# STARCELL

Advanced strategies for substitution of critical raw materials in photovoltaics (H2020-NMBP-03-2016-720907)

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# OUTLINE

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ACKNOWLEDGEMENTS

STARCELL

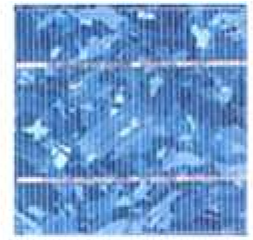
## Classification of available PV technologies

### Wafer-based Si

- Rigid (Si-wafer)
- Cut out of blocks (ingots)
- Technology mature, long lifetimes

Mono-crystalline

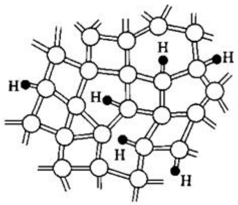
Poly-crystalline



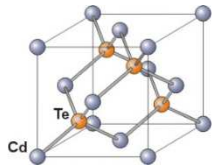
### Thin Film PV

- Deposition of thin films, choice of substrate
- High cost reduction potential
- Low energy payback times

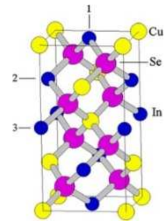
Amorphous Si




CdTe



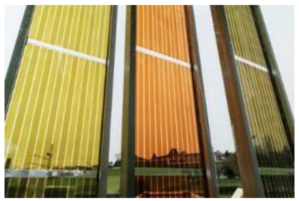

$Cu(In,Ga)(S,Se)_2$



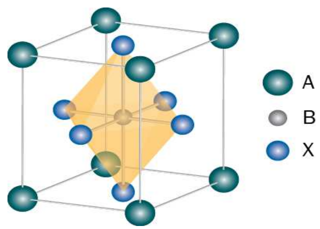

### Emerging PV

- Promising, but still less mature technologies
- New materials and concept
- Efficiency or stability main challenges

OPV/DSSC/QD



Perovskites



# 1. INTRODUCTION

## 1.1. Critical raw materials in PV

EUROPEAN COMMISSION

Brussels, 26.5.2014
COM(2014) 297 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative

{SWD(2014) 171 final}

| Raw materials | Main producers (2010, 2011, 2012) | Main sources of imports into the EU (mainly 2012) | Substitutability index* | End-of-life recycling input rate** |
|---|---|---|---|---|
| Gallium[5] | China 69 % (refined) | USA 49 % | 0.60 | 0 % |
| | Germany 10 % (refined) | China 39 % | | |
| | Kazakhstan 6 % (refined) | Hong Kong 8 % | | |
| Indium | China 58 % | China 24 % ↓ | 0.82 | 0 % |
| | Japan 10 % | Hong Kong 19 % ↑ | | |
| | Korea 10 % | Canada 13 % | | |
| | Canada 10 % | Japan 11 % | | |
| Silicon metal (Silicium) | China 56 % | Norway 38 % | 0.81 | 0% |
| | Brazil 11 % | Brazil 24 % | | |
| | USA 8%; Norway 8 % | China 8 % | | |
| | France 6 % | Russia 7 % | | |

- In, Ga and Silicon Metal are identified by the EC as critical raw materials with high difficulty in substituting these materials:
  - ❖ In and Ga are used in commercial Cu(In,Ga)$Se_2$ thin film PV modules:
    - o In is mainly used in the flat screen industry
    - o Ga is mainly used in lighting applications
  - ❖ Silicon metal is used in commercial crystalline and microcrystalline Si PV modules
    - o Si is mainly used in the aluminium casting, ferrosilicon and microelectronic

# 1. INTRODUCTION

## 1.1. Critical raw materials in PV

The STARCELL

*Table 7.* Estimated use of CRM and tellurium for the three main PV technologies in the market based on meeting the entire past (2014) and forecast (2019 and 2030) PV market demands.

| PV technology | CRM usage [tonnes per GW] | CRM usage to cover [entire PV market demand] (and percentage of existing/forecast global supply of CRM) | | | |
|---|---|---|---|---|---|
| | | 2014 | 2019 | | 2030 |
| | | [40GW] | Low Scenario [121 GW] | High Scenario [158 GW] | [300GW] |
| **Crystalline Silicon** [2] | 6,000t *Silicon metal* | 240,000t (12.7%) | 726t (27.9%) | 948t (36.4%) | 1,800,00t (NA) |
| **CdTe** | 93t *Tellurium** | 3,720t (501%) | 11,300t (900%) | 14,700t (1170%) | 27,900t (1300%) |
| **CIGS** [46] | 7.2t *Gallium* | 288t (100%) | 871t (193%) | 1,137t (252%) | *2,160t (324%)* |
| | 14.4t *Indium* | 1008t (74%) | 3,049t (160%) | 3,980t (209%) | 7,557t (288%) |

*(*) Tellurium is not currently included in the list of CRMs, although availability will likely limit the growth of CdTe technology*

