ECODESIGN FOR SPACE AND AEROSPACE

LIFE CYCLE ASSESSMENT RESULTS OF PHOTOVOLTAIC CELLS FOR SPACE HARDWARE

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Agenda

- Methodology: life cycle assessment (LCA)
- Background
- Scope of Work
- Photovoltaics for space: Characterisation
- Photovoltaics for space: Environmental Impacts

LCA – environmental scores for ecodesign

Life cycle thinking
environmental, social and economic impacts of a product over its entire life cycle (*lifecycleinitiative.org*)

Ecodesign
design considering the environmental impact of a product through its life cycle

Life cycle assessment (LCA)
mapping, quantification and evaluation of life cycle impact of product systems

European Commission

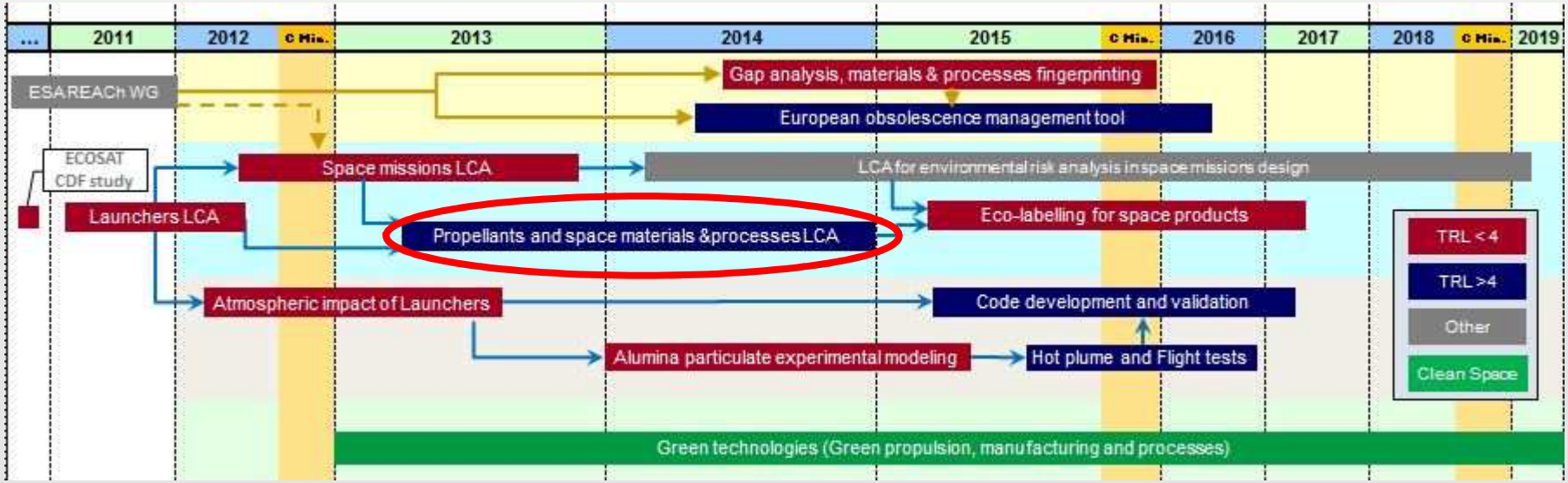
ESA & ecodesign

ESA, with the **Clean Space initiative**, wants to give a **pro-active answer to the environmental challenges both on ground and in space**, including its own operations as well as operations performed by European space industry in the frame of ESA programmes.

Branch 1	Branch 2	Branch 3	Branch 4
Eco-Design	Green Technologies	Debris Mitigation	Active Debris Removal
Evaluate the environmental impact and monitor legislation risk	Green propulsion, green electronics, new materials and processes	Technologies to support	Technologies to support

ESA & ecodesign

Establish a common ecodesign framework for the European space sector, including the development of tools and systems to evaluate the environmental impact and legislation compliance of programmes.



ESA Clean Space Road map - Branch 1 Eco design

ESA & ecodesign

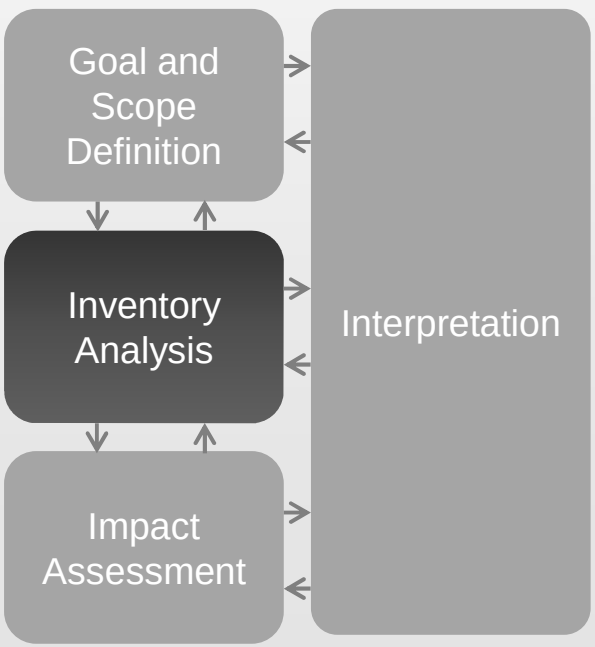
- Ecodesign part of concurrent design
- Studies conducted by ESA for several space systems, including full missions
- Conclusion: more detail required for representation of space context

