Sunset Power Solutions

Live Brightly.

SPS

Eco-Entrepreneurship Project Final Report for Master of Environmental Science and Management

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Sunset Power Solutions

As authors of this Eco-Entrepreneurship Thesis Project report, we are proud to archive this report in the Bren School's library of Eco-Entrepreneurship Projects. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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Sean Parker

The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Eco-Entrepreneurship Project fulfills a core requirement for the Masters of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small teams of students conduct customer discovery research to develop a business model for a new environmental venture, in addition to focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Eco-Entrepreneurship Thesis Project Final Report is authored by MESM students and has been reviewed and approved in May 2017 by:

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Emily Cotter

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Sangwon Suh

Table of Contents

Snapshot: What We Do

Sunset Power Solutions provides clean, wireless lighting for any social occasion. Our product, the MoonLite, repurposes second-life lithium-ion batteries from electric vehicles to provide a stylish and easy-to-use lighting solution. The MoonLite runs on battery power for up to 15 hours, freeing event professionals from the hassle of laying and concealing power cables for lights, and significantly reducing their event setup and take-down time.

Compared to cabled lighting that runs on peak grid electricity or fuel-powered generators, the MoonLite is also better for the environment. Because it's battery-powered, event professionals can downsize, and in some cases completely eliminate, fossil fuel generators that are typically used to provide power at events. This means fewer greenhouse gas emissions, and less noise from dirty generators.

Our innovative business model capitalizes on the growth of electric vehicles (EVs) in the US. An EV battery is generally replaced after 100,000 miles, when they have degraded by 20-30% of their original capacity. While they can no longer meet the performance needs of EVs, these batteries still have a lot of power potential, and can be put to good use. This has opened up opportunities for a variety of "second-life" applications, such as the MoonLite. By working with automakers to procure second-life lithium-ion batteries at significantly lower cost than new batteries, we are able to produce a premium product at a fraction of the price. Additionally, this post-EV use case extends the useful life of valuable natural resources mined for battery development, of which the extraction is energy-intensive. Sunset Power Solutions is helping the world Live Brightly, one battery at a time.

Snapshot: Who We Are

Ali Uribe

Ali studied environmental studies and studio art as an undergraduate at Dartmouth College. She became increasingly interested in the emerging problem of e-waste disposal, and corporate social responsibility. As a graduate student at the Bren School, Ali is specializing in Corporate Environmental Management. Her interest for the responsible handling of e-waste, and eye for design lend themselves well to the core mission of Sunset Power Solutions.

Brian Jones

Brian studied Biology as an undergraduate at Penn State University before joining the Peace Corps and volunteering in Madagascar. After running a marine conservation program for a number of years, Brian came to the Bren School to refocus his career on the clean energy transition. Within the Sunset Power Solutions team, Brian is involved in researching emerging industry trends, developing financial models, and quantifying environmental benefits.

Jess Leader

Before coming to Bren, Jess was an editor for the Huffington Post's "Green News" vertical. As Director of Eco, Wellness and Social Responsibility for the HuffPost Partner Studio, she collaborated with partners like NRG, Chipotle, and Johnson & Johnson on environmentally-aware brand campaigns. Jess came to the Bren School to explore the politics of environmental decision-making. With SPS, Jess is responsible for team strategy, communications, and outreach.

Sean Parker

While enrolled full time at the Bren School, Sean works for the University on various construction projects across campus. He is interested in corporate sustainability, and, as vice-president of the local Net Impact chapter, works with the Bren community and alumni to promote sustainable business events, activities and opportunities for the Bren School. Sean brings technical design expertise, as well as a sound understanding of energy project development to the SPS team.

Snapshot: How We Did It

The Eco-E Opportunity

The electrification of transportation is taking the world by storm. Not only has the personal electric vehicle (EV) market flourished and seen an impressive upward trajectory in the automotive industry, but new auxiliary technologies are emerging in response to this growth. While a variety of factors play into the changing landscape, the evolution of the rechargeable battery has been integral to wide scale adoption of EVs. For over a century, lead acid and nickel cadmium were the established chemistries for rechargeable batteries. However, low power density, high maintenance needs, and fast degradation rates were significant obstacles for their use in EVs.

When lithium ion was introduced to the commercial market in the 1990s, this opened a door for high-power rechargeable battery applications, such as EVs. Ever since the first lithium-ion battery (LiB) based EV was introduced to the market in 2009, auto makers have adopted this chemistry base with alacrity. Today, the majority of new battery-based EVs are built with lithium-ion batteries. However, the power potential of LiBs has surpassed this linear use case. Although the battery can last through thousands of cycles, they are often retired once the battery has degraded to only about 80% of its original capacity. Between energy storage, fuel-based power generation and more, a number of other low-density battery applications are vying for affordable LiBs. As the EV market grows, and more of these batteries are retired from vehicles with significant power capacity still available, the potential for a second-life marketplace is exceptional.

Sunset Power Solutions was born after the team identified this trend and opportunity. We explored a number of potential applications, such as energy storage, commercial power generator substitution, and more. After speaking to more than 105 experts, academics, and potential customers, we found that building a cables-free lighting system would solve a well-defined customer pain point while simultaneously capitalizing on the second-life LiB market opportunity.

Customer Research

In order to validate this opportunity, the team interviewed more than 105 experts, industry leaders, and potential customers. We validated our business model through the feedback of 30 event professionals, who helped test our hypotheses about the need for a cables-free event lighting solution. We found that an overwhelming majority of event professionals would prefer not to use generators, struggle with running and concealing cables for lighting, and that they would be willing to pay more for a product that eased these pain points.

Business Model

Using second-life lithium-ion batteries, we assembled a working prototype which will serve as proof of concept for this industry. Our primary value proposition is a cordless event lighting solution. The MoonLite reduces setup time and labor costs, eliminates unsightly and hazardous power cords from events, and reduces the need for fossil fuel generators. Retailing at $1,250 per unit, the MoonLite will initially be sold directly to event professionals. We expect our financials to break-even in Year 3, with sales of 1,400 units, and will grow annual revenue to $18 million by Year 5.

Environmental Benefits

The MoonLite has significant environmental benefits. Our primary benefit is the downsizing and displacement of diesel generators. We found that over the course of its life, one MoonLite can displace up to 16 metric tons of CO_2 emissions, equivalent to taking 3.5 passenger vehicles off the road for an entire year. However, a number of societal environmental benefits come from this product as well. The MoonLite extends the useful life of lithium-ion batteries, the production of which negatively impacts both the environment, as well as human health. It encourages the adoption of LED lights over incandescent, and can be charged with grid electricity during off-peak hours.

Next Steps

In addition to refining our value proposition and product design through continued customer interviews and demonstrations, we plan to secure seed funding and look for market opportunities beyond event lighting.

Acronyms & Terminology

BEV – Battery-Powered Electric Vehicle
CAGR – Compound Annual Growth Rate
CCI – Consumer Confidence Index
CEC – Community Environmental Council
CO_2 – Carbon Dioxide
CPUC – California Public Utilities Commission
EIA – U.S. Energy Information Administration
EOL – End of Life
EPA – U.S. Environmental Protection Agency
EV – Electric vehicle
HEV – Hybrid Electric Vehicle
IoT – Internet of Things
Kg – Kilogram
kWh – Kilowatt hour
LED - Light emitting diode
LiB – Lithium-ion battery
OEM – Original equipment manufacturer
PG&E – Pacific Gas and Electric
PHEV – Plugin Hybrid Electric Vehicle
PM – Particulate Matter
SAM – Segmented Available Market
SCE – Southern California Edison
SPS – Sunset Power Solutions
TAM – Total Available Market
UCSB – University of California, Santa Barbara


Photo: Victor S. Brigola / Fraunhofer IAO

Section 1: Introduction and Background

- Electric vehicles (EVs) are experiencing rapid growth in the United States, and are expected to exceed annual sales of 500,000 by 2020.

- Lithium-ion batteries from EVs are typically replaced after around 100,000 miles, when they still have 70 - 80% of their original capacity left. This presents an opportunity for “second-life” applications, including energy storage, EV charging, and diesel generator replacement.

- After exploring a number of potential applications, cables-free event lighting presented the most compelling opportunity. This is a $350 million industry with a well-defined customer pain point that could be feasibly addressed by second-life LiBs.

Background: Technology

Electric Vehicles

The U.S. electric vehicle[1] (EV) market has been growing steadily since 2008, with sales expected to take off over the next five years (Figure 1).[2] *Electric vehicle* is a term that encompasses three vehicle classes: hybrid EVs (HEVs), plug-in hybrid EVs (PHEVs), and battery EVs (BEVs). See Table 1 for more information on the different type of EVs, and example models.