- In a low scenario for 2019:
  - 28% of produced silicon metal will be required for PV, or
  - 193% of produced In and 160% of produced Ga, or
  - 501% of produced Te

# EC call for substitution of critical raw materials in key technologies: H2020-NMBP-03-2016

EU Programmes 2014-2020

- Search Topics
- Updates
- Calls
  - H2020
  - 3rd Health Programme
  - Asylum, Migration and Integration Fund
  - Consumer Programme
  - COSME
  - Hercule III Programme
  - Internal Security Fund - Borders
  - Internal Security Fund - Police
  - Justice Programme
  - Pilot Projects & Preparatory Actions
  - Promotion of Agricultural Products
  - Research Fund for Coal & Steel
  - Rights, Equality and Citizenship Programme
  - Union Civil Protection Mechanism

## TOPIC : Innovative and sustainable materials solutions for the substitution of critical raw materials in the electric power system

**Topic identifier:** NMBP-03-2016
**Publication date:** 14 October 2015

**Types of action:** RIA Research and Innovation action
**DeadlineModel:** two-stage
**Opening date:** 15 October 2015
**Deadline:** 08 December 2015 17:00:00
**2nd stage Deadline:** 24 May 2016 17:00:00

Time Zone : (Brussels time)

Horizon 2020 — H2020 website
Pillar: Industrial Leadership
Work Programme Year: H2020-2016-2017
Work Programme Part: Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing
Call : H2020-NMBP-2016-2017 — Call budget overview

### Topic Description

\+ More

**Specific Challenge**:

The ambition of the European Union to achieve a secure, competitive and sustainable energy system by 2050 has become a priority. The electric power system will play a pivotal role in the overall energy mix.

### Topic conditions and documents

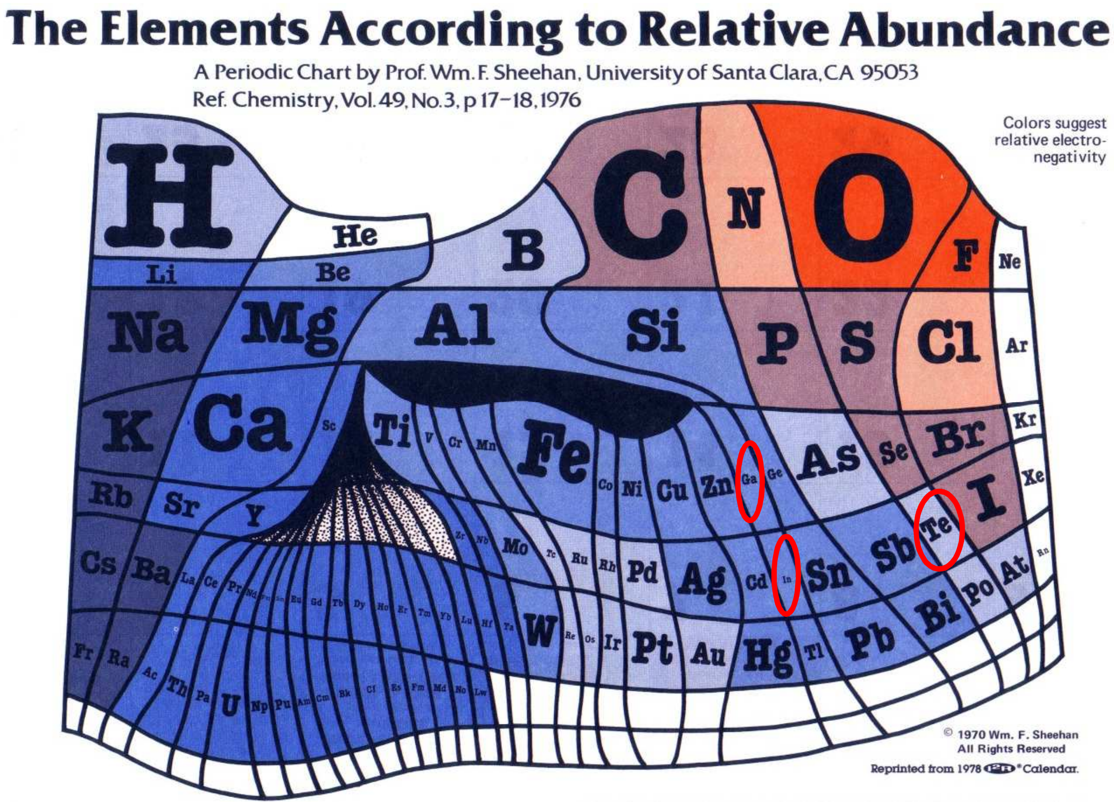
\+ More

**Please read carefully all provisions below before the preparation of your application.**

### Submission Service

No submission system is open for this topic.

