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An Overview on Recycling of Photovoltaic Modules at the End of Life

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Abstract: "Solar energy is clean, renewable, sustainable, and cost-effective, but it also requires time to develop by individual". Due to the current situation of fossil fuels eradication and over-exploitation across the world. The energy demands of the world are to be fulfilled by renewable energy sources. Among this Solar energy has the maximum potential to be exploited to the maximum level to full fill the energy demands of the world. Renewable energies contribute to the environmental, social, and economic development of countries [1]. There are various of clean and renewable energy sources such as Solar, biomass, wind, hydrogen, fuel cell, nanocomposite, and supercapacitor. Each of the energy sources are suitable for specific geographical locations and can suits from region to region [6]. Since ages Sun has been praised as a vitalizer of life. The total Solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 122 PW·year = 3,850,000 exajoules (EJ) per year. Most of the world's population live in areas with insolation levels of 150–300 watts/m2, or 3.5–7.0 kWh/m2 per day [2 google- Solar Wikipedia]. Solar energy is the most secure and ubiquitous source of energy to meet the power needs after coal exploitation. In present time installation of photovoltaic (PV) Solar modules are growing extremely fast. As result of the increase, the volume of modules that reach the end of their life will grow at the same rate in the near future. Global installed PV capacity reached around 773 GW at the end of 2020 [3] and is expected to rise further to 2840 GW by 2030 and 4500 GW by 2050 [4, 5-Abstract]. Considering an average module lifetime of 25 years, the worldwide Solar PV waste is anticipated to reach between 4%-14% of total generation capacity by 2030 and rise to over 80% (around 78 million tonnes) by 2050 [5-Abstract]. Therefore, the disposal of PV modules will become a pertinent environmental issue in the next decades. Eventually, there is plenty of room for progress in this area. This review present core reality of Photovoltaic Life Cycle, Photovoltaic Technology, Photovoltaic Recycling Process as well as global Waste Management Regulation in different countries and the Environmental & Economic Aspects of recycling. At present, PV recycling management in many countries envisages to extend the duties of the manufacturers of PV materials to encompass their eventual disposal or reuse. However, further improvements in the economic viability, practicality, high recovery rate and environmental performance of the PV industry with respect to recycling its products are indispensable. There is potential to develop new pathway for PV waste management industry development and offer employment and prospects for both public and private sector investors.
Keywords: Recycling, End of life (EoL), Photovoltaic, Waste, Regulatory, c-Si, Thin film, Life cycle

I. INTRODUCTION

Photovoltaics (PV), made from semiconducting materials, convert photons into electricity. When sunlight hits these materials, photons with a certain wavelength trigger electrons to flow through the materials to produce direct current (DC) electricity. Commercial PV materials include multi-crystalline silicon, mono-crystalline silicon, amorphous silicon, and thin film technologies, such as cadmium telluride (Cd-Te), and copper indium Di-selenide (CIS). A typical PV system consists of the PV module and the balance of system (BOS) structures for mounting the PV modules and converting the generated electricity to alternate current (AC) electricity of the proper magnitude for usage in the power grid [6].

Photovoltaic (PV) energy production is one of the most promising and mature technologies for renewable energy production. PV technology is environmentally friendly, flexible to scale based on preferred capacity and has become a popular means of generating power [5]. The first substantial PV installation happened in the early 1990s and since 2000s Solar PV electricity distribution has grown extremely fast. Solar energy technology is currently the third most used renewable energy source in the world after hydro and wind power, which occupy the first and second position, respectively [6]. Solar energy is safe, efficient, non-polluting, and reliable. Therefore, PV technology has a very exciting prospect as a way of fulfilling the world's future energy needs. There is now a large market for PV modules which have the potential to globally produce clean energy. Moreover, it is expected that within the current century, PV-generated electricity will become the primary global energy source [7].

Global installed PV capacity reached around 773 GW at the end of 2020 [3] and is expected to rise further to 2840 GW by 2030 and 4500 GW by 2050 [4, 5-Abstract]. The Solar PV energy demand globally has risen-up around 30% annual growth rate, higher than any other emerging renewable energy-based technologies. Although, we understand that Solar PV is a clean source of energy and environmentally friendly technology but like any other technology its ages and degrade with time. It is expected that silicon based Solar PV modules' lifetime is around 25-30 years and after that it ultimately requires decommissioning of PV modules and proper recycling and disposal of the system components. Considering an average modules' lifetime of 25 years, the worldwide Solar PV waste is anticipated to reach between 4%-14% of total generation capacity (around 8 million tonnes) by 2030 and rise to over 80% (around 78 million tonnes) by 2050 [5- Abstract].

