Baldwin Planning Board
Meeting Minutes 10/22/2020

Roll Call: Planning Board Members: Chairman David Strock, Jo Pierce, Bob Flint
Board of Selectmen: NA
CEO: Wes Sunderland
Others: Members of the public
Bill Thompson of BH2M Inc. for Sand Pond and Freemont Woods Developments
Dave Kane – Long Road Energy

Agenda:

- Review the minutes of the last meeting
- Discuss status of Van Hertel, Sr.'s request for certain waivers for subdivisions on Freedom Road.
- Wes Sunderland's report regarding solar farm pollution
- Entertain motion to adjourn

The Chairman called the meeting to order at 7:03 PM.

- The minutes of the last meeting were approved as written.

- The Board reviewed the two reports related to waiver requests in the Sand Pond Woods and Freemont Woods subdivision applications. A letter dated 8 Oct 2020 from Mark Cenci, Maine Geologist #467 to Bill Thompson addresses the request for a waiver to the need to study ground water flows and their impact on nitrates in discharged into streams. A letter dated 5 Oct 2020 from Alexander A. Finamore, LSE #391, CWS #267, owner of Mainely Soils LLC to Bill Thompson addresses the request for waiver for high intensity soil surveys for the two subdivisions. The board voted to grant conditional waivers conditionally based on the facts that the projects are small, they have relatively uniform geology, test pits have been dug and flagged for each lot and all test pits have been judge suitable for septic systems. The waivers could be reviewed if the circumstances of the projects change. Copies of the waiver requests are attached.

  The board also reviewed from the 13 Aug 2020 review of the subdivision that the plans show the location of power poles, access roads for the lot without road frontage, shared curb cuts, and these being reflected in the respective deeds.

  It was not clear if the land had been removed from the tree growth tax program but the fees/penalties would need to be paid prior to final approval.

  The board voted to provide Preliminary Approval for the two projects with conditions mentioned above with a vote of 3 to 0.

- The CEO, Wes Sunderland, gave a comprehensive report on his concerns about potential long term hazardous pollution from solar farms. There are no solar farm specific regulations in the town's Land Use Regulation. Baldwin has one approved solar farm under construction and three additional ones under consideration. The issue presented by the CEO mainly revolved around end of life disposal of the solar panels or abandonment of the projects in mid life and subsequent cleanup problems and expenses. The panels are also subject to degradation by severe weather such as tornadoes or hurricanes. During the discussions, it was revealed that Maine DEP has requirements for projects that occupy land area greater than 20 acres to file decommissioning plans and bonds. Although all of the projects being considered appear to exceed the 20 acre requirement, the board agreed this is an area that should be further investigated. The presentation materials from the CEO are attached.

- It was voted to adjourn.

Submitted by: Bob Flint

Attachments: Waiver Requests
CEO Presentation on Solar Farms

October 5, 2020

Bill Thompson
BH2M, Inc.
28 State Street
Gorham, ME 04038

RE: Soil Survey Waiver Request
Sand Pond Road Subdivision, Baldwin, Maine

Dear Mr. Thompson:

On November 8, 2019, forteen test pits were dug and assessed on 14 proposed residential house lots within the proposed Sand Pond Road Subdivision located on the both sides of Sand Pond Road in Baldwin by Alexander Finamore, LSE #391. The parcel is identified by the Town of Baldwin as Tax Map 1 Lots 93 and 94d. Each test pit was located with a submeter accuracy Trimble Geo handheld GPS unit and marked with a pink and black striped flag. One test pit was dug in each proposed lot. All of the test pits contained suitable soils to support a 'First Time System' according to the Maine Subsurface Wastewater Disposal Rules. Please find the soil profile descriptions of the test pits attached.

The Natural Resource Conservation Service soil survey mapping identifies native soils at the site as being formed within sandy outwash or eolian deposits (Windsor and Au Gres series) (Web Soil Survey, 2020). The Windsor series is an excessively drained drained sandy soil map unit. The Au Gres series is a deep poorly drained soil map unit portions of which contain hydric (wetland) soils. Soils within the site and the general vicinity have previously been superficially altered by recent logging activity.

Test pits were compared to the Cumberland County Medium Intensity Soil survey to determine congruence. It is of the site evaluators opinion that the soils observed onsite match the Medium Intensity soil survey closely. The wetland boundary delineated onsite further details the boundary between poorly drained and excessively drained soil conditions.

Due to the similarities of the soils observed within the pits dug for septic suitability to the Cumberland County Medium Intensity Soil survey mapping, it is of the site evaluator's opinion that a high intensity soil survey may be waived for site development purposes.

If you have any questions, please feel free to email me at: alfinamore@yahoo.com or call

207-650-4313.

Sincerely,

Alexander A. Finamore, LSE #391, CWS #267
Owner - Mainely Soils, LLC

Mark Cenci
Geologic, Inc.

CERTIFIED GEOLOGIST/LICENSED SITE EVALUATOR

93 Mill Road • North Yarmouth, Maine 04097
Cell: 207.329.3524 • mark@markcenci.com
www.markcenci.com

Date: October 8, 2020

To: William Thompson
Berry Huff McDonald Milligan, Inc.
28 State Street
Gorham. ME 04038

RE: Nitrates in groundwater from proposed residential projects, Baldwin

Mr. Thompson:

I reviewed the two plans you provided me, *Sand Pond Woods* and *Freemont Woods*, by BH2M, revised, 7/28/20. These plans depict the site topography, the lot and test pit locations and the delineated wetlands by Alex Finamore. Also reviewed were the test pits logs of Alex Finamore. In addition, I reviewed the topographic information published by the USGS, the watershed and aquifer analysis of the Maine Geological Survey and published wetland information of the *National Wetlands Inventory*.

My conclusion is that groundwater flow on these two parcels is easterly to an unnamed stream that flows southerly from Sand Pond to Quaker Brook. Wetlands are mapped along this stream, which will remove all remnant nitrates from the groundwater as it discharges to the stream.

Nitrates from septic systems will not move to any existing abutter of the two projects, and will remain on the parcels being developed. Septic systems located as shown at the test pits of Finamore are suitable for nitrate-nitrogen concentrations, given the groundwater flow directions on the site.