## We need new sustainable solutions based on earth crust abundant elements

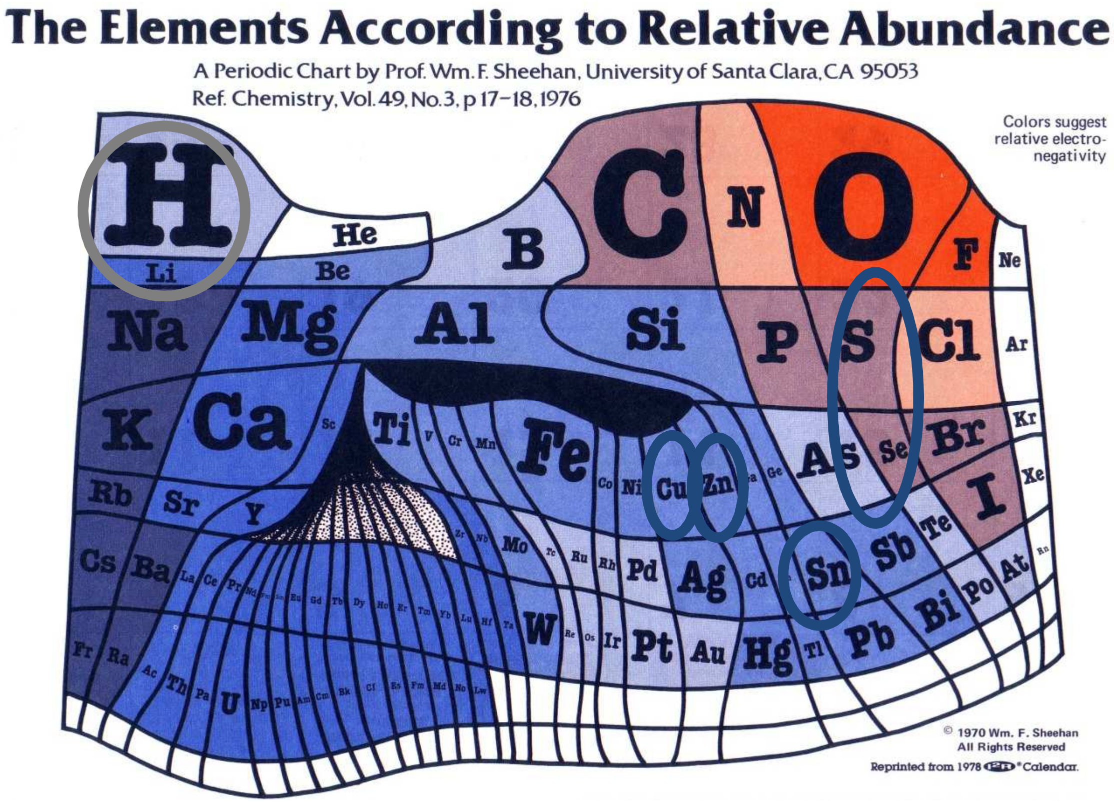



- In, Ga and silicon metal are considered scarce materials that can have concerns for the future development of thin films PV technologies (additionally Cd has the toxicity associated problems)

WE NEED TO EXPLORE MATERIALS BASED ON EARTH ABUNDANT ELEMENTS

# 1. INTRODUCTION

## 1.2. Advanced solutions: beyond the state-of-the-art




AFTER SEVERAL YEARS OF RESEARCH

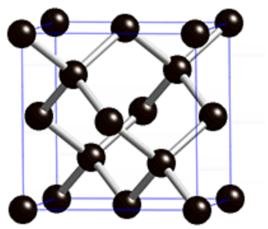
- Cu-chalcogenide based absorbers: where kesterites ($Cu_2ZnSn(S,Se)_4$) are at the forefront on new inorganic thin film PVs

# 1. INTRODUCTION

## 1.2. Advanced solutions: beyond the state-of-the-art

**Diamantine**

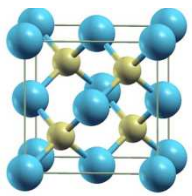
C, Si



**Chalcogenides**

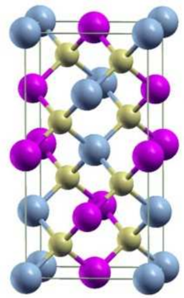
**Zink blende**

ZnSe, CdTe
Cd(Te,Se)



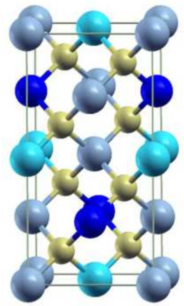

**Chalcopyrite**

$CuInSe_2$
$Cu(In,Ga)(S,Se)_2$




**Kesterite**

$Cu_2ZnSnSe_4$
$Cu_2(Cd,Zn)(Ge,Sn)Se_4$




Group IV element → Metal (II) Zn,Cd,Hg (+2) → M' (+1) Al,Cu,Ag, → M' (+1)

Metal (II) Zn,Cd,Hg (+2) → M'' (+3) In,Ga → M (+2); M''' (+4)