Data issue

- Technologies for advanced applications often earlier in development, proprietary info.
- Extrapolating conventional ecodesign tools into high-end manufacturing may carry vital errors.

Specific context

- Advanced materials and additional requirements
- Smaller, specialized production
- Higher requirements for testing & quality



LCA Framework – ISO 14040:2006

ESA & ecodesign

Ongoing life cycle assessments for European Space Agency

- Life cycle assessment of space materials and manufacture processes (2015)
- Life cycle assessment of space propellants (2015-2016)

Main Objectives and Critical issues for success

- **Increase the background inventory** beyond the standard LCI processes, i.e., achieve more than mere merging of existing databases and review of previous work;
- **Integrate space aspects into the inventory datasets**, i.e., conditions regarding limited production volumes, specialized production, and specific space material and manufacturing requirements;
- **Involve space industry as reviewers and data providers**, especially non-LSI, i.e., the actual manufacturers.

Purpose

- Provide environmental ecodesign scores representative of space context

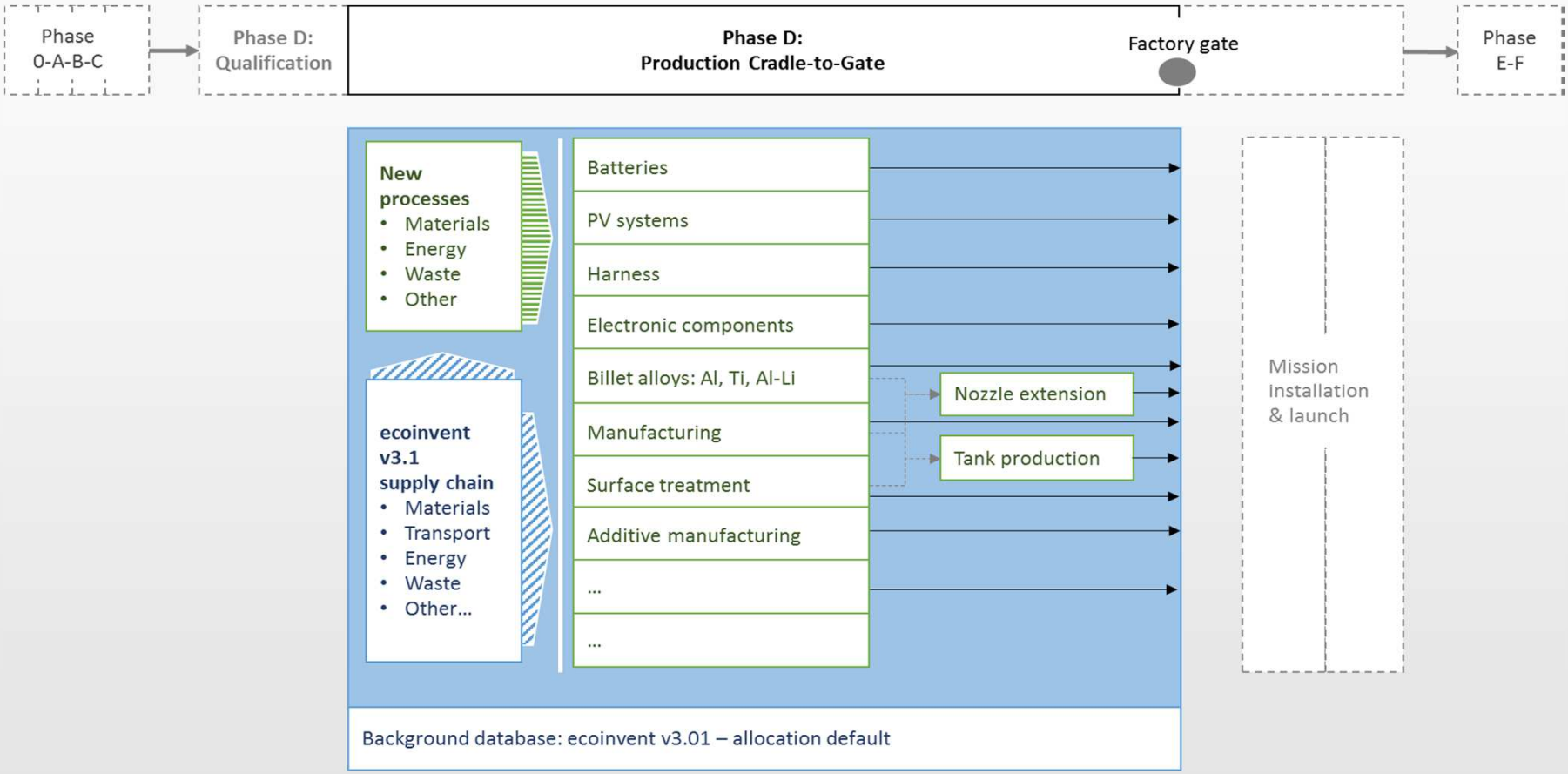
= *basis for an ecodesign tool for space & aerospace*

