HARVARD | BUSINESS | SCHOOL

9-219-009

REV: AUGUST 7, 2018

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Project Helios: Harvesting the Sun

In late 2017, Ashley Telkes gazed across the sunlit woods adjacent to her home near Boston, Massachusetts. The sunny day reminded her of the decision she needed to make regarding her home. A marine biologist, Telkes was acutely aware of the impact that modern society was having on the environment and, to this end, she had tried to be cognizant of her own impact on the environment. Since purchasing her home, Telkes had pursued a number of passive measures to minimize her "carbon footprint," including re-insulating the roof and walls, opting for ceiling fans instead of air conditioning, and replacing incandescent lights with energy efficient LED bulbs. However, she was now confronted with a much bigger decision: whether or not to invest in solar panels to generate electricity for her home.

Although Telkes was pre-disposed to pursue environmentally friendly alternatives, she could not afford to make a poor financial decision. Telkes understood that the solar project would entail significant up-front expenses requiring that she withdraw money from her long-term savings to finance the project. She also knew that state subsidies to encourage the development of new solar power projects were likely to be reduced in the near future, potentially making it disadvantageous to delay. Although she had often thought that installing solar panels might be worthwhile, work and other commitments had not yet allowed Telkes sufficient time to work through the details of the project. However, time was now running out. The deadline to qualify for current state subsidies was looming and she needed to decide if pursuing a major solar power project for her home made financial sense.

Solar Power Generation

The idea of generating electrical power from the sun dated back to 1839 when, at age 19, Alexandre Edmond Becquerel discovered that an electric current could be generated by shining light on certain materials (the photovoltaic effect.)[1] However, it would take another 100 years for the first practical solar cell to be developed. In 1954, three Bell Labs scientists, Daryl Chapin, Calvin Fuller, and Gerald Pearson, demonstrated what they called a "solar battery," using it to power a small toy Ferris wheel.[2] Although the practicality and efficiency of their solar cell was limited,[a] recognition of their achievement

[a] Chapin, Fuller, and Pearson believed that an "ideal" solar cell might be able to convert as much as 23% of the sun's energy into usable electrical energy (the efficiency of the solar cell.) However, their demonstration solar cell was capable of converting only 6% of available solar energy into electricity. By 2009, with improved designs and advance materials, scientist were able to construct solar cells with over 40% efficiency.

Professor Mark Egan and Senior Lecturer E. Scott Mayfield prepared this case. The homeowner is based on an actual person whose identity is disguised. Funding for the development of this case was provided by Harvard Business School. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

was immediate. In a front-page article, the *New York Times* stated that the work of Chapin, Fuller, and Pearson "may mark the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams — the harnessing of the almost limitless energy of the sun for the uses of civilization."[3]

Initially, adoption of solar power was slow and confined primarily to toys or high cost applications in remote areas, such as satellites and lighthouses.[4] Eventually, government subsidies and technological improvements had led to more wide spread adoption. The efficiency of solar cells had increased significantly and, by 2018, ranged from 15% to 22%.[5] In addition, following "Swanson's Law"[b], the price of solar cells had fallen exponentially.[6] Since 2010, the average cost of generating a kilowatt-hour[c] (kWh) of power from residential solar panels had fallen by over 60% from $7.24/kWh to $2.40/kWh.[7] By 2018, over 50,000 megawatts of solar generating capacity had been installed in the U.S. (**Exhibit 1** shows the development of U.S. solar generation capacity through 2017.)

Table A Solar Irradiance by Location and Season (kWh/m²/day)

	Boston	Chicago	Houston	Los Angeles	Miami	Phoenix	Seattle
Latitude	42.21	41.89	29.77	34.05	25.77	33.45	47.61
Longitude	-71.30	-87.62	-95.38	-118.26	-80.18	-112.06	-122.34
Season							
Jan - Mar	3.9	3.4	4.5	5.3	5.6	5.7	2.5
Apr - Jun	5.8	5.9	6.1	7.0	6.4	7.9	5.5
Jul - Sep	5.9	6.0	6.1	7.3	6.0	7.1	5.8
Oct - Dec	3.2	2.9	4.6	5.0	5.1	5.3	2.0
Yearly Avg	**4.7**	**4.5**	**5.3**	**6.1**	**5.8**	**6.5**	**4.0**

Source: Source: https://pvwatts.nrel.gov/pvwatts.php (accessed 6/18/18).

Notes: Data are for a south-facing fixed roof array tilted at 20 degrees. Reported solar irradiance data account for typical cloud cover and environmental conditions associated with historical seasonal weather patterns.