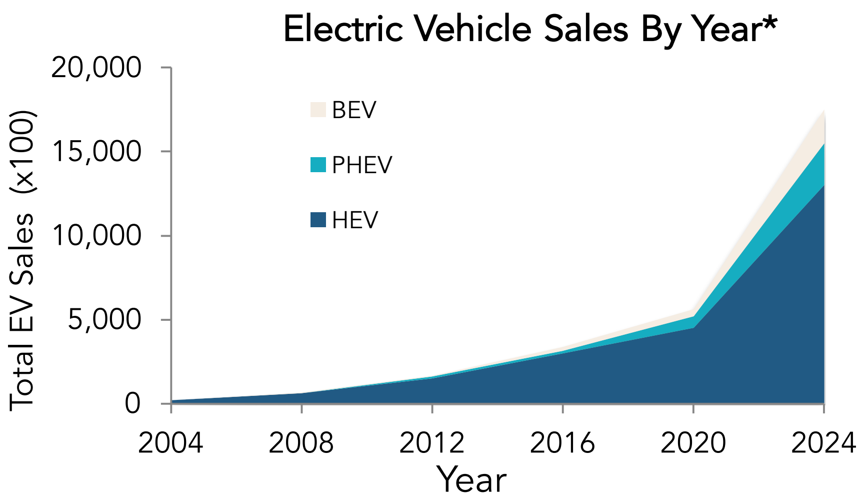

Figure 1 Historic and projected electric vehicle sales through 2024 (Source: Goldman Sachs)

Established automakers, such as Chevrolet and Nissan, have developed battery-powered EVs that can meet the needs of an average Americans' daily commute at an affordable price.[3] Additionally, Tesla, as a startup automaker, has built its business model around developing a mass-market, all-electric vehicle: the Model 3, which is already reported to have over 400,000 reservations, and deliveries scheduled for mid-2017.[4]

Table 1 Type of EVs, descriptions, and example models

Type	Description	Models
Hybrid electric vehicle (HEV)	Internal combustion engine (ICE) powers drivetrain, and is assisted by electric motor	Toyota Prius
Plug-in hybrid electric vehicle (PHEV)	Electric motor drivetrain, with onboard ICE that recharges battery	Chevy Volt, Toyota Prius Prime
Battery electric vehicle (BEV)	Electric motor powered only by batteries that are charged with grid power	Nissan Leaf, Tesla Model S, Chevy Bolt

This begs the question of "why now?" The growth in EVs is timely, and primarily driven by two factors: the decreasing cost of lithium-ion battery (LiB) technology, and federal and state incentives that effectively lower the cost of purchasing new EVs.[5]

Lithium-Ion Batteries

Beginning in 1991, LiBs were first used in mobile phones, laptops, and smaller electronics. However, lithium-ion batteries are particularly well suited for use in EVs, as they have a higher energy density and lower maintenance needs than other battery chemistries, like nickel-cadmium.[6] In 2009, Tesla released the Roadster -- the first EV powered by a lithium-ion battery and fully highway-legal. While nickel-cadmium batteries dominated earlier generations of HEVs, like the Toyota Prius, new PHEVs and BEVs, like the Chevrolet's Volt and Bolt, Nissan's Leaf, and Tesla's Model 3, all use lithium-ion chemistries. Now, less than a decade after the first LiB-based EV, manufacturers are able to design reliable vehicles with a range of over 200 miles at an accessible price for many middle-class consumers using this technology.

However, like all batteries, LiBs degrade over time. Manufacturer warranties typically cover EV batteries for up to 100,000 miles, or 8-10 years,[7] at which point the vehicles experience decreased range and acceleration, as well as increased charge times.[8] Yet these batteries still typically have between 70 – 80% of their original capacity.[9]

Empirical research shows that there is potential for "second-life" uses for LiBs once they've been retired from EVs.[10] While most of this research has focused on the use of second-life LiBs as grid-based energy storage, there are numerous other potential applications, including mobile EV-charging and generator replacement. The private sector has taken notice, and already a number of startup companies have begun developing products using second-life LiBs. These include Spiers New Technologies, which works with OEM auto manufacturers to "create second-life opportunities for advanced battery packs",[11] as well as FreeWire Technologies, with its Mobi line of EV chargers, and MobiGen line of generator replacements.

Background: Business Model

After identifying this trend, the Sunset Power Team recognized our position on the cusp of broad availability of second-life LiBs. We then began exploring opportunities to put these batteries to use in a way that delivers value to customers while providing an environmental benefit. Our goal was to connect with OEMs for low-cost, post-EV batteries that can be repurposed to a lower-density use case. (Figure 2)

Concept #1: Energy storage

We first looked at grid-based energy storage as a viable opportunity in the second-life battery market. Customers across the spectrum are adopting energy storage solutions to address specific energy needs, ranging from personal home use to behind- and front-of-meter demand response pain points.

In residential applications, homeowners with rooftop solar use energy storage to capture more energy from renewable sources while bringing down their costs for grid electricity. These customers charge batteries during the day, when solar arrays produce more electricity than their home consumes. They can then discharge batteries at night to reduce the amount of electricity drawn from the grid.[12]

Additionally, businesses are using behind-the-meter[13] energy storage to reduce peak demand and lower charges on their energy bills.[14] Finally, utilities are deploying front-of-the-meter energy storage to improve grid stability and provide peak power during the evening hours, when renewable energy sources fall off but demand on the grid remains high.[15] Industry experts view wide-scale deployment of front-of-the-meter energy storage as a key to solving the issue of the "duck curve": As more renewables are integrated into an

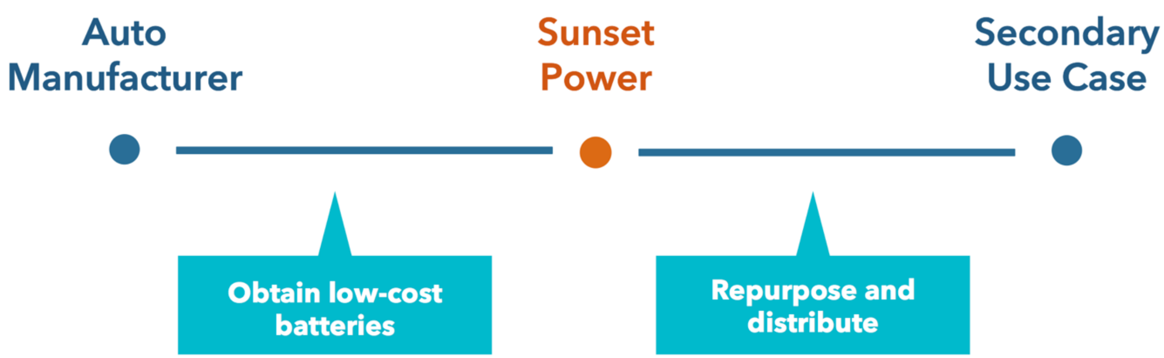

Figure 2 The SPS business model concept

energy portfolio, more energy is available during non-peak hours, creating a growing schism between energy need and availability. Batteries allow utilities to store growing amounts of intermittent renewable energy without needing to build expensive, inefficient natural gas "peaker" plants.[16]

According to Greentech Media, an industry research organization and popular blog, energy storage saw a compound annual growth rate (CAGR) of 243% in 2015, and is projected to grow to 1.5 gigawatts of annual deployments by 2020, which is a 540% increase over 2015 levels.[17] A number of technologies comprise the energy storage space; however, lithium-ion batteries make up a large majority of deployments,[18] despite the fact that this technology remains expensive.[19] We thus saw an opportunity to use inexpensive, second-life LiBs to offer a more affordable energy storage solution.

While energy storage is a high-growth market, interviews with industry experts helped us identify two key barriers to employing our second-life batteries in an energy storage solution: 1) Risk aversion and lack of price sensitivity in electric utilities, and 2) Regulatory hurdles that incentivize new lithium-ion batteries.

First, much of the industry's growth is being driven by electric utility procurements that result from regulatory mandates.[20] Utilities, as we learned through conversations with experts in the field, aren't highly price sensitive, since they are able to simply pass the costs of energy storage on to ratepayers. Additionally, they value reliability and view second-life LiBs as an unproven technology. Utility professionals indicated that, despite the cost savings, they would be unlikely to choose a startup company who uses new technology, and doesn't have a proven track record of historical successes, compared to established energy storage companies.

Second, programs that provide financial incentives for energy storage, like California's Self Generation Incentive Program, specifically exclude second-life lithium-ion batteries. This erodes the price advantage as the primary value proposition of a second-life battery system.

These reasons, as well as the intense competition we saw emerging in the energy storage industry, led us to explore other use cases. The team still saw value in the energy space, which led us to a tangential industry: Fossil fuel generators, and their many use cases.

Concept #2: Generator replacement

After pivoting away from grid-based energy storage, the team analyzed the opportunity to replace generators with second-life LiBs in situations where either a) there was no access to grid electricity, or b) grid electricity was inadequate, such as events with high power demands that could not be met by available venue power.