System elements

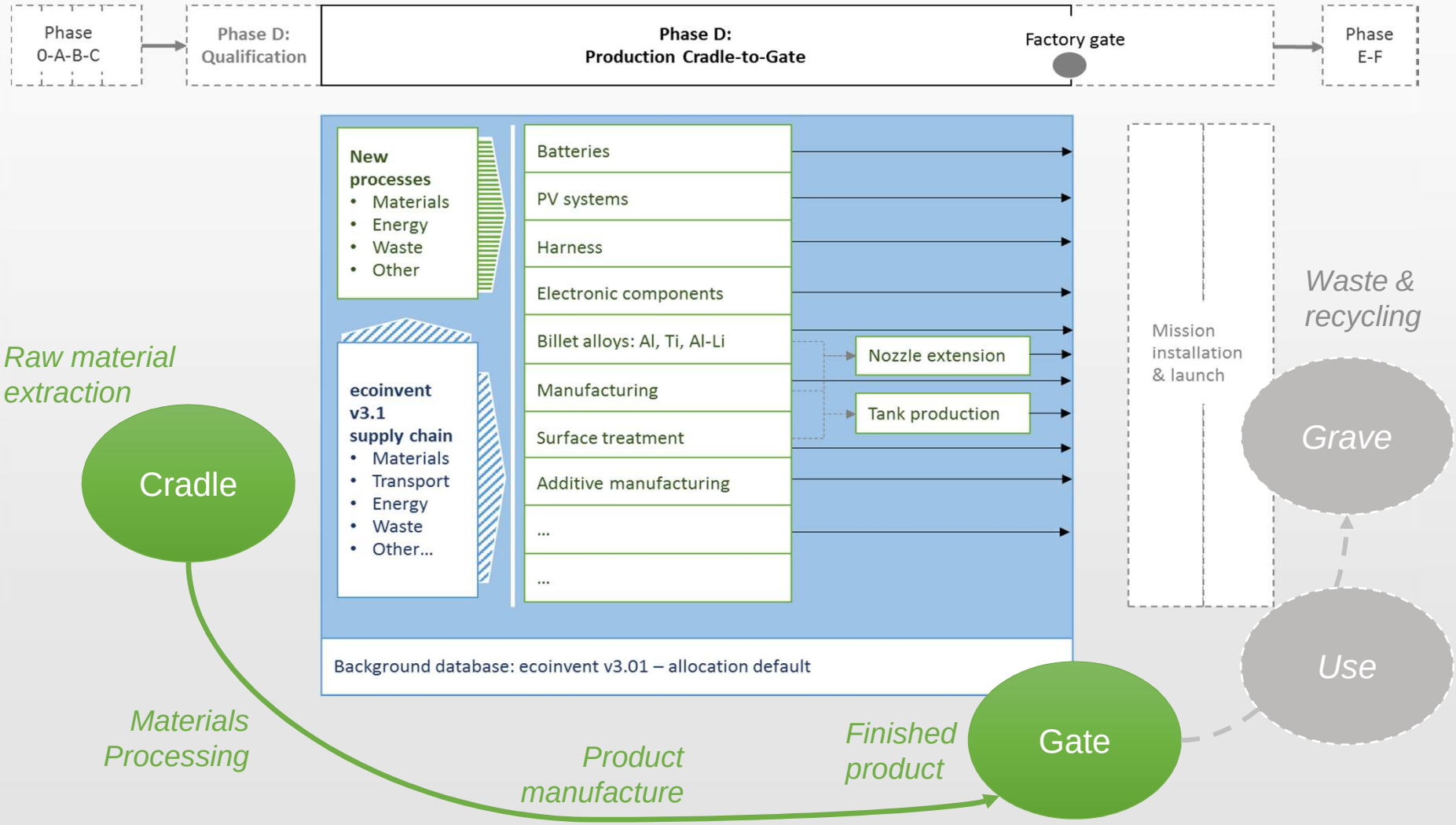
- **Photovoltaics**
- Materials
  - Al & Ti alloys
  - Thermoplastics
- Machining
  - Turning
  - Milling
  - Drilling
  - Laser cutting
  - Electroforming
  - EDM
  - Welding (TIG, MIG, SAW, FSW)
  - Polishing
- Heat Treatment
- Tanks production
- Nozzle extension production
- Structural elements
  - Al honeycombs
  - CFRP/GFRP
  - Sandwich Panels
- Additive manufacturing
  - Direct energy deposition
  - Direct metal laser sintering
  - Electron beam melting
  - Selective laser melting
- Non-Destructive Inspections
- Electronics/Electronic components
- Li-ion battery
- Harness components

