



Rapport / Report

Environmental risks regarding the use and end-of-life disposal of CdTe PV modules

20092155-00-5-R
16 April 2010

This report is a translation of NGI report no. 20092155-00-1-R, dated 17 February 2010: "*Miljørisiko i forbindelse med CdTe PV moduler, forhold ved bruk og sluttdisponering*" (in Norwegian)

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Project

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Summary

The Norwegian Geotechnical Institute (NGI) has conducted a literature study on emissions and environmental effects of cadmium telluride (CdTe) PV modules, in relation to use, final disposal and uncontrolled dumping. In addition, a leaching test on CdTe PV module materials was conducted in accordance with European directives as they are implemented in Norwegian requirements..

A review of available literature shows that there is very little data on CdTe's biogeochemical properties and on how this compound behaves in the environment. Available Life Cycle Analyses (LCAs) concluded or assumed that emissions of cadmium and tellurium caused by the use of CdTe PV modules will be close to zero, as the layer of CdTe is believed to be well protected by the glass encapsulating the modules. Regarding emissions in connection to end-use of the modules, recycling of the modules is assumed in the available LCA studies. However, any emission levels based on data associated with recycling or disposal are not included in the studies, and are commonly assumed to be negligible.

There is also very little data in the available literature on human toxicity of CdTe. In several studies, it is hypothesized that the toxicity of CdTe does not exceed the elemental components (Cd, Te). Some studies further indicate that acute toxicity of CdTe appears to be substantially lower than the elemental components. No studies on ecotoxicity could be found in the literature.

Results from the leaching test (batch test) conducted by the NGI indicated that leaching of tellurium and cadmium from crushed CdTe PV module materials does occur. Leaching of tellurium is significantly higher compared with cadmium, which is likely attributable to the relatively high pH of the leachate (pH 9.6). This pH is favorable to Te dissolution, due to the formation of soluble tellurium oxyanions. CdTe dissolves in the leachate, but much of the dissolved Cd is retained in the solid material as a result of re-precipitation into different compounds as well as sorption. The leaching exceeds the leaching limits for disposal at a landfill for inert waste, but lies within the limits for an ordinary landfill. Leaching test at lower and a more environmental relevant pH (<8) is expected to provide an increased leaching of cadmium, and at levels that likely exceed the limit for ordinary landfills.

Current landfills have strict requirements for bottom/side sealing and collection of landfill leachate. Thus the risk of uncontrolled spreading of Cd and Te contamination in connection with disposal of CdTe-modules at approved landfills is considered to be low. However, at high loadings, elevated concentrations may appear in the leachate water. Uncontrolled dumping of CdTe-modules will result in substantially greater environmental risks compared with disposal in approved landfill sites. In addition to the risk of direct exposure, cadmium and tellurium components will be mobilized to a greater extent, where they can spread directly to soil, water and groundwater with potential exposure to living organisms outside the dumping area. Conditions in uncontrolled deposition sites that will increase CdTe weathering and mobilization include exposure to air, precipitation, and exposure to low pH in the case of Cd.

Summary (cont.)



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Based on the obtained literature, publicly available documentation is considered to be insufficient for an assessment of environmental risks in connection with the use and final disposal of CdTe PV modules. This applies primarily to the documentation on the geochemical behavior and toxicity of the compounds CdTe and tellurium. As a first approach we recommend laboratory tests for better documentation of the geochemical behavior, such as leaching of CdTe-modul material at lower pH (<8).

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Appendix A: Laboratory report from batch test on CdTe PV module material

Review- and reference page

This report is a translation of NGI report No 20092155-00-1-R, dated 17 February 2010; “*Miljørisiko i forbindelse med CdTe PV moduler, forhold ved bruk og sluttdisponering*” (in Norwegian).

1 Introduction

The Norwegian Geotechnical Institute (NGI) has conducted a literature study on the environmental risks associated with thin layer cadmium telluride (CdTe) photovoltaic (PV) modules.

This work was financed by REC, SolarWorld, Wacker, and Photovoltech after the European recycling association PVCYCLE in 2009 proposed a joint and several liabilities scheme implying that the manufacturers of crystalline silicon solar modules should also take on responsibilities for waste management of PV modules containing cadmium. The same companies have also initiated a leaching study on c-Si modules as a follow-up.

The objective of the study is to assess available documentation on emissions and environmental effects of CdTe, in relation to use, the final disposal and uncontrolled dumping.

The work has consisted of a literature search and review of both peer review articles and information on the Internet. The following search engines have mainly been used:

- ISI Web of Knowledge
- Scirus
- Google

NGI considered all identified studies of relevance, but it cannot be ruled out that other publications or other sources of information exist, which may contain additional information, that NGI was not aware of during preparation of this study.

The report also includes results from a leaching test (batch test) performed on a new thin-layer CdTe PV module. Column tests on the same materials are ongoing. These results will be reported separately.

Any opinions, findings, conclusions or recommendations expressed in this report are those arrived at by NGI after considering the available information and do not necessarily reflect the views of the acknowledged companies. The use of the results from this study is done at the user's own risk.

2 Relevant Norwegian and European laws and regulations

An overview of directives and regulations that are relevant for the use of CdTe PV modules in Norway and the European Community are as follows:

RoHS Directive

The Restriction of Hazardous Substances (RoHS) Directive (2002/95/EC) prohibits the use of cadmium, mercury and other hazardous substances in new electric and electronic products. For cadmium, the maximum concentration in materials is set to 0.01% based on weight. Exemptions from the Directive (Art. 5(1) (b)) are possible for certain applications if the removal of hazardous substances is not technically feasible, or if the negative environmental, health and / or consumer safety impacts of removal outweigh the benefits of the product. The objectives of the RoHS directive are very closely linked to the WEEE (Waste from Electrical and Electronic Equipment) directive.

Currently, it is uncertain whether solar modules containing cadmium will acquire a permanent exemption from this directive.

The RoHS Directive is implemented in Norwegian legislation through the directive on product regulations (*Forskrift om begrensning i bruk av helse- og miljøfarlige kjemikalier og andre produkter*, trans. “Regulation on the restriction of the use of health and environmentally hazardous chemicals and other products”).

WEEE Directive

The Waste from Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) aims to reduce the use of resources, increase the reuse and recycling of electronic goods, and to ensure an environmentally safe, final disposal of electrical and electronic waste. The WEEE directive requires that manufacturers of these types of products must finance a system for collecting, processing, recycling and final disposal. Waste from CdTe PV modules fall under this directive. The WEEE directive is implemented in the Norwegian legislation through the Waste Regulations, Chapter 1 “*Kasserte elektriske og elektroniske produkter*” (trans. “Discarded electrical and electronic products”).

Norwegian Waste regulation (Avfallsforskriften), Chapter 11 regarding hazardous waste

The purpose of Chapter 11 of the Norwegian Waste Regulations (*Avfallsforskriften*) is to ensure that hazardous wastes will be handled in a manner that does not create pollution or harm to humans or animals or pose any risk in this regard, and to contribute to appropriate and acceptable systems for the handling of hazardous waste. Hazardous wastes that these regulations apply to include those in the European Waste List (EWL) along with some additional Norwegian adjustments (given in Annex 1 to Chapter 11 of the *Avfallsforskriften*), and also to other waste where the content of hazardous substances exceeds specified limits (given in Annex 3 to Chapter 11 of the *Avfallsforskriften*).

