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## REVIEW OF LEACH TESTS

# Review and Comments on Reports by NGL: Environmental Risks Regarding the Use and Final Disposal of CdTe PV Modules and Leaching from CdTe PV Module Material - Results from Batch, Column and Availability Tests

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REPORT

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**Distribution:**

First Solar - 1 copy (pdf)  
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### Executive Summary

First Solar, Inc. ("First Solar") is one of the world's largest manufacturers of photovoltaic (PV) modules. First Solar modules use an advanced semiconductor material based on a compound of cadmium and tellurium ("CdTe") rather than silicon. First Solar requested Golder Associates (UK) ("Golder") to review reports prepared by NGI on the environmental risks and potential leaching of CdTe PV modules.

Based on Golder's assessment of the analytical data presented in the NGI reports, as supplement by First Solar, Golder concludes that First Solar CdTe PV modules would be classified as non-hazardous waste in the European Union should they enter the waste stream.

Leach testing is not required as part of the process for classifying waste as either hazardous or non-hazardous. If, however, waste is to be deposited in an inert or hazardous landfill, leach testing is necessary to demonstrate compliance with the relevant waste acceptance criteria. The results of leach testing reviewed as part of this project indicate that end-of-life PV modules would meet the requirements for disposal of stable non-reactive hazardous wastes disposed of in a non-hazardous waste site. In addition, First Solar operates a pre-funded take-back programme for end-of-life modules thereby minimizing the risk of disposal in a landfill or in an uncontrolled manner.

Golder considers that some of the conclusions drawn by NGI, especially those derived from the total availability testing (a very aggressive leach test undertaken on ground-up material with acidic conditions) are not relevant nor true. The only leach tests relevant to compliance with the Waste Acceptance Criteria (WAC) are the batch tests and the up-flow percolation test.



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### 1.0 INTRODUCTION

First Solar Inc (First Solar) has forwarded two reports to Golder Associates (UK) Ltd for review and comment. The reports, were commissioned by REC, SolarWorld, Wacker, and Photovolttech (crystalline silicon PV companies) to determine the environmental impacts and waste classification should a CdTe module enter a waste stream.

On the whole, Golder considers that NGI seems to have undertaken a detailed study and have examined EU waste classification, leach testing as well as performed a literature search for life cycle assessment and toxicity of cadmium (Cd) and tellurium (Te). The leach tests they have undertaken are a subset of those that can be used within the EU for assessing the sentencing of waste to a landfill. We believe, however, that NGI has misinterpreted some parts of the Landfill Directive.

### 2.0 THE FIRST REPORT (REFERENCE NO. 20092155-00-5-R)

Under the Landfill Directive, there are three classes of landfill; inert, non-hazardous and hazardous, and each has increasing engineering requirements reflecting the risks posed to the environment from the waste that each class can accept.

It was agreed by the committee dealing with developing the waste acceptance criteria that there should be WAC limit values for inert waste and for hazardous wastes. Non-hazardous wastes are not regulated by WAC limit values. However, there is a special case for a certain type of stable, non-reactive hazardous wastes (such as asbestos) where the extra engineering included in a hazardous waste landfill is not needed. In the case of this latter waste, it was agreed that if stable non-reactive wastes can be deposited in a non-hazardous waste landfill, they should be deposited in a separate cell, and that all wastes placed in this separate cell needed to meet a limit value for non-hazardous waste. Not that this limit value is not relevant for non-hazardous waste deposited in a non-hazardous landfill.

In Table 4 on Page 17 of the first NGI report (Environmental Risks Regard the Use and End-of-Life disposal of CdTe PV modules), they present limit values for three classes of landfill along with the results from a batch test at LS 10. Their landfill classes are Inert, Ordinary, and Hazardous waste landfills. As indicated above, limit values were not issued for "ordinary landfills", only inert and hazardous waste landfills and stable non-reactive hazardous waste cells. The Directive does allow Member States to set their own non-hazardous waste acceptance criteria and it is possible that the Norwegian Government has adopted these values for "ordinary waste" but such a system has not been implemented on a European wide scale. A foot note to the table says "hazardous wastes disposed of to ordinary landfill". Such a practice is not permitted in the EU and only stable non-reactive hazardous waste is permitted to be disposed of within a separate cell in an "ordinary" (we assume non-hazardous) landfill. Numerically the limit values in Table 4 concur to those published in the Directive for inert, stable non-reactive hazardous waste, and hazardous waste limit values.

It must be stated that the definition of a hazardous waste is not reliant upon a leach test. Rather, a waste that is classified as hazardous cannot be sentenced to landfill unless the leach test results are below the limit values for its specific class of hazardous waste. Nor does the leach test dictate whether a waste is stable non-reactive or otherwise. The classification of the waste lies apart from the results of leach testing. The picture is different with inert waste. Certain inert wastes can be sentenced to landfill disposal without the need for leach tests (typically very inert materials such as glass, bricks, uncontaminated stones, ceramics, etc). Other wastes would need to pass an inert landfill leach test limit value in order to be accepted at an inert landfill.

