Asian Journal of Chemistry; Vol. 33, No. 6 (2021), 1215-1221

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2021.23105

Disposal Method of Crystalline Silicon Photovoltaic Panels: A Case Studies in Malaysia

S.M. Ho[1,*], S.N. Ng[2] and M.A. Munaaim[3]

[1]INTI International University, Putra Nilai, 71800, Negeri Sembilan, Malaysia
[2]Department of Chemustry, School of Environmental Engineering, Universiti Malaysia Perlis, Malaysia
[3]Mega Jati Consult Sdn Bhd, 52200 Kuala Lumpur, Malaysia

*Corresponding author: Tel: +60 6 79820000; E-mail: soonmin.ho@newinti.edu.my

Received: 26 December 2020; *Accepted*: 17 March 2021; *Published online*: 5 June 2021; AJC-20346

Previous studies have highlighted that fossil fuel accounted for the largest share of total energy consumption in worldwide if compared to renewable energy. However, it has many disadvantages such as emission of carbon dioxide gas, contributes to global warming, creates pollution, contributes to acid rain and unsafe. Nowadays, many solar power plants have been built in order to replace fossil fuel. Solar energy has bright future due to some advantages such as pollution free, cheap renewable energy, easy install solar cell panel and less maintenance. Solar photovoltaic development has remarkably grown since the early 2000s. Because an average panel lifetime is 30 years, 17,000 tonnes of solar panel wastes are anticipated in the year 2030 in Malaysia. As the solar photovoltaic market increases, so will the volume of decommissioned photovoltaic panels. Growing photovoltaic panel waste represents a new environmental challenge, but also miraculous opportunities to create value and pursue new solar photovoltaic end-of-life industries economic route.

Keywords: Solar energy, Renewable energy, Crystalline silicon photovoltaic panel, Disposal, Solar radiation.

INTRODUCTION

Malaysia aims to change electricity production from fossil fuels to renewable energy sources. Government expects to increase the renewable energy [1] such as wind, geothermal, biomass, hydro and solar energy to 20% of the production mix by year 2025. Malaysia is situated in equatorial region [2], the monthly average sunshine duration about 4 to 8 h. Table-1 showed the solar irradiance level of different towns in Malaysia [3]. Kota Kinabalu and Kuching provinces received the highest and the lowest solar radiation, respectively. There are several programs or projects were implemented in order to enhance the development of solar energy in Malaysia. The installed capacity of solar energy increased from 0.54 MW (2010), 165.78 MW (2014), 370.07 MW (2017) to 882.02 MW (2019) due to the availability of sufficient sunlight [4] and irradiance level. The government expects to achieve the second largest producer of solar energy in the world and to reach 45% reduction [5] of greenhouse gas emission by 2030. Table-2 shows that five projects having a capacity almost 500 MW have been selected under Malaysia Large Scale Solar programme [6,7]. Malaysia solar industries have made a great strides and are the world third largest manufacturers of photovoltaic equipments such as solar wafers, solar cells and solar panels (Table-3).

TABLE-1
SOLAR IRRADIANCE LEVEL OF DIFFERENT TOWNS IN MALAYSIA

Kuching	1470 kWh/m^2
Kota Kinabalu	1900 kWh/m^2
Johor Bahru	1625 kWh/m^2
Petaling Jaya	1571 kWh/m^2
Seremban	1572 kWh/m^2
Senai	1629 kWh/m^2
Kuantan	1601 kWh/m^2
Ipoh	1739 kWh/m^2
Bandar Baru Bangi	1487 kWh/m^2
Bayan Lepas	1809 kWh/m^2
Taiping	1768 kWh/m^2

Photovoltaic panel can convert the sun energy into electricity [8]. Electricity produced could be used for powering household appliances and equipment. The panels are made out of small photovoltaic cells that are connected together [9]. Currently, the panels could be divided into three groups [10],

TABLE-2
PHOTOVOLTAIC PROJECTS UNDER MALAYSIA LARGE SCALE SOLAR PROGRAMME IN PENINSULAR MALAYSIA

Developer	Location	Capacity (MW)
ib vogt GmbH and Coara Solar Sdn Bhd	Marang, Terengganu	100
Cypark Resources Berhad and Impian Bumiria Sdn Bhd	Marang, Terengganu	100
JKH Renewables Sdn Bhd and Solarpack Asia Sdn Bhd	Kuala Muda, Kedah	90.88
ENGIE Energie Services SA and TTL Energy Sdn Bhd	Kerian, Perak	100
Konsortium Beseri Jaya Sdn Bhd and Hanwha Energy Corp Singapore Pte Ltd	Pekan, Pahang	100