All water wells will be located greater than 100 feet from these sites, which will provide suitable protection. The septic systems serving the lots of Freemont Woods should not be constructed less than 50 feet from Sand Pond Road, which will afford the proposed lots of Sand Pond Woods added protection.

Given the favorable site conditions, the soils, the lot density and the groundwater flow direction on the two projects, further analysis of nitrate-nitrogen impacts is not necessary and a waiver for further study is justified.

Please contact me, email preferred, if you have questions.

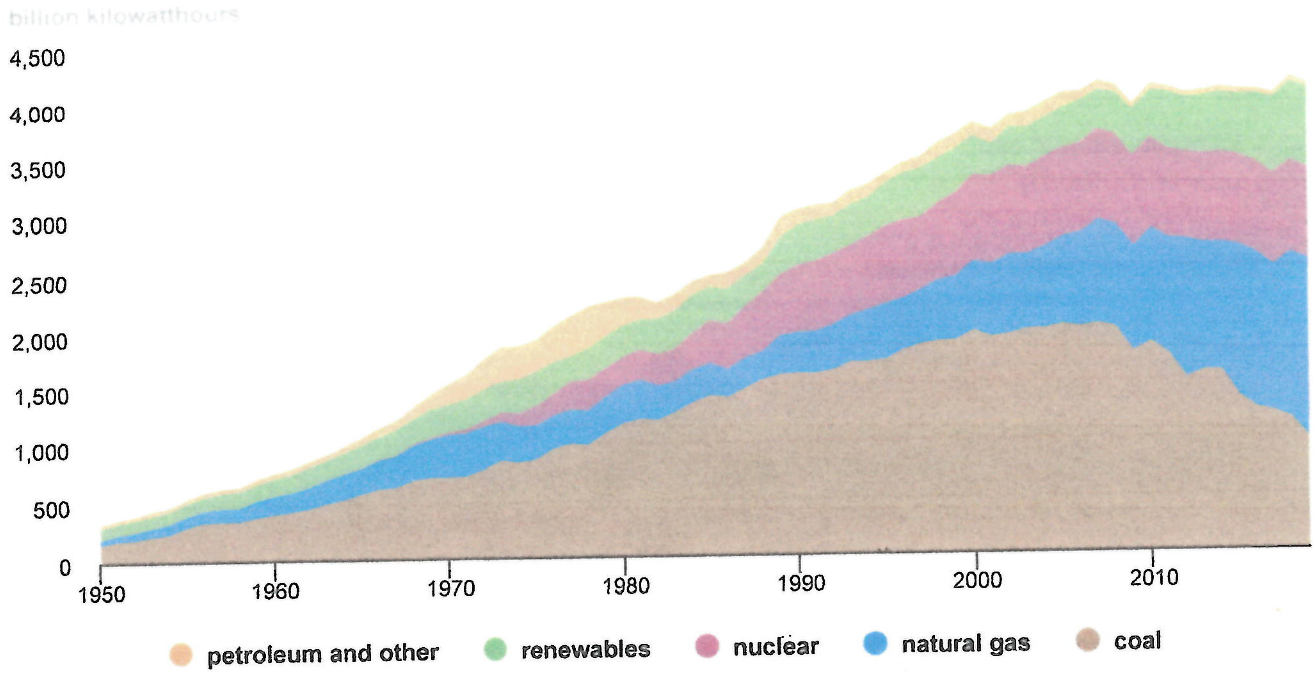
Mark Cenci, Maine Geologist #467

Given the favorable site conditions, the soils, the lot density and the groundwater flow direction on the two projects, further analysis of nitrate-nitrogen impacts is not necessary and a waiver for further study is justified.

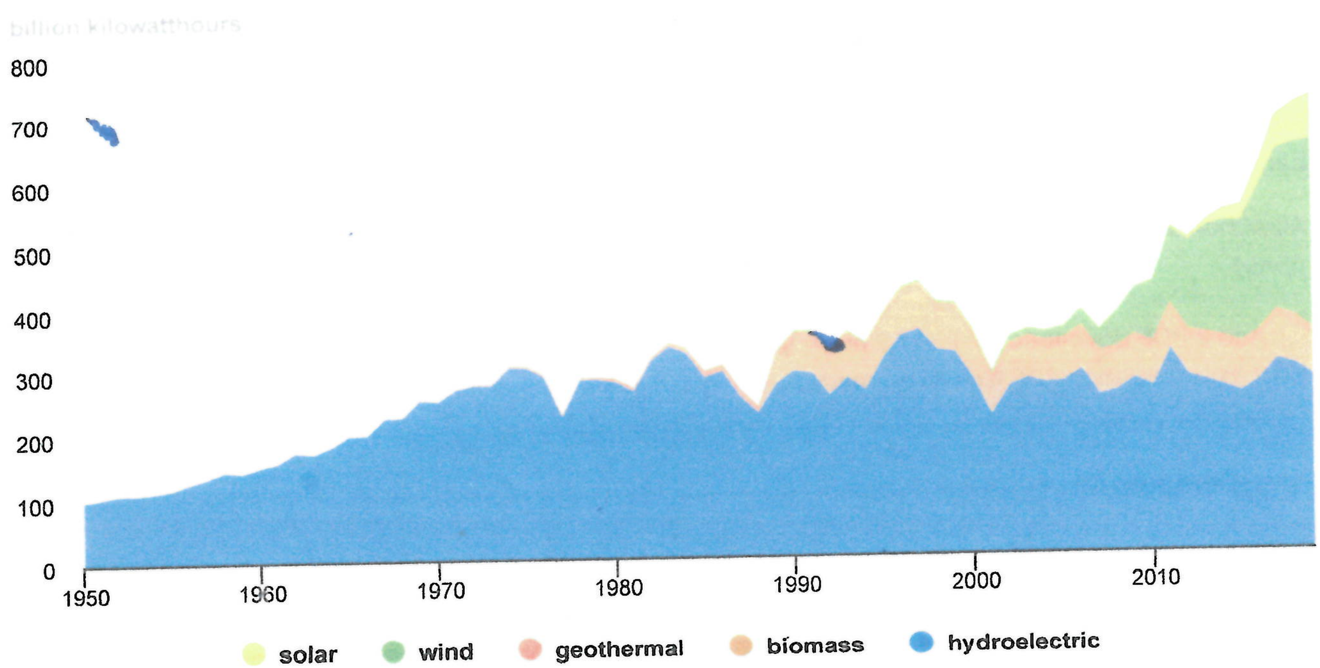
Please contact me, email preferred, if you have questions.

