ROSI
return of silicon

A truly circular economy for the photovoltaic industry and beyond

Coriolis seminar

Dr. Yun Luo
Dr. Guy Chichignoud, Mr. Daniel Bajolet
& ROSI Team

November 2022

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I. PV value chain

II. End of life PV modules and their regulation

III. Bottleneck of recycling and ROSI's choice of technologies

IV. Silicon: critical raw material

V. ROSI and its vision

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I. **PV value chain**

II. End of life PV modules and their regulation

III. Bottleneck of recycling and ROSI's choice of technologies

IV. Silicon: critical raw material

V. ROSI and its vision

Intensive in Capex, energy, and CO2

6 kg of materials per 1 kg of silicon


Quartz


Wood


Coal

Natural resources

13kWh/kg

Metallurgic-grade silicon

63kWh/kg

PV-grade silicon

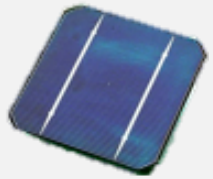
47kWh/kg

Silicon powder (Kerf)

40% loss

State-of-the-art Capex:
2,5B$ for 200kt PV-Si

Wafers



Solar cells

Panels

Photovoltaic plants

high-value silicon & silver

100% loss

End-of-life PV modules

Intensive in Capex, energy, and CO2

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Natural resources

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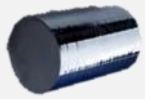
Metallurgic-grade silicon

②

PV-grade silicon



Silicon powder (Kerf)

40% loss

③

Wafers

④

Solar cells

⑤

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End-of-life PV modules

Natural ressources and electricity intensive process for MG-Si

6 kg of materials per 1 kg of silicon


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Natural resources

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Metallurgic-grade silicon

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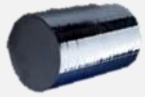
PV-grade silicon



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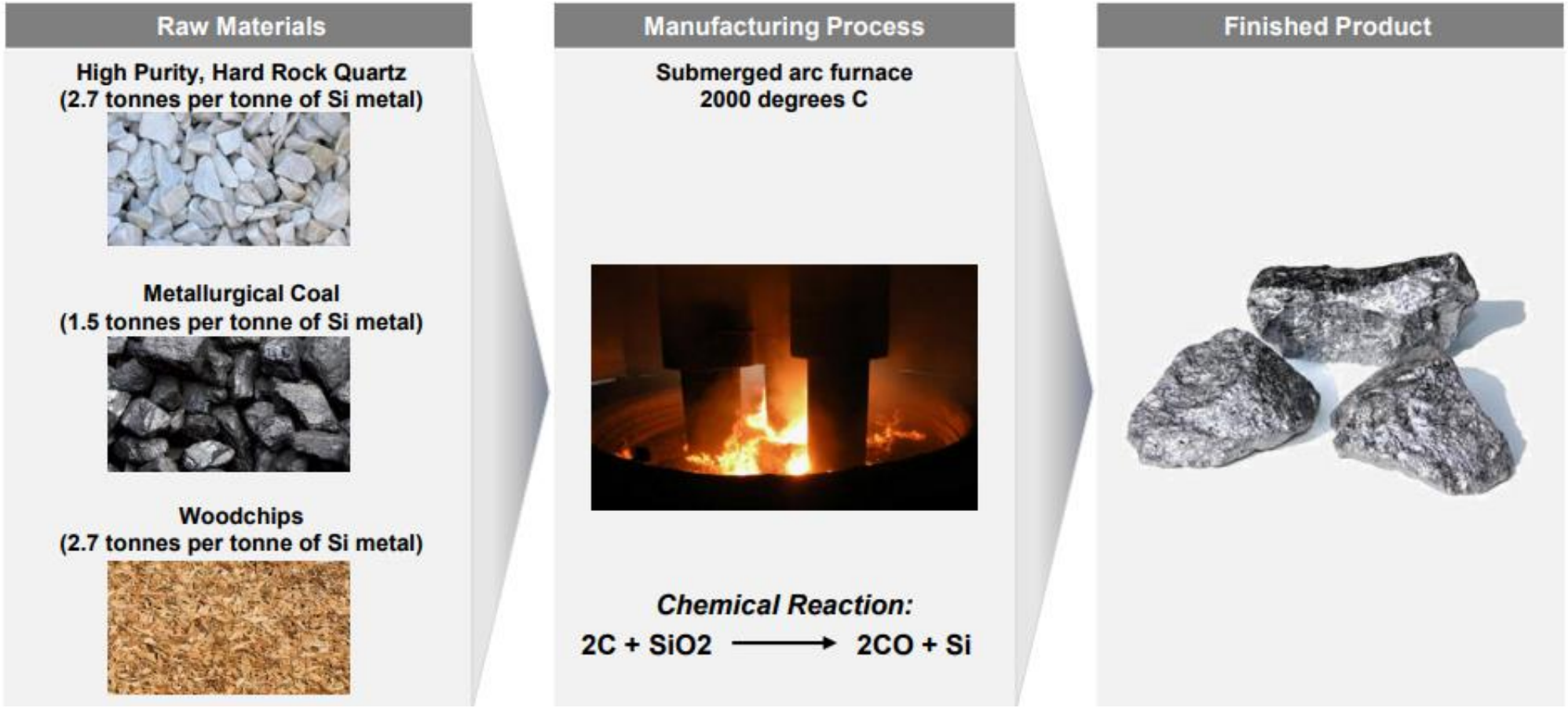
End-of-life PV modules

Production of MG-Si

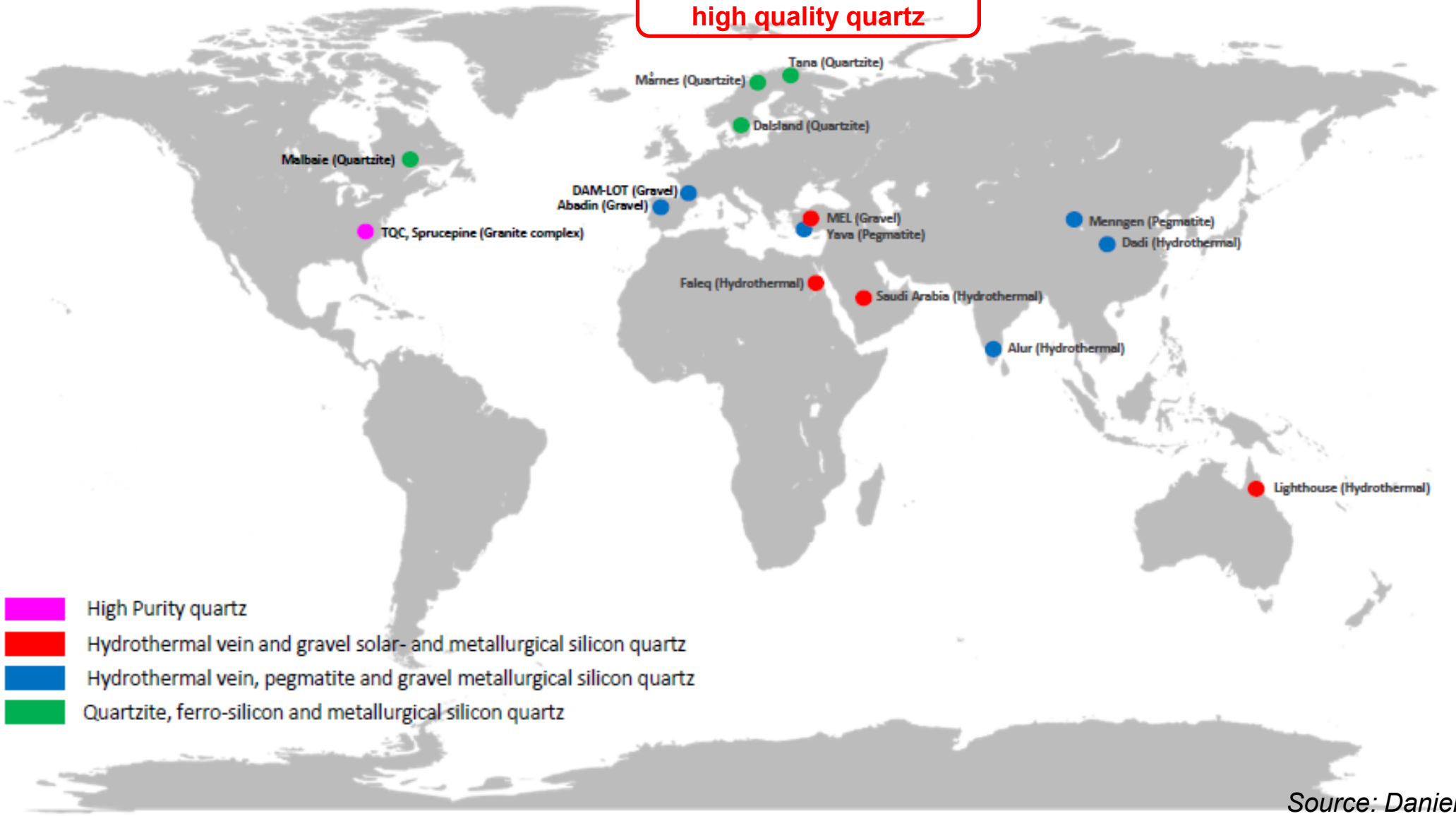
- **Standard manufacturing requires six tons of raw materials to produce one ton of silicon metal**