TABLE-3
PHOTOVOLTAICS MANUFACTURING IN MALAYSIA

Company	Location	Solar cells capacity
TS Solartech	Penang Science Park	500 MW
First Solar	Kulim Hi-Tech Park	2000 MW
JA Solar	Penang	400 MW
Jinko Solar	Penang	500 MW
Panasonic Energy Malaysia	Kulim Hi tech Park	300 MW
Q-cells Malaysia	Cyberjaya	1100 MW
Sun Power	Malacca	1400 MW
Longi Solar	Kuching, Sarawak	600 MW

namely monocrystalline photovoltaic panel (most efficient and expensive), polycrystalline photovoltaic panel (less efficient but more affordable) and thin films photovoltaic panel (the cheapest and least efficient). In this work, disposal methods of monocrystalline photovoltaic panels will be highlighted and discussed.

Solar energy is one of the renewable energy. It has many advantages if compared to other renewable energies such as biomass, hydro, wind and geothermal energy (Table-4). Solar photovoltaic development has remarkably grown since the early 2000s. Because an average panel lifetime is 30 years, 17,000 tonnes of solar panel wastes are anticipated in the year 2030 in Malaysia. As the solar photovoltaic market increases, so will the volume of decommissioned photovoltaic panels. Increasing the photovoltaic panel wastes represents a new environmental challenge, but also miraculous opportunities to create value and pursue new solar photovoltaic end-of-life industries economic route [25].

Malaysia has developed a comprehensive set of legal provisions related to the management of toxic and hazardous wastes. The regulation [26] is based on the cradle to grave principle as shown in Table-5. A facility which generates, stores, transports, treats or disposes scheduled waste is subject to the following regulations based on Malaysia's Department of Environmental are as follows:

Global photovoltaic waste management: It is proposed that the global solar energy leaderboard current approaches to the management of photovoltaic waste. The current management of most comprehensive end-of-life panels is used in the selected EU membered countries, including China, Japan, UK, India and USA. Six case studies were selected to study of maturity of the development of photovoltaic waste management.

In Germany, Deutsche solar developed a recycling system mainly to recycle the standard crystalline silicon module. This system is widely used. The system is used to separate module components in two steps of processes (Fig. 1).

TABLE-4
ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF RENEWABLE ENERGIES

The advantages of solar energy:
• It does not pollute the water [11]; • Low maintenance costs [12]; • Reduces electricity bills [13]; • It does not produce greenhouse gases [14]

The disadvantages of:

Wind energy	Ref.	Hydro energy	Ref.	Geothermal energy	Ref.	Biomass energy	Ref.
Noise	[15]	Expensive	[18]	High initial capital costs	[20]	Not entirely clean	[22]
Remoteness of location	[16]	Droughts		Releases greenhouse gasses		Relatively inefficient	
Aesthetic impact		Affected fish habitats	[19]	Inefficient geothermal heat pump		Lead to deforestation	[23]
Wind turbines dangerous to animals	[17]	Limited reservoirs		Sustainability issues	[21]	It needs a lot of space	[24]

TABLE-5
NATIONAL RULES AND REGULATION

No	Legislation/Regulations/Guidelines
1	Environmental Quality (Scheduled Wastes) Regulations 2005
2	National Renewable Energy Policy and Action Plan
3	Environmental Quality (Prescribed Conveyance) (Scheduled Wastes) Order 2005
4	Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Order 1989
5	Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal Facilities) Regulations 1989
6	Customs (Prohibition of Export) Order (Amendment)(No. 2) 1993
7	Customs (Prohibition of Import) Order (Amendment)(No. 2) 1993
8	Renewable Energy Act 2011
9	Sustainable Energy Development Authority Act 2011
10	Basel Convention Control of Transboundary Movements of Hazardous Wastes and Their Disposal