This opportunity arose because generators present users with a number of issues. They are often noisy, and thus inappropriate for most social events (such as weddings, parties, and corporate events). While a few of the newer, high-end generator models can muffle the noise, like Honda's WhisperQuiet line, these are also more expensive. In addition to noise concerns, the exhaust from fuel combustion is hazardous to human health. Generators must therefore be located outdoors, in well ventilated areas, and away from people.[21] This can be a logistical nightmare in many scenarios.

Finally, they require routine maintenance every 250 hours of operation, which becomes both expensive and time consuming.[22]

We spoke to 104 potential customers from a variety of industries, including film and photography, food trucks, general contractors, and event professionals. While we found that generator use was generally problematic across these industries, we also discovered that each industry had unique energy requirements and specific pain points that would need to be addressed by a custom second-life battery product. Designing a one-size fits all solution that could cut across multiple use cases would prove challenging. However, through the course of these interviews, we did identify a specific, well-defined pain point that could be addressed by a second-life battery product: event lighting.

Final Concept: Event lighting

As the team spoke with event professionals about generators, we realized that event lighting in particular presented a number of clear pain points that could be addressed by battery power. First, event managers struggle the most with generator pain points. They would prefer not to use them, as generators are loud, their exhaust limits where they can be placed, and, for those that own their generators, maintenance is an ongoing hassle. Second, unique pain points for this group revolved around lighting itself. Running cables for lights is time-consuming, extending event setup time and increasing labor costs; cables are also unsightly and present tripping hazards for event guests. The event professionals we spoke with were very excited about the idea of cordless lighting, and had relatively homogenous needs with regards to the duration and intensity of light they would need.

To further explore whether or not event lighting presented a suitable business opportunity, we conducted extensive research on the event lighting industry (Chapter 2), and spoke to 30 event professionals (Chapter 3) to better determine their pain points and develop a unique product offering.

Endnotes for Section 1

[1] We use "electric vehicles" as an umbrella term that encompasses hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and purely battery-powered electric vehicles (BEVs)

[2] Kooroshy, J., Ibbotson, A., Lee, B., Bingham, D.R., and Simons, W. (2015) *The Low Carbon Economy: GS SUSTAIN equity investor's guide to a low carbon world, 2015-25.* Goldman Sachs. Retrieved from: http://www.goldmansachs.com/our-thinking/pages/new-energy-landscape-folder/report-the-low-carbon-economy/report.pdf

[3] Linkov, J., (29 December, 2015) "The Most Satisfying Commuter Cars. *Consumer Reports*. Retrieved from: http://www.consumerreports.org/cars-the-most-satisfying-cars-for-commuting/

[4] Lambert, F., (7 June, 2016) "Tesla Model 3: there's a way to see where you are in the queue, check it before Tesla finds out." *Electrek*. Retrieved from: https://electrek.co/2016/06/07/tesla-model-3-reservation-queue-number/

[5] California Air Resources Board. "Vehicles" *Plug-in Electric Vehicle Resource Center*. Retrieved from: https://driveclean.ca.gov/pev/Costs/Vehicles.php

[6] Battery University. "Is Lithium-ion the Ideal Battery?" Retrieved from: http://batteryuniversity.com/learn/archive/is_lithium_ion_the_ideal_battery

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[8] FEV North America. (2015) Battery Durability in Electrified Vehicle Applications: A Review of Degradation Mechanisms and Durability Testing. Draft Report prepared for the Environmental Protection Agency

[9]American Chemical Society. (2013) "Understanding the life of lithium-ion batteries in electric vehicles." Retrieved from: https://www.acs.org/content/acs/en/pressroom/newsreleases/2013/april/understanding-the-life-of-lithium-ion-batteries-in-electric-vehicles.html

[10] Foster, M., Isely, P., Standridge, C.R., and Hasan, M.M. (2014) Feasibility assessment of remanufacturing, repurposing, and recycling end of vehicle application lithium-ion batteries. *Journal of Industrial Engineering and Management*. Vol. 7. Pp. 698 – 715.

[11] Spiers New Technologies. *Life Cycle Management.* Retrieved from: http://www.spiersnewtechnologies.com/#lifecycle-management

[12] Martin, R., (7 September, 2015) "Home Energy Storage Enters New Era" *MIT Tecnology Review.* Retrieved from: https://www.technologyreview.com/s/541336/home-energy-storage-enters-a-new-era/

[13] "Behind the meter" refers to an energy storage system that is located behind the owner's electricity meter, and generally does not discharge electricity back to the grid. "Front of the meter" energy storage, on the other hand, is not located behind any individual's electricity meter, and charges/discharges directly to/from the grid.

[14] Onderdonk, John. *California Institute of Technology*. Personal interview. 20 April 2016.

[15] Maloney, P., (22 December, 2015) "Storage in 2016: Utility-scale long-duration markets take the lead." *Utility Dive.* Retrieved from: http://www.utilitydive.com/news/storage-in-2016-utility-scale-long-duration-markets-take-the-lead/411232/

[16] Ibid.

[17] Munsell, M., (3 March, 2016) US Energy Storage Market Grew 243% in 2015, Largest Year on Record. *Greentech Media*. Retrieved from:https://www.greentechmedia.com/articles/read/us-energy-storage-market-grew-243-in-2015-largest-year-on-record

[18] D'Aprile, P., Newman, J., and Pinner, D., (2016) The new economics of energy storage. *Mckinsey & Company.* Retrieved from: http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/the-new-economics-of-energy-storage

[19] Ibid.

[20] An example of this is California's AB 2514, which directed the three major investor-owned utilities (IOUs) to procure at least 1.3 GW of energy storage by 2020.

[21] Rego, John. *Sony Studios.* Personal interview. 26 October 2016.

[22] Ballonoff, Loni. *Spark Creative Events.* Personal interview. 18 October 2016.

Photo: Dan O'Day / Junebug Weddings

Section 2: Business Environment Analysis

- Private event lighting is a $350 million subset of the $2.8 billion rental industry, which is growing at 4.2% CAGR.

- Ambient light at events is currently provided primarily by three products: bistro lights, chandelier lights, and, increasingly, balloon lights. There is currently no cordless ambient event lighting solution available.

- Event professionals have significant pain points related to generator use at events, as well as running and concealing cables for lights.

Analysis: Market Opportunity

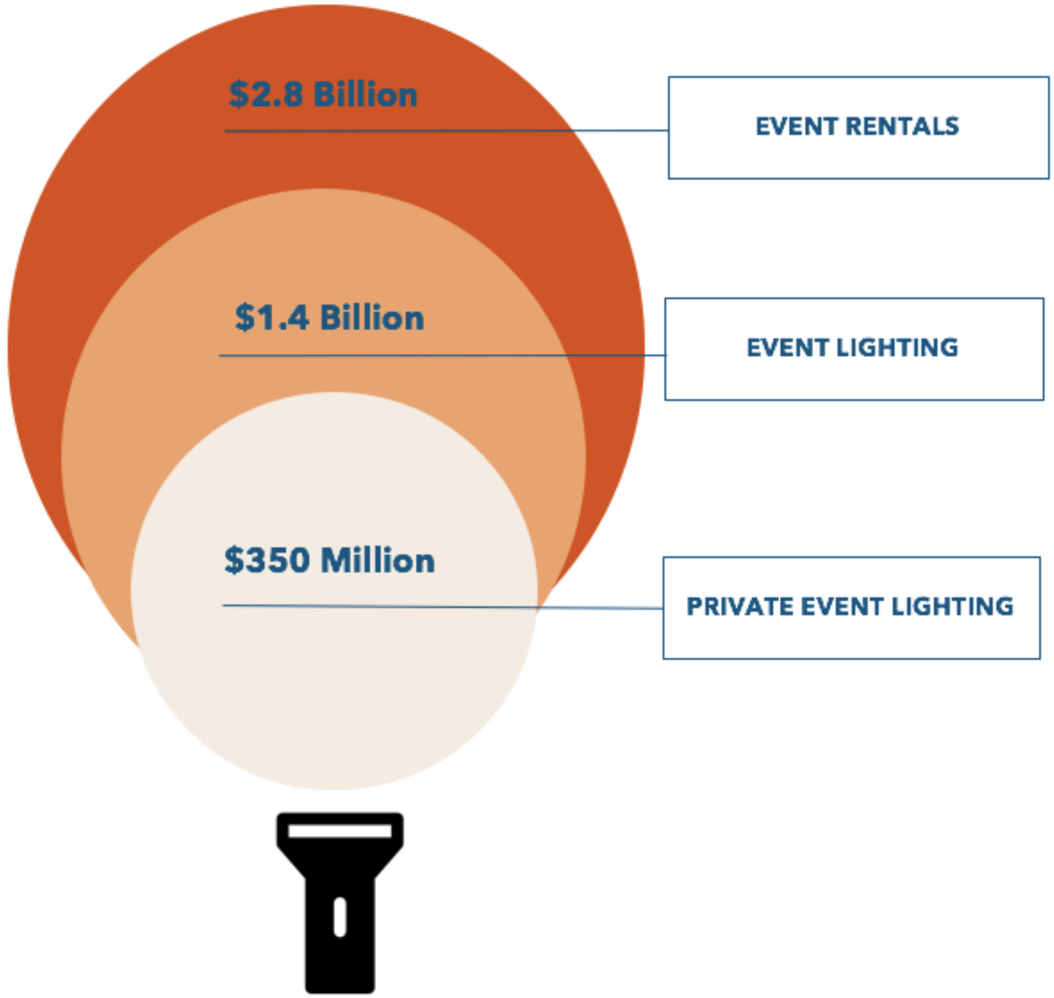

Figure 3 Sunset Power Solutions' initial market opportunity, broken down by TAM, SAM, and target market.