Source: May Global Business Group INC

Production of MG-Si

Europe has very limited high quality quartz



Source: Daniel Bajolet

Carbon emission of MG-Si production

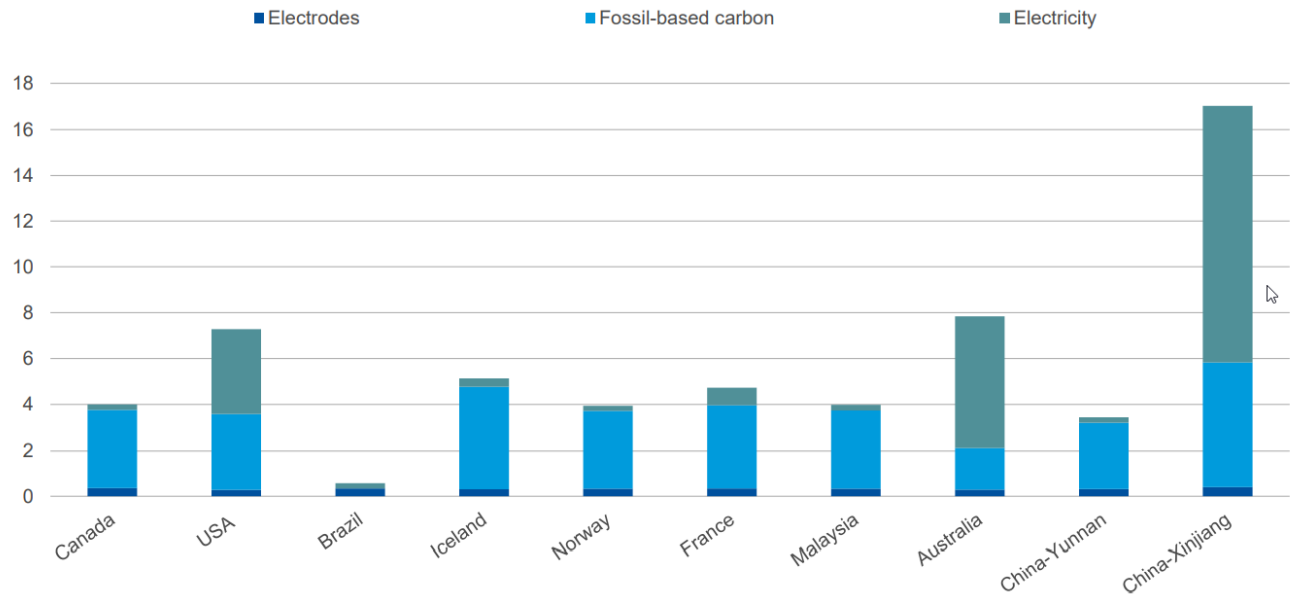
Total carbon emission for MG-Si production is mainly linked to:

- Fixed Carbon to reduce SiO2 to Si:
  - 400kg per ton of quartz
- Intensive electricity consumption:
  - 11 000 – 13 500kwh/t

Electricity price competitivity is decisive:

- Norway – hydro
- Iceland – hydro & geothermal
- France – nuclear
- Quebec/Canada – hydro
- Brazil – hydro & other renewables

Indicative emissions from electricity, fossil-based carbon and electrodes per t of silicon, t CO_2



Source: CRU Group

Main stream routes to obtain PV-grade silicon

6 kg of materials per 1 kg of silicon


Quartz


Wood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Natural resources

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Metallurgic-grade silicon

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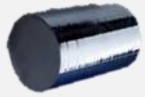
PV-grade silicon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⑤

Panels


Photovoltaic plants

high-value silicon & silver

100% loss

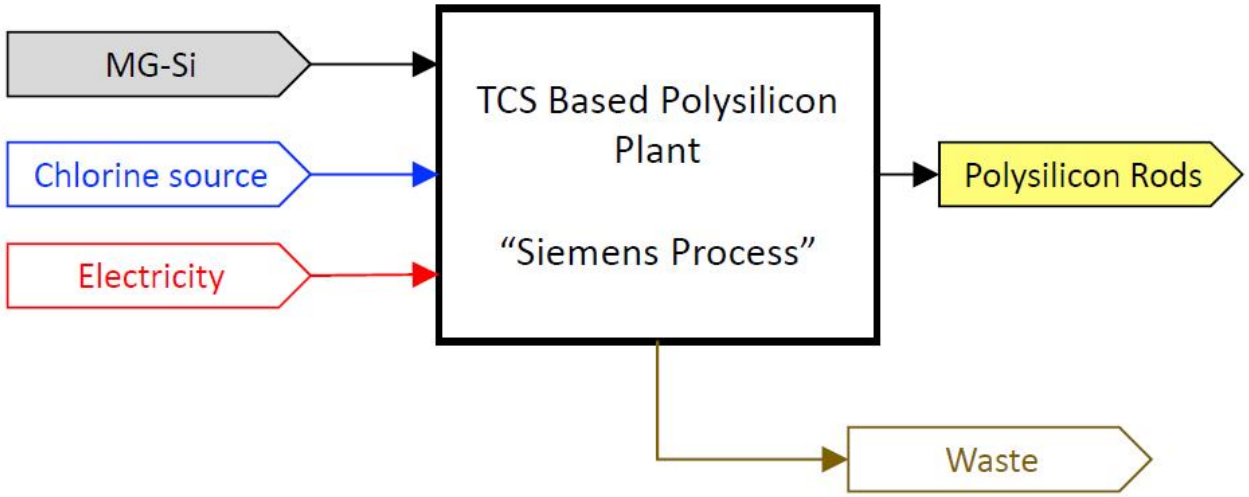

End-of-life PV modules

Solar cells

Main stream route to obtain PV-grade silicon - hydrochlorination

Trichlorosilane (TCS) Based Polysilicon – Most Common

1) Most solar-grade polysilicon is grown in rods by thermal decomposition of trichlorosilane (TCS; $HSiCl_3$)



