UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the Matter of	)	Docket Nos. 50-266 and 50-301 NRC–2021–0021
NextEra Energy Point Beach, LLC	)	March 23, 2021
(Point Beach Nuclear Plant, Units 1 and 2)	)	
	)	

* * * * *

DECLARATION OF ALVIN COMPAAN, PH. D.

Under penalty of perjury, I, Alvin Compaan, declare as follows:

1. My name is Alvin Compaan. I reside in the Toledo, Ohio metropolitan area. I hold a Ph.D. in Physics from the University of Chicago and am a Professor Emeritus of physics from the University of Toledo. I presently am the President of Lucintech Inc., a research and development company with numerous patents in photovoltaics technology and thin-film neutron detectors. I have extensive academic and practical experience in photovoltaic solar power and its commercial applications both land-based and aerospace-based. I have been active in educating the public through TEDx and similar talks and through scientific presentations across the nation, State of Ohio, and to the Ohio legislature. I am the inventor of 12 patents in the area of solar and nuclear detectors and have authored more than 270 publications in refereed professional journals and conference proceedings. Between 1987 and 2009 at the University of Toledo I was the principal advisor to 20 Ph.D. and M.S. students and 13 postdoctoral fellows. My curriculum vitae is attached as Exhibit 7 to this Declaration.

2. I was asked by Physicians for Social Responsibility-Wisconsin to review the Environmental Report for NextEra Energy Point Beach, LLC's Point Beach Nuclear Plant, Units 1 and 2. What follows are my observations and conclusions, offered to a reasonable degree of scientific certainty based on my experience and relevant information sources.

The Case for Solar Electric Power to Replace Point Beach Nuclear

3. Contention: Solar Electric (Photovoltaic) Power. The Next Era Point Beach (hereinafter, NEPB) Environmental Report [*Applicant's Environmental Report Subsequent Operating License Renewal Point Beach Nuclear Plant Units 1 and 2*] fails to adequately evaluate the full potential for renewable energy sources, such as solar electric power or

photovoltaics (hereinafter "solar power"), to offset the loss of energy production from NEPB, and to make the requested license renewal action from 2030 to 2053 unnecessary. In violation of the requirements of 10 C.F.R. §51.53(c)(3)(iii) and of the GEIS § 8.1, the NEPB Environmental Report (§ 7.2) treats all of the alternatives to license renewal except for a) new nuclear, and b) the combination of natural gas combined cycle and 25MW on-site solar with battery storage as unreasonable and does not provide a substantial analysis of the potential for significant alternatives, such as a full solar power plus storage, in the Region of Interest for the requested relicensing period of 2030 to 2053. The scope of the Supplemental Environment Impact Statement (SEIS) is improperly narrow, and the issue of the need for NEPB as a means of satisfying demand forecasts for the relicensing period must be revisited due to dramatically-changing circumstances in the regional energy mix that are currently underway already during this decade of NEPB's remaining operating license (2013 to 2033), and can especially be expected to accelerate and materialize over two decades to come covering NEPB's requested license extension period extending to 2053.

4. Applicant Misconceptions Apparent in Solar Analysis in Environmental Report--The entire discussion of solar power in the NEPB application for renewal is reproduced below. This illustrates the shallow, cursory, and often out-of-date treatment of this very viable alternative to extending operation of NEPB to 80 years.

From: *NEPB Environmental Report (pp. 7-8, 7-9)*

7.2.2.2.2 Solar

Solar PV systems consist of interconnected PV cells that convert sunlight into electricity. Concentrated solar power (CSP) systems utilize mirrors to reflect and concentrate sunlight onto receivers to convert solar energy into thermal energy that in turn produces electricity. Solar PV can make use of both direct solar radiation and diffuse horizontal radiation, which is one reason PV is technically feasible in more areas of the United States than CSP technologies. The amount of direct and horizontal solar irradiation varies across the United States with northernmost states, including Wisconsin, experiencing the lowest annual solar irradiation in the United States. The annual average direct solar irradiation for Wisconsin is less than 4.0 to 4.4 kWh/m2/day and horizontal solar irradiance is less than 4.0 to 4.25 kWh/m2/day (NREL 2018a; NREL 2018b). The solar irradiance factors into the generating capacity of a facility. EIA estimated the generating capacity factor for solar generation for U.S. facilities at 30 percent (EIA 2020a); however, NEER estimated the generation capacity for the PB solar facility co-located with PBN to be 19.77 to 23.19 percent. (PB Solar 2019, Section 2.1). In contrast, the generation capacities of nuclear and natural gas-fired generation facilities are approximately 90 and 87 percent, respectively (EIA 2020a).

> Solar generation is intermittent by nature with no generation during nighttime hours. During the day, generation can fluctuate from hour to hour as solar irradiance varies. For a solar power facility to replace a baseload energy source, energy storage would have to be included for the solar facility. Energy storage technology has progressed in recent years, increasing the potential for solar facilities coupled with energy storage such as battery storage to mitigate solar's intermittent generation. For example, FPL has implemented a utility-scale battery storage facility to provide energy storage for one of its solar farms located in Florida (FPL 2019).
>
> A solar facility with the generating capacity to replace PBN's baseload generation would require a large amount of land and multiple sites. The Point Beach solar PV facility, a facility without energy storage, is approximately 565 acres with an installed capacity of 100 MW. (PB Solar 2019, Sections 1.1.1.3 and 2.1) The ratio of the acreage of the PB solar facility to its capacity can be used as a planning guide for the acreage needed to site a solar facility in Wisconsin. Using this ratio of 5.65 acres per 100 MW, the acreage needed for solar to replace PBN generation would be 6,780 acres. To consider solar as a replacement for a baseload energy source, battery storage, or other energy storage means, would have to be added at the facilities. Energy storage would require additional acreage. Due to the amount of solar generating capacity needed to replace the entire PBN baseload generation and the lower efficiencies in producing electricity from solar power versus nuclear power, the land acreage required to install solar generation would be significant. Depending on the location of the solar facilities, the land use disturbances could result in MODERATE to LARGE impacts on wildlife habitats, vegetation, land use, and aesthetics.
>
> Solar by itself is not considered a reasonable alternative for the replacement of the PBN generation because it cannot provide baseload energy. Solar with battery storage could be a reasonable alternative; however, its generation capacity is far less than nuclear generation. Furthermore, the solar generation capacity estimated for a Wisconsin location is also approximately two-thirds of that estimated by EIA as a U.S. average. The generation capacity would require the facilities to encompass more than 6,780 acres. Thus, discrete solar is an unreasonable alternative to the proposed action given that (1) solar must be coupled with energy storage to provide baseload energy; (2) the generation capacity of solar is significantly lower than other generation sources and lower still due to Wisconsin's solar irradiation levels; and (3) while solar coupled with energy storage could provide baseload energy, more than 6,780 acres would be converted to solar generation, which would result in significant impacts to wildlife habitats, vegetation, land use, and aesthetics at multiple sites. Solar with energy storage is a component of both combination alternatives and was not considered further as a discrete alternative due to the acreage requirements.

5. In the following discussion, we will introduce and support the following claims regarding misconceptions apparent in the above solar analysis in the Environmental Report of the NextEra Energy Point Beach Nuclear (hereinafter NEPB) License Renewal Application:

   a. <u>The NEPB Environmental Report fails to adequately assess the solar option</u>--We add comments and corrections to several details of the NEPB Environmental Report on the solar alternative. These include improved estimates for solar electricity production for modern solar panels based on the solar irradiation resource for Wisconsin. We use these to obtain an improved estimate of land area required to fully replace NEPB with solar. We will show in subsequent claims that the NEPB's conclusion of "…MODERATE to LARGE impacts on wildlife habitats, vegetation, land use, and aesthetics" are wholly unsupported and should be assessed as MINIMAL.

b. Solar is low cost and available--The supply of modules is growing rapidly and cost of solar power has been falling dramatically so that today solar power is the lowest cost electricity in many regions of the U.S. and internationally. In contrast even with established nuclear, this declining cost curve provides a strong incentive to examine the solar option in detail.
c. Solar is suited to Wisconsin--Suitability of solar in the NEPB territory. NEPB's discussion of the solar resource appropriate for flat solar modules (kWh of sunlight per square meter per day) in Wisconsin is approximately valid but we have used a more appropriate estimation method that includes optimally tilted panels and the small losses that occur with inverters that convert DC to AC power
d. Land and rooftop space is readily available for Solar—In this section, we directly address NEPB's conclusion that discrete Solar must be rejected because of excessive "acreage requirements" and consequent impacts on "wildlife habitats, vegetation, land use, and aesthetics."
e. Several excellent options are available for energy storage--A variety of energy storage technologies is available today to balance the intermittency of solar. These include pumped hydroelectricity and battery storage. We choose to focus on battery storage since the technology of large-scale batteries for electricity energy storage has been improving rapidly and the costs have been dropping quickly. This makes solar plus battery storage a very attractive and adaptable alternative to replace NEPB nuclear power
f. Solar + Storage is scalable and adaptable--Modern electricity usage requires adaptability which Solar + storage is ideally suited to provide much better than baseload nuclear. Solar power is an intermittent power source, as discussed in the NEPB Environmental Report, however, the delivery of solar power closely follows the time-of-day demand curve, which can mitigate some of the need for baseload power.
g. Solar has minimal environmental impacts--Solar has extremely low environmental impacts even compared with existing nuclear plants. Nuclear power from existing nuclear plants is often considered to be carbon free but this is not true when the complete fuel cycle of nuclear power is considered. Actually, solar power has a CO_2 footprint that is smaller than the full fuel chain of nuclear, even for existing nuclear power plants such as NEPB.

a. The NEPB Environmental Report fails to adequately assess the solar option.