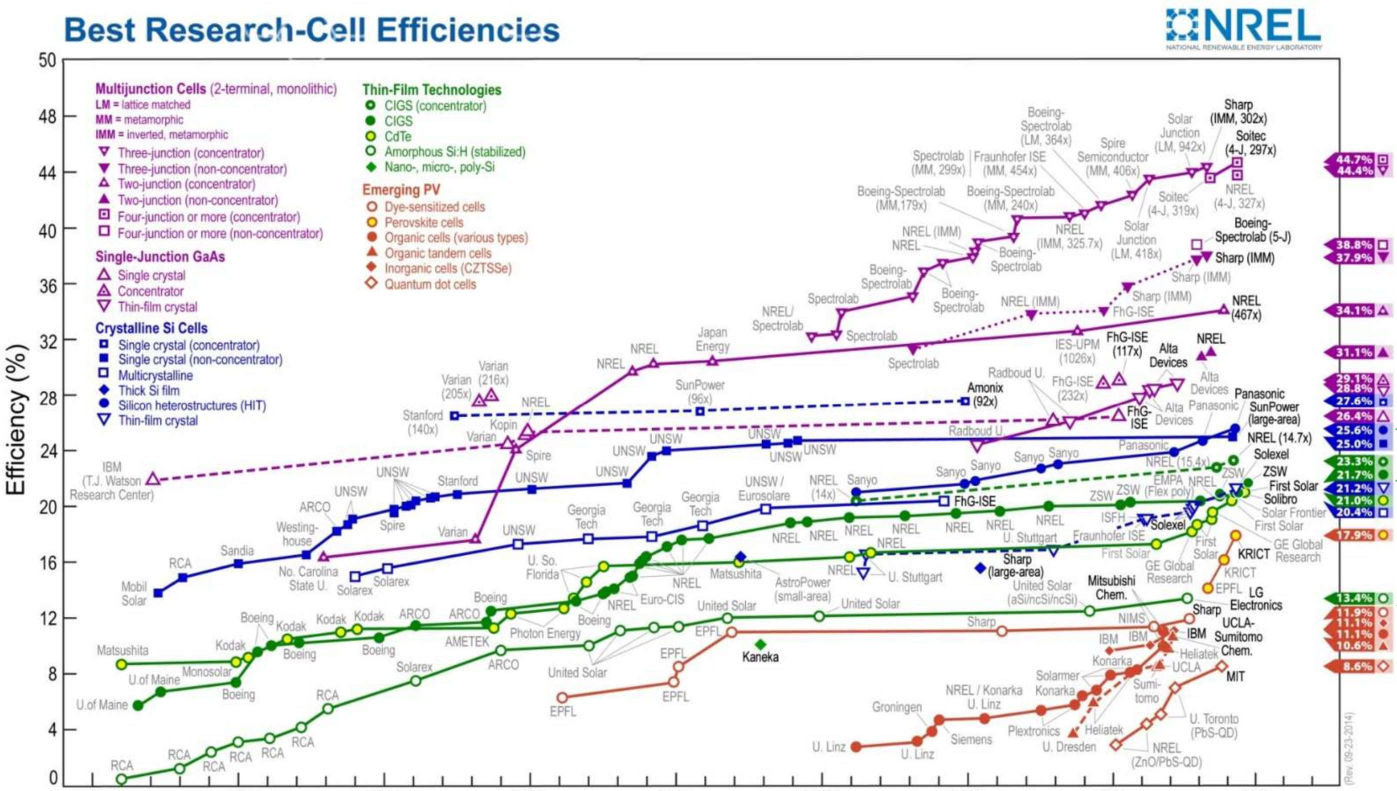
Group IV element → Chalcogen (VI) Se, S, Te (-2) → Ch (-2) → Ch (-2)

Similar structure -> similar opto-electronic properties

Compatible technologies

# 1. INTRODUCTION

## 1.2. Advanced solutions: beyond the state-of-the-art




Si (mono-cryst)

CIGS, Si-poly and CdTe

CZTS

- Conversion efficiency at laboratory scale still lower than conventional PV technologies
- Relatively new technology, lack of maturity
- Requires a lot of efforts from the scientific community to achieve same maturity level than CIGS and CdTe

# OUTLINE

# Advanced strategies for substitution of critical raw materials in photovoltaics

**Call: NMBP-03-2016**: "Innovative and sustainable materials solutions for the substitution of critical raw materials (CRM) in the electric power systems, in particular CRM in materials used in photovoltaic cells". Research and Innovation Action (RIA).

**Coordinator**: IREC (Dr. Edgardo Saucedo)
**Duration**: 36 months (01/01/2017-31/12/2019)
www.starcell.eu

**Consortium**: 13 partners
**Budget**: 6:218.203 €

STARCELL aims to substitute two critical raw materials (In and Ga) used in conventional thin film photovoltaic (PV) technologies, via the introduction of sustainable kesterite ($Cu_2ZnSn(S,Se)_4$ – CZTS) semiconductors.

STARCELL MAIN OBJECTIVE:
Eliminate all materials classified as CRM from cost effective thin film PV technologies through development and use of earth abundant kesterite materials from Cu, Zn, Sn, S and Se.