Mark Cenci, Maine Geologist #467

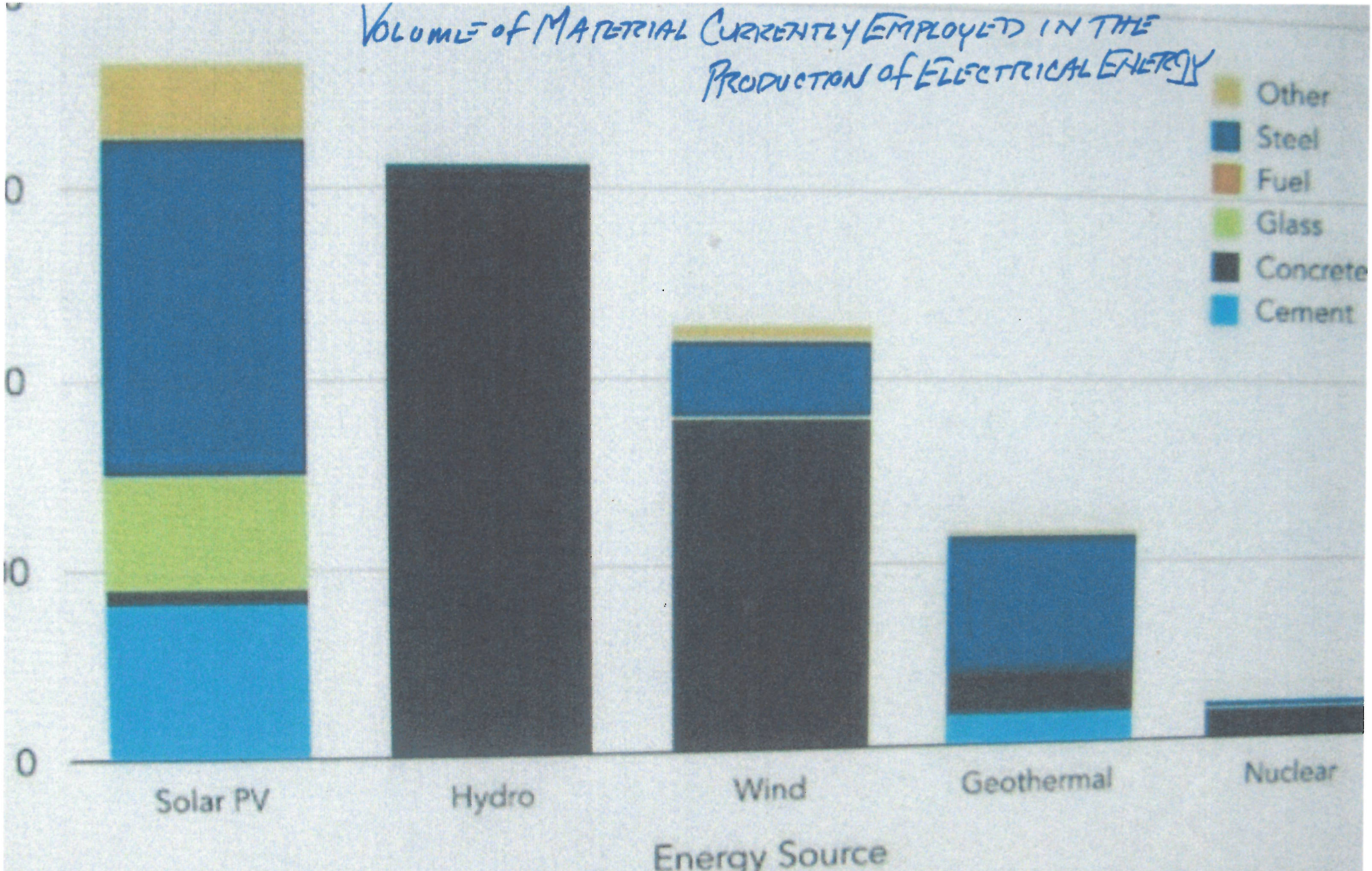
U.S. electricity generation by major energy source, 1950-2019