$Si(s) + 3SiCl4(g) + 2H2(g) = 4HSiCl3(g)$

$4HSiCl3(g) \rightarrow Si(s) + 3SiCl4(g) + 2H2(g)$

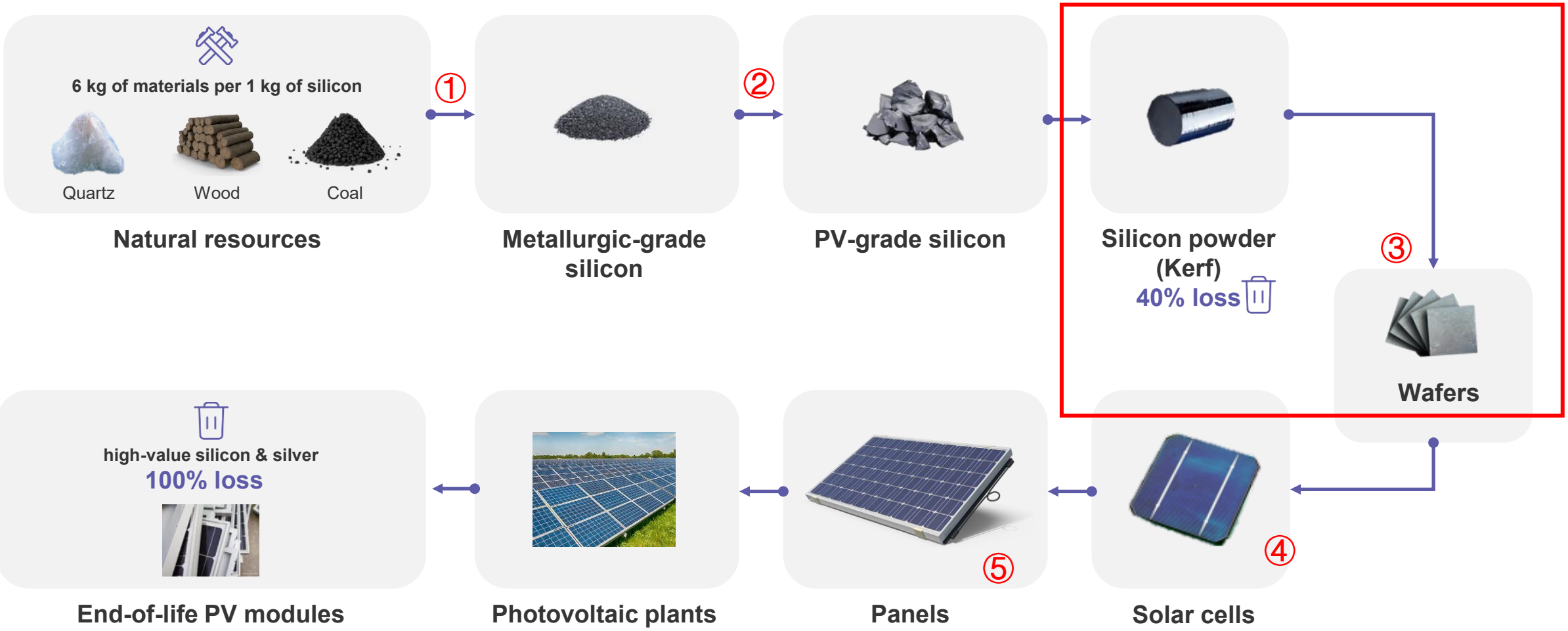
Source: Alan Crawford Consulting

Main stream routes to obtain PV-grade silicon

A poly-Si production site is large, complicated, and with very high industrial risk.

Source: REC

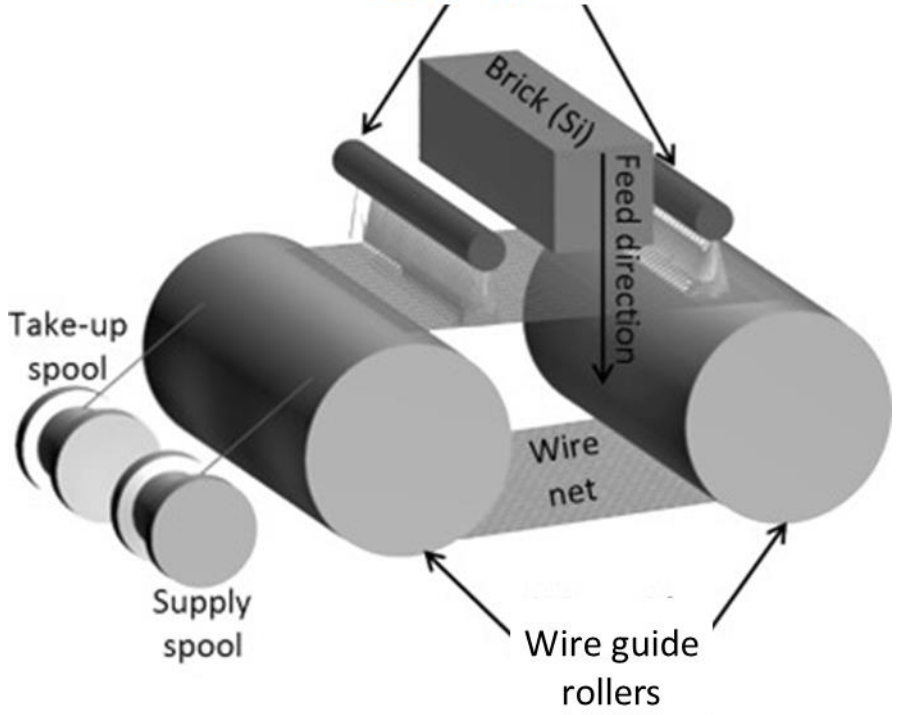
First significant value loss



First significant value loss

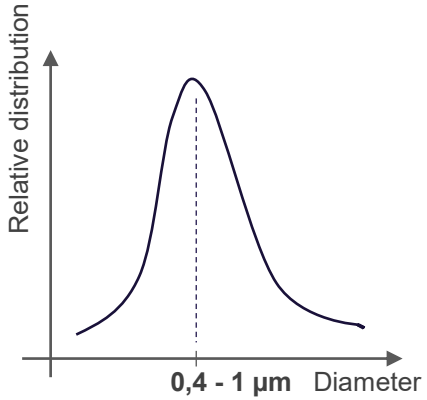
Additives:
- Lubrication, cooling, washing

Diluted Additives spray:



After sawing

Coolant + kerf mixture
- **High TOC value**
- **Discharge silicon**



Si kerf powder size

Solar cells – a delicate current generating device

6 kg of materials per 1 kg of silicon

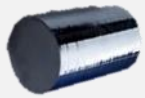
Natural resources

①

Metallurgic-grade silicon

②

PV-grade silicon



Silicon powder (Kerf)

40% loss

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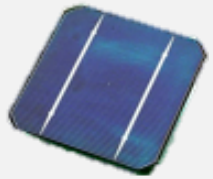
Wafers



④

Solar cells

⑤

Panels

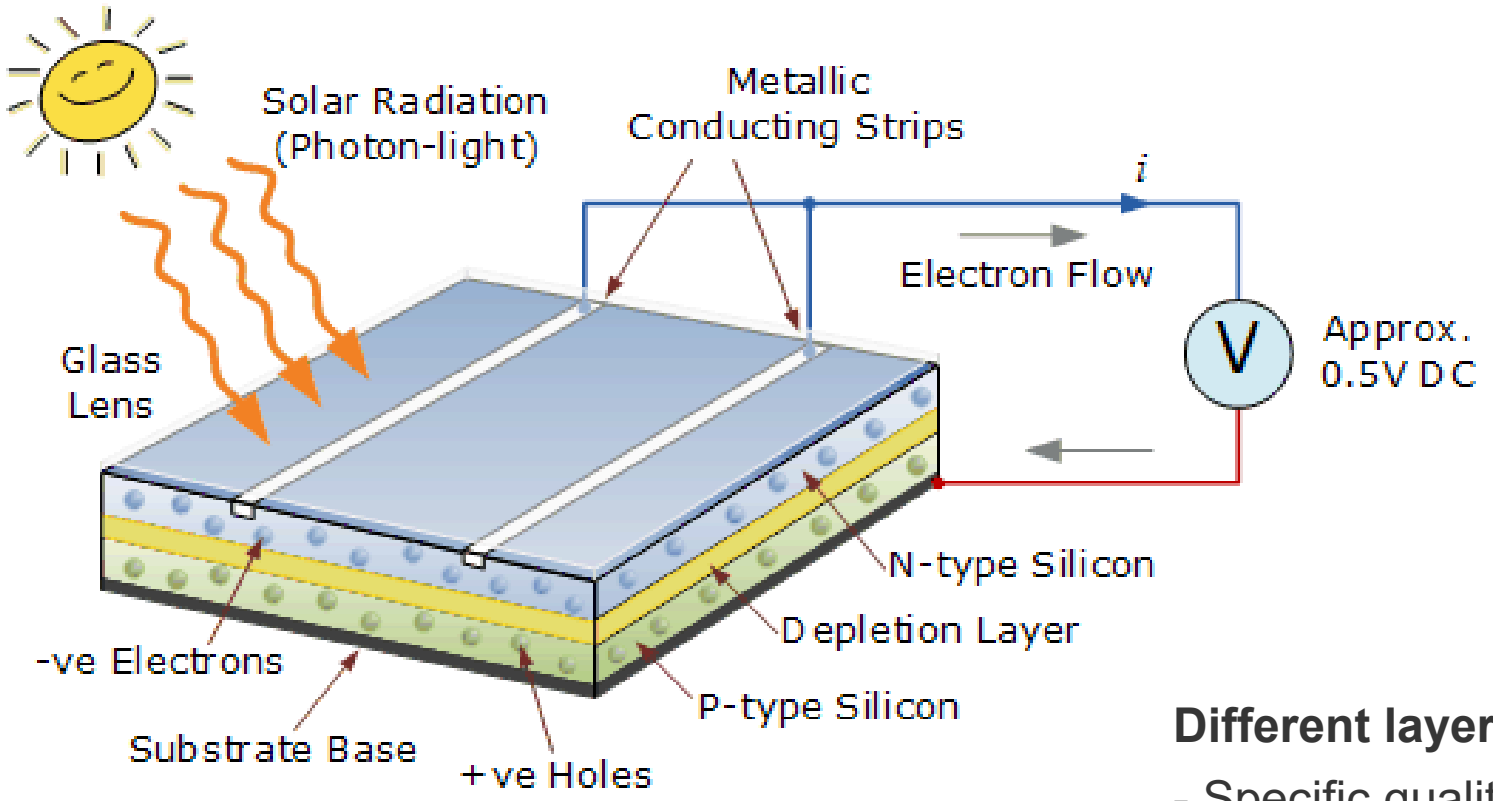
Photovoltaic plants

high-value silicon & silver

100% loss

End-of-life PV modules

Solar cells – a delicate current generating device



Different layers are doped differently

- Specific quality in the recycled silicon
- Reintegration route must be specially designed