STARCELL TARGET:
Optimise materials, processes and devices to achieve a kesterite solar cell with 18% efficiency (16% at mini-module level) at a cost ≤ 0.30 €/Wp at TRL5.

## 2. STARCELL description

### 2.1. Main Characteristics and Objectives

- 13 Partners
- 8 Countries
- 3 Continents
- 5 Research Institutes
- 4 Universities
- 4 Companies
- More than 45 researchers involved

## 2. STARCELL description

### 2.2. Consortium

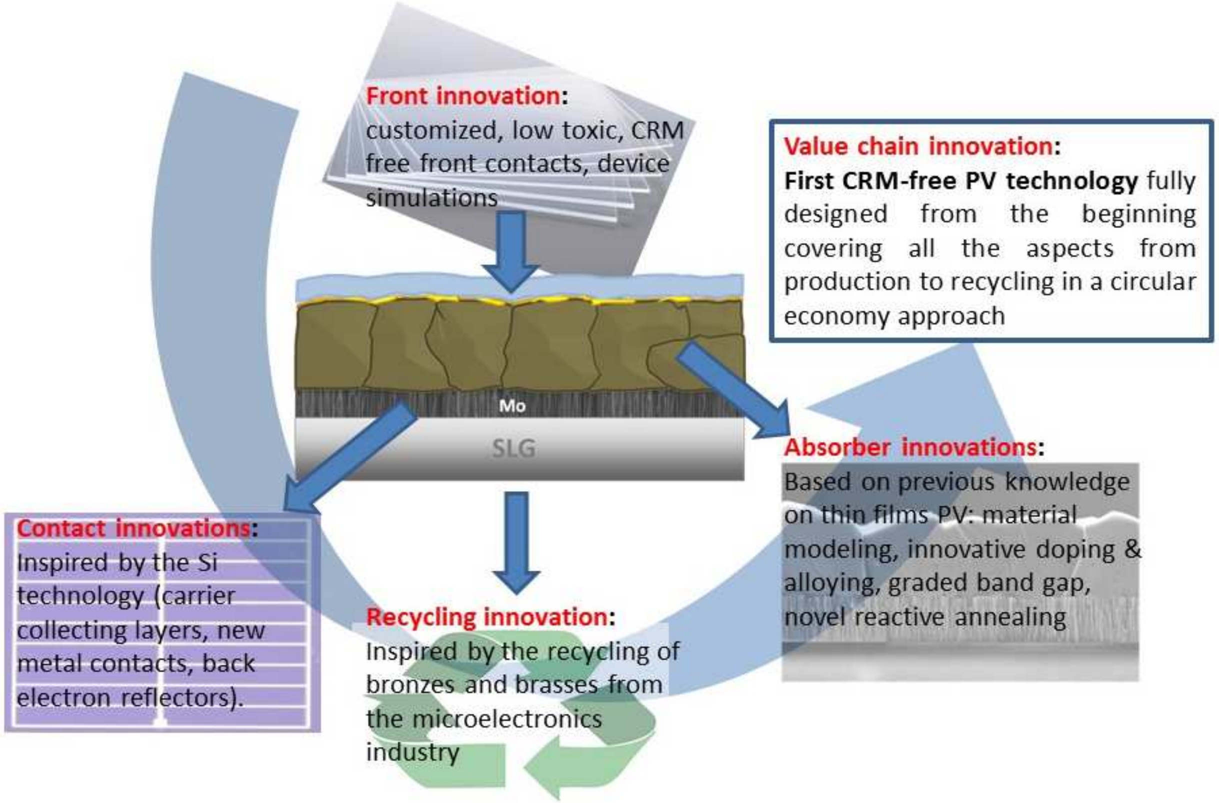
| Partner | Logo | Expertise | Main role in STARCELL |
|---|---|---|---|
| 1. IREC (ES) | | Development of high efficiency CZTSSe absorbers by sequential process. | Coordinator. Absorber, Interfaces, devices. |
| 2. CEA (FR) | | Development of Cd-free buffer layers. Simulation. | Buffer layers, simulation, LCA. |
| 3. EMPA (SW) | | High efficiency CIGS and CZTSSe devices. Several world records. | Absorber, interfaces, buffer layers, devices. |
| 4. UU (SE) | | Large expertise in surface characterization at nanoscale level: TEM, EELS, EDX, XPS... | Advanced surface characterization. |
| 5. ICL (UK) | | Worldwide recognized group in modelling of chalcogenide materials. | Material modelling. |
| 6. HZB (DE) | | Worldwide recognized group in the characterization of CZTSSe solar cells. | Optical/Electrical characterization. Mini-modules. |
| 7. MLU (DE) | | Large experience in CIGS and CZTSSe simulation and characterization. | Device modelling. In-situ characterization. |
| 8. IMRA (FR) | | Leading European company in the development of high eff. CZTSSe solar cells | Absorber, interfaces, devices, mini-modules, exploitation. |
| 9. MIDSUMMER (SE) | | Very recognized CIGS modules and PV equipments producer | Mini-modules, homogeneity, exploitation. |
| 10. WIREC (ES) | | Large experience in materials recycling for microelectronic industry (including Zn, Sn, Cu) | Material supply chain, recycling/reuse, exploitation. |
| 11. AYESA (ES) | | Leading company in the development of PV solar plants | In field devices testing. Exploitation. |
| 12. AIST (JP) | | Most recognized Japanese institute in the development of CIGS and CZTSSe solar cells. | Absorber, devices. Benchmarking and certification. |
| 13. UDuke (US) | | Kesterite world record holder by several years. | Absorber, interfaces. Benchmarking. |