However, with the increase in installations, the number of Solar panels reaching their EoL stage will rise steadily [8]. Solar panels will become a form of hazardous waste when the useful life is over and may harm the environment if they are not recovered or disposed of properly. However, a sound management for Solar panels EoL is gradually becoming an important environmental issue. Therefore, an appropriate recycling of PV waste will become gradually more significant, considering the growing number of installations and extension of production. The utilization of valuable resources and the potential for waste generation at the EoL cycle of PV technologies has imposed a proper planning for a PV recycling infrastructure [9]. To certify the sustainability of PV in large scales of deployment, it is crucial to establish low-cost recycling technologies for the evolving PV industry in parallel with the swift commercialization of these new technologies.

Furthermore, recycling processes for all the different PV technologies are not yet well developed. The processes are well developed for mono or multi crystalline silicon. First Solar [10] has an established recycling process for Cd-Te, but for other thin films there are still room for improvements.

Only about 10% of PV modules are recycled worldwide. The main reason for that is the lack of regulation. It has been shown that, for the current recycling technologies, silicon-based modules do not have enough valuable materials to be recovered and the cost of the recycling process is always higher than the landfill option (not considering the externalities), making recycling an economically unfavorable option [11]. In addition, the recycling of Solar PV modules can ensure the sustainability of the long-term supply chain [12], thereby increasing the recovery of energy and embedded materials and, also, reducing CO_2 emissions and energy payback time (EPBT) related to this industry. The focus should be on the avoidance of damage to the PV cells and module materials, economic feasibility, and high recovery rate of materials that have some monetary value or are scares or are hazardous, that can be reused in the supply chain. Finally, the next step for the industry and researchers is to create module designs that are "recycling-friendly" [13].

Moreover, currently only Europe has a strong regulatory framework in place to support recycling, but other countries are starting to build specific frameworks related to PV waste. It's clear that sustainable development of the PV industry should be supported by regulatory frameworks and institutions across the globe. There must be adequate management policies for photovoltaic modules when they reach their end-of-life (EoL) or when they are not able to produce electricity any longer.

Therefore, Solar PV module EoL management is an evolving field that requires further research and development. The key aim of this study is to highlight an updated review of the waste generation of Solar modules and a sketch of the present status of recovery efforts, policies on Solar module EOL management and recycling. The review also anticipates the base of Solar module recycling recommending future directions for public policymakers [5].

II. PHOTOVOLTAIC LIFE CYCLE

Life cycle is a framework for considering the environmental inputs and outputs of a product or process from cradle to grave (Fig-1) [6].

The life-cycle stages of photovoltaics involve:

1) The production of raw materials,
2) Their processing and purification,
3) The manufacture of modules and balance of system (BOS) components,
4) The installation and use of the systems, and
5) Their decommissioning and disposal or recycling.

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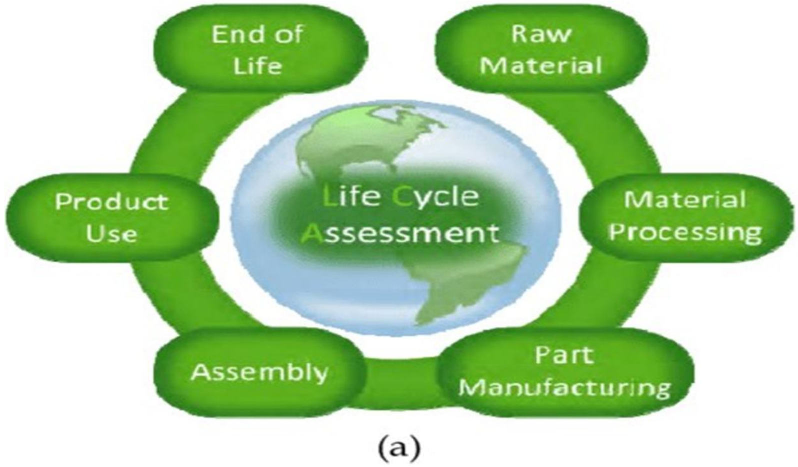

Fig.-1. Photovoltaic life cycle [15]

III. PHOTOVOLTAIC TECHNOLOGIES

Since the recycling of waste photovoltaic (PV) modules has already begun to be commercialized, various technologies for PV module recycling are under development in order to improve process efficiency, economics, recovery and recycling rates, and environmental performance. To meet the needs for future recycling and recovery operations, further efforts including the acceleration of technology R&D, are expected. However, presently for recycling two main classifications are considered for PV cell technologies: crystalline silicon (c-Si), which is the dominant cell technology of existing and currently sold modules; and compound PV technology, which includes thin film modules like cadmium-telluride (CdTe) and copper-indium-gallium-selenium (CIGS) [14]. Recycling technologies of these two main classifications (c-Si PV modules and compound (CdTe & CIGS)) of PV modules are having different characteristics in the module structures and the metals contained in them. One important difference is that the objective of eliminating the encapsulant from the laminated structure of compound PV modules is to recover both the cover glass and the substrate glass which has the semiconductor layer, whereas the objectives for c-Si modules is separating and recovering glass, Si cells, and other metals [14].