The decision to invest in solar power depended critically on a site's location. Because of the tilt in the Earth's axis, the amount of available energy from the sun (solar irradiance) varied by location and season, with the number of daylight hours and the strength of the sun increasing in summer and decreasing in winter. In addition, prevailing weather patterns also affected the amount of solar energy that reached the ground at a specific location. (**Table A** provides average solar irradiance for various U.S. cities.) For example, the average daily solar irradiance per square meter in Phoenix was 6.5 kWh,

[b] Named after Richard Swanson, the founder of SunPower, Inc., Swanson's Law was the solar equivalent to Moore's Law and suggested that the cost of photovoltaic cells would fall by 20% with each doubling of global manufacturing capacity (https://www.economist.com/news/2012/11/21/sunny-uplands).

[c] A watt, a kilowatt (1000 watts), or a megawatt (1 million watts) describes the amount of power a device provides (or consumes) at a point in time. A kilowatt-hour (kWh) describes the amount of energy a device provides (or consumes) per hour. For example, powering a 1000 watt light bulb for one hour consumes one kilowatt-hour of electricity. Similarly, powering a 100 watt light bulb for 10 hours also consumes one kilowatt-hour of electricity.

while in Seattle it was only 4.0 kWh. As a result, the potential solar power that could be generated in Phoenix was greater than in Seattle.

The Investment Opportunity

To assess the potential solar panel investment, Telkes first reviewed her past electricity usage to determine her expected future consumption of electricity. Based on her monthly electric bills from 2017, Telkes consumed 8,551 kilowatt-hours of electricity per year, which had been relatively constant over the past few years. Because she typically spent the summer months conducting experiments on oceanographic research vessels, her energy consumption was significantly lower during the six months from April through September than for the six months from October through March. Telkes expected this pattern to continue in the future and that her *annual* consumption of electricity would remain constant over time. Including all generating and transmission costs, on average, her local utility company charged Telkes 21.3 cents per kilowatt-hour, such that she spent $1,818 in total on electricity in 2017. (**Exhibit 2** shows Telkes' usage of electricity in 2017.) Telkes anticipated that the cost of electricity would increase over time at the overall rate of inflation, which she expected would be about 3.0% per year.

Having estimated her expected future consumption of electricity, Telkes hired a consultant to determine the best location for the solar array and the amount of electricity that she could generate. The consultant determined that the best option was to construct a solar array consisting of 23 solar panels on the southeast facing roof of her house. The array would have a surface area of about 39 square meters and an efficiency rating of 19.3%. Based on these specifications, the proposed solar array would cost $30,500 to install and have the potential to generate 13,085 kilowatt-hours of electricity in its first year of operation.[d] The consultant cautioned, however, that because of the wooded nature of Telkes' property, her actual realized production would be substantially less. Having conducted a "shade study" of the location, the consultant anticipated that – in practice – the solar array would produce only 5,988 kilowatt-hours of electricity per year. However, the consultant proposed that by removing several particularly tall and poorly situated trees, the array would likely produce 8,367 kilowatt-hours of electricity per year. The consultant anticipated the cost to remove the trees would be about $3,000. (**Exhibit 3** summarizes the consultant's analyses of the array's expected monthly production under the two scenarios.)

To determine her expected savings from the project, Telkes compared her expected future consumption of electricity with the expected future production of electricity from the solar array. Her potential savings from the project depended on her decision regarding the tree removal proposal as well as the Massachusetts regulatory framework regarding *net metering*. (**Exhibit 4** provides an analysis of Telkes' pro forma 2017 net energy usage with the proposed solar array and full net metering.) Current Massachusetts regulations mandated *full* net metering,[e] which required utilities to credit consumers at retail prices for the excess electricity they generated.[8] These regulations meant that Telkes would receive <u>full credit</u> for the excess power she supplied to the utility during the summer months that would be used to offset the cost of the power that she demanded from the utility during the winter months. Although current Massachusetts regulations required that utilities purchase excess power at retail prices, Telkes was aware that other states were considering regulatory changes that would only require utilities to credit

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[d] The solar array was expected to have a useful life of 30 years, but its output was expected to decrease over time by about 0.5% per year. The system's inverter, which converted the DC current generated by the array into AC current that could be used in the home, had a shorter useful life and would need to be replaced in year 15 at a cost of $1,663.

[e] As of 2018, 43 states had adopted net metering policies. States without net metering laws generally purchased excess power from residential consumers at a discount to retail prices and/or had capacity limitations on net metering (freeingthegrid.org).

consumers for excess power at wholesale prices.[f] If Massachusetts were to change its net metering regulations and adopt a wholesale pricing framework, Telkes could receive as little 3 cents per kilowatt hour for the excess power she generated during the summer months.[9]

Regulatory Incentives

Both the state of Massachusetts and the Federal Government offered incentives to encourage the development of solar power projects. If Telkes went forward with the project, she would qualify for a $1,000 residential energy tax credit from the state of Massachusetts. In addition to the state tax credit, she also would qualify for a federal solar tax credit equal to 30% of the installation cost of her project. If Telkes decided to go forward with the solar project, she would realize $10,150 (=30%x $30,500+$1,000) in tax savings in the year after she installed the solar array.