Solar modules – designed to be long lasting

6 kg of materials per 1 kg of silicon

Quartz Wood Coal

Natural resources

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Metallurgic-grade silicon

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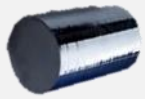
PV-grade silicon



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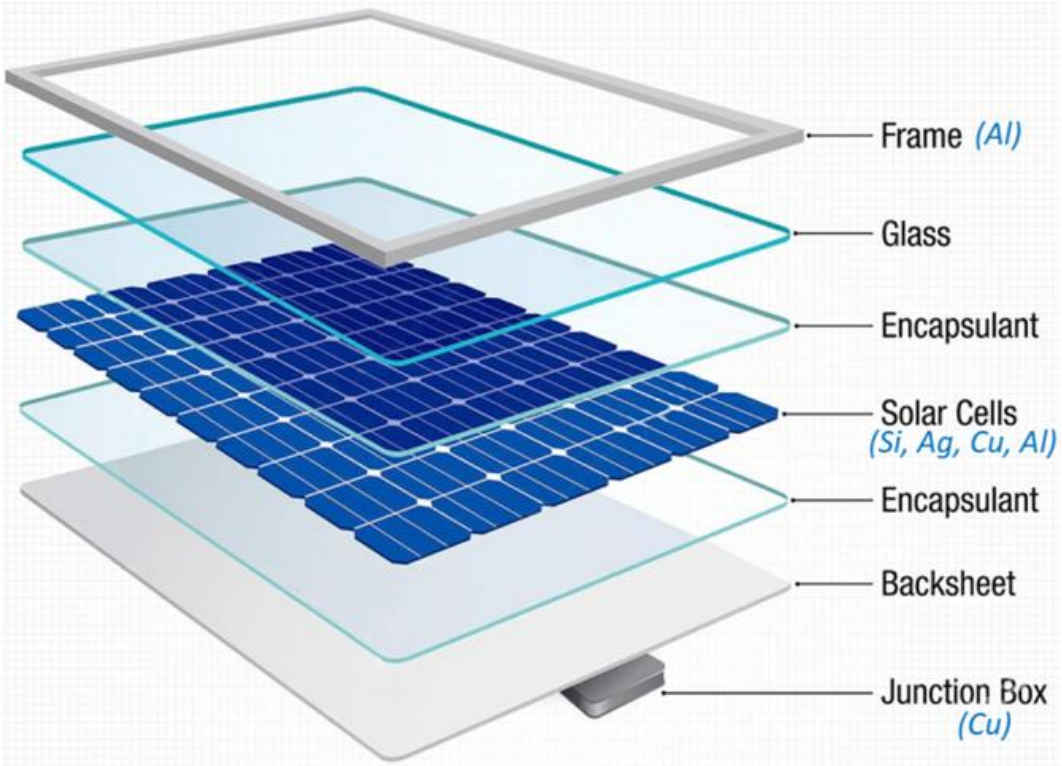
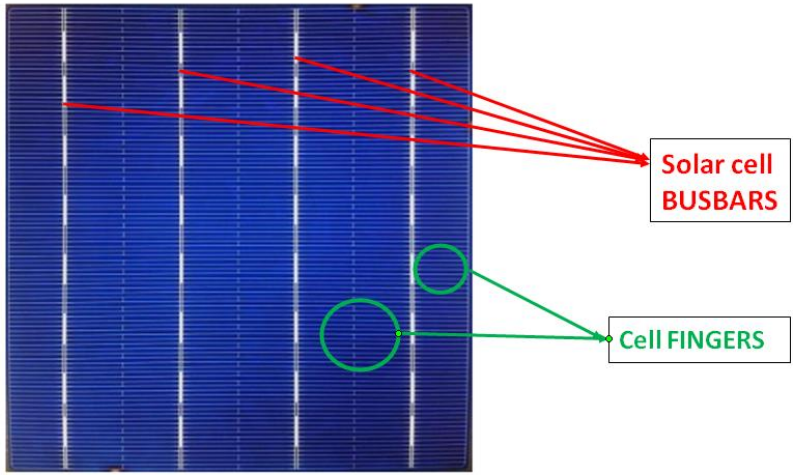
End-of-life PV modules

Solar modules – designed to be long lasting

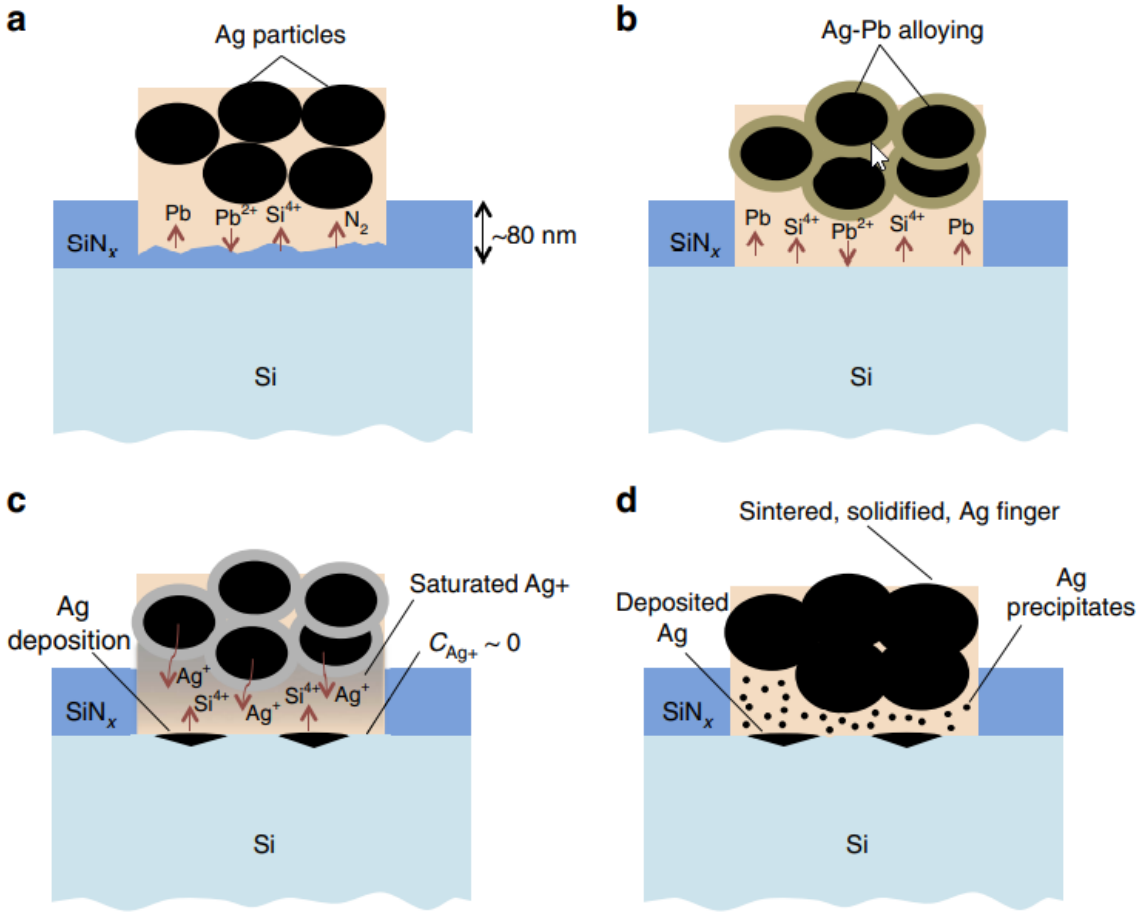


Good encapsulation is ensured by a good cross-linking of EVA (ethylene vinyl acetate) during lamination as well as good adhesion by adhesion promotors.

Silver – important role for electricity extraction



Screen printing: Ag particles, organic binders and metal-oxide glass frit (PbO based).