A. Crystalline Silicon Technology (c-Si)

Crystalline Si (c-Si) technologies dominate the current market share of PV modules (more than 90%). The aluminum back surface field (Al-BSF) [16] is the current industry standard technology but the passivated emitter and rear cell (PERC) [17] is gaining importance in the world market and is expected to replace the Al-BSF technology in the future. The hetero junction (HIT) cells are also expected to gain some space with predictions of 15% of the total market share by 2027 [18]. Besides that, Si-based tandem Solar technologies are expected to appear in mass production after 2019 [18]. There are different cell structures for crystalline silicon-based PV cells [19]. The cells are electrically interconnected (with tabbing), creating a string of cells in series (60 or 72 cells are standard numbers used) and assembled into modules to generate electricity (Figure 1).

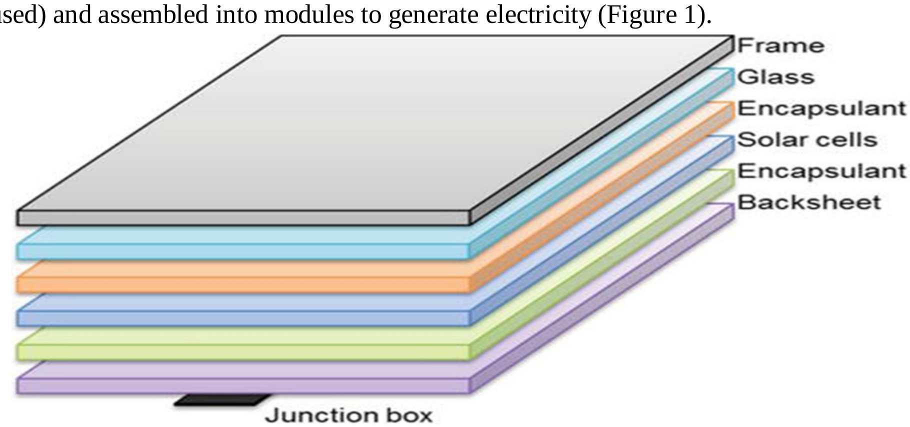

Fig.-2. Silicon Solar module basic structure [19].

A typical crystalline silicon (c-Si) PV module contains approximately 75% of the total weight is from the module surface (glass), 10% polymer (encapsulant and back sheet foil), 8% aluminum (mostly the frame), 5% silicon (Solar cells), 1% copper (interconnectors) and less than 0.1% silver (contact lines) and other metals (mostly tin and lead) [21]. The rest of the components have a small percentage of the module weight.

The EU directive [21] established recycling targets in terms of module weight and also expresses the intention to increase the collection rates to allow the progressive recycling of more material and less to be landfilled. Even with targets aiming for 65% recycling product weight, some of the current studied recycling processes can recycle over 80% of the weight of a PV module. However, there is still incentive to improve, considering that most of the weight is from glass and frame, which are relatively easy to remove, depending on the recycling process.

B. Thin-film Technologies

Thin film represent less than 10% of the total PV industry [22]. The currently dominant technologies are cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (a-Si) with, approximately, 65%, 25% and 10% of the total thin-film market share, respectively [23].

Thin-film Solar cells were developed with the aim of providing low cost and flexible geometries, using relatively small material quantities. CdTe, CIGS and a-Si are the main technologies for thin-film PV modules [24]. CdTe is the most widely used thin-film technology. It contains significant amounts of cadmium (Cd), an element with relative toxicity, which presents an environmental problem that has been studied worldwide [25, 26]. CIGS has a very high optical absorption coefficient because it is a direct band gap material (can be tuned between 1.0 and 2.4 eV by varying the In/Ga and Se/S ratios [27]) and efficiency of approximately 15.7 ± 0.5% for high bandgap [28]. A-Si has low toxicity and cost, but also low durability and it is less efficient compared with the other thin-film technologies [41]. Current projections expect the a-Si module market to disappear in the near future, since they cannot compete on costs or efficiency [22].

Basically, thin-film modules consist of thin layers of semiconducting material (CdTe, CIGS or a-Si) deposited on a substrate (glass, polymer or metal) (Figure 3).