STARCELL: the project where the sun will never set

## 2. STARCELL description

### 2.2. Consortium

STARCELL

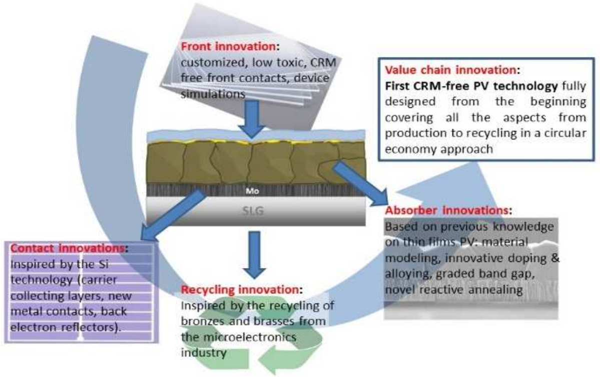


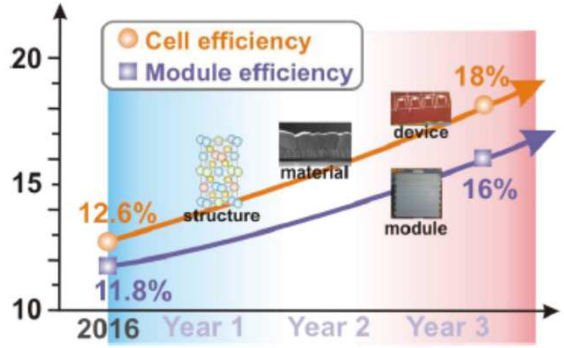

Our strategy is based in a circular-economy approach:

- Only sustainable materials and processes will be developed
- Design of the complete value chain from the beginning: from materials supply up to recycling aspects

## 2. STARCELL description

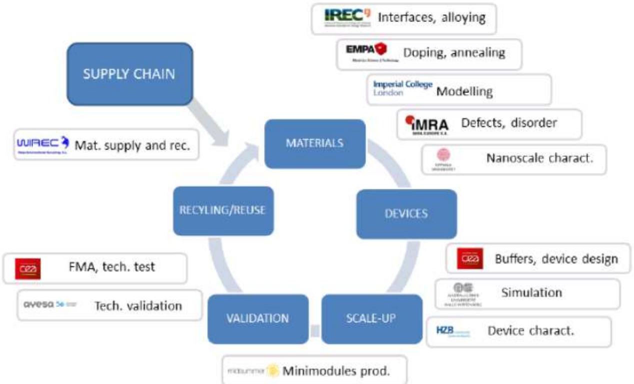
### 2.3. Strategies: short and long term vision




In a **short term** we are introducing **innovative approaches** to better understand kesterite absorbers and to improve the PV devices properties

In a **mid term** we expect to **increase** the solar cell devices conversion **efficiency** at both, laboratory scale (1 $cm^2$) and minimodule (10x10 $cm^2$)




In a **long term** to stablish a **fully sustainable, cost-efficient, and free of critical raw materials** PV technology available for the European Society.