CdTe waste from solar cell industry is not listed as hazardous waste in the EWL. The lowest limit for hazardous substances in Annex 3 is 0.1%. For some

compounds such as cadmium-fluoride and cadmium-chloride, there are specific limits of 0.01%.

Currently it is not clear whether CdTe PV-containing waste will be classified as hazardous waste. The layer of semiconductor material itself contains approximately 50% cadmium and may therefore be classified as hazardous waste. If the whole CdTe PV module is defined as a homogeneous waste unit (total 12 kg) with a cadmium amount of 4.6 g per module (see also Chapter 3.1), the percentage of Cd is about 0.04%, and will thus be lower than the limit for hazardous waste of 0.1%.

Norwegian Waste regulation (Avfallsforskriften), Chapter 9 regarding waste disposal.

Chapter 9 of the Norwegian Waste Regulation (*Avfallsforskriften*, formerly *Deponiforskriften*) is an implementation of the EU landfill directive (EU Council Directive 1999/31/EF about disposal of waste). The purpose of this chapter is to ensure that disposal of waste takes place in a responsible and controlled manner so that adverse effects on the environment and human health will be prevented or reduced as far as possible. In accordance with the Regulations there are three different categories of landfills:

- 1) Landfills for hazardous waste
- 2) Landfills for ordinary waste
- 3) Landfills for inert waste.

Each landfill category has different quality standard requirements regarding bottom and side sealing, with the strictest requirements for landfills of hazardous waste. Annex II of Chapter 9 specifies leaching limits for waste to be deposited at the different landfill categories. Leaching threshold values exist for cadmium, though not for tellurium.

3 Photovoltaic modules based on thin film CdTe

3.1 Module description

The CdTe PV module consists of a thin stack of a transparent conductive oxide (TCO) (about 1 μm), a very thin layer of cadmium sulphide (CdS) (50 nm), and a layer of CdTe (about 2 μm), placed on a 3 mm thick glass substrate. The rear side contact is formed by a metal layer (e.g. copper). The stack is encapsulated with the polymer ethyl vinyl acetate and another glass layer. Sunlight passes through the TCO and CdS layers, and into the CdTe layer in which it generates electricity. This electricity is then transferred by electrical contacts from the TCO-and copper layers. A schematic cross section of a hypothetical CdTe thin film layer PV module is shown in Fig. 1.

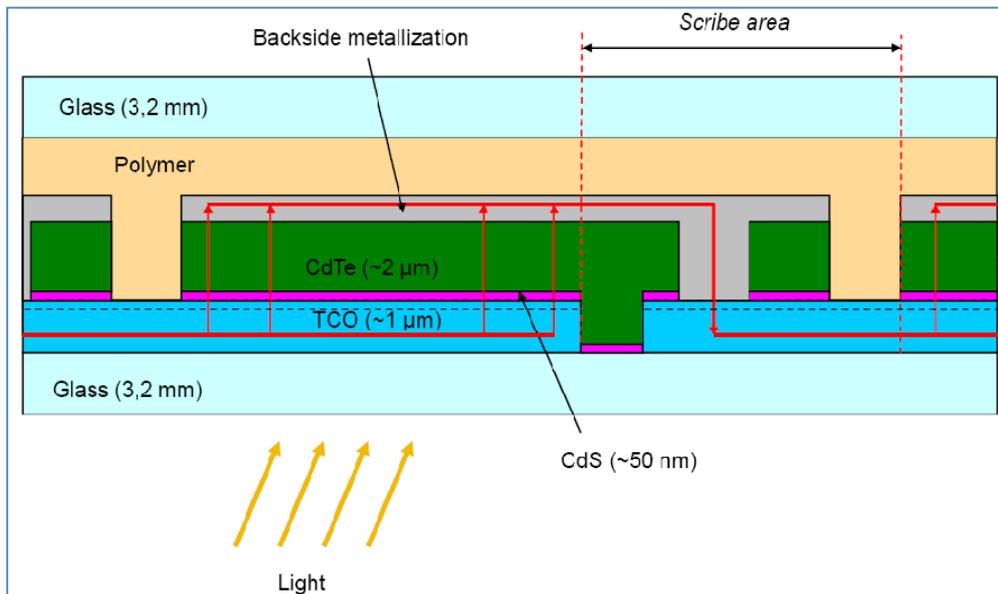


Figure 1 Cross section of a thin film CdTe PV module.

The size of the module is normally 0.72 m² (1.20 m × 0.60 m) with a weight of 12 kg. The total thickness is 6.8 mm. The amount of cadmium per module is about 4.6 g, i.e. 6.4 g per m². A typical solar park at 1 MW nominal power contains approximately 60 kg cadmium.

3.2 Cadmium telluride (CdTe)

Environmental risks associated with use and disposal of CdTe PV modules will be largely related to the contents of cadmium telluride (CdTe). CdTe is a black crystalline powder that does not occur naturally in the environment. The compound is inflammable and exhibits low water solubility. CdTe will be degraded under the influence of atmospheric moisture due to the generation of volatile hydrogen telluride (H₂Te), which is a toxic and a water soluble gas. Under dry conditions, CdTe reacts with atmospheric oxygen to form oxides of Cd and Te (Harris 1994, Angstrom Sciences, Material Safety Data Sheet Safety Data Sheets).

The cadmium raw material is typically produced as a by-product of zinc (Zn) production. Tellurium raw material is typically generated as a by-product of copper (Cu) production (Fthenakis, 2004).

3.3 Future production volumes of CdTe-modules

The total production volume of CdTe modules in 2009 is estimated to approximately comprise of 65 tons of cadmium. This estimated amount is based on information available from First Solar (which was the leading producer of

CdTe modules in 2009), where they report a production volume of 1.1 GW_p, a panel efficiency of 11% and a CdTe layer of 2.2 μm thickness^{1,2}.

The European Photovoltaic Industry Association (EPIA) has presented three scenarios for the total contribution of solar energy to the European electricity supply for the year 2020 in the document "Set for 2020". Table 1 shows projected overall amounts of cadmium that can be present in the European solar power plant based on EPIA's different scenarios ("baseline", "accelerated growth", "paradigm shift") together with various, projected market share scenarios for CdTe technology. It is estimated in this table that by the year 2020 installed panels will have an efficiency of 14% on average, and that the thickness of the CdTe layer will be reduced to 1.0 μm.

Table 1 Projected amount of cadmium (in tons) in European solar power plants in 2020 for three various EPIA-scenarios.

EPIA scenario	Market share for CdTe-technology		
	10 %	20 %	40 %
Baseline (130 GW _p)	230	461	922
Accelerated growth (195 GW _p)	346	691	1383
Paradigm shift (390 GW _p)	691	1383	2766

Projections shown in Table 1 indicate that already by the year 2020 there will be a substantial increases in the amount of cadmium present in solar cells (at least a five-fold increase for the most base-line, smallest market share scenario), and that this amount is largely dependent on the future market direction for CdTe technology. This predicts that future demands will require a large scale strategy for dealing with end-of-life treatment for CdTe PV modules, either via recycling or disposal.

3.4 Recycling of CdTe modules

The estimated lifetime for CdTe modules is 25-30 years. As of today, there has been little waste generated from this type of PV system, and thus there is currently little practical experience with the recycling of this type of waste. (Held 2009, Fthenakis 2004).