Through our industry research, we found that our initial target market was the private event lighting sector. This is a subset of event lighting, which is part of the event rentals market. (Figure 3)

Total Addressable Market

Our total available market (TAM), is the event rentals industry. In 2016, event rentals were forecast to reach $2.8 billion, and the industry has grown at a compound annual growth rate (CAGR) of 4.2% over the past five years.[1] Industry analysts predict that this growth, which is roughly double the projected growth in GDP, is expected to continue for at least five more years, buoyed by strong corporate profits, and increasing disposable income.[2]

Segmented Addressable Market

The event rentals market encompasses a wide range of items necessary for event planning, from basic needs like tables, chairs, and decorations, to higher-end products, such as audio-visual equipment and lighting. Sunset Power Solutions is focusing specifically on the event lighting industry which, according to industry experts, makes up approximately half of the event rentals market.[3] This accounts for an estimated $1.4 billion in annual revenue.

Target market

Events, and therefore event lighting, can be broadly broken down into two categories: public events and private events. Public events include festivals, concerts, and conventions – in a nutshell, any type of event that might require a ticket for entrance. Private events, on the other hand, are often invite-focused. This includes weddings, birthday parties, and corporate functions. Our product offering (discussed in detail in Chapter 4) is tailored to private events, and focuses specifically on "professional lighting"—this includes products that provide ambient light for events, but does not include DJ lighting, or decorative uplighting and pin lighting. The lighting industry experts we spoke to indicated that professional lighting for private events is an approximately $350 million industry.

"Going green is one of the great business opportunities of the 21st century, and the rapid growth of green weddings and green wedding consulting groups is not surprising."

-David Cooperrider, Case Western Reserve University[10]

Analysis: Industry Trends

In addition to steady growth of the event rentals industry, our research identified two trends that underscored private event lighting as an attractive market for us to enter: 1) A healthy economy, and 2) Increased environmental awareness. As the US economy continues to recover from the Great Recession of 2008, consumer confidence, and disposable income, is rising steadily. Concurrently, consumers are becoming more environmentally conscious, and will thus be more receptive to products that reduce the environmental impact associated with their event.

Economic recovery

It is widely accepted that, as disposable income increases, so too does consumption of goods.[4] Empirical research conducted through Stanford University has shown that this axiom is especially true when economic shocks are transient, and consumers are confident that income will continue to increase.[5] The Consumer Confidence Index (CCI) is a useful indicator to gauge how American consumers feel about the economy, and thus how willing they are to spend their disposable income. The CCI has risen steadily since 2008, reaching 125.6 in March 2017, its highest level since 2000.[6]

This is especially encouraging for the events industry, which is largely dependent upon discretionary spending. The catering industry, which we look to as a close proxy of the event rentals industry, contracted by 0.7% from 2007 to 2012, which reflects the period of slow recovery for the US economy.[7] It has since grown at a CAGR of 1.3%.[8]

Environmental awareness

The event industry has a reputation for being ahead of the curve on environmental stewardship.[9] Weddings in particular have become considerably more environmentally conscious, with some couples are opting for electronic invitations over paper and others choosing compostable plates and flatware, organic menus, and electric limousines for the bridal parties.[10]

Our business model is both quantifiably and socially "green." By extending the life of lithium-ion batteries, and displacing dirty fossil fuel generators, our product will appeal to more eco-conscious consumers, and allow us to capitalize on this emerging consumer preference. In Chapter 5, we describe the environmental benefits of our product in more detail.

Analysis: Technology Trends

Lithium-ion batteries

As previously mentioned, lithium-ion batteries have been lauded for both their lower maintenance needs and superior energy density,[11] which is twice that of the nickel-cadmium batteries that were initially used in mobile devices.[12]

Historically, cost has been a barrier to LiB adoption. The technology, however, is rapidly advancing, and energy density has been increasing at a CAGR of 5% while cost has been decreasing at 8%. Bloomberg New Energy Finance reports that LiB packs used in EVs have dropped from around $1,000/kWh in 2010, to $350/kWh in 2015.[13]

Decreasing costs and increased performance means that LiBs are likely to continue to be the predominant battery chemistry used in EVs, short-duration energy storage, and other battery-based applications.[14]

LED lights

Light-emitting diodes (LEDs) are a highly energy efficient alternative to typical incandescent lights.[15] Not only do they consume about one-fifth the energy of their incandescent counterparts (on a per-lumen basis), but they also have a much longer lifespan. An LED bulb can last between 25,000 - 50,000 hours, whereas an incandescent bulb typically burns out after about 1,000 hours.[16]

Figure 4 A range of currently available LEDs. Photo courtesy of US Department of Energy

> "Lithium-ion is taking over the market, without serious competition. It accounts for all the growth."
>
> -Cosmin Laslau, Lux Research[14]

Similar to LiBs, LEDs have not yet been widely adopted due to their high price. In addition, early iterations emit a harsh white light that turns off consumers.[17] This is changing, however, as LED technology rapidly evolves. The price of LEDs has decreased rapidly in recent years, and is projected to continue its downward trajectory. Additionally, the light emitted by LEDs is becoming more versatile and now includes a warmer glow. These bulbs are increasingly being produced in the brightness and form factors to which consumers are accustomed.[18]

Analysis: Pain Points

Customer research led the team to identify two major pain points in the event lighting industry that present an opportunity for battery-powered lighting: 1) issues surrounding running and concealing cables for lights, and 2) reliance on loud, dirty generators. Here we briefly introduce these pain points.

Pain Point #1: Unsightly and hazardous cables

Available lighting products all require a connection to either venue or generator power, meaning that event professionals must run and conceal power cables. This adds time to event setup, impacts the aesthetics of meticulously planned décor, and creates tripping hazards for guests.

Figure 5 Example of heavy cabling used for event lighting

Longer setup times create a two-fold problem for event professionals. First, they require more employee-hours, increasing labor costs for the event professional. Second, many event venues limit the amount of time vendors have for setup, with some charging a premium for earlier access. In this sense, shorter setup times can serve as a competitive advantage for lighting professionals.

Pain Point #2: Reliance on generators

Many event professionals we interviewed use fossil fuel generators to supply power for events. The need for generators typically arises from one of two reasons. First, the event location may be far from a connection to the main electricity source. For example, a wedding on a beach, or a charity fundraiser at a vineyard may struggle with power sourcing. Second, venue power may not be able to meet the event's power needs. For example, power needs may exceed the rated amperage for a venue electrical circuit, or specialized audiovisual equipment may require three-phase electricity.

Generators, however, present the event professional with a number of pain points, as previously mentioned. They are loud, and can ruin an event's ambiance, they emit exhaust that is hazardous to human health, and, importantly, generators require ongoing maintenance and repairs, which become both costly and time-consuming for the owner. Stricter regulations on generators also mean that owners are being forced to phase out older generators, and that newer, cleaner models are becoming more expensive.

Figure 6 Event professionals installing a set of outdoor string lights at the UC Santa Barbara campus. This type of installation typically takes around four hours.

Analysis: The Competitive Environment

Ambient event lighting is supplied primarily by three distinct designs: bistro lights, chandelier lights, and balloon lights.

Photo: Hayneedle.com

Bistro lights

Description: Individual strings of 20 to 50 small "Edison" style bulbs. They emit warm ambient light, and can be wrapped around objects or strung along poles throughout an event venue. Bistro lights are popular for outdoor events, however, they require a direct power source, and securing them can make setup and breakdown time-consuming.

Typical offerings and price: $65 for one 48-foot string of Bulbrite incandescent bistro lights; $130 for one 50-foot strong of LED lights from Hometown Evolution, Inc.

Photo: Shangri-La Weddings

Chandelier lights

Description: Ornate chandeliers are often used for indoor events or outdoor ones under tents. These are typically used for weddings, and plug into venue or generator power. Considered to be the most elegant solution, these lights put a premium on design over utility, and are often both inappropriate for more casual events, as well as beyond their budget.

