Materials Sustainability for the Photovoltaic Industry

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The purpose of this article is to demystify and explain that in the next decades, the photovoltaic (PV) industry supply chain will be able to responsibly manage sustainable materials flows by a combination of efficient materials extraction, usage, recycling, product design and substitution.

The PV industry has been growing at between 20-40 percent per annum over the last few years and is expected to continue the same trend into the foreseeable future. The European Photovoltaic Industry Association (EPIA) has prepared various scenarios suggesting that by 2020, the annual market in Europe for PV installations could amount to between 80 and 160 GWp/year depending on the scenario chosen.

Current state-of-the-art PV comprise several technologies, including wafer-

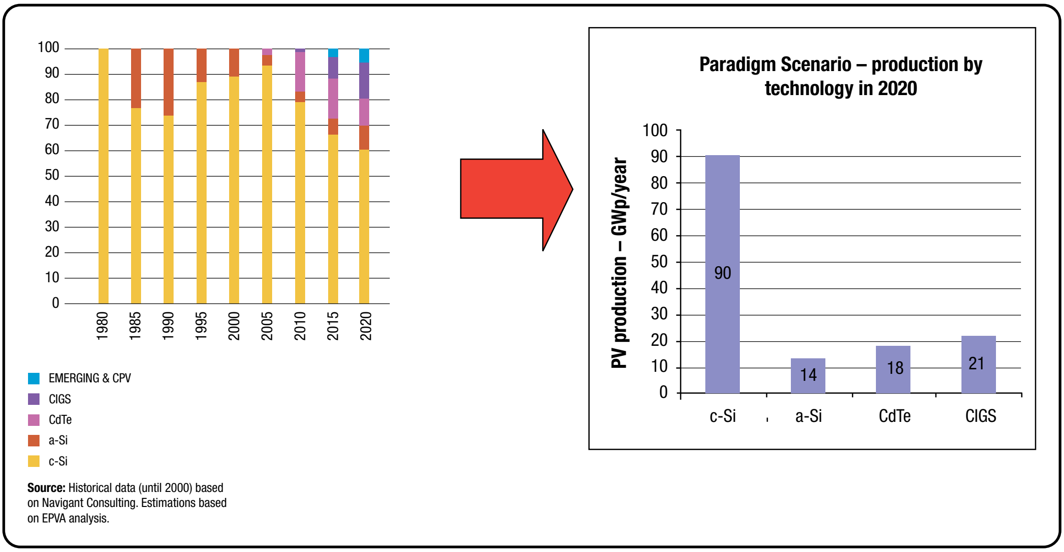


Figure 1 – Scenario for PV Production in 2020 by Key Technology (www.epia.org)

based crystalline silicon; three distinct thin film active layer categories (thin film Si; CdTe; CIGS); as well as high-efficiency multi-junction concentrator systems (CPV). Each one of these technologies relies on the usage of specific materials with varying degrees of availability criticality.[1]

It is not useful to speculate on the market share breakdown of each PV technology beyond 2020. This will be determined according to their respective cost and performance, and the market penetration of newer PV technologies. It is generally expected that wafer-based c-Si technologies will remain the dominant PV technology in 2020 with between 50-70 percent of the total installations and the rest being divided among the other PV technologies.[2]

In Table 1, it can be seen that for 2020, as a whole, the PV industry will not be responsible for exhausting the available resources of elements considered.

However, PV will be in competition with other industries and products for access to these raw materials. Taking into consideration the likely evolution of the competing industries, improvements in primary and secondary sources as well as the many improvements anticipated in PV cell and module design, it is not expected that the materials supply situation will be stressed for the PV manufacturing industry before 2020. By that time, viable alternatives that are currently being developed will have become commercially available to take over the relay.

One useful point to note is that the mere fact that an industry relies on critical materials is not in itself a condemnation. If this were to be the case, then we would have no microelectronics industry

Metal	PV production 2020	Specific metal requirement in 2020	Paradigm scenario total demand in 2020 for PV	Estimated annual world-wide primary production 2010	Recycled material 2010	Total production 2010	2020 PV demand vs 2010 total production
	GWp/year	Tons/GWp	Tons	Tons/year	Tons/year	Tons/year	%
c-Si	90						
Ag		59	5310			32900	16%
CIGS	21						
In		53	1113	550	750	1300	86%
Ga		12	258	110	30	140	185%
Se		50	1050	3000	50	3050	34%
CdTe	18						
Te		56	1008	465	35	500	202%

Table 1 – Summary of Key Materials Requirements for the PV Industry in 2020 Under the Paradigm Shift Scenario

today and no flat panel displays (FPD). The latter alone consumes 80 percent of today's indium supply for depositing the ITO transparent conductive oxide (TCO). However, any such implicated industry must be able to demonstrate a responsible attitude and clear roadmap to materials sustainability.