Held (2009) and Rauegi (2009a) describe a potential method for the recycling of CdTe PV modules which include:

1. Crushing to a size of 4.5 mm.
2. Extraction with sulfuric acid (H₂SO₄) to remove the semiconductor film. Subsequent addition of hydrogen peroxide (H₂O₂) to form the Te tellurium-acid.

¹ W_p is a unit of solar panel capacity. 1 W_p installed capacity gives 1 W electrical power under Standard Test Conditions (STC).

² Efficiency, as indicated in%, is the relationship between light irradiance (W / m²) and generated electric power per surface area of module (W / m²) at STC.

3. Separation of solid and aqueous phase (spiral classification).
4. Separation of glass and laminate foil (solid phase). Glass is recycled and the laminate-waste is incinerated.
5. Precipitation of metals (aqueous phase) by addition of NaOH (pH increase). Precipitated sludge undergoes thickening and filtering. It is reported that around 95% of semiconductor material (Cd, Te) in the filter cake is recovered by this process. There are, however, no documented data for this process.

Fthenakis et al. (2006) tested a method for recovery of cadmium and tellurium in the lab based on the same principle by leaching with H_2SO_4 and H_2O_2 , followed by cation-exchange separation of Cd from Te. This achieved a high recycling efficiency for Cd and Te, and demonstrated that it is technically possible to effectively recycle both Cd and Te from the modules. It is unknown whether this type of recycling has been attempted done on an industrial scale.

Currently the module manufacturer First Solar has established a recycling program for used CdTe modules, where registered users can return the modules for recycling for free (Raugei, 2009a).

4 Life cycle analyses of CdTe PV

There are several Life Cycle Analyses (LCA) on CdTe PV module products (e.g. Held 2008; Fthenakis et al 2008; Fthenakis 2004, Ito 2008, Sinha et al 2008). The LCA work has mainly focused on possible emissions and impacts from cadmium throughout the product life cycle.

An LCA conducted by Fthenakis (2004) at Brookhaven National Laboratory (BNL), USA, gives a comprehensive description of emissions associated with the production of the raw materials Cd and Te. The starting point for these emissions is from the concentrates extracted from zinc and copper refining, respectively, and emissions continue throughout the production of the CdTe PV modules. Based on data from their own experiments and data from Steinberger (1998) (see also chapter 5.1), Fthenakis concludes that emissions during use of the modules are negligible. The study also assumed that the used CdTe material will either be recycled or disposed of in an environmentally acceptable manner, and end-of-life emissions are therefore set to zero.

In a later LCA conducted by the same research institution (Fthenakis and Kim 2007; Fthenakis 2008), CdTe PV modules are compared to different types of silicon-based PV modules. The study gives no additional information about the emission of CdTe during use or final disposal. The study from 2008 includes the effect categories such as emissions of greenhouse gases and heavy metals (to air). Emissions associated with recycling and final disposal of PV modules are, again, set to zero (Fthenakis 2008, Supporting Information).

Raugei et al. (2007) conducted an LCA with comparison of CdTe and copper-indium-diselenide (CIS) with polysilicon PV modules. Effect categories included in the study are energy, energy payback time, the emission of greenhouse gases, acidification, and aquatic ecotoxicity potential. For emissions regarding use, the study refers to Fthenakis (2004) and Fthenakis etc. (2005). The study does not include emissions associated with recycling or final disposal of CdTe PV modules.

In an LCA study conducted by Held et al. (2008) effect categories such as acidification, eutrophication, global warming, photo-chemical oxidation and the use of fossil fuels are taken into account, while toxicity aspects are not taken into account. This was rationalized on the basis that there was no generally accepted characterization method for this effect category at the time of the analysis.

Several LCA studies assume that the discharge during normal use of CdTe PV modules will be zero. This is because the thin layer of CdTe and CdS are enclosed in a very strong glass with little risk of human exposure or transport into the environment. If the modules are destroyed during use and are exposed to rain, emissions can occur; however, a very low vapour pressure and water solubility are expected to result in only trace emissions into the environment (Fthenakis 2008; Sinha et al 2008; Raugei 2008).

After end of lifetime for CdTe PV products, several LCA studies expect that the obligation for manufacturers to collect the used products and a functioning recycling system minimizes the need for landfill disposal and the risk of unwanted spreading of pollution (e.g. Sinha et al 2008; Raugei 2008). However, because of the establishment of recycling facilities for CdTe PV modules on an industrial scale were not put in place prior to these studies, and because there are little data on emissions and assessment of environmental consequences associated with the recycling or disposal process, these assumptions need to be treated as currently hypothetical.

Raugei (2009) conducted the first detailed LCA that accounted for the "end-of-life" stage of CdTe PV modules. The study was conducted based on a recycling process that had been tested on a full scale, in which emissions of Cd to air and water per kg of Cd content were calculated. The study included only estimates of the quantity of emissions and compared it with Cd emissions in connection with NiCd batteries. Raugei (2008) has also conducted an analysis of future use and emissions of Cd associated with CdTe PV modules. These analyses concluded that in 2050, one-third of Cd use worldwide will be linked to the PV industry, while emissions will be marginal. Thus, it was assumed that nearly all material will be recycled or taken care of in a manner that does not cause emissions.

Held (2009) conducted an LCA to evaluate the environmental consequences of the recycling of CdTe modules based on the recycling process described in Section 3.3. The study included effect categories such as acidification, eutrophication,

greenhouse gas emissions and photo-chemical oxidation and the use of fossil fuels. The study did not include emissions of metals.

Based on review of available literature on life cycle analysis that includes CdTe, the following summary can be made:

- The documentation on discharge of cadmium and tellurium in connection with the extraction of raw materials and production of modules seems to be satisfactory
- LCAs include emissions associated with the use of CdTe modules, though most studies assume this to be zero due to the protection of the thin film by encasing glass. However, documentation regarding emissions during use is very limited.
- Most LCA studies assume that the material will be recycled. Emissions associated with recycling are covered only to a limited degree.
- Emissions associated with the final disposal (landfill, dumping) are not included in the analysis.
- The effect category “Toxicity” seems largely to be left out due to lack of documentation

5 Emissions and mobility of CdTe

5.1 Literature

To assess the behavior and potential environmental risk of CdTe in the environment, documentation regarding mobility and possible emission potential is necessary. In this section studies related to emissions and mobility of CdTe are summarized. Essentially, the available literature is comprised of leaching studies and emissions that occur upon exposure to fire.

Baumann et al. (1995) describes standard leaching tests (leaching tests related to the EU landfill directive and the US toxic characteristic leaching procedure, TCLP), which were conducted by the energy company BP on their Apollo modules (CdTe PV modules). The results for cadmium in these tests show concentrations of 0.022 ± 0.03 mg/l and 0.22 ± 0.11 mg/l respectively for the EU-test and TCLP test. The values are below the respective benchmark limits of 0.1 mg/l and 1.0 mg/l.

Thumm et al (in Moskowitz, 1994) refers to leaching studies (4 different standardized tests, 24 h shaking) conducted on fragments of solar panels based on copper-indium-diselenid (CIS) and CdTe. A landfill situation was simulated using acidified water or supply of complexing agents. Zinc, molybdenum and selenium are reported to give the highest leaching from the solar modules. Zinc exhibits the highest leaching at low pH, and is present in high concentrations with complexing agents. Molybdenum and selenium, which were present in the leachate as

oxyanions, exhibited the highest leaching at the highest pH tested. No results for cadmium and tellurium are given in this study.