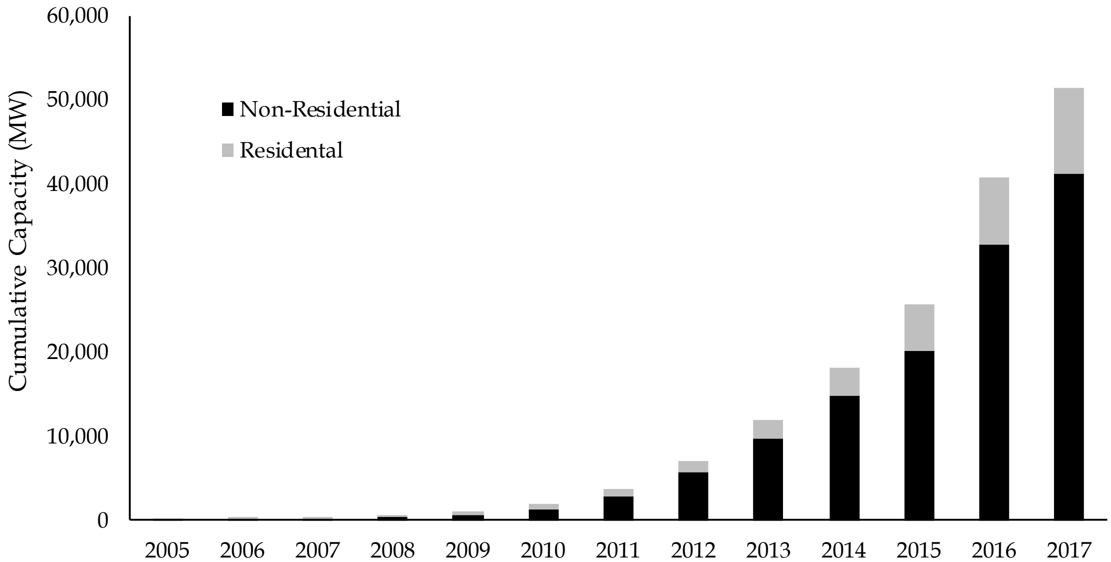
Electric utilities in Massachusetts were also subject to a renewable portfolio standard (RPS) that required them to generate a specific percentage of their electricity from solar each year. To meet the RPS, utilities could either generate electricity from renewable resources or purchase renewable energy credits from other utilities or households that generated electricity from renewable resources. Under the Massachusetts program, Telkes' solar array would be eligible to earn solar renewable energy credits (SRECs) for the next ten years. Specifically, for each 1.25 MWh of solar power that she produced, Telkes would earn one SREC. In addition to creating a market for trading SRECs in which the price fluctuated based on supply and demand, Massachusetts also determined a guaranteed minimum price schedule at which SRECs could be sold in each year. Based on these minimum prices, if Telkes produced 6.25 MWh of electricity in 2018, she would earn 5.0 SRECs (= 6.25/1.25) worth $1,355 (= 5.0 x $271). If Telkes decided to go forward with the solar project, the receipt of SRECs in each of the next ten years would be another benefit to consider. (**Exhibit 5** shows the schedule of minimum SREC prices.)

Conclusion

Understanding that federal and state incentive programs could be curtailed or reduced in the near future, Telkes needed to make a decision regarding the potential solar power project. She first wanted to establish whether going forward with her project made financial sense. Because the major costs associated with the project would be incurred immediately but the potential benefits would be realized over time, Telkes needed to determine the net present value of the costs and benefits of the project. To determine an appropriate discount rate, Telkes relied on a recent survey of discount rates used by financial investors in large solar power projects. Based on these survey data, she determined that the appropriate discount rate for her solar project was 5.0%.[10] In addition to financial factors, Telkes knew that her ultimate decision would also depend on the intangible costs and benefits of going solar. As the shadows from the adjacent tree line lengthened, the time to commit was fast approaching. The sun was beginning to set and a decision was required.

[f] For example, in 2015, the Nevada Public Utilities Commission abandoned full net metering for both existing and new solar installations and moved to a framework that credited consumers for excess electricity generation at the wholesale rate (http://puc.nv.gov/uploadedFiles/pucnvgov/Content/Consumers/Be_Informed/Fact_Sheet_Net_Metering.pdf).

Exhibit 1 Cumulative Solar Photovoltaic Capacity in the U.S. (Megawatts)



Source: Solar Energy Industries Association/ GTM Research Solar Market Insight Year-In-Review Report.

Notes: Cumulative capacity is calculated as the sum of annual photovoltaic power installed since 2005.