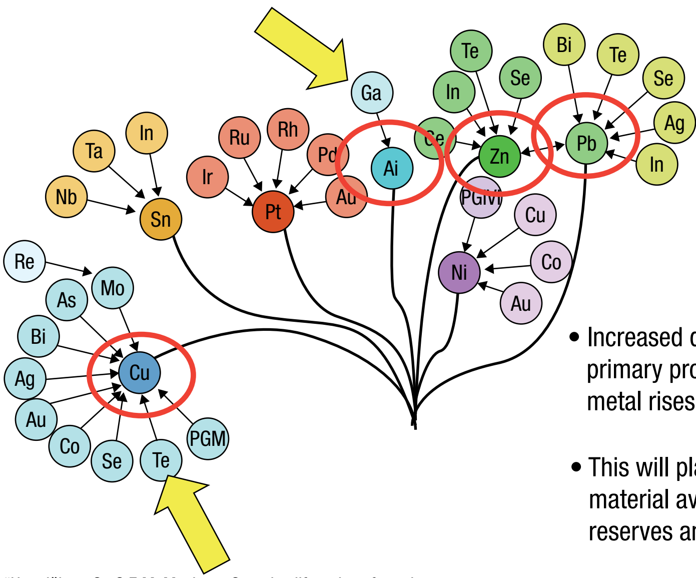
Materials Availability: Supply

Materials availability is a very complex topic with a notable lack of universally accepted public data. However, certain materials are more critical than others; hence, the growing concern among policymakers worldwide regarding their availability.

Firstly though, we need to note the following distinct but interrelated categories of availability:

a) a given material's **intrinsic availability** (based on total identified and accessible reserves)
b) its **economic availability** (based on relatively simple short-term economic reasoning)
c) its **economic availability** (based on the available industrial infrastructure that will enable effective extraction/recovery/refining).

In instances of **intrinsic availability**, this is further complicated inasmuch as certain materials such as indium,



- Increased demand can only be met by primary production if demand for major metal rises accordingly.
- This will place an absolute cap on total material availability in terms of total reserves and production capacity.

… hence supply is finite

Source: "Hagelüken, C., C.E.M. Meskers: Complex lifecycles of precious and special metals, in: Graedel, T., E. van der Voet (eds): Linkages of Sustainability. Strüngmann Forum Report, vol. 4. Cambridge, MA: MIT press, 2009."

Figure 2 – The Mining Tree

selenium, gallium, tellurium and germanium are principally sourced as byproducts from major commodity metal ores such as copper (in instances of tellurium) and zinc (in instances of indium).[1]

It would not be economic, at any feasible price, to mine such ores just to valorize these byproducts. So there is a conjunctural cap on critical materials availability based on the growth of the world economy. Obviously, this situation is different for silicon and silver; these elements are found at high concentration in specific minerals and are typically not mined as byproducts.

The recovery yield of primary sources is of course a key factor in materials availability. The present recovery yield of such byproducts is inherently inefficient, and much progress can yet be made by enticing the mining and extraction industries to raise their recovery rates.[1] This can be encouraged by, for example, long-term supply contracts, which will allow the mining industry to better manage the risk of getting a reasonable return on such investments.

Figure 3 illustrates schematically the typical materials flows during the life cycle of associated byproduct metals. Evidently, the volume values to apply are specific for