(+ Common processes)

System boundaries: Cradle to Gate



System boundaries: Cradle to Gate



Environmental impacts

Environmental impact	Abbbreviation - unit	Impact indicator source
Abiotic resource depletion – fossils	ADEPLf - MJ	CML 2002
Abiotic resource depletion – minerals	ADEPLm - kg Sb eq	CML 2002
Metal depletion potential	MDEPL - kg Fe eq	Recipe H/midpoint
Global warming potential (100 years)	GWP - kg CO2 eq	IPCC 2007
Ozone depletion potential	ODEPL - kg CFC-11 eq	ODP 1999 (WMO)
Air acidification potential	ACID kg - SO2 eq	CML 2002
Photochemical ozone formation potential	PCHEM - kg NMVOC	Recipe H/midpoint
Particulate matter formation potential	PMAT - kg PM10 eq	Recipe H/midpoint
Freshwater eutrophication potential	FWEUT - kg P eq	Recipe H/midpoint
Marine eutrophication potential	MWEUT - kg N eq	Recipe H/midpoint
Human toxicity potential – noncancerous	HTOXnc - CTUh	USEtox (Rosenbaum 2008)
Human toxicity potential – cancerous	HTOXc - CTUh	USEtox (Rosenbaum 2008)
Freshwater ecotoxicity potential	FWTOX - CTUe	USEtox (Rosenbaum 2008)
Marine ecotoxicity potential	MWTOX - kg 1,4-DB eq	CML 2002
Ionizing radiation potential	IORAD - kg U235 eq	Recipe H/midpoint
Primary energy consumption	PRENE - MJ	Cumulative energy demand
Gross water consumption	WDEPL – m^3	Elementary flow aggregate
Critical raw materials – all substances	CRMall - kg CRM	Elementary flow aggregate
Critical raw materials – rare earth elements	CRMree - kg CRM	Elementary flow aggregate
REACH substances	REACH - kg REACH	Elementary flow aggregate

Environmental impacts

Conventional impact methods

- Climate change emissions: CO_2-equivalents
- Priority emissions: acidification, eutrophication, particulates, smog, ozone depletion, ionizing
- Toxic emissions: cancerous & non-cancerous, ecotoxic emissions
- Resource issues: primary energy use, water use, mineral and fossil depletion

REACH obsolesence

- Use and release of hazardous substances as defined in the REACH authorization list
- 31 substances, with high representation from chromic compounds

Critical raw materials

- Dependence of critical raw materials, defined by European Commission
- 39 substances, mostly metals

Photovoltaics for space

Background

- Prior studies consider land installations, i.e., Si-based – **cost issue**
- Space applications
    - Higher efficiencies of the technology – **weight issue**
    - Radiation-hardness, small temperature coefficients, high reliability, high voltage and low currents – **physical/technical properties**