J. D. Fields et al, Nature Communications, 01/04/2016

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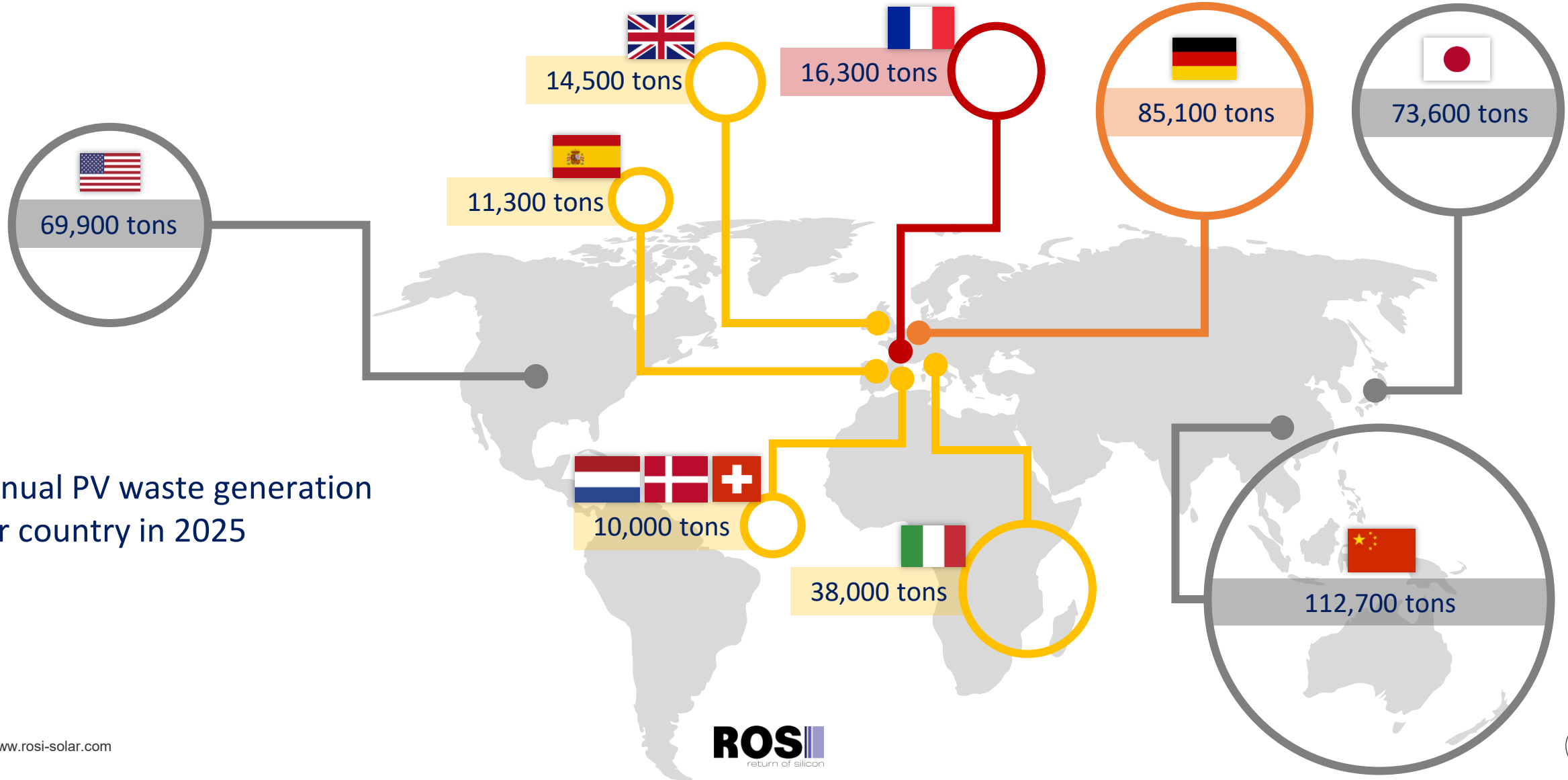
Sources of old modules

- Modules with degraded performance (less than 20% original power output)
- Modules broken by weathering (hail, rain, snow etc)
- Repowering projects
- Out of specification from PV production
  - 1GW production with 1% out-of-specification -> 500 tons per year

Solar modules – A Tsunami is coming



Annual PV waste generation per country in 2025

EU regulations

- **EU regulation:**
  - PV modules recycling: **legal obligation** in WEEE directive
  - EU Member States have **national regulations**
  - Recycling targets: **80%** since 2018

- **Dedicated EPR* system with financing mechanism to foster recycling in EU**

** Extended producer responsibility*

Update on the WEEE directives

- **Purpose and scope**:
  - **5 evaluation criteria**: effectiveness, efficiency, relevance, coherence and EU added value
  - Examples of issues that evaluation is expected to address:
    - WEEE is one of the fastest growing waste streams in Europe- waste prevention and reuse
    - The WEEE collection is unsatisfactory- it needs to be significantly increased (doubled)
    - WEEE contains precious and critical raw materials the recovery of which is significant for the circular economy
  - help determine whether a review is needed.
- **Timeline**
  - **Call for evidence:** "Have your say" web-portal – 4weeks: from 6 October to 3 November 2022
  - **Study** to support the evaluation of the WEEE Directive (to be launched soon)
    - 12-week open public consultation: to be launched in Q1 2023
    - Targeted consultation of stakeholders and Member States (meetings/ workshops/ etc)
    - Workshop (probably in Q3 2023)
- **Commission Staff Working Document:** planned for adoption in the Q2 2024.

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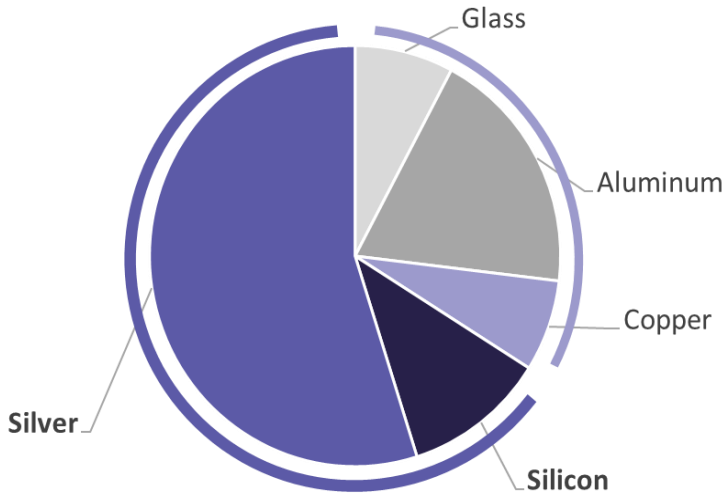
Challenge for proper PV module recycling

Low purity recycling today
- Mechanical shredding leads to value loss as the separated materials are hardly pure
- Recycling activities live on gate-fee

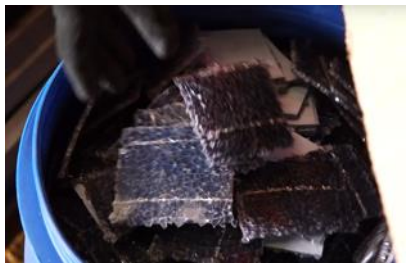


Value of recyclable materials in end-of-life PV modules

High purity recycling from today on
- High value comes from high purity
- Profitability comes from high volume

Bottle-necks:
- Proper delamination to access the materials with high purity
- Cost-effectivity
- Environmentally friendly
- Reintegration into industries of value