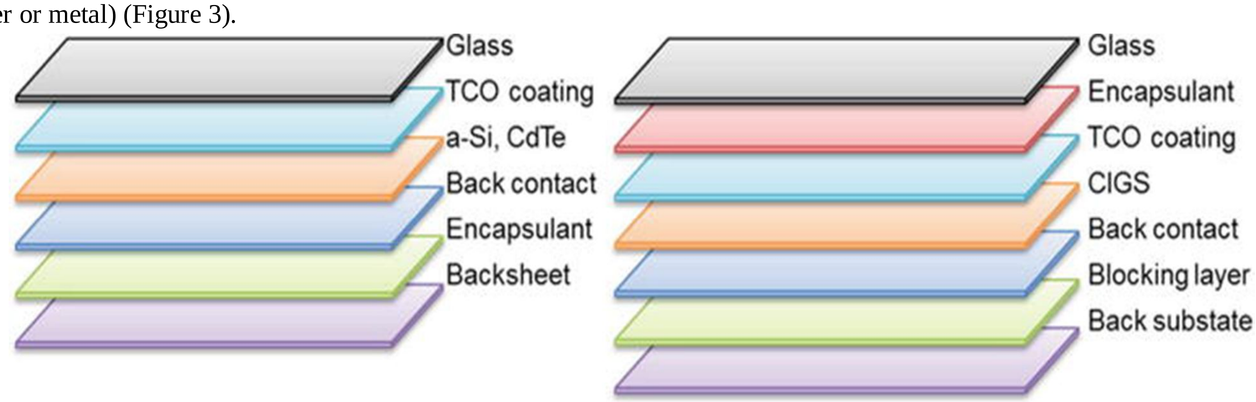

Fig. -3. Thin-film Solar module basic structures [24].

IV. PHOTOVOLTAIC RECYCLING PROCESS

'Recycling' as a means of end-of-life management',

The end-of-life management of waste PV modules offers opportunities related to each of the 3 Rs of sustainable waste management [14].

1) *Reduce:* As R&D and technological advances continue with a maturing industry, the composition of a typical PV module is expected to require fewer raw materials. In addition, hazardous materials are typically subject to rigorous treatment requirements with specific classifications, depending on the jurisdiction. Given current trends in relation to R&D and module efficiency, the raw material inputs and toxicity for both c-Si and thin-film technologies could be reduced significantly [14].
2) *Reuse:* Rapid global PV growth may result in an associated secondary market for panel components and materials. Early failures in the lifetime of a module present repair and reuse opportunities. Potentially, repaired PV modules can be resold on the world market at a reduced market price. Even operational but underperforming panels by standards of the first owner may meet expectations of a second owner [14].

3) *Recycle:* As current PV installations reach the final decommissioning stage, recycling and material recovery will be preferable to module disposal. The nascent PV recycling industry typically treats end-of-life PV modules through separate batch runs within existing plants that were built to recycle one of the main materials of a PV modules, e.g., glass or metal. This allows for material recovery of major components and meets current regulatory requirements (i.e., in Europe). In the long term, however, dedicated module recycling plants can increase treatment capacities and maximize revenues owing to better output quality levels and the ability to recover a greater fraction of embodied materials [14].

End-of-life management with material recovery is preferable to disposal in terms of environmental impacts and resource efficiency as a way to manage end-of-life PV systems. When recycling processes themselves are efficient, recycling not only reduces waste and waste-related emissions but also offers the potential for reducing the energy use and emissions related to virgin-material production. This could be particularly significant for raw materials with high levels of impurities (e.g., semiconductor precursor material), which often require an energy-intensive pre-treatment to achieve required purity levels. Recycling is also important for the long-term management of resource-constrained metals used in PV modules.

PV modules are largely recyclable. Materials such as glass, aluminum and semiconductors can, theoretically, be recovered and reused. Hence it is vital that consumers, industry, and PV producers take responsibility for the EoL of these modules. So far, the most common methods for recycling c-Si PV modules are based on mechanical, thermal, and chemical processes.

Although thin-film Solar cells use far less material than c-Si cells, there are concerns about the availability and toxicity of materials such as tellurium (Te), indium (In), and cadmium (Cd), for example. Furthermore, the production processes also generate greenhouse gases emissions during some reactor-cleaning operations. Because of these issues, it is very important to focus on the recycling of PV modules for all the technologies.