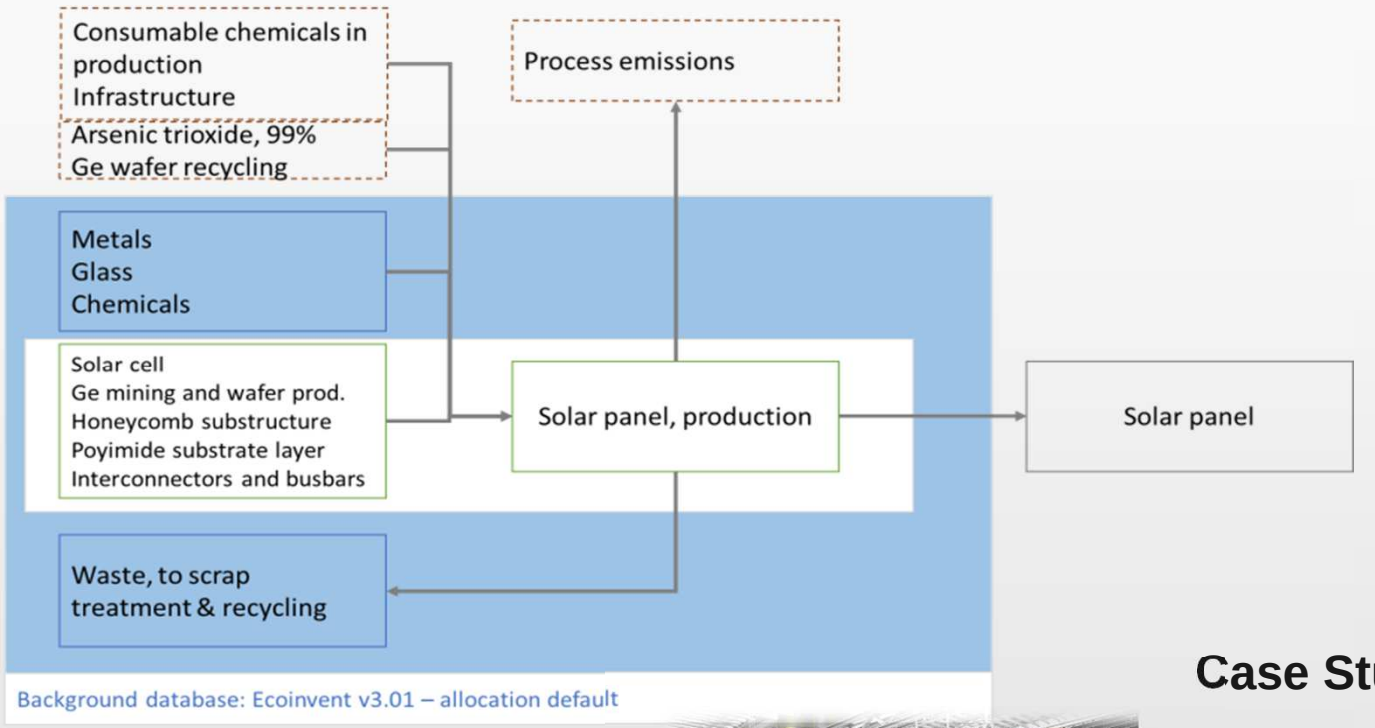
Main challenges

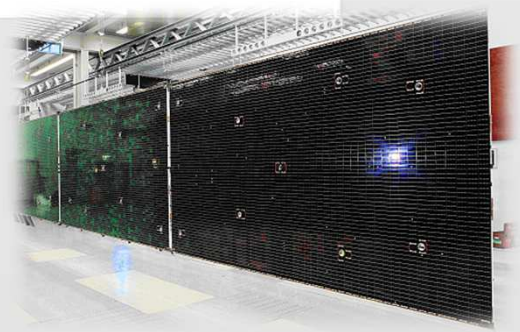
- Lack of detailed product descriptions
- Materials missing in data libraries: Germanium extraction and wafer production (critical raw material)

Basis for analysis (functional unit)

- One solar panel with triple junction solar cells of the type GaInP/GaAs/Ge on 150 µm Ge wafer
    - The cell efficiency in the range 28-30%.
    - Modeled from product datasheets and descriptions from relevant suppliers.
    - Cradle-to-gate scope.

Photovoltaics for space: System Boundaries





Case Study Panel:

Alphabus solar array

Panel width: 2 480 mm
Panel length: 3 915 mm
Panel thickness: 20.5 mm

Photovoltaics for space

Solar panel with triple junction solar cells of the type GaInP/GaAs/Ge on 150 µm Ge wafer