Steinberger (1998) conducted outdoor leaching experiments on samples from various types of PV modules (CdTe, CIS) at the Fraunhofer-Institut für Festkörpertechnologie, Munich. As a "worst case" scenario, sub-samples were crushed to fragments (approx. 10 mm). Additional, leaching studies on intact modules located outdoors were conducted. The results for the CdTe modules are shown in Table 2. For comparison, the German drinking water standards are shown in column 4.

Table 2 Results from leaching tests on CdTe PV modules (from Steinberger 1998)

	Concentration in eluates from fragmented PV module (CdTe)	Concentration in eluates from roofs with PV modules (CdTe)*	German drinking water standards (1998)
Cd (µg/l)	1000	5	5
Te (µg/l)	300	1.5	-
Ni (µg/l)	100	5	50

* calculated based on the total PV roof area of 100 m² and damaged roof area of 0.5 m².

The results of the leaching tests results in Table 2 can be summarized as indicating low health and environmental risk, even for the "worst-case" scenario.

The test design in Steinberger (1998) can be looked upon as a large-scale column test. If the cadmium concentration from the leaching test on fragmented module (1000 µg / l) is compared with the current leaching limits for waste (column test, C₀), the Cd concentration in the eluate exceeds the limit for disposal at ordinary waste sites, though not for hazardous waste sites. If the concentration of cadmium in eluate from the roof with PV modules is compared with Norwegian fresh water quality standards, it would fall under the most polluted category, Class V (very strongly polluted; Cd > 0.4 µg/l) (SFT, 1997) Thus the conclusions reached for this 1998 study (low risk for human health and the environment), are not in agreement with current Norwegian regulation and concentration benchmarks.

Further studies on leaching (emissions) from CdTe PV modules to water or soil were not found in literature.

Fthenakis et al. (2005) performed standardized tests on emissions CdTe PV modules that were exposed to fire. The modules were exposed to temperatures of between 760 and 1100 ° C for periods between 30 minutes and 3 hours. Emissions of cadmium were estimated to be only 0.04 to 0.06% of the Cd-content of the module, the rest was encapsulated in the molten glass matrix. Emissions of tellurium was also low at temperatures up to 900 ° C, but increased significantly at temperatures up to 1100 ° C (22.5%). The conclusion of the study is that the

emissions associated with fires, with temperatures typical of residential fires (750 to 900 ° C), is negligible (Fthenakis, 2005). It should be noted that the combustion chamber of a waste incinerator the temperature can rise to approx. 1100 ° C (Chandler et al, 1997).

5.2 Leaching tests conducted at NGI

5.2.1 Material and method

A one-step batch test was conducted on a new CdTe PV module in accordance with the requirements of the Norwegian waste regulations, Annex II (MD, 2004). The module was provided from REC and sent to Analytical Chemical & Testing Services (ALS) for crushing to a size < 4 mm. The batch test was carried out by NGI.

The test is conducted according to EN (Norwegian Standard - European Norm) 12457 "Characterization of waste – Leaching - Compliance test for leaching of granular waste materials and sludges". The sample material is shaken for 24 hours with deionized water at a liquid-to-solid ratio of 10 (L / S = 10)³. pH and conductivity were measured in the eluate. The eluate was analyzed for elements required in the Norwegian Waste Regulation, Chapter 9. Annex II (MD, 2004) by an accredited laboratory (ALS). The original laboratory analysis reports from the leaching test are given in Appendix A. The total amount of cadmium and tellurium in the samples is about 400 mg/kg (see also Chapter 2).

5.2.2 Results

Results from the measurement of pH and conductivity of the eluate are given in Table 3. Results from the element analysis of the eluate are presented in Table 4. The results are compared with leaching limits for waste deposited at a landfill for inert waste, hazardous waste deposited along with ordinary waste in an ordinary landfill, and limits for waste disposed at a landfill for hazardous waste, see also Chapter 2.

Table 3 pH and conductivity in eluaet from batch test

Sample	pH	Conductivity (µS/cm)
Thin film CdTe PV module	9.6	50.6

pH in the eluate is measured to 9.6 and can be characterized as basic. The conductivity is 50 µS/cm. This can be considered as it is indicative of low salt concentration.

³ L/S = Liquid/Solid; L/S = 10 implies there is 10 liters of water per kg of solid.

Table 4 Results from batch test on CdTe PV module material in mg/kg

Parameter	Thin layer CdTe module mg/kg dw	Limit for inert waste landfills (mg/kg dw)	Limit for an ordinary waste landfill* (mg/kg dw)	Limit for a hazardous waste landfill (mg/kg dw)
As	<0.01	0.5	2	25
Ba	0.04	20	100	300
Cd	0.73	0.04	1	5
Cr	0.16	0.5	10	70
Cu	0.01	2	50	100
Hg	<0.0002	0.01	0.2	2
Mo	2.55	0.5	10	30
Ni	<0.005	0.4	10	40
Pb	0.02	0.5	10	50
Sb	0.13	0.06	0.7	5
Se	0.01	0.1	0.5	7
Zn	<0.02	4	50	200
Te**	6.13	-	-	-
Chloride	<6	800	15000	25000
Sulohate	<0.5	1000	20000	50000
DOC	25	500	800	1000

* hazardous waste deposited along with ordinary waste in an ordinary landfill

**no limit reported

The batch leaching test on the CdTe module (Table 4) shows that the eluate exceeded the limits for waste disposed at a landfill for inert waste for the elements cadmium, molybdenum and antimony (highlighted in gray color). However the leaching lies within the limits for waste that can be deposited on an ordinary landfill.

The Cd and Te eluate concentrations are 72.6 µg/l ($6.5 \cdot 10^{-7}$ mol/l) and 613 µg/l ($4.8 \cdot 10^{-6}$ mol/l) respectively. Theoretically, dissolving 1 mol CdTe will produce 1 mol of Cd and 1 mol of Te. The concentration of Te in the eluate is significantly higher compared with cadmium, and indicates that Cd precipitates as another species and / or adsorbs to solids during the test period. The pH in the eluate is 9.6. At this pH, Cd solubility is low, and is possible precipitated as Cd(OH)₂ and CdCO₃. Based on a mass balance, a Cd amount equivalent to 4.66 mg/kg dw is likely present as precipitated cadmium salts. These are soluble at lower pH. Leaching at more acidic environment can theoretically provide a leakage that exceeds the limits for hazardous waste.

Figure 2 shows the activity diagram for cadmium in relation to pH. The establishment of the chart is based on the measured values of macro elements (Ca, Mg, Na, Cl, SO₄) in eluate from the batch leaching test of the CdTe module material. If the activity of Cd is assumed to be the concentration of cadmium, this gives a log of activity at -6.19. With a pH of 9.6, the eluate sample lies within the field of CdCO₃ (otavite). The graph clearly shows that the solubility of cadmium increases at lower pH values. It should be noted that the chart is based on thermodynamic equilibrium being achieved between the different species.