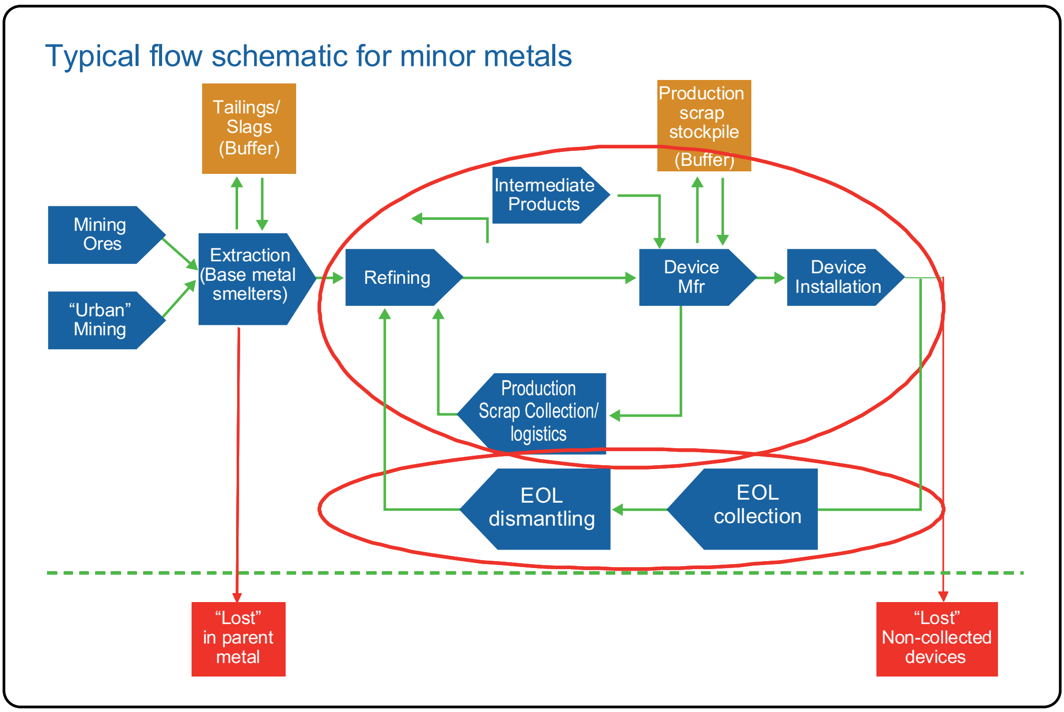


Figure 3 – Process Scheme for the Formation of a Local Back-Surface Field With Laser Chemical Processing (LCP)

each material, but the schema remains similar. As mentioned above, the recovery yield can be made far more effective with appropriate economic driver mechanisms in place. In addition, there are significant "reserves" for such materials buried in the historical tailings and slag deposits.

The **economic availability** is also linked to this previous point. The laws of supply and demand will influence the trading price of such metals. As the prices rise, so will the estimated recoverable reserves for that material.

Recycling is a popular discussion topic, and there are a number of opportunities to enhance the total materials availability equation through effective recycling. This can take place at two points on the supply chain.

The first recycling source is PV device production scrap and it is the one that will have the greatest short- to medium-term impact on materials availability. With current vapor-based deposition techniques, only 30-40 percent of the material actually is deposited on the solar device. The remaining 60-70 percent remains in non-consumed targets or deposited on the reactor chamber walls and shieldings. The industry is working in a number of directions to reduce such losses:

- firstly, although some recycling already takes place, more can be and is being done to recover higher amounts of such material
- increasing the production yields and performances of "good" devices
- using more efficient deposition processes and tools (e.g., rotary targets, which allow higher usage rate of target material)
- developing new deposition processes such as printing or electrodeposition where it is expected to achieve materials utilization rates of up to 95 percent

The second source is end-of-life (EOL) recycling. It is important for the industry to demonstrate environmental sustainability with respect to decommissioning EOL systems. In Europe, the PV industry has been organizing itself around "PV cycle" to work in collaboration with legislators toward a unified recycling scheme. It is interesting to note that PV cycle membership has grown to represent some 90 percent of the players putting PV modules onto the market.[3] The volumes of PV modules from this source will start to rise dramatically once a sufficient number of modules are effectively at their EOL cycle. But this is not expected to happen before 2020.

A key point with respect to EOL recycling is that EOL devices other than PV also contain useful critical metals for the PV industry. So a third recycling source would be to better exploit the "urban mine."

A good example of this would be the effective recovery of indium from EOL flat panel displays (FDPs). Such devices have a much shorter technical life than PV modules and currently consume about 80 percent of today's indium. Critical materials are typically present only in trace amounts in any device and actual recovery in any recycling scheme will entirely depend on having in place the appropriate technical, economic and, if necessary, legislative enablers.

Technical availability is linked to the readiness of the materials industry to respond in a timely fashion to the device manufacturing industry needs and is a short-term phenomenon. A typical example is the shortage of polycrystalline due to the unexpectedly high growth rates experienced by the crystalline silicon PV industry starting around 2005. After two to three years of severe shortage, the laws of supply and demand were able to regulate pricing sufficiently to encourage the necessary investments by the manufacturers of high-purity silicon. Today and for the foreseeable future, there is no anticipated shortage of polysilicon material, and any future shortages will be resolved by industrial investment within the lead time necessary for new plant build.