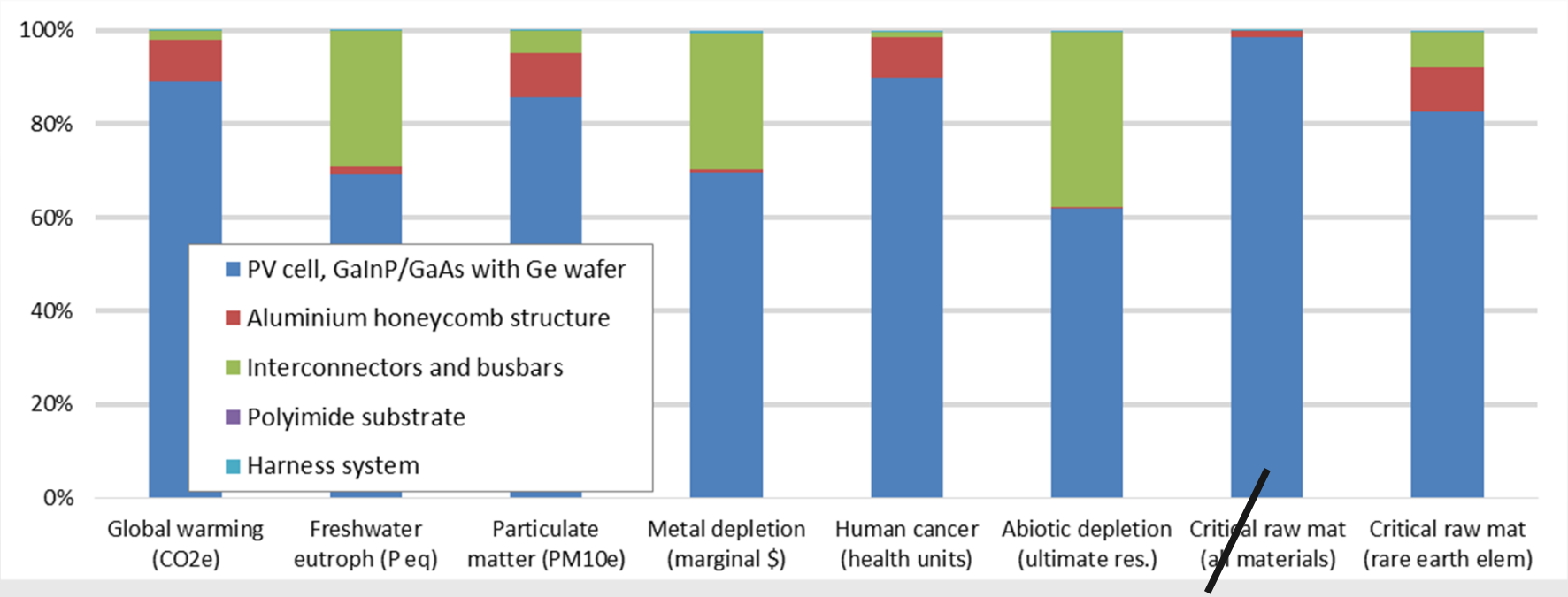
Solar Panel

Solar Cells

Glass	75-150 µm
Metal Layer	gold or silver as thin stripes, covering about 5% of the front surface area: 1-10 µm
GaInP	0.3-0.5 µm
GaAs	3-5 µm
Ge Wafer	140-150 µm
Metal Layer	gold or silver as thin stripes, covering about 5% of the front surface area: 1-10 µm
Tunnel junctions	two tunnel junctions of doped GaInP and GaAs: 0.03 µm
Panel substrate	Al honeycomb structure w/CFRP facing sheets : 20.02 mm.
Polyimide layer	covering full panel area: 50 µm
Harness	eight cables in the full panel length as proxy for harnessing.
Interconnectors and busbars	5% of panel substrate covered: 12.5 µm

Environmental impact of GaInP/GaAs/Ge wafer PV

solar panel assembly



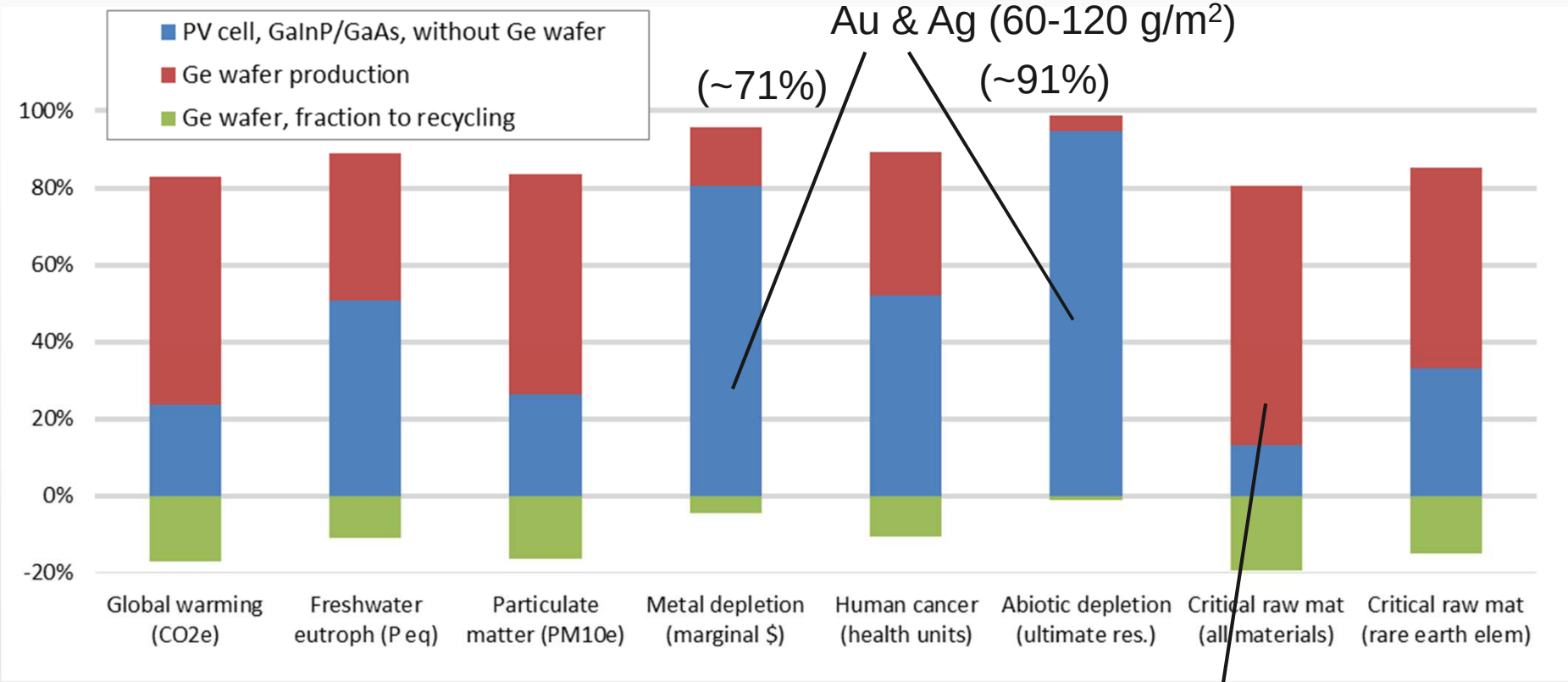
69 kg (~7,1 kg/m^2)