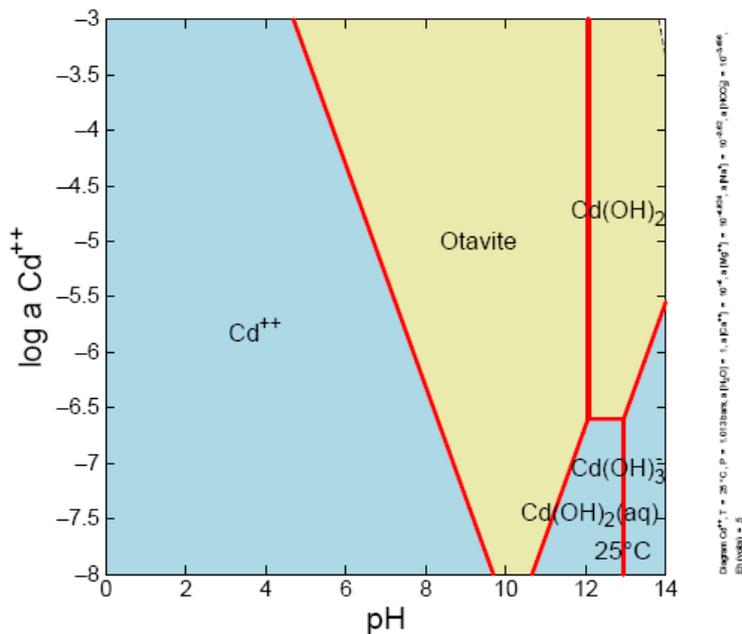


Figure 2 Activity diagram that shows the solubility of cadmium in relation to pH. Blue color indicates species in solution, brown color indicates a solid mineral phase. The values on the y-axis are given in log activity. Measured concentrations from the batch tests on the CdTe module material are used in the mode. The bicarbonate concentration is set to 0.35 mM.

Depending on the redox conditions in the water phase, tellurium probably occurs as an oxyanion (HTeO_4^- , TeO_3^{2-}) (Harada, 2008). Due to relatively high pH in the eluate, the oxyanions will be sorbed to solid phase only to a limited degree. Higher concentration of molybdenum (Mo) and antimony (Sb) further indicate that an elevated leaching of oxyanions has occurred in the batch test.

HTeO_4^-

6 Toxicity studies

6.1 Toxicity studies on CdTe

Harris et al (1994) refers to one of the first toxicity studies on CdTe. The results indicate no reproductive effects in short-term animal studies with concentrations up to 250 mg/kg/d (oral intake). Higher concentrations showed toxic effects. There were proven effects such as weight loss, but no changes in the structure of the liver or kidney, and no changes in fertility. Based on these results, it was assumed that the toxicity of CdTe is not higher than the parent components (Cd, Te).

Early published studies on the toxicity of CdTe were carried out at the National Institute of Environmental Health Sciences (NIEHS) in collaboration with Brookhaven National Laboratory (BNL). The first NIEHS study included acute pulmonary toxicity of CdTe compared with other PV modules (Morgan et al, 1995). A follow-up study focused on pulmonary related absorption and distribution, and sub-chronic end-points (Morgan et al, 1997). These studies, where applied concentration varied between 12.5 and 100 mg/kg, documented an effect of weight loss, and a possible effect on kidneys, pulmonary activity as well as death in exposed rats.

Based on publications from Morgan and three other unpublished toxicological studies on CdTe, a reference dose (RFD) for the intake of CdTe of 0.0006 mg/kg/d for CdTe was established (Fthenakis et al, 1999). Because of the large uncertainty in the data, a safety factor of 10,000 was used. This value is in the same range as for oral intake of Cd permitted in drinking water.

Based on rat experiments and methods described by guidelines of the OECD (Organization for Economic Co-operation and Development) and EPA (U.S. Environmental Protection Agency), a median lethal concentration for CdTe of 2.71 mg/l and a median lethal dose of >2000 mg/kg was established (Zayed et al, 2009). The results of the studies show that CdTe has a significantly lower toxicity compared to Cd.

Generally there is limited information on toxicity of CdTe in the available literature. The studies that have been carried out only include acute toxicity, and documentation on the effect of long-term exposure to CdTe cannot be found. Several studies make the conclusion that CdTe is probably less toxic compared with Cd due to lower solubility in water (Fthenakis and Zweibel, 2003). However, no documentation on the environmentally long term behavior of CdTe (stability, leaching) and the possibility of chronic exposure to living organisms, as well as studies on the toxicity of CdTe to soil or aquatic organisms (ecotoxicity tests) is available. A plausible way to model the toxic pathway of CdTe in the absence of such data is to account for the amount of cadmium and tellurium that dissolves into solution, and account for the toxicity corresponding to the dissolved concentration parent components (Section 6.3).

6.2 Toxicity studies of CdTe in quantum dots

CdTe is also used in quantum dots. Quantum dots are semiconductor nanocrystals (2-100 nm) with unique optical properties and used for various applications such as cell labeling, protein trafficking and DNA detection. In a study by Schneider et al (2009) on the effect of water-soluble CdTe-core quantum dots with a diameter <5 nm with a polar ligand (thioglycolic acid, TGA or tripeptide glutathione, GSH) in bacteria, it was presented that the toxicity to bacteria depends on the exposure concentrations, surface chemistry and coating. Toxicity responses are believed to occur due to the formation of TeO₂ and CdO as a result of oxidation on the surface. Dumas et al (2009) tested the cytotoxicity of CdTe on 4 different strains,

and also demonstrated that the toxicity responses were caused by reactive oxygen species (ROS). Zhang et al (2007) reported functional toxicity of CdTe nanoparticles both in vitro and in vivo.

Currently, it is uncertain whether the CdTe quantum dots have the same toxic properties as the CdTe used in PV modules.

6.3 Cadmium and tellurium toxicity

Cadmium

Cadmium is a trace element in the lithosphere with an estimated average concentration of 0.2 mg/kg. Cadmium is not an essential element for living organisms, but holds a high acute and chronic toxicity. Inhalation of high concentrations of cadmium can cause severe pulmonary edema and death. Oral intake of cadmium in high concentrations causes severe gastrointestinal irritation, vomiting and diarrhea. Long-term exposure to cadmium leads to accumulation in the kidneys and possible kidney cancer. Other long-term effects are pulmonary edema and osteoporosis. Cadmium is classified as a possible carcinogen (Sinha, 2008).

Norwegian drinking water standard for cadmium is 5 µg/l. The World Health Organization (WHO) guideline value is 3 µg/l.

Tellurium

Tellurium is a rare element in the environment, and no essential biochemical function for humans is known. No carcinogenic or mutagenic effects are known. Ingestion of tellurium induces dizziness, nausea and headaches and gives a metallic taste and dryness in the mouth. Small amounts of tellurium are less toxic than selenium (which is located just above tellurium on the periodic table), due to easily reduction to zerovalent tellurium in the organism. Tellurium can also be reduced to the toxic dimethyl telluride (Me_2Te : $\text{H}_3\text{C}-\text{Te}-\text{CH}_3$), which may cause damage to blood, liver, heart and kidneys. The compound gives a smell of garlic ("tellurium breath" of $(\text{CH}_3)_2\text{Te}$), which is emitted through sweat and breath. Particles of tellurium and tellurium (IV) oxide that may be generated when tellurium is exposed to fire are very toxic. The toxicity of tellurium depends on the oxidation state and the chemical form where Te (IV) is 10 times more toxic compared to Te (VI) (Harada 2008; Wikipedia 2009).

LD50 values for mice and rats for ingestion of telluride powder is reported to be respectively 20 mg/kg and 83 mg/kg (Baumann, 1995). Tellurium is reported to possess a high bacterial toxicity compared with other metals such as selenium, chromium, cadmium, mercury and copper (Chasteen, 2009).