PV life cycle is a not-for-profit organization which goal is to manage PV waste through their waste management program for Solar PV technologies [30]. PV Cycle was the first to establish a PV recycling process and PV waste logistics throughout the EU. In 2016 their process of recycling PV achieved a record recycling rate of 96% for c-Si PV modules (fraction of solid recycled) [31], which is a percentage that surpasses the current European WEEE standards. The process begins with the removal of the cables, junction box and frame from the PV module. Then, the module is shredded, sorted, and separated. The separation of the materials allows them to be sent to specific recycling processes associated with each material.

Nowadays, Japan, Europe and the US are focused on research and development related to Solar module recycling [5]. Most efforts related to Solar module recycling concentrate on Si modules and aim to recover and recycle the most important parts. As stated above, there are presently three different types of recycling process applied to Solar PV modules which are physical, thermal and chemical as illustrated in Fig. 6

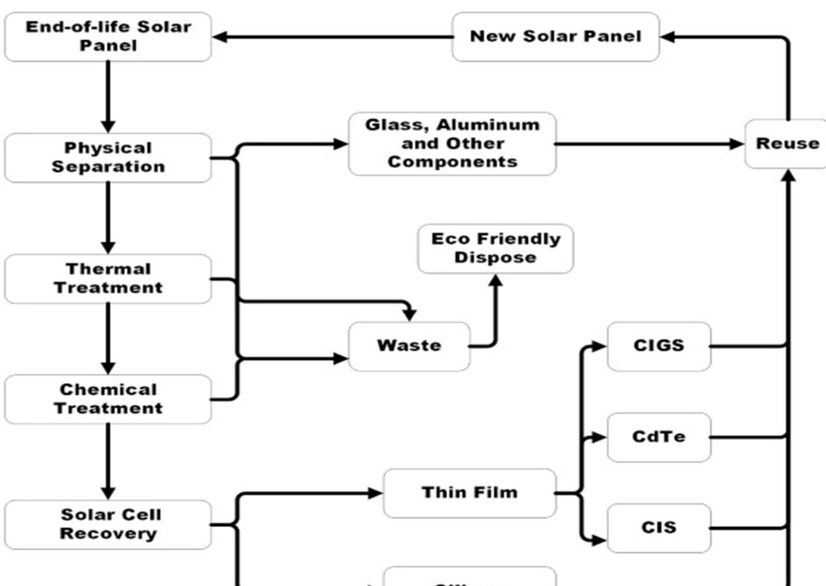

Fig.- 4. Different types of Solar PV recycling processes [5]

A. Physical Separation

This involves separating different broken panels. Junction boxes, embedded cables and Al frames are removed by dismantling the panels or modules. The individual and total toxicity of various parts (junction boxes, panels, and cables) are inspected by crushing and shredding them [32]. EVA (ethylene vinyl acetate) is an encapsulant and sealant for solar cells/modules, ensuring their reliability and performance. The frame bonds the components together and keeps the overall structure light by providing mechanical strength. After they are separated from the modules, frames can be recycled using secondary metallurgy [33].

B. Thermal Treatment

Thermal treatment involves combustion or burning. The PV modules are heated in a furnace at temperatures between 500 and 600°C. Components containing polymers are burned in a furnace but other materials like glass, Si cells and metals are separated manually. Leftover glass and metals removed can be sent to recycling units. The new wafers can be created using recycled Si wafers.

C. Thermal Treatment

Chemical treatment involves immersing PV modules in solvents where components are separated after chemical reactions. However, this approach is more time consuming than the thermal treatment.

The recovery of Si cells is higher in chemical treatment compared with thermal processes

V. PHOTOVOLTAIC WASTE MANAGEMENT REGULATION IN DIFFERENT COUNTRIES

As explained that PV waste potential is going to rise rapidly after 2030 and more new countries will be planning to establish PV recycling industries for safe collection and recycling of PV module. It is essential to have stakeholder’s involvement with every step of the PV system life cycle. Therefore, adequate policies and regulations should be implemented with efficient processes for PV module end-of-life treatment. Regulatory frameworks should include the development of life cycle management techniques and recycling technologies for material recovery. In this section current approaches to PV waste management in different countries are reviewed. It begins with an overview of how today’s most comprehensive end-of-life PV regulation i.e. the EU WEEE Directive. WEEE is applied in selected EU member states, including Germany and the UK .