U.S. electricity generation from renewable energy sources, 1950-2019

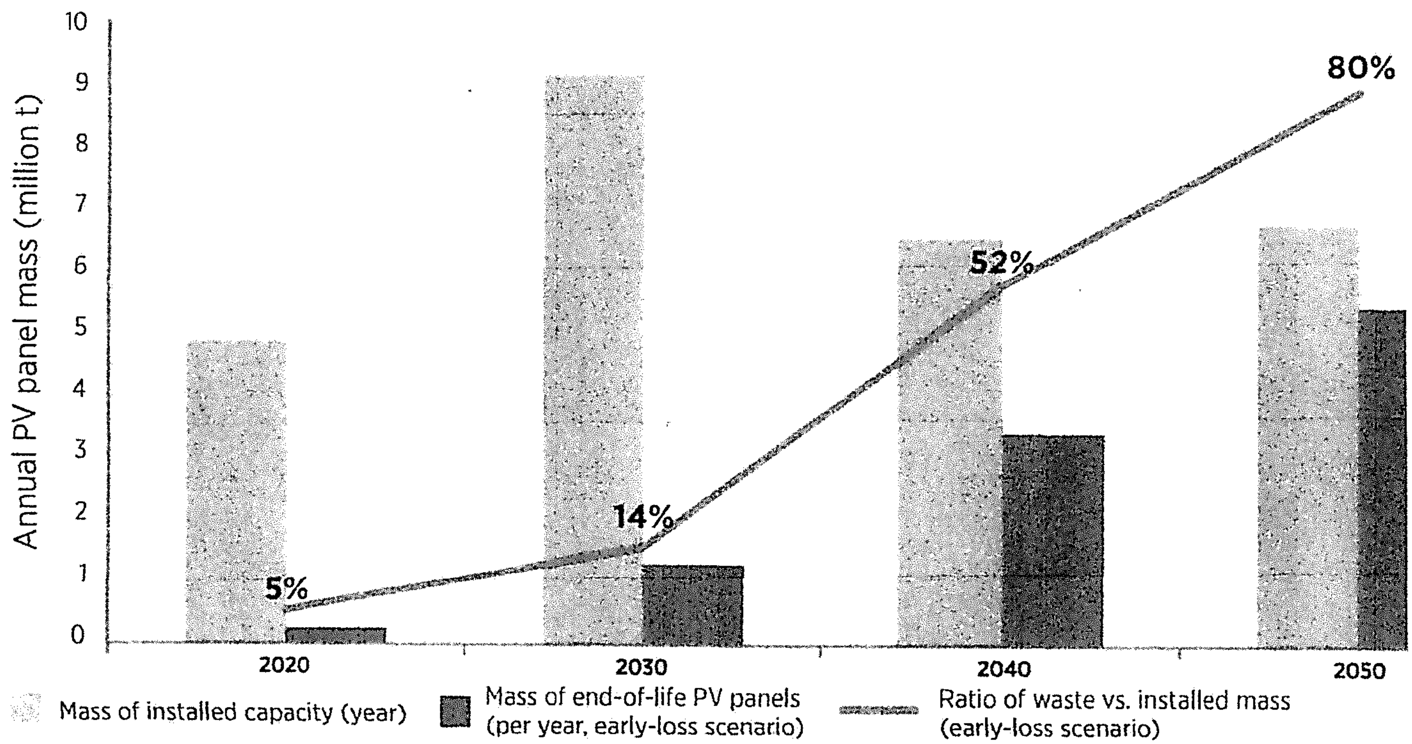


eia



Sources: DOE Quadrennial Technology Review, Table 10.
Murray, R.L. and Holbert, K.E. 2015. Nuclear energy: an introduction to the concepts, systems, and applications of nuclear processes (7th ed.). Elsevier.

Figure 8 Annually installed and end-of-life PV panels 2020-2050 (in % waste vs. t installed) by (top) and regular-loss scenario (bottom)



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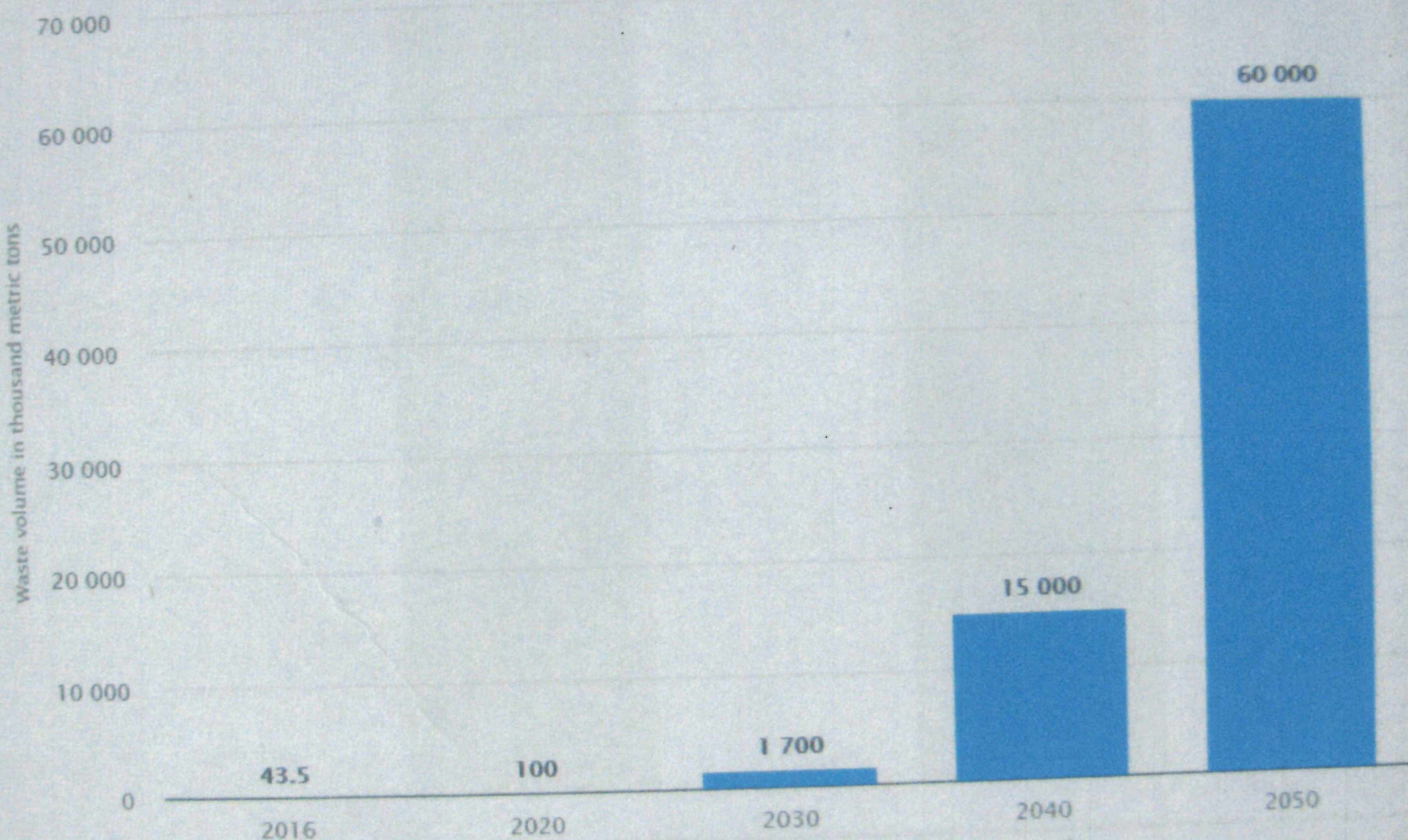
Projected cumulative volume ... 2050 (in 1,000 metric tons)*

Solar PV. Panel Waste



SOLAR: TOXIC ELEMENTS & COMPOUNDS

Toxic chemicals and compounds used within the "electron wafers" and used to manufacture these wafers that are sandwiched between two sheets of glass forming the PV panels.