Norwegian exposure limit for tellurium in the working environment is set to 0.1 mg/m³ air. Currently there is no Norwegian drinking water standard or recommended standards from the WHO for tellurium. The lack of threshold limits

is due to very limited technical use of this metalloid and because background concentrations in the environment are very low (it is considered to be a rare element).

7 Behavior and mobility of CdTe regarding disposal at landfills

Based on the reviewed literature and knowledge about the biogeochemical conditions in soil, water and landfills, an assessment of the expected behavior of CdTe by deposition in controlled and uncontrolled landfills is made.

7.1 Landfill disposal

Currently there is no waste classification for end-of-life CdTe PV modules. If the module is considered as a homogeneous waste, the total content and the leaching of Cd (standard batch test) correspond to ordinary waste, whereas the separate CdTe-layer would be classified as hazardous waste.

Normally, waste in a landfill for ordinary waste (municipal waste landfill) undergoes various phases as a result of changing chemical and biological processes as deposited waste ages. These can be summarized as follows(Christensen and Kjeldsen 1989; Kjeldsen et al 2002):

1. An initial oxic phase in which aerobic degradation occurs.
2. An acid fermentation phase, which results in the accumulation of volatile fatty acids and alcohols and a decrease in the pH of leachate.
3. A methane phase, in which methane is formed (methanogenesis) and the pH in leachate increases again.
4. An air intrusion phase, in which, after the methane production decreases, oxygen penetrates the waste masses due to a concentration gradient. CO₂ concentration is expected to increase at this phase due to oxidation of methane. Inorganic compounds, such as precipitated sulfides can be oxidized, which results in the mobilization of precipitated metals.

Most current (Norwegian) landfills are in the methane phase with a neutral pH, where metals are believed to be precipitated as sulfides. The content of metals in the leachate from these kind of landfills is therefore low. Median cadmium concentrations in leachate from Norwegian landfills is 0.2 µg/l. Cadmium concentration in European landfill leachates is reported to range between 0.1 to 400 µg/l (Kjeldsen et al, 2002). No data on tellurium in landfill leachate could be found. Little transport of other oxyanions (As, Sb, Mo) from landfills indicates that these elements (and also Te) commonly exist as sulfides. However, during the life of a landfill it is expected that the metal contents in leachate water will increase as a result of gradual oxidation of metal sulfides (upon the onset of the air intrusion phase).

No documentation on the behavior of CdTe in a landfill or under various environmental chemical conditions could be found. But under ambient conditions in contact with water (H₂O) and air (O₂), it is expected that exposed CdTe will dissolve as Cd and Te ions that can be readily transported into the environment (Harris, 1994). It is expected that cadmium will be released as Cd²⁺, which under reducing conditions (methane formation phase) will precipitate as CdS. The speciation of tellurium is not known, but will probably speciate to zerovalent Te⁰ and tellurium sulfide (Te₂S₃).

The chemical processes that occur in landfills are complex, competitive and heterogeneously distributed; thus, mobilization and transport of Cd and Te will depend on a number of co-occurring processes and conditions such as complexation, redox conditions, sorption site availability, and precipitation. Dissolved cadmium may form complexes with chloride, carbonate and organic ligands, which may exist in high concentrations in leachate. Tellurium is probably transported into leachate predominately as a free oxyanion (under more oxic conditions). Tellurium sorbs well to iron oxides and can thus be retained by this sorption process in the landfill (Environmental Protection Agency 1996; Harada 2008)

In accordance with Norwegian and European landfill regulations, bottom and side sealing is required at ordinary landfills for landfill leachate collection. In Norway, there is currently no explicit requirement for leachate treatment. If necessary a treatment must be carried out before discharge to the recipient. After the completion of the landfill, emissions should be monitored for a minimum period of 30 years. Unsatisfactory bottom/side sealing may cause pollution transport via pore water to the soil and groundwater.

Based on this assessment the following summary is provided regarding the disposal of used CdTe modules:

- With today's strict requirements for collection of landfill leachate, possible deposition of CdTe modules on a regular landfill is considered to pose a small to limited risk regarding the uncontrolled transport of pollution to soil and groundwater.
- Disposal at a regular landfill will result in negligible risks for direct exposure to living organisms.
- Reduced access to water and reducing conditions may lead to a slowing of the degradation process, thus preventing higher concentrations of Cd or Te to occur in landfill leachate in the short-term. Over the long-term, oxygen may penetrate into reduction zones in the landfill, resulting in possible and hard-to-predict changes in the leaching potential and effects on the landfill leachate.
- 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. Control of this is facilitated through requirements for leaching and pollution potential outlined in Norwegian waste

regulation (*Avfallsforskriften*) and the European landfill directive. Batch test conducted in accordance with the waste regulations indicates that the leaching of cadmium from CdTe modules is within the requirement for an ordinary landfill. It should be noted, however, that if the leaching test is carried out at a lower pH it is likely that the leaching limits for ordinary landfill would be exceeded.

7.2 Uncontrolled disposal

If CdTe PV modules are disposed in an uncontrolled manner, additional release of CdTe (compared to a controlled disposal) would be dependent on the potential destruction of the glass layers which encapsulate the CdTe-film. If the CdTe-film is exposed to natural precipitation and atmospheric air, the compounds are expected to volatilize, dissolve and oxidize over time.

In soil solution cadmium occurs mainly as free divalent Cd^{2+} ions. The transport in soil is usually controlled by sorption on soil particles (clay particles, Fe/Mn oxides, organic matter). Cadmium forms complexes with inorganic ligands, such as chloride and carbonate, as well as organic ligands, which may lead to increased mobility of cadmium. Naturally, the transport of cadmium will be dependent on the specific site conditions (Miljøstyrelsen, Danish Environmental Protection Agency, 1996)

There is limited data on the geochemical behavior of tellurium in water and soil. When CdTe is exposed to precipitation and air (oxidizing conditions), tellurium is expected to oxidize to tetravalent tellurite (TeO_3^{2-}) and/or hexavalent tellurate (TeO_4^{2-}), where tellurite is the most stable compound in the environment. Sorption and retention will depend on the oxidation state, as tellurate is more retained in soils than tellurite. For both species iron oxides are important sorbents in the soil. Due to the amphoteric character of the oxides, sorption is strongly pH-dependent (Harada 2008; Chasteen 2009). Normally, negatively charged oxyanions are more mobile than cationic metals (e.g. Cd^{2+}).

In addition to the geochemical conditions and the rate of degradation of the PV material, the environmental risks associated with any uncontrolled dumping of CdTe will depend on local conditions, such as ground conditions (transport and retention of land and ground water), climatic conditions (precipitation, temperature) and the potential exposure (people, animals).

Norwegian threshold value for cadmium in soil is low, 1.5 mg/kg dw (SFT, 2009). There is currently no threshold value for tellurium in soil.

In summary, the environmental risks associated with uncontrolled dumping of CdTe modules will be significantly higher compared with the controlled disposal at a landfill. This is mainly because

- Degradation and dissolution of exposed CdTe layers is expected to be significantly quicker under exposure to precipitation and ambient air.
- pH in the natural environment is often lower than that found in landfill leachate. A decrease in pH can cause a significant increase in the solubility of cadmium.
- Leaching of Cd and Te components can spread directly to soil and water, thus, uncontrolled depositions would most likely result in higher exposure to living organisms.