No industrial scale mechanical solution for high purity Si, Ag, & Cu

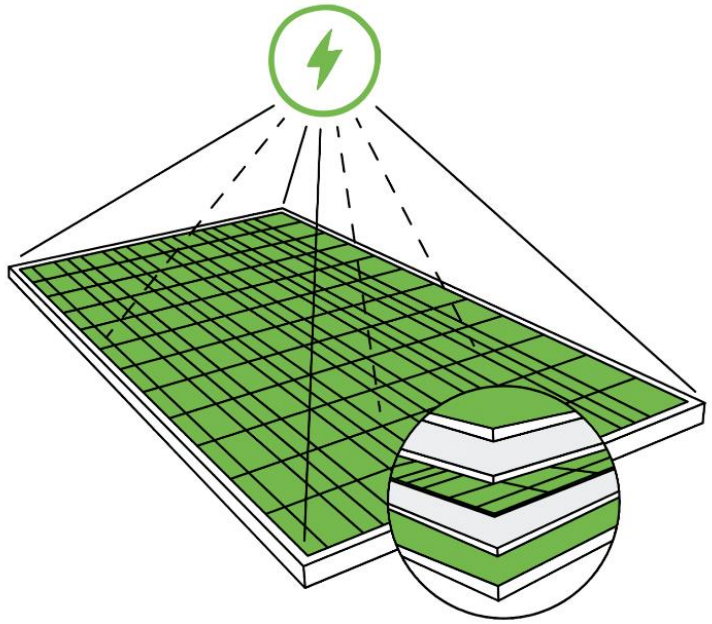


Publicly accessible photos from internet

Promising delamination methods

FLAXRES

sustainable future
through smart technology



LuxChemtech GmbH

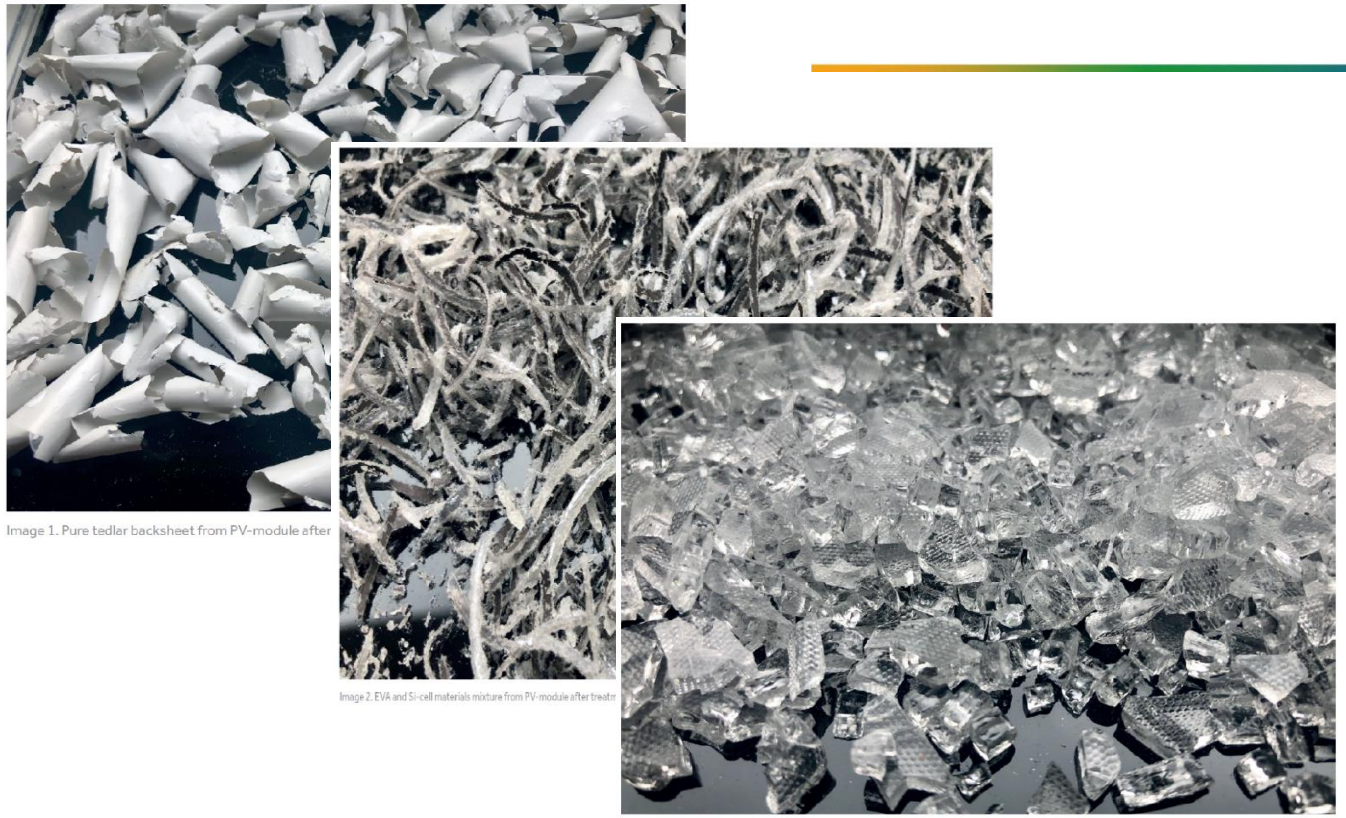


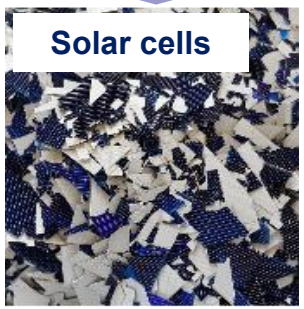
Image 1. Pure tedlar backsheet from PV-module after

Image 2. EVA and Si-cell materials mixture from PV-module after treatm

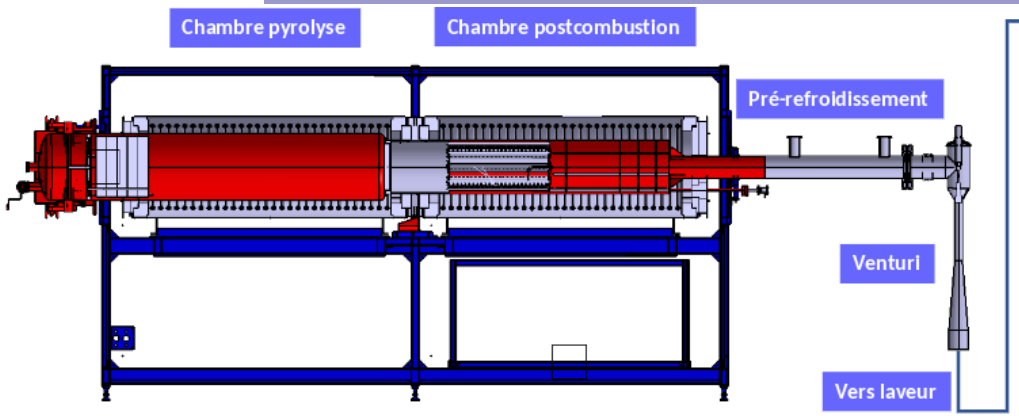
Image 5. Glass cullet outcome from Aqualux.

Publicly accessible photos from internet

ROSI's choice of technologies



Delamination through a controlled pyrolysis process



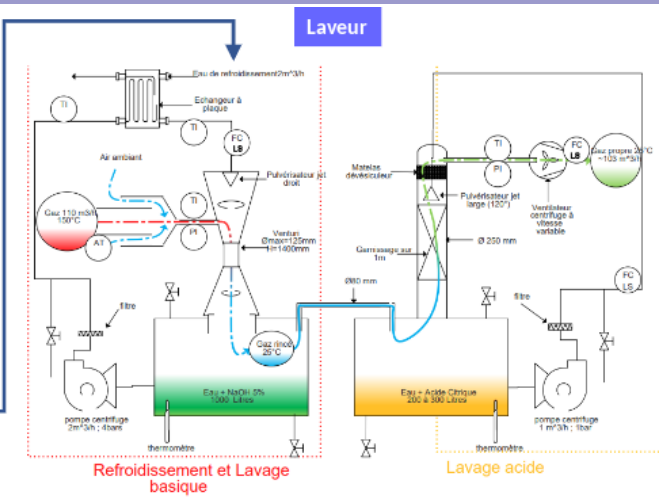
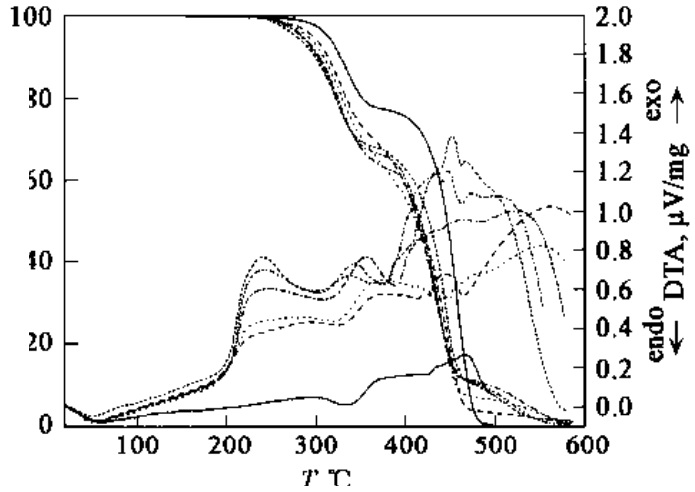


Table 1 Thermal properties of EVA copolymers measured by DSC

Elvax* grade	VA, wt.%	Melt point, ℃	Heat of fusion, J/g
40W	40	47	23
150	33	63	34
240	28	74	–
360	25	78	53
460	18	88	65
660	12	96	78
760	9	100	82

Note: * given by Dulpon Company

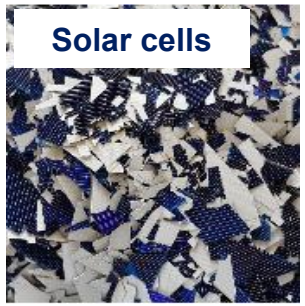


N_2 ····· Air
---- 0.5 vol.% O_2 + 99.5 vol.% N_2
- - 5 vol.% O_2 + 95 vol.% N_2
- - - - 10 vol.% O_2 + 90 vol.% N_2
——— 15 vol.% O_2 + 85 vol.% N_2