The batch leach test results obtained by NGI from testing the PV modules passed the leaching limit value for wastes disposed of to a non-hazardous landfill accepting stable non-reactive hazardous wastes. This means that the leaching capacity of the PV modules is at the lower end of the risk spectrum. The limit values were selected to ensure that wastes sentenced to a Landfill Directive compliant landfill (presumably all landfills within the EU) will not cause environmental damage.



We have determined that the PV module is not classified as a hazardous waste under the EU Hazardous Waste Directive, and so the leaching tests have no relevance to the disposal of PV modules to a non-hazardous waste landfill. We note, however, that First Solar operates a pre-funded take-back service for end-of-life modules, to encourage recycling of the modules. As such, the disposal of First Solar CdTe modules to landfills, even though legally permissible, is expected to be minimal as this service is offered at no cost to the module owner.

On Page 17 of the Report, NGI claims that leaching of Cd would be higher if more acidic conditions were applied to the test method. It is a generally recognised fact (confirmed later in their own report on Page 21) that most landfills remain at a neutral to slightly alkaline pH for most of their lifecycle (that is during the methanogenic phase). The short acetogenic phase, where the pH may fall to pH 5, lasts only a matter of weeks or months, whereas the methanogenic phase will likely last for centuries. During this methanogenic phase, metal ions will readily be rendered immobile by the formation of metal sulphides (a fact acknowledged by NGI). Low concentrations of Cd are observed to be present in leachate in most landfills, but often less than 1 µg/l. While it is also acknowledged that ultimately there will be an air intrusion phase, we are not aware of any modern landfill entering such a phase as yet, and it will be many decades if not centuries before we are able to observe first hand whether Cd sulphides do indeed oxidise and remobilise.

We note that in addition to leach tests NGI have undertaken total availability tests. Such tests are rarely conducted in isolation and usually requested as part of a suite of tests that would include pH dependence tests for waste characterisation, rather than compliance. The aim of undertaking such detailed testing would be to gain an understanding of the behaviour of a waste across the full spectrum of pH conditions so that in addition to landfill disposal options, other treatment options can be evaluated as means of treating the waste to reduce the mobility of contaminants. Certain leachate modelling packages (such as LeachXS) also require pH dependence testing to fully characterise certain wastes. The results they obtained from this testing is discussed later in this letter when we address comments on their second report.

On Page 22 of their first report, NGI summarise their concerns relating to landfill disposal of PV modules.

Firstly, NGI is concerned regarding seepage to groundwater via leakage through the landfill side or base. While they consider the risk to be small, they go on to say that such a discharge could lead to uncontrolled pollution of soil and groundwater. We find this difficult to envisage as typical leachate concentrations of Cd in Norway (in common with the rest of the EU) are often below 1 µg/l and the drinking water standard for Cd is 5 µg/l. Furthermore the leach tests that they have conducted showed that the amount of Cd leaching was well below the threshold for stable non-reactive hazardous waste that could, legally, be disposed of to a non-hazardous landfill, and hence already at a level that is protective of the environment. We are not aware of any naturally occurring processes that can result in the concentration of Cd flowing within groundwater to be concentrated. Processes such as dilution, advection, dispersion, and partitioning all lead to lower concentrations.

We are in agreement with the next two points in their summary, namely that landfilling of modules will pose negligible risk to living organisms and that the redox conditions within the landfill will favour the creation of insoluble sulphides, thus limiting migration further.

In the last part of their summary they state that despite the results of the leach testing that showed that the waste would have met the limit for Ordinary Landfills (or more correctly for stable non-reactive hazardous wastes), that "*Out of diligence, it is desirable to reduce the supply of toxic compounds such as cadmium and tellurium to ordinary landfills, particularly if they are prone to leaching*". Firstly, the EU has set a limit value that is greater than zero, so a complete ban is not considered in the Landfill Directive. Secondly, NGI having determined that the leaching rate is low (as Cd met the limit values for "ordinary waste") now seem to suggest that the modules are prone to leaching. If we examine the column test results in the second report, it is quite clear that, CdTe PV modules are not prone to leaching. Thirdly, as previous mentioned, First Solar has a take-back and recycling program for end-of-life modules to encourage the recovery of valuable raw material and to minimize the number of modules disposed of as waste.

NGI's consideration of uncontrolled disposal warrants some commentary. Firstly, it would be illegal to dispose of a waste in an uncontrolled manner within the EU, and it is difficult to envisage such an action



going unnoticed within the highly regulated EU. Secondly, the disposal of CdTe modules in an unauthorised manner would represent a very minor environmental risk given the low leaching capacity of the CdTe modules. As NGI state, Cd is readily sorbed onto soil particles (clays, silts and ferrous complexes) which means that they are significantly less mobile in the environment and the concentrations entering groundwater or surface water are reduced markedly.

