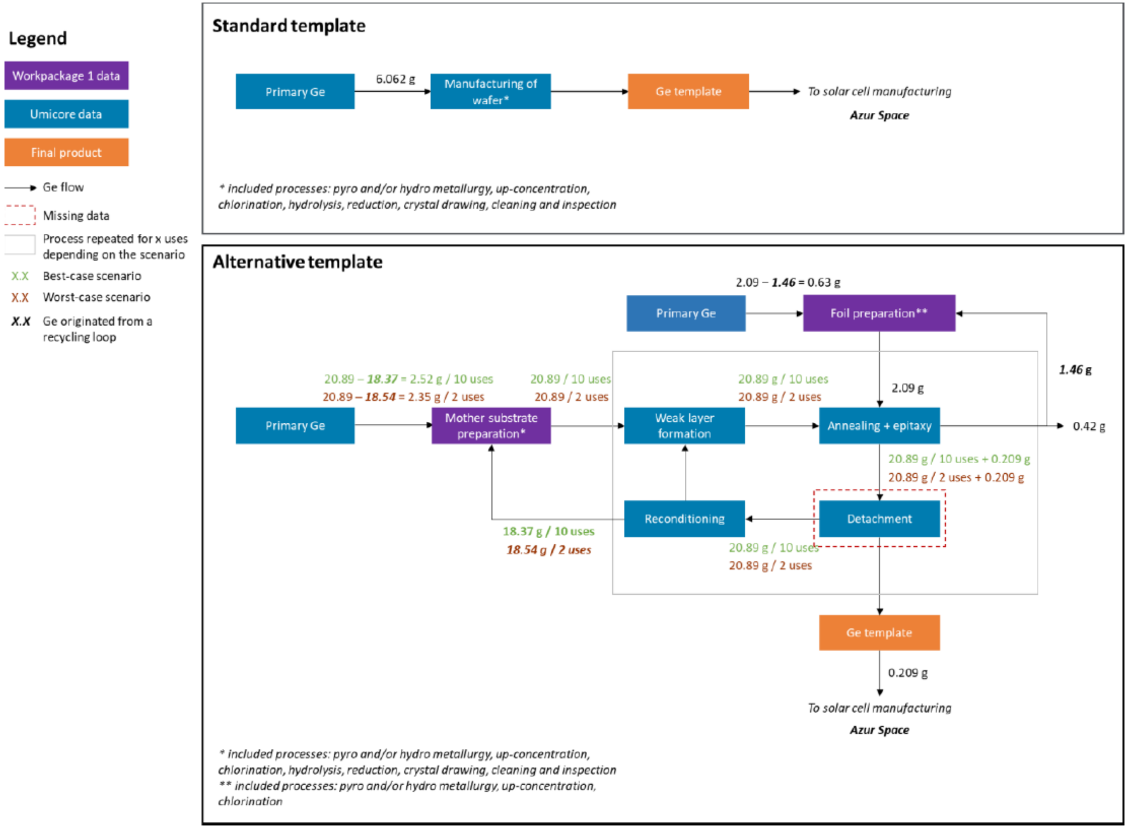
(held via MS Teams)

T. Kubera, Heilbronn

Life Cycle Analysis

Sytem boundary and functional unit

“Manufacturing of one 4” germanium template for III-V solar cell deposition (78.5 cm² surface area)”