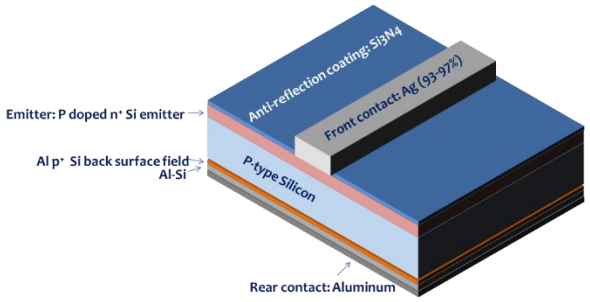
TGA/DTA of EVA copolymer at constant heating K/min under different oxidizing atmospheres

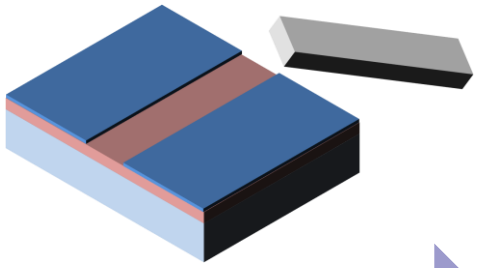
Zeng et al, Journal of Environmental Sciences, 16, 6 , p889, 2004

ROSI's choice of technologies

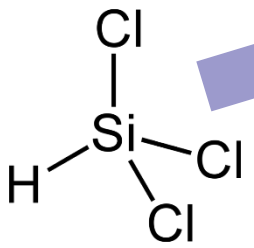


A patented mild chemical-mechanical route



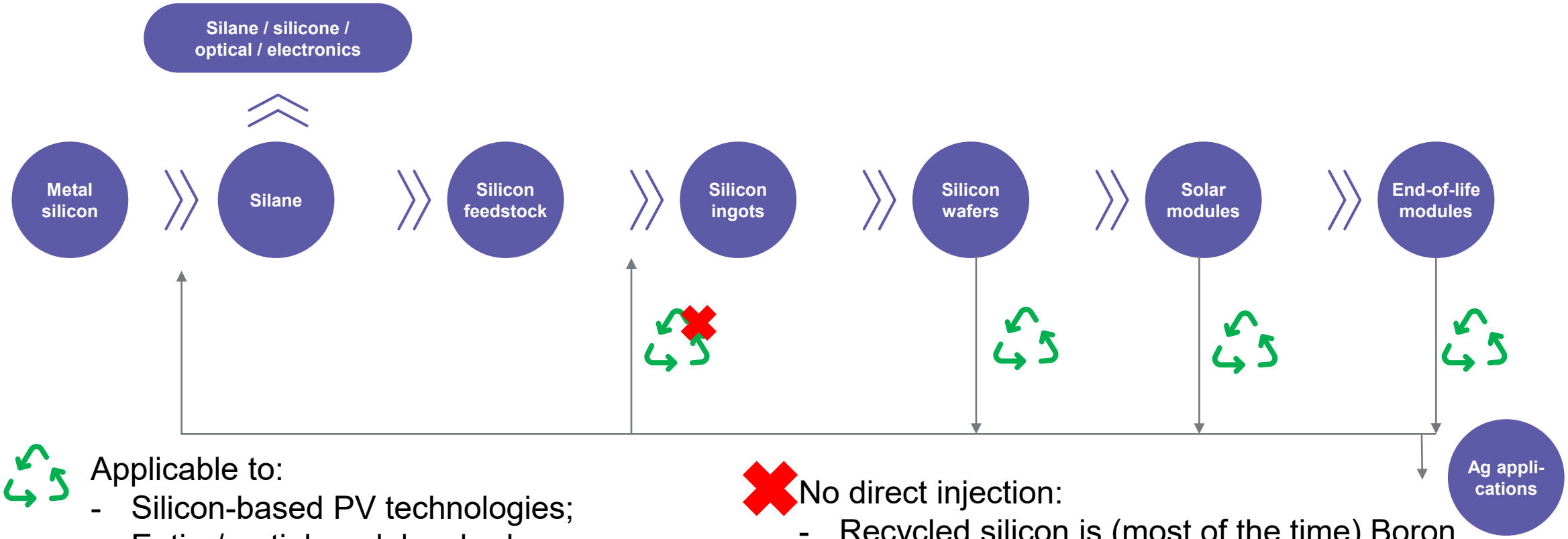


ROSI patent



- PV
- Semi-conductor
- Optics
- Battery storage

ROSI's choice of technologies for reintegrating recycled materials



Applicable to:
- Silicon-based PV technologies;
- Entire/partial modules, broken modules, out-of-norm modules/cells from PV production lines or transportation

-> For high purity silane (including PV/semiconductor/battery) market

No direct injection:
- Recycled silicon is (most of the time) Boron doped. Boron segregates difficultly.
- Even with some technologies to help segregating (EM field), process cost is high and loss of silicon materials is important

-> no chance to contribute to high efficiency cells

Some reflections

Market volume – we have absolutely enough volume to start the activities

2min per module – 650 modules per day @3shifts – 300 days per year – less than 4000 tons per year

Fluorinated polymer in the backsheet – no problem for pyrolysis with state-of-the art gas treatment systems

Within the exigence French emission ranges

No traditional hydrometallurgical route for metal recycling – for the reason of environment and the cost

Importance in the process integration – profitability shall not come from gate-fee

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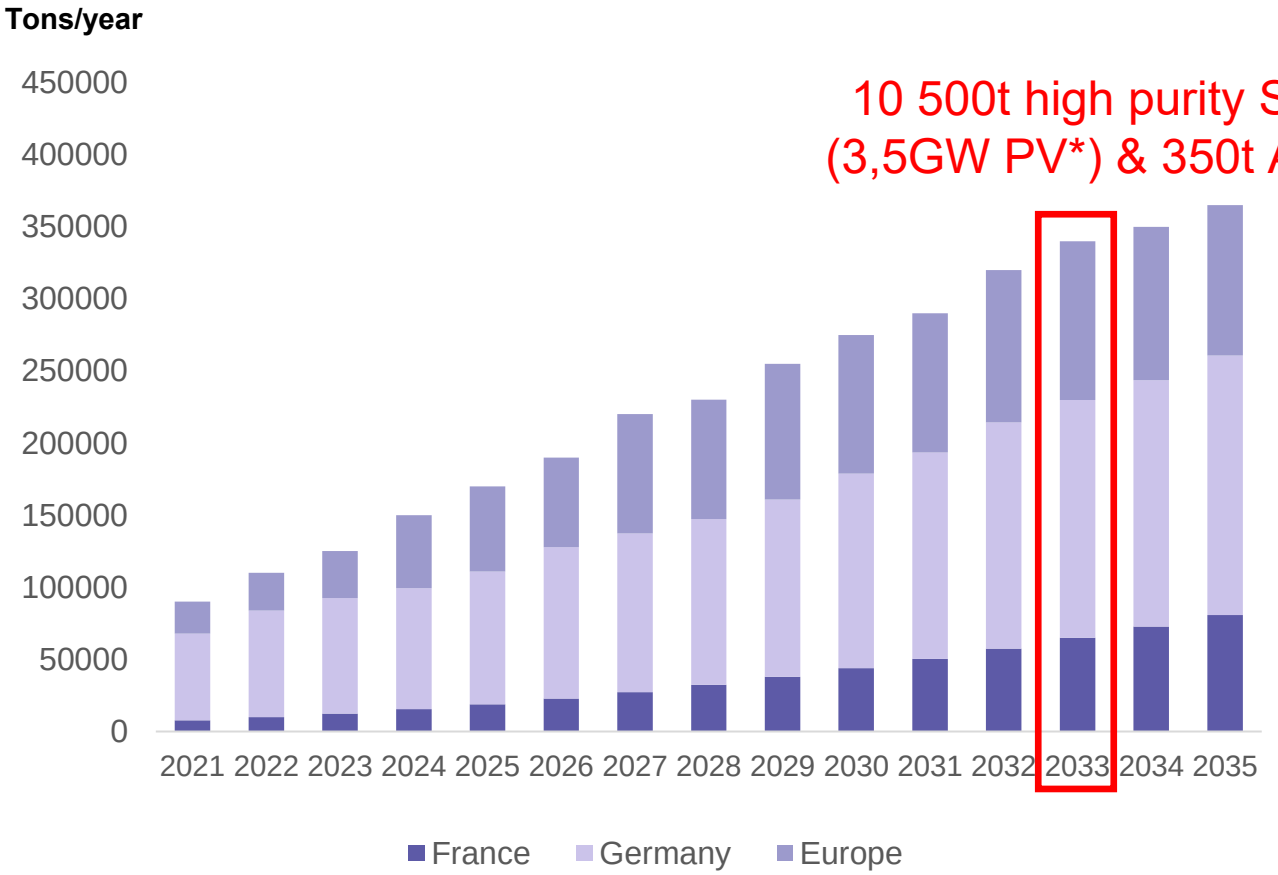
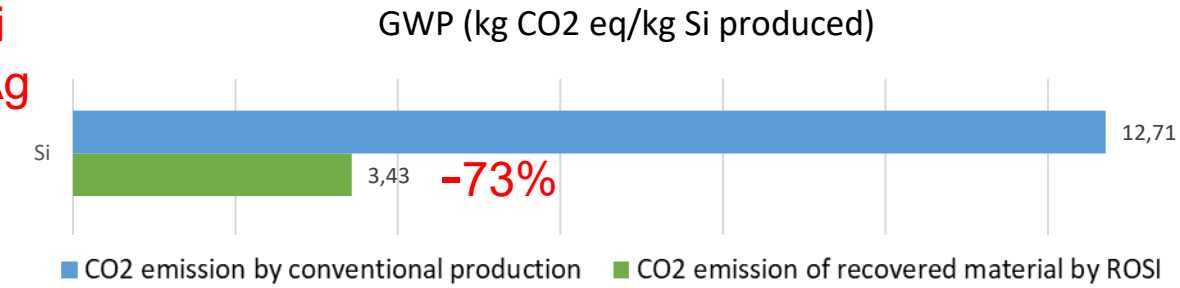
Si: a big benefit to the industry