Typical offerings and price: Quality chandelier lights appropriate for events cost upwards of $4,000, and the typical offering is around $6,500.

Photo: Arizona Uplighting

Balloon lights

Description: Balloon lights typically consist of an inflatable balloon with attached fan that encases a lamp and diffuses light 360 degrees. The light is held up by a mast, and is powered either by plugging into a power source or a generator attached at the base. Only the AirStar Sirocco 2-S, is battery powered. Balloon lights are primarily used for construction lighting, but are becoming more prevalent in the event space.

Typical offerings and price: The Sirocco series offers a battery-powered, 60-watt LED for $2,750, and a 2000-watt halogen, plug-in model for approximately $3,000.

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Section 3: Research and Product Development

- We interviewed 30 event professionals to test our hypotheses about the need for a cables-free event lighting solution.

- An overwhelming majority of event professionals say that they would prefer not to use generators, and that running and concealing cables for lighting is a major pain point.

- Using second-life lithium-ion batteries, and a number of inexpensive inputs, we assembled a working prototype which will serve as proof of concept, while allowing us to gather feedback from event professionals on design, brightness, and price point.

Research: Customer Discovery

As discussed in Chapter 1, we spoke with over 100 industry experts and potential customers (Table 2) on our way to determining that private event lighting was an opportunity worth exploring in depth.

Table 2 Summary of industry expert and customer interviews

Interviewer segment	Number of Interviews
Experts	
Engineers	10
Industry Experts	25
Sub-Total Experts	35
Customers	
Solar & Commercial	12
Utilities	6
Generator users	22
Event Lighting	30
Sub-Total Customer	70
TOTAL	**105**

We interviewed 30 event professionals, which included both event managers (n=9) and event rental companies (n=21). Event managers typically interface directly with clients who wish to host an event, and work with a venue and vendors to provide the necessary services. Event managers own little to none of the equipment that is actually used for the event.

Event rental companies, on the other hand, generally do not interface directly with the client, but are hired by the event manager to provide specific services. The rental companies typically own their equipment, and rent it out for the event, though they will, on occasion, rent equipment they don't own from another rental company.

Our interviews aimed to test following three hypotheses:

1. **Generator use is problematic in the event space.**
2. **Cables are time consuming, and pose a tripping hazard to guests.**
3. **Event professionals are willing to pay for a cordless, battery-powered lighting solution.**

In addition to this hypothesis testing, we learned about the type of events generally handled by these event professionals, the types of lighting products they use, and who their customers are, and their specific needs and concerns.

Hypothesis #1: Cabling is an issue.

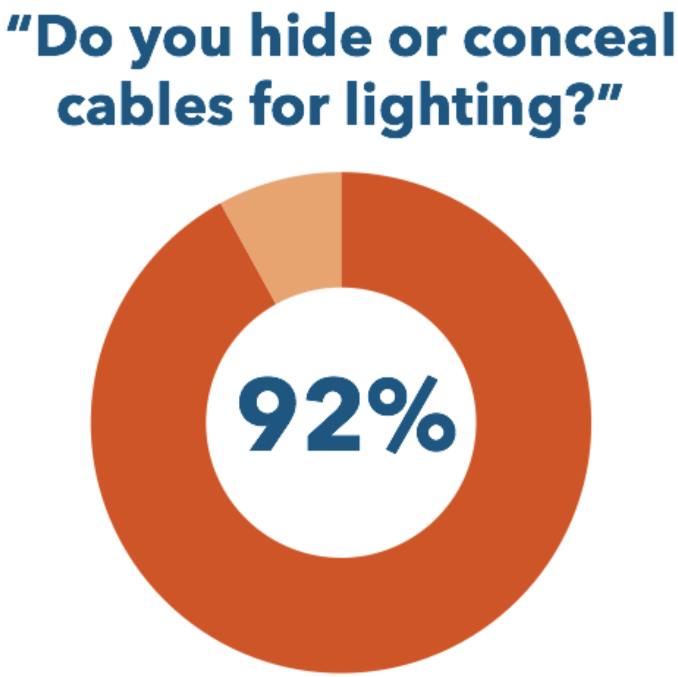

Figure 7 Percent of event professionals who say they hide or conceal cables for lighting as part of event setup

To test our first hypothesis, we asked event professionals how long they typically spend setting up lights, and if running and concealing cables was an issue for them.

Lighting setup times varied widely. Interviewees cited anywhere from four hours for smaller events, to two days for larger events. We accompanied one event company on a setup, and observed that installing six sets of market lights at an outdoor patio that took approximately four hours.

Additionally, we learned that many venues limit how far in advance event professionals can access the location for setup, while others actually charge a premium to allow earlier access. Faster setup times are thus a valuable competitive advantage for lighting professionals.

Overall, 92% of the event rental companies we spoke to said that they spend time concealing cables, with many sharing anecdotes about especially challenging setups that required creative solutions for hiding cables.

Hypothesis #2: Generators are an issue.

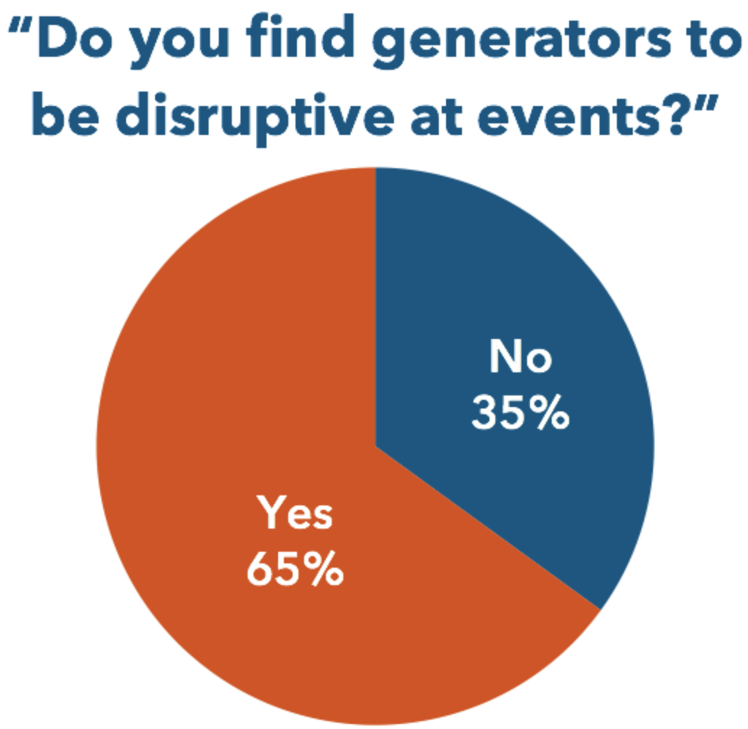

Figure 8 Event professionals' responses when asked if they find generators to be disruptive at events

Next, we asked respondents about generator use at events. Specifically, we wanted to know what proportion of events require generators, and if the event professionals found the noise, exhaust, and setup/refueling of generators to be an issue.

Of our 30 interviewees, only 20 of them deal directly with generators. The others either always used venue power, or were provided a generator via the venue or another event vendor. Eighty percent of respondents who deal directly with generators (16 out of 20) cited one or more issues with generator use. The most frequently cited issue was noise (13 out of 16), followed by dealing with exhaust (3 out of 16). About half of the respondents who cited noise as an issue said that they use "Whisper Quiet" noise attenuating generators, which help to reduce, but do not completely eliminate, the noise.

Hypothesis #3: Customers are willing to pay more for cable-free lighting.

Finally, we asked event professionals what type of lights they were currently using, and if they would be willing to pay for a cables-free alternative to their preferred lighting solution. Sixty-one percent of respondents (17 out of 28) said that they would definitely be willing to pay more for cordless lights, while an additional 21% (6 out of 28) said they might be willing to pay more. A typical "maybe" response hinged on their ability to pass the additional cost along to the end-user.

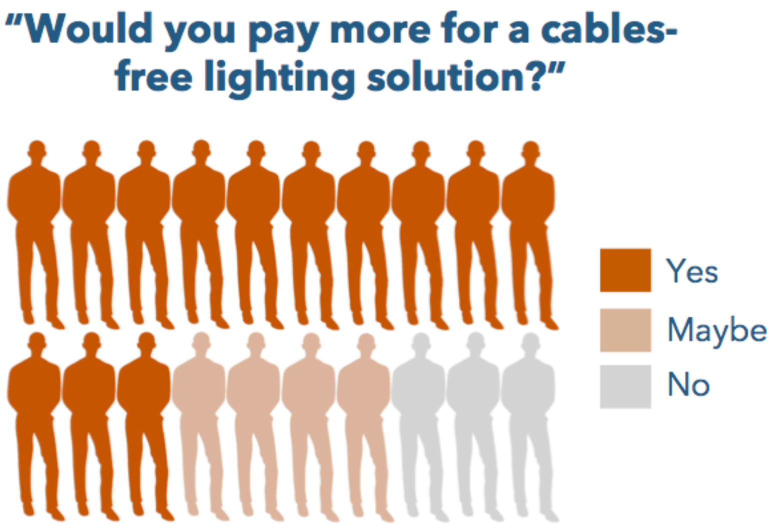

Figure 9 Event professionals responding "Yes" or "Maybe" when asked if they would pay more for a cables-free lighting solution

Of the respondents who were willing to pay more for a cables-free lighting solution, the average markup cited topped 70%, positioning this opportunity as a viable financial incentive.