CADMIUM	
CADMIUM TELLURIDE ------------------	Used in "thin-film" PV panels (new & current use)
CADMIUM GALLIUM SELENIDE	
COPPER INDIUM SELENIDE	Some compounds employed in older panels
COPPER INDIUM GALLIUM SELENIDE	but not currently used.
LITHIUM IRON TELLURIDE	
LEAD -------------------	sometimes used in glass manufacturing
HEXAFLUOROETHANE -------------------	Used during manufacturing
SILICON TETRACHKORIDE ------------------	by-product in manufacturing
AMORPHOUS SILICON	

Chemicals ending in "ium" are *heavy metals.* Heavy metals are toxic.
Chemicals ending in "ide" are 2 element compounds.

Cadmium is a poison known to cause birth defects & cancer. 80% of cadmium are used in rechargeable batteries. (currently there are moves to eliminate the use of cadmium, along with lead, mercury, & arsenic.
Gallium is a soft silvery metal used in electronic circuits,
Indium is a soft silvery metal that is stable in air & water. Indium conducts electricity, bonds strongly to glass & is transparent.
Lithium is highly active and flammable, must be stored in mineral oil. Not highly toxic. Used to manufacture airplane parts and used in some batteries.

Law in Physics: Matter can neither be created nor destroyed.
Therefore, matter changes "state of existence": gas – liquid – solid.
The chemical compounds will not disappear. They can change state, solid into a liquid solution.
Chemical bonding as co-valent (sharing electron orbits) and ionic (switching electron orbits).
Electron bonding is difficult to separate.

Definition: HEAVY METALS.
Heavy metals are ELEMENTS that weigh at least 4000 Kg per cubic meter.
--------- Conversion of measurement --------
Kg to LBS: 1 Kg = 2 lbs. or .45 Kg = 1 lb.
1 cubic meter is about 3"= larger than a cubic yard. 1 meter = 39.37"
1 cubic meter @ 4000 Kg = about 8000+ lbs. = 4 tons+
1 cu. M. = 36 cu. Ft. 1 cu. Yd. = 27 cu. Ft. 1 cu. Yd. = 75% cu. M. 1 cu. Yd. = 6000 lbs. = 3 ton
Comparison: 1 cu. Yd. sand/gravel = 2000= lbs. 1 cu. Yd. concrete @ 150 lbs./cu. Ft. = 4050 lbs.

SOLAR PANEL WASTRE: Panel volume analysis.

How many panels in Baldwin: projected estimate.

Sunraise: 16,400 panels occupy 19 aces = 850 panels per acre. 850 x ac. Use = total panels

Sunraise	Maietta gravel quarry	----------------	25ac./19ac. Use = ¾	16,400
Estes	Baldwin/Hiram line	-----------------	125ac./40ac. Use = 1/3	34,400
McDonald	Rt. 113 (across fr. Office)	-----------------	140ac./45ac. Use = 1/3	38,240
Jo Pierce	River Road land	-----------------	150ac./50ac. Use = 1/3	42,500
			Total-------	131,150
			Equals-----	28 truck box

Volume of Waste as compared to how many trailer truck boxes in volume.

1 panel = 15 sq. ft. x ½" thick = .6 cu. ft.
1 box trailer = 8'x8'x44' = 2816 cu. Ft.
2816 cu. Ft. ./. .6 cu. Ft. = 4673 panels per box
131,150 panels ./. 4673 panels per box = 28 truck boxes for panel volume of waste

The Question is, Where is this panel volume going to end up as waste ?

Weight of toxic waste:

Panels weigh about 45 lbs. per panel
Glass = 90% of panel
Toxic chemicals = 2% of panel
45 lbs. x 2% = .9 lbs. toxic waste

131,150 panels @ 45 lbs. ea. = 5,901,750 lbs. total weight
131,150 panels @ .9 lbs. toxic waste = 119,835 lbs. of toxic chemicals
119,835 lbs. ./. 2000 lbs. = 59 tons toxic waste

59 tons of toxic chemicals potentially possible to leach into the soil and ground water.

MARK KLIZOS
CON-ED, 914-365-0118

COPY - U.S.P.A.

SOLAR QUESTIONS ANSWERS

USDA
United States Department of Agriculture

Rural Development

Sent VIA Email

September 2, 2020

Selectmen's Office
Town of Baldwin
534 Pequawket Trail
West Baldwin, ME 040951

Dear Selectmen's Office:

This letter is to initiate the Executive Order 12372, "Intergovernmental Review of Federal Programs" process. USDA Rural Development is being asked to consider providing financial assistance for the proposal described below and your comments are invited on this proposal regarding:

1. Consistency with State and local government planning goals;
2. Extent to which the proposal duplicates, runs counter to, or needs to be coordinated with other activities, or might be revised to increase its effectiveness;
3. Contribution to achieving State or local government goals relating to natural and human resources, or economic and community development;
4. Extent of environmental impacts and alternatives that should be considered in the Agency's environmental review;
5. Influence on area growth or delivery of services, including any disproportionate effects on minority groups;
6. Impacts on energy resource supply and demand;
7. Possible displacement of people or businesses; and
8. Location in a Coastal Zone or Coastal Barrier Resource Area and consistency with any State coastal management plan.

The proposed project involves the construction of a 6.84 MW (DC) ground-mounted solar array. The development will occupy approximately 28 acres and will be located at 1093 Pequawket Trail in West Baldwin (almost across from Douglas Hill Road).

1094/1074

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wsunderland@roadrunner.com

To: brian.wilson@usda.gov.
Subject: Review of Federal Programs

To: Brian A. Wilson USDA Rural Development – Questionnaire. Sept. 2020

Response: Solar Array of about 28 acres located at 1094 Pequawket Trail, West Baldwin, Maine. 04091
Wes Sunderland, Code Enforcement Officer, Baldwin, has handled the permitting of this solar farm since the beginning of inquiry at about fall of 2019.

COMMENTS:

#6. Impacts of energy resource supply and demand.

Answer: The permit had listed slightly over 8 MW energy produced yearly. The acreage was approximately 28 acres purchased and 19 acres of solar array.
This rural area has a hydroelectric dam located at the town border located in Hiram and on the Saco River. It is about ½ mile from the solar array location. This is excellent for power back-up when solar production is down.