Exhibit 2 Telkes' Monthly Electricity Consumption: 2017

Month	Usage (kWh)	Rate ($/kWh)	Total Cost ($)
Jan	1,019	0.210	214
Feb	914	0.213	195
Mar	1,000	0.212	212
Apr	897	0.213	191
May	531	0.218	116
Jun	473	0.220	104
Jul	430	0.217	93
Aug	318	0.221	70
Sep	461	0.215	99
Oct	521	0.213	111
Nov	987	0.207	205
Dec	1,000	0.207	207
Total Year	**8,551**	**0.213**	**1,818**

Sources: Homeowner data.

Exhibit 3 Expected Monthly Electricity Production

Month	Solar Irradiance (kWh/m^2/day)	Array Size (m^2)	Number of Days	Panel Efficiency (%)	Potential Production (kWh)	Shade Study Scenarios: Available Sunlight (%) Keep Trees	Available Sunlight (%) Remove	Expected Production (kWh) Keep Trees	Expected Production (kWh) Remove
Jan	3.1	39.4	31	19.3%	739	17%	21%	126	155
Feb	4.0	39.4	28	19.3%	847	25%	39%	212	330
Mar	4.7	39.4	31	19.3%	1,106	34%	65%	376	719
Apr	5.5	39.4	30	19.3%	1,259	50%	76%	629	956
May	5.8	39.4	31	19.3%	1,375	63%	78%	866	1,072
Jun	6.2	39.4	30	19.3%	1,409	68%	82%	958	1,155
Jul	6.4	39.4	31	19.3%	1,513	67%	80%	1,013	1,210
Aug	5.9	39.4	31	19.3%	1,383	57%	77%	788	1,065
Sep	5.3	39.4	30	19.3%	1,211	42%	75%	509	908
Oct	4.0	39.4	31	19.3%	951	29%	53%	276	504
Nov	3.1	39.4	30	19.3%	712	20%	27%	142	192
Dec	2.5	39.4	31	19.3%	581	16%	17%	93	99
Total Year	**4.7**				**13,085**			**5,988**	**8,367**

Sources: https://pvwatts.nrel.gov/pvwatts.php (accessed 6/18/18) and homeowner data.

Exhibit 4 Pro Forma 2017 Net energy Usage with Full Net Metering (kWh, unless stated otherwise)

	Actual	Pro Forma Net Usage	
Month	**Usage**	**Keep Trees**	**Remove Trees**
Jan	1,019	893	864
Feb	914	702	584
Mar	1,000	624	281
Apr	897	268	(59)
May	531	(335)	(541)
Jun	473	(485)	(682)
Jul	430	(583)	(780)
Aug	318	(470)	(747)
Sep	461	(48)	(447)
Oct	521	245	17
Nov	987	845	795
Dec	1,000	907	901
Total Year			
Kilowatt-hours	8,551	2,563	184
Dollars [1]	$ 1,818	$ 545	$ 39
Implied 2017 Savings (Actual - Pro Forma)			
Kilowatt-hours		5,988	8,367
Dollars		$ 1,274	$ 1,779

Sources: Homeowner data and casewriter calculations.

Note: [1] Calculated based on an assumed cost of $0.213 per consumed kilowatt-hour. Power generated in excess of consumption (negative values) credited at the same price.

Exhibit 5 SREC Price Schedule

Year	SREC Price ($)
2018	271
2019	257
2020	244
2021	232
2022	221
2023	210
2024	199
2025	189
2026	180
2027	171

Sources: https://www.mass.gov/service-details/solar-carve-out-i-and-ii-clearinghouse-auction (accessed 6/28/18).

Notes: Notes: Reported prices are for SREC-II and are net of fees.

Endnotes

[1] "This Month in Physics History," APS News, American Physical Society, April 2009. Website: https://www.aps.org/publications/apsnews/200904/physicshistory.cfm, accessed July 11, 2018.

[2] Ibid.

[3] Vast power of the sun is tapped by battery using sand ingredient," *New York Times*, April 26, 1954.

[4] "The history of Solar," U.S. department of Energy, https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf, accessed July 11, 2018.

[5] "What are the most efficient solar panels on the market?," EnergySage, https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market, accessed July 11, 2018.

[6] "Sunny uplands." *The Economist,* 2012.

[7] "US Photovoltaic System Cost Benchmark: Q1 2017," National Renewable Energy Laboratory, 2017, https://www.nrel.gov/docs/fy17osti/68925.pdf.

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[9] "New England's Wholesale Prices in 2017 were the Second-Lowest Since 2003," ISO New England, 2018, https://www.iso-ne.com/static-assets/documents/2018/03/20180306_pr_2017prices.pdf.

[10] "Renewable Energy Discount Rate Survey Results - 2017," Grant Thorton, January 2018 and casewriter estimates.