Gallium
Germanium
Indium

Fluorspar
~96%

Environmental impact of GaInP/GaAs/Ge wafer PV

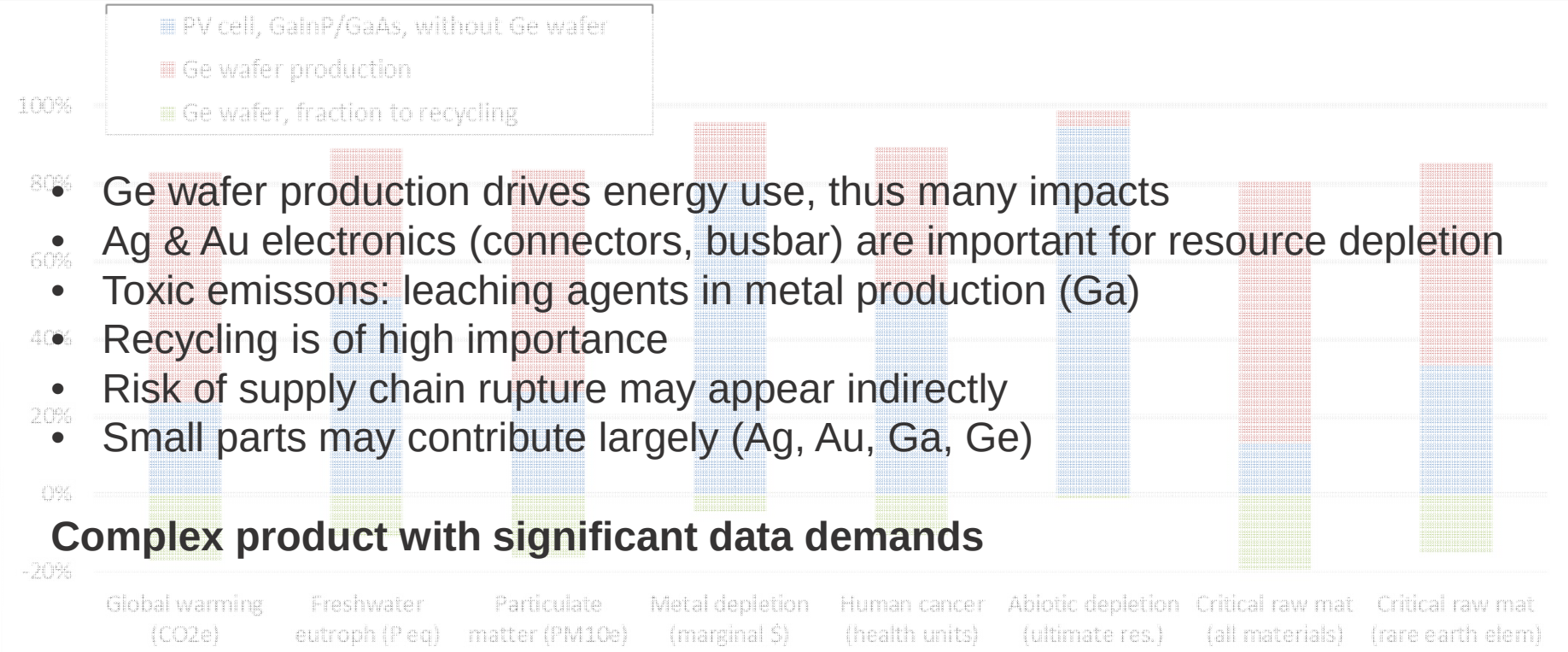
photovoltaic cell production



Fluorspar { Chlorination and Hydrolisis (~46%)
Cleaning and Inspection (~21%)