6. Solar panels collect energy directly from the sun but also light energy indirectly scattered from clouds and the blue sky. For Wisconsin the optimum solar energy collection, averaged over a year, occurs with panels facing south and tilted about 30 degrees from

the horizontal. This maximizes energy collection over the year. We have used NREL's online PV Watts Calculator to calculate typical power produced from standard solar panels, after converting to alternating current by inverters. [https://pvwatts.nrel.gov/] This analysis shows that for Wisconsin, a capacity factor for solar of 20% is reasonable, as suggested in the NEPB Environmental Report. The NEPB report also does not discuss the derating of typically 14% in converting DC solar power to AC power. Our calculation using PV Watts includes this. We do agree with the NEPB report on the need for electricity energy storage to create baseload power and we calculate this storage requirement.

7. NEPB used the PB Solar facility example to estimate required land area of 565 acres per 100 MW of solar. (The stated 5.65 acres per 100 MW is a typo; it should be 5.65 acres per 1 MW. However, the calculated result of needing 6780 acres for a 1200 MW peak solar facility is about right.) Recent industry experience near Minneapolis showed 5.0-5.4 acres per MW for fixed rack solar and 6 acres for single-axis tracking mounts. [conversation with Brian Burandt, V.P. Power Supply and Business Development, Connexus Energy https://www.connexusenergy.com/]

8. However, we strongly disagree with the conclusion stated in the final paragraph on p. 7-9 which states: "Thus, discrete solar is an unreasonable alternative to the proposed action [second license renewal]…and was not considered further as a discrete alternative due to the acreage requirements." (emphasis added). In Claim 3 below, we complete the calculation of solar power and estimated land area needed to establish solar + storage as a baseload replacement for 1200 MW of baseload power and show that land and rooftop space entirely located in Wisconsin is not a constraint for the solar + storage alternative.

9. Consequently, we argue that the NEPB Environmental Report is seriously deficient in its consideration of solar power as a viable alternative power source for NEPB customers. The full rationale for this conclusion is elaborated in Claims **b** through **g** below.

b. Solar is low cost and available

10. Many utilities and electricity generators have seen the rapid drop in costs for solar panels and have recognized the opportunities associated with solar electricity for feeding power into the electricity grid. The attached chart (Exhibit 1) presents the experience curve for PV module prices since 1976. Experience curves plot price vs. cumulative production on logarithmic scales with several years highlighted on the graph. [Ketan Joshi in Cosmos Newsletter April 16, 2017, https://cosmosmagazine.com/technology/hurdles-on-the-path-to-a-solar-powered-world/] Note the price drop from $3.00/watt in 2008 to $0.25/watt in 2020. This stunning drop in price in the worldwide market is a major reason for the rise in installations of solar systems in the last decade. Solar now often provides the cheapest source of electricity to the consumer.

11. As manufacturing volume increases and price drops, solar systems have become the generation technology of choice for U.S. utilities and consumers. This is illustrated in Exhibit 2 which shows the electricity capacity additions to the U.S. electrical grid between 2010 and 2020. The data show that for many of the last five years solar systems accounted for the largest amount of additions to the electrical grid capacity. Solar accounted for 43% of all additions to the grid in 2020. The increase in solar is larger than for wind and also for natural gas, with coal and nuclear accounting for negligible additions.

12. To appreciate the scale and rate of growth in the amount of solar which has been added to the US electricity grid in recent years, consider Exhibit 3 which provides historical data and projections on three different types of solar installations: large utility-scale installations, medium size commercial rooftop installations, and smaller residential rooftop installations. The total amount of solar generation capacity added in 2020 was approximately 20,000 megawatts or 20 gigawatts. Note that total U.S. solar installations in 2020 are many times larger than the 1.2 GW power output of the Point Beach Nuclear generating facility. This demonstrates that the manufacturing supply and installation capacity for solar systems could easily accommodate the installation of solar that could replace Point Beach Nuclear facility by 2030 or 2033. The data of Exhibit 3 also confirm the consistent growth rate of 30% to 40% annually, and that growth is projected to continue over the next decade.

13. To appreciate the rate of growth of solar in the United states and its potential impact on the utility industry, we quote from a report appearing in Greentech Media on March 12, 2021. This is from an analysis of a market report by Collin Smith of the firm Wood MacKenzie: [https://www.greentechmedia.com/articles/read/so-big-its-boring-the-rise-of-utility-scale-solar?utm_medium=email&utm_source=Daily&utm_campaign=GTMDaily]

> "In the second quarter of 2020, the U.S. hit 50 gigawatts of cumulative operating utility solar, without much pause to consider how momentous a milestone it was. In 2011, utility solar reached 1 gigawatt. It took roughly nine years for the country to hit 50 gigawatts, but now it's on track to reach 100 gigawatts by the end of 2023. Under Wood Mackenzie's current forecast, U.S. utility solar will surpass 250 gigawatts by 2029 and reach more than 1 terawatt of utility PV somewhere between 2042 and 2045."

c. Solar is suited to Wisconsin and the NEPB territory.

14. It is commonly believed that the desert southwest is the only region of the U.S. for which solar systems are economically viable for grid electricity and that northern states including Wisconsin are not attractive for solar power. There is some truth to the belief that the most promising geographic area for the expansion of PV systems is the West; however, dismissing the potential of solar in Wisconsin is based on a common misperception that solar energy from flat modules, the most common type of photovoltaic panel, is only generated from direct (clear sky) radiation from the sun, so-called "direct solar" irradiance.

However, all flat panel modules collect light quite well over much of the sky, which is particularly important on cloudy and partly cloudy days. Thus, the appropriate measure of photovoltaic solar energy production is the full-sky or global irradiance, not just the direct solar irradiance. To illustrate this, Exhibit 4 gives the NREL map of global solar irradiance for the U.S. Note that more than half of Wisconsin has annual global solar irradiance as good as the northern tip of California, and only 10% less than northern Florida and eastern Texas. Exhibit 4 also shows that the ratio of global solar irradiance in southern California or west Texas to southern Wisconsin is about 1.25, so that a southern Wisconsin system will generate 80% of the annual energy of the same size system in some of the best locations in the U.S.

15. At the state level, California, Texas, and Florida have recognized the benefits of solar and have moved aggressively to promote solar. This is illustrated by the table of Exhibit 5 which is taken from Wood Mackenzie's U.S. Solar Market Insight Report 2020 available at: www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight/. All three states installed about 3,000 MW of solar just in the year 2020. This is a peak power 2.5 times the power of Point Beach Nuclear.

16. To be accurate about the annual energy production of solar in Wisconsin, we have used the modeling program from the National Renewable Energy Laboratory (NREL), NREL's PV Watts (https://pvwatts.nrel.gov/) to determine the energy production near Madison and near Green Bay. Energy production was calculated for ground-mounted arrays facing south tilted at 30 degrees above horizontal. This is close to the optimum configuration. The PV Watts model includes typical inverter efficiency and therefore calculates the annual AC energy output for a 1.0 MW(DC) array of 1,357 MWh for Madison and 1,380 MWh for Green Bay. When the Green Bay output is averaged over 24 hr x 365 days (=8760 hr), the average output per hour is 0.157 MW (alternating current power from the inverter). Thus to replace the baseload 1200 MW Point Beach Nuclear with solar system(s) requires a total solar system(s) capacity of

(1200 MW/0.157 MW) x 1 MW (peak) = 7643 MW (peak DC).

17. Assuming a typical land area requirement of 5.5 acres/MW, we estimate the total land area needed for these solar systems would be 42,000 acres. In one giant array, this would occupy 65.7 square miles or a square 8.1 miles per side. This array size seems prohibitive, but in the following section (Claim **d**) we discuss several options for configurations that are eminently reasonable including commercial and residential rooftops, as well as using non-farmed land from the U.S. Conservation Reserve Program which totals nearly 100,000 acres in Wisconsin.

18. Solar technology is already proven for Wisconsin. Relatively large solar farms are already successfully operating in the state. As of May 2020, BlueEarth Renewables alone was operating 23 MW of solar farms in Wisconsin with sizes ranging from 1.1 MW to 7.45 MW. [https://bluearthrenewables.com/projects/butter-solar-projects/] In addition, on

March 17, 2021, three of Wisconsin's largest utilities announced plans to spend $446 million on a second large-scale solar farm with battery storage. [Wisconsin utilities planning second large solar-plus-storage project : Institute for Energy Economics & Financial Analysis] The 250 MW solar field would occupy about 2000 acres and include battery storage with capacity of 300 MWh.

