PV Module Design for Recycling Guidelines

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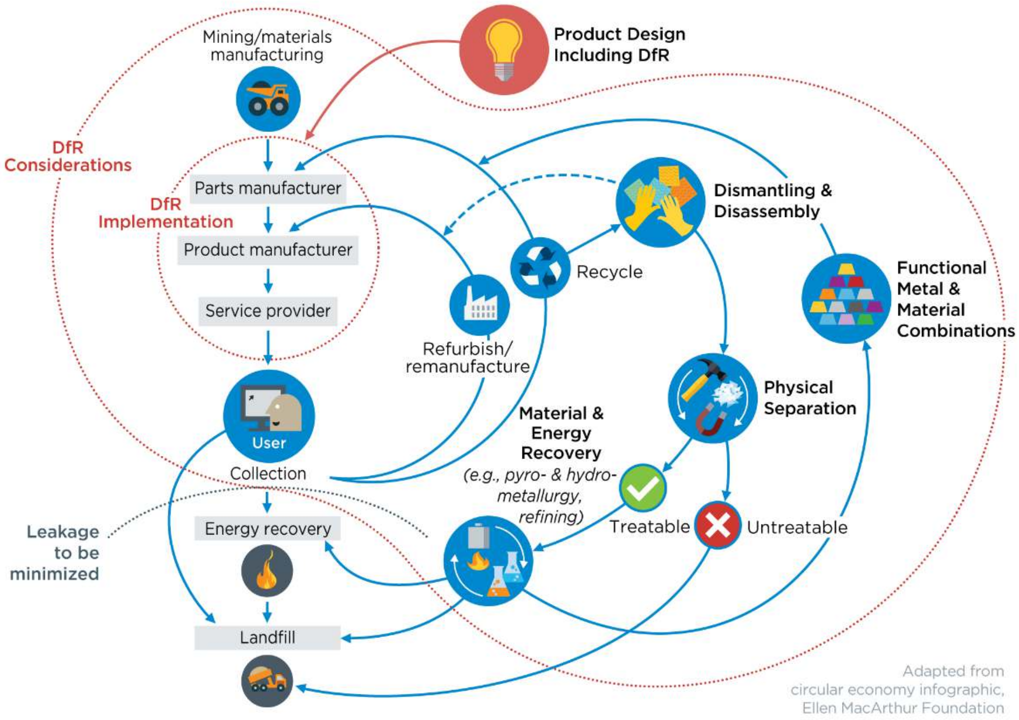
Design for recycling (DfR) guidelines – Motivation and Scope

- Two ways to improve recyclability:
  - Design a better recycling process, and/or
  - Implement Design for Recycling (DfR) strategies prior to the product manufacturing stage.
- DfR strategies are a function of both the product in question, as well as the nature of available recycling processes.
  - The relationship between a circular economy, recycling stages, the implementation of, and considerations necessary for, effective DfR are illustrated in the figure to the right.
- A literature review was performed to compile a preliminary list of DfR best practices.
  - Results were socialized with international experts including industry.
- Our list consists of 10 overarching DfR guidelines, and 6 PV-specific DfR guidelines & observations.



In some cases, as shown by the dotted line, DfR may enable the direct recovery of intact components for immediate reuse, thus bypassing significant intermediate energy expenditures and potential materials losses.
(Modified from the Ellen McArthur Foundation)

General DfR Guidelines (applicable to PV and also other technologies)

1. Product requirements such as functionality, longevity, reliability, and cost are critical; DfR should support or enhance these aspects but may result in trade-offs between recyclability and product performance and cost.
2. Material choice and the ability to liberate separate materials are critical to DfR outcomes.
3. Recycling outcomes can be enhanced by minimizing hazardous materials in products, or by recovering these materials completely via DfR.
4. Minimizing and managing hard-to-recycle materials can improve overall recycling yield.
5. Minimizing non-reversible adhesives or similar bonds, especially over whole surfaces and for dissimilar materials, can facilitate disassembly and material liberation.
6. Design for disassembly (DfD) can improve recyclability.
7. Estimating recyclability improvements and economic and environmental impacts due to DfR is important for continuous improvement, identification, and weighing of trade-offs and communicating value.
8. Using labels to identify recyclable and non-recyclable materials helps recyclers classify feedstocks; labelling standardization is important for uptake and utilization.
9. Designing products to use recycled materials promotes circular manufacturing.

Crystalline silicon-specific guidelines, and comment on CdTe

Crystalline silicon:

1. Durable identification of module construction and composition could enable safer and more efficient recycling processes.
2. Backsheet composition (e.g., fluorine) has particularly important implications for recyclability.
3. Metal choices can have significant impacts on recycling processes and costs. (e.g., substituting silver with copper/nickel; lead)
4. Minimizing encapsulant use or using reversible encapsulants can facilitate disassembly of PV modules.
5. Decreasing the number and complexity of module materials presents trade-offs related to recyclability and economics. (e.g., framed vs. frameless)
6. Using different sealants in the aluminium frame could enable module separation without component damage.

Comment on CdTe

- First Solar manufactures and recycles CdTe systems (improving to a 3rd version over 10 years)
- Integrating manufacturing and recycling in the same facility and supply chain enabled the establishment of a best practice for DfR implementation:
  - The recycling division is part of the approval chain for new module designs, ensuring recyclability is considered in developing new module designs.

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