Environmental impact of GaInP/GaAs/Ge wafer PV

photovoltaic cell production

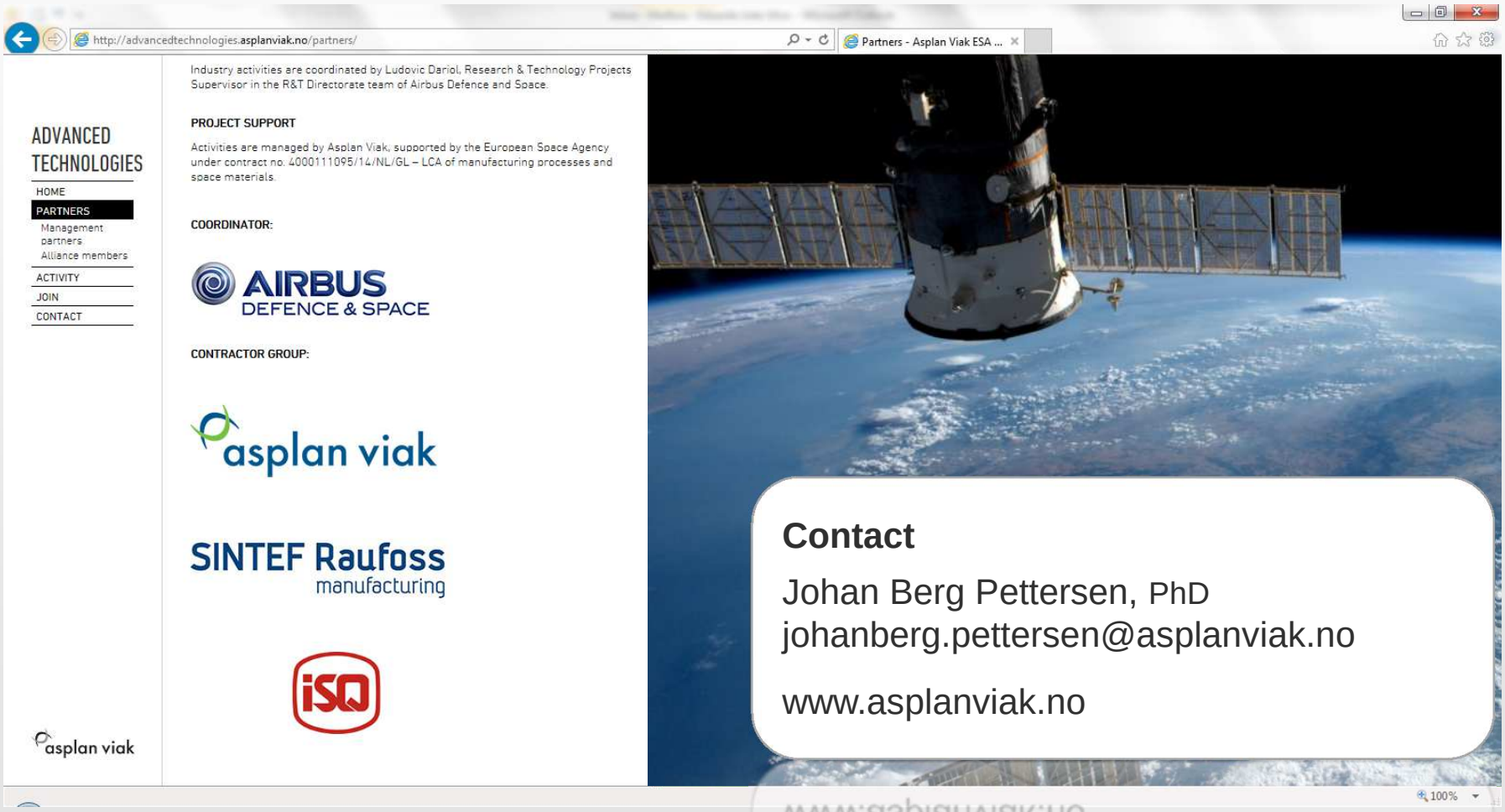


- Ge wafer production drives energy use, thus many impacts
- Ag & Au electronics (connectors, busbar) are important for resource depletion
- Toxic emissons: leaching agents in metal production (Ga)
- Recycling is of high importance
- Risk of supply chain rupture may appear indirectly
- Small parts may contribute largely (Ag, Au, Ga, Ge)

Complex product with significant data demands

Ecodesign alliance for advanced technologies

http://advancedtechnologies.asplanviak.no/



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THANK YOU

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