19. It is clear that utility operators, municipal authorities, as well as large numbers of merchant businesses and homeowners recognize the value of moving to renewable electricity generation from solar including adding a storage option with batteries. It is now appropriate to consider carefully some of the most attractive places for locating that solar.

d. Land and rooftop space is readily available for solar in Wisconsin

20. Preceding claims have established that solar power is a very viable replacement for Point Beach Nuclear power for several reasons: 1) Solar is one of the cheapest options for providing electricity and the costs are continuing to decline. 2) Manufacturing capacity is easily capable of supplying quantities needed for full replacement of the Point Beach Nuclear capacity. And 3) solar radiation in Wisconsin is completely sufficient for the needed solar generation. In addition to these major benefits, however, it is important to consider where the solar modules can be located and have minimal environmental impact, even though in general, the environmental impact of solar is very low. In this section, we consider two opportunities for the location of solar to illustrate solar's adaptability. Note that solar is not constrained by needing access to cooling water. The first opportunity is to place solar on commercial and residential rooftops. The second opportunity is to place solar on farmland which is already set aside from production and is participating in the US Conservation Reserve Program.

21. The National Renewable Energy Laboratory has recently built a modeling tool to determine the available rooftops which are oriented properly and free of shading and other obstructions to serve as suitable locations for solar rooftop installations. This tool is called the State and Local Planning for Energy or SLOPE. [https://www.energy.gov/eere/slsc/downloads/state-and-local-planning-energy-slope-platform-overview] For the State of Wisconsin, this tool shows that residential rooftops could provide suitable space for average generation (over 24 hours) of 1382 MW of solar electric (total annual energy generation of 12,111,240 MWh). Commercial rooftop space suitable for solar panels could deliver average generation of 1760 MW (total annual energy generation of 15,415,280 MWh). For comparison, PB Nuclear operating at 1200 MW for a full year of 8760 hours would generate a total electric energy of 10,512,000 MWh. Thus, we observe that the SLOPE tool demonstrates that either residential rooftops alone or commercial rooftops alone could host solar panels sufficient to cover all of the yearly electricity energy output of the PB Nuclear.

22. A second attractive location for placing solar modules, perhaps the most attractive, would

be to place the modules on land which has already been removed from active producing farmland and set aside in the US Conservation Reserve Program. Almost 100,000 acres in Wisconsin are currently enrolled in the conservation program. Using the ratio of 5.5 acres per 1 megawatt of solar, the Conservation Reserve Program land in Wisconsin could accommodate more than 18,000 MW of solar generation power. At a capacity factor of 20%, this 18,000 MW of solar peak power would generate a total electric energy per year of 31,536,000 MWh or three (3) times the annual energy output of PB Nuclear. This opportunity and other benefits of using conservation program land for solar have been analyzed in detail by the organization, Renew Wisconsin.

23. Renew Wisconsin states: https://www.renewwisconsin.org/solar-and-agricultural-land-use/

> ***Farm Land: Energy Production & Conservation***
>
> Our research turned up another unexpected fact: many farmers today are already in the energy production business. About 37% of the corn already grown in Wisconsin is used for ethanol, a common form of biofuel. Another way to look at this is that more than one million acres of farmland are allocated each year, on average, for the production of corn for biofuel.
>
> If just 11% of that land was allocated for solar PV, rather than ethanol production, we would generate enough power to supply 50% of our state's electricity demand exclusively from solar. Incorporating solar onto the farm is simply another form of Wisconsin-made energy that farmers can provide our state.
>
> Not only would the footprint of land to meet 50% of our electricity needs be small relative to other uses, it is a more efficient use of land as well. One acre of corn produces enough ethanol for an E15 vehicle to travel about 11,000 miles over the course of a year. One acre of solar PV provides enough energy equivalent to power 715,000 miles worth of battery electric vehicle travel.
>
> It is also worth keeping in mind that federal taxpayers are already paying to take cropland out of production through the U.S. Conservation Reserve Program. Today in Wisconsin, nearly 100,000 acres are not being farmed in order to preserve the land, but also to reduce the total amount of crops produced in order to manage oversupply.
>
> Farmland preservation programs require subsidy through tax dollars paid to the federal government. In contrast, utility-scale solar projects provide very similar land preservation and conservation benefits as the Conservation Reserve Program, but do not require taxpayer dollars. In fact, they inject money into the host communities through host lease payments, the county and municipal aid distribution formula and utility aid distribution formula found under Wisconsin's Shared Revenue Formula, and increased local spending.

24. To summarize this Claim on where to place the large amount of solar needed to replace PB Nuclear, we have provided two examples: one for rooftops and a second for Conservation Reserve land. However, these are only two examples. In general, a mixture of lo-

cations is likely to be the best solution. That would include traditional solar farms from 10 to 100 megawatts or more each, high voltage power line transmission easements, awnings, parking lot canopies, landfills, brownfields, and on highway rights-of-way, as well as rooftop installations and installations on Conservation Reserve land. The beauty of solar generation is that it is adaptable to a wide variety of configurations. Furthermore, on Conservation Reserve Land, landfills, brownfields, easements, and rights-of-way, the ground under the solar modules can be used for growing native grasses and other wildlife habitat, further reducing the already low environmental footprint.

e. Several excellent options are available for energy storage

25. The intermittency of solar and its related low capacity factor of ~20% means that energy storage is very important for solar to be a replacement for the baseload power from PB Nuclear. It must be pointed out, however, that nuclear plants do not have a 100% capacity factor but under ideal conditions must periodically be shut down for refueling. Other events or "excursions" often lead to additional shutdowns so that the nominal baseload power is not always available; Typically the nuclear plant capacity factor is about 90%. This means that the utility grid must be able to fill in for the periods when refueling and other outages occur and nuclear power is not available. These outages may extend for several weeks.

26, Furthermore, nuclear plants are unable to follow the demand curve of usage which typically peaks in the daytime and is very low at night. In the 1970's when several nuclear plants were built in Michigan, the utilities also constructed a pumped-water energy storage facility on the top of a dune near Ludington. This pumped hydro facility allowed Detroit Edison to send excess power from their Fermi II reactor more than 200 miles across the State of Michigan at nighttime to the Ludington facility to pump water from Lake Michigan to be released during daytime hours when peak demand occurs. The installation of new, more powerful turbines at the Ludington facility is scheduled for completion in 2021 to allow the facility to continue to serve nuclear plants as well as the increasing solar and wind installations in Michigan. [https://en.wikipedia.org/wiki/Ludington_Pumped_Storage_Power_Plant] (Note that the distance from Point Beach Nuclear plant to Ludington is only 60 miles across Lake Michigan.)

27. This example illustrates that variable demand, intermittent output from power plants is an issue that generators and utilities have dealt with for many years. Storage of energy is not new even for electricity which is generally difficult to store. In 2020 there are several different technologies that can be used to store utility-scale electricity. These include pumped hydro, underground compressed air energy storage [https://www.sciencedirect.com/science/article/pii/B9780128034408000063], electrolysis of water to produce hydrogen, and battery storage. In this Claim we will focus on battery energy storage which is becoming increasingly popular in combination with solar and wind. This battery technology is continually improving, and costs are dropping rapidly.

28. One example of the complementarity between large-scale battery storage and large-scale solar is the power plant now under construction by Florida Power and Light, which is a

subsidiary of NextEra Energy, the owner of Point Beach Nuclear. This FPL project now under construction was highlighted recently by Energy Storage News. [https://www.energy-storage.news/news/work-begins-on-409mw-900mwh-florida-battery-project-to-ease-natural-gas-pla]

29. An excerpt from the February 2, 2021, article follows:

> Construction work has begun in the US on what is claimed to be the world's biggest solar-charged battery storage project, by utility company Florida Power & Light (FPL).
>
> FPL, which is a subsidiary of major US power producer NextEra Energy, announced its plans for the 409MW / 900MWh project, FPL Manatee Energy Storage Center in Manatee County, Florida, back in March 2019. The battery energy storage system (BESS) is co-located with FPL's existing Manatee Solar Energy Center ground-mounted solar PV plant and is expected to be up and running towards the end of this year.
>
> The BESS is being deployed by the utility along with a number of smaller solar and energy storage projects nearby to enable to retirement of two ageing natural gas plants built in the 1970s, which have a combined generation capacity of over 1,600MW. FPL said that in addition to resulting in carbon dioxide emissions reductions, the Manatee battery project will also save its customers some US$100 million over the lifetime of the project by offsetting fuel costs and running on sunshine.

30. The worldwide numbers for battery energy storage deployed in 2020 show 3500 MWh of batteries installed usually with solar or wind. This report is from Wood MacKenzie and the U.S. Energy Storage Association (ESA). We quote from the article: [https://www.renewableenergyworld.com/storage/new-energy-storage-deployment-topped-record-3500-mwh-in-2020-esa-report-shows/]

> "2020 is the first year that advanced energy storage deployments surpassed gigawatt scale—a tremendous milestone on the path to our aspiration of 100 GW by 2030," said Jason Burwen, U.S. Energy Storage Association Interim CEO. "With continuing storage cost declines and growing policy support and regulatory reform in states and the federal government, energy storage is on an accelerating trajectory to enable a resilient, decarbonized, and affordable electric grid for all."

31. In conclusion, it should be clear that with recent advances in battery storage technology, increasing manufacturing scale, and reductions in costs, battery energy storage is a very viable option to combine with solar to provide a durable and reliable solution to the limited capacity factor of solar.

f. Solar + Storage is scalable and adaptable

32. The time period for this subsequent license renewal application for Point Beach Nuclear extends from 2030 to 2050 and in this period of time it is quite likely that requirements for electricity generation on the grid will change dramatically. In general, modern electricity usage requires adaptability which Solar + Storage is ideally suited to provide, much better than baseload nuclear. The increasing adoption of energy efficiency

standards and incentives, increasing adoption of wind and solar, and demand-side management, will all have important effects on the demand curve for electricity.