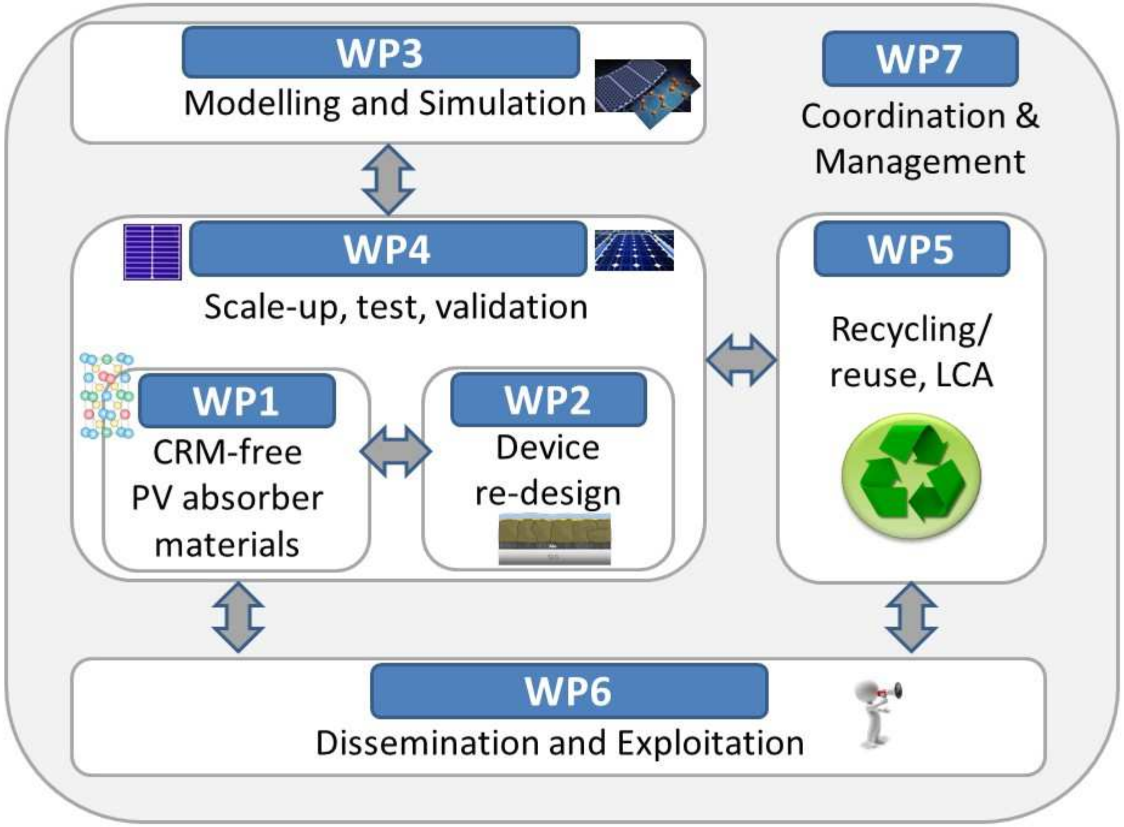
# 2. STARCELL description

## 2.3. Strategies: short and long term vision

# OUTLINE

# 3. Structure

## 3.1. Workpackages

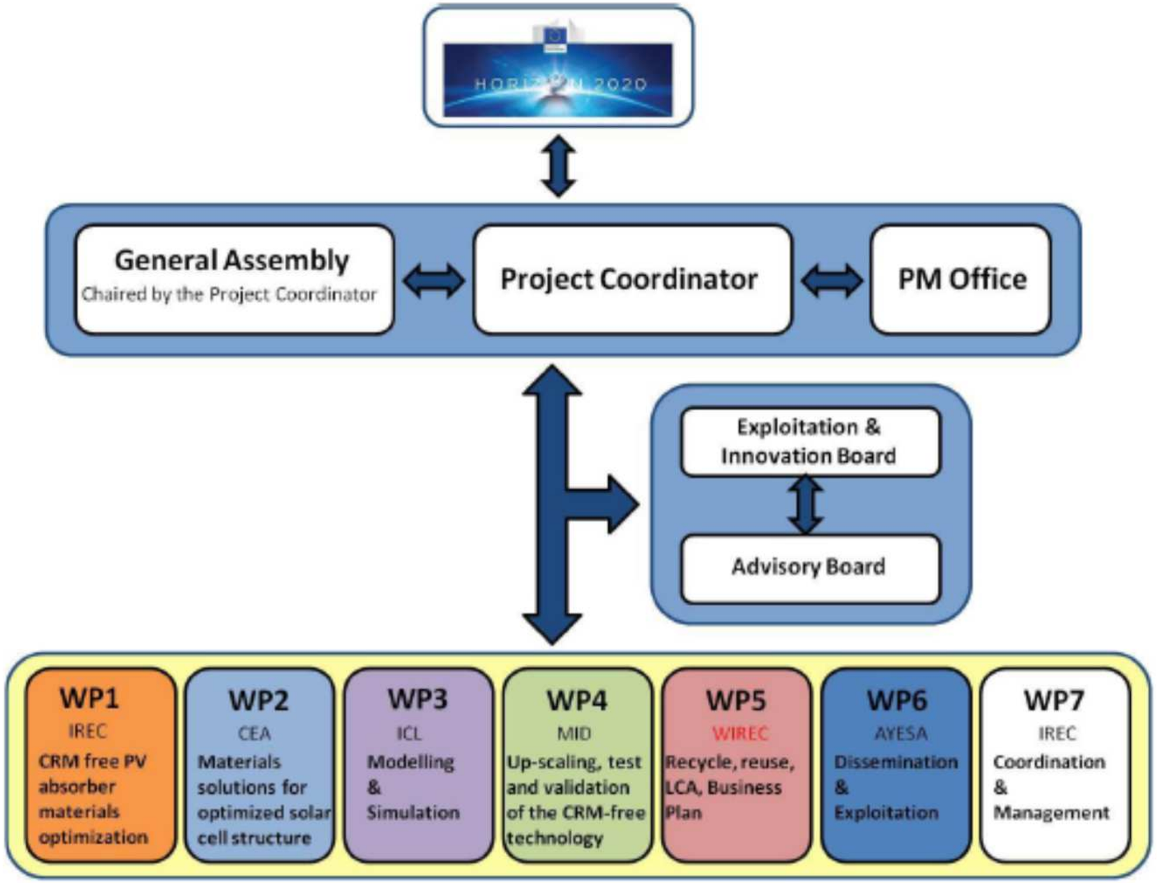



**7 Workpackages including:**

- Absorber
- Devices
- Modelling (materials and devices)
- Scale-up
- Recycling
- Dissemination and Exploitation