Research: Customer Ecosystem

Larry the Lighting Professional

Role: Our customer. Larry purchases products directly from us, and then rents them out for events. Larry may also take care of other rental items like tents, audio-visual equipment, and generators.

Needs and concerns: Larry needs quality products that meet the needs of Evelyn. He knows that his customers will pay for quality service, but only to a certain point, and so he needs to remain affordable. He's also concerned about his labor costs and setup time. Running and concealing cables for lighting increase his labor costs, and create headaches in terms of liability for tripping hazards.

Evelyn the Event Manager

Role: Larry's customer, and our indirect end user. Evelyn plans events, and contracts with vendors like Larry to provide services including catering, lighting, and music.

Needs and concerns: Evelyn needs to cater to her customers' tastes, but must also be mindful of their budget. She needs vendors that can provide reliable service at a good price. Evelyn also works directly with the event venue—she's aware that the venue needs her and her vendors to setup and take-down quickly, and she may have to pay a premium to have earlier access to a venue.

Nick and Wendy Newlywed

Role: Evelyn's customer and our end user. They hire Evelyn to plan their wedding, and communicate to her if they have any special ideas or needs for their wedding.

Needs and concerns: Cost—while they know a wedding is not cheap, they need to keep costs down where they can, so they can afford to have as many of their friends and family as possible. They are also mindful of their environmental impact; though the overall atmosphere of their day is most important, they would like to reduce their footprint as much as possible, and know that many of their friends feel the same way.

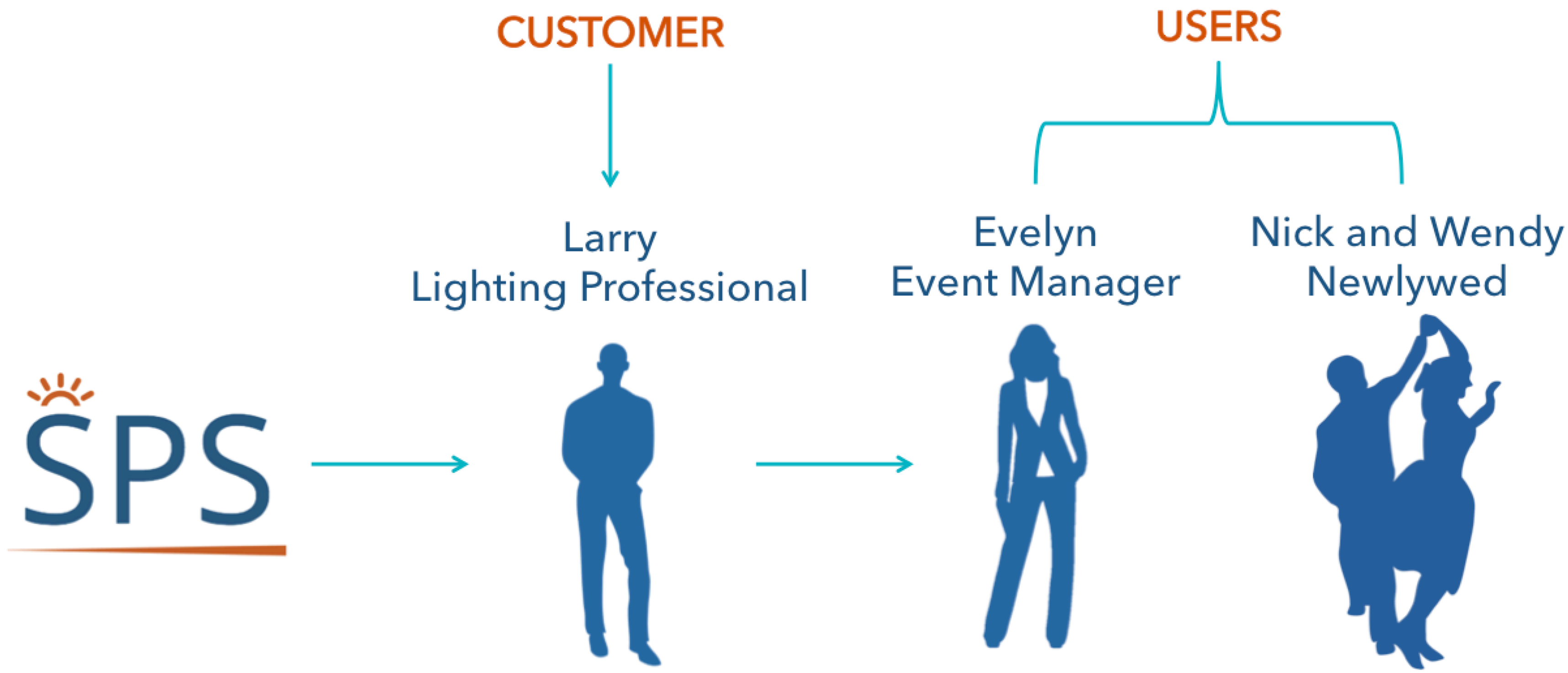

Figure 10 The SPS customer ecosystem

"If you guys can make this work, I'll buy it."

-Lighting professional in Tucson, Arizona

"If we could save money on generators and use it on lights, that would be great."

-Event manager in Santa Barbara, CA

Development: Minimum Viable Product

With the results of our customer research in hand, we aimed to design a minimum viable product (MVP) that would meet the needs of event professionals. Specifically, we wanted to design a battery-powered lighting solution that would blend in seamlessly at events, while providing enough light, and lasting at least 10 hours, which is significantly more than enough time for the typical 6-8 hours of lighting needed that was described to us by event professionals.

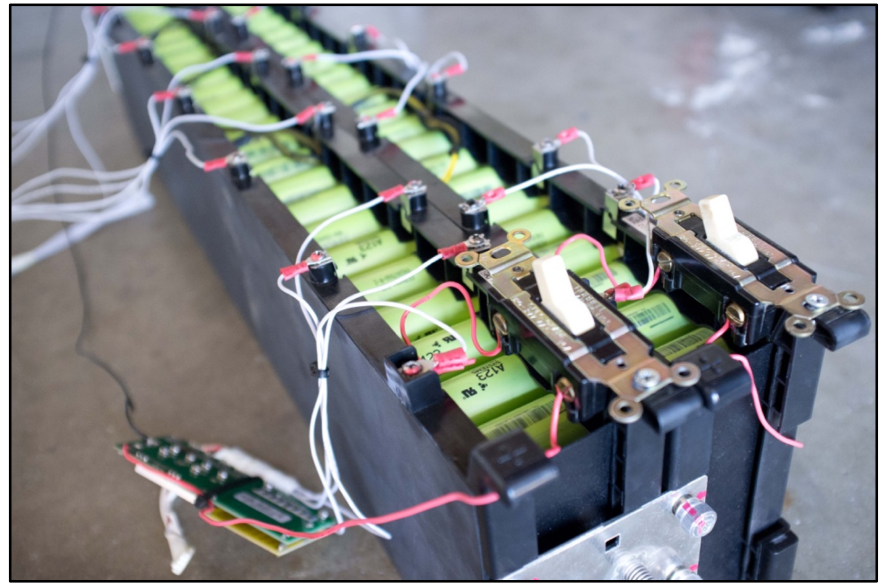

Figure 11 A lithium-ion battery module with custom battery management system and circuit interrupters

Battery and electrical components

To do this, we acquired a number of second-life A123 lithium iron-phosphate battery modules, previously used in grid-based energy storage. These were sourced from FreeWire Technologies, an energy startup in the San Francisco Bay Area.

We enlisted the help of an electrical engineer, Christian Bayless, who is currently pursuing a PhD in UCSB's Electrical Engineering department, and previously worked with second-life LiBs. Christian helped the team follow proper safety procedures when handling the batteries, in addition to making sure we sourced appropriate electrical components. Additionally, he oversaw the construction of our prototype.

We purchased electrical components, a light fixture, and housing through online retailers, and adapted them manually to suit our needs. Our product design calls for a 100-watt, 1,200 lumen LED; however, due to budget constraints, we used a smaller, 18-watt LED for our MVP.