33. One example of this type of change is shown by recent demand in the California ISO. California has been a leader in providing incentives for adoption of wind and solar for their environmental advantages. In Exhibit 6 we show the demand for electricity on the CAISO which illustrates how these environmentally sustainable and intermittent energy generation sources such as wind and solar change the need for baseload power. The graph of Exhibit 6 shows that demand for electricity in megawatts (MW) on the CAISO interconnect for March 18, 2021. The orange trace shows the actual demand; the black trace shows the net demand after the wind power and solar power have been subtracted. Note that, for March 18 without wind and solar, CAISO could have accommodated a baseload of 20,000 MW, but with wind and solar the baseload was only 11,000 MW. Although the maximum demand was well over 25,000 MW the minimum demand on March 18 was only 11,000 MW. As the amount of solar and wind increase, this minimum demand could go all the way to zero so that no baseload power would be required in the middle of the day, for some days on the CAISO interconnect. This is the reason that the State of California provides strong incentives, and in some cases regulations, for battery storage to be installed together with solar and wind. Note that a large nuclear power plant like Point Beach, or for that matter a large coal-fired power plant, cannot be cycled down and up in power fast enough to follow this demand curve. There is too much thermal energy stored in a 600 MW energy generation facility to dial back the steam generation so quickly. So it is quite possible that by 2030 a 1200 MW supply of baseload power to replace PB Nuclear may be entirely superfluous.

34. The type of changes to the electricity demand curve experienced in California will inevitability come to other regions of the United states. This will likely include the State of Wisconsin and the other states served by the Midwest ISO interconnect. Recent appointments made by the Governor to Wisconsin's Public Service Commission point toward impending changes. In 2020, Tyler Huebner was appointed to the PSC of Wisconsin and some of these changes were described in a recent article in the online journal Utility Dive (July 6, 2020). https://www.utilitydive.com/news/taking-charge-wisconsins-newest-utility-commissioner-on-the-states-util/580494/

> Gov. Evers is also utilizing an opportunity to reshape the state's Public Service Commission. In March, he made his second commissioner appointment on the three-person commission, nominating Tyler Huebner, who served as executive director of renewable energy advocacy group RENEW Wisconsin from 2013 until his appointment this spring. Before RENEW, Huebner worked at the U.S Department of Energy's Office of Energy Efficiency and Renewable Energy, as well as the Wisconsin Division of Energy Services.....
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> …
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> Going into his new role, Huebner was very focused on what strategies would be needed to decarbonize the energy sector, he told Utility Dive.

> "How is this transition going to happen in a way that's balanced? You've got the utilities, we've got ratepayers, we've got the switch to renewables," he said. "I had a lot of experience in that world coming into this role."
>
> Huebner was assigned to oversee the state's Office of Energy Innovation and Focus on Energy programs, where he will work on improving energy efficiency policies as well as integrating new technologies such as electric vehicle charging infrastructure and other distributed energy resources. And part of the question, he says, as the state faces a rapidly changing power grid is how to continue ensuring utilities are incentivized to be part of this shift.
>
> "One of the things that's top of mind for us is how does energy efficiency and demand response and distributed resources fit into this utility-scale changeover," he said.
>
> "How do we do energy efficiency or demand response or customer-side renewables in a way that can count towards the utility's actual capacity and energy needs so that they're part of the plan"

g. Solar has minimal environmental impacts

35. Although nuclear power has low carbon dioxide emissions <u>during</u> power production, the carbon emissions from the overall fuel and power plant lifecycle are significant. An analysis of more than 100 lifecycle emission studies was done by B. Sovacool and published in Energy Policy **36**, 2950-2963 (2008). The best estimate of greenhouse gas emissions from <u>already-constructed</u> nuclear power plants was given as 66 grams of CO_2 equivalent per kWh. These emissions come mostly from the mining, milling, enrichment, waste management and disposal, and decommissioning. Solar power also has no emissions <u>during</u> power generation. Again there are some emissions during manufacture, mining, milling and purification. Several groups have analyzed emissions from PV power, most recently Kim and Fthenakis. [V.M. Fthenakis, H.C. Kim, and E. Alsema, Environ. Sci. Technol. 42, 2168-2174 (2008).] Their analyses include emissions from all energy sources including from mining, purification, materials suppliers and the electricity used in module production. For energy used in solar module production, Kim and Fthenakis used the average generation mix currently in the U.S. Their results show even lower CO_2 equivalent emissions from solar power than from nuclear. Of the solar technologies, crystalline silicon wafer-based modules had greenhouse gas emissions of 50 g of CO2-equivalent and thin-film cadmium telluride modules had only 20 g of CO2-equivalent emissions per kWh. Since 2008, the average manufactured module efficiencies have increased by about 20%, so the emissions per kWh are estimated for solar as ranging from 16 to 40 grams of CO2-equivalent, well below that of nuclear power.

36. Considerations of time-of-day availability of PV and details of the fuel mix will vary from state-to-state. On average the GHG [greenhouse gas] emissions will be less than derived without consideration of these factors. However, it is likely that carbon cap and trade policies will be implemented during the time frame of the requested NEPB license

extension and these would place a premium on generation sources with the lowest emissions. This would further favor solar power.

CONCLUSION

37. In conclusion, over the last decade technological advancements, manufacturing growth, deployment experience, and rapidly dropping prices have all established solar photovoltaics and battery storage as the most attractive technologies for grid power in Wisconsin. Not only does solar plus battery storage have compelling economic advantages today, solar plus battery storage has the lowest environmental footprint of any technology. It can power today's modern grid with the flexible and nimble response times that are demanded from a modern grid where voltage and frequency stability are of utmost importance. For these reasons and all the other environmental issues presented in the preceding discussion, we contend that the 20-year subsequent operating license renewals for the Point Beach Nuclear Plant units 1 and 2 should be denied.

March 22, 2021
Date

Alvin Compaan

Exhibit 1 Source: Ketan Joshi in Cosmos Newsletter April 16, 2017, https://cosmosmagazine.com/technology/hurdles-on-the-path-to-a-solar-powered-world/

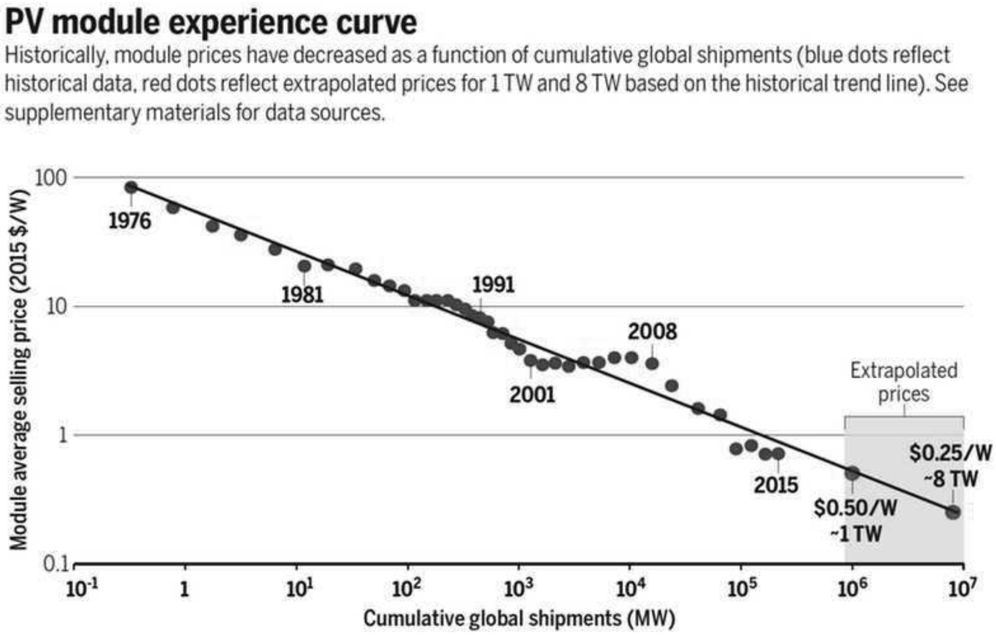


Exhibit 2 from: https://www.woodmac.com/news/opinion/four-ways-us-solar-broke-records-in-2020/?utm_campaign=pandr&utm_medium=email&utm_source=pardot&utm_content=four-ways-us-solar-broke-records-in-2020