It is calculated that the average annual sun exposure to solar panels is 9 hours per day, at most. This means back-up from other sources, hydro as well as fossil fuels, shall be employed for at least 15 hours average per day. Therefore "green solar energy" is not as favorable as may be thought about. Also, peak hours of electric demand is approximately 4pm to 8pm (maybe 9+pm). The sun is down the majority of this time. Other conventional electric plants must replace demand. Although the gain from solar energy is a help it is the minority of time and not at peak demand time. Is it worth the cost and effort ?

Only where solar energy is collected on residential roof tops can batteries be employed to store energy for use when the sun is not present. Batteries do no exist to store a daily volume of a 8MKw solar panel annual production.

#3. Contribution to achieving State or local government goals relating to natural and human resources, or economic and community development.

Answer: No comment concerning State goals, and local government goals are not established concerning solarfarms. It has recently been observed that many solar endeavors have entered the geographic area (and probably state wide) to "grab up land" while it is available.

Obviously, this is economically driven for the investors to position themselves first and eventually gain profit. Although the consumers may benefit through reduced power costs and lower billings, there is a "long term" factor waiting in the future. That is solar panel waste ! Is there a State program to assess clean-up costs and set aside, escrow, money from solar farm investors to contend with this future dilemma to properly dispose of solar panels. That is, to handle the toxic threat. This is a "real threat" and is occurring world wide, is not being dealt with properly, and is growing exponentially. Baldwin does not have any facility to dump waste, it is transported to a neighboring town. And, there are no current plans to establish a waste dump to contend with toxic materials from solar panels. A lot of answers need to be formulated.

#4. Extent of environmental impacts and alternatives that should be considered in the Agency's environmental review.

Answer: (A.) land: Four land categories should be considered (maybe more ?).

I. Best land - is useless land as deserts, wasteland, depleted gravel quarries, etc. (This solar farm is located in a closed quarry, perfect !

2. Abandoned industrial sites, parking lots, and similar, etc. Again, favorable land use.

3. Land that has low expectations as farm land, non-tillable soil, forests that have poor soil, etc. Caution should be exercised in this choice.

4. Farm land, both productive or future potential productivity. Must be definitely & totally avoided. Man's future will depend on food growth.

(History). The Central America Mayan population use to be 2 million, then quickly depopulated to 50,000 (before the Spanish arrived). It is believed the cause was "soil depletion" !!

(B.) Toxic chemical compounds used to fabricate the "electronic wafers" sandwiched between two sheets of glass. PHYSICS law: Matter can neither be created or destroyed. These chemical compounds will not disappear. The chemicals are: Lead, Cadmium, Lithium-Iron-Telluride, Cadmium Telluride, Copper Indium Selenide, Cadmium Gallium Selenide, Copper Indium Gallium Selenide, Hexafluoroethane (during manufacturing), & Silicon Tetrachloride (a byproduct of producing crystalline silicon during manufacturing). May have missed a few !! Not all are used. Some are in the past and now others used as replacements as manufacturing techniques change and improve. All have some toxic elements of "varying" degree in strength. All chemical bonding forms shall remain as poisons to animal life. Chemicals ending in "ium" are metals & heavy metals. Chemicals ending in "ide" are 2 element compounds. BAD.

(c.) Economic. Currently, solar panels cannot economically be dismantled and salvaged. The cost to salvage and reclaim material is more than the material gained is worth. Therefore, most solar panels are THROWN away in landfills. BAD. What really needs to be avoided is "breakage of the glass". This occurs in two ways: I. thrown away in landfills and breakage occurs, 2. Breakage on solar racks while in use due to weather elements, wind, hail, tornado, whatever, etc. The result is the toxic compounds "leach" out thru the glass cracks, or totally broken glass, and enter the ground. NOW, toxic chemicals enter the water table and move. Remember, these toxic elements do not break down, poison forever, and accumulative.

(D.) There is a definite NEED to establish proper disposal of the solar panels. Toxic waste LEACHING into the ground MUST be prevented. Therefore, the solar farm creators should be required to fund the disposal of solar panels in the future. Financial escrow of funds should account for any future disposal both at "end of life" or "short term life" by element damage of these solar panels. If no funds exist from solar entrepreneurs, then tax payers will pay the bill. The gain of cheep solar electricity will be lost when taxes for disposal is paid by the consumer, not the provider.

Currently, it should be observed, electric production by solar is a small minor portion of ALL electric production whereas solar waste production is the most of all electric sources. (That' the simple analysis, to see it on a graph tells a better story). NÓ country, in the world, currently has control over waste except a few European countries. The U.S. is aware and beginning to act, but it is slow and has resistance in some political arenas. WASTE IS NOT GOING TO GO AWAY.

FOOTNOTE: Baldwin, Me., has recently accepted the first solar farm in this town. It is nicely situated in a closed gravel quarry pit area, the best place. Still, solar waste will evolve and become a reality in 25+ years. However, Two other entrepreneurs have approached this town. One is considering a large tract of land with "a lot" of stream protection and resource protection land space. This is in its infancy stage but efforts have been started to relocate delineation lines for shoreland and resource protection zones. If lines are moved, the WATER WILL STILL BE THERE. This is a most critical situation and everlasting damage to the habitat of this land and to both humans and wildlife will have occurred. The toxic chemicals shall always remain in the water table.

There are over 16,000 solar panels for the first solar farm, this is small. To discuss 40 to 50,000 panels is a reasonable expectation. Eventually, waste accumulation will be more than anyone has anticipated or imagined !! WHAT IS GOING TO BE DONE TO CONTROL WASTE IS THE BIG QUESTION ?? IS SOLAR WORTH THE DAMAGE CAUSED ?

A partial answer is to have ONLY roof top residential solar collecting arrays. This provides 24 hour electric source with battery back-up thus reducing the solar farm dependency on back-up fossil fuel electricity and reducing fossil fuel CO_2 output, (hydro is OK). BUT, there still remains a 25-30 year life span on roof top panels and a waste accumulation remains. ALSO, battery waste will be added to the problem. The answers do not come easily. Solar photovoltaic energy is a temporary fix in disguise, not really so great !!