Annual end-of-life PV modules to be treated in Europe (tons/year)



** Recycling of PV modules and kerf can cover a majority of RM need for EU PV manufacturing.*



The poly-silicon need for relocalising EU-PV production can rely fully on the recycling of end-of-life PV modules and wafer sawing kerf in the coming years.

Si – CRM for EU industries

- Every GW PV manufacturing
  -> 3 000 ton of high purity silicon
- Battery:
  EU ambition of 300GWh by 2025
  ->30 000 tons of high purity silicon

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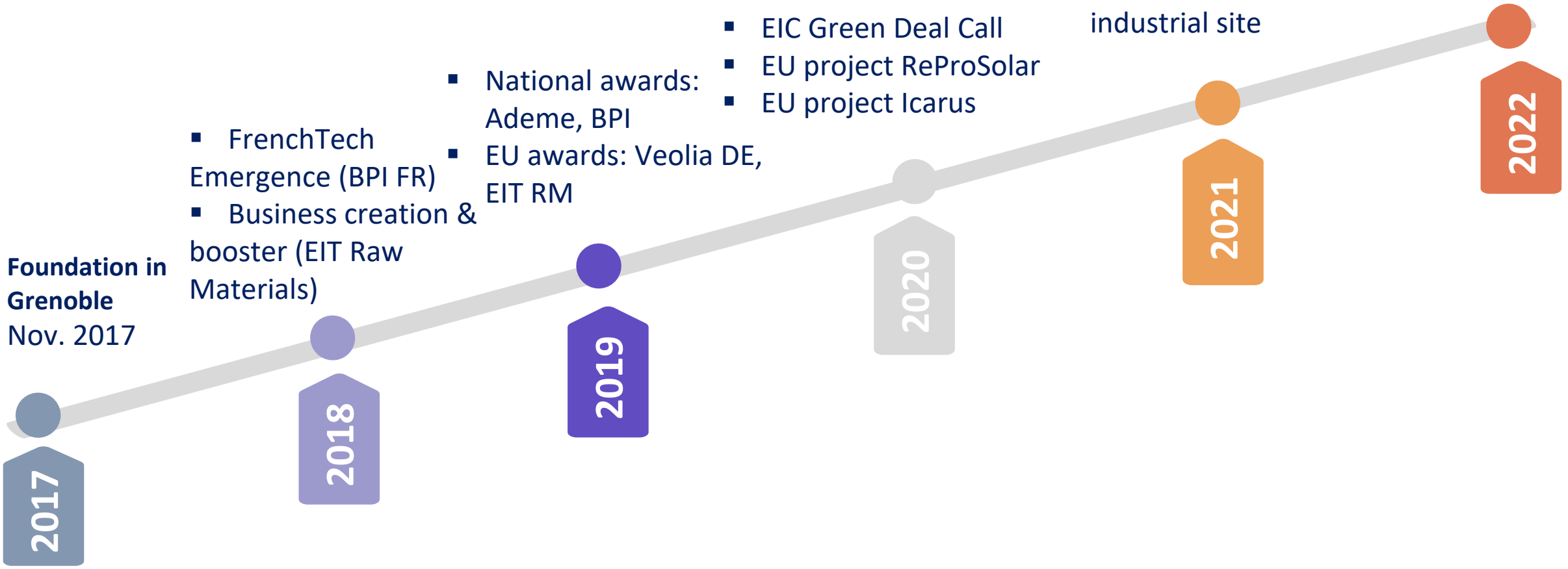
ROSI milestones



A dynamic and devoted team

Dr. Yun Luo
Co-founder & CEO

Antoine Chalaux
CMO

Dr. Guy Chichignoud
Co-founder & CTO

Sébastien Schneider
CFO

Engaged young team (25 FTE)

Impact of ROSI and its technologies

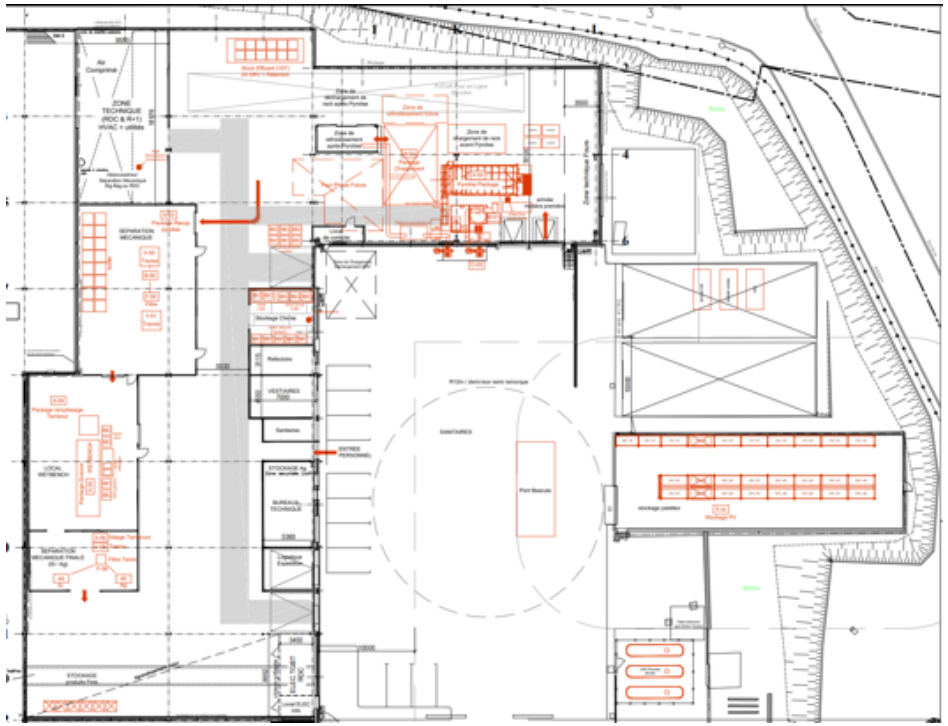
"Industry 5.0" award from the European Commission 2022.

1st prize, Special category – blue and green economy, SIT from the European Investment Bank 2022

National laureate of startup category of 'Entrepreneur of the year EY 2022

World’s first dedicated high purity recycling site

CEG – Centre d’Excellence de Grenoble



- Applicable for all the Si-PV modules morphology (w/t glass & Al & J-box, integer/broken modules)

- High purity recycled raw materials

Join us for this adventure!

Important values:

- Open, dynamic, objective, and modest in mindset;
- Feet on the ground;
- Believe in the power of rational technology;
- Understand that business is P(erson)-2-P(erson).

Ingénieur·e développement industriel

Contrat / **CDI**
Localisation / **Saint Martin d'Hères**

ROSI est une start-up qui ambitionne de mettre la technologie au service de l'économie circulaire de demain. Nous avons à cœur de proposer des solutions innovantes pour recycler et revaloriser les matières premières issues de l'industrie photovoltaïque.

Nous maîtrisons les enjeux industriels et technologiques de notre filière. Nous sommes convaincus que

Chef de projet – Création de ligne industrielle H/F

Vertrag / CDD gefolgt von CDI
Contrat / CDD suivi par CDI
Standort / Deutschland
Localisation / Allemagne

ROSI ist eine Start-up Firma, die sich zum Ziel gesetzt hat, Technologien in den Dienst der Kreislaufwirtschaft

Technico-commercial H/F

Contrat / **CDI**
Localisation / **Saint Martin d'Hères**

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Nous maîtrisons les enjeux industriels et technologiques de notre filière. Nous sommes convaincus que nous pouvons la faire évoluer pour la rendre circulaire. C'est dans cet objectif que nous nous attachons

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ROSI

return of silicon

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