8 Summary and conclusions

There is little documented information about the environmental effects of CdTe PV modules, in relation to use, reuse, and any final disposal, in the available literature. The existing studies mainly originate from relatively few research institutions, where a major contributor is the Brookhaven National Laboratory (BNL) in the United States. This institution has been working on issues related to the use of CdTe in the photovoltaic industry for a long time.

Very few data is found regarding behavior of CdTe in the environment, its solubility, and in what form cadmium and tellurium are released. Regarding the elements individually, in general there is little knowledge on behavior of Te in soil and water, especially compared to Cd. Moreover, limited documentation of human toxicological effects of Te is found. In several studies, it is believed that the toxicity of CdTe does not exceed the parent components (Cd, Te). Acute toxicity of CdTe appears to be significantly lower. No studies on ecotoxicity are currently available.

A main part of the available literature is related to the LCA of CdTe PV modules. Most LCA studies implicitly assumed zero discharge of metals in relation to use, when the layer of CdTe is well protected by glass layers. Only one study (Steinberger, 1998) is found where leaching from CdTe PV modules has been accounted for (for larger scale outdoor solar power plants). When it comes to end-of-life emissions, recycling of the modules is generally also assumed in LCA assessments. Any emissions associated with recycling or end disposal are, however, only to a very small extent included in the LCA studies.

Current landfills have strict requirements for bottom and side sealing for the collection of landfill leachate. Thus the risk of uncontrolled spreading of Cd and Te contamination in connection with the disposal of CdTe-modules at approved landfills is considered to be low. Despite this, ideally it is preferable to reduce the amount of potentially toxic compounds (or toxic compound precursors) that are deposited in ordinary landfills, due to potential contamination of leachate. This is currently regulated by ensuring requirements for the leaching and pollution potential of waste are met (see requirements for leaching tests on the waste in Norway (*Avfallsforskriften*, Chapter 9, Annex II) and the European landfill directive (EU Council Directive 1999/31/EF)). Results from the standardized

leaching test conducted by NGI quantified the leaching of tellurium and cadmium from CdTe module material (using distilled water). Leaching of tellurium is substantially higher compared to cadmium, which is believed to be due to a relatively high pH of the leachate. CdTe dissolves to Cd and Te ions, but the Cd is retained in the solid material as a result of precipitation as different species and sorption. Cd has a low solubility in this pH range, and the basic pH of the leachate favours the occurrence of dissolved oxyanions of Te, Mo and Sb. The leaching exceeds the leaching limits for disposal at a landfill for inert waste, but lies within the limits for an ordinary landfill (Norwegian waste regulation, Chapter 9, Annex II). Leaching test at lower and more environmental relevant pH (<8) are expected to provide an increased leaching of Cd, and at a level that probably exceeds the regulatory limit for ordinary landfills.

Uncontrolled dumping of CdTe modules will provide substantially greater environmental risks compared with controlled disposal. In addition to the risk of direct exposure, cadmium and tellurium components may mobilize and spread directly to soil, water and groundwater with potential exposure to living organisms outside the dumping area. Open exposure to air and precipitation will lead to a faster weathering of the CdTe-layer and dissolution into individual components. A lower pH will lead to increased solubility of cadmium in the leachate.

Based on the obtained literature, the publicly available documentation is considered to be insufficient for a comprehensive assessment of environmental risks in connection with the use and final disposal of CdTe PV modules. Thus, conclusions here based on this literature are considered preliminary. This applies primarily to the documentation on the geochemical behavior and toxicity of the compounds CdTe and tellurium. As a first approach we recommend laboratory tests for better documentation of the geochemical behavior, such as:

- Long-term solubility tests of the CdTe modules.
- pH depending leaching tests to study the effect of pH on the leaching of the material .
- Determination of the state and speciation of the mobilized compounds found in leachate.

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Appendix A: Laboratory report from batch test on CdTe PV module material



NGI
v/ Gudny Okkerhaug
Songsveien 72

0806 Oslo

Oslo, 2010.01.13

62003 Analyseresultater fra NGI miljølaboratorium

Prosjektnavn: Solcell panel
Prosjektnummer: 20092155 -
Prøvetype: Solcell panel
Antall prøver: 1
Mottatt dato: 2009.12.21
Anmerkninger: Reviderad rapport, parameter SO4- har lagts till.

Hovedkontor:
Pb. 3930 Ullevål Stadion
0806 Oslo

Avd Trondheim:
Pb. 1230 Pirsenteret
7462 Trondheim

T 22 02 30 00
F 22 23 04 48

Kontnr 5096 05 01281
Org. nr 958 254 318 MVA

ngi@ngi.no
www.ngi.no

Følgende analyser har blitt utført:

Parameter	Intern pros. MLP	MLP basert på	Akkreditert	Måleområde	Analysedato
Vanninnhold	005	NS 8013	Ja	1-50 vekt %	2009.12.21-2009.12.22
Ristetest	430	NS-EN 12457	Ja	Begrenset av det.gr	2009.12.21-2009.12.22
pH i vann	020	NS 4720	Ja	pH 3-11	2009.12.22-2009.12.22
Ledn.evn. i vann	030	NS-ISO 7888	Ja	15-13.000 µS/cm	2009.12.22-2009.12.22

Usikkerhet oppgis ved henvendelse til laboratoriet

Resultatene i vedleggene gjelder utelukkende den prøve som er oppgitt på arket.
Rapporten skal ikke gjengis i utdrag uten skriftlig godkjenning fra laboratoriet. Resultatene kan derimot benyttes av NGIs prosjektleder i eventuell videre rapportering til NGIs eksterne kunder

Vennlig hilsen
for NORGES GEOTEKNISKE INSTITUTT

Arne Pettersen
Teknisk leder miljølaboratorium

BS EN ISO 9001
Sertifisert av BSI
Reg. No. FS 32989

Norges Geotekniske Institutt - Miljølaboratoriet



Ristetest MLP 430 - 1 trinn (NS-EN 12457)

Prosjektnr.: 20092155

Prosjekttittel: Solcell panel

Prøven navn: Solcell

Intern ref: 430-091221a

Dato/kontroll:

13/1-10 AP

Materialkarakterisering

Beskrivelse av forsøket

Vanninnhold (%) 0
Vekt tørr prøve (g) 175,0

1-trinns ristetest, NS-EN12457

175 gram prøve ble tilsatt rent vann til L/S=10, og ristet i 24 timer ved 10 rpm. Etter 15 min. henstand ble prøven filtrert (0,45µm).

Forsøket ble utført ved romtemperatur (20 ± 5°C)

Alle kjemiske analyser av eluat er utført av underleverendør

Ett-trinns utvasking til L/S = 10

	L/S = 10
Volum utvaskingsvæske tilsatt (ml)	1750,0

	pH	Ledningsevne (µS/cm)
L/S = 10	9,6	50,6

Konsentrasjon og utvasking av tungmetaller

Navn	Konsentrasjon (µg/l) L/S = 10	Utvasket L/S=10 (mg/kg ts)
Ca	4030	40,3
Fe	16,6	0,166
K	<500	< 5,00
Mg	362	3,62
Na	5600	56,0
S	165	1,65
Al	6240	62,4
As	<1	< 0,0100
Ba	3,90	0,0390
Cd	72,6	0,726
Co	<0,05	< 0,000500
Cr	15,5	0,155
Cu	1,12	0,0112
Hg	<0,02	< 0,000200
Mn	1,08	0,0108
Ni	<0,5	< 0,00500
Pb	1,99	0,0199
Zn	<2	< 0,0200
Mo	255	2,55

Kommentarer

Utlekking av organiske forbindelser er ikke akkreditert.
Vanninnholdet er beregnet i forhold til mengde tørr prøve.

