Study Report

First Solar CdTe Module Technology and Environment Impact Assessment

Paper One

Lifecycle Assessment of First Solar CdTe Modules –Safety and Energy Output

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0. Introduction

A peer review was conducted under the leadership of China Renewable Energy Society and was funded by First Solar Inc. The purpose of this project was to comprehensively evaluate lifecycle environment, health and safety (EHS) impacts and energy output of First Solar's CdTe PV modules. The expert panel was composed of five experts from the Institute of Electrical Engineering of the Chinese Academy of Sciences, a national-level research institution, and All-China Environment Federation, a cause-oriented civil organization under auspice of the Chinese Ministry of Environment Protection, none having direct interest relation with First Solar. The two experts from the Institute of Electrical Engineering focus on research of compound films, crystalline silicon PV modules and materials, while the other three experts from All-China Environment Federation demonstrate proven expertise in environment impact assessment.

The project report comprises of two parts. This part, Paper One, assesses the lifecycle safety and energy output of CdTe modules. The second part assesses the environment, health and safety (EHS) aspects of CdTe modules. Inputs available to this research project include:

i) Published third-party research papers related to CdTe's lifecycle EHS and unpublished in-house statistics furnished by First Solar concerning CdTe modules' potential EHS risks and energy yield characteristics.

ii) Site tour to First Solar's plant in Kulim, Malaysia and communications with executives of the facility, covering:

- CdTe module production and recycling processes;
- Module quality reliability lab;
- In-house wastewater treatment facility;
- Debriefing on First Solar's EHS efforts.

First Solar ensures authenticity and validity of all the data provided by it.

1. Lifecycle assessment of safety of CdTe modules

1.1 Toxicological analysis

For a long time, researchers have referred to cadmium, a toxic element that may cause liver and kidney damage, or itai-itai disease as a result of calcium loss from body, and even cancer in cases of long-term contact, when studying toxicity of CdTe. A compound of cadmium that is insoluble in water, CdTe features maximum stability and very high bond energy and may react with acid. Its melting point is 1,041℃. However, basic data about its solubility in various acid solutions at different pH values are limited (S.Kaczmar, 2011). In fact, the so-called “read-across” approach is the most prudential method to judge toxicity of CdTe from cadmium. However the result might not be justifiable for this compound as physical, chemical and toxicological properties of CdTe have been proven to be much different to cadmium and other cadmium components.

CdTe is very stable. Table 1 compares it with several other Cd compounds. Cd, and such Cd compounds as $Cd(OH)_2$ and $CdCl_2$ are carcinogenic. But there are no research findings on carcinogenicity of CdTe.

Zayed and others (Zayed. J, 2009) evaluated acute inhalation and oral toxicities of CdTe in rats and found the median lethal concentration and dose to be three orders of magnitude higher than that of Cd. Prior testing by Chapin (1994) showed no detectable effects of CdTe on male or female rat reproduction. In-depth research on toxicity of CdTe by S. Kaczmar (2011) came to the following conclusions: no mutagenic activity causing genetic mutation was found in CdTe during bacterial reverse mutation test which compares to positive mutagenicity results for Cd (Ochi and Ohsawa, 1983; Oberly et al., 1982). The bioavailability of CdTe was evaluated with a simulated gastric fluid (pH of 1.5) and yielded 11 mg of cadmium per g of cadmium telluride (~1%) which compares to a read-across value of 100% for cadmium chloride. Acute toxicity was evaluated for Zebra fish at the limit of solubility for CdTe, and there was no toxic effect (fatal or indirectly fatal) on fish. Overall, CdTe is differentiated from Cd, showing low toxicity in the fields above.

Table 1 Comparison of several Cd compounds (V.M. Fthenakis 2004)

Compound	Temperature(melting point, ℃)	Temperature(boiling point, ℃)	Solubility (g/L)	Carcinogenic
Cd	321	765	Insoluble	Yes

$Cd(OH)_2$	300	–	2:6 x10^{-3}	Yes
CdTe	1,041	–	Insoluble	Unknown
CdS	1,750	–	1x10^{-3}	Possible
$CdCl_2$	568	960	1400	Yes

From the table above we can see that physical properties and toxicology of CdTe is obviously different from those of elemental Cd. So they should be treated differently. It should also be noted that there is no research data and findings on human-related toxicology and carcinogenicity of CdTe.

1.2 Safety in CdTe module production

1.2.1 Safety of staff under normal operation

Two of the core principles at First Solar are "Safety First" and "People Matter". Since the first day of CdTe module production, the company has developed strict management measures to prevent the impact of Cd compounds on staff and the environment during production. FS ensures safety of the working environment by monitoring content of Cd in the air frequently. Routine medical monitoring is performed on workers who have the potential to be exposed to Cd containing dust. Employee medical monitoring data for over a decade shows that the employees' blood cadmium and urine cadmium[1] level is far below the limit.

Production of CdTe modules has the potential to bring Cd-containing dust into the air. In their field study at First Solar's facility in Kulim, Malaysia, the experts observed that air pollution control equipment is used to ensure containment. Production processes are supported by local exhaust ventilation equipped with High Efficiency Particulate Air (HEPA) filters to ensure Cd dust is not emitted into the work environment. During equipment cleaning and maintenance, FS equips its staff with HEPA filter cartridges to protect them from cadmium dust. Many countries and organizations set occupational exposure limits (OEL[2]) (Table 2) for Cd exposure. FS adopts stricter standards than local OEL and provides necessary actions that must be taken when content of total cadmium

[1]Urine cadmium level indicates the effect of long-term cadmium exposure, blood cadmium shows the impact of short-term cadmium exposure. β-2 microglobulin level is a secondary indictor. Presence of low molecular-weight proteins (such as β-2 microglobulin) excretion marks abnormal renal function.

[2]OEL (occupational exposure limit): Limit of Cd content in the air to which workers may be exposed without wearing respiratory protection appliances during a certain period of time (time-weighted average)

or small Cd particles in the air reaches 1.0 μg/m^3 and 0.8 μg/m^3 respectively.

Table 2 Occupational exposure limit (OEL) for Cd exposure

	U.S.	US-ACGIH(American Conference of Governmental Industrial Hygienists)	Malaysia	First Solar
8 hours OEL(total cadmium[3])	5μg/m^3	10μg/m^3	10μg/m^3	5 μg/m^3
12 hours OEL(total cadmium)	2.5μg/m^3	5μg/m^3	5μg/m^3	2.5 μg/m^3
Threshold above which measures must be taken (total cadmium)	2.5μg/m^3 8h 1.25μg/m^3 12h	N/A	N/A	1.0 μg/m^3
8 hours OEL(small Cd particles[4])	N/A	2μg/m^3	2μg/m^3	2 μg/m^3
12 hoursOEL(small Cd particles,)	N/A	1μg/m^3	1μg/m^3	1 μg/m^3
Threshold above which measures must be taken (small Cd particles)	N/A	N/A	N/A	0.8 μg/m^3

Kulim plant in Malaysia monitors Cd content in the air, including the data measured at specific positions and by air collectors fixed on workers working for 8 or 12hours. Average content measured at specific positions in the plant is below 0.16 μg/m^3(Fig. 1) constantly, and significantly lower than the threshold 1 μg/m^3 above. The results from air collectors show that Cd exposure risks of different steps are different, the highest during semiconductor deposition and

[3]Cd particles of all size
[4]Cd particles smaller than 10 μm

$CdCl_2$ spraying and curing oven, reaching nearly 0.5 µg/m^3, but still far below FS's threshold (Fig. 2).

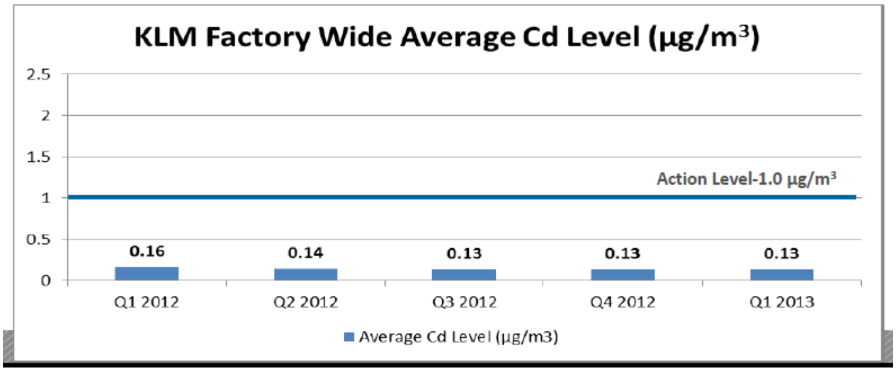


Fig. 1 Average historic Cd content in Kulim plant (provided by First Solar)

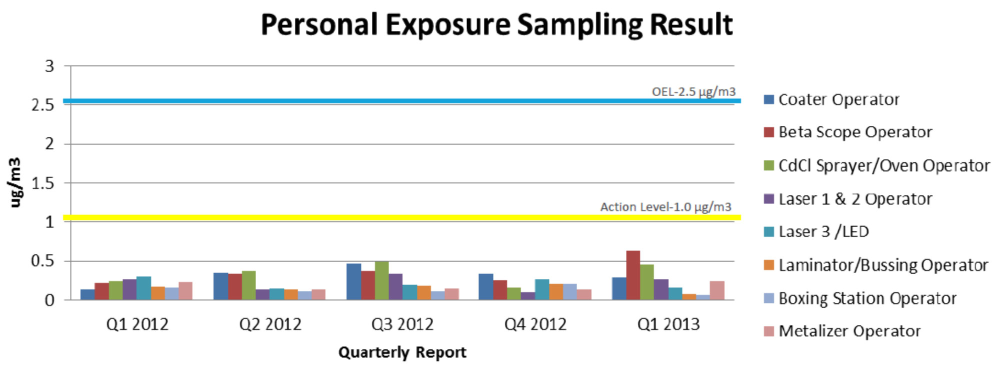


Fig. 2 Exposure sampling result of different steps in Kulim plant (provided by First Solar)

The only manufacturing activity that FS has recorded in excess of the 5 µg/m^3 is maintenance to the semiconductor deposition equipment (John R. Bohland, 2000). The First Solar high-speed vapor transport deposition process has a high semiconductor utilization rate but it is currently not possible to direct 100% of the inputted material to the glass substrate. With time, parts of the deposition chamber accumulate a small amount of CdS and CdTe semiconductors and must be cleaned. The cleaning staff wear respiratory protection appliances equipped with HEPA filter cartridges to protect themselves from inhaling cadmium-compound dust during these maintenance activities.

Fig. 3 Semiconductor deposition equipment maintenance (provided by First Solar)

FS has data of biological employee tests for over 5 years, which are completed by a third party[5]. Malaysia's national Occupational Safety and Health Administration (Malaysia OSH) provides content limit of blood and urine cadmium in employees of 5 μg/L and 3μg/g creatinine respectively[6].

FS tests blood and urine cadmium content in employees regularly. Kulim plant monitored blood and urine cadmium levels of over a thousand employees from 2007 to 2012, finding that the value is far below the limit set by OSHA(Fig. 4). It is important to note that statistics of 2011 and 2012 are not available for this Report because they are still being processed.

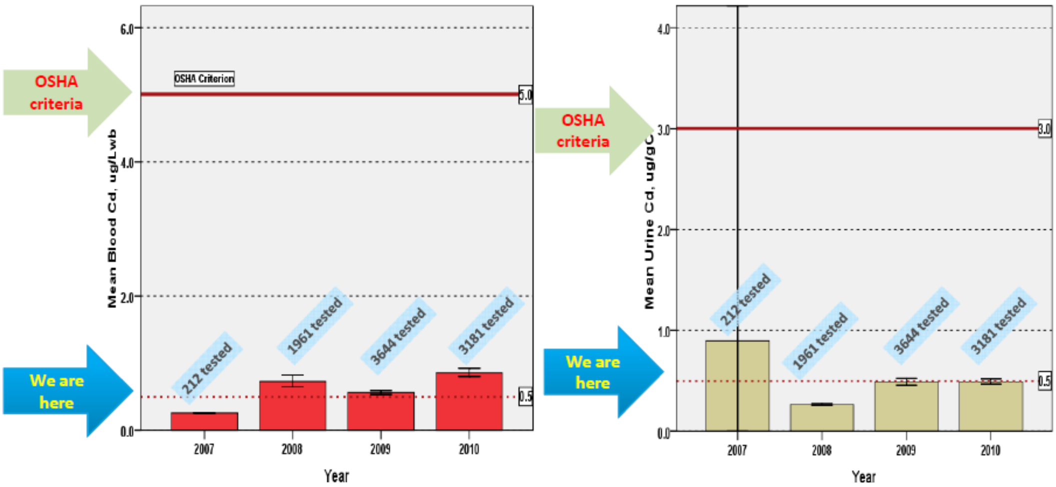


Fig. 4 Average blood and urine cadmium levels of the employees in Kulim plant (provided by FS)

Fig. 2 above shows that semiconductor equipment maintenance and

[5] Universiti Sains Malaysia Centre for Advanced Analytical Toxicology Services (CAATS)
[6] Limits set by Malaysia: blood cadmium 5μg/L, urine cadmium 3μg/g (creatinine).

$CdCl_2$spraying and curing oven workers are exposed to the environment with the highest Cd content. The two monitoring results from blood and urine cadmium samples of several such workers picked by Kulim plant are both far below the set limit (dotted line in blue).

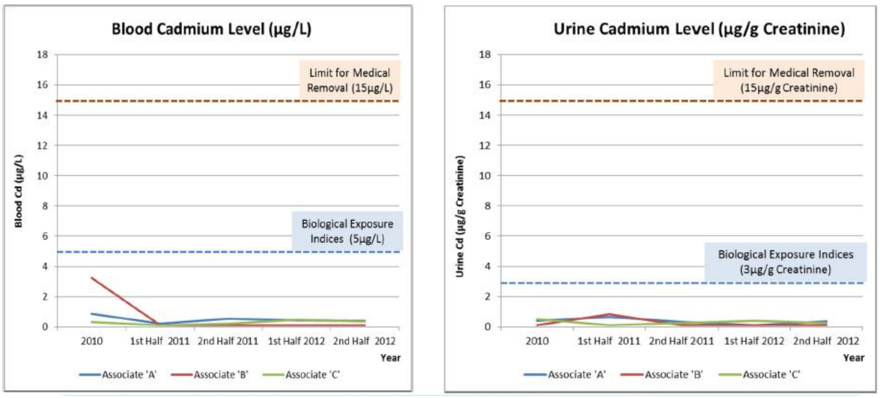


Fig. 5 Blood and urine cadmium levels of semiconductor equipment maintenance workers (provided by FS) obtained semiannually.

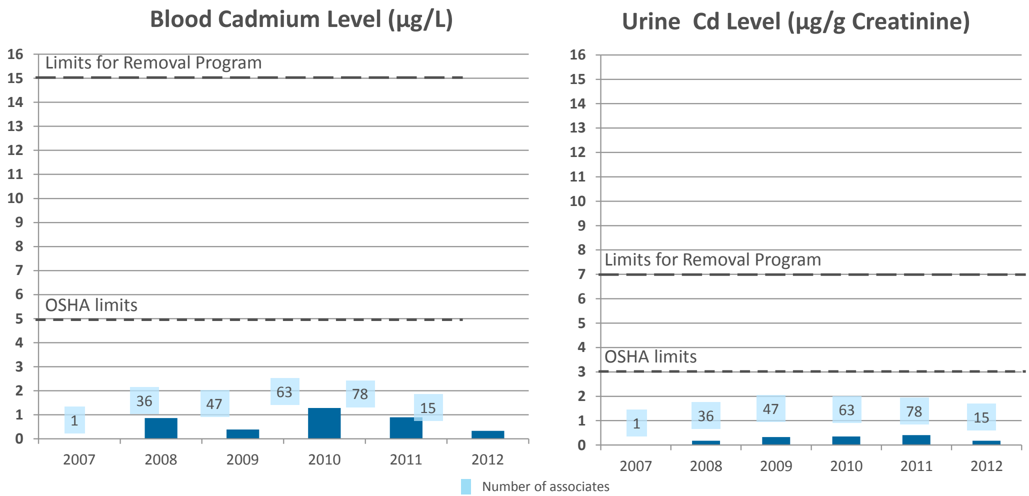


Fig. 6 Blood and urine cadmium levels of $CdCl_2$ curing oven workers (provided by FS) obtained annually prior to 2012 and triennially beginning 2012.

In addition, FS' ongoing monitoring shows that smoking cigarettes increases Cd content in the human body. FS compares blood and urine cadmium levels in smokers and non-smokers prior to (1,253 persons) and after (2,458 persons) employment, and finds that blood cadmium level in smokers is apparently higher than that in non-smokers, but there is no obvious difference between blood and urine cadmium levels prior to and after employment.