# 3. Structure

## 3.2. Management




STARCELL is an objective-driven project which comprises three different decision levels:

1) **Strategic level**: The General Assembly is formed by one senior representative of each partner. The assembly, assisted by the Exploitation and Innovation Board and the Advisory Board, is responsible for the high level monitoring and control of the project development;
2) **Operational level**: The Project Coordinator, assisted by the Project Management Office (PMO), will implement the decisions taken by the General Assembly, being the single contact point with the EC, and in charge of reporting duties.
3) **Content level**: Each WP will have a WP leader that will be responsible for monitoring the development and implementation of the technical activity in agreement with the quality requirements fixed by the General Assembly. The WP leaders will directly report to the Project Coordinator.

3. Structure

3.3. Impact

*Table 11.* Summary of the scale-up of the technology.

| Phase | Goal | Timing | Investment | Funding sources | Partners involved |
|---|---|---|---|---|---|
| Technology development | Achieve TRL5 (10x10 cm²), Eff.=16% | 2017-2019 | €5m | Horizon 2020 project | STARCELL consortium |
| Technology scale-up to minimodule size | Achieve TRL6 (30x30 cm²), Eff.=16% | 2020-2022 | €3m | Private Investment (AYESA), cofounded by H2020/National public funds | STARCELL consortium |
| Scale-up to commercial module size & certification (10MW$_p$). | Achieve TRL9 (1.2x0.6 m²), Eff.=14% (0.40€/W$_p$) | 2023-2024 | €10m | Private Investment (AYESA) | AYESA |
| Medium scale production & commercialization (150MW$_p$) | Eff.=16% (0.30€/W$_p$) | 2025-2026 | €73m | Private Investment (AYESA) | AYESA |
| Large scale production plant (1GWp) | Eff.=18% (0.20€/W$_p$) | 2027-2030 | €275m | Private Investment (AYESA) | AYESA |

*Table 12.* Financial plan for small production scale.

| STARCELL | 10MW | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **PV Manufacturing Capacity (MW)** | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| **Total Unitary Cost (k€/MW)** | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| **Total Revenues (M€)** | 8.6 | 8.6 | 8.5 | 8.4 | 8.4 | 8.4 | 8.3 |
| **Total Costs (M€)** | 5.3 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.5 |
| Depreciation \| Equipment: | 1.43 | 1.43 | 1.43 | 1.43 | 1.43 | 1.43 | 1.43 |
| Depreciation \| Building: | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Capital Costs: | 0.55 | 0.48 | 0.40 | 0.33 | 0.25 | 0.18 | 0.10 |
| Utilities: | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.19 | 0.19 |
| Labour: | 0.52 | 0.54 | 0.55 | 0.57 | 0.59 | 0.60 | 0.62 |
| Materials: | 2.40 | 2.47 | 2.55 | 2.62 | 2.70 | 2.78 | 2.87 |
| Maintenance: | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.19 | 0.19 |
| **EBITDA (M€)** | **4.82** | **4.74** | **4.66** | **4.58** | **4.50** | **4.43** | **4.36** |
| **NPV (M€)** | **-6.4** | **-2.1** | **1.9** | **5.7** | **9.2** | **12.5** | **15.6** |

**Medium-scale (150MW):** The scale-up of the production facilities to the 150MW scale will require an investment estimated to be €273m. The gross income generated at this stage over a five years period (2027-31) is expected to be €435.3m, with a NPV=€103m (ROI=130%).

In a medium scale production scenario, a technology like the one under development in STARCELL can give revenues of about 435 M€ in 6 years of commercialization.

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ACKNOWLEDGEMENTS

STARCELL

# CONCLUSIONS

- All valuable PV technologies are necessary to cover the future demand for clean and sustainable energy

- For Europe, it will be very difficult to achieve an efficient control in the production of Si-based, CdTe and CIGS production, due to the strong dependence on raw materials from foreign countries

- Development of technologies based solutions fully free of critical raw materials, as those proposed in STARCELL, is relevant to warrant a sustainable growth of PV in Europe, ensuring energetic independency in the future

- Kesterites is positioned as one of the most interesting CRM free alternatives free of toxic elements, but require for a strong effort involving public and private investments to achieve technological maturity

# ACKNOWLEDGEMENTS


*IREC – Solar Energy Materials and System Group*

EUROPEAN COMMISION H2020 PROGRAMME
STARCELL PROJECT (H2020-NMBP-03-2016-720907)

Nanotechnologies and Advanced Materials for Energy Cluster (NAMEC) for the invitation

# Thanks for your attention!