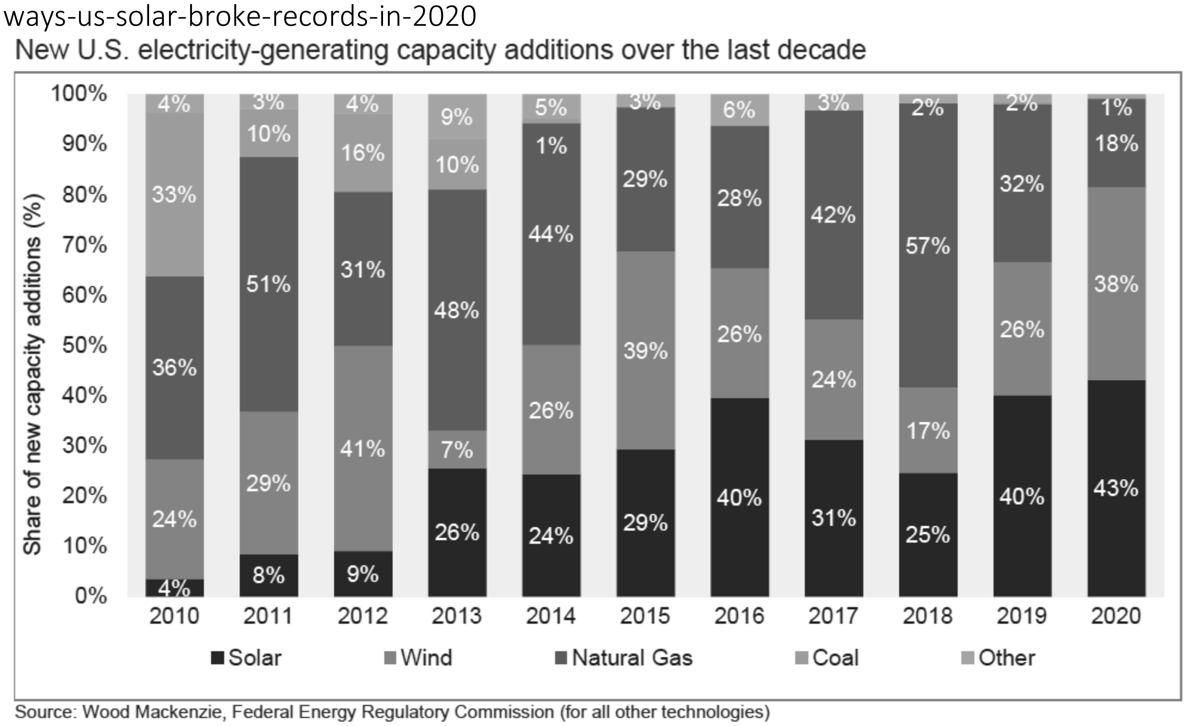
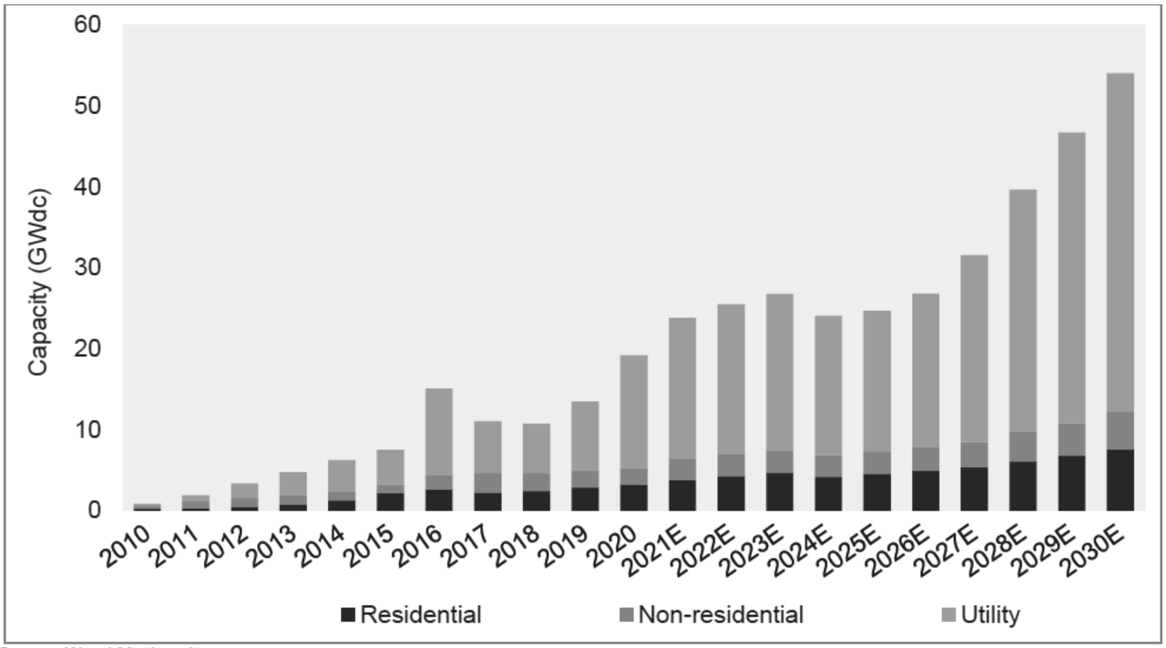


Exhibit 3 from: https://www.woodmac.com/news/opinion/four-ways-us-solar-broke-records-in-2020/?utm_campaign=pandr&utm_medium=email&utm_source=pardot&utm_content=four-ways-us-solar-broke-records-in-2020

U.S. solar PV installations and forecast, 2010-2030E



Source: Wood Mackenzie

Exhibit 4 from: https://www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg

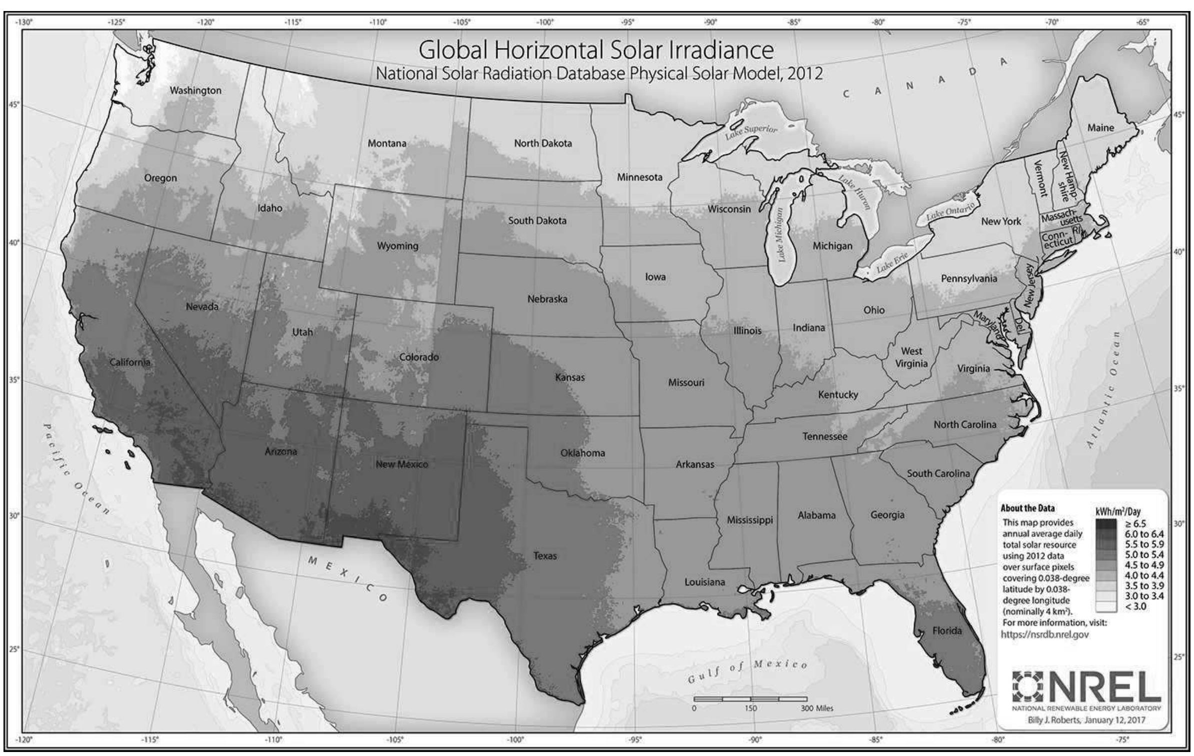


Exhibit 5 from: Wood MacKenzie U.S. Solar Market Insight Report 2020 available at: www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight/.

State solar PV installation rankings, 2020

	Rank			Installations (MW_{dc})		
State	2018	2019	2020	2018	2019	2020
California	1	1	1	3,236	3,103	3,904
Texas	2	2	2	1,010	1,412	3,425
Florida	4	3	3	865	1,366	2,822
Virginia	14	19	4	142	132	1,406
North Carolina	3	4	5	935	965	785
South Carolina	13	7	6	151	516	617
New York	6	8	7	441	473	544
Arizona	9	5	8	343	916	503
Utah	26	20	9	55	122	427
New Jersey	8	9	10	380	451	387

Exhibit 6: chart constructed by A. Compaan using data downloaded on 3/19/21 from: http://www.caiso.com/todaysoutlook/pages/default.aspx