Despite the smaller LED, we designed and mounted a 1.4 kWh battery pack, which would be adequate to power a 100-watt LED at full brightness for the requisite 10 hours. While this battery pack could power our 18-watt lamp for over 70 hours, we wanted to ensure that we were accurately reflecting the weight and footprint of the battery pack that would be required for the 100-watt lamp.

We fitted our 1.4 kWh battery modules with battery management systems (BMS) to ensure that the battery is "balanced", meaning each individual cell charges and discharges evenly. We also installed a voltage regulator, allowing us to adjust the battery voltage for our 18-watt LED. As designed, our battery can charge in about 4 hours from a typical 120-volt household circuit.

Housing and support

For the infrastructure surrounding our MVP, we purchased a stainless steel propane patio heater from an online retailer, removed the head and heating element, and modified the base to allow us to mount our battery pack. We specifically chose a patio heater model with a cocktail table attachment so that our MVP would have added functionality in an event setting.

In order to reflect modern lighting design, we secured an unused globe housing for the light fixture and created black fabric skirting to conceal the bottom portion.

Swappable heads

A key component of our value proposition is versatility, leading us to design even our MVP with the most design flexibility possible. We plan to expand the product through a line of swappable light fixtures that gives event professionals flexibility in the look of their light, while still utilizing the same battery base. To prove this concept, we built our MVP with the ability to swap out the globe head fixture for strings of bistro lights. We achieved this by mounting the light fixtures to a piece of PVC pipe that inserts into the top of the MoonLite, and by including a quick-connect feature in the wiring of the light fixtures, allowing for easy connection to the battery pack.

Research: Overview

Our industry and customer research demonstrated the need for a cordless event lighting solution, while our MVP, the MoonLite, proved that we could construct a working light using second-life LiBs and widely available components. In Chapter 4, we build a business model around the MoonLite, detail our financial projections, and describe how we will get, keep, and grow a customer base.

Figure 12 The SPS Ecosystem with swappable heads

Section 4: Business Model and Strategy

- Our primary value proposition is that we offer a cordless event lighting solution, the MoonLite, that reduces setup time and labor costs, eliminates unsightly and hazardous power cords from events, and reduces the need for fossil fuel generators.

- We will sell the MoonLite direct to event professionals at a price of $1,250 per unit. We project hitting break-even in Year 3, with sales of 1,400 units, and will grow annual revenue to $18 million by Year 5.

- To keep customers, we will develop a line of swappable heads and interchangeable battery packs, and will develop a take-back program for spent lithium-ion battery packs.

- To grow our customer base, we will look to expand our product offering to meet the needs of hotels, restaurants, and home users.

Cables-free

Battery powered and remote control operated, eliminating the need for cables

Battery-powered

Charged with grid electricity, meaning less need for loud, polluting generators

Versatile

Appropriate for a wide range of events, with easily swappable light fixtures

Business Model: Our Value Proposition

Our value proposition to event professionals is three-fold: We provide a **cordless lighting solution** that reduces setup time, and eliminates unsightly tripping hazards, while **reducing dependence on loud, polluting generators**. Our line of **swappable heads provides versatility** allowing event professionals to easily change the look of the MoonLite, depending on event needs and customer tastes.

Cordless lighting

Our customer research showed that running and concealing cables is a significant pain point for event professionals. The MoonLite's battery pack lasts for at least ten hours, more than enough for a typical event, and untethers event professionals from the need to plug into venue power or generators. This dramatically reduces setup time, saving on labor costs, and allowing lighting professionals to get in and out of venues quicker. It also means less unsightly cables that detract from event aesthetics and create tripping hazards for guest.

Decreased dependence on generators

Because the MoonLite's batteries can be charged with grid electricity from a typical wall outlet, event professionals can downsize, and, in some cases, completely eliminate the use of generators. The result is less noise and exhaust from generators, and decreased generator maintenance costs.

Versatility

Client needs and tastes vary, meaning that event professionals want a versatile product that can meet these diverse needs. We're designing a line of swappable heads that can be changed effortlessly, giving event professionals an added degree of flexibility.

Reduced environmental footprint

In addition to these three primary value propositions, the MoonLite extends the useful life of lithium-ion batteries, which are resource intensive to produce. It also displaces generators with cleaner grid electricity, reducing greenhouse gas emissions associated with fossil fuel generators.

Business Model: Financials

Fixed costs

Our fixed costs consist primarily of employee salaries, leasing office and warehouse space, and marketing. A detailed breakdown of fixed and variable costs can be found in Appendix 2.

<u>Salaries and benefits</u>

SPS will begin with a core team of three full-time employees who share equal equity stakes in the company. This team forms the company nucleus, and will only receive 0.25 full-time equivalent (FTE) salaries until the business becomes cash-flow positive. This team will provide organizational management, product design, and drive sales and marketing.

Table 3 Employee salaries and benefits in Year 5, under current growth projections

Position	Number	Gross salary
Chief Executive Officer	1	$110,000
Chief Technology Officer	1	$85,000
VP of Marketing and Sales	1	$85,000
Technician	3	$182,326
Customer Service Representative	5	$303,877
Employee benefits (25% of gross salary)		$191,551
Total salaries and employee benefits		**$957,753**

As sales grow between Year 1 and 5, we will hire two full-time technicians and two full-time customer service representatives, each earning a $50,000 gross salary plus benefits. By Year 5, our gross salaries for full-time staff, including 25% set aside for employee benefits, totals around $960,000, or 8% of projected gross revenue.

<u>Office and warehouse leasing</u>

We estimate a monthly rent of $12,500 per month for a 10,000 ft^2 combined warehouse and office space. This estimate is based on information we received from similar tech start-up companies operating in the San Francisco Bay Area. We assume a 10% annual escalator, which is in-line with recent reports of real estate increases in the Bay Area.

<u>Marketing</u>

To achieve our intended level of growth, we will need to invest heavily in marketing. While 39% of Chief Marketing Officers reported investing between 6% to 9% of gross revenue on marketing needs, this amount will likely need to be expanded for a startup that intends to rapidly capture market share.[1] Some experts estimate that startup marketing budgets should be as high as 12% to 20% of an annual budget.[2] We plan to allocate 15% of projected annual revenues to marketing. Our marketing budget thus grows from approximately $47,000 in Year 0 to $2.8 million in Year 5.

Variable Costs

<u>Cost of goods sold (COGS)</u>

With our current design, commercially available components, and estimates of labor costs, our production cost for one MoonLIte is around $900. We estimate that, over the next five years, we can reduce this production cost by 50%, to around $450. We will achieve these reductions through: 1) economies of scale in both component sourcing and production, 2) decreasing prices for LED and battery technology, and 3) refinements in our design and manufacturing process. These cost reductions are in line with what other second-life LiB startup companies have experienced.[3]

Table 4 Cost of production for the MoonLite prototype

Component	Unit price ($)	Number	Total cost ($)
Hardware			
100-watt LED lamp	$220	1	$220.00
Second-life LiB (kWh)	$80	1.67	$133.60
Charger	$80	1	$80
Battery management system	$20	4	$80
Circuit breaker	$19	1	$19
Voltage regulator	$11	1	$11
12-gauge wire	$0.66	100	$66
Housing	$60	1	$60
Services/Labor			
Construction	$150	1	$150
LiB end-of-life disposal	$75	1	$75
Unit cost (prototype)			$914.60

Revenue model and pricing

We will use a traditional sales model, selling the MoonLite directly to event and lighting professionals, at a price of $1,250. At our current COGS of $900 per unit, that gives us a 28% margin, however this margin increases steadily to 63% in Year 5, as we drive down our COGS, as explained above.

Because the MoonLite offers a unique value proposition without a perfectly analogous product, we were unable to do a direct price comparison. Instead, we adopted a two-pronged approach to selecting a price point.

First, we researched pricing for other lighting products assessed in our competitive analysis. These figures range from $325 for five 50-foot sets of string lights, to more than $4,000 for chandelier lighting. While the string lights appear to have a clear cost advantage, they are only rated to last up to 2,500 hours, compared to 50,000 hours for a typical LED. Owners must replace the incandescent string lights **20 times** over the lifespan of the MoonLite, which significantly decreases their cost savings.

Table 5 5-year projections of revenue, fixed and variable costs, and net profit

Item \ Year	0	1	2	3	4	5
Revenue	$ 312,500	$ 702,500	$ 1,580,000	$ 3,555,000	$ 7,998,750	$ 17,996,250
Fixed costs	$ (382,175)	$ (528,095)	$ (716,543)	$ (1,087,120)	$ (1,615,512)	$ (2,930,268)
Variable costs	$ (228,583)	$ (462,470)	$ (924,574)	$ (1,820,255)	$ (3,510,491)	$ (6,581,829)
Net profit	$ (298,258)	$ (288,065)	$ (61,117)	$ 647,625	$ 2,872,746	$ 8,484,154

Second, we gleaned information from event managers about a typical event's budget for lights and generator rentals. We learned that a typical event will budget around $500 for market lights and $600 for a generator rental. We also learned that rental companies aim to recover their cost of equipment in 10-14 rentals. Because we assume that the majority of event and lighting professionals who purchase the MoonLite will rent them to clients, we can adopt a simple rule of thumb that their rental price would be 8% of the price of one unit.