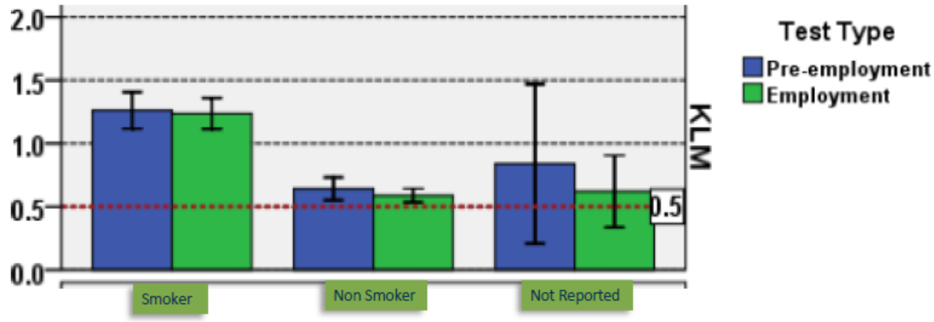


Fig. 7 Comparison of blood cadmium level in smokers and non-smokers prior to and after employment (provided by FS)

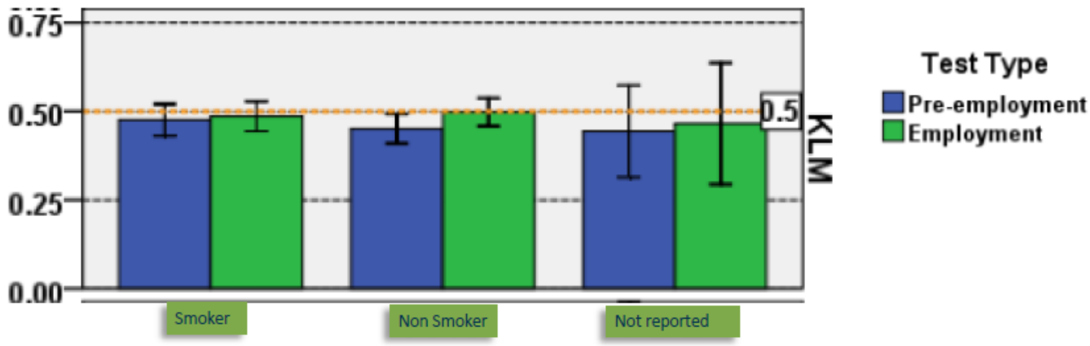


Fig. 8 Comparison of urine cadmium level in smokers and non-smokers prior to and after employment (provided by FS)

1.2.2 Safety of staff in case of emergency

Potential safety risks that need to be managed by FS CdTe module production plants include potential exposure to cadmium compounds used in manufacturing. Since cadmium compounds are deposited mainly in airtight vacuum chambers, exposure is unlikely to happen during normal production and operation. This is determined by physical properties of CdTe and is supported by the data gained from KLM. When the temperature in the vacuum environment is higher than 300°C, CdTe will change from solid state directly to gaseous state. But when the temperature is lower than 300°C, or the ambient pressure rises, the sublimation process will weaken until condensation, and CdTe will come back to solid state rapidly. Saturated vapor pressure of CdTe at 150°C is 10^{-11} Pa only. It's impossible for CdTe to exist in gaseous state under normal temperature and pressure. These physical properties make production of CdTe thin-film safe. Once the vacuum or high-temperature environment is damaged, CdTe vapors will condense to solid particles, which will stay on the wall of chamber or pipe; it will not spread in gaseous state, further limiting any potential human exposure. First Solar also uses HEPA filters on all equipment that has the potential to generate Cd containing dusts to ensure Cd levels are controlled to well below the FS action level. Before usage, FS will detect leakage of each filter to ensure its normal operation. For accidents, FS developed a complete Cd leakage treatment measure package to minimize the possible impact of Cd on human body and the environment. First Solar also uses HEPA filters on all equipment that has the potential to generate Cd containing dusts to ensure Cd levels are controlled to well below the FS action level. First Solar leak-checks each HEPA filter prior to use to confirm that the filter is functioning properly. To ensure workplace safety, FS also developed safety codes for accidental injury, fire, power and chemicals. FS holds OHSAS18001 certificate.

1.3 Safety in CdTe module usage

1.3.1 Safety under normal operation

CdTe modules release no vapor or dust under normal conditions because CdTe features high melting point, low saturated vapor pressure and is insoluble in water. The CdTe semiconductor material is well encapsulated between two 3-mmsheets of glass and a layer of industrial laminate until the end of the lifecycle, and is very unlikely to be exposed to the outside environment. Such encapsulation option is required to ensure performance and stability of products, rather than by environmental protection regulations. Therefore, CdTe modules will not emit any Cd compounds under normal operation.

1.3.2 Safety in case of foreseeable accidents

Possibly, Cd exposure during normal usage of CdTe modules may happen in case of accidents. This Report reviews the research findings on the potential for cadmium compounds to be released from CdTe modules when fire happens or modules crack.

Brookhaven National Laboratory studied the impact of fire on CdTe modules with double glasses under certain conditions (V. M. Fthenakis, 2005). In the test, modules were cut into samples with size of 25×3 cm. In accordance with American Society for Testing and Materials(ASTM)'s "Fire Tests of Building Construction and Materials (E119-98)" and the "Standard for Fire Test of Roof Deck Constructions (UL 1256)" of U.S. Underwriters Laboratories(UL), the samples are exposed to the environment of 760~1,100℃ for 30 minutes to 3hours. Most of Cd diffuses into the glass in such test (Fig. 9). Only little (0.4~0.6 percent of the Cd content) Cd was released into air (Table 3). The small Cd loss occurs from the edges of the PV module through the space of the two glass sheets [7] before they fuse together. In PV modules of actual size, since the ratio of perimeter to area is smaller than our samples, the actual Cd loss during fires will be extremely small (<0.04% of the Cd content).

Table 3 Loss of mass of tested samples at different temperature

Test	Temperature(℃)	Weight loss((% sample)	Cd emission		Tellurium emission	
			(g/m²)	((% of Cd content)	(g/m²)	((% of Te content)
1	760	1.9	0.056	0.6	0.046	0.4
2	900	2.1	0.033	0.4	0.141	1.2
3	1000	1.9	0.048	0.5	1.334	11.6
4	1100	2.2	0.037	0.4	2.680	22.5

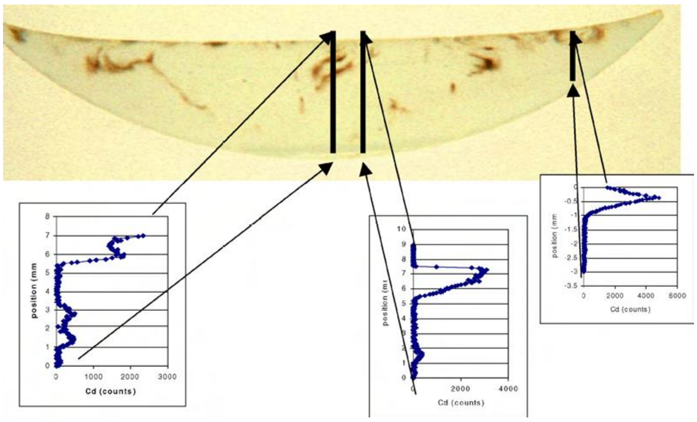


Fig. 9 X-ray fluorescence microprobe analysis–vertical slice from middle of sample heated at 1100˚C; Cd counts in the center and the sides of the slice

Bavarian Environmental Protection Agency calculated distribution of Cd released during fire with VDI3783 air dispersion model (Beckmann and Mennenga 2011). The highest determined value is – as expected – in a fire with the largest area (1,000 m^2) with the maximum cadmium module contents which have been found in literature and are several times higher than those of

[7]FS modules have two sheets of glass

FS' CdTe modules (66.4 g/m^2) and at the shortest calculable distance (100 m) from the emission site assuming in the calculations that all cadmium contained in the module is released completely from the CdTe compound as cadmium fumes. However, the calculated concentration of cadmium (0.66 mg/m^3) is still substantially below the AEGL-2[8]Cd evaluation values. A serious danger for the immediate neighborhood and general public can certainly be excluded when modules containing CdTe burn.

Module breakage is rare, occurring in approximately 1% (average: 0.04 percent/year) of modules over the 25-year warranty operating life (Sinha, P., Balas, R., et al, 2012). Of these breakages, over one-third occurs during shipping and installation and is removed for takeback and recycling. 80 percent of such breakage is caused by glass internal stress and impact. FS confirms that such breakage consists of glass fracture in most cases because laminated materials are used between the two sheets of glass. Such fractures are very small, so potential CdTe exposure area is very small too.

While unlikely, it is possible for CdTe in modules to enter soil along with rain and be released into air by dust if module breakage is not discovered or takeback measures are not taken in a timely manner. Sinha P.(Sinha, P., Balas, R., et al, 2012) evaluated potential exposures to Cd from rainwater leaching of broken CdTe thin-film cells in a commercial building scenario by analyzing Cd destination and transfer mechanism. In this analysis, an average breakage rate of 0.04%/year is applied. The evaluation considers the worst-case scenario in which the total mass of Cd in each broken module is released. Leaching from broken modules is modeled and residential screening levels are used to evaluate potential health impacts to on-site workers and off-site residents. Potential exposures to Cd from rainwater leaching of broken modules in a commercial building scenario are highly unlikely to pose a potential health risk to on-site workers or off-site residents.

1.4 Safety in end-of-life disposal of CdTe modules

CdTe modules abandoned several years after end of their 25-year quality warranty period, during the warranty period due to various reasons and during production because of non-conforming quality need to be disposed of properly. Available options include: landfilling, incineration or recycling.

According to the results of U.S. EPA Toxicity Characteristic Leachate Procedure (TCLP) (Wegmann, 2011), Cd with leaching level of less than 1 mg/L may be treated as non-hazardous waste. For this TCLP test, the CdTe

[8] AEGL: Acute Exposure Guideline Level. AEGL-2 refers to the level that will lead to irreversible or serious physical damage to general people.

modules were broken into 1 cm fragments which were agitated in a mixture of sodium acetate/acetic acid (pH 2.8-4.93) (note that nitric acid/sulfuric acid solution is required by China) for 18 hours. FS has no hazardous waste leaching test results for China. CdTe modules incinerated will release 5 g/kg of Cd ideally, and the remaining Cd will be encapsulated in fused glass, no longer contaminating the environment (Marco Raugei, 2012).

In 2005, FS established a complete recycling mechanism for the end-of-life CdTe modules, the first comprehensive pre-paid collection and recycling system in the industry. Under this program, after the 25-year warranty service life ends, the modules will be taken back, the glass sheets separated to take out the metal and semiconductors in the middle. The recovered materials will be reused to manufacture new products. All the pre-payment, covering all the cost needed to dismantle, gather, transport and recycle end-of-life CdTe modules, by a third party audited and supervised by an independent third party. In addition to the pre-funded recycling option which has historically been provided, recycling can also currently be funded through recycling service agreements. In the European Union under the WEEE Directive, recycling for Business-to-Consumer PV sales is expected to be funded with a joint liability scheme in which PV manufacturers contribute to a joint fund for collection and recycling as well as insurance to cover the case of bankruptcy. Note that the WEEE Directive distinguishes between Business-to-Consumer and Business-to-Business transactions when mandating effective financing mechanisms. Under the latter, recycling is expected to be financed through contractual agreements between the businesses. It is believed that in China, the Business-to-Consumer transaction under supervision of the government or industry association is a more viable option.

FS has a mature recycling process, which is shown in Fig. 10 below.

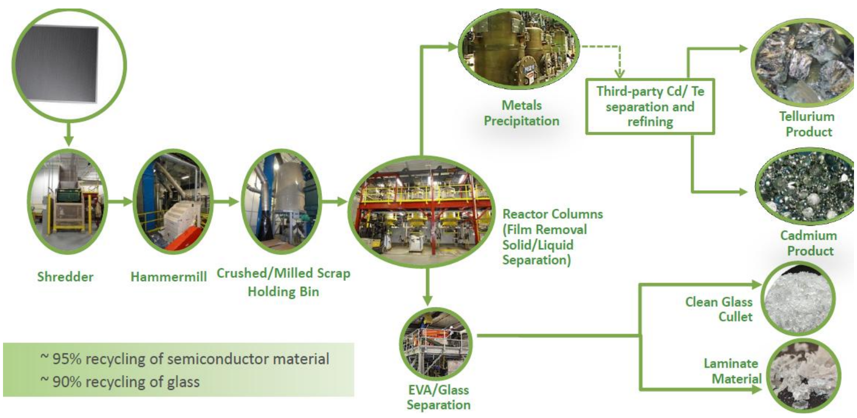


Fig. 10 FS CdTe module recycling process

i) End-of-life modules or the modules broken or deemed non-conforming during production are delivered to the recovery plant.

ii) Shredder: Putting modules into the shredder.

iii) Hammermill: Use the hammermill to grind crushed modules 4-5mm fragments to enable subsequent reaction.

iv) Holding bin

v) Reactor column: Putting the fragments into column reactor. Adding strong acid to make sure semiconductor materials in modules fully react with acid. Separating the solid (EVA and glass) from the liquid (metal-rich acid solution).

vi) Metal precipitation: Pumping the liquid into the liquid tank for three steps of precipitation;

vii) Refining by third-parties: Filter pressing the metal precipitated into Cd or tellurium-rich cakes and delivering them to third-parties for Cd and tellurium refining. Up to 95 percent of metal is reused.

viii) EVA/glass separation: Separating EVA from glass

ix) Glass recycling: Cleaning and drying glass. Nearly 90 percent of glass is recycled by third-parties to produce new glass.

x) EVA collection: Collecting EVA and disposing of it according to local waste disposal standards.

Module recycling recovers most of the mass of modules, including about 95 percent of CdTe and about 90 percent of glass. Recycling of tellurium and Cd reduces the impact of Cd release on the environment and ensures safety of modules after their lifecycle to the environment.

Furthermore, FS module recycling brings many other benefits: i) Reducing the land occupied by landfills and incineration pollution; ii) Lowering lifecycle energy consumption and GHG emissions of CdTe PV (Sinha, P., M. Cossette, et al, 2012); iii) alleviating the imbalance between tellurium (scarce resource) supply and demand in future (M. Marwede and A. Reller, 2012).

FS uses complete precautions for module recycling, including HEPA filter cartridges and acid gas spraying and scrubbing device, as well as plants' wastewater treatment system discharging effluent meeting local discharge standards. So there will be no Cd pollution during recycling process under normal circumstances.

1.5 Lifecycle Cd emission of CdTe modules

Lifecycle of Cd in CdTe modules includes zinc mining, Cd refining, CdTe production, CdTe module production, CdTe module operation, end-of-life CdTe module disposal.

According to Fthenakis (Fthenakis, 2004), of the Cd emission during zinc mining and smelting, 0.58 percent of the total may be attributed to Cd.

According to the research findings of Fthenakis (Fthenakis, 2004), Cd refining and CdTe production are patented technologies possessed by only several companies. It is shown that the Cd dust generated is processed by HEPA filter cartridges before being released into air (6g/t).

FS adopts many measures during module production and recycling to ensure Cd emissions are far below the national standard, minimizing potential Cd pollution risks. FS' CdTe module production uses Vapor Transport Deposition to deposit CdTe and CdS thin-films in airtight chambers, depositing a layer of CdTe that is thinner than 3 micron. There is only 6g of Cd in a whole module (0.72 m^2) (Sinha, P., Balas, R., et al, 2012). Cd-containing exhaust gas generated during production is treated by HEPA before being emitted, which filters out up to 99.97 percent of 0.3-μm dust that is the most difficult to be filtered. So only 0.4 mg/kg of Cd is released into air (Raugei and Fthenakis, 2010). Cd ion in Cd-containing wastewater from production line is removed in the wastewater treatment works through metal precipitation and ion exchange methods. Concentration of Cd in Cd-containing wastewater is monitored prior to discharge through ICP method. The wastewater meeting discharge standards may be discharged. In the rare case when wastewater does not meet the discharge standard it is returned for re-treatment. The concentration value is 0.01~0.015 mg Cd/L under normal production conditions, far below the value set by Malaysian government , which is 0.02 mg/L.

First Solar generates small quantities of hazardous (solid) waste from disposal of cadmium contaminated personal protection devices and maintenance of process filtration equipment (John R. Bohland, 2000). In a large-scale production factility, hazardous wastes also include sludge generated in waste water disposal. The wastes will be disposed of in accordance with the national standards for disposal of hazardous wastes. CdTe wastes generated during maintenance of deposition chamber will be delivered to third-parties for recycling of tellurium and Cd.

1) Direct release of Cd into air

According to the research findings of Fthenakis (Fthenakis, 2004), using 1 ton of Cd in the manufacturing of CdTe PV modules releases 15.25g of Cd into the air throughout the entire lifecycle of the modules, and generating 1 GWh of power releases a total of 19.8mg, a very low level. See Table 4 for Cd emission into air of CdTe modules during the whole lifecycle.

Table 4 Cd emission into air of CdTe modules during the whole lifecycle

Process	Release into air (g Cd/ton Cd)	Contribution (percent)	Release into air		
			(g/ ton (Cd))	(mg/m^2)	(mg/GWh)
1. Zinc exploitation	2.7	0.58	0.0157	0.0001	0.02
2. Zinc smelting/refining	40	0.58	0.2320	0.0016	0.3
3. Cd refining	6	100	6	0.042	7.79
4. CdTe production	6	100	6	0.042	7.79
5. CdTe PV module production	3	100	3	0.021	3.9
6. CdTe module operation	0	100	0	0	0
7. End-of-life disposal/recycling of CdTe PV modules	0	100	0	0	0
Total			15.25	0.11	19.8

Assumptions:

1. Exploitation of one ton of zinc ore generates 30g of dust.

2. Smelting/refining of one ton of zinc generates 0.2g of Cd.

3. Ratio of zinc to Cd content in zinc ore is 200.

4. Average content of Cd in zinc ore is 220ppm.

5. HEPA filters could filter out up to 99.97 percent of submicron dust in exhaust gas from PV production.

6. Calculation of energy output of per unit of Cd is based on:

- Modules with 7g Cd/m^2

- 10 percent of photoelectric conversion efficiency (note that average efficiency in year 2012 is 12.7%)

- Average intensity in U.S. (1800KWh/m^2/year)

- 30years of expected service life of PV modules

- Therefore, 1kg of Cd generates 0.77GWh of power during the service life of PV products.

2) Direct release of Cd through wastewater

Table 5 summarizes discharge of Cd wastewater provided by Raugei (Raugei and Fthenakis 2010). Most of the Cd wastewater is generated during recycling.

Process	Zinc exploitation	Cd refining, CdTe processing, CdTe production	Operation	Recycling	Total
Cd discharge through wastewater	0	0.3mg/m^2	0	1 mg/m^2	1.3 mg/m^2

3) Direct release of Cd through wastes

Existing research findings on release of Cd through wastes are very limited. Raugei (Raugei and Fthenakis 2010) believes that no CdTe PV plant discharges Cd into soil now. In the opinion of Bohland (John R. Bohland, 2000), a small quantity of wastes are generated during disposal of cadmium contaminated personal protection devices and maintenance of process filtration equipment into approved landfills. In a large-scale production facility, this also includes sludge generated during waste water treatment. Howeve, the aggregate direct release is lower than 1,000 kg/month.

4) Comparison of life-cycle atmospheric Cd emission between CdTe PV systems and other technologies

Comparison of life-cycle atmospheric Cd emission (including direct and indirect emission) between CdTe PV systems and other technologies by Fthenakis (Fthenakis, 2008) shows that Cd emission by CdTe PV systems (0.3g Cd/GWh) is significantly less than that by oil-fired power plants (43.3gCd/GWh), coal-fired power plants (3.1g Cd/GWh), and even lower than mono-Si and multi-Si (0.9g Cd/GWh). Cd emission by oil and coal-fired power plants comes from the Cd in such fossil fuels, while emission by crystalline silicon technology from consumption of power from the grid generated with coal. It is important to note that direct Cd emission (0.02 g/GWh only) during the whole lifecycle of CdTe, including emission by material refining and synthesis, module production, operation and recycling, is significantly less than indirect emission (as high as 0.28 g/GWh), including that caused by power consumption during glass production, material encapsulation, BOS and module production. It should be noted that the data above is based on U.S.' reality, i.e., thermal power accounts for only 44 percent of the total output, while in China, this proportion will be higher, affecting the indirect emission value.

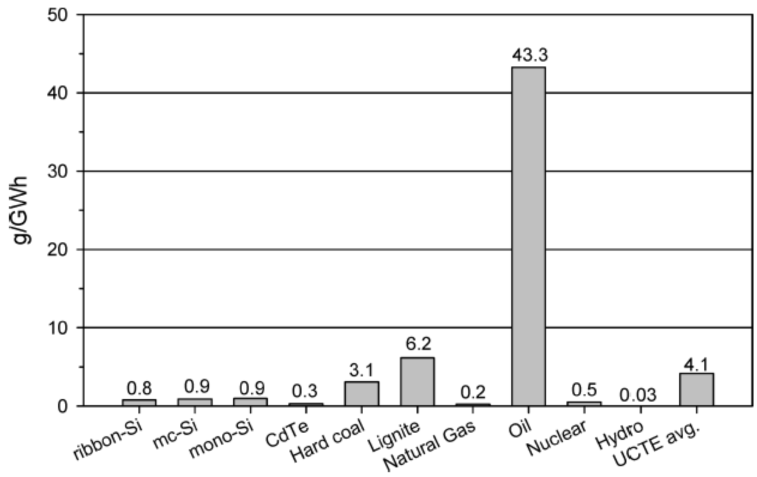


Fig. 11 Life-cycle atmospheric Cd emission of different power generation technologies (energy output: 1,700KWh/m^2/year, system efficiency: 0.8, service life: 30years, indirect Cd emission caused by BOS considered)

2. Benefits from CdTe PV module usage

2.1 Generating power with CdTe PV modules is an effective way to control Cd pollution

Cd is mainly generated during zinc production. Because yield of zinc is very large, output of Cd, as by-products, is also very impressive. Such Cd needs to either be used in other places or disposed of as required by the government.

General disposal method is landfilling by cementing. The most ideal use is low-consumption [9] applications, creating added value while reducing Cd emission risk. CdTe PV modules may be regarded as low-risk, sustainable and ideal application because: i)CdTe PV modules are low-consumption Cd application. Cd is converted to CdTe, a stable compound, then completely encapsulated during operation and recycled at the end of lifecycle (FS established a complete CdTe module recycling mechanism); ii)Such modules have less impact on the environment than other applications. Among the four major Cd applications (nickel-cadmium rechargeable battery: 82 percent, pigment: 10 percent, electrofacing: 6 percent, stabilizer for plastics: 1.5 percent)(UNEP, 2006; ICDA, 2005), CdTe PV modules and nickel-cadmium battery are low-consumption Cd application (Cd in nickel-cadmium batteries could be 100 percent recycled in principle). Pigment, electrofacing and stabilizer are high-consumption Cd application, where Cd will dissipate and inevitably cause Cd pollution. Compared with nickel-cadmium batteries, CdTe in CdTe modules is more stable than $Cd(OH)_2$ in nickel-cadmium batteries in terms of solubility, melting and boiling points. In addition, CdTe modules are larger than nickel-cadmium batteries, easier to be disposed of at the end of lifecycle; iii) Last but not least, CdTe modules convert solar energy into power, reducing consumption of conventional energy sources and lowering Cd emissions produced by conventional power generation technologies (such as thermal power).

2.2 Industry-scale application of CdTe PV modules is feasible;

2.2.1 CdTe modules have the lowest life cycle carbon footprint and fastest energy payback time

Peng (Peng, 2013) summarized lifecycle research on different PV technologies in the past, finding that all researchers hold the same view that lifecycle carbon emission by PV technologies is an order of magnitude smaller than that of fossil-based electricity. Among the five common PV technologies (mono-Si, multi-Si, amorphous silicon, CdTe, CIS), CdTe modules presents the best environmental performance in terms of energy payback time (0.75 - 2.1 years only (Fig. 13)) and carbon emission rate (generally between 14 to 35g CO_2/kWh (Fig. 12)) due to its low life-cycle energy requirement and relatively high conversion efficiency. See Fig. 12 and Fig. 13 for comparison between CdTe and other PV systems in terms of GHG emission and energy payback time.

[9]Low-consumption Cd application: The degree of Cd dissipation into the environment is very low, Cd in products could be recycled effectively

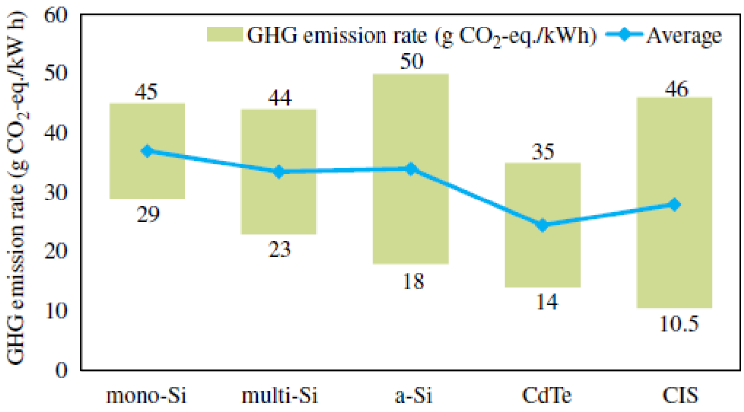


Fig. 12 GHG emission rate of different PV systems

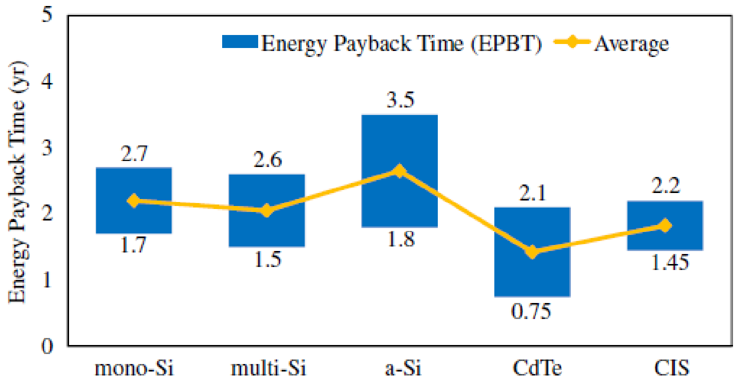


Fig. 13 Energy payback time of different PV systems

2.2.2 Excellent in quality and reliability

FS has done a lot of work to ensure reliability of CdTe modules, which have passed International IEC61646 test, North American UL1703 test and Chinese Golden Sun test.

According to Strevel (2012), a study made by the U.S. National Renewable Energy Laboratories (NREL) on efficiency degradation rates of five common PV modules (amorphous silicon, CdTe, CIGS, mono-Si, multi-Si) installed before and after 2000 shows (Fig. 14) that FS realized the lowest degradation rate for thin-film CdTe thin-film products installed after 2000 through technology improvement and strict production process control, 0.5-0.8 percent/year only, comparable to traditional crystalline silicon technologies (Strevel, N, 2012). The 17-year performance monitoring on a PV system in Golden, Colorado, USA by NREL reports a long-term degradation rate linear fit of –0.53%/year. After almost two decades of monitoring, NREL confirms the excellent reliability of First Solar’s module technology, with no module failures in system operation.

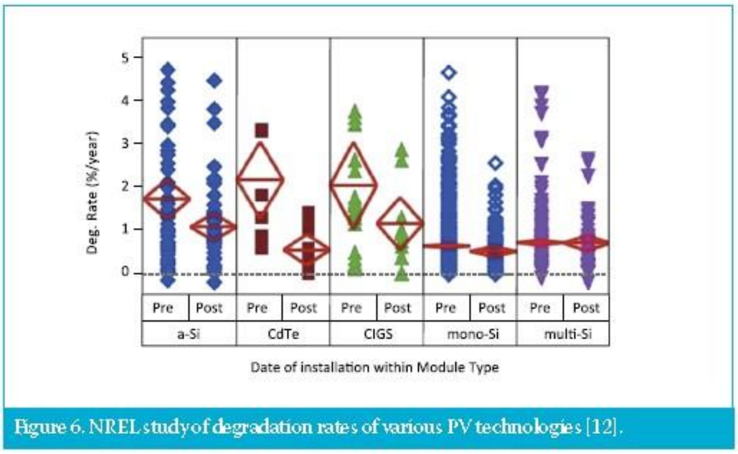
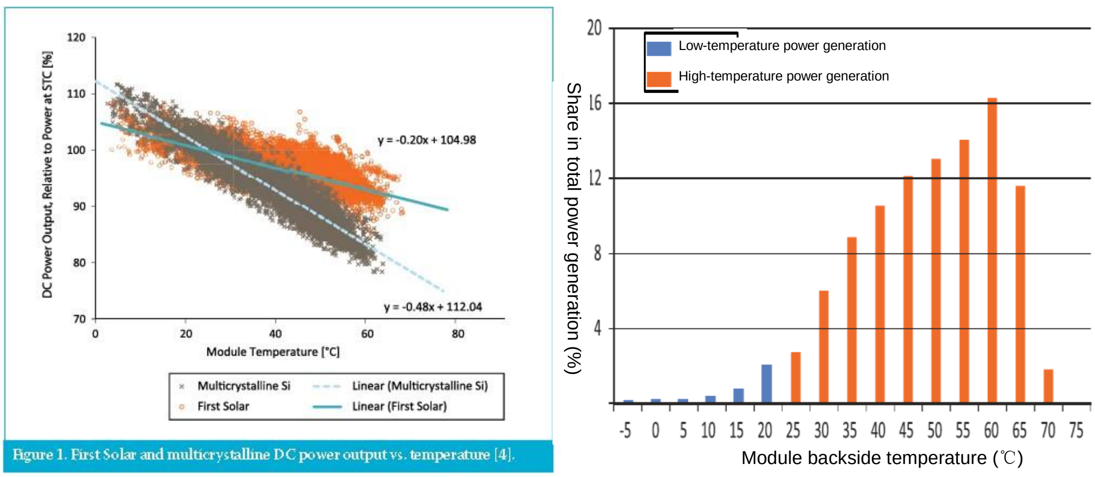


Fig. 14 NREL study on long-term degradation rates of various PV technologies

2.2.3 Low temperature coefficient

First Solar's thin-film CdTe solar modules have a proven high- temperature performance advantage over typical crystalline silicon solar modules. The leading contributor to this performance advantage is the lower temperature coefficient [10] of CdTe semiconductor material, which delivers higher energy yields at elevated temperatures. Crystalline silicon solar modules typically have a temperature coefficient of –0.45 to –0.5% per degree Celsius. First Solar's CdTe PV modules have a temperature coefficient of –0.25% per degree Celsius, resulting in about half the incremental power loss compared to conventional solar modules. Fig. 15a shows the DC power of two PV systems consisting of CdTe and multicrystalline silicon (mc-Si) modules. As module temperatures rise above 25°C(Fig. 15b), CdTe solar modules experience an increasing performance advantage, which is relevant because in high-temperature climates the majority of solar energy production occurs when the module operating temperature is much greater than 25°C. Comparison performed by a major system integrator concluded that, in southern Italy (Strevel, N, 2012), CdTe modules outperformed mc-Si in annual specific yield by 5.7%.

[10]Temperature coefficient expresses the rate of reduction of power output as a function of module operating temperature rise.



a) b)

Fig. 15 a) First Solar and multicrystalline DC power output vs. temperature.

Fig. 15 b) Annual temperature distribution of power generation of CdTe modules in desert area.

2.2.4 Supply of tellurium could support massive production of CdTe modules.

Te, a humble nonmetal that is actually abundant in the universe, is rare in Earth's crust. The existing supply is obtained almost exclusively through Te recovery as a by-product of refining copper. We do not know the reserve of tellurium. If the market's demand for tellurium increases continuously, tellurium exploration will be stimulated. The annual supply is between 500 to 1,500 MT/year, which will increase with rise of copper demand, typically 3-5 percent/year.

CdTe modules' demand for tellurium is 90-130kg/MW (Zweibel.K. 2010). Current supply may produce 10 GW per year. But the following three factors will eliminate tellurium resource restrictions on the yield of CdTe modules: i) The annual supply will increase with rise of copper demand, typically 3-5 percent/year. In addition, many new bismuth telluride and undersea tellurium beds were discovered; ii) Module production technology is progressing, and there is space for improvement of module conversion efficiency. Thickness of CdTe in PV modules is likely to reduce from 3 μm to hundreds of nanometer, lowering Cd consumption per Wp; iii) As a large amount of modules reach the end of lifecycle, many tellurium resources in modules will be recycled. Conservative estimation shows that, by 2040, 10-50 percent of tellurium needed by CdTe module production will be met by such recovered resources (M. Marwede 2012). Considering improvement of module and tellurium recycling efficiency (97 percent of tellurium in abandoned modules is recycled, and 90 percent of it is refined to high-purity tellurium), by 2038, tellurium recovered from end-of-life modules will be likely to meet the demand of the whole CdTe PV industry (M. Marwede 2012).

3. Conclusions

1) **CdTe module is a promising PV technology.** CdTe PV technology is inexpensive and efficient. FS expressed that efficiency of its CdTe modules could reach 14.9 percent by the end of 2014, close to that of multi-Si modules, and the cost of CdTe modules may be lowered by 10 percent. Good quality, reliability, and temperature coefficient of CdTe enable CdTe modules to operate stably and efficiently during the 25-year lifecycle. Given the low lifecycle CO_2emissions and short energy payback time of CdTe PV, wide application may effectively help us realize the goal of energy conservation and emission reduction.

2) **CdTe is a very stable compound, less toxic than elemental Cd.** The experiment of acute inhalation and oral toxicities of CdTe in rats found that CdTe less toxic than elemental Cd. Acute toxicity was evaluated for Zebra fish at the limit of solubility for CdTe, and there was no toxic effect (fatal or indirectly fatal) on fish. Solubility and bioavailability of CdTe is significantly lower than other Cd compounds. So CdTe compound and elemental Cd shall be treated differently in terms of toxicity. It should be noted that there is no research data on the toxicity to the human and carcinogenicity of CdTe.

3) **FS manufacturing plant takes effective measures to ensure production safety.** First Solar has been adopting excellent management system processes and policies during module production and recycling to protect the environment and workers' health and safety. Actual Cd emissions into the atmosphere and water are well below Malaysia's limits. First Solar is very active in ensuring environmental safety and avoiding safety risks. First Solar plant has obtained ISO9001, ISO14001 and OHSAS18001 certificates.

4) **Modules have no or little impact on the environment and the surrounding population during operation.** CdTe will not escape from modules under normal operation. Existing research findings show that, in case of foreseeable accidents, such as fire, almost all (99.96 percent) Cd in CdTe will be encapsulated in glass, only 0.04 percent of Cd will go into air before the two glass sheets fuse together. Under average module breakage rate (0.04 percent/year), since CdTe is thin and in small quantity, even release of all Cd in modules is highly unlikely to pose a potential

health risk to on-site workers or off-site residents.

5) **FS' recycling measures and technologies ensure environmental safety of end-of-life modules.** First Solar has introduced an excellent module collection and recycling mechanism to recover CdTe PV modules from users reducing Cd pollution risk of end-of-life modules. Currently about 95 percent of Cd and tellurium could be recovered.

6) **Generating power with CdTe PV modules is an effective way to control Cd pollution.** Cd comes mainly from zinc and lead smelting. Even if CdTe PV modules have no demand for Cd, significant volumes of Cd will be released during zinc and lead exploitation and smelting every day. CdTe PV modules are an effective way to reduce Cd pollution risk because CdTe is the most stable among Cd compounds, and CdTe is well encapsulated in modules, which could be recycled by FS' recycling mechanism with 95% recovery at the end of the modules' lifecycle. Therefore, compared with other high-consumption Cd applications, CdTe modules are safer for the environment. Most of all, CdTe modules convert solar energy into power, reducing consumption of conventional energy sources and lowering Cd and other greenhouse gas emissions released by oil or coal-powered power generation.

7) Considering rapid progress of CdTe PV technologies and improvement of module efficiency after 2011, data in this Report might be inapplicable to new products launched by FS in future. The trend needs to be proved by many new research activities.

4. Suggestions

CdTe module is a competitive, low-cost and efficient PV technology. As long as necessary treatment measures are in place to control Cd pollution during the lifecycle of CdTe modules, it could generate power in a cleaner and more environmentally-friendly way than other PV technologies. Given that many typical Cd-polluted areas are seen in China, and the government and public pay close attention to the problem, we hereby put forward the following suggestions:

1) It is advisable that China includes CdTe, a competitive PV generation technology, into its 13th Five-year Plan as a commercial-scale PV technology, and improve its CdTe research and production technology level.

2) The PV Industry should establish a recycling and takeback mechanism for

China by reference to the mandatory mechanism for end-of-life PV module recycling to be enforced as of 2014 by EU WEEE. Such a mechanism is a necessary prerequisite for China to deploy CdTe PV modules and mitigate the risks of Cd contamination. In addition, ensuring enforcement of such mechanisms will strengthen the public's confidence in safety of the technology. FS is suggested to work with the Chinese government in this regard.

3) Since CdTe modules retire generally after 25years or a longer period of time, FS is suggested to share CdTe recycling technologies with China to make sure massive recycling of such modules in China is feasible technically after the 25-year period, so as to eliminate the concerns of the public and industry.

4) FS should carry out tests by referring to the Standard on Hazardous Waste Leaching Experiments and suggest relevant authorities to give effective disposal plans when the modules could not be recycled in light of the results.

5) Given that many regions see acid rain, CdTe leaching experiments should be carried out at different pH values to give CdTe handling suggestions to ensure environmental safety.

6) FS should disclose important data and literature to the public and academic community to guide them in treating toxicity and harm of CdTe and elemental Cd differently, and help them know how FS takes measures to control Cd emissions.

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First Solar CdTe PV Cell Technology and Environmental Impact Assessment Report

China Environmental United (Beijing) ENV. Protection CO.LTD

December 2013, Beijing

Paper Two

Environmental Impact Assessment and Suggestions for First Solar CdTe PV Cells

Contents

1 Analysis of CdTe PV cell pollutant migration patterns

Heavy metal migration and transformation refer to movement of the spatial position and transformation of the existing form in the natural environment and the resulting enrichment and dispersion process. Heavy metal migration and transformation in the environment are subject to impact and control of physical, chemical, biological and other factors.

CdTe's lifecycle consists of: (1) mining of zinc, lead, and copper ores, (2) Cd and Te as by-products of smelting/refining of zinc, lead, and copper, (3) purification of Cd and Te, (4) production of CdTe, (5) manufacture of CdTe PV modules, and, (6) recycling or disposal of end-of-life modules.

1.1 Analysis of CdTe PV cell migration pattern in water

This section considers the potential for CdTe to enter water bodies in the phases of mining of ores, purification and synthesis, and decommissioning and recycling. In the production phase, residual pollutants from treated process wastewater in CdTe PV cell manufacturing may enter water bodies. In the current vapor transport deposition-based manufacturing, the total Cd emissions from all manufacturing and recycling operations are 0.4 mg Cd/kg Cd. Including all the items in the lifecycle inventory of PV-module manufacturing, it's calculated here a total of 1.3 mg (Cd)/m^2 of module (Raugei and Fthenakis 2010). Virtually no emissions are associated with the operational phase, because cadmium in CdTe PV modules is present only as chemically stable cadmium compounds (i.e. CdTe and CdS) that are enclosed and sealed within two glass panes. Thus, we do not expect any emissions while the modules are in use Even in accidental fires, CdTe would be captured in the molten glass and very little could be released into the environment(V. M. Fthenakis, 2005). Releases to the aquatic environment could potentially occur after decommissioning only if such modules are disposed of in unlined landfills without leachate collection and treatment systems and assuming that the cadmium compounds leach out. However, cadmium telluride is encapsulated between two sheets of glass and is unlikely to leach to the environment under normal conditions.

By the material movement pattern, there are three basic types of migration of heavy metals from CdTe PV cell projects: mechanical, physicochemical and biological migration. Mechanical migration refers to heavy metal ions being mechanically transported by water currents in the dissolved or particulate form. The migration process is in line with hydraulics principles. Physicochemical migration refers to the migration and transformation process of heavy metals in the form of simple ions, complex ions or soluble molecules through a series of physical and chemical actions (hydrolysis, oxidation, reduction, precipitation, dissolving, complexation, chelation, adsorption, etc.) in the environment. This is the most important migration and transformation pattern of heavy metals in the aquatic environment. The migration and transformation result decides the presence, enrichment status and potential ecological risks of heavy metals in the aquatic environment. Biological migration refers to migration of heavy metals through metabolism, growth and death of organisms. This complicated migration process is a combination of physical chemistry and biology. All heavy metals can migrate through organisms. Consequently, heavy metals are enriched in some organisms and constitute a hazard to humans through amplification of the food chain.

Adsorption of colloid is a major way for heavy metals in water to transform into the solid phase. Adsorption of colloid has a significant impact on process transformation of heavy metals in the aquatic environment and biological and ecological effects. With high surface area, surface energy and charge, colloid can strongly adsorb various molecules and ions and thus has a significant impact on the migration of heavy metal ions in water bodies. In natural water bodies, only an extremely low amount of cadmium telluride and its associated heavy metal products is dissolved, mainly enriched in the solid phase.

1.2 Analysis of CdTe PV cell dispersion pattern in ambient air

The reference case of atmospheric cadmium emissions during lifecycle of CdTe PV modules are shown in Table 4 in Paper One. The results in the table reflect the allocation of Cd emissions during mining, smelting and refining to Cd (0.58 percent allocation) as well as Zn production (remainder of allocation).

Table 4 in Paper One shows that the reference estimate of total air emissions is 0.02 g Cd/GWh of electricity produced (Fthenakis, 2004),. The main contributor to Cd air emission in the later assessment was PV utilization, under the assumption of Cd loss during fires. As discussed earlier, extensive experimental tests proved that Cd emissions are limited by capture in molten glass during fires. Also, the assessment uses more recent data for determining emissions during mining, smelting/refining, and decommissioning of end-of-life products.

During the PV power plant construction and operation phases, CdTe solar cells are durable and do not produce any emissions during extreme conditions of accelerated aging in thermal cycles from +80 to 80°C. Every PV generation, regardless of technology, is a zero-emissions process. The thin CdTe/CdS layers are encapsulated between sheets of glass or plastic. Unless the module is ground to a fine dust, dust particles cannot be generated. The melting point of CdTe is 1,041°C, and evaporation starts at 1,050°C. Sublimation occurs at lower temperatures, but the vapor pressure of CdTe at 800°C is only 2.5 torr (0.003 atm). The melting point of CdS is 1,750°C and its vapor pressure due to sublimation is only 0.1 torr at 800°C. Therefore, it is impossible for any vapors or dust to be emitted when using PV modules under normal operating conditions.

The two leading methods of making CdTe thin films- electro-deposition and vapor transport -- use cadmium very efficiently. About 1% is wasted in the former process, and about 10-30% in the latter. In both processes, the cadmium is collected and is safely disposed of or recycled. The controlled (with HEPA filters) vapor emissions into the atmosphere amount to 3 g of Cd per ton of Cd used (Fthenakis, 2004).

CdTe PV cells will not generate cadmium emissions into the air throughout their use and recycling. PV modules have an expected lifecycle of 25-30 years and will not emit cadmium emissions into the air when they are normally used since the semiconductor material is sealed between two glass panes with an industriallaminate . Atmospheric emissions during/ after decommissioning will be zero. Even if pieces of modules inadvertently make it to a municipal waste incinerator, cadmium will dissolve in the molten glass and would become part of the solid waste (Marco Raugei, 2012).

Pollutants in the atmosphere are transported, mixed and diluted under the impact of the horizontal movement of air, turbulent diffusion and atmospheric disturbances of varying scales.

Wind and turbulence are the most direct and essential factor that determines the state of diffusion of pollutants in the atmosphere and the determinant of pollutant dispersion. Weather conditions that are conducive to increasing wind speed and enhancing turbulence are all conducive to dilution and diffusion of pollutants. Otherwise, the pollution will become worse.

Wind’s impact on diffusion of pollutants has two dimensions: overall transport and dilution. Wind direction determines the direction of pollutant migration, while wind speed determines the speed of pollutant migration. Pollutants are always transported from the windward side to the leeward side. The leeward side of the pollution source has to face heavier pollution compared to the windward side. So it’s necessary to know local wind direction to decide the ambient pollution in an area. Plus, the higher the wind speed is, the more air containing pollutants is cleaned in a unit time, the better the dilution effect is. In general, the concentration of pollutants in the atmosphere is proportional to the total emissions of pollutants, and is inversely proportional to wind speed.

In addition to overall horizontal movement, the atmosphere has secondary movements of varying scales that are different from the direction of main flow, also known as vortex flow. Such extremely irregular atmospheric movement is called atmospheric turbulence. Atmospheric turbulence is related to atmospheric thermodynamic factors -- atmospheric vertical stability, near-surface wind speed, underlying surface and other mechanical factors. The turbulence resulting from the former is called thermal turbulence, while that resulting from the latter is called mechanical turbulence. Atmospheric turbulence is the combined result of the above two types of turbulences. Atmospheric turbulence is most represented by near-surface atmosphere conditions. Alternating high and low wind speed and swaying wind direction are concrete manifestation of atmospheric turbulence. Atmospheric turbulence leads to intensive mixing of various parts in the turbulence field. When pollutants are emitted into the atmosphere, the highly concentrated pollutants are constantly mixed with clean air and irregularly dispersed towards other directions due to turbulent mixing. As a result, pollutants are continuously diluted.

Pollutants dispersed in the atmosphere then enter soil and water bodies through dry and wet deposition and follow the pollutant dispersion patterns thereof. As further discussed in section 3.1, the atmospheric dispersion of worst-case emissions from a CdTe PV array fire have been modeled by Beckmann and Mennenga (2011), with ground-level Cd concentrations estimated to be below health screening levels in the surrounding environment.

1.3 Analysis of CdTe PV cell migration pattern in soil

In the lifecycle of cadmium telluride, cadmium enters soil directly only in (1) mining of zinc and lead ores and (2) smelting and refining of zinc and lead and indirectly through ambient air and water in other processes.

There are many forms of cadmium in soil. But there are generally two categories: water-soluble and non-water-soluble cadmium. Ionic and complex state water-soluble cadmium represented by $CdCl_2$, Cd $(WO_3)_2$ can be absorbed by crops and thus pose high risks for living creatures. Insoluble cadmium compounds such as CdS, $CdCO_3$, falling under the category of non-water-soluble cadmium, are hard to migrate and be absorbed by plants. The two categories are mutually convertible under certain conditions.

The migration and transformation of cadmium in soil is greatly influenced by the activity of hydrogen ions (pH) and the activity of electrons (Eh). When the soil is acidic, the solubility of cadmium is high; conversely, when the soil is alkaline, the solubility of cadmium is low. Studies show that, pH and exchangeable calcium in soil are negatively correlated to the content of cadmium in rice.

Sonoda et al. in Japan studied cadmium adsorption by soil Eh. Under oxidizing conditions (500mV), when soil and cadmium containing solution interact, over 20% of adsorbed cadmium is exchangeable. When phosphate is added, exchangeable cadmium decreases, while insoluble cadmium increases. But available cadmium reaches up to 45%. When soil is in reducing conditions (200mV), the addition of phosphate can further reduce exchangeable cadmium and increase insoluble cadmium, because reducing conditions are conducive to the formation of insoluble cadmium phosphate. Especially when Eh drops to 0mV, no matter whether phosphoric acid is applied or not, insoluble cadmium in soil will increase anyway. It will lead to the formation of not only phosphate, but also more stable cadmium sulfide. Mizuno et al. in Japan believe that rice's absorption of Cd from soil is closely related Eh. Insoluble cadmium CdS on one hand is subject to redox reaction:

$$CdS \rightleftharpoons \rightleftharpoons Cd^{2+}+S^{2-}, S^{2-}-2^{e} \rightleftharpoons \rightleftharpoons S\downarrow$$

leading to increased concentration of available Cd^{2+}; on the other hand, sulfur ions are oxidized into sulfuric acid, leading to decreased soil pH and increased CdS solubility.

Study on cadmium-polluted soil shows that the content of Cd is related to that of Zn, Pb and etc. to some extent. Where the content of cadmium is high, the content of Zn, Pb and Cu is high as well. The presence of zinc can inhibit the absorption of cadmium in plants. Therefore, in addition to the impact of soil pH and Eh, the migration and transformation of cadmium is subject to the impact of accompanying ions, such as Zn^{2+},Pb^{2+},Fe^{2+},Cu^{2+}, Mn^{2+}, Ca^{2+}, PO^{3-} and etc. When the content of available Cd^{2+} in soil is high, there's a good chance that the content of cadmium in rice is also high.

Due to topsoil's adsorption and chemical fixation of cadmium, cadmium in soil is usually concentrated within several centimeters from the soil surface. Meanwhile, in soil, cadmium delivers minimum pollution capacity, which is an important feature of cadmium pollution in soil. Therefore, a slight increase in the cadmium content in soil can drive up the content of cadmium in rice accordingly. For this, a stringent environmental standard has been put in place to control soil cadmium pollution, no more than 1.0ppm, to be specific.

2 CdTe PV cells' cumulative environmental impact assessment

2.1 Analysis of CdTe PV cells' cumulative impact on water

The analysis of cumulative environmental impact of CdTe PV cell projects shall take cumulative impact of other related projects in the past, present and foreseeable future into consideration.

The CdTe life cycle assessment (LCA) analysis shows that (1) mining of zinc, lead, and copper ores, (2) smelting/refining of zinc, lead, and copper, (3) purification of Cd and Te, (4) production of CdTe, (5) manufacture of CdTe PV modules, and, (6) disposal of end-of-life modules, all have an impact on the aquatic environment.

CdTe thin-film solar cell projects will not bring heavy metal pollution in water bodies during construction and operation. Surface water and groundwater contamination may occur to some extent during the early mining and smelting phases. As stated earlier, Table 4 in Paper One reflects the allocation of Cd emissions during mining, smelting and refining to Cd (0.58 percent allocation) as well as Zn production (remainder of allocation).

Relevant studies and First Solar data show that module manufacturing and recycling of end-of-life modules can bring residual levels of cadmium pollution to water after on-site wastewater treatment (1.3 mg Cd/m^2 of module; Raugei and Fthenakis 2010). Addressing sewage generated during CdTe solar cell module manufacturing, diversion by type, treatment by nature and individual monitoring shall be adopted. After being subject to physical or chemical action, some cadmium into water bodies remain in water bodies, some are enriched in bottom mud, and some enter the food chain after being absorbed by aquatic plants and animals and thus pose potential health risks to humans, animals and plants. Residual levels of cadmium in treated wastewater from module manufacturing and recycling are in accordance with regulatory discharge limits. See further discussion in section 4.1 and Table 8.

2.2 Analysis of CdTe PV cells' cumulative impact on air

The CdTe LCA analysis shows that (1) mining of zinc, lead, and copper ores, (2) cadmium and tellurium from zinc, lead, and copper smelting/refining, (3) cadmium and tellurium purification, (4) CdTe production, (5) CdTe module manufacturing and (6) disposal of end-of-life modules all have an impact on the ambient air.

CdTe thin-film solar cell projects will not increase heavy metal pollution to the environment during the normal installation and operation phases, but can bring cadmium pollution to the atmosphere to some extent in the early phases including mining, ore grinding, roasting, smelting and refining. Relevant studies and First Solar data show that cadmium pollution to the atmospheric environment can be generated during solar PV module manufacturing, thin-film production and laser engraving. Cadmium-containing exhaust from the processes is generally disposed of in a compliant manner after dust collection . The remaining residual cadmium-containing pollutants in exhaust after dust collection are recirculated within the manufacturing facility with average factory-wide Cd concentrations in indoor air (<0.2 $\mu g/m^3$) that are well below occupational exposure limits (5 $\mu g/m^3$).

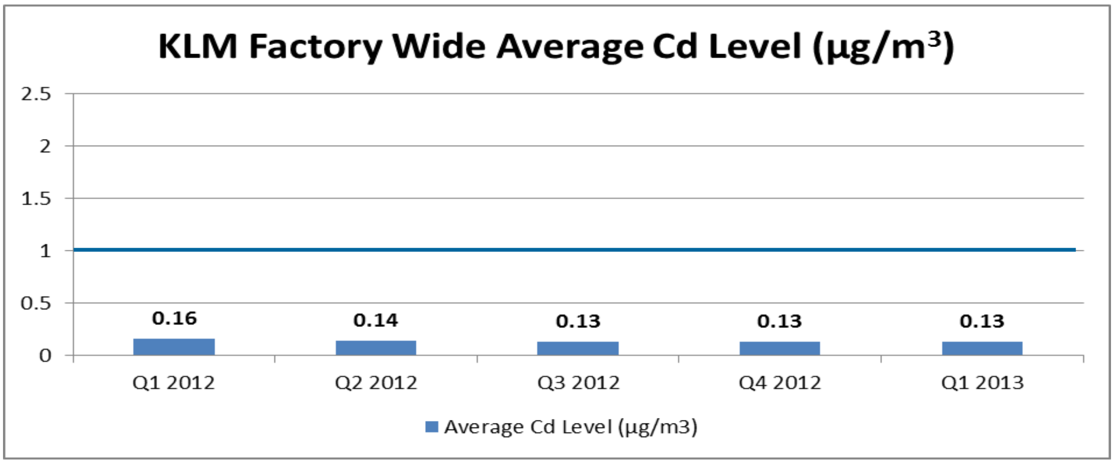
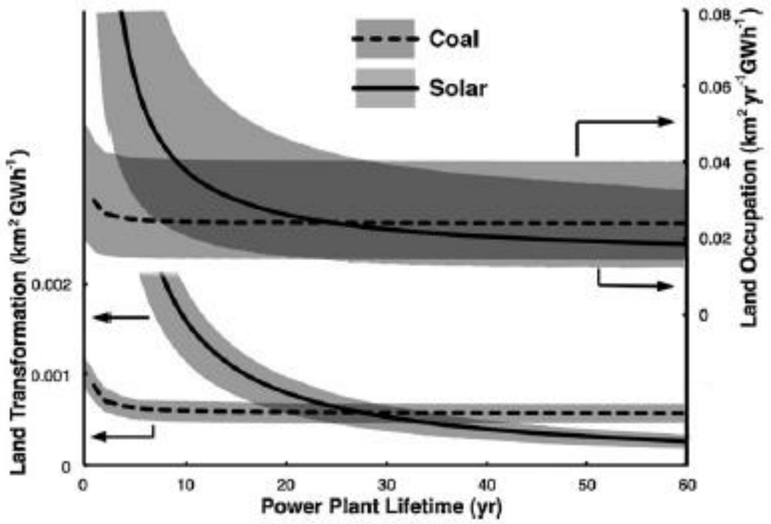


Figure 1. KLM factory wide average Cd level

2.3 Analysis of CdTe PV cells' cumulative impact on land

Cadmium telluride has an impact on land throughout the six processes of LCA. However, since only the module use process is studied according to First Solar data, the present document provides cumulative impact analysis of the said process only. So do the following chapters.

According to the study of Turney and Fthenakis (2011), land transformation and land occupation throughout the lifecycle during the operation phase are calculated as shown in Figure 2.



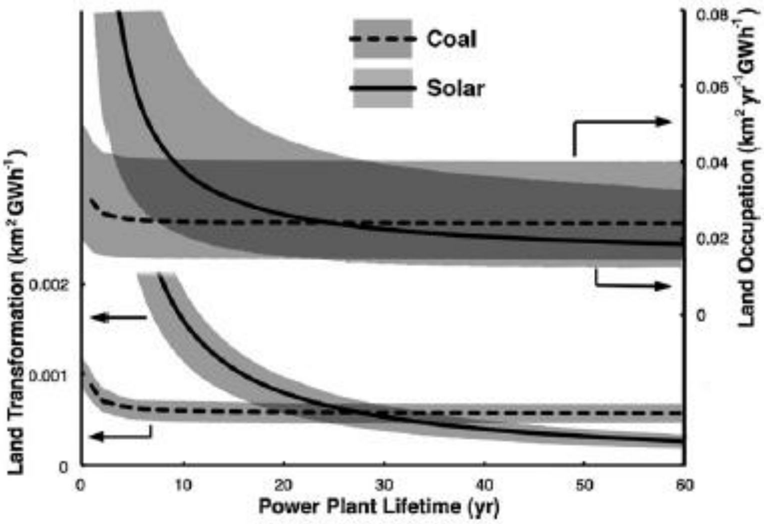


Figure 2 Comparisons of land use intensity metrics for large-scale solar and coal power.

The results for land transformation show parity between solar and coal at 26 years, whereas those for land occupation show parity at 24 years. The latter is a more informed metric since it includes information about the recycling times of land following disturbance. A 30-year old photovoltaic plant is seen to occupy15% less land than a coal power plant of the same age per GWh generated. As the age of the power plant increases, the land use intensity of photovoltaic power becomes significantly smaller than that for coal power. The sensitivity in the calculations, as dependent on input parameters, is shown by the shaded belts in Fig. 2. Land transformation per plant capacity km^2 $GW^{-1}{}_{ac}$ show parity between solar and coal after 30years, with a range from 27 to 40 years (data not plotted).

2.4 Analysis of CdTe PV cells' cumulative impact on ecology

The study of Turney and Fthenakis (2011) shows that solar power plants have a certain impact on wildlife and habitat.

The majority impact to wildlife and habitat is due to land occupation by the power plant itself. The power plant is typically enclosed by a fence. Hiding spots, preying strategy, food availability will all be affected. Power plants can also prevent growth of vegetation or keep free of vegetation. In either case, a significant alteration to the vegetation occurs. The PV panels themselves will cast shadows and change the microclimate, causing an unstudied effect on vegetation.

McCrary et al. measured death of birds, bats, and insects at the Solar One concentrating solar power tower near Daggett, California, USA in desert land. Six birds per year died and hundreds of insects per hour were incinerated in the intense light. This impact was concluded to be low compared to other anthropogenic sources of bird and insect fatality. The environmental impact statement for the solar power tower Ivanpah Solar Electric Generating System, California, USA reported that “significant impact” would occur for the threatened desert tortoise, five special-status animal species, and five special-status plants in the local area. An environmental impact report prepared for the 550MWp Topaz photovoltaic project located in grasslands and abandoned farmlands of central California, USA found the potential for significant impact to dozens of protected animal and plant species in the region. For both projects, extensive mitigation programs were implemented to reduce the impacts to acceptable levels.

The impact to wildlife will be tightly correlated to the biodiversity of the land on which the power plant is built. Sunlight and water availability can significantly alter the biodiversity in any of these biomes, by a factor of two, and endangered species can live in any biome. Consequently, a customized study of the wildlife and ecosystem surrounding each power plant is recommended as a best practice. For example, see U.S. project environmental impact reports in References. In addition, power plants’ impact on biological corridors is obvious.

In addition to potential impacts on biodiversity, solar projects can have potential benefits for biodiversity due to their static use of land. Although construction projects always involve disturbance of existing flora and fauna, with solar parks there is a chance to improve the quality of habitats for various plant and animal species and even to create new habitats (T. Peschel, 2010).Table 1 summarizes ecological impacts of solar power plants displacing power generated by the traditional U.S. technologies.

Table 1 Impacts to wildlife and habitat of solar energy relative to traditional U.S. power generation (Turney and Fthenakis, 2011).

Impact category	Effect relative to traditional power	Beneficial or detrimental	Priority	Comments
Exposure to hazardous chemicals				
Acid rain: SO NOx	Reduces emissions	Beneficial	Moderate	Solar power emits ~ 25× less
Nitrogen, eutrophication	Reduces emissions	Beneficial	Moderate	Solar emits much less
Mercury	Reduces emissions	Beneficial	Moderate	Solar power emits ~ 30× less
Other: e.g., Cd, Pb, particulates	Reduces emissions	Beneficial	Moderate	Solar emits much less

Oil spills	Reduces risk	Beneficial	High	Note: BP Horizon Spill, Valdez Spill
Physical dangers				
Cooling water intake hazards	Eliminates hazard	Beneficial	Moderate	Thermoelectric cooling is relegated
Birds: flight hazards	Transmission lines	Detrimental	Low	Solar needs additional transmission line
Roadway and railway hazard	Eliminates hazard	Beneficial	Low	Road and railway kill is likely reduced
Habitat				
Habitat fragmentation	Neutral	Neutral	Moderate	Needs research and observation
Local habitat quality	Reduces mining	Beneficial	Moderate	Mining vs. solar farms; needs research
Land transformation	Neutral	Neutral	Moderate	Needs research and observation
Climate change	Reduce change	Beneficial	High	Solar emits ~ 25× less greenhouse gases

2.5 Analysis of CdTe PV cells' cumulative impact on climate change

The study of Turney and Fthenakis (2011) shows that, solar power plants have a positive impact on climate change due to reduced emissions of carbon dioxide compared to traditional power generation.

Given~72GWh km^{-2} yr^{-1} as time-averaged generation for the solar power plant, emissions of CO_2 from the remainder of the lifecycle of solar power are 16-40 g CO_2 kWh^{-1} for 1,700 $kWhm^{-2}$ yr^{-1}insolation. The net emission results in Table 2 shows that solar power is still a very low carbon alternative to traditional U.S. power generation.

Table 2 Emissions of CO_2 from the lifecycle of large-scale solar power.

Carbon dioxide emissions (g CO_2 kWh^{-1})		
	Best case	Worst case
Loss of forest sequestration	+0.0	+8.6

Respiration of soil biomass	+0.0	+1.9
Oxidation of cut biomass	+0.0	+35.8
Other phases of the lifecycle	+16.0	+40.0
Total emissions of solar	+16.0	+86.3
Fossil fuel emissions avoidance	-850.0	-650.0
Total including avoidance	-834.0	-563.7

Methane and nitrous oxide are also important greenhouse gases released by coal power plants. For comparison, the radioactive forcing of CO_2, methane, and nitrous oxide, respectively, is 1.7, 0.5, and $0.2Wm^{-2}$, and fossil fuel combustion contributes 73%, 27%, and 8% of the respective amounts. Emissions of CH_4 and NO_2 from the lifecycle of solar power in forests are likely to be much lower than from fossil fuels, suggesting another GHG benefit for switching electricity generation from fossil to solar power.

Land use affects local climate, microclimate, and surface temperatures, e.g., urban heat islands exist near metropolitan areas. Solar panels have low reflectivity and convert a large fraction of insolation into heat, which leads to concern that they may affect global or local climate. Nemet investigated the effect on global climate due to albedo change from widespread installation of solar panels and found the effect to be small compared to benefits from the accompanying reduction in greenhouse gas emissions. Nemet did not consider local climates or microclimates though they have been recently evaluated by Fthenakis and Yu (2013) who observed prompt dissipation of thermal energy with distance from alarge solar farm and complete cooling of the solar array at night.

Table 3 lists the climate change impacts from solar energy in forested regions. The presence of the forest affects most of the impacts, particularly the CO2 emissions. Field research is needed to establish the effect of the power plant on local climate and micro-climates.

Table 3 Impacts to climate change from solar power, relative to traditional U.S. power generation (Turney and Fthenakis, 2011).

Impact category	Effect relative to traditional power	Beneficial or detrimental	Priority	Comments
		Global climate		
CO_2 emissions	Reduces CO_2 emissions	Beneficial	High	Strong benefit
Other GHG	Reduces GHG	Beneficial	High	Strong benefit

emissions	emissions			
Change in surface albedo	Lower albedo	Neutral	Low	The magnitude of the effect is low
Local climate				
Change in surface albedo	Lower albedo	Unknown	Moderate	Needs research and observation
Other surface energy flows	Unknown	Unknown	Low	Needs research and observation

2.6 Analysis of CdTe PV cells' cumulative impact on the social environment

The study of Turney and Fthenakis (2011) shows that solar power plants have both positive and negative impact on the social environment.

Table 4 lists the impacts to human health and well-being from solar energy in forested regions. Most of the impacts are beneficial, due to a reduction in toxic emissions arising from the combustion of fossil fuels. For example, a recent study found that 49% of lakes and reservoirs in the U.S. contain fish with concentrations of mercury (Hg) above safe consumption limits. Solar power equipment releases 50-1,000 times less direct Hg emissions than traditional electricity generation, i.e., ~0.1gHgGWh^{-1} as compared to ~15gHgGWh^{-1} from coal. In the US, at least 65% of the mercury deposited in lakes and reservoirs originates from burning fossil fuels. Photovoltaics made with CdTe emit ~0.02 g Cd GWh^{-1} when manufactured with clean electricity, which is 100-300 times smaller than emissions from coal power generation. Emissions of NO_x, SO_2, and many other pollutants, are orders of magnitude smaller than those from traditional power. Emissions of these toxics and others, including particulates, are significant burdens on human health. Carbon dioxide emissions also pose risks to human health and well-being, due to climate change and the associated effects: sea level rise, extreme weather, food security, and socioeconomic change. Fossil fuel power plants emit a large proportion of greenhouse gases worldwide, and much of the remaining emissions are due to petroleum use that can be partly replaced by electricity from clean power sources.

Impacts on aesthetics and recreational opportunities from solar power are less clear. Recent proposed legislation introduced in California attempted to place large tracts of land out-of-bounds for solar energy plants, partly due to recreational and visual impacts, and partly for ecological concerns (Woody, 2009). The visual and recreational impacts are difficult to quantify but much progress has been made by the U.S. Forest Service over the past decades toward appraising visual resources during land development. A similar approach could be used for recreational resources. Regarding recreational resources, note that a switch to solar power would decrease mercury deposition on lakes and rivers, thereby improving their utility for fishing and recreation. Mountaintop mining could also be reduced or displaced by deployment of large-scale solar power, thereby opening vast amounts of highland forest to recreational opportunity.

Table 4 Impacts to human health and well-being relative to traditional U.S. power generation (Turney and Fthenakis, 2011).

Impact category	Effect relative to traditional power	Beneficial or detrimental	Priority	Comments
Exposure to hazardous chemicals				
Emissions of mercury	Reduces emissions	Beneficial	Moderate	Solar emits ~ 30× less
Emissions of cadmium	Reduces emissions	Beneficial	High	Solar emits ~ 150× less
Emissions of other toxics	Reduces emissions	Beneficial	Moderate	Solar emits much less
Emissions of particulates	Reduces emissions	Beneficial	High	Solar emits much less
Other impacts				
Noise	Reduces noise	Beneficial	Low	Less mining noise; less train noise
Recreational resources	Reduces pollution	Beneficial	Moderate	Cleaner air; cleaner fishing
Visual aesthetics	Similar to fossils	Neutral	Moderate	Solar farms vs. open pit mines
Climate change	Reduces change	Beneficial	High	Solar emits ~ 25× less g h g
Land occupation	Similar to fossils	Neutral	Moderate	See Section 4.1. of Turney and Fthenakis (2011)

3 Environmental risk assessment

3.1 Environmental risk assessment

Since the U.S. have a proven track record in installation and operation of CdTe PV power plants, for example, in California and Arizona, and a similar project has been introduced to Ordos, Inner Mongolia in 2010, it does make sense to refer to EIS or ESA documents in the U.S. In these documents, environmental risks are summarized in two aspects: (i) disaster risks incurred from various disasters (due to natural, human factors), e.g. geological disasters, earthquakes, floods and fires; and (ii) health risks incurred from exposure to pollution or hazardous substances. Particular attention is given to biological resources including flora and fauna and environmentally sensitive locations such as schools and hospitals.

Based on the review of available literature and the comparison of EIA documents on CdTe PV power plants in China and other countries, lifecycle analysis is conducted. The emphasis is put on environmental risk assessment for the CdTe cell production, PV power plants installation and operation, and decommissioning and disposal phases, which is summarized as follows.

(1) Manufacture of CdTe module

The processes from purchase of raw materials to manufacture of modules are all carried out in a closed workshop. Generated atmospheric pollutants generally enter the ventilation system of the workshop equipped with highly efficient HEPA (High Efficiency Particulate Air) filters. The efficiency of HEPA filters in collecting particulates of mean diameter of 0.3um is 99.97%. Cleaning wastewater from all workshop sections all flow to the in-house sewage treatment plant for centralized treatment. In this way, wastewater and air emissions generated at the site are effectively controlled. So, environment risks from the manufacture process mainly lie in substances and equipments of concern and resulting credible incidents such as equipment start/stop, maintenance, environmental equipment failure and fires.

i. Identify risk sources

Substances and equipments of concern are covered herein. Substances of concern mainly include toxic, hazardous, inflammable and explosive substances. Glass carrier cleaning related acids and alkalis and other harmful substances during manufacture of CdTe modules all fall under the category. As trade secrets are involved, only concentrated sulfuric acid, sodium hydroxide and etc. are identified for the present. Specifics will be given in the project EIA phase.

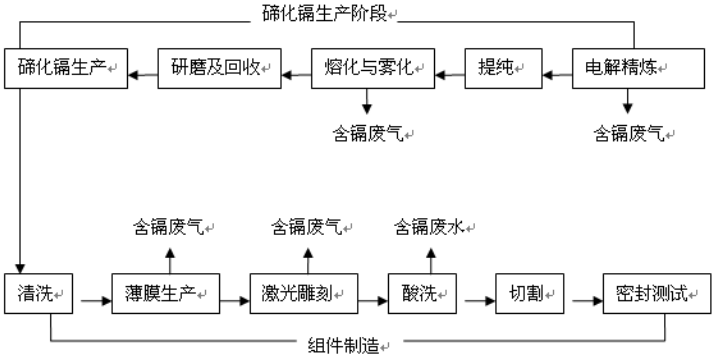


Figure 3 Manufacture process of CdTe solar modules

Currently available information shows that major substances of concern during manufacture of modules include concentrated sulfuric acid and sodium hydroxide. The specific scale of risk and whether they shall be classified as major risk sources need to be further determined based on the use and storage volume. According to the manufacturing process of CdTe solar modules, manufacturing equipments available in the workshop sections of semiconductor deposition, cell definition, and module finishingare where cadmium containing equipment exhaust and waste water are generated.

ii. Identify environmental risk-related credible incidents

Environmental risk-related credible incidents during manufacture of CdTe solar modules include equipment maintenance, start/stop, incidental sewage efflux at sewage treatment facilities, environmental equipment failure, fires, and etc.

With regards to incidental sewage efflux at sewage treatment facilities, production and cleaning wastewater are all transported into the in-house wastewater treatment system, treated on a batch basis and discharged after the applicable wastewater discharge standards are met. (the Chinese version still retains this sentence) Therefore, sewage treatment facilities shall have sufficient capacity. It’s advisable to conduct online monitoring of heavy metals (Cd), acidity (pH) and chemical oxygen demand (COD) in water pollutants and develop contingency plans. For example, treated wastewater in First Solar manufacturing and recycling facilities is held in batch discharge tanks and tested before being confirmed for discharge.

HEPA filter failure may lead to inadvertent cadmium particulate emissions within the manufacturing facility. However, since CdTe can hardly exist in the gaseous state at normal temperature, pressure, once the vacuum or high temperature environment is damaged, CdTe vapor will condense rapidly into solid particles clinging to the cavity or pipe wall and thus hardly diffuse in the gaseous state to pose health risks to human beings. Specific risk mitigation measures include guaranteed filter replacement frequency, automated filter efficiency monitoring systems, effective job and settlement records, training in the use and inspection of filters and etc.

(2) PV power plant installation and operation

Environmental risks from PV power plant installation and operation are summarized as follows:

i. Improper use, storage and disposal of petroleum products could lead to emissions into the aquatic or terrestrial environment, which, when going beyond a certain dose, can pose potential threat to human health. Such risks can occur in the underlying construction and operation phases. The specifics are as follows:

a. The underlying construction phase: Risk-induced behaviors may include installation of site channels, excavation of wells and establishment of a temporary storage tank, site grading and removal of surface vegetation, development of drainage control systems, underground structures and outdoor switching stations, deployment of transmission lines, laying of solar photovoltaic panels, deployment of fire prevention systems and etc.

By means of strict control and management of hazardous substances and timely removal of oil spills, the occurrence of sudden disasters and release of harmful substances during the construction phase are usually short-term and can be controlled within the construction site, and the risk level thereof is acceptable.

b. The operation and maintenance phases of the power plant: Risk-induced behaviors may include daily transportation of petroleum products as used in vehicles, and use and improper disposal of hazardous substances, hydraulic fluids, and herbicides. Along with the operation of the project, hazardous substances including lubricants, and waste oils adsorbents can also be generated.

c. The decommissioning phase of powerplants: Containment measures in the power plant decommissioning phase are necessary to limit the release of petroleum substances.

ii. Risks related to activation of pollutants in soil or groundwater to increase exposure of humans or wildlife and pose health hazards when the exposure level exceeds the threshold.

a. The underlying construction phase: Risk-induced behaviors include disturbance of the soil environment at the site that was once a contaminated site or agricultural sewage irrigation area in the underlying construction phase, which may become a new source of pollution and increase the amount of exposure of onsite staff.

b. The operation and maintenance phase: The disturbance to soil and underground water in this phase is smaller than that in the underlying construction phase. The replacement of panels, substation equipment and digital surveillance systems within a small framework may bring some environmental risks to staff exposed to hazardous substances.

c. The decommissioning phase: This phase may cause pollution disturbance of soil and groundwater. Related behaviors include removal of solar panels and brackets, underground facilities at least 2 feet deep, buildings, and power transmission poles and conductors, and closing and abandoning wells and underground oil tanks. Once leakage of hazardous substances is identified, it’s necessary to remove impacted soil and dispose of responsibly.

iii. Risks related to workers that are exposed to pollutants or the concentration of hazardous substances is excessive and goes beyond the OSHA allowable amount; or result in the public’s direct and indirect contact and thus increased exposure.

In the three phases of underlying construction, operation and decommissioning, the exposure of workers to hazardous substances is temporary. Workers shall operate in strict accordance with OSHA requirements, which, however, cannot avoid the risk of incidents. So it’s necessary to develop and follow *Contingency Plans for Environmental Risks*.

iv. Risks related to the increase in the exposure amount of residents of the land on which the power plant is built, or to causing significant damage, injury or death;

a. The underlying construction phase: risk-induced behaviors may include engineering activities and use of equipment, which can lead to loss, increased risk of injury, and even death as a result of electric shock and wildland fires. Fires are related to cigarette lighter, refueling and driving, etc.

b. The operation and maintenance phase: The occurrence probability of risk during operation is related to arc and line sparks. Environmental risks can be mitigated by taking measures such as deployment of baffle walls and fire systems and enclosing of electronic equipments.

v. Fires

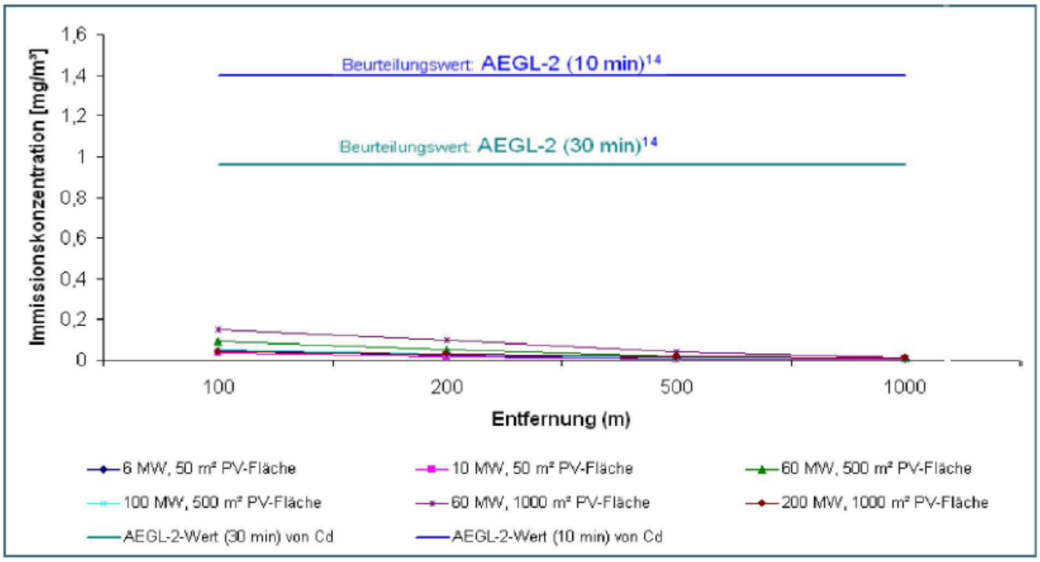
CdTe thin-film cells, the central part of solar modules, are located between two sheets of glass. Such modules contain the semiconductor CdTe consisting of the compound of heavy metal Cd and non-metallic Te. In China, CdTe has been included in the Hazardous Wastes Catalogue. But regarding solar thin-film modules, requirements are not clearly defined yet. Due to its presence, the heavy metal Cd is deemed a key target under the environmental risk assessment.

Vasilis M. Fthenakis analyzed routine releases and potential accidental releases of cadmium compounds in PV cells in *Lifecycle impact analysis of cadmium in CdTe PV production* released in 2003, concluding that it's impossible for any vapors or dust to be emitted when using PV modules under normal conditions and CdTe releases are unlikely to occur during accidental breakage. The only scenario of potential exposure is if a fire consumes the PV module and releases cadmium from the material into the air.

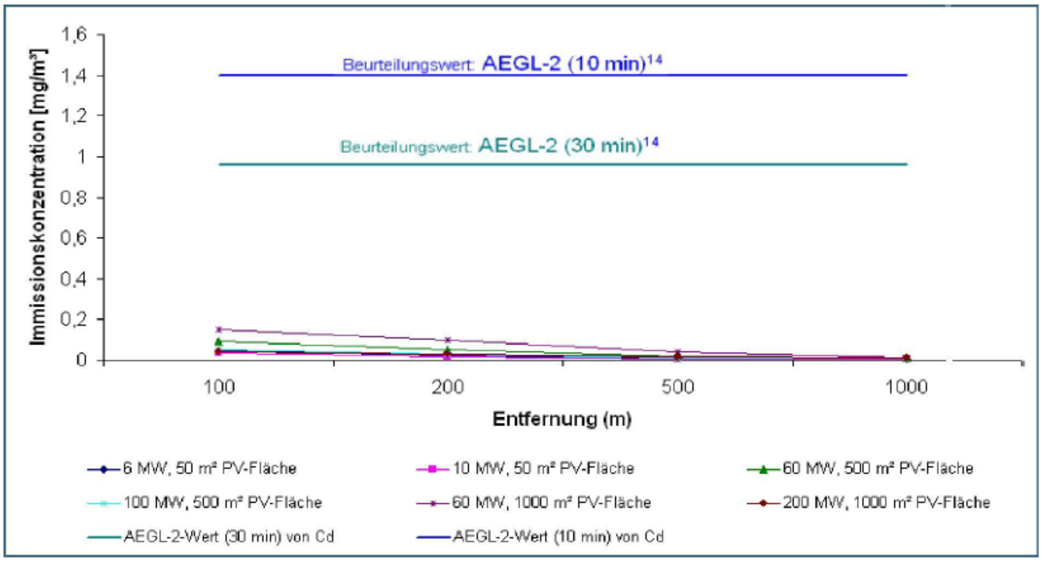
In fully developed house fires, flame temperatures can reach 800-1,000°C. In industrial fires where other fuels are present, higher flame temperatures could occur. Steinberger conducted thermogravimetric analyses of pure CdTe and reported that the material, exposed to air, remains stable until about 1,050°C, whereas it started to evaporate at around 900°C under non-oxidizing conditions (lack of air). But it shall be noted that oxidizing conditions are the only realistic ones for high temperature tests, since lack of oxygen would extinguish the fire. Some studies show that when the flame temperature reaches above 700°C, the glass will melt and wrap around the CdTe thin-film before solidifying. So 99.96% of Cd will be retained in glass. Plus, in previous studies, samples were cut from the center of standard modules. But in the real word, a cm-wide blank area without cadmium is reserved on the four sides of conventional modules. The design is aimed at preventing edge leakage. Cd needs to diffuse 1cm to reach the opening of the edge, so the actual leakage probability may be even lower than that shown in Fthenakis' study.

In general, the release of CdTe from conventional CdTe modules encapsulated in glass pieces in fires is low and negligible.

It is worth noting that in Worst-case Fire Dispersion Modeling (assuming total release of Cd) the accidental release model is used for calculation(Beckmann and Mennenga 2011). Assuming roof-top Cd emission source strength 50 m^2, 500 m^2, and 1000 $m^2$to be respectively mapped to 14-66 g Cd/m^2, ground-level Cd concentrations [mg Cd/m^3]depending on the distance (from 100m to 10,000 m) from the fire site are estimated. The mapping relation is as shown in the figure below. According to the acute exposure guideline levels (AEGL) for Cd and safety threshold 4 mg/m^3 for CdO, within a certain distance, the ground-level Cd concentrations are estimated to be below environmental screening levels in the surrounding environment.



Depiction of cadmium emission concentrations depending on the distance from the fire site with average cadmium contents of 14.0 g/m^2 (Case 1).



Depiction of cadmium emission concentrations depending on the distance from the fire site with average cadmium contents of 14.0 g/m^2 (Case 1).

Figure 4 Ground-level Cd concentration depending on the distance [mg Cd/m^3]

Mitigation measures: As with any large structure or building, it’s necessary to develop strict *Emergency Plans for Fire Incidents* and make drills, and set up health protection distance based on the actual need in project-specific environmental impact assessment to ensure the safety of sensitive points in the surrounding environment of the project. Plus, necessary measures, e.g. protective equipments and clothings, shall be taken before proceeding to firefighting.

vii. Damaged PV modules

In the early construction period of the project, the damage of individual panels can hardly be avoided when PV solar panels are installed. Plus, damage and leaching risks can potentially occur during waste treatment of solar panels after decommissioning of the power plant.

Under normal circumstances, when modules are damaged in dry or neutral aqueous environment, cadmium leaching to the surrounding environment is negligible. But in acid rain environment, Cd emissions shall be highlighted. In China, erosion and dissolution of acid rain in some regions may lead to leaching of cadmium from modules. So it’s advisable to perform independent leaching test for modules in the case. Note that the presence of acid alone is not sufficient to cause leaching. For example, the recycling process requires crushing modules to mm-scale pieces and agitating in acid to recover semiconductor materials. Module breakage rate is below 1% over 25 years (0.04%/yr), over one-third of which occurs during shipping and installation. In addition, routine inspections and power output monitoring diagnose broken modules for takeback and recycling. Most module breakage is limited to small fractures rather than shattering due to the lamination of the two sheets of glass, which limits potential exposure area.

(3) Decommissioning

PV deployment is beginning to globalize beyond the EU into emerging markets, where end-of-life collection and recycling is voluntary and landfill is currently the predominant form of waste disposal. As PV solar panels under condition of damage and acidic leaching may generate cadmium ions, there are potential environmental risks and health risks to residents living besides landfills. This is a top concern in other countries along with the development of CdTe PV cells, but relevant research hasn’t been conducted in China yet.

Releases to the aquatic environment could occur after decommissioning only if such modules end up in unlined landfills, the semiconductor materials leach out, and there is no leachate collection and treatment system. However, cadmium telluride is encapsulated between two sheets of glass which are laminated and is unlikely to leach to the environment under normal conditions. But there are risks in acid conditions. An independent leaching toxicity test of the modules shall be performed prior to disposing of modules to landfill.

Vasilis M. Fthenakis (2004) concluded that the environmental risks from CdTe PV are minimal. The estimated atmospheric emissions of 0.02 g of Cd per GWh of electricity produced during all the phases of the modules’ life, are extremely low. Large-scale use of CdTe PV modules does not present any risks to health and the environment, and recycling the modules at the end of their useful life completely resolves any environmental concerns.

Recycling of waste solar panels is the best way to minimize the environmental risks thereof and conserve resources. And it's also feasible for the present to submit to qualified organizations for disposal at landfills.

3.2Emergency response and remedial measures in case of incidents

1) Enable well-regulated storage, use and disposal of hazardous substances.

Where hazardous substances are involved, a responsibility owner shall be delegated. H*azardous Substances Regulations* shall be developed and put in place for strict management of their use. Hazardous wastes, e.g. shall be submitted to qualified organizations for disposal.

2) Establish fire and accident pools and take measures to guarantee effective drainage and prevent flooding

(i) set up fire and accident pools near the solar panel quarter to prevent fires; (ii) based on the site terrain, build drainage and water conservancy facilities, e.g. regional drains, flood intercepting trenches, etc., to address sudden flooding; and (iii) develop *Fire Prevention Measure for the Construction and Operation Phases* and *Flood Prevention Measure for the Construction and Operation Phases* and put them in place.

3) Develop *Contingency Plans for Incidents and Environmental Risks*

The Contingency Plans shall be developed in strict compliance with the *Guidance on Preparing Emergency Rescue Plans for Hazardous Chemicals Incidents* to cover (i) hazardous targets, available safety, fire and personal protective equipments and tools in the vicinity and their distribution; (ii) emergency rescue organizations, personnel and responsibilities; (iii) alarm and communications; (iv) disposal measures after occurrence of incidents; (v) staff evacuation; (vi) danger zone isolation; (vii) detection, rescue, relief and control measures; (viii) treatment of the injured; (ix) site protection and decontamination; (x) emergency rescue guarantee; (xi)triggers for graded emergency response; (xii) emergency rescue termination procedures; (xiii) emergency response training programs; and (xiv) drill programs.

4) Develop other plans and preventive measures, including, SWPP (Stormwater Pollution Prevention Plan), SPCC (Spill Prevention Control and Countermeasure Plan) and HSP (Health and Safety Plans).

5) Highlight recycling of solar panels and eliminate arbitrary abandonment. Introduce *Solar Cell Recycling*, *Solid Waste Recycling*, etc.

3.3 Human health risk assessment

(1) Eco-toxicity of Cd and CdTe

Cd is a relatively rare element in the earth's crust. Elemental cadmium is a silver white or lead gray metal, with a density of 8.642 g/cm^3, melting point of 321 °C, and boiling point of 765 °C (Table 1). Environmental issues incurred by cadmium exposure, including cadmium ecotoxicology, migration and transformation in flora and fauna, ecological issues as a result of bioaccumulation and biomagnification, and tissue damage, endocrine disorders, cardiovascular diseases, reproductive dysfunction and cancer triggered by accumulation in human body, have become a common concern. The Itai-itai disease found in Japan, a well documented public nuisance, is caused by cadmium poisoning.

In contrast, little is known about CdTe's toxicological profile and regulatory agencies usually apply cadmium (Cd) criteria as a best approximation. However, due to relative stabilization and low solubility, CdTe may have different toxicological properties. Joseph Zayed and Suzanne Philippe studied acute oral and inhalation toxicities in rats with cadmium telluride. This study showed that the median lethal concentration of CdTe is 2.71 mg/L/4 hours while its median lethal oral dose was considered to be greater than 2,000 mg/kg. According to cadmium toxicity data of The Registry of Toxic Effects of Chemical Substances data bank, for 4 hours of exposure, this concentration leads to a value of 0.0031 mg/L/4 hours, which is very much lower than the value for CdTe (2.71 mg/L/4 hours). For aquatic organisms, S. Kaczmar (2011) studied CdTe's acute aquatic toxicity to zebra fish and concluded that CdTe is not toxic (fatal or indirectly fatal) to fish under water saturation.

(2) Human health risk practices and assessment

From PV power plant operation to module decommissioning under the project, it's not likely to emit any vapor or dust when PV modules are used under normal conditions. In general, it's believed that CdTe will not have adverse effects on human body until CdTe containing dust is ingested and inhaled or improperly disposed of (e.g. improper use of gloves). Therefore, in the U.S., potential risks to human body from disposal of end-of-life modules at landfills are highlighted. Regarding health risks from the manufacturing process, emphasis is put on occupational safety and health evaluation.

Parikhit Sinhaet. al. performed fate and transport analysis to evaluate potential exposures to cadmium (Cd) from cadmium telluride (CdTe) photovoltaics (PV) for rainwater leaching from broken modules in a commercial building scenario.In this highly conservative study, where all the CdTe content of the broken modules was assumed to be released to the environment, results showed that exposure point concentrations in soil, air, and groundwater are one to six orders of magnitude below conservative (residential soil, residential air, drinking water) human health screening levels. Potential exposures to Cd from rainwater leaching of broken modules in a commercial building scenario are highly unlikely to pose a potential health risk to on-site workers or off-site residents.

Swiatoslav Kaczmar evaluated the potential for human health and ecological impacts from disposal of CdTe photovoltaics in non-sanitary landfills. The evaluation considered potential human health and ecological impacts from waste disposal to an unlined landfill under acidic conditions. With respect to human health impacts, estimated cancer risks were well below the screening limit (1.0×10^{-6}) for both landfill conditions. Likewise, chronic non-cancer hazard indices (HI) for both acidic and basic landfill conditions are well below the screening limit (1), indicating that the land-filling of CdTe PV modules would not be expected to result inreleases of Cd to groundwater or surface pathways at levels representing potential health impacts.

(3) Occupational safety and health assessment

Due to high concentration and long-time of Cd exposure during manufacture of CdTe PV solar modules, the impact on human health shall be highlighted. It's necessary to perform occupational safety and health assessment. During the operation phase and after decommissioning, along with declining exposure, occupational safety and health risks drop as well. For human health risk assessment, urine cadmium levels are primarily indicative of long term cadmium exposure, blood cadmium levels are primarily indicative of recent exposure, and β-2 microglobulin levels are a secondary indicator.

i. Cadmium exposure

The CdTe module manufacturing process will inevitably bring exposure to cadmium containing dust. Related processes and environmental monitoring data of the Kulim module manufacturing facility in Malaysia show that there are no module processing steps that result in worker exposure at or above $5\mu g/M^3$ for an 8-hour time weighted average which is the OSHA (US Occupational and Health Administration) PEL (permissible exposure limit) for cadmium. The only manufacturing activity in excess of the OSHA PEL is maintenance to the semiconductor deposition equipment and spraying of $CdCl_2$. Addressing this, First Solar adopts High Efficiency ParticulateAir (HEPA) filters to protect from cadmium dust. Plus, equipment maintenance and cleaning workers must wear appropriate protection such as protective clothing for risk prevention.

ii. Employee health test results

Over the past decade, First Solar has accumulated much data on biological test results of its workers. The tests are carried out by a third party. John R. Bohland and Ken Smigielski documented over 700 medical monitoring tests on workers from First Solar, Ohio in the U.S., to track any biological responses to occupational cadmium exposures. A total of 44 samples were acquired. The facility, put into operation for 10 years, has the longest operating duration of any First Solar manufacturing facility. The test results showed compliant blood cadmium and urine cadmium results.

Take the Kulim facility in Malaysia as an example. Malaysia OSHPELs for blood and urine cadmium concentration are 5μg/L and 3μg/g respectively. In 2007-2012, the Kulim facility has carried out blood and urine cadmium concentration monitoring of over 1,000 workers for six consecutive years and concluded that the values stay far below OSHA PELs. The statistical data for 2011 and 2012 are still being processed.

The semiconductor deposition equipment maintenance and $CdCl_2$ spaying and baking processes pose higher risks. Amongst these workers, maintenance staff are subject to a blood and urine cadmium test every six months, while staff exposed to $CdCl_2$were subject to the test annually prior to 2012 and once every three years beginning2012. Test results showed that staff engaged in the two processes are still in a safe working environment.

iii. Risk mitigation measures

First Solar is trying to mitigate health risks from the manufacturing processes in the following ways: (i) strengthen environmental monitoring in different workshops to ensure compliant cadmium exposure concentration; (ii) request workers to wear protective clothing and respiratory protection equipped with HEPA filter cartridges when engaged in equipment maintenance and cleaning; (iii) keep close monitoring of workers' health checks and increase the monitor frequency for high-risk processes, e.g. organize a blood and urine cadmium test for semiconductor deposition equipment maintenance staff every six months; (iv) conduct on-the-job employee training and increase risk prevention awareness; and (v) develop contingency plans and perform regular drills.

4CdTe cell lifecycle CP assessment

4.1 CdTe cell lifecycle CP assessment

(1) CP indicators in EIA

The selection of indicators shall be conducted in light of the principle of being systematic, independent and pragmatic. Cleaner production (CP) indicators in EIA include manufacturing process and equipment requirements, resource and energy utilization indicators, product indicators, pollutant emission indicators (prior to end treatment), waste recycling indicators, etc. Manufacturing process and equipment indicators and product indicators are qualitative indicators, while the others are quantitative indicators.

Throughout the lifecycle of CdTe PV cells, cleaner production is mainly embodied in mining and smelting of lead and zinc ores, synthesis of CdTe and disposal of waste solar panels. The reference indicators for the three phases are as shown in the table below.

Table 5 Reference indicators by phase throughout the lifecycle of CdTe PV solar modules

Lifecycle	Indicator	Content	Remark
Lead and zinc ore mining and smelting	Manufacturing process and equipment requirements	Sophistication of manufacturing processes and equipments	Refer to *Cleaner Production Assessment Indicators for the Lead and Zinc Industry (Trial)*
	Resource and energy utilization indicators	Resource utilization rate, water consumption rate, water recycling rate, energy consumption rate (coal power, etc.)	
	Pollutant generation indicators (prior to end treatment)	Tons of COD, SO_2 and Cd generation	
Synthesis of CdTe PV modules	Manufacturing process and equipment requirements	Sophistication of manufacturing processes and equipments	Compare to other solar panel industries
	Resource and energy utilization indicators	Water consumption rate, water recycling rate, energy consumption rate (coal power, etc.)	
	Pollutant generation indicators (prior to end treatment)	Tons of COD, SO_2 and Cd generation	
	Cadmium recycling indicator	Cadmium recycling indicator	
Disposal of waste PV panels	Waste recycling indicator	Waste PV panel recycling rate; if pollutants are recycles, then water resources, energy consumption rate and metal cadmium	It’s advisable to submit to qualified organizations for centralized disposal or recycling

		recycling rate shall be considered	

(2) Lifecycle based cleaner production and pollutant emissions

i. Overview of existing literature resources on energy use

Parikhit Sinha, Amy Meader, et al. (2013) in their study of lifecycle water usage in CdTe photovoltaics summarized energy and resource consumption per unit.

Table 6 Key life cycle inventory (LCI) parameters during CdTe production

Lifecycle Phase	Parameter	Value	Unit per m^2 module	Sample Size
Module (weighted average across U.S., German, and Malaysian facilities)	Electricity	29.7	kwh	3
	Solar Glass	8.39	kg	3
	Glass Tempering	8.39	kg	3
	Flat Glass	8.15	kg	3
	Tap water (from utility bills)	182.8	kg	3
BOS (from Topaz Solar Farm, California)	Steel, low-alloyed	10.2	kg	3
	Zinc coating	0.63	m2	3
	Tap water [5]	89.1	kg	3
	Inverter, 500kW	0.00022	-	3
	Copper	0.88	kg	3
Takeback and Recycling (from U.S. facility)	Electricity	4.38	kwh	3
	Hydrogen peroxide, 50% in water	0.57	kg	3
	Transport, van < 3.5 tonne	1.62	t-km	3
	Transport, lorry > 16 tonne	8.67	t-km	3
	Water deionized (from instrument readings)	5.42	kg	3

Table 7 Direct and total lifecycle water withdrawal (L/MWH) for CdTe PV

Lifecycle Phase	Direct (on-site)	Total
Module	31	224
BOS[a]	15	106-150
Takeback and Recycling	1	51
Total	47	382-425

Calculated based on the above table, the water withdrawal throughout the lifecycle of CdTe photovoltaics stays at around 382-485L/Mwh. The statistical data in LCI of CdTe cells show that direct energy and water consumption per m^2 PV module in the lifecycle is 34 kWh and 277 L respectively.

ii. Pollutant emissions in First Solar practices

Take the Kulim facility in Malaysia as an example. Pollutant emissions per m^2 during the manufacturing process are as shown in Table 8. Given the sharp fluctuations, the indicators are only used for analogy reference for cleaner production indicators.

Table 8 Pollutant emissions during the manufacture of PV modules

Final Discharge Parameters	**Regulatory Final Discharge Limit**	**Waste stream from manufacturing/others (min-max)**	**KLM1 WWTP Actual Final Discharge (min-max)**	**KLM2 WWTP Actual Final Discharge (min-max)**	**KLM3/4 WWTP Actual Final Discharge (min-max)**	**KLM5/6 WWTP Actual Final Discharge (min-max)**
pH	**5.5-9**	1 - 10	6.6- 7.6	6.9- 7.6	6.9- 7.6	7.0- 7.7
COD (mg/L)	**200**	90 - 450	1 - 64	1 - 47	0 - 20	1 - 54
Cadmium (mg/L)	**0.02**	15- 80	0- 0.005	0- 0.005	0- 0.005	0.005-0.010
Iron (mg/L)	**5.0**	10 - 20	0 - 2	0- 0.09	0- 0.16	0- 0.15

4.2 Aggregate indicators suggestions

According to the *Twelfth Five-Year Plan for Environmental Protection in China*, the country exerts control and management on the total emissions of the four major pollutants of COD, SO2, NH3-N and NOX. So it’s advisable to adopt the combined emissions of the above four conventional pollutants as a pollution emission indicator.

Also, in the *Twelfth Five-Year Plan for Heavy Metal Pollution Integrated Control (2011)*, the control over total heavy metal emissions is introduced for the first time, and the five heavy metals including mercury, chromium, cadmium, lead and arsenic are defined as the key targets subject to monitoring and pollutant emission control. The Plan divides the country into two categories: priority areas, including 14 major provinces such as Inner Mongolia, Hunan, Guangxi and Qinghai and 138 key protection zones, and non-priority areas. So it's advisable to adopt the total emissions of the heavy metal cadmium as another pollutant emission indicator.

5. Environmental measures and suggestions for CdTe PV cell projects

5.1Mitigation measures for reduced impact on water

In the mining phase, heavy metal wastewater mainly consists of underground drainage, leaching wastewater from waste rock piles, production water for mining and underground water gushing in mines. Mitigation measures for the mining phase and the rest of the life cycle include: (i) set up centralized collection tanks for recycling or effluence after treatment, adopt cutting-edge ore selection and mining technologies, and minimize underground water gushing to reduce the impact on surface water and groundwater; (ii) decide on appropriate sites featuring good solar resources, low population density and sufficient land area for construction and operation of CdTe solar power plants; (iii) carry out wastewater recycling in a stringent manner to minimize wastewater effluence during production of CdTe powder and manufacture of PV modules; (iv) prevent leaching at landfills in the decommissioning phase and deploy leachate collection and treatment systems; (v) develop sound project management plans and emergency response plans, and adopt lifecycle management and pollutant control technologies; and (vi) develop well-designed training mechanisms and responsibility matrixes and put them in place.

5.2Mitigation measures for reduced impact on air

In the mining phase, exhaust pollutants include underground ventilation exhaust from underground blasting, drilling, loading and unloading and dust. Mitigation measures are as follows: (i) reduce dust by spraying water and minimize dust's impact on workers by requesting them to wear personal protection; (ii) enable regular water sprayingon waste rock dumps and ore yards for dust suppression since open ore yards and motor transport can generate dust, and partition using and timely soil reclamation of waste rock dumps to minimize dust's impact on the air; (iii) adopt cutting-edge gas recycling and treatment and reuse technologies and ensure workers' safety protection in the smelting and refining process; (iv) develop sound project management plans and emergency response plans, and adopt lifecycle management and pollutant control technologies; and (v) develop well-designed training mechanisms and responsibility matrixes and put them in place.

During PV project construction, site sprinkling with water several times a day can effectively control dust. Reduced vehicle travel speed can also make a difference. Dust can also come from building material stacking in open air and mixing operations. Minimizing such operations on windy days and reducing building material stacking in open air is an effective way to control such dust.

5.3Mitigation measures for reduced impact on land

CdTe LCA pollutant emission phase analysis shows that the phases including (1) mining of zinc, lead, and copper ores, (2) Cd and Te as byproducts of smelting/refining of zinc, lead, and copper, (3) purification of Cd and Te, (4) production of CdTe, (5) manufacture of CdTe PV modules, and, (6) disposal of end-of-life modules can all have environmental impacts on land use.

To improve land utilization and reduce CdTe solar cell projects' impact on land, it's advisable to take the following measures: (i) reduce land use in the mining phase and minimize underground mining; (ii) reduce land use in other phases.

Regarding the mining phase, the project's impact on land mainly includes temporary land occupation in the construction phase and permanent land occupation upon project completion. For land damaged due to temporary land occupation in the construction phase, it's advisable to backfill the mined-out area with waste rocks, cover with topsoil, and then make the land smooth and compact during the mine closure period. After mine closure, all on-site production and living facilities shall be removed. The temporary waste rock dumps shall be covered with soil and leveled for ecological restoration.

During PV project construction, for disturbed ground within the site, coverage by gravel and use of soil stabilizers can be adopted to protect disturbed bare ground and minimize soil erosion. To prevent new soil erosion as a result of wind erosion of temporary mounds and sand and gravel dumps, simple protection around such mounds can be enabled. Steel plates can be placed around the mounds for wind blocking and anti-dust nets used to cover temporary mounds within the site on windy days. The surface of such mounds can be sprinkled with water to prevent wind erosion. Excavation needs to be backfilled promptly and the amount of mounds minimized. Upon completion of construction, temporary buildings should be removed and construction waste should be transported for disposal in accordance with the sanitation authority.

5.4Mitigation measures for reduced impact on ecology

CdTe LCA pollutant emission phase analysis shows that of (1) mining of zinc, lead, and copper ores, (2) Cd and Te as byproducts of zinc, lead, and copper smelting/refining (3) purification of Cd and Te, (4) production of CdTe, (5) manufacture of CdTe PV modules, and, (6) disposal of end-of-life modules, (1) and (5) have a greater impact on the ecology.

In the mining phase, minimize temporary land occupation and damage to vegetation. In the reclamation phase, perform topsoil backfill in an orderly manner so that the precious surface humus on the plateau can be effectively preserved and utilized, increase the success rate of vegetation recycling, and strengthen the tending of reclaimed sites.

In the operation phase, (i) strictly prohibit treading on vegetation and soil and avoid human activities' adverse impact on vegetation and soil; (ii) increase workers' environmental awareness; and (iii) strictly prohibit hunting of wild animals.

The protection and restoration from the project's ecological impact shall be performed in the order of "avoidance→reduction→compensation" to minimize human activities' damage to natural resources and the ecological environment and thus meet the goal of "a balance between development and preservation".

6 Environmental supervision and management during production and project implementation

6.1 Environmental supervision and management during production

To ensure effective operation of the environmental management system during the project's production and operation process, it's necessary to develop environmental management programs, which shall cover:

(1) To put applicable national and local environmental guidelines, policies and laws and regulations in place, organize environmental education and technical training, improve employees' environmental awareness and technical levels, and enable increased responsibility for pollution control;

(2) To develop long-term environmental protection plans and annual pollution control plans and put them in place, regularly check the operational status of

environmental facilities and equipment maintenance and management, and strictly control emissions of waste water, waste gases and solid wastes;

(3) To stay informed of internal pollutant emissions status and develop internal environmental reports accordingly;

(4) To effectively balance and control environmental funds and make payment for excessive emissions;

(5) To assist line authorities in putting the policy of “environmental facilities must be designed, deployed and put into operation along with major works” in place, and participate in the validation and final acceptance of environmental programs;

(6) To organize environmental monitoring, check the company’s environmental status and report environmental monitoring information to line authorities in a timely manner;

(7) To investigate and handle internal pollution incidents and disputes, organize experiments and researches on waste treatment and use technologies, and develop classified and graded filing and handling systems of pollution incidents;

(8) To develop a companywide EMS (Environmental Management System) to enable compliance with ISO14000; and

(9) To develop cleaner production audit plans in light of the principle of “Prevention First” to achieve combined environmental and economic benefits.

Note that First Solar manufacturing and recycling facilities have obtained ISO9001, ISO14001 and OHSAS18001 certificates.

6.2 Environmental supervision and management during project implementation

Throughout project construction, local authorities of environmental protection, water conservancy, transportation and sanitation constitute the central part of environmental monitoring during project construction, while in a specific or sensitive process, banking, auditing, judiciary and media organizations are also an integral part of the monitoring system.

(1) The contract entered into between and by the project owner and contractor shall cover provisions of environmental protection during project construction, including ecological protection (water and soil conservation), environmental pollution control, pollutant emissions management, environmental education for construction workers and rewards and penalties thereof.

(2) The contractor shall increase environmental awareness, strengthen

environmental management of living quarters and construction sites, develop reasonable schedules, enable rigorous planning and civilized construction, put all environmental measures in place, implement and operate environmental facilities along with major works at the same time, earmark environmental funds, and avoid poor quality and delay.

(3) The contractor shall pay special attention to soil and water conservation during project construction, protect soil and vegetation along the project area as far as possible.

(4) For construction sites, living quarters and other temporary construction facilities, strengthen environmental management and avoid fugitive emissions of sewage from construction, which shall be transported to designated locations if possible. At sites with heavy dust, dust suppression measures shall be taken. Upon completion of project construction, the contractor shall clean up and restore construction sites in a timely manner and properly dispose of living waste and ballast from construction to reduce dust. Construction sites shall be in compliance with the *Emission standard of environment noise for boundary of construction site (GB12523-2011)*.

(5) Take compensatory measures seriously, conduct construction supervision and inspection of environmental facilities properly, guarantee the quality of environmental facilities, and put the policy of “environmental facilities must be designed, deployed and put into operation along with major works” in place.

7Consistency analysis of CdTe PV project

7.1 Consistency with existing policies and regulations

In the Encouraged Catalogue of Encouraged Foreign Investment Industries in The *Catalogue for the Guidance of Foreign Investment Industries (2007 Revision)*, (18) under 21 “Communications equipments, computers and other electronic equipments manufacturing” of III “Manufacturing” defines “Manufacture of hi-tech green batteries: nickel-hydrogen batteries, nickel-zinc batteries, silver zinc batteries, lithium-ion batteries, high-capacity wholly sealed maintenance-proof lead-acid batteries, solar cells, fuel cells and cylindrical zinc-air batteries. "

February 2013, the *Catalogue for the Guidance on Adjustment of Industrial Structure* (2011 Version) (Revised)

I Encouraged

5. New Energy (1) solar thermal power systems, solar photovoltaic power generation system integration technology development and application, inverter control system development and manufacturing

19. Light industry (18) various advanced solar photovoltaic cells and high purity crystalline silicon (conversion efficiency of monocrystalline silicon solar cells > 17%, polycrystalline silicon cells > 16%, silicon-based thin-film cells > 7%, CdTe cells > 9%, copper indium gallium selenide cell > 12%).

According to Liu Xiangxin (2013), the U.S. and EU both hold a positive attitude towards the CdTe PV industry, but have environmental regulation of cadmium compounds. The U.S. Brookhaven National Laboratory and Department of Energy have applied to list CdTe into the National Toxicology Program (NTP) as a subject of human long-term exposure research to collect objective data. The EU has restrictions on electronic products containing cadmium, requiring that the cadmium content in materials shall not be greater than 0.01% (i.e. 100 ppm) though PV has been excluded from the scope of the RoHS restriction.

The EU WEEE Directive, that came into effect in August 2005 and was recently revised, requests manufacturers of EEE products to ensure takeback and recycling of waste EEE products in scope. Photovoltaic panels are included in the scope of the recast WEEE Directive, requiring producers as of 2014 to fulfill the collection and recovery regulations in the 27 EU Member States.

Due to its low cost of manufacturing, relatively high efficiency and energy yield, and environmental attributes including successful recycling strategies, First Solar's CdTe solar panels have been widely recognized in major EU markets represented by Germany. The development of a third party based recycling mechanism has now become a regulatory prerequisite for all PVPV module manufacturers to access the market under the recast WEEE Directive (European Union, 2012, Directive 2012/19/EU).

In June 2010, the European Regulators excluded photovoltaic modules from the scope of the RoHS Directive, and separated the scope of RoHS from the scope of WEEE.Beginning in 2014, PV modules will be included in the scope of the EU WEEE Directive.(the deleted sentence is retained in the revised Chinese version.)

The EU's cadmium management policies are exemplary to other countries and regions and have led to the introduction of similar policies in China, South Korea, Japan and California. China, for example, has now exerted the same restrictions on cadmium containing products as RoHS in the EU by introducing the *Administrative Catalogue for the Control of Pollution Caused by Electronic Information Products*. Products containing hazardous elements will be included in the catalogue if alternatives thereto are already technically and financially feasible. Products in the catalogue are not allowed to enter the market until they are certified by China Compulsory Certification. Products not included in the catalogue or export and military products are not subject to the restrictions. The most recent Catalogue has not included photovoltaic products containing CdTe and CdS. But CdTe has already been listed in the *Catalogue* *of Toxic Chemicals Severely Restricted on the Import and Export in China (2012)*. Regarding its import and export, an application must be filed to the Ministry of Environmental Protection of the P.R.C.

Table 9 The *Catalogue of Toxic Chemicals Severely Restricted on the Import and Export in China (2012)*

S/N	Chemical	Alias	Customs Product Number	Unit
65	CdTe		2842902000	Kg

In summary, China encourages solar power and solar cells, but as in the EU and U.S. imposes restrictions on the use of the toxic heavy metal cadmium. It lists CdTe in the *Catalogue of Toxic Chemicals Severely Restricted on the Import and Export in China.*

7.2 Attainment of increased public awareness

In recent years, China has witnessed some environmental group events, from the maglev project in Shanghai to the PX project in Xiamen, and from the molybdenum-copper project in Shifang to the sewage discharge project in Qidong, featuring increasing participants, scope and impact. These events are all related to environmental protection, particularly EIA.

In these environmental group events, the public rely on reasonable and lawful approaches to protect their own interests and influence an individual project and even environmental decision-making at higher levels. The growing power of the public, as the principal part of the society and a bottom-up power compared to the government, on the one hand is a manifestation of social democracy and progress, and on the other hand is thought-provoking.

China has been valuing information disclosure and public participation. The release of *Regulation of the People's Republic of China on the Disclosure of Government Information* and *Measures for the Disclosure of Environmental Information (Trial)* in May 2008 was conducive to the public’s right to access environmental information, supervise and participate in. The *Interim Measures for Public Participation in the Environmental Impact Assessment* released in March 2006 announced public participation in EIA and defined the procedures, contents and ways of public participation. This is the first and the only of its kind in China to address public participation in administrative approval so far. The introduction of *Measures for the Disclosure of Environmental Information (Trial)* and *Interim Measures for Public Participation in the Environmental Impact Assessment* represents a major breakthrough in information disclosure and public participation in the field of administrative approval in China.

The introduction of public participation in EIA can help (i) guarantee the public's right to access environmental information, supervise and participate in, increase the public's environmental awareness, accelerate the tackling of environmental issues in China, and identify new ways to environmental protection; (ii) increase the public's part in environmental decision-making, promote democratic decision-making, reduce decision-making risks, and enable more scientific decision-making; and (iii) build a platform where the government and the public interact so that decision-makers can get access to public opinion in a timely manner, alleviate social conflicts and promote social harmony and progress.

EIA has been legalized in all developed countries and some Asian countries. Public participation is a part of it. For specific projects, Article 6 in *Interim Measures for Public Participation in the Environmental Impact Assessment* states that "for a project that requires public opinion, the environmental impact statement without public input shall not be accepted by the administrative department of environmental protection."

The introduction of public participation in a specific project can help properly guide the public and take the initiative. The early consideration of adverse impact on the environment and society is the key to successful implementation and operation of a project.

In the CdTe PV project as with large-scale construction projects in general, a variety of approaches including expert evaluation, seminars and media campaigns can be leveraged to help the public gain insights into the project's environmental impact and thus accept the project. The specifics are as follows:

(1) Organize expert argumentation to get scientific and fair conclusions;

(2) Disclose project information in an active and timely manner, e.g. perform two announcements as required in the EIA phase, and post annual environmental reports at the company website in the operation phase;

(3) Organize hearings or seminars to enable the public's access to project information and thus eliminate the public's concerns. Invite the public to visit the plant in the operation phase if necessary;

(4) Respond to the public's questions in a timely manner; and

(5) Collect inputs from the public in the phases of project proposal, feasibility study and EIA in light of the principles of openness and visibility.

7.3 Attainment of existing standards

Currently available standards in China that are related to cadmium emissions and acceptable concentration: *Integrated emission standard of air pollutants* (GB16297-1996), *Quality standard for ground water* (GB/T14848-93), *Environmental quality standards for surface water* (GB3838-2002), *Integrated* *wastewater discharge standard* (GB8978-1996), *Environmental quality standard for soils* (GB 15618-1995) and etc.

Table 10Aquatic environment standards by level

	Designation	I	II	III	IV	V
Quality standard for ground water(GB/T14848-93)	Cadmium (mg/L)	≤0.0001	≤0.001	≤0.01	≤0.01	>0.01
Environmental quality standards for surface water(GB3838-2002)	Cadmium (mg/L)	≤0.001	≤0.005	≤0.005	≤0.005	≤0.01
Integrated wastewater discharge standard(GB8978-1996)	Total cadmium (mg/L)	Maximum acceptable concentration≤0.1				

Table 11 *Integrated emission standard of air pollutants*

S/N	Pollutant	Maximum acceptable emission concentration (mg/m^3)	Maximum acceptable emission rate (kg/h)			Monitoring concentration threshold of fugitive emission	
			Emission pipe (m)	L2	L3	Monitoring point	Concentration (mg/m^3)
11	Cadmium and its compounds	0.85	15 20 30 40 50 60 70 80	0.050 0.090 0.29 0.50 0.77 1.1 1.5 2.1	0.080 0.13 0.44 0.77 1.2 1.7 2.3 3.2	Maximum concentration beyond border	0.040

Table 12 Environmental quality standard for soils

Level	L1	L2			L3
Soil pH	Natural background	<6.5	6.5-7.5	>7.5	>6.5
Cadmium (mg/kg) ≤	0.20	0.30	0.60	1.0	

In the U.S., there isn't a uniform water use classification standard available. When the nationwide water quality assessment is conducted, eight water uses are considered pursuant to Section 305(b) "Water Quality Assessment" of the federal *Clean Water Act*. There are four stream water uses. In the biennial nationwide river water quality assessment, the states evaluate stream segments for attainment of those uses and report to EPA for summary.

On the basis of stream water use attainment assessment, there are three other water quality indicators that can help further identify water impairment: major, moderate and minor stressors. The environmental standards for water in China and the U.S. are significantly different. The standards system in the U.S. is more flexible, which is in line with Chinese standards in general.

Malaysia has relatively strict environmental standards, setting the cadmium emissions limit to 0.02mg/L, compared to 0.1 mg/L in China.

Moreover, according to the *National Catalogue of Hazard Waste* (Order No. 1, 2008, of the Ministry of Environmental Protection (MEP) and the National Development and Reform Commission (NDRC)):

Article 4 Solid and liquid wastes that are not included in this Catalogue or the *Catalogue for Classification of Medical Wastes* and identified, according to the national standards and methods to identify hazardous wastes and by experts who are organized by the competent environmental protection department under the State Council, to possess hazardous properties and thus belong to hazardous waste shall be added to this Catalogue at a proper timing.

Article 5 The nature of the compound of hazardous waste and non-hazardous waste shall be determined in accordance with the national standard for identifying hazardous wastes.

There's no way to determine whether CdTe solar cell wastes are hazardous wastes based on FS data only. So it's advisable to conduct identification for extraction toxicity as soon as possible.

7.4 Suggestions

(1) To identify whether a CdTe solar panel is hazardous waste pursuant to the *Identification standards for hazardous wastes -- Identification for extraction toxicity* (GB 5085.3-2007) as soon as possible. If a CdTe solar panel is identified as hazardous waste, it can be recycled or disposed of pursuant to the *Standard on the Pollution Control in Landfill Hazardous Waste* (GB 18598-2001).

(2) To develop CdTe related emissions standards. Given that there aren't CdTe emission standards available in China yet and cadmium is a toxic heavy metal, it's necessary to introduce one as soon as possible to ensure the safety during its use and production. Note that in the absence of CdTe-specific emission standards, Cd standards have been conservatively applied.

(3) Given that First Solar has had a CdTe thin-film installed base up to 7Gw in

the US, EU and Japan and that the plants installed have been operating reliably, it is advisable for China to install a test CdTe thin-film PV system with moderate capacity at a secure and controllable site for runtime and environment impact assessment, to provide reliable inputs for decision-making.

(4) According to the *Twelfth Five-Year Plan for Environmental Protection*, China will conduct planned management of total emissions of the four major pollutants including COD, SO_2, NH_3-N and NO_X. So it's advisable to calculate the emissions of the above four conventional pollutants per m^2 solar panel as the pollutant emission indicator.

(5) Also, in the *Twelfth Five-Year Plan for Heavy Metal Pollution Integrated Control (2011)*, the control over total heavy metal emissions is introduced for the first time, and the five heavy metals including mercury, chromium, cadmium, lead and arsenic are defined as the key targets subject to monitoring and pollutant emission control. The Plan divides the country into two categories: priority areas, including 14 major provinces such as Inner Mongolia, Hunan, Guangxi and Qinghai and 138 key protection zones, and non-priority areas. So it's advisable to regard cadmium as a special pollutant and calculate cadmium emissions per m^2 solar panel. For the layout of the CdTe solar cell industry, it's necessary to take local conditions into consideration, keep in line with ecological function zoning, avoid the ecological red line, and select areas with potentials and high environmental capacity for the project site.

(6) To ensure workers' personal protection, set reasonable working hours and job rotation systems, and define reasonable safety distances.

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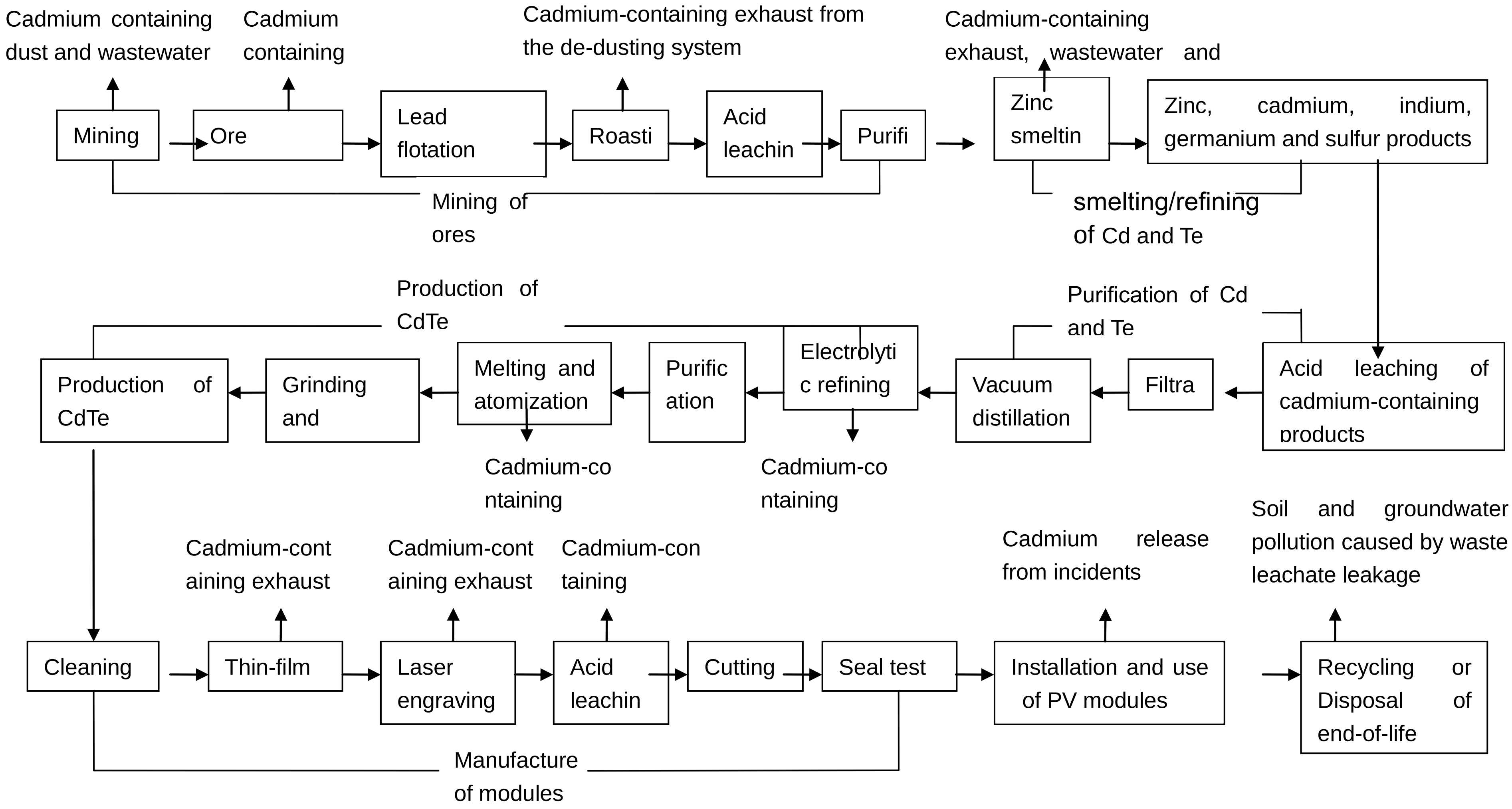

Appended drawing Analysis of cadmium emission processes in the lifecycle of CdTe PV