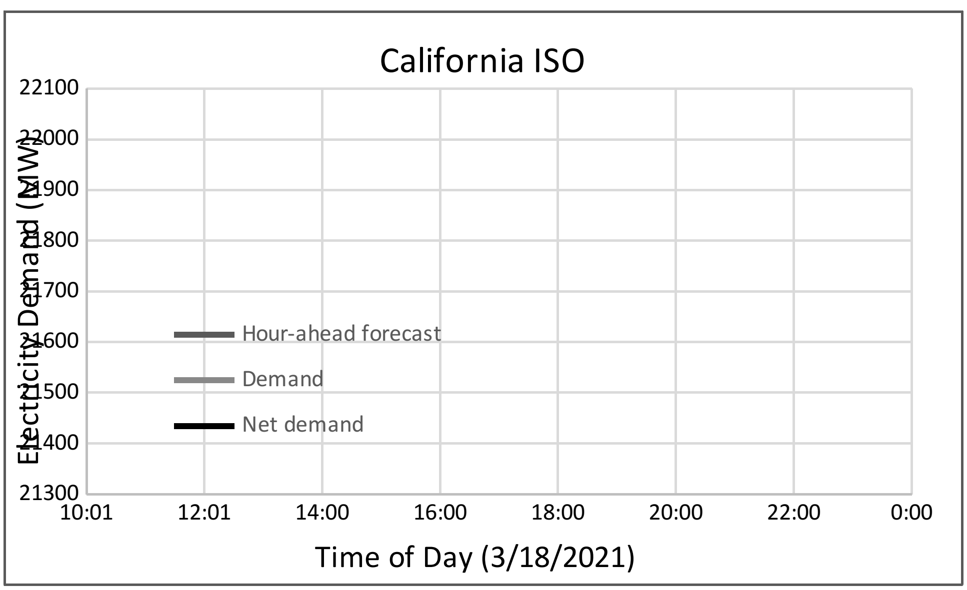


Exhibit 7: Alvin D. Compaan, Curriculum Vitae

NAME: Alvin Compaan
DEGREES: A.B., Calvin College, 1965
M.S., University of Chicago, 1966
Ph.D., University of Chicago, 1971

EXPERIENCE:
Teaching Assistant, University of Chicago, 1965-66
NDEA Title IV Fellow, University of Chicago, 1968-69
NSF Trainee, University of Chicago, 1969-1971
Research Associate, New York University, 1971-1973
Assistant Professor, Kansas State University, 1973-1977
Associate Professor, Kansas State University, 1977-1981
Professor, Kansas State University 1981-1987
Alexander von Humboldt Fellow, (Guest Scientist Max Planck Institute für Festkörperforschung - Stuttgart) 1982-1983
Professor of Physics, The Univ. of Toledo 1987-2005
Director, Thin Films Research Inst., 1991-96
TUBITAK Distinguished Senior Visitor, Bilkent U., Ankara, July-Aug. 1994
Guest Scientist: National Research Council--Ottawa (with J.J. Dubowski), Oct-Dec. 1994
Director, Center for Materials Science and Engineering, 1996-
Chair, Dept. of Physics and Astronomy, July 2004-2008
Distinguished University Professor of Physics, The Univ. of Toledo, 2005-2009
Distinguished University Professor of Physics, Emeritus 2009-
Chief Technology Officer and Co-Founder, Xunlight 26 Solar, LLC, 2008
President and CEO, Lucintech Inc, 2012-

HONORARY AND PROFESSIONAL SOCIETIES:
American Physical Society, A.A.A.S., International Society for Optical Engineering (SPIE),Union of Concerned Scientists, Materials Research Society, Sigma Xi, Sigma Pi Sigma

FIELDS OF RESEARCH COMPETENCE:
Resonant Raman Scattering, Semiconductor Physics, Laser Annealing of Semiconductors, Ion Implantation Studies, Thin Film Solar Cells, Laser Scribing, RF Sputtering, Pulsed Laser Deposition

REFEREE FOR:
Physical Review, Physical Review Letters, Journal of Applied Physics, Applied Physics Letters, J. Vacuum Science & Technology, Surface Science, Physica Scripta, NSF, ARO, DOE, Research Corp

PATENTS AWARDED: 12 U.S. utility patents

EXTRAMURAL FUNDING:

Research Corporation - "Spectroscopic Studies of Pure and Implanted Cuprous Oxide Using Tunable Lasers" ($10,000) 6/75 - 6/76.

NSF - "Raman and Photoluminescence Studies of Pure and Implanted Cuprous Oxide" ($48,000) 12/76 - 5/79

NSF - "Laser Light Scattering Studies of Exciton and Free Carrier Relaxation in Pure and Implanted Semiconductors" ($27,700) 2/79 -7/80.

IBM - "Design, Construction and Test of a Pupillary Response Visibility Meter (PRVM)" ($28,194) 3/80 - 9/80 (with C. Bennett, P.I.).

ONR - "Raman Studies of Surface Temperature in Laser-Heated Semiconductors" ($360,759) 4/80 - 9/84.

NSF (Science in Developing Countries) - "Pulsed Laser Annealing of Some Elementary and Compound Semiconductors" ($9,625) 3/83 - 2/85.

NSF (Chemical Instrumentation) - "A Tunable Pulsed Dye Laser Facility" ($101,700) 2/84 - 1/85 (with K. Klabunde, P.I., and five others).

USAF - UES "Summer Faculty Research" ($9,052) 5/85-7/85.

USAF - UES "Below-Melt-Threshold Excimer-Laser-Annealing of GaAs" ($20,000) 10/85-9/86.

USARO-BATTELLE "Excimer Laser Processing of HgCdTe", ($14,389), 4/87-8/87.

NSF - International Travel Grant to attend "Workshop on Advanced Raman Spectroscopy" in Kanpur, India, 7-11 Dec. 1987 ($1,641).

OBOR Grant - Research Challenge Program - "Central Materials Facility," 7/88 - 12/89 ($10,000) (with S. A. Lee, R. G. Bohn and C. Y. Tai).

Ohio's Thomas Edison Program and Glasstech, Inc., "Advanced Processing for Thin Film Solar Cells", 6/89 - 6/91 ($500,000) (with C.Y. Tai, co-investigator).

Ohio's Thomas Edison Program and Solar Cells, Inc., "Laser Processing for CdTe Solar Cells", 6/89 - 6/90 ($100,000) (with R.G. Bohn, co-investigator).

Solar Energy Research Institute (with collaborative efforts from Glasstech, Solar Cells, and Glasstech Solar), "Cadmium Telluride Solar Submodules Using Laser-Driven Vapor Deposition," 07/90-12/93 ($475,407) with R. G. Bohn as Co-Investigator.

Co-Investigator on SBIR grant with Principal Investigator from AVCA Corp. (Vaughn Baltzly). (Funded for $50,000, 6 months, starting September 1990).

Ford Motor Company - "Solar Photovoltaics," 10/91 - 9/92 ($30,000).

NASA, "Photophysics and Hydrogen Processing of Interstellar Carbon Solids," with A. N. Witt as Principal Investigator and C. Y. Tai, ($66,877), 8/92-.

National Renewable Energy Laboratory (NREL) "High Efficiency Thin Film CdTe-Based Solar Cells" (1/21/94-1/20/97) $374,848 (with R.G. Bohn and Y. Rajakarunanayake as co-investigators).

NSF, "High Resolution Spectroscopy for Undergraduates," 9/94-9/96, ($23,566 with UT match of $23,566) (with A.N. Witt and L.J. Curtis as co-PIs)

OBOR Research Challenge Program, "Semiconductor Thin Films for Large-Area Photo-Assisted Field Emission," $30,300 (6/94-6/95) with B.G. Bagley as co-PI.

NREL, "Optimization of Laser Scribing for Thin-Film PV Modules," ($255,000; 4/95 - 10/97), three lower-tier subcontractors: Solar Cells Inc., (Toledo, OH), International Solar Electric Technologies (ISET), (Los Angeles, CA), and C J Laser Corp., (Dayton, OH).

NREL, "High Efficiency Thin Film CdTe-Based Solar Cells" (extension) ($124,000; 1/21/97-3/31/98) (with R.G. Bohn as co-I)

NSF, "U.S.-Mexico Cooperative Research: Thin-Film Materials for Photovoltaics," INT-9901383, ($28,500 6/99-6/02)

NREL, "High Efficiency Thin-Film Cadmium Telluride and Amorphous Silicon Based Solar Cells," ($870,000; 2/1/98 - 1/30/01) (with X. Deng as Co-P.I. and R.G. Bohn as co-I)

NREL, "Acquisition of Hot-wire Deposition Chamber and In Situ Optical Absorption measurement for Thin Film Solar Cell Fabrication," $98,450 (funded 50/50 NREL and UT) 7/1/98--6/30-00.

NREL, "High Efficiency Thin-Film Cadmium Telluride and Amorphous Silicon Based Solar Cells," (2/1/98 - 1/30/01) [addition of $54,000), (with X. Deng as Co-P.I. and R.G. Bohn as co-I).

Solar Cells Inc., "Electrical and Optical Characterization of Photovoltaic Materials," 1/20/97 - 7/31/98 ($66,936).

Solar Cells Inc., "Laser Scribing and Optical Characterization of Photovoltaic materials," ($15,214.50 to date).

Electro Plasma Inc., "Collaborative Research on Color Plasma Displays with Enhanced Brightness," 1/1/99—8/25/00 ($109,274) (with X. Deng as Co-I)

Electro Plasma Inc., “Collaborative Research on Color Plasma Displays with Enhanced Brightness,” 4/01 – 3/02 ($112,990) (Compaan, P.I.)

NREL, "High Efficiency Thin-Film Cadmium Telluride and Amorphous Silicon Based Solar Cells," funded extension 3/5/01 to 10/15/01, $115,000.(*Compaan and Deng co-P.I.s, Bohn, co-I*)

NREL High Performance Photovoltaics Program, "Polycrystalline Thin-Film II-VI top cells for tandem photovoltaics,"($768,749 for 24 months, 4/3/01 – 6/3/03) (with V. Karpov and X. Deng as co-investigators and with First Solar, LLC, as a lower-tier subcontractor)

NREL "The fabrication and physics of high efficiency CdTe thin-film solar cells," ($770,265, 9/01-8/04) (Compaan and Karpov, co-P.I.s, Deng, Bohn, & Giolando as co-Is)

NSF “Partnership for Innovation “Northwest Ohio Partnership on Alternative Energy Systems” (Frank J. Calzonetti, P.I., Coleman, Compaan, Deng, Stuart, co-Is)[$600,000, 10/1/02—9/30/05]

First Solar “Development of On-line diagnostics,” ($15,805, 10/31/03—12/31/03) Compaan, P.I.