With this approach, we arrived at a price point of $1,250 per unit, placing the MoonLite squarely between market lights and the second most-expensive product, balloon lights. Using our 8% rental price rule-of-thumb as a benchmark, this means that the MoonLite would rent for around $100 per unit. With an average budget of $500 for market lights, that would allow for five MoonLites, which will easily meet the lighting needs of a 100-person event.

5-year projections and break-even point

By bringing the MoonLite to an established market, SPS is offering an innovative product that corresponds to a well-articulated customer pain point. For these reasons, we project that sales will grow steadily, at an annual rate of 125%. Beginning with a sales volume of 250 units in Year 0, we project that sales will grow to 14,400 units annually by Year 5.

There are approximately 10,500 event rental companies in the U.S.[4] If we assume that our marketing efforts are able to reach 50% of these companies, and that 10% of these convert into actual sales, with each buying 20 lights on average, this translates to annual sales of 21,000 units.

Under current cost and revenue projections, we surpass our break-even point in Year 3, when we achieve a total sales volume of 2,800 units. Across our first five years, SPS has a net profit of $11.4 million, with a Net Present Value of $7.1 million, at a discount rate of 10%.

Start-up needs

SPS requires $610,000 in Year 0 to cover staff salaries, legal fees, leasing and outfitting a workspace, and purchasing components and labor costs for an initial production run of 250 units. We will need a total investment of $650,000 until we go cash flow positive in Year 3.

Business Model: Customer Acquisition

We developed a customer acquisition strategy around the "Get-Keep-Grow" framework employed by Steve Blank's Lean Launchpad.

Get

Through our customer discovery, we found that event managers learn about new products primarily through word-of-mouth, trade shows, and online advertising. With lighting products in particular, these customers value in-person demonstrations, and an opportunity to see the actual product.

We plan to acquire our first ten customers through free local demonstrations at events like Earth Day, and subsequently capitalize on the resulting buzz and word of mouth. Through proof-of-concept and a refined prototype, we will convert these free trials into actual sales while simultaneously gathering positive customer testimonials that will support future marketing efforts.

Beyond word-of-mouth, the most common way that event planners learn about new products is by attending tradeshows like Live Design International (LDI), and Catersource.[5] These annual shows include product exhibitions, which would be a perfect opportunity to provide event professionals with in-person demonstrations and a direct communication opportunity.

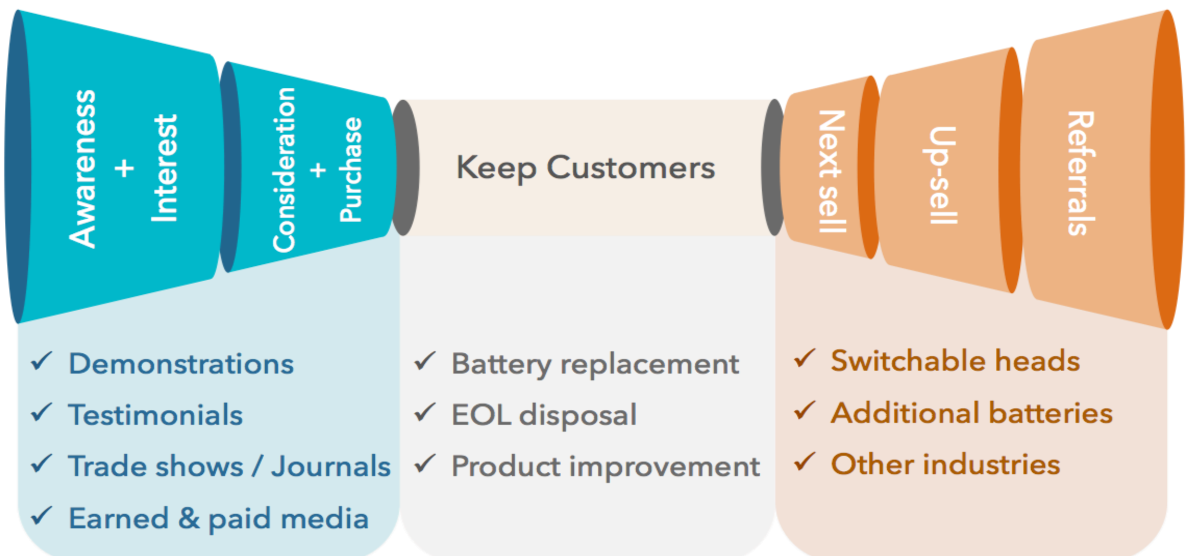

Figure 13 The SPS "Get - Keep - Grow" sales funnel

Additionally, we will continue to acquire customers by advertising in event-specific trade journals, such as BizBash[6] and Special Events.[7] BizBash is the largest media source for event planners, with over 225,000 monthly users. Special Events is not far behind, with an average monthly market reach of 87,500.

Keep

Our strategy for keeping existing customers is two-fold:

1. Provide free replacement batteries and end-of-life disposal of spent lithium ion batteries for the useful life of each LED lamp.

2. Refine our product offering to meet the evolving needs of our customer and stay ahead of our competition.

Empirical research shows that LiBs in their secondary application experience exponential degradation once they've surpassed an additional 1,000-2,000 discharge cycles and/or a capacity reduction below 60 percent. Based on the battery capacity and the average length of events, we estimate that one battery pack will last for approximately 25,000 hours, or roughly half the life of the LED lamp. The battery packs will have a modular design, which simplifies replacement of degraded batteries. As the original pack reaches the end of its life, SPS will supply a second battery, free of charge. This ongoing relationship provides an important touchpoint with customers, allowing SPS to ensure customer satisfaction, gather feedback on product design and performance, and make existing customers aware of new product offerings.
Additionally, SPS will handle end-of-life recycling of spent LiBs so that our customers don't have to. This avoids a potential headache for the customer while ensuring spent batteries are properly disposed of existing e-waste problems are not exacerbated.

Finally, we will continue to refine our product, based on customer feedback, to ensure that customer needs are being met.

Grow

Our expansion plan includes both intra-market growth as well as exploration of alternative markets. Within the events space, we'll develop a line of swappable heads, giving event managers more control over the look of their event. We will also offer additional battery packs for sale to companies that may not have the ability to charge lights between events.

Other sectors of the lighting industry can benefit from this product as well. Specifically, restaurants, hotels, apartment complexes and more will be able to directly buy our light. Tangential industries, such as construction lighting, provide clear opportunities as well. Roadside construction crews burdened by noise restrictions in residential areas and air quality permits are looking for a quiet, exhaust-free lighting solution. Contractors often need to work inside buildings without electricity or lights. Running a generator inside is not an option, and so a battery-powered lighting option would be ideal. For each of these cases, we would conduct further customer research to identify specific pain points, and tailor a product offering to their specific needs for brightness, and duration.

Business Model: Key Partners and Resources

Battery Sourcing

The current design and cost structure of the MoonLite depends upon obtaining second-life LiBs at a price substantially less than new LiBs. We will establish partnerships with second-life LiB suppliers, similar to those of other startups in the second-life LiB industry. Potential partners include OEM car manufactures that use these batteries in EVs, like Nissan and Chevrolet. They also include energy storage companies, like AES.

We are confident that we can secure a reliable supply of second-life LiBs for the following reasons:

1. Second-life LiBs represent a waste stream for automakers. Currently, they are stored on-site, but automakers have not developed long-term plans to address used LiBs.[8]

2. Automakers are actively developing partnerships, such as that between BMW, EVgo, and the University of San Diego, piloting EV charging stations that use second-life LiBs, as well as the partnership between Nissan and FreeWire Technologies, where second-life LiBs are used as mobile EV charging and generator replacements.

3. The cost of new LiBs is rapidly declining, reducing demand for second-life LiBs and thus further driving down the cost of one of our key inputs. Once new LiBs have become cheap enough, we will consider switching costs and benefits that may allow for improved performance and ease of manufacturing.

Beyond securing batteries, the rest of the MoonLite's design uses widely available components. While we we do not anticipate problems securing these items, we will look to develop partnerships that allow us to streamline ordering, and secure favorable pricing.

LiB Recycling Centers

Batteries are considered hazardous waste, and therefore cannot be disposed of in traditional landfills. Instead, universal waste handler or authorized recycling facilities must appropriately break down and dispose of the materials.[9] While a recognized standard exists for lead-acid car battery recycling, there is no current equivalent for lithium-ion, since the technology is relatively new in the battