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New PV Technologies: What about their recyclability?

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RD at LEITAT

RD divisions

- ADVANCED MATERIALS
- FAST MOVING CONSUMER GOODS
- ENVIRONMENTAL & BIO TECHNOLOGIES: EBT
- DEVICES, DESIGN AND ENGINEERING: D2E ✓
- BIOMEDICINE
- SAFETY & SOSTENIBILITY

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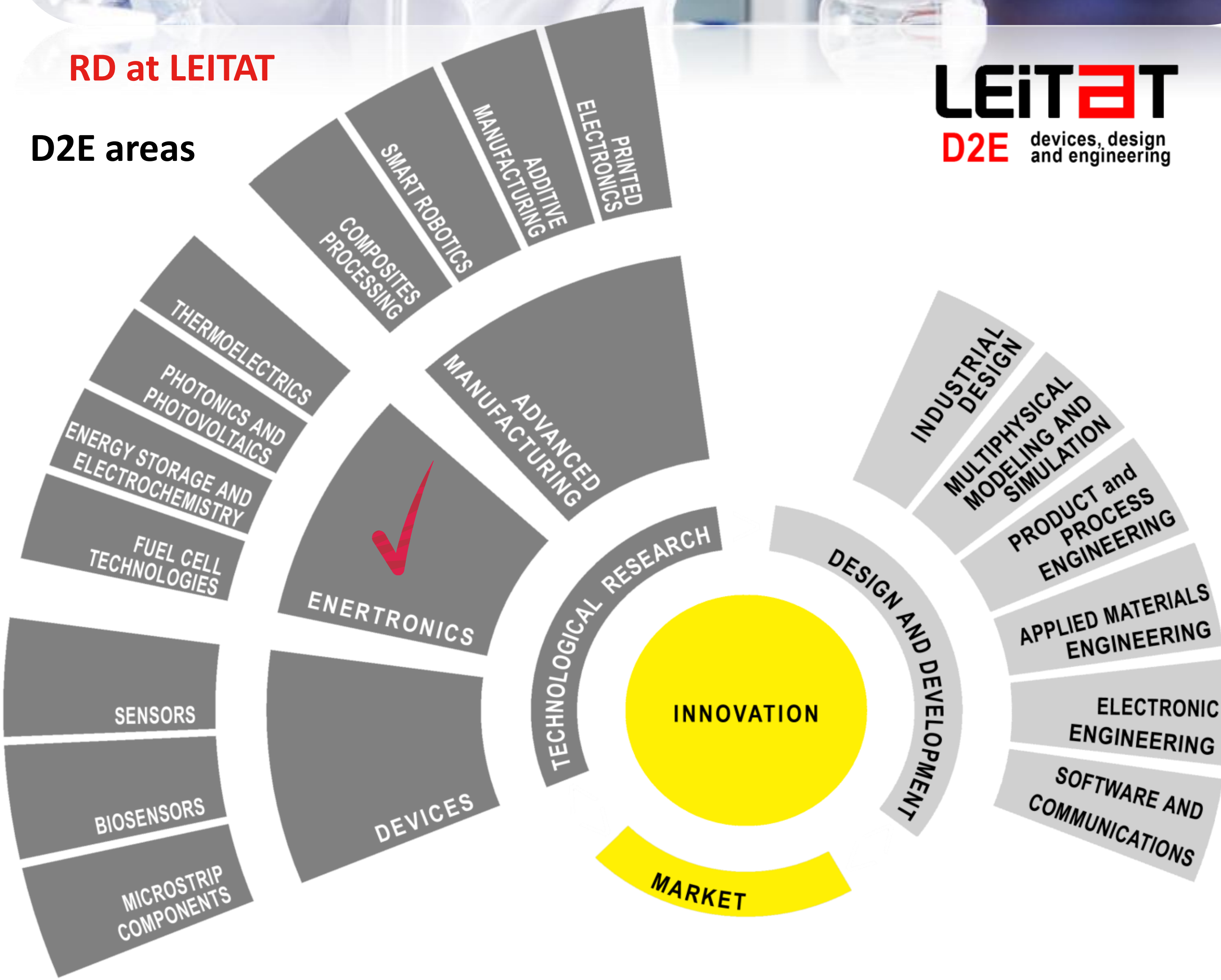
RD at LEITAT

D2E areas



LEITAT D2E devices, design and engineering

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Renewable Energies

- **Solar Energy**
- Bio-Electrochemical Systems
- Applied Photonics
- Thermoelectricty

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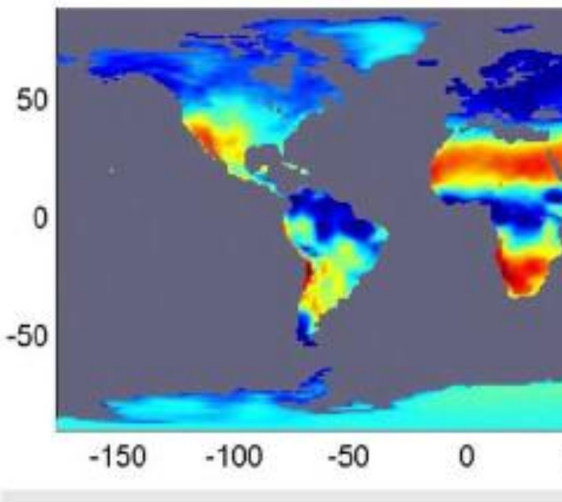
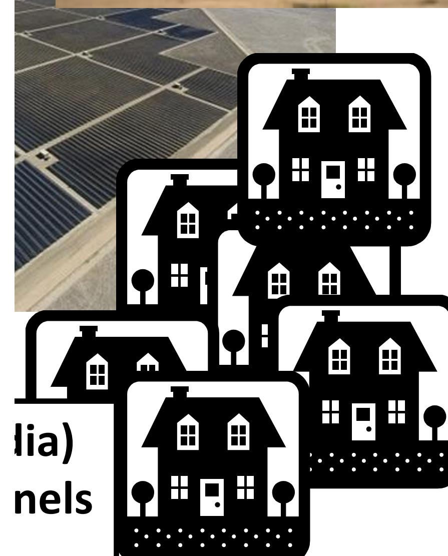
PV, Where?





> The solar energy that reaches the earth in one hour is about as much as the total energy used by every one on the planet for an entire year.[9]

dia)
nels

5KW

>490 toneladas CO_2
>94000 cars

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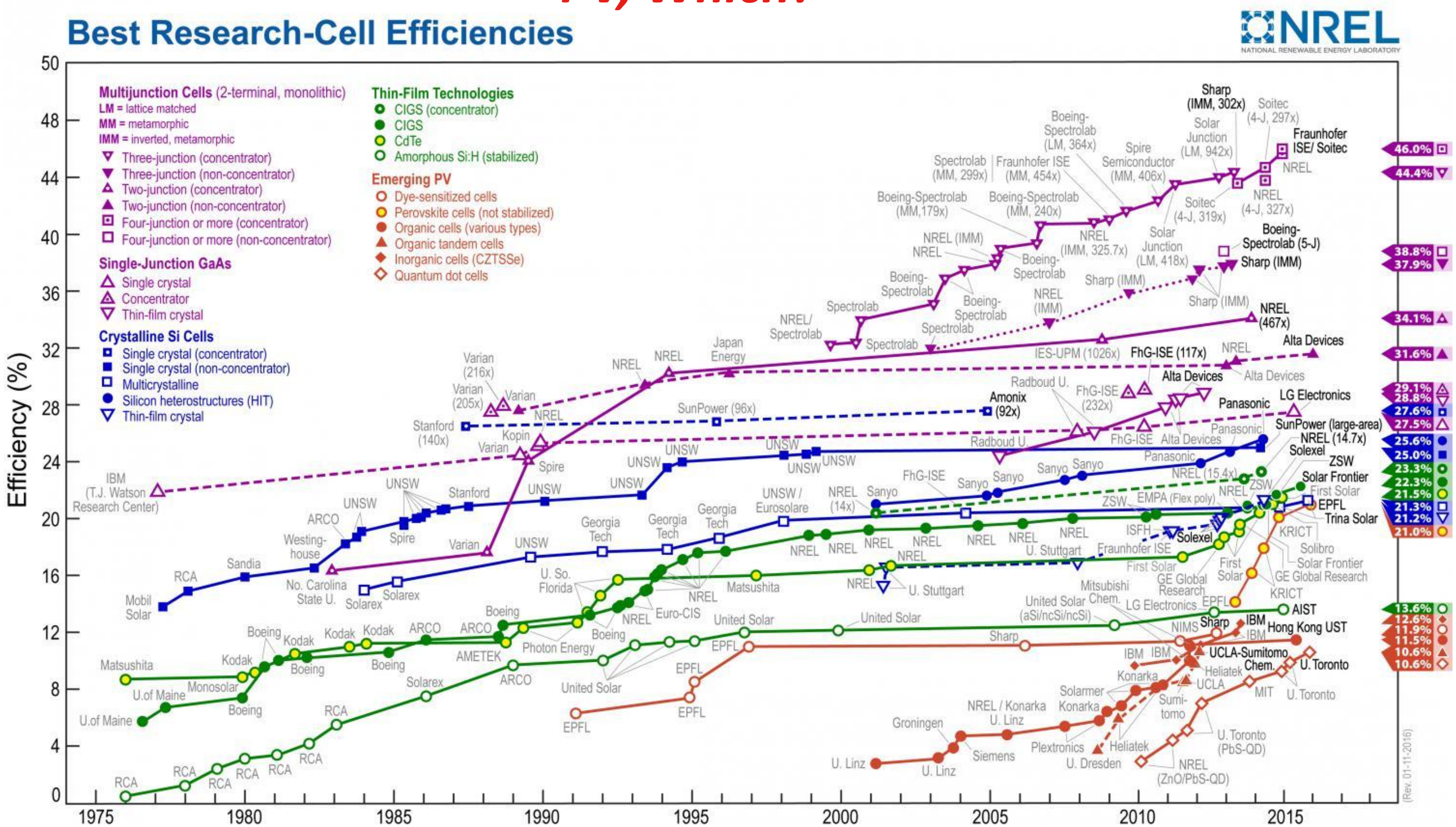
PV, Which?



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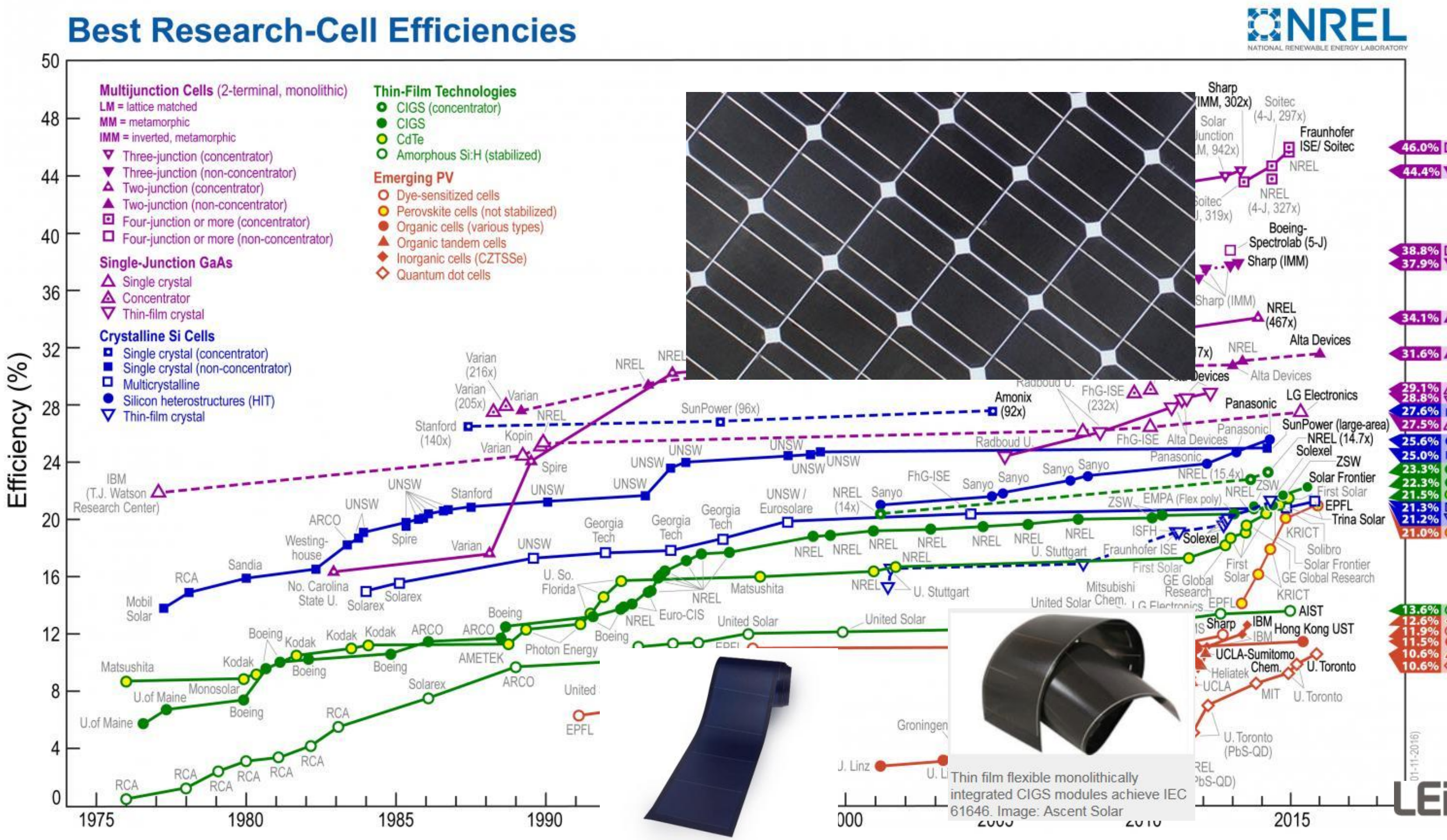
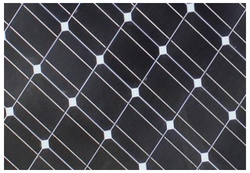
Mature vs Under Development Technologies



Thin film flexible monolithically integrated CIGS modules achieve IEC 61646. Image: Ascent Solar

Mature vs Under Development Technologies



<u>cSi: advantages:</u> including silicon (2º most abundant element), with significant base of knowledge, & there are many vendors who provide equipment so there are relatively low barriers to entry for new companies.

<u>cSi: concerns:</u> Amount of energy that it takes to manufacture the silicon and in the production of the cells. Reduce performance with low light and high temperartures. ***RD in progress***.

<u>aSi, advantages</u>: based silicon, also uses significantly smaller amounts of silicon than a cSi. Thinner conductive layers, & requires significantly less energy to produce than cSi. Working well in low light and hot Temperatures, compatible with BIPV.

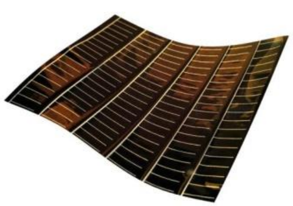
<u>aSi, concerns</u>: Low efficiencies, high performance at lowest deposition rates, photodegradation. ***RD in progress***.

Mature vs Under Development Technologies

Thin film flexible monolithically integrated CIGS modules achieve IEC 61646. Image: Ascent Solar

CIGS, advantages: have high efficiencies for thin film with laboratory efficiencies of over 20%.

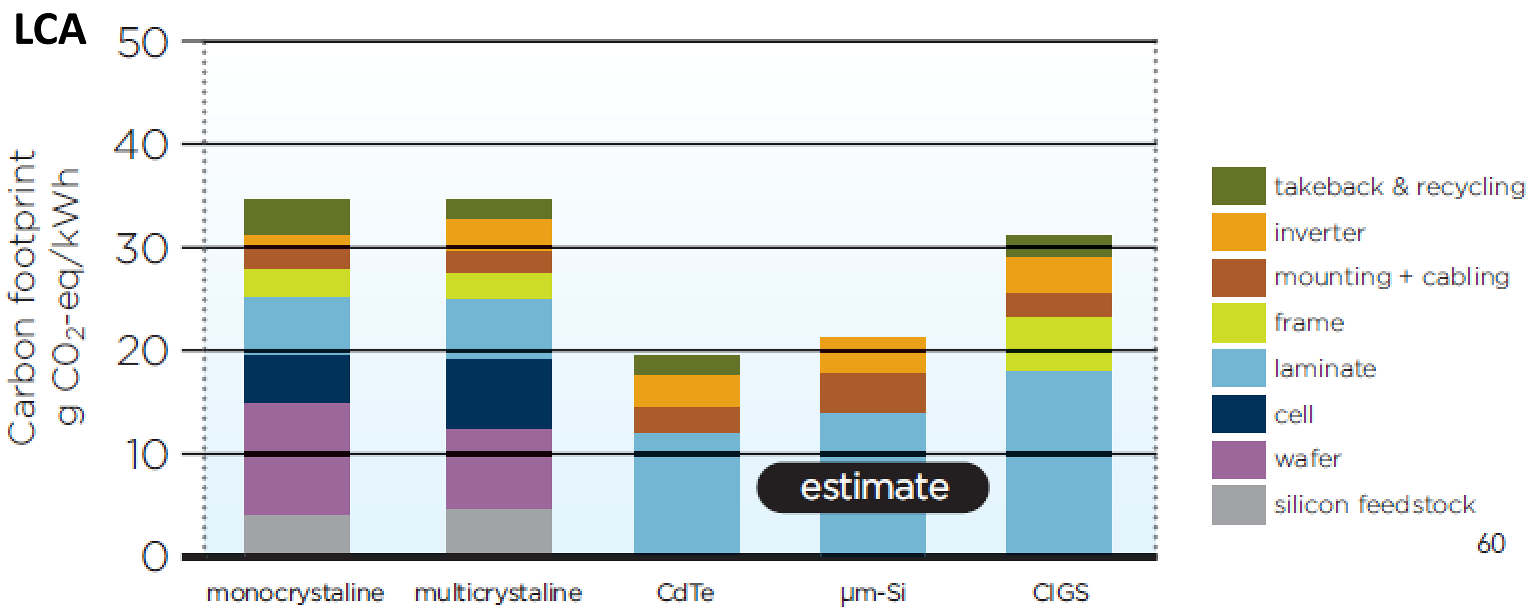
CIGS, challenges: There must be strict uniformity in the manufacturing process and increasing deposition rates lowers the efficiency of the cells. In addition, there is no industry standard for fabrication and there are few options for purchasing manufacturing equipment. ***RD in progress.***



CdTe; advantages: lowest cost to manufacture of all of the thin film technologies & very tolerant to impurities.

CdTe; challenges: Cd toxicity is know, starting studies on the possible issues related to CdTe. Not standarized manufacturing processes. ***RD in progress.***

Mature vs Under Development Technologies



Carbon footprint of components of five PV technologies

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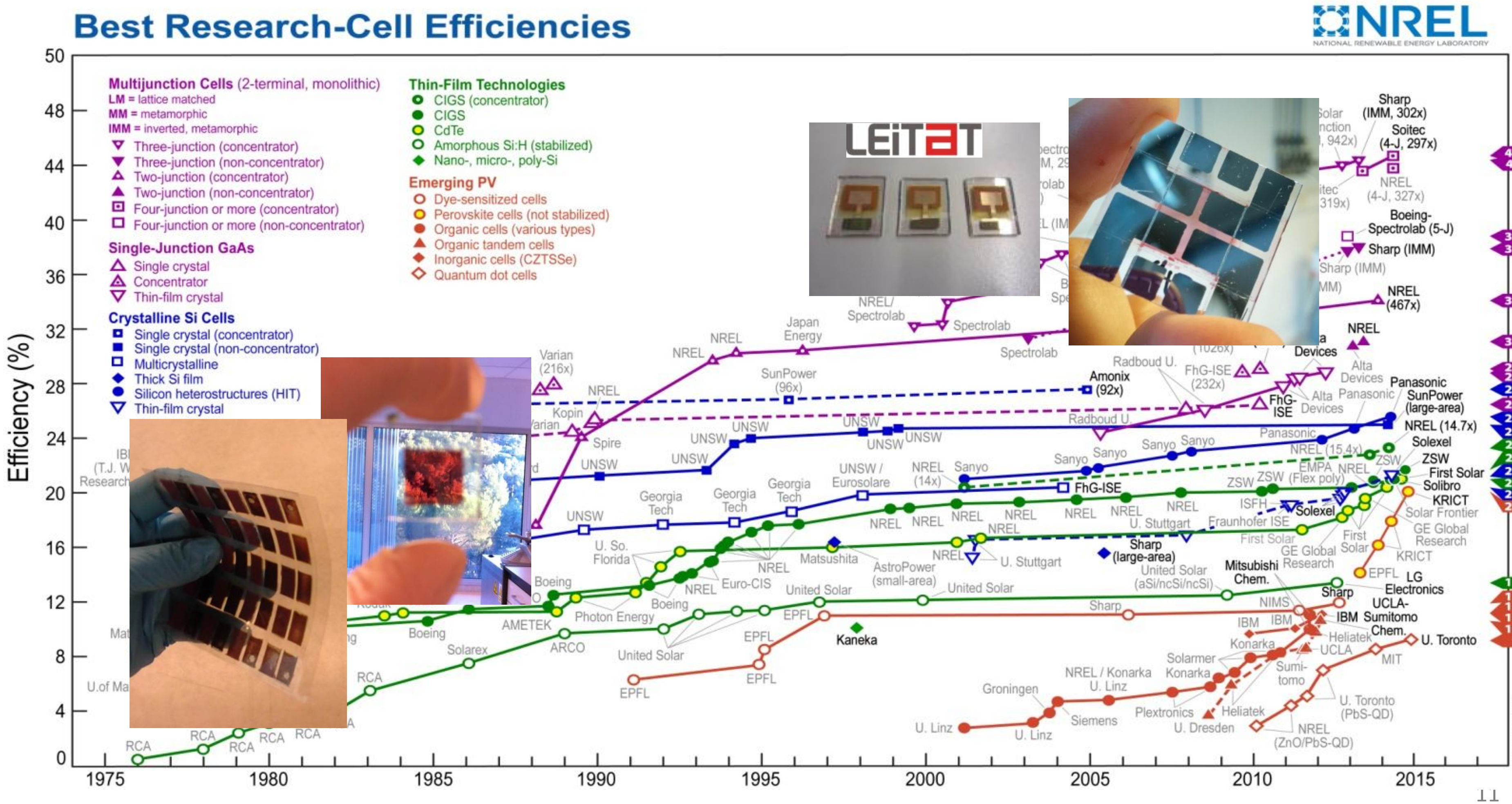
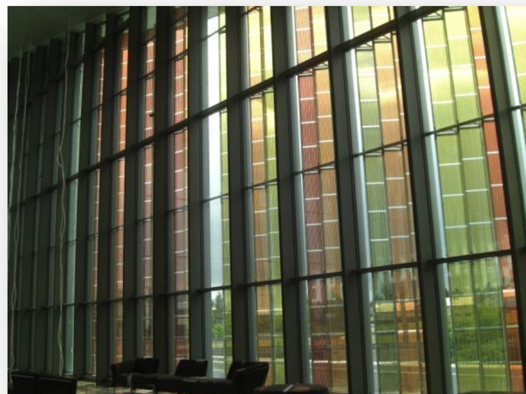
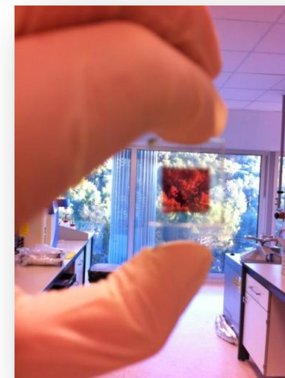
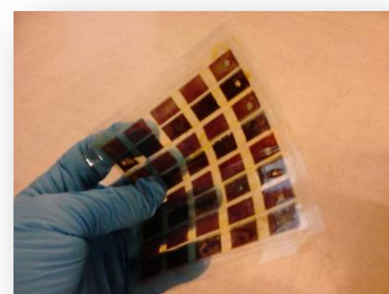
Mature vs Under Development Technologies

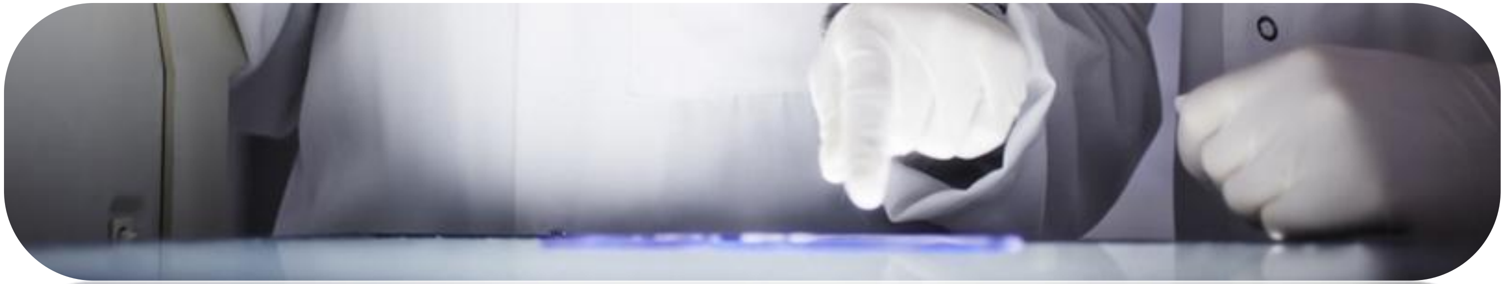


Target applications: BIPV and IoT

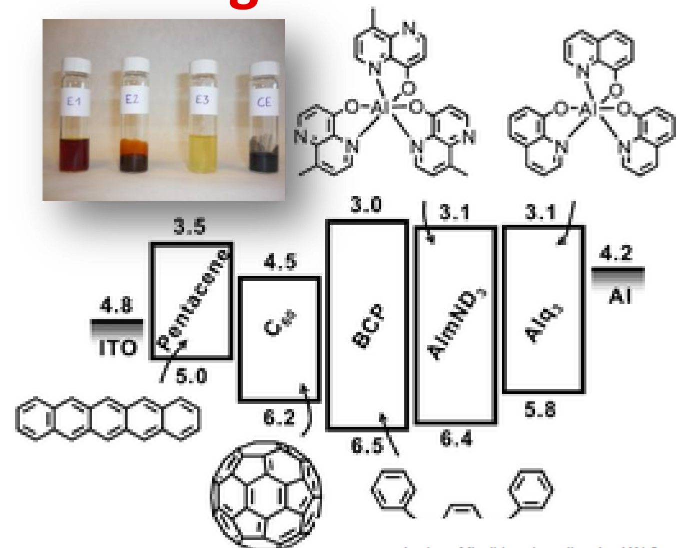








What happen with new PV technologies?



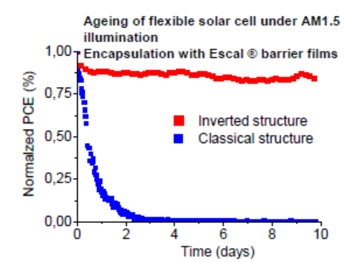
<u>**State of the art**</u>**:**

•At lab scale and demo

•Materials & designs under development

•OPV and DSSC has low performance, and PSC has higher performance.

•Challengues: (1) stability & (2) recyclability



STABILITY

•Degradation factors: oxygen, temperatures, photodegradation & humidity.

•ISOS community: congreso de referencia, nuevas normas.

•Robin Round tests

ISOS-7 14 International Summit on OPV Stability

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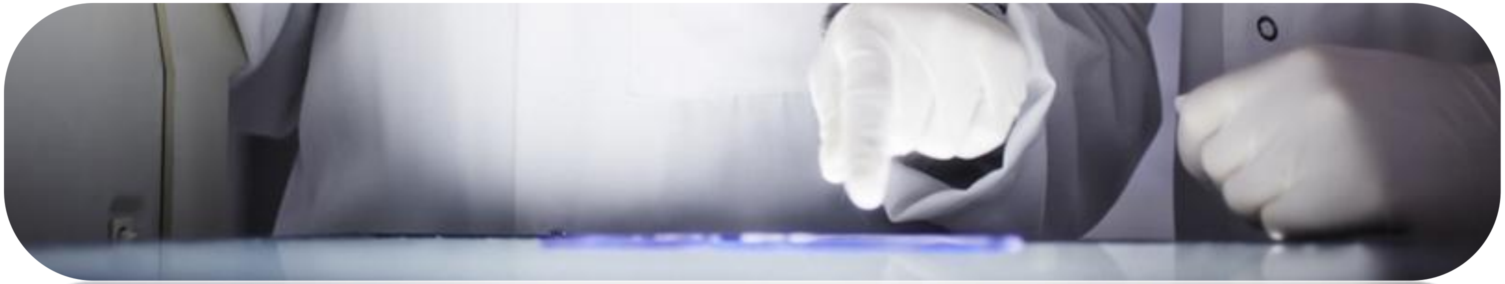
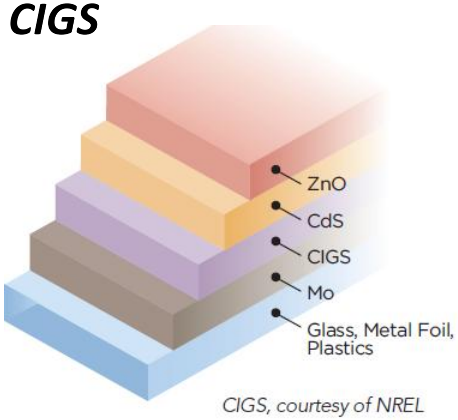


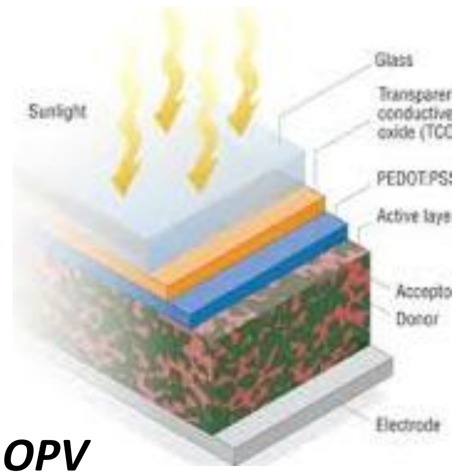
What happen with recyclability?

<u>Different designs :</u> including metal, inorganic and organic semiconductors. Different type of layers :single material, blended layer, no homogeneous layer, nanoparticules as absorbers and for improvement light absorption…… ***RD in progress***.

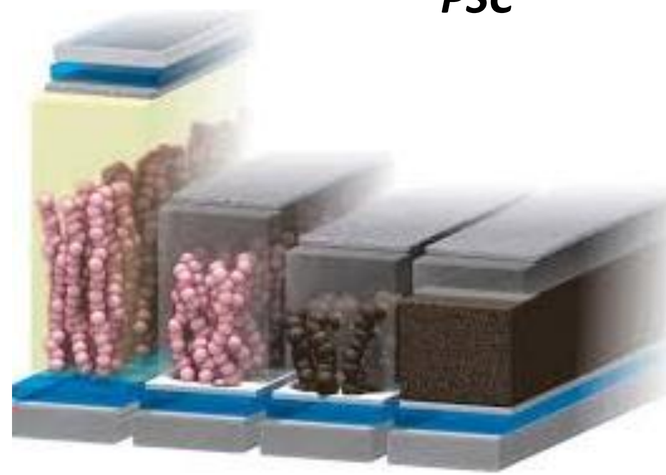
CIGS



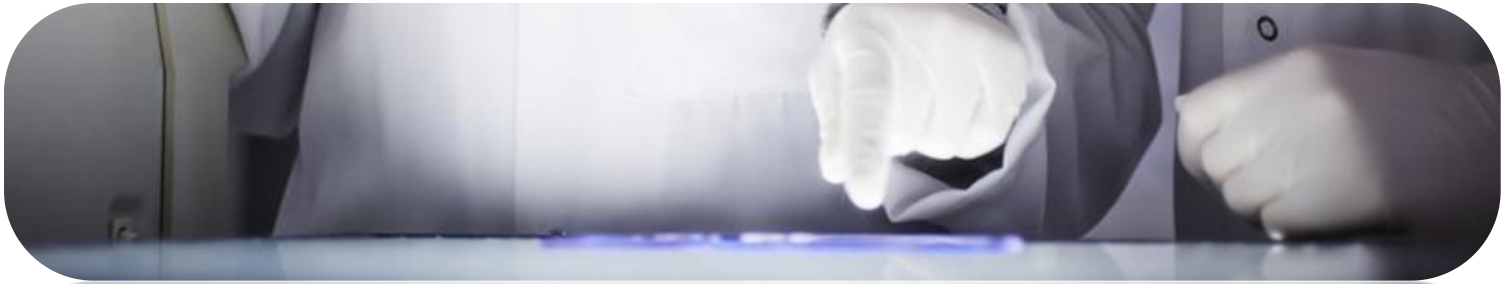
OPV



PSC



How to get recycled semiconductor and metals? How to do it in sustainaible way ??



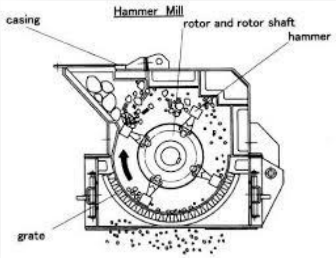
What happen with recyclability?

• **Current processes** included physical and chemical methods: shredding, smelting, hydrometallurgical separation, refining, hammer-mill, etc.

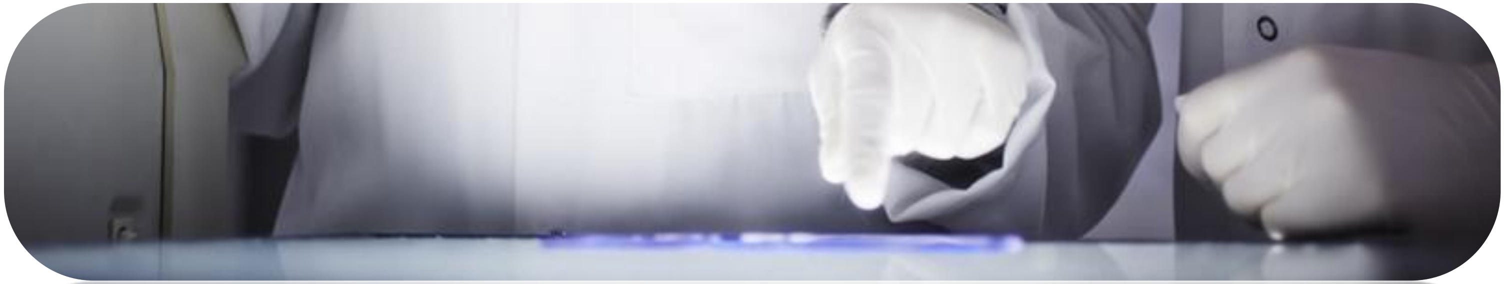
Examples:

#1: Cd, Te, Se and and contact metals (e.g., Ni) can be treated in copper smelters where the shredded material is processed through a liquid metal bath reactor, converters and anode furnaces.

#2: Ethylene vinyl acetate (EVA) and plastic decompose at the high temperatures of the smelter (e.g.,1000-1400ºC) into CO_2 and monomeric vapors.



#3: In the furnaces, the anodes collect molten Cu and the metals dissolved in it. These anodes are "refined" to recover Te, Se, NI, etc… Cd can be recovered in Zn smelter, which cannot accept CdTe scrap.



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What happen with recyclability?

• PV power plants and its use as energy harvester will increase in the next decades

•Critical raw materials such as Indium (CIGS/OPV), Gallium (CIGS), and Tellurium (CdTe) will be requested

•Recycling from current PV solar plants is a must but Si solar Plant last at least 30 years!!!

•This materials also are needed for other app: displays, electronics, etc.

•They are minor byproducts of aluminum (…2100), zinc (…2030), copper (..2060) and lead production (2030); taking into account known reserves.

PV should be manufactured in a sustainable way including the end of life of the final product.

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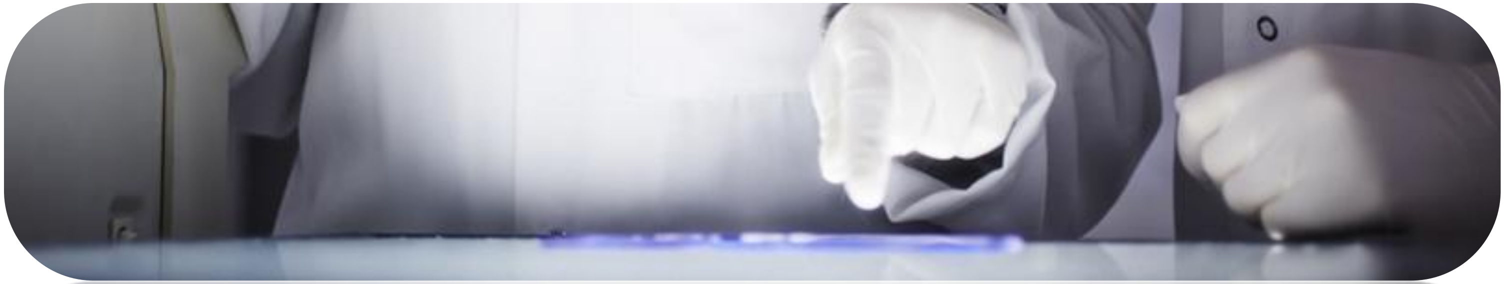


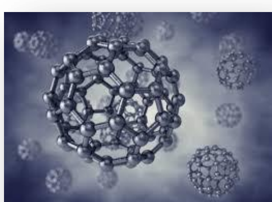
What happen with recyclability?

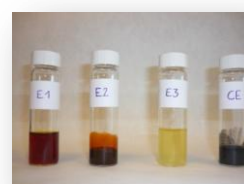
<u>New Materials Involved</u>:

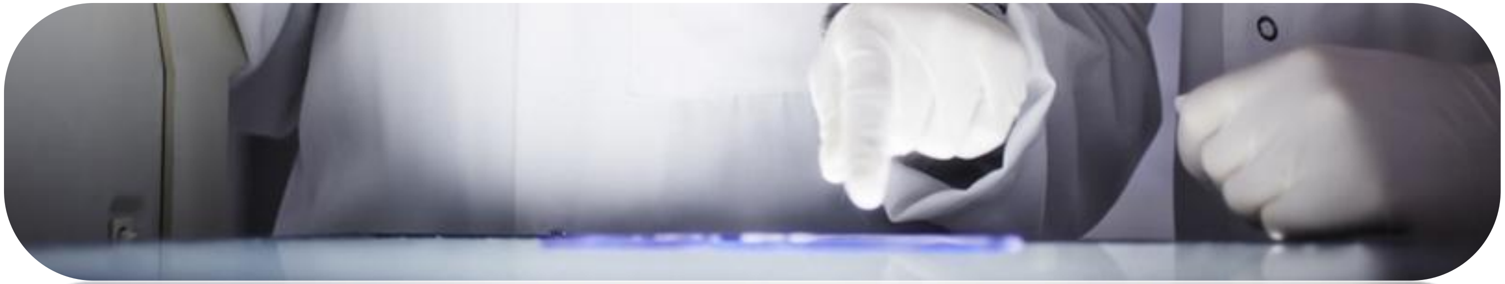
Nanomaterials use is a big concern either during manufacturing, usage, or end-of life which will escape into the air or water and cause damage either to the environment or to human life... ***RD in progress***.

Organic semiconductor can be synthesized in laboratories, but green chemistry and non toxic solvents should be used…. ***RD in progress***.

Polymeric conductors as semiconductor, in combination with metal can achieved properties similar to metallic electrodes.





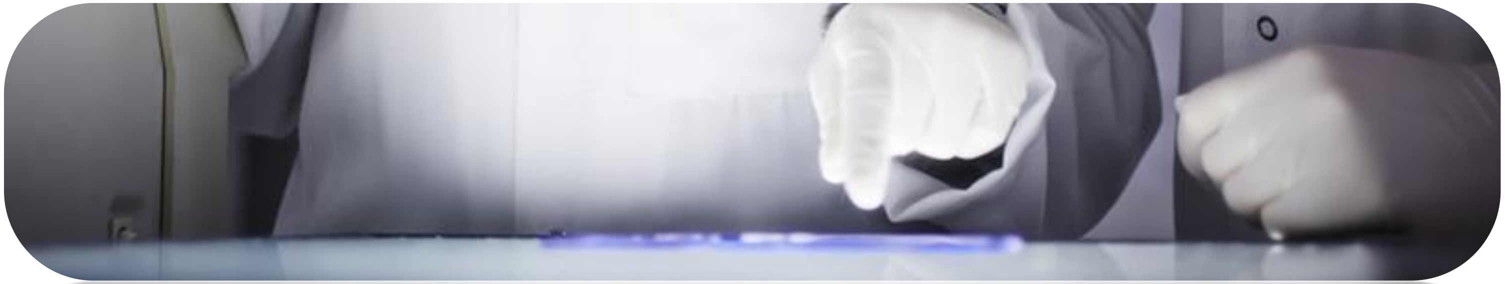


What happen with recyclability?

Table III. Solar technology considered and associated material inventory.

Device	mc-Si	HIT mc-Si/a-Si	c-Si	CIGS	CIGS	CdTe	CZTSS	CZTSSe	GaAs	OPV
Description	Research	Commercial	Layer transfer process	Research	Commercial	Commercial	Kesterite $Cu_2ZnSnSe_4$ research	Kesterite $Cu_2ZnSn(Se,S)_4$ research	Thin film alta technology research	P3HT:C_{60}PCBM plastic substrate research
Reference	[38]	[39]	[40]	[41]	[42]	[43], [44]	[45]	[46]	[47], [48]	[49]
η (%)	25	19.0	19.1	20.3	11.15	11.2	9.7	10.7		5
Materials usage (g/m^2)	Glass (8900) EVA (960) Al (1.35) Si (183.36) Ti (0.14) Pd (0.003) Ag (0.21) Mg (0.07) PET (349) Other (103)	Glass (8900) EVA (960) Ag (0.53) Zn (0.90) a-Si (0.09) Si (228) PET (349) Other (103)	Glass (8900) EVA (960) Al (1.84) Si (90.43) PET (349) Other (103)	Glass (17 800) EVA (960) Mo (2.81) Cu (2.12) In (3.84) Ga (2.34) Se (5.28) Cd (0.19) Zn (1.37) Ni (0.02) Al (0.04) Mg (0.13) Other (1.99)	Glass (17 800) EVA (960) Mo (4.11) Cu (1.19) In (2.35) Ga (1.31) Se (2.96) Zn (0.45) Al (1.35) Other (0.15)	Glass (17 800) EVA (960) Sn (0.75) Cd (10.54) Te (11.54) Ni (0.02) Al (0.03) Mg (0.13) Other (0.64)	Glass (17 800) EVA (960) Mo (3.29) Se (8.14) Cu (2.76) Zn (1.41) Sn (2.64) Cd (0.22) In (0.30) Ni (0.05) Al (0.05) Mg (0.14) Other (2.01)	Glass (17 800) EVA (960) Mo (2.50) Se (4.66) Cu (2.76) Zn (1.60) Sn (2.95) Cd (0.22) In (0.30) Ni (0.05) Al (0.05) Mg (0.14) Other (3.65)	PET (346) EVA (50) Ga (3.38) As (3.18) Al (0.32) Pt (0.43) Ti (0.18) Au (1.62) Pd (0.003) Ge (0.009)	PET (346) EVA(50) In (0.68) Sn (0.23) Al (1.15) Ti (0.05) Other (1.8)

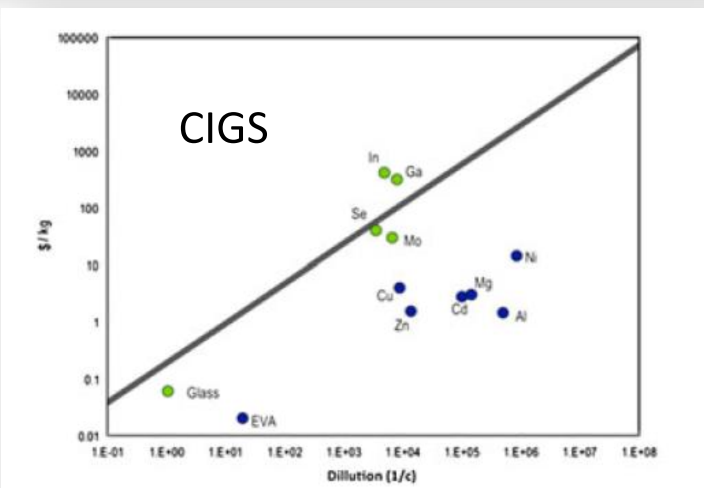
The materials usage is calculated in term of elements to be recycled and normalized for 1m^2 laminate and therefore other elements such as the frame and connectors are not included.



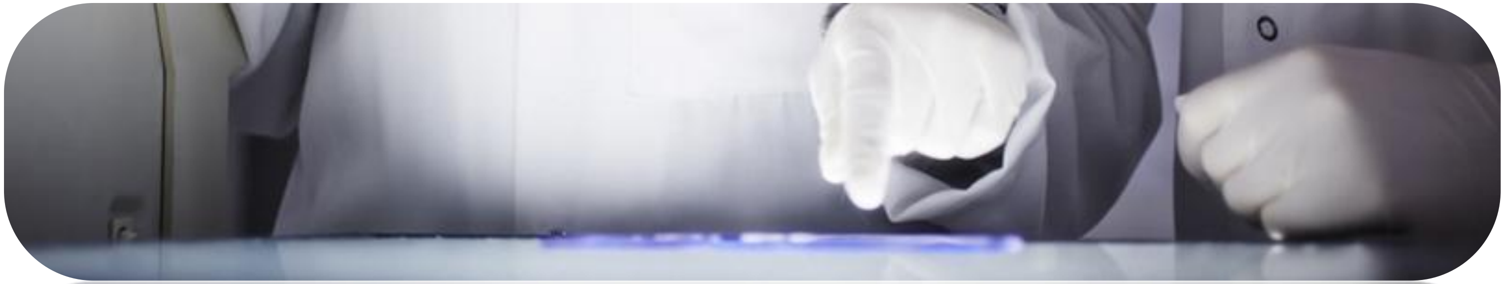
What happen with recyclability?

Table IV. Recycled material inventory considered to compute the photovoltaics value and recycling complexity at end-of-life.

Device	mc-Si	HIT	c-Si	CIGS research	CIGS commercial	CdTe	CZTSS	CZTSSe	GaAs	OPV
Recycled material (g/m^2)	Glass (8900) Si (183.36) Ag (0.21)	Glass (8900) Ag (0.53) Si (228)	Glass (8900) Si (90.43)	Glass (17 800) Mo (2.81) In (3.843) Ga (2.34) Se (5.28)	Glass (17 800) Mo (4.11) In (2.35) Ga (1.31) Se (2.96)	Glass (17 800) Cd (10.54) Te (11.54)	Glass (17 800) Mo (3.29) Se (8.14) In (0.30)	Glass (17 800) Mo (2.50) Se (4.66) In (0.38)	PET (346) Ga (3.38) Pt (0.43) Au (1.62) Pd (0.003) Ge (0.009) Other (53.67)	PET (346) In (0.68)
Recyclable material (% mass)	86.5	86.6	86.4	94.9	94.9	94.9	94.8	94.8	86.8	86.80



Sherwood graph: material price vs its dilution
recycled elements lie above the Sherwood line



What happen with recyclability?

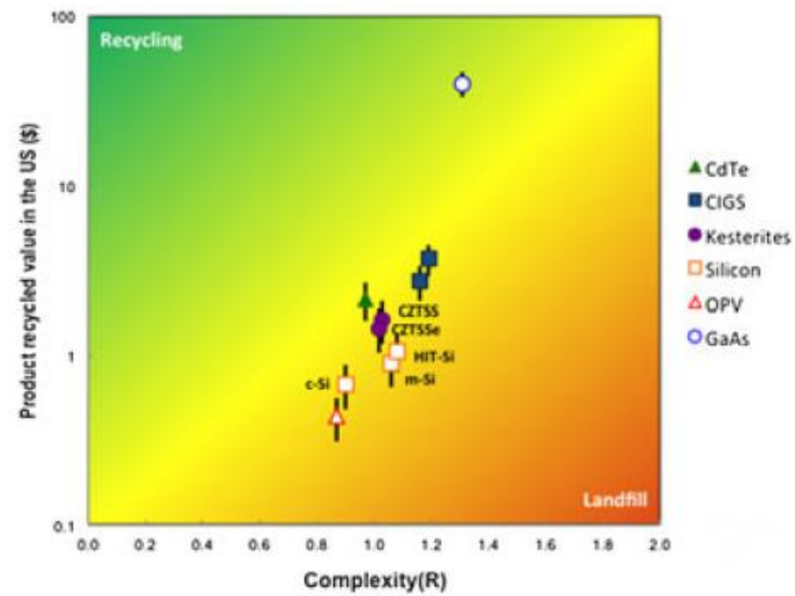
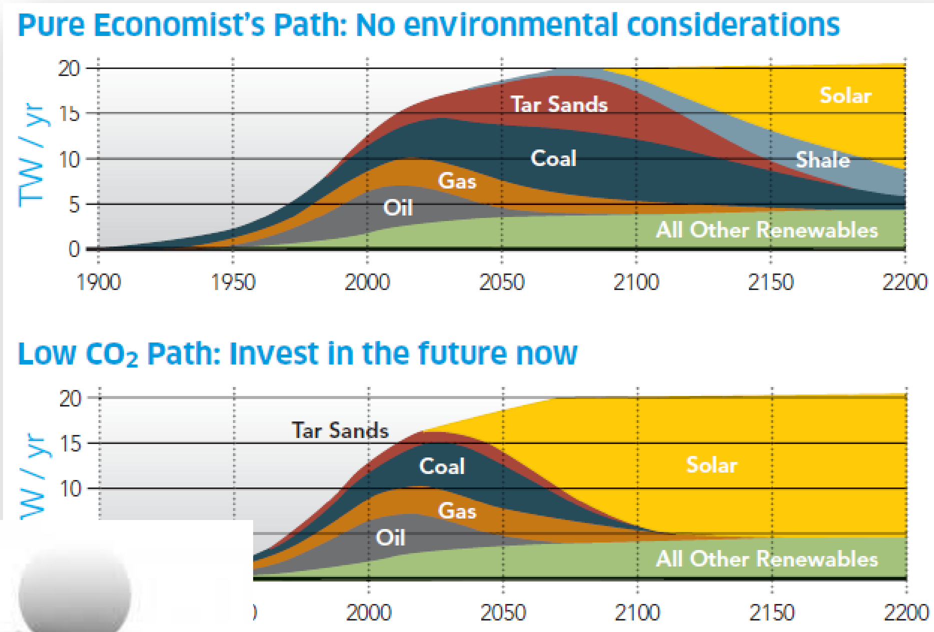
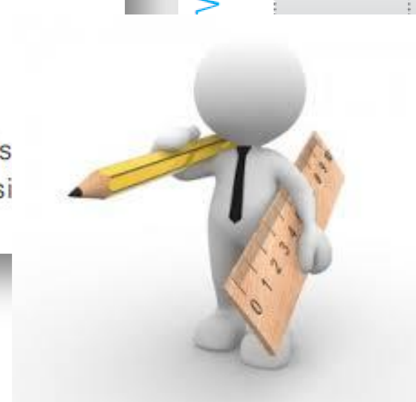
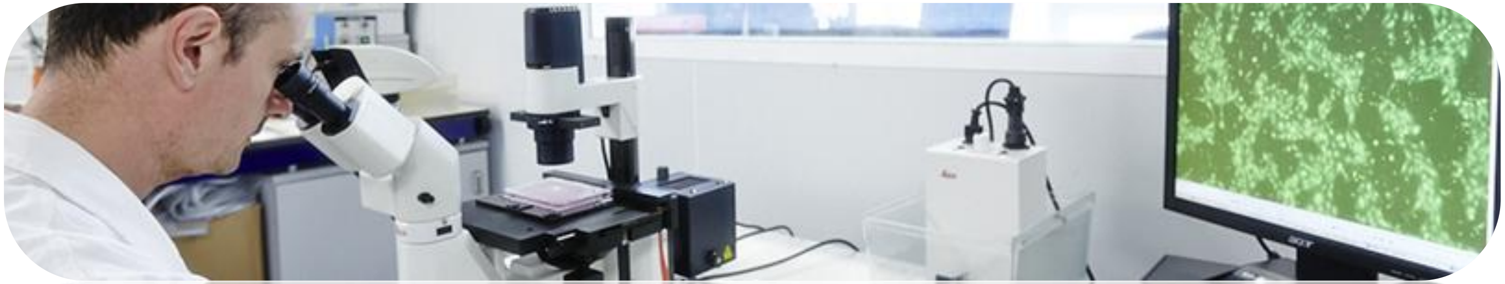


Figure 3. End-of-life options for photovoltaics panels function of product recycled value and complexity (R) usi Renyi entropy for $q = 0.15$.



l of remaining fossil reserves and renewable sources,
t Nelson, NREL



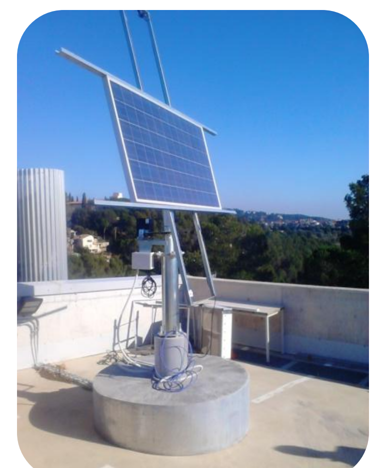


What happen with recyclability?

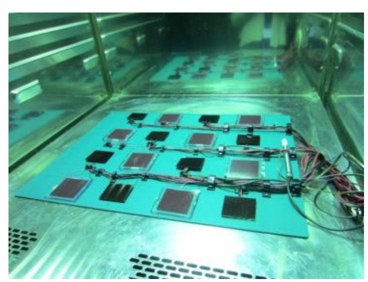
Climatic chamber for saline test

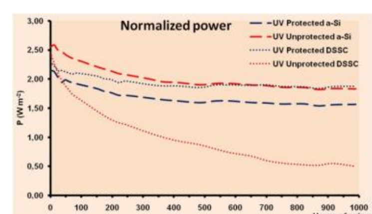
IEC61215 IEC6164

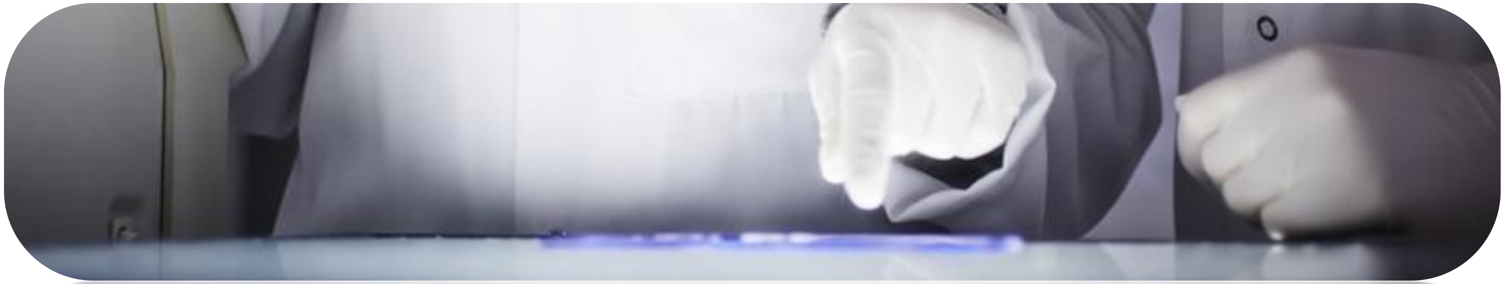
Climatic chamber (without/with light (MHL)) also Xenotest and UV chamber from Atlas



P. Bosch-Jimenez, et al. Stability of Dye Sensitized Solar Cells for Indoor Applications: a Comparison with Amorphous Silicon under Low Irradiation. Oral EUPVSEC, 3DO.9.5 (2013)







What happen with recyclability?

New processes in manufacturability: New Vacuum processes such as Atomic Layer Deposition. Printing techniques from other wellknown fields: screen printing, slot die, …in R2R or S2S line manufacture…….
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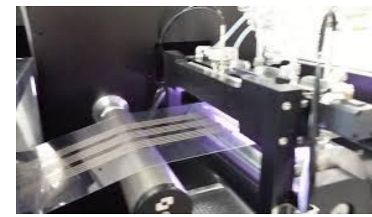

Few bibliography about recyclability and LCA (and LCC) of new PV technologies: Main papers are related to Si based technology and thin films . RD focus on increase efficiency. … ***RD in progress***.

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What SHOULD happen with new PV technologies?

Develop BEST PRACTICES from RD to industrial

- Develop the solar cell and PV panels with end-of-life in mind using a **“Life flow”**
- Implementing an **extended producer responsibility** program can best ensure that companies reduce waste during manufacturing, modules are recovered at the end of their useful life, that there is accountability for safe and proper dismantling of modules, and that the component parts are reused either in new modules or in different products.
- **Standardization** of Life Flow model for all PV technologies: working under WEEE and fit current policies under a unique framework.

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