Air Force Research Lab-Kirtland, “Light-weight and flexible thin-film solar cells based on a-Si and CdTe,” $1,647,545 11/20/02 – 12/31/06 (Compaan, P.I., Deng co-P.I., co-Is: Collins, Giolando, Marsillac, Karpov)

NREL “Sputtered II-VI alloys and structures for tandem PV,” ($780,000, 11/1/03—2/28/07)(Compaan, P.I., co-investigators: Karpov, Collins, Giolando)

NSF-STTR-through ITN Energy Systems, “P-type CdSe for thin-film top cells enabling high-efficiency monolithic tandem photovoltaics,” $50,000, 8/1/03--7/31/04 (Compaan, UT P.I.)

Air Force Research Lab-Wright Patterson (via Universal Technologies Corp), “Photovoltaic hydrogen for portable, on-demand power,” $1,620,000, 8/1/03—7/31/06 (Deng, P.I., co-Is: Compaan, Coleman, Giolando, Lipscomb)

Ohio Department of Development—“Center for Photovoltaic Electricity and Hydrogen,” $2,000,000 for capital equipment (1/1/04—6/30/07), Compaan, P.I., with co-Is: Giolando, Deng, Karpov

Air Force Research Lab-Kirtland, “Light-weight and flexible thin-film solar cells based on a-Si, CdTe, and CIGS” $2,517,932, 11/20/02-11/17/07 (Compaan, P.I., Deng co-P.I., co-Is: Collins, Giolando, Marsillac, Karpov)

Ohio Department of Development—“Center for Photovoltaic Electricity and Hydrogen-Enhanced Activities,” $99,920 (7/1/05—6/30/07) Compaan, P.I., with co-Is: Giolando, Deng, Collins, Karpov

NREL "The fabrication and physics of CdTe devices by sputtering," ($1,155,546, 3/1/05-4/30/08) (Compaan and Karpov, co-P.I.s, Collins & Giolando as co-Is)

Ohio Department of Development-- “Wright Center of Innovation: Photovoltaics Innovation and Commercialization” (6/1/07-5/30/10, $18.6 M, R. Collins, P.I.; Compaan one of 15 co-investigators) [UT is the lead institution ($9.3M) with Ohio State University ($6.8M) and Bowling Green State U ($2.5M)]

U.S. Dept. of Energy, University Photovoltaic Process and Product Development Support program, “Improved CdTe PV Modules by APVD,” R. Collins, P.I., Compaan, co-P.I., with co-Is Giolando, Marsillac and two industrial partners, Calyxo, USA, and Pilkington. $1,164,175 (05/15/08 – 5/14/11)

Xunlight 26 Solar/Ohio Dept. of Development-Advanced Energy Program—“Flexible Thin-Film CdTe PV Modules,” Collins, P.I., $360,000 (06/01/08 – 05/30/10)

Garland/Ohio Dept. of Development-Advanced Energy Program—“Garland BIPV Systems,” Compaan, P.I., $300,000 (6/01/08 – 5/30/10)

Ascent Solar/SBIR Phase II—“CdSe top cells for CdSe/CIGS Tandems,” K. Wieland, P.I., Compaan co-I, $200,000 (7/1/09 - 6/30/10)

Triton, Inc/SBIR phase II—“Laser Scribing Studies—Phase II,” $31,593 (6/1/08 - 12/30/09)

Air Force Research Lab-Kirtland, “Rapidly Deployable Solar Electricity and Fuel Sources,” $3,343,571, 4/8/08-10/1/09 (Marsillac, P.I., Deng co-P.I., Collins, co-PI, Compaan, co-PI, Giolando, Bigioni, Amar, Khare) [Additional 12 month funded extension to 10/1/2010, $2,980,860.]

Ohio Department of Development, Ohio Research Scholars Program, “Northwest Ohio Innovators in Thin Film Photovoltaics,” R.W. Collins, P.I., Co-P.Is: S. Marsillac, A. Compaan, F. Calzonetti, (July 2008-June 2013; $8,038,462)

PEER-REVIEWED PUBLICATIONS:

1. A. Compaan, L. Q. Lambert and I. D. Abella, Phys. Rev. Lett. 20, 1089 (1968) "Photon-Echo Dependence on Intensity."
2. L. Q. Lambert, A. Compaan and I. D. Abella, Phys. Ltrs. 30A, 153 (1969) "Modulation and Fast Decay of Photon-Echoes in Ruby."

3. A. Compaan, L. Q. Lambert and I. D. Abella, Optics Communications 3, 236 (1971) "Level Crossing Effects and Spin-Dependent Decay of Circularly Polarized Photon Echoes in Ruby."
4 A. Compaan and I. D. Abella, Phys. Rev. Ltrs. 27, 23 (1971) "Evidence of Strong Optical Super-radiant Damping in Ruby."
5. L. Q. Lambert, A. Compaan and I. D. Abella, Phys. Rev. A4, 2022 (1971) "Effects of Nearly Degenerate States on Photon-Echo Behavior."
6. A. Compaan, Phys. Rev. B5, 4450 (1972) "Concentration-Dependent Photo-Echo Decay in Ruby."
7. A. Compaan and H. Z. Cummins, Phys. Rev. B6, 4753 (1972) "Raman Scattering, Luminescence and Exciton-Phonon Coupling in Cu_2O."
8. A. Compaan and H. Z. Cummins, Phys. Rev. Ltrs. 31, 41 (1973) "Resonant Quadrupole-Dipole Raman Scattering at the 1S Yellow Exciton in Cu_2O."
9. A. Compaan, W. D. Langer, D. Eden and H. L. Swinney, Astrophysical Journ. 185, L105 (1973) "Collisional Excitation of CO by H_2."
10. A. Compaan, L. Q. Lambert and I. D. Abella, Phys. Rev. A8, 1641 (1973) "Short Time-Interval Behavior of Photon Echoes in Ruby Near Level Crossings."
11. A. Compaan, Solid State Commun. 16, 293 (1975) "Surface Damage Effects on Allowed and Forbidden Phonon Raman Scattering in Cuprous Oxide."
12. I. D. Abella, A. Compaan and L. Q. Lambert, Laser Spectroscopy, R. G. Brewer, ed., Plenum, p. 457 (1974) "Observation of Superhyperfine Modulation and Quantum Beats in Photon-Echo Spectroscopy in Ruby."
13. D. Powell, A. Compaan, J. R. Macdonald and R. A. Forman, Phys. Rev. B12, 20 (1975) "Raman Scattering Study of Ion-Implantation- Produced Damage in Cu_2O."
14. A. Z. Genack, H. Z. Cummins, M. A. Washington, R. A. Forman and A. Compaan, Phys. Rev. B12, 2478 (1975) "Quadrupole-Dipole Raman Scattering at the 1S Yellow Exciton in Cu_2O."
15. M. A. Washington, A. Z. Genack, H. Z. Cummins and A. Compaan, in Proceedings of the Third International Conference on Light Scattering in Solids, edited by M. Balkanski, R. C. C. Leite, and S. P. S. Porto, Flammarion Sciences, Paris, p. 29 (1976) "First Order Resonant Raman Scattering in the Yellow Exciton Series of Cu_2O."
16. A. Z. Genack, H. Z. Cummins, M. A. Washington and A. Compaan in Proceedings of the Third International Conference on Light Scattering in Solids, edited by M. Balkanski, R. C. C. Leite, and S. P. S. Porto, Flammarion Sciences, Paris, p. 34 (1976) "Symmetry - Forbidden Resonant Raman Scattering from Polar Phonons in Cu_2O."
17. A. Compaan, A. Z. Genack, H. Z. Cummins and M. Washington in Proceedings of the Third International Conference on Light Scattering in Solids, edited by M. Balkanski, R. C. C. Leite, and S. P. S. Porto, Flammarion Sciences, Paris, p. 39 (1976) "Experimental Tests of the Quadrupole - Dipole Raman Scattering Tensor in Cu_2O."
18. A. Compaan and J. R. Macdonald in Proceedings of the Third International Conference on Light Scattering in Solids, edited by M. Balkanski, R. C. C. Leite and S. P. S. Porto, Flammarion Sciences, Paris p. 612 (1976) "Resonance Raman Study of Ion- Implantation Produced Damage in Cu_2O."
19. R. M. Habiger and A. Compaan, Solid State Commun. 18, 1531 (1976) "Photoluminescence at High Exciton Densities in Cuprous Oxide."
20. J. F. Hesse, S. C. Abbi and A. Compaan, J. Appl. Phys. 47, 5467 (1976) "Resonance Raman Study of Annealing in Cadmium-Implanted Cuprous Oxide."
21. M. A. Washington, A. Z. Genack, H. Z. Cummins, R. H. Bruce, A. Compaan and R. A. Forman, Phys. Rev. B15, 2145 (1977) "Spectroscopy of Excited Yellow Exciton States in Cu_2O by Resonant Raman Scattering."
22. A. Compaan, Applied Spectroscopy Reviews, 13, 295-369 (1977) "Resonance Raman Scattering with Tunable Lasers."
23. R. M. Habiger and A. Compaan, Solid State Commun. 26, 533 (1977) "Lineshape Studies of the 1S Yellow Exciton in Cu_2O by Resonance Raman Scattering."

24. S. Chandra, A. Compaan and E. Wiener-Avnear, "Coherence and Quantum Optics IV" (1978), L. Mandel and E. Wolf eds. Plenum Press, New York, p. 27 "Higher Order Coherent Raman Scattering."
25. A. Compaan, E. Wiener-Avnear and S. Chandra, Phys. Rev. A17, 1083 (1978) "Second Order Coherent Raman Scattering."
26. E. Wiener-Avnear, S. Chandra and A. Compaan, Appl. Phys. Lett. 32, 268 (1978) "Third Order Nonlinear Suceptibility Ratios by CARS of Mixtures: CS_2 in C_6H_6."
27. A. Compaan and R. M. Habiger, 14th International Conf. on the Physics of Semiconductors, Edinburgh, Inst. Phys. Conf. Ser. No. 43 (c) 1979, p. 489 "Resonance Raman Measurements of Exciton- Phonon Dynamics in Cu_2O."
28. R. M. Habiger and A. Compaan, Phys. Rev. B18, 2907 (1978) "Width of Resonance Raman Enhancement Profiles in Cu_2O: The Phonon- Lifetime Contribution."
29. A. Compaan and S. Chandra, Optics Letters 4, 1970 (1978) "CARS with Counterpropagating Laser Beams."
30. S. Chandra, A. Compaan and E. Wiener-Avnear, Appl. Phys. Lett. 33, 867 (1978) "Coherent Raman Scattering with Three Lasers."
31. J. F. Hesse and A. Compaan, J. Appl. Phys. 50, 206 (1979) "Resonance Raman Studies of Annealing in He-, Na-, and Cd- Implanted Cuprous Oxide."
32. S. Chandra and A. Compaan, Optics Communications 31, 73 (1979) "Double Frequency Dye Lasers with a Continuously Variable Power Ratio."
33. H. W. Lo and A. Compaan, J. Appl. Phys. 51, 1565 (1980) "Raman Measurements of Temperature During CW Laser Heating of Silicon."
34. H. W. Lo and A. Compaan, Phys. Rev. Lett. 44, 1064 (1980) "Raman Measurement of Temperature During Pulsed Laser Heating of Silicon."
35. S. Chandra, A. Compaan and E. Wiener-Avnear, J. Raman Spectroscopy 10, 103 (1981) "Phase Matching in Coherent Anti- Stokes Raman Scattering."
36. A. Compaan and H. W. Lo in Laser and Electron Beam Processing of Materials, edited by C. W. White and P. S. Peercy, Academic Press, New York (1980) p. 71, "Raman Temperature Measurements During Laser Heating of Silicon."
37. A. Compaan and H. W. Lo in 11th Int. Conf. on Defects and Radiation Effects in Semiconductors, Proceedings (Sept. 8-11, 1980, Oiso, Japan), Inst. of Phys. Conference Series (London) (1981) p. 467, "Pulsed Raman Measurements of Laser-Heated Silicon."
38. H. W. Lo and A. Compaan, Appl. Phys. Lett. 38, 179 (1981) "Pulsed Raman Measurement of the Onset of Recrystallization in Laser Annealing."
39. A. Compaan, H. W. Lo, A. Aydinli and M. C. Lee, in Laser and Electron-Beam Solid Interactions and Materials Processing, Gibbons, Hess and Sigmon, eds. (North Holland, 1981) p. 15, "Time-Resolved Raman Scattering and Transmission Measurements During Pulsed Laser Annealing."
40. M. C. Lee, H. W. Lo, A. Aydinli and A. Compaan, Appl. Phys. Lett. 38, 499 (1981) "Time-Resolved Optical Transmission of Pulsed Laser-Irradiated Silicon."
41. A. Aydinli, H. W. Lo, M. C. Lee and A. Compaan, Phys. Rev. Lett. 46, 1640 (1981) "Induced Absorption in Silicon Under Intense Laser Excitation: Evidence for a Self-Confined Plasma."
42. J. A. Van Vechten and A. D. Compaan, Sol. State Commun. 39, 867 (1981) "Plasma Annealing State of Semiconductors; Plasmon Condensation to a Superconductivity-Like State at 1000K?"
43. A. Aydinli, A. Compaan, H. W. Lo and M. C. Lee, Phys. Lett. 86A, 199 (1981) "Time Resolved Transmission of GaAs Under Intense Laser Excitation."
44. A. Aydinli, H. W. Lo, M. C. Lee and A. Compaan, Phys. Rev. Lett. 47, 1565 (1981) "Aydinli et al. Respond" (response to comment on "Induced Absorption ...").
45. A. Aydinli, M. C. Lee, H. W. Lo and A. Compaan, Phys. Rev. Lett. 47, 1676 (1981) "Comment on 'Lattice Temperature During Pulsed Laser Annealing'."
46. A. Compaan, H.W. Lo, M.C. Lee & A. Aydinli, J. de Phys. (Paris) 42, C6-453 (1981), "Pulsed Raman Measurements of Inhibited Electron-Phonon Coupling at High Plasma Densities in Silicon."
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GRADUATE STUDENTS DIRECTED

Robert M. Habiger
M.S. December 1975 "Photoluminescence Studies of the Yellow Series Free Exciton in Cuprous Oxide Using Pulsed and Continuous Wave Tunable Dye Lasers"
Ph.D. August 1978 "A Study of Exciton Lifetimes in Cuprous Oxide Using Tunable Dye Lasers"

Joseph F. Hesse
M.S. August 1977 "Resonance Raman Scattering and Optical Reflectivity Studies of Ion-Implantation-Produced Damage in Cuprous Oxide"

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Ph.D. August 1982 "Raman Measurements of Lattice Temperature in Silicon Under Intense Pulsed Laser Excitation"

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Ph.D. September 1984 "Transient Raman Studies of Intense Laser-Irradiated Silicon Under Pulsed Laser Annealing Conditions"

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Ph.D. May 1989 "Optical Studies of Extremely Heavily Doped n-GaAs Produced by Pulsed Laser Annealing"

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Ph.D. December 1991 "Thin Film Preparation Using Pulsed Laser Deposition"

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M.S. August 1988 "Laser Annealing Studies of HgCdTe and Surface Profiling Using Raman Spectroscopy"

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M.S. April 1991 "Photoluminescence and Raman Scattering from CdTe and CdS Films Grown by Laser-Driven Physical Vapor Deposition"

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M.S. Feb. 1991 "Spectral Quantum Efficiency Measurements in CdTe/CdS Solar Cells"

Marc Savage
M.S. Dec. 1992 "Raman Studies of Heavily Doped Polycrystalline Si-Films Prepared by Excimer-Laser Annealing of Doped a-Si:H."

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M.S. June 1993 "Photoluminescence Studies of CdS and CdTe Films Grown by LDPVD and RF Sputtering."

Zhirong Feng
M.S. June 1994 "Photoreflectance and Electroreflectance Studies of CdTe Films and CdTe/CdS Heterostructures"

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Ph.D. June 1995 "CdTe and CdS Thin Film Preparation Using RF Plenum Magnetron Sputtering"

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Ph.D. Oct. 1996 "Photoluminescence and Raman Studies of CdTe, CdS_xTe_{1-x} Alloys and CdS/CdTe Thin-Film Solar Cells"

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M.S. Mar. 1997 "Capacitance Measurements for Quantitative Analysis of Sputtered CdTe Solar Cells"

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M.S. Dec. 1997 "Optical Absorption of CdS_xTe_{1-x} Alloy Films at 10K"

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M.S., Dec. 1998 "SIMS Analysis of Cu in ZnTe-Based Back Contacts for CdTe/CdS Solar Cells"

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Ph.D., December 2002, "Superstrate and Substrate Type CdTe Solar Cells and Monolithic Integration of Photovoltaic Materials"

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M.S. 1997
Ph.D. August 1999, :Photoluminescence Study of Cu-doped CdTe and Related Stability Issues for CdS/CdTe Solar-Cell Devices"

Shogo Nakade
M.S., May 1999 "Time-Resolved Reflectivity Measurements on Thin-Film Photovoltaic Materials"

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M.S. June 2000

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M.S., June 1999 "ZnTe:N Film as a Back Contact Material for Solar Cells"

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M.S. December 2003

Ph.D. December 2005, “Studies of rf sputtered ZnTe:N and CdS for photovoltaic applications”

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M.S. 2005
Ph.D. December 2007, “Studies of two-terminal and four-terminal polycrystalline thin-film tandem solar cells based on II-VI materials.”

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Ph.D. December 2005, “Extended X-ray Absorption Fine Structure (EXAFS) and Photoluminescence Studies of CdTe Material”

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Akhlesh Gupta	4/01-7/05
Sunghyun Lee	3/02-2/04
Diana Shvydka	9/02-10/06
Shanli Wang	7/02-6/05
Xavier Mathew	7/05-7/06
Jennifer Drayton	1/06-1/07
Xiangxin Liu	6/07--
Snigdha Gupta	3/07—3/08
James Walker	3/07-8/07
Kristopher Wieland	7/07--