Wes Sunderland: CEO. 625-7000 Wes

Assessment of the Risks Associated with Thin Film Solar Panel Technology

Submitted to

First Solar

by

The Virginia Center for Coal and Energy Research
Virginia Tech

8 March 2019
Blacksburg, Virginia, USA

Report Authors

The primary author for this report is William Reynolds, Jr., Professor, Department of Materials Science and Engineering, Virginia Tech; contributing author is Michael Karmis, Stonie Barker Professor, Department of Mining and Minerals Engineering & Director, Virginia Center for Coal and Energy Research (VCCER), Virginia Tech.

The work reported herein was performed and managed independently by VCCER. The assessments and opinions expressed are those of the authors.

Acknowledgments

The authors thank First Solar, Inc., for providing access to audit its Perrysburg, OH, manufacturing and recycling facilities. The authors would like to acknowledge the following First Solar, Inc., personnel for coordinating the plant visit and responding to questions: Dr. Parikhit Sinha, Senior Scientist; Clarence Hertzfeld, Plant Manager; Jacob Benjamin, Recycling; John Brewis, Reliability Lab; Lou Trippel, Vice President, Product Management; and, Thomas Sullivan, Director of Environmental Health and Safety, North America.

1 Summary

This report reviews the environmental risk profile of utility-scale cadmium telluride (CdTe) photovoltaic installations with relevant information from the scientific literature and an audit of the manufacturing and recycling facilities of a domestic manufacturer. Current photovoltaic technologies are described, and the environmental and health issues associated with CdTe are identified. Solubility measurements, bioavailability, acute aquatic toxicity, oral and inhalation toxicity, and mutagenicity studies all confirm CdTe has different physical, chemical, and toxicological properties than Cd. The CdTe compound is less leachable and less toxic than elemental Cd. The risks to the environment arising from broken solar panels during adverse events are considered by reviewing experimental results, theoretical worst-case modeling, and observational data from historical events. In each case considered, the potential negative health and safety impacts of utility-scale photovoltaic installations are low. The need for end-of-life management of solar panels is highlighted in the context of recycling to recover valuable and environmentally sensitive materials. Based upon the potential environmental health and safety impacts of CdTe photovoltaic installations across their life cycle, it is concluded they pose little to no risk under normal operating conditions and foreseeable accidents such as fire, breakage, and extreme weather events like tornadoes and hurricanes.

2 Background

The *2018 Virginia Energy Plan*, required under Virginia Code § 67-201, was released by Governor Northam on October 2, 2018. The plan emphasizes that the legislature has supported:

- 5,000 megawatts (MW) of utility-owned and utility-operated wind and solar resources deemed in the public interest
- 500 MW of rooftop solar resources that are less than 1 MW in size deemed in the public interest
- $1.1 billion investment in energy efficiency programs by investor-owned utilities, and
- Cost recovery structures for projects that modernize the grid and support the integration of distributed energy resources.

The Plan also noted: "Given the economic development opportunities in the solar sector, solar energy has significant room to grow in the coming years. The Solar Energy Industries Association projects that solar energy will grow by an additional 2,293 MW over the next five years."

2.1 Purpose and Scope

This report reviews available risk assessments for cadmium telluride (CdTe) semiconductor materials used in the construction of thin film photovoltaic solar technology under consideration for Virginia solar facilities. The review is based upon a survey of technical literature and an audit of the manufacturing and recycling facilities of one domestic manufacturer of CdTe solar panels.

2.2 Photovoltaic Technologies

Technologies for converting solar energy directly into electrical energy, called photovoltaic or PV systems, have evolved rapidly over the past several decades. Commercial photovoltaic systems developed over this period may be grouped into three categories. First generation photovoltaics rely on crystalline silicon (c-Si) in either a single crystal or polycrystalline form to convert solar radiation to electric current. Second generation photovoltaics employ a thin film material such as amorphous silicon (a-Si), multi-junction amorphous and polycrystalline silicon, cadmium telluride (CdTe), copper indium diselenide or disulphide (CIS), or copper indium gallium diselenide/disulphide (CIGS) to do the energy conversion. Third generation photovoltaics add solar concentrators and trackers to the system and may use other semiconductor materials for the conversion process [4]. Each technology has specific strengths and weaknesses, and the overall driver behind all these technologies is the need to reduce the energy cost for consumers. The energy return is often couched in terms of parameters like the "energy payback time," which represents the time needed for a particular technology to produce the energy used to manufacture, install, operate, and decommission it [4].

Weather also plays an important role in the economy of photovoltaic technologies. Solar insolation (a measure of solar strength), temperature, and relative humidity are weather-related factors that impact the energy production of a solar facility. Insolation affects the amount of primary energy available for conversion to electricity, temperature influences the conversion efficiency of the photovoltaic semiconductor, and humidity affects the energy spectrum that falls on the solar panels. The solar insolation for Virginia is roughly halfway between the low values found in the northeast United States and the peak values found in the deserts of the American southwest. Virginia's temperature and humidity are both fairly high. Given these weather-related factors, the leading utility-scale photovoltaic technology is arguably thin film CdTe photovoltaics [10]. For this reason, the remainder of this report will focus on this technology.

3.1 Environmental and Health Issues

Some stakeholders have raised environmental and health concerns with thin film photovoltaic installations because of the use of cadmium compounds in the semiconductor thin film. Cadmium (Cd) is a heavy metal that has adverse effects on human health [11]. Cadmium occurs naturally in soil; the average concentration in Virginia soils is 0.15 mg of Cd/kg soil [12]. Common contributors of cadmium to the environment from human activity are the combustion of coal for power generation and the application of commercial fertilizers for agriculture. Human exposure to cadmium is higher for smokers than non-smokers [13]. Once dissolved in water, Cd can be incorporated into the tissue of crop plants [14] and make its way into the food chain.

Given the potential impact it poses on crops, one approach to assessing environmental hazards of Cd is to estimate the extent to which Cd contamination increases the Cd concentration of soil. For example, this strategy has been used to estimate that the Cd expelled during combustion at a 3000 MW coal-fired power plant deposits 0.00002 mg of Cd/kg soil over the land adjacent to the power plant [15]. A similar approach has been used to show that fertilizing soil with Cd-rich municipal sewage sludge may increase the Cd content of soil by 10 to 15% [12].