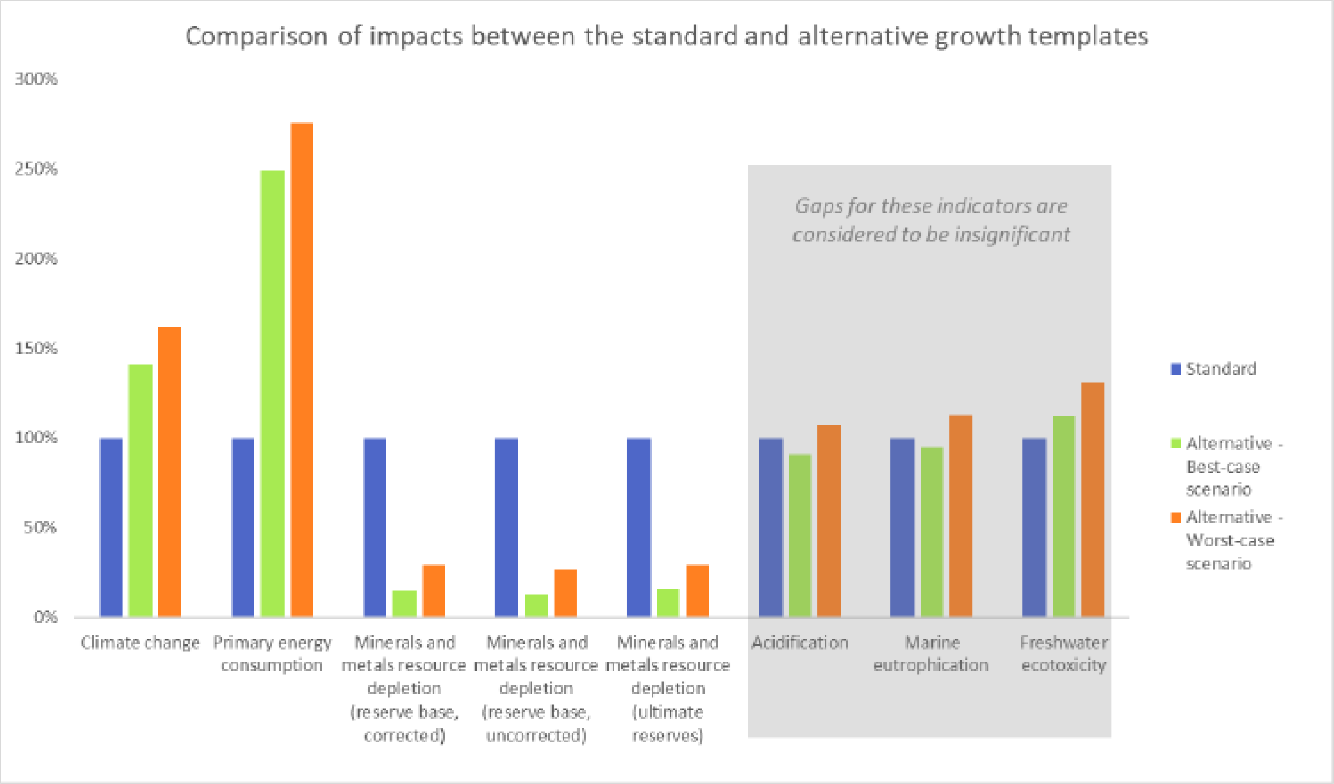
Life cycle inventory (LCI)

Significant reduction in primary germanium

Inputs and outputs	Units	Standard template	Alternative template – best-case scenario	Alternative template – worst-case scenario
Primary germanium	kg	6.74E-03	8.82E-04	1.81E-03
Electricity	kWh	8.73	34.17	35.37
Natural gas	MJ	3.19	0.45	0.89
Coal	MJ	17.68	2.50	4.93
Other energy	MJ	1.29	0.18	0.36
Compressed air	Nm3	7.73	0.83	1.89
Steam	kg	0.16	0.02	0.05
Water	kg	286.92	13.14	52.54
Chemicals and consumables	kg	2.84	1.18	1.57
Wastewater	kg	0.00	1.38	1.38

Comparison of impacts

Important reduction in minerals and resource depletion



Conclusions

- Key goals were achieved:

1. Recycling of backgrinding waters of Azur Space is now operational
2. The proof of concept of Ge-on-Ge engineered substrates as alternative growth substrates was successful

- Umicore is continuing development of the Ge-on-Ge engineered substrates in the ESA ELLA project
- The Ge-on-Ge engineered substrate is a promising concept that attracts interest from the European value chain


Let's connect!
umicore
Electro-Optic Materials
APPLICATION KNOW-HOW
METALS
CHEMISTRY MATERIAL SCIENCE METALLURGY
MATERIAL SOLUTIONS
RECYCLING
CONNECTIVITY MEGATREND
MORE STRINGENT EMISSION CONTROL
RESOURCE SCARCITY
ELECTRIFICATION OF THE AUTOMOBILE
UNIQUE BUSINESS MODEL
SUPPORTIVE MEGATRENDS
INDUSTRY LEADER IN SUSTAINABILITY

Date