Substitution

Technology is forever evolving, and there is a permanent quest for better performance and cheaper products. In a number of instances outside of PV, we can anticipate the substitution of critical materials, e.g., indium in FPDs, GaAs for germanium, and there are potentially cheaper alternatives for tellurium and selenium in certain metallurgical, glass and catalyst applications. The trading price of the metal will drive the substitution of the critical materials and in the end, in the free economic market, it will be the application that is prepared or able to pay the highest price that will ensure access to the material.

In summary, the materials supply chain has a number of opportunities to meet the increasing requirements of a fast-growing PV industry through a combination of increased primary extraction, more effective recycling (principally for production scrap) and eventually, substitution.

Materials Requirements: Demand

Taken as a whole, the PV industry is in the enviable position of having a number of adjacent technologies that can effectively substitute for each other depending (simplistically) on their relative price/performance ratios. This fact has a significant underlying advantage with respect to materials availability. Since there is limited overlap for the critical materials of each of the competing technologies (indium being the exception), if at any time a materials shortage in one technology appears (whether it be intrinsic or conjunctural), there will be a substitute PV technology ready in waiting. This was already witnessed during the shortage of polycrystalline material around 2005-2007, when extra emphasis was placed on developing thin film technologies with no materials availability issues. The aftereffects of this phenomenon are still seen today with a thin film PV industry that was able to reach critical mass and that is now offering viable alternatives to the traditional crystalline silicon PV.

Since materials represent a clearly identifiable cost item in the overall production costs, all the PV technologies stakeholders are continually searching to reduce the amount of materials required per kWh of electricity production. This is being approached in a number of ways:

- increasing the efficiency of the device (all technology roadmaps converge on this goal); important examples are heterojunction solar cells, micromorph film-silicon and by improved light-management of solar devices

- reducing material layer thicknesses
  - crystalline-Si is expected to go from 180 μm wafer thickness to 120 μm (and even 50 μm over time)
  - new deposition processes to reduce the amount of silver required for top contacts in c-Si as well as to substitute silver for copper
  - thinner photoactive layers – as production processes and light management become better understood and mastered, it is possible to reduce accordingly the layer thicknesses
- developing CPV systems that rely on very high optical concentration factors to reduce the size of the cell and consequently the intrinsic amount of materials required
- production processes are being adapted or developed to reduce the materials wastage

Another parallel initiative being undertaken by the PV industry is to develop **alternative thin film materials** systems focusing on non-critical elements not subject to potential shortage.[4,5] An example of this is the development of kesterites (Cu, Zn, Sn, S), where notable progress has been made in the labs over the last two to three years with demonstrated performance of 9.6 percent efficiency for the latest developments.[4] A second parallel route is the development of organic-compound-based PV devices (based on C, O and H, N and S).

Some of these new approaches have a significant potential in both cost reduction and sustainability. Much work has yet to be done to bring them to the state of reliable industrialization. Their introduction will be based on economic arguments rather than fears of materials shortage in the individual PV technologies.

Conclusions

As in all fast-growing industries, the supply chain will face challenges for intrinsic materials availability as well as conjunctural events.

Efforts are being made within the materials supply chain to minimize any supply constraints. The relevant actions include increasing materials availability through improving initial extraction, more efficient usage of the materials in production, more effective recycling of critical materials and improved device performances with lower materials requirements.

Since PV technologies may stand in as a substitute for another, any momentary materials supply issues in one may be mitigated by switching to another.

Based on the above analysis and the expected growth rates for PV as a whole, it is not expected that the current PV technologies will face any intrinsic supply restrictions until 2030.

In the medium term, a number of significant research efforts are under way to develop PV technologies based on materials systems that will face no supply restrictions in the foreseeable future. It is anticipated that these alternative technologies will be ready for industrialization well before the critical period for the current PV technologies is reached.

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About the Authors

Peter Rigby *studied mechanical engineering at Bath University in the U.K., completed with an MBA at INSEAD. Between 2001 and 2011, he was responsible for Umicore's internal innovation & New Business Development unit (Umagine) and has been the driver for a number of new PV-related programs within Umicore, including studies into recycling and specialty materials availability. Peter is an active member of the EPIA and the European PV Technology Platform. Since April 2011, he has changed his focus toward European Government Relations and funding policy.*

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