In analogous fashion, a simple mass balance (that ignores chemical differences between CdTe and Cd) suggests extracting the Cd contained in a typical CdTe thin film photovoltaic module and mixing it with the underlying soil could increase the concentration of Cd by an amount similar to that expected from fertilizing with municipal sludge. However, using this approach to assess the environmental risk from photovoltaic systems of CdTe is fundamentally flawed for two reasons: (1) it treats the toxicity of cadmium telluride as equivalent to that of cadmium without recognizing the significant chemical differences between the two [16, 17], and (2) it misrepresents the ways in which CdTe photovoltaic solar panels interact with the environment [18].

First, the environmental risks of CdTe and Cd cannot be assumed to be equivalent because the two substances are not chemically interchangeable. To draw a simple analogy, the properties of water (H_2O) are not similar to those of hydrogen gas (H_2) just because the two species both contain hydrogen. Just as it is improper to assume water can burn because hydrogen burns, it is invalid to treat CdTe as if it were as toxic as Cd.

The chemical difference between cadmium telluride and cadmium is partially reflected in their different physical properties. Cadmium telluride has a high melting point (1092°C) relative to that of elemental cadmium (324°C) and tellurium (449°C) [16]. The much higher melting point of CdTe reflects a strong chemical affinity of Cd for Te (bond strength > 5 eV) and the chemical stability of this compound [16]. In qualitative terms, cadmium and tellurium bind strongly to each other, so the cadmium in a CdTe molecule is less chemically available to react with other chemical species. For this reason, the toxicity of CdTe is expected to be different from that of elemental Cd, and CdTe also may have very different

At the system level, the quality of a utility-scale solar installation's electrical, mechanical, and energy yield can be certified by independent oversight agencies such as the VDE Testing and Certification Institute [25]. Many solar facilities also employ real-time tracking of energy yield with a granularity down to the level of a small number of connected panels. This level of monitoring makes it practical to identify photovoltaic panel failures and their location as soon as they occur. Real-time monitoring helps ensure panels that become damaged by adverse events like storms are located immediately and quickly repaired or taken out of service. This kind of pro-active monitoring is important to maintain the energy yield of an installation, but it also mitigates the environmental risk of CdTe release from broken modules.

3.3 Adverse Events

The approach used in this report to assess potential risks from adverse events is to review: (*i*) experimental results, (*ii*) theoretical worst-case modeling, and (*iii*) observational data from historical events.

3.3.1 Field Breakage

Several assessments of the risks associated with the leaching of CdTe from broken photovoltaic modules are available. There are data from experiments simulating the exposure of broken modules to rain, there is worst-case total release modeling, and there are studies of the loss of metals from shredded photovoltaic modules (crystalline silicon and thin film types).

The fate of CdTe in broken solar module pieces subjected to rainfall was tested by Steinberger [26], who found no critical increase in soil Cd concentrations after 1 year of leaching in an outdoor experiment with actual rainwater. Also, tests in Japan subjected modules with 1 to 5 cracks to a quantity of simulated acid rain (pH 5) equivalent to 40 days of average rainfall; these experiments produced elution concentrations below Cd drainage and waste criteria [27].

In worst-case total release modeling, the extent of Cd leaching from broken CdTe modules in rainwater has been explored under different scenarios [28], and Cd concentrations were predicted to fall well below conservative human health screening levels [28].

A study by Tammaro [29] demonstrated that tumbling shredded photovoltaic modules in water for a day caused water to pick up detectable concentrations of most of the metals found in the original solar panels (Al, Pb, Sb, Ag, Cd from crystalline silicon solar panels and Al, Cr, Cd, Te, Se, Cu, Pb from thin film solar panels). However, it is not clear how the leaching behavior of a tumbled aggregate of centimeter-sized pieces relates to solar panels broken in service.

damaged by the tornado (1.8%). The damaged panels were collected, approximately 135,000 were recycled, and the remainder were disposed of. Sampling of soil and module pieces from the tornado event passed Toxicity Characteristic Leaching Procedure tests, and an environmental non-governmental agency contacted the U.S. Bureau of Land Management and reported no indication of soil contamination. *Link: Desert Sunlight Tornado Damage*.

September 2017 Hurricane Maria (category 5, maximum wind speed of 175 mph) struck the Sonnedix Horizon facility (Salinas Solar Park) in Puerto Rico and caused minor damage to the photovoltaic modules. Of the installation's 167,832 modules, only 872 were damaged (0.52%). *Link: Status Report After Hurricane Maria*.

September 2018 Hurricane Florence (category 4, maximum wind speed of 130 mph) struck the Carolinas causing minimal damage to the solar facilities of Duke Energy and Strata Solar, the two largest solar power operators in North Carolina, with over 20 facilities utilizing CdTe photovoltaics. Only one site experienced wind damage: 12 modules were damaged out of a total of more than 600,000 modules (0.002%). *Link: Minimal Damage After Hurricane Florence*.

October 2018 Hurricane Michael (category 4) struck Florida causing no damage to the solar facility of GameChange Solar in Tallahassee FL. *Link: GameChange Solar Systems Emerge Unscathed from Hurricane Michael*.

Only a small number of modules were damaged in each of the hurricanes noted. Consequently, the documented hurricanes did not cause any release of CdTe to the environment. Damage from the California tornado in 2015 was more serious, but even with the larger number of broken panels, environmental tests demonstrated CdTe was not released into the environment.

4 End of Life Management

At the end of the 25 to 30 year service life of the solar panels in a utility-scale photovoltaic installation, a significant volume of solar panels must be decommissioned, disposed of, or recycled. It was recognized at least a decade ago that large solar facilities presented unique challenges and opportunities for recycling photovoltaic modules [34]. One challenge is that the semiconductor material, CdTe, is a very small fraction of a thin film photovoltaic module ($\sim 0.1\%$ by weight), but it still must be extracted to provide raw material for future thin film photovoltaic module production. Because of the small quantity and low solubility of semiconductor material and the module encapsulation, the modules are characterized as federal non-hazardous waste at end-of-life using the Toxicity Characteristic Leaching Procedure [31].

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