Norges Geotekniske Institutt - Miljølaboratoriet



Ristetest MLP 430 - 1 trinn (NS-EN 12457)

Prosjektnr.: 20092155 Prosjekttittel: Solcell panel

Prøven navn: Solcell Intern ref: 430-091221a

Dato/kontroll: 13/1-10 AP

Materialkarakterisering

Beskrivelse av forsøket

Vanninnhold (%) 0
Vekt tørr prøve (g) 175,0

1-trinns ristetest, NS-EN12457

175 gram prøve ble tilsatt rent vann til L/S=10, og ristet i 24 timer ved 10 rpm. Etter 15 min. henstand ble prøven filtrert (0,45µm).

Forsøket ble utført ved romtemperatur (20 ± 5°C)

Alle kjemiske analyser av eluat er utført av underleverendør

Ett-trinns utvasking til L/S = 10

	L/S = 10
Volum utvaskingsvæske tilsatt (ml)	1750,0

	pH	Ledningsevne (µS/cm)
L/S = 10	9,6	50,6

Konsentrasjon og utvasking av tungmetaller

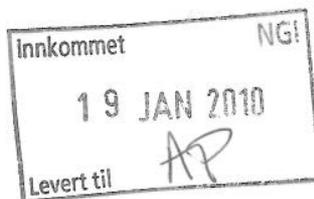
Navn	Konsentrasjon (µg/l) L/S = 10	Utvasket L/S=10 (mg/kg ts)
Sb	12,7	0,127
Se	0,987	0,00987
Te	613	6,13
Klorid (Cl-)	<600	< 6,00
Fluorid (F-)	<150	< 1,50
DOC	2500	25,0
Sulfat (SO4)	<500	< 5,00

Kommentarer

Utlekking av organiske forbindelser er ikke akkreditert.
Vanninnholdet er beregnet i forhold til mengde tørr prøve.

Rapport

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**N0909232**

1PZF5Y3HGW2



Prosjekt **Solcelle panel**
 Bestnr **20092155**
 Registrert **2009-12-23**
 Utstedt **2010-01-08**

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Analyse av vann

Deres prøvenavn	Solcelle 430-4s10				
	Eluat				
Labnummer	N00090102				
Analyse	Resultater	Usikkerhet (\pm)	Enhet	Metode	Utført
Ca	4.03	0.48	mg/l	1	E
Fe	0.0166	0.0056	mg/l	1	H
K	<0.5		mg/l	1	E
Mg	0.362	0.045	mg/l	1	E
Na	5.60	0.70	mg/l	1	E
S	0.165	0.080	mg/l	1	E
Al	6240	1360	μ g/l	1	H
As	<1		μ g/l	1	H
Ba	3.90	0.77	μ g/l	1	H
Cd	72.6	12.3	μ g/l	1	H
Co	<0.05		μ g/l	1	H
Cr	15.5	3.2	μ g/l	1	H
Cu	1.12	0.29	μ g/l	1	H
Hg	<0.02		μ g/l	1	F
Mn	1.08	0.55	μ g/l	1	H
Ni	<0.5		μ g/l	1	H
Pb	1.99	0.39	μ g/l	1	H
Zn	<2		μ g/l	1	H
Mo	255	53	μ g/l	1	H
Sb	12.7	3.1	μ g/l	1	H
Se*	0.987		μ g/l	1	G
Te*	613		μ g/l	1	S
Klorid (Cl-)	<0.60		mg/l	2	1
Fluorid (F-)	<0.15		mg/l	2	1
Sulfat (SO4)	<0.50		mg/l	2	1
DOC	2.5	0.17	mg/l	2	1

Rapport

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1PZF5Y3HGW2



* etter parameternavn indikerer uakkreditert analyse.

Metodespesifikasjon	
1	<p>Analyse av tungmetaller (V-3A)</p> <p>Metode: EPA metoder 200.7 og 200.8 (modifisert) Forbehandling: Filtrering Surgjøring med 1 ml salpetersyre per 100 ml prøve</p>
2	<p>Bestemmelse av Klorid, fluorid, sulfat og DOC.</p> <p>Metode: Klorid, fluorid og sulfat: EN ISO 10304-1/-2-D19/20 DOC: DIN EN 1484-H3 Deteksjon og kvantifisering: Klorid, fluorid og sulfat: Ionekromatografi DOC: IR-fotometri</p>

Underleverandør ¹	
E	<p>ICP-AES</p> <p>Ansvarlig laboratorium: ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, Sverige Akkreditering: SWEDAC, registreringsnr. 1087</p>
F	<p>AFS</p> <p>Ansvarlig laboratorium: ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, Sverige Akkreditering: SWEDAC, registreringsnr. 1087</p>
G	<p>AFS</p> <p>Ansvarlig laboratorium: ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, Sverige Akkreditering: SWEDAC, registreringsnr. 1087</p>
H	<p>ICP-SFMS</p> <p>Ansvarlig laboratorium: ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, Sverige Akkreditering: SWEDAC, registreringsnr. 1087</p>
S	<p>ICP-SFMS</p> <p>Ansvarlig laboratorium: ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, Sverige Akkreditering: SWEDAC, registreringsnr. 1087</p>
1	<p>Ansvarlig laboratorium: GBA, Flensburger Strasse 15, 25421 Pinneberg, Tyskland Akkreditering: DAR, registreringsnr. DAC-PL-0040-97</p>

Måleusikkerheten angis som en utvidet måleusikkerhet (etter definisjon i "Guide to the Expression of Uncertainty in Measurement", ISO, Geneva, Switzerland 1993) beregnet med en dekningsfaktor på 2 noe som gir et konfidensintervall på om lag 95%.

Måleusikkerhet fra underleverandører angis ofte som en utvidet usikkerhet beregnet med dekningsfaktor 2. For ytterligere informasjon, kontakt laboratoriet.

Denne rapporten får kun gjengis i sin helhet, om ikke utførende laboratorium på forhånd har skriftlig godkjent annet.

Angående laboratoriets ansvar i forbindelse med oppdrag, se aktuell produktkatalog eller vår webside www.alsglobal.no

¹ Utførende teknisk enhet (innen ALS Scandinavia) eller laboratorium (underleverandør).

Kontroll- og referanseside/ Review and reference page



Dokumentinformasjon/Document information					
Dokumenttittel/Document title Environmental risks regarding the use and end-of-life of CdTe PV modules			Dokument nr./Document No. 20092155-5-R		
Dokumenttype/Type of document		Distribusjon/Distribution		Dato/Date 2010-04-16	
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Oppdragsgiver/Client REC ASA et al.					
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Land, fylke/Country, County				Havområde/Offshore area	
Kommune/Municipality				Felt navn/Field name	
Sted/Location				Sted/Location	
Kartblad/Map				Felt, blokknr./Field, Block No.	
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NGI (Norges Geotekniske Institutt) er et internasjonalt ledende senter for forskning og rådgivning innen geofagene. Vi utvikler optimale løsninger for samfunnet, og tilbyr ekspertise om jord, berg og snø og deres påvirkning på miljøet, konstruksjoner og anlegg.

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NGI was awarded Centre of Excellence status in 2002 and leads the International Centre for Geohazards (ICG).

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