A. EU’s Waste Electrical and Electronic Equipment Directive (WEEE Directive)

PV module recycling was mandated starting in 2012 through the Waste Electrical and Electronic Equipment (WEEE) Directive, which includes collection, recovery, and recycling targets for waste from electrical and electronic equipment, including photovoltaic panels. Since 2012, all 28 EU member states have transposed the PV requirements into national law, requiring all producers that put PV panels on the market within the European Union to either operate their own take-back and recycling systems or join what are known as producer compliance schemes. Corresponding to the WEEE Directive, a number of European R&D initiatives are driving the improvement of recycling technologies for the different PV technology families. These initiatives aim to decrease recycling costs and increase the potential revenue streams from the secondary raw materials recovered through the recycling process. The European Commission also asked the European Committee for Electrotechnical Standardization (CENELEC) to develop specific PV treatment standards for different fractions of module the waste stream to support a high-value recycling approach. A supplementary standard and technical specification for PV module collection and treatment are under development within the Working Group 6 of the Technical Committee 111X “Environment” of CENELEC. The findings are due to be released in 2017 and also may be incorporated into future revisions of the WEEE Directive [34].

B. United State of America (USA)’s regulatory framework

No federal regulations currently exist in the United States regarding the collection and recycling of end of-life PV modules, therefore, the country’s general waste regulations apply. But there are some states such as like California, Washington those have started operating to develop their own regulation and law for PV module utilization and recycling. California is in the process of developing a regulation for the management of end-of-life PV modules among its borders, however many steps are required to be followed before this regulation is enforced. In California’s 2014- 2015 legislative session, Senate Bill 489 was presented, that enables the California Department of Toxic Elements Control to alter the classification of end-of-life PV modules identified as hazardous waste to universal waste. In July 2017, the Washington state passed Senate Bill 5939, that modifies state renewable energy system tax incentives and requires a takeback and recycling program for end-of-life PV modules.

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The law emphasizes the PV module makers for introducing the product plans that describe how they'll give financial backing to the employment program at different locations in that state. This plan describes that a manufacturer may join in a national program if its purpose meets the objective of the state program. It also specified the requirement that manufacturers who willing to introduce their PV modules in the state of Washington after July 1, 2017, are accountable to provide financing to the recycling program for their units. PV module producers who do not provide their recycling plan details will not allow sell Solar modules after January 1, 2021 [34].

C. Japan's regulatory frameworks

Japan has no specific regulations for end-of-life PV panels, which, therefore, must be treated under the general regulatory framework for waste management (the Waste Management and Public Cleansing Act). The act defines wastes, industrial waste generator and handler responsibilities, and industrial waste management aspects, including landfill disposal. Ministry of Economy, Trade and Industry (METI) and Ministry of Environment (MOE) have jointly assessed how to handle end-of-life renewable energy equipment such as PV, Solar water heaters and wind turbines. In June 2015, a roadmap for promoting a scheme for collection, recycling and proper treatment was developed (16], covering the promotion of technology R&D, environmentally friendly designs, guidelines for dismantling equipment, transportation, and treatment, and publicity to users. Based on this roadmap, the first edition of a guideline promoting proper end-of-life treatment for PV modules including recycling was published in April 2016 [17]. The guideline covers basic information such as relevant laws and regulations on decommissioning, transportation, reuse, recycling, and industrial waste disposal.

It is expected that the roadmap and the guideline will lead to further consideration of policies pertaining to the end-of-life management of waste PV modules [34].

D. China's regulatory frameworks

At present, however, PV modules are not included the waste electrical and electronic products processing directory of the regulation. The National High-tech R&D Program for PV Recycling and Safety Disposal Research has provided recommendations for developing policy guidelines to address PV waste challenges. In February 2009, the State Council of China disseminated the Waste Electrical and Electronic Product Recycling Management Regulation which came into force in January 2011 (State Council of the People's Arvind Sharma et al Global review of policies & guidelines for… 605 Republic of China, 2011). The 2011 regulation become mandatory that e-waste to be collected in different ways and recycled in a centralized processing system. Manufactures can collect and recycle the products by themselves or entrust collection to the venders, after-sales service companies or e-waste recyclers and entrust recycling/ disposal to qualified institutions. On the policy side, the recommendations include the need for special rules and regulations for end-of life PV module recycling, targets for recycling rates and the developing necessary financial frameworks. Whereas, technology and R&D side, recommendations focused on developing and demonstrating high efficiency, low-cost and low-energy-consumption recycling technologies and processes for crystalline Si module and thin-film PV modules. In the 13th, 5-Year Plan for 2016-2020, directions for accelerating the end-of-life management of waste PV modules are described [34].

E. Korea's regulatory frameworks

There are no specific guidelines or regulations governing the end-of-life management of waste PV modules in Korea. However, the report of "2015 energy information and policy support projects" from Ministry of Trade, Industry and Energy (MOTIE) presented a proposal for additional guidelines mandating to report PV waste disposal under "Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy" as a measure to increase PV recycling [30]. According to the report [30], it would be economical to amend rules covering PV waste to the present law on renewable energy instead of producing a brand-new guideline for PV module waste.

The report also suggested that a public establishment ought to be elite to handle the procedures associated with coverage of PV module waste disposal, as presently there isn't any establishments responsible of reporting this information. There are two new projects for PV module recycling were funded in 2016 focused on research, development, and demonstration of recycling facility with a capacity of 2 tons per day. The project also targets to reclaim unbroken wafers from PV waste modules with a yield of <70% reduce the electricity [34]

F. India's regulatory frameworks

India falls on the same category and has no regulations on PV system components collection, recovery, and recycling of end-of-life PV module. At present, PV modules generated waste are treated under general waste regulations. Any policy related to waste is developed by the Ministry of Environment, Forest and Climate Change under the 2016 Solid Waste Management Rules and the Hazardous and Other Wastes (Management and Transboundary Movement) Rules (Ministry of Environment, Forest and Climate Change, 2016a and 2016b). Recently, amended Hazardous Waste Rules also include use of Toxicity Characteristic Leaching Procedure and it requires authorization from the State Pollution Control Board under certain conditions. The Legislation is covered the requirements for general e-waste and restrictions on the use of hazardous substances in electronic equipment are included in the E-waste (Management and Handling) Rules of 2016. However, these rules have limited scope and only apply to household electronics products, not on the PV modules.

VI. ENVIRONMENTAL ASPECTS

Several studies have analyzed the impacts of recycling processes for PV modules on the environment. There are advantages and disadvantages of the different methods, considering all the stages, from the collection of the PV modules to the end of the recycling process. An environmental study made for the European Full Recovery End-of-Life Photovoltaic (FRELP) project showed that environmental impacts from c-Si recycling processes come from plastic incineration and some chemical and mechanical treatments (sieving, acid leaching, electrolysis, and neutralization) for the recovery of metals [35].

Additionally, before the recycled silicon from Solar cells can be used again, further chemical treatment is necessary, as well as for silver and aluminum. The chemical treatments have the potential of producing environmental impacts. Besides that, it is important to note that no process can recycle 100% of recovered materials from Solar modules yet [36].

Nevertheless, for the PV life cycle c-Si recycling process it was shown that there is a significant decrease in Global Warming Potential impacts (up to 20% compared to the process of making cells) [37] and for CdTe modules, there is and environmental benefit from the glass and copper recycling [38].

When comparing c-Si recycling and landfill EoL scenarios it was found that the environmental impacts from the recycling process are lower than for landfill, assuming that the recycled resources go back to the PV cells and modules manufacturing. These results considered that the recycling process involving dismantling, remelting, thermal and chemical treatments [36].

There are opportunities and challenges related to PV recycling processes. Although it was already show that there are environmental benefits, the recycling methods still need to improve in order to achieve better recovery rates and work on the transportation issues.

VII. ECONOMIC ASPECTS

The recovery of valuable materials during the recycling of PV modules can have great economical value. The extraction of secondary raw material from EoL PV modules, if made in an efficient way, can make them available to the market again [39].

Attention has been paid particularly to silver. PV modules that reach their EoL will build up a large stock of embodied raw materials (as mentioned previously), which can be recovered and become available for other uses or even for Solar cells again. However, this will not occur before 2025, according to some forecasts [39].

The ITRPV predicts that, by 2030, the total material value recovered from PV recycling can reach USD 450 million. With this amount it is possible to produce 60 million PV modules (18 GW), which would be approximately 33% of the 2015 production [18].

Considering Si, up to 30,000 t of silicon can theoretically be recovered in 2030 [18], which is the amount of silicon needed to produce approximately 45 million new modules.

VIII. CONCLUSION

"The core idea of PV Cycle is to do something sustainable and replace dirty energy with clean energy". All technologies eventually degrade to the point where they enter their end-of-life stage and eventually must be replaced. This is also true for PV modules, though PV modules have relatively long lifetimes of approximately 25 years or more. In anticipation of the large volume of waste PV modules and to continue to be considered a clean energy technology, various activities related to the proper management of waste PV modules have been developed and need to be developed prior to year 2030.

Currently, the recycling of PV modules is commercialized. However, to improve the process efficiency, recovery and recycling rates, cost effectiveness, and environmental performance capabilities of these methods, several approaches need to be developed and implement in PV sector.

For smooth recycling of PV modules at the end-of-life, government must adopt hardline policies to enforce the manufacturers of Solar PV materials to consider the consequence of their products on the environment. It is also essential to gain the support of the social media, public and non-government organization. To extend the responsibilities of producer not only in the PV manufacturing sector, but also throughout the entire ancillary energy industry, to be responsible for the eventual disposal or reuse of the products. Strict regulatory framework is needed to manage the waster PV modules in the circular economy form. Innovative management programs like establishment of business models which is set up to procure circular business models including take back, refund deposition system and product service for industry.

The pace of R&D will accelerate permitting researchers to resolve issues and contribute to the PV module recycling schemes, as well for the end-of-life management of PV modules.

Landfill treatment to the Solar waste is to be reduced or avoided and procurement of green way to tackle the waste should be put forward.

On the wrap corner on this overview on recycling technologies of PV waste are extensively explored not just on labs and pilot plants, but some are also commercially available

Now sum-up this review with beautiful quote of Tony Cardenas - *"If recycling, then we must focus our efforts on mitigating negative impacts to our community while protecting our environment"*.

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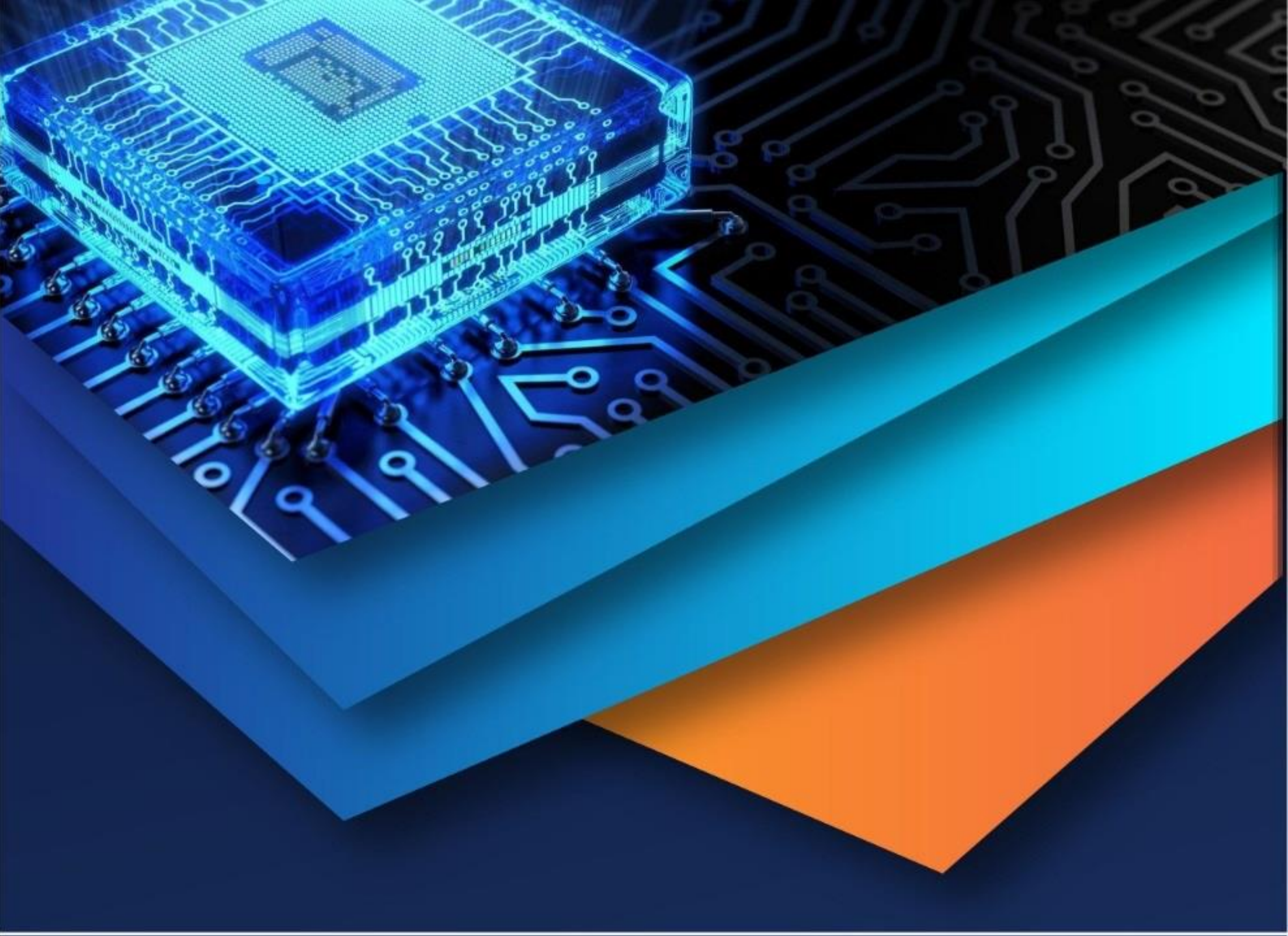

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