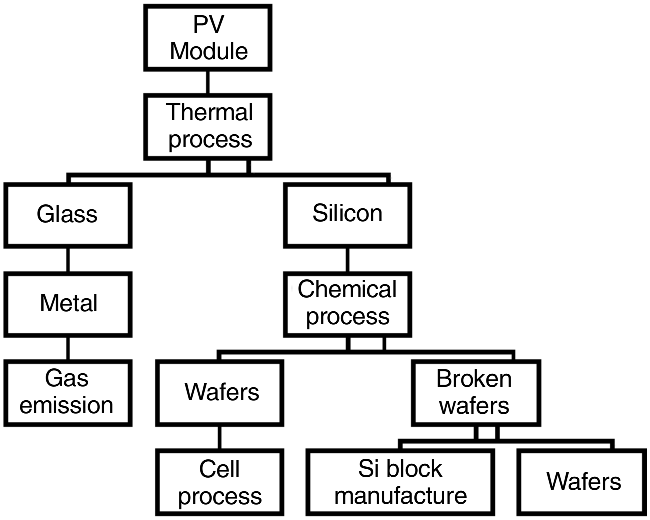


Fig. 1. Crystalline silicon module processing procedure in Frelberg

First, a frame and glass are sorted and disassembled for recycling. Subsequently, the thermal treatment is employed to remove glass plates and metal frames. The solar cell array is left sandwiched between a back sheet and resin of ethylene vinyl acetate (EVA). To obtain at the cells, the back sheet and resin must be removed [27]. Copper, plastic materials and silicon powder are obtained at the end of the entire process [28].

Second, the structure of solar cell is removed through etching for silicon wafer recovery. Etching is performed by subjecting the solar cell to a chemical process and by cleaning till a novel silicon wafer is obtained. Retreated wafers can be reetched and employed as new solar cells. Etching process steps include anti-reflection coating removal, metallization removal, surface finishing, n+ and p+ doping isotropic removal, rinsing and drying [29]. However, solar silicon recovery from the broken solar cell is highly economical. This technology enables the recycling of completely worn-out modules, broken modules, and production waste and provides recycling rates of >95% [30].

Due to its low waste volume, the mature recycling industry of photovoltaic panels is not available in China. Under China's Safety Disposal Research and National High-tech R&D Programme photovoltaic recycling from 2012-2015, China has focused on two recycling methods for crystalline silicon solar photovoltaic management. These techniques are based on thermal or physical recycling. Physical recycling involves various processes, such as cryogenic grinding, crushing and separating yield glass cullet, aluminium, ethylene vinyl acetate, copper, back sheet particles, and a mixture of silicon powders. The recycling rate is approximately 90% by mass. However, due to its low purity, silicon cannot be recycled to be used in photovoltaic industries. In thermal recycling, clean cell debris is subjected to a thermal treatment, and then, is employed in the chemical experiments for silver, silicon and aluminium recycling [31].

United Kingdom has specified some rules for defining photovoltaic producers and thus, has provided an extended producer responsibility principle when WEEE directive was transposed in the National Law. In National Legislation, the UK government developed a novel separate category for financing the recycling and collection of photovoltaic panels [32]. The development of this separate photovoltaic category provided the photovoltaic sector considerable control over the financing of photovoltaic panel recycling and collection.

Fig. 2 presents an example of the technology of photovoltaic recycling developed in 2014 under New Energy and Industrial Technology Development Organization (NEDO). The technology allows different panels (thin-film Si, c-Si and copper indium selenide) to be separated automatically and comprises four main processes: back sheet removal, aluminium frame removal, copper indium selenide (CIS) layer scraping (only for CIS panels) and the burning of ethylene vinyl acetate resin. Currently, technology is in the experimental phase. The early loss annual throughput of technology is approximately 12 and 7 MW for c-Si and CIS panels, respectively, depending on the type and size of panel [34]. This throughput is attained by investigating optimal collection, removal, sorting and developing a low-cost recycling technology.

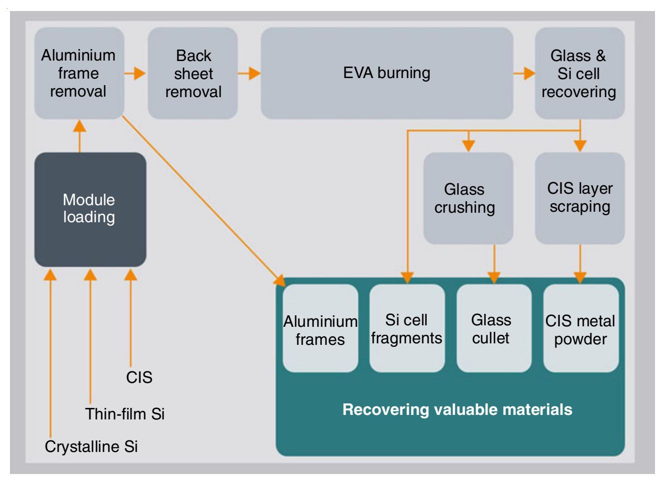


Fig. 2. Foundation for Advancement of International Science (FAIS) PV panel recycling system [Ref. 33]

The Resource Conservation and Recovery Act does not specify any requirements for photovoltaic panels. For waste management, the panels must be treated under the general regulatory framework. Two types of hazardous wastes are as listed and characteristic hazardous wastes. Listed hazardous waste is the actual listings of specific hazardous waste types. Because the end-of-life photovoltaic panel is not the listed hazardous waste, these panels must be analyzed using the characteristic hazardous waste method. This purpose is achieved by determining whether extracts from the sample representative of waste comprises contaminants which exceed regulatory levels.

Recently, photovoltaic has been deployed on a large scale; thus, the major waste volumes of end-of-life photovoltaic may not be expected in India until after 2030. General waste regulations cover the waste generated through photovoltaic panels. For photovoltaic panels, numerous recycling processes and treatment are under development worldwide; however, only two recycling methods and treatments are tailored for photo-

TABLE-6
SPECIFICATION OF EDXRF TEST

Instrumentation	Measurements were performed using PANalytical MiniPal 4 – a benchtop energy dispersive X-ray fluorescence (EDXRF) spectrometer, spectrometer, equipped with a 30 kV rhodium anode tube, a helium purge facility, a high-resolution Silicon Drift Detector, a spinner and a 12-position removable sample changer [Ref. 36]
Sample	S-ENERGY, Model SM-295PC8
Sample preparation	Manual dismantling to separate aluminium frame and cut solar soft layer into required circular diameter of 2.3 cm. The outer glass protective layer is removed leaving the soft layer of cell encapsulate by EVA to put in sample cup of XRF machine.
Measurement procedure	The total measurement time per sample was less than 20 min

voltaic panels. These methods are tested and implemented at First Solar′s treatment Co. and Deutsche Solar′s treatment Cp. for cadmium telluride and crystalline silicon panels, respectively.

Disposal of c-Si photovoltaic panels suggested for implementation in Malaysia: Thanam Industry Sdn Bhd is the licensed provider of recycling solutions and waste management in Malaysia. These solutions comprise all the common recycling services that incorporate the areas of material storage, recycling and transformation into safe disposal or renewable resources [35]. The elemental analysis energy dispersive X-ray fluorescence (EDXRF) analysis is based on the following principle, when excited using an external energy source, individual atoms emit the X-ray photons of a characteristic wavelength or energy. The test was performed to compare the data result with the theoretical element. Table-6 presents specification to conduct the test.

Under the same conditions, two tests were performed to optimise the accuracy excitation of the element group. The element result was tabulated after the sample result was obtained. The results were compared with the measurement conditions presented in Table-7. A solar panel comprises approximately 75% glass; however, this glass is removed before tests. Therefore, silica cannot be detected. Table-8 presents the details of sample preparation.

TABLE-7
MAJOR STANDARD ELEMENT IN SOLAR PANEL

Condition	Filter	Element composition in descending order
1	No	Al, Si, Cu, Ag, Pb
2	No	

According to solar panel weight, the respective element weight composition was a silicon solar panel (Table-9). According to element composition, the respective element percentage constitutes the total elements detected in the solar panel sample. The comparison of references with the EDXRF provided the trend of the element composition constituting in solar panels, where silicon has the highest composition. The literature has shown that silicon has the highest weight composition in the total weight of solar panels.

Lead and copper are the main elements employed in solar panel manufacturing. Lead and copper interchange the position and copper is supposed show a higher percentage than lead. Because lead and copper exhibit a similar percentage composition, the location of percentage compositions may interchange

TABLE-8
FLOW ON PREPARATION OF SAMPLE TO TEST

	1. A faulty solar panel is obtained from solar PV site in Kuala Perlis.
	2. Solar panel side and Aluminium frame is screwed. a screw driver is used to manual unscrew it.
	3. After unscrewed, the frame bounded 4 sides of solar panel is removed.
	4. Photo shows solar panel after frame is dismantled.
	5. Solar panel is in fragile form without frame support. A small piece of solar panel is cut using saw.
	6. A width × length (6 cm × 8 cm) solar panel is cut off.
	7. Glass covered on the solar panel is removed by bare hand wearing gloves. A soft layer of solar film is obtained.
	8. The film is then cut into circular shape of 2.5 cm diameter using a scissor. 2 samples are prepared.
	9. Two thin films are located in position 1 and 2 in the XRF machine.
	10. The result is obtained after 10 min calibration. Elements in solar film is then tabulated and analysis.

TABLE-9
COMPARISON OF CALIBRATION RESULT

Material content	Calibration result 1 (%)	Calibration result 2 (%)
Silicon	56.3	52.4
Calcium	23.9	25.8
Bismuth	5.0	2.3
Copper	2.28	1.71
Thorium	2.2	–
Lead	2.1	2.4
Titanium	1.9	–
Others	7.0	13.9

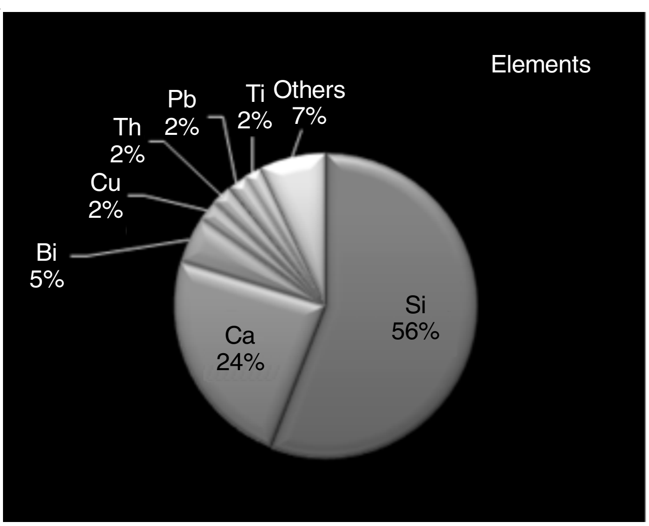
in the process of obtaining the solar layer, in which elements scattering for two cut positions are different. The amount of copper scattered on the surface of area sample 2 is small; other element presents 13.9% composition, which is considerably higher than copper composition. The calibration results (Fig. 3) exhibited a strong correlation between the intensities and certified concentrations for major element silicon. The accurate analyses of P, Si, and S is highly attributed to powerful software correction models and outstanding detector resolution.

Six countries with the most experience in the production of the solar panel recycles were assessed. To recycle crystalline-silicon-based solar panels, the recycling technique of Deutsche Solar Recycling Company is commonly used. For the initiation of recycling, from the installation sites, solar panels are removed. These panels transported for waste treatment. Silicon-based solar photovoltaic recycling involves two major stages: (i) solar photovoltaic cell separation and (ii) solar photovoltaic cell surface cleaning [36]. Photovoltaic panel components are separated and the valuable materials recovered then recycled. Fig. 4 shows the process conducted to recycle the solar panel.

To acquire silicon for reutilization in the production of novel modules, following processes are required: chemical and thermal treatment and physical dismantling (Table-10). Once back films and ethylene vinyl acetate (EVA) are burned, cells can be separated physically and processed individually. During thermal burning, the glass plates do not break due to EVA and back sheet deformation when temperature is accurately controlled, which renders recycling easy [37].

Copper and silicon are recovered after the chemical treatment. According to photovoltaic cell technology, for the universal etching solution, mixture compositions must be modified. From the economic perspective, considering the supply level and cost, pure silicon that can be recycled from the photovoltaic cell is the most valuable material used for development. Glass, copper and aluminium can be recovered from c-Si panels with cumulative yields of >85% of the total mass of panels.

Recoverable metals are transported to companies, where refinement and recyclization metals as secondary metals are performed. Glass, which can retain high purity and be separated, is recycled as the glass cullet. Materials, which are difficult to recover, separate and recycle are transported to the landfill and are classified and regulated as hazardous contents.



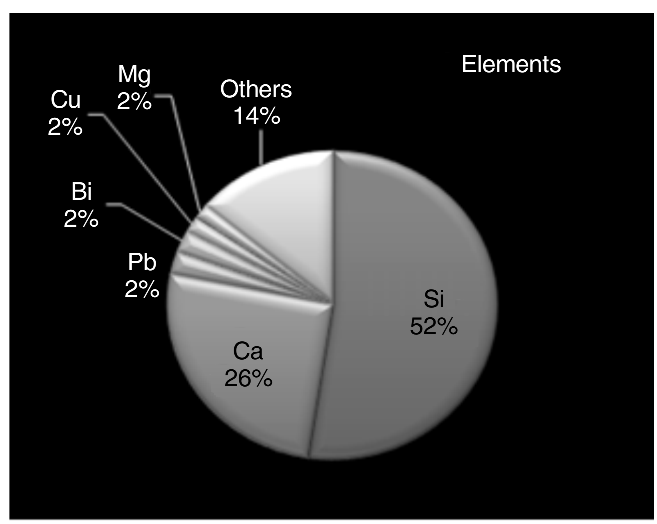


Fig. 3. Calibration result on sample 1 & 2

TABLE-10
SUGGESTED RECYCLING SILICON PROCESS INVOLVED FOR CRYSTALLINE SILICON SOLAR PANEL

Process	Description
Physical dismantle	Module is broken down to remove the metal frames.
Thermal delamination	Wafer array Solar module is heated at 450°C for 45 min. The EVA and back films evaporate. Aim of heating: To recover the no-breaking glass plate. Vapour form combusts in the air portion act as a heat source for the reactor.
Chemical etching	To remove layers of materials from silicon base in order: Silver coating, front metal coating, back metal coating, anti-reflective coating and n-p junction.
Cell rinsing	Silicon cell recover is rinse thoroughly in deionized water.
Silicon powder/plate	Silicon substrate can be obtain and classify suitability to reuse in new solar panel production or in other related field.

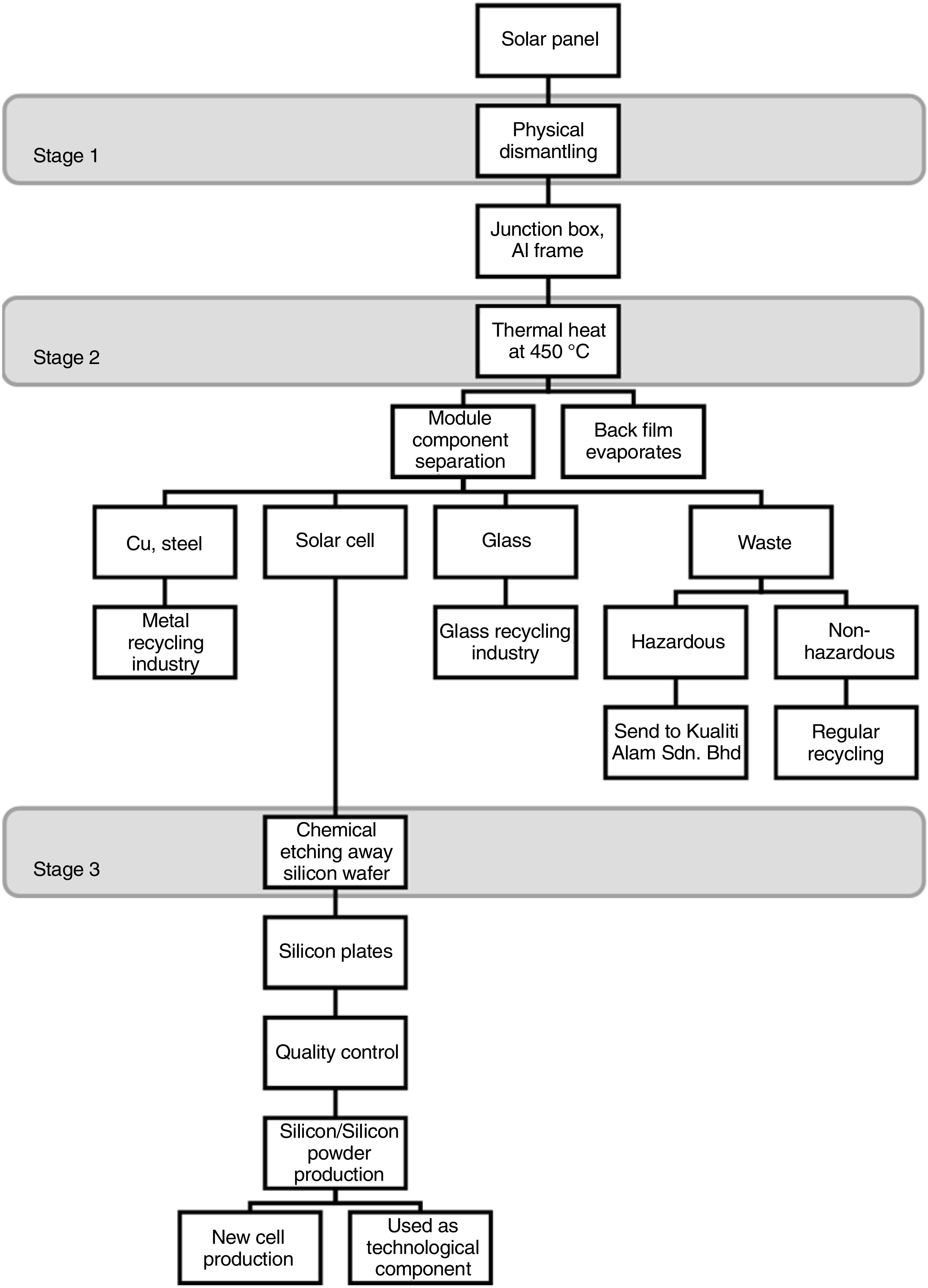


Fig. 4. Recycling process suggested to be implemented in Malaysia

The e-wastes having no commercial value has to be disposed at premises/sites licensed by the Department of Environment, Malaysia [38].

The National Survey Report found that the market price of a standard module crystalline silicon is US $ 0.63/W. Considering all the solar panels installed until 2018, which will undergo recycling when they attain their end life, the overall value of potential materials that were recovered by 2018 from the photovoltaic panel treatment is up to US $ 24.72 billion. This amount is equivalent to 39.8 MW or the current value of raw materials required to produce 15,937 units of novel solar panels.

Conclusion

Solar photovoltaic development rapidly received attention globally. With the expansion of the solar photovoltaic market, panel waste can increase. This phenomenon presents the new environmental challenge and provides opportunities to pursue new solar photovoltaic end-of-life industries through an economic route and create value. End-of-life photovoltaic panel management presents a potential to construct novel approaches to industry growth and provides employment opportunities to various stakeholders. Recycling >90% of a solar panel through innovative technologies that are under development is possible.

ACKNOWLEDGEMENTS

This research work was supported by INTI International University, Negeri Sembilan, Malaysia.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. M. Mohanan and Y.I. Go, *Global Challanges*, **4**, 1900093 (2020); https://doi.org/10.1002/gch2.201900093
2. S. Mekhilef, A. Safari, W. Mustaffa, R. Saidur, R. Omar and M. Younis, *Renew. Sustain. Energy Rev.*, **16**, 386 (2012); https://doi.org/10.1016/j.rser.2011.08.003
3. J.O. Petinrin and M. Shaaban, *Renew. Sustain. Energy Rev.*, **50**, 967 (2015); https://doi.org/10.1016/j.rser.2015.04.146
4. M. Vaka, R. Walvekar, A.K. Rasheed and M. Khalid, *J. Clean. Prod.*, **273**, 122834 (2020); https://doi.org/10.1016/j.jclepro.2020.122834
5. R. Khan and Y.I. Go, *Global Challanges*, **4**, 1900060 (2019); https://doi.org/10.1002/gch2.201900060
6. https://renewablesnow.com/news/malaysia-shortlists-491-mw-of-projects-in-3rd-solar-tender-682716/
7. https://en.wikipedia.org/wiki/Photovoltaics_manufacturing_in_Malaysia
8. S.M. Ho, C. Edmund, G. Adewale, B. Hammed and Y. Ahmed, *Eurasian J. Anal. Chem.*, **13**, 312 (2018).
9. E.H. Adeh, S.P. Good, M. Calaf and C. Higgins, *Sci. Rep.*, **9**, 11442 (2019); https://doi.org/10.1038/s41598-019-47803-3
10. A.M. Bagher, M.M.A. Vahid and M. Mohsen, *Am. J. Opt. Photon.*, **3**, 94 (2015); https://doi.org/10.11648/j.ajop.20150305.17
11. M.H. Ahmadi, M. Ghazvini, M. Sadeghzadeh, M.A. Nazari and M. Ghalandari, *Nano Struct. Nano Objects*, **20**, 100386 (2019); https://doi.org/10.1016/j.nanoso.2019.100386
12. S.M. Ho, A. Lomi, C. Edmund and L. Urrego, *Int. J. Renew. Energy Res.*, **9**, 86 (2019).
13. H. Sharma, A. Haque and Z. Jaffery, *Ad Hoc Netw.*, **94**, 101966 (2019); https://doi.org/10.1016/j.adhoc.2019.101966
14. S.M. Ho, E. Saif, B. Tarik, N. Ng and M. Munaaim, *Int. J. Emerg. Technol.*, **10**, 106 (2019).
15. J. Wang, S. Gu, C. Zhang, G. Hu, G. Chen, K. Yang, H. Li, Y. Lai, G. Litak and D. Yurchenko, *Energy Convers. Manage.*, **213**, 112835 (2020); https://doi.org/10.1016/j.enconman.2020.112835
16. M.S. Nazir, N. Ali, M. Bilal and H.M.N. Iqbal, *Curr. Opin. Environ. Sci. Health*, **13**, 85 (2020); https://doi.org/10.1016/j.coesh.2020.01.002
17. J. Feng, L. Feng, J. Wang and C. King, *Resour. Conserv. Recycling*, **152**, 104484 (2020); https://doi.org/10.1016/j.resconrec.2019.104484
18. S.M. Ho, S. Wagh and A. Kadier, Eds. S.M. Ho, Sources of Clean Energy: Solar and Hydropower Energy, In: Renewable Energy Sources & Environment Protection, International Research Publication House, India (2018).
19. Z. Guo, S. Ge, X. Yao, H. Li and X. Li, *Int. J. Energy Res.*, **44**, 192 (2020); https://doi.org/10.1002/er.4890
20. A. Anderson and B. Rezaie, *Appl. Energy*, **248**, 18 (2019); https://doi.org/10.1016/j.apenergy.2019.04.102
21. A.G. Olabi, M. Mahmoud, B. Soudan, T. Wilberforce and M. Ramadan, *Renew. Energy*, **147**, 2003 (2020); https://doi.org/10.1016/j.renene.2019.09.140
22. A. Datta, A. Hossain and S. Roy, *Asian J. Chem.*, **31**, 1851 (2019); https://doi.org/10.14233/ajchem.2019.22098
23. E. Guresci, *ICE Proc. Energy*, **173**, 141 (2020); https://doi.org/10.1680/jener.19.00069
24. M. Hamza, M. Ayoub, R. Shamsuddin, A. Mukhtar, S. Saqib, I. Zahid, M. Ameen, S. Ullah, A.G. Al-Sehemi and M. Ibrahim, *Environ. Technol. Innov.*, **21**, 101200 (2021); https://doi.org/10.1016/j.eti.2020.101200
25. K. Tasnia, S. Begum, Z. Tasnim and M. Ziaur, 10th International Conference on Electrical and Computer Engineering (ICECE), pp 445-448 (2018).
26. Malaysia Department of Environmental, DOE (2018).
27. Solarteam (2018) from http://2011.solarteam.org/
28. Greenmatch (2018) from https://www.greenmatch.co.uk/
29. E. Klugmann-Radziemska, P. Ostrowski, K. Drabczyk, P. Panek and M. Szkodo, *Sol. Energy Mater. Sol. Cells*, **94**, 2275 (2010); https://doi.org/10.1016/j.solmat.2010.07.025
30. http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0210_engl_internetx.pdf
31. J. Zhang and L. Fang, International Conference on Power Engineering & Energy, Environment (PEEE2016), pp 1-5 (2016). https://doi.org/10.12783/dteees/peee2016/3828
32. UK Department for Business Innovation and Skills, WEEE Regulations 2013-Government Guidance Notes (2014).
33. IRENA and IEA-PVPS; End-of-Life Management: Solar Photovoltaic Panels (2016).
34. K. Komoto, Developments on PV recycling in Japan. In Proceedings 24th European Photovoltaic Solar Energy Conference, Hamburg (2014).
35. Thanam (2018) from http://www.thanam.com.my/
36. B. Mu, W. Wang, J. Zhang and A. Wang, *RSC Adv.*, **4**, 39439 (2014); https://doi.org/10.1039/C4RA05892E
37. T. Wang, J. Hsiao and C. Du, Recycling of Materials from Silicon Base Solar Cell Module, 38th IEEE Photovoltaic Specialists Conference (2012); https://doi.org/10.1109/PVSC.2012.6318071
38. Malaysia Department of Environmental (2018); https://www.doe.gov.my/portalv1/tentang-jas/perundangan/akta-kaedah-peraturan-arahan-2/akta