In summary of their Risk Report (reference no 20092155-00-5-R), the leaching tests of CdTe modules that were undertaken are irrelevant as the material is not classified as either an inert waste or as a hazardous waste. Only those wastes require leach testing prior to landfill disposal to ensure that they meet the limit values for the class of landfill that the wastes will be disposed of at. Non-hazardous wastes do not need to be leach tested unless they are being disposed of in the same cell as stable non-reactive hazardous wastes. Non-hazardous wastes cannot be disposed of to an inert site.

The fact that in the batch tests the samples tested met the criteria in relation to “ordinary landfill” (a criteria that in the EU Decision Document that is applied to stable non-reactive hazardous waste) means that the leaching profile or emissions profile of the CdTe modules meets the requirements for landfilling of hazardous waste to a non-hazardous waste site. The leach test limit values were specifically set at levels that are protective to human health and the environment based on assumptions that the landfill at which the disposal is taking place meets the EU Landfill Directive minimum engineering standards (and all EU landfills need to do this). In other words, the Cd emissions from the modules are at such low levels there will be no discernable impact upon the environment from their proper disposal. All of this assumes that the pre-funded take-back program offered by First Solar is not utilised by the disposer.

### 3.0 THE SECOND REPORT (REFERENCE NO. 20092155-00-6-R)

The second report (Leaching from CdTe PV module material – results from batch, column and availability tests Reference No. 20092155-00-6-R), contains details of the tests undertaken and the results obtained.

The batch leach test results were reported in the first report (ref. 20092155-00-5-R), while the results of the column and total availability tests are set out in this second report along with a commentary by NGI on the results.

The batch test results have already been discussed in this report and are not repeated here. At the top of Page 12 the report states that there are no limit leach concentration values for LS 10. This is true, only the cumulative leaching value at LS 10 is used, and not the concentration of the eluate at that LS ratio. At the other end of the timescale of the test the Co value (concentration of the first collected sample) is taken at LS 0.1. LS 0.1 values are used as an alternative<sup>1</sup> to total leached values to regulate hazardous waste and inert wastes destined for landfill and are a representation of the leaching values that are related to the most readily leachable components. (It should be noted however, that batch tests cannot produce a Co value and it is far more common to regulate solely on the basis of the LS 10 value obtained from a batch test and not the Co value obtained from the column test.)

The results at LS 0.1 (i.e. Co) show Cd concentration at less than detect, and NGI rightly concludes that the Cd is not readily leachable. Molybdenum was present at a Co value that exceeded both inert and stable non-reactive hazardous waste limits (but as the modules are not hazardous wastes the leaching values are of academic interest only).

On Page 13 the results of L/S 10 cumulative leach values are presented along with eluate concentration for Cd and Te, and here NGI concludes that even at LS 10 the concentration of Cd in the eluate remains low. Concentrations of Te are higher, but none of the limit values for any class waste to any class of landfill within the regulation contain reference to Te.

The total availability leach test (starting on Page 14) is an aggressive leaching test that is not used to derive limit values; rather it is used to place into context the results of other leach tests and specifically pH

<sup>1</sup> The EU Decision Document 2003/33



dependency test. In other words, it is used for waste characterisation, but not for compliance testing. In this test method the PV will have been ground up to around 0.125 mm particles. Such physical damage to a PV module within a landfill is not conceivable. Furthermore, within a landfill environment, the low pH conditions mimicked in this test would not exist. As such the test fails to provide any information that would be useful in defining an appropriate disposal method. NGI draws the conclusion on the total Cd that has been leached (even at neutral pH) from this ground up material is greater than that permitted for hazardous waste. This is not true. The test methods used to define acceptable leaching of hazardous waste within landfills are the batch leach test and the column or up-flow percolation test – both of which they have undertaken and both of which showed that if a CdTe module was classed as hazardous waste (which it is not) they would have passed their respective leach tests.

The total availability test is not an appropriate test to determine whether any waste can be sentenced to any class of landfill, and therefore drawing these conclusions is neither accurate nor professional.

## 4.0 CONCLUSIONS

Golder has undertaken a review of two reports prepared by NGI relating to the environmental risks regarding the disposal of CdTe modules and leach tests that NGI have commissioned on CdTe PV modules.

The leach tests that are used within the EU for WAC testing (the batch test and the up-flow percolation test) show that the leaching potential of the modules is small and that the modules, while not acceptable for disposal in an inert landfill, would be acceptable in other classes of landfill. However, it should be stressed that as the CdTe modules are not classified as hazardous waste, there is no need to undertake WAC leaching tests for the disposal of these modules at a non-hazardous landfill. Indeed, given that the WAC limit values have been specified at levels that are protective of the environment, the disposal of modules to non-hazardous landfill represents an environmentally acceptable method of disposal. That said, First Solar operate a pre-funded take-back programme for end-of-life modules and so the landfilling of these modules should be a rare event.

Tests undertaken by NGI relating to the total availability of metals is not a test used for compliance for the Landfill Directive; rather it is a test used to characterise waste. Results from these aggressive leach tests should not be compared to the limit values from the batch or column tests that have been specified as the appropriate test methods for WAC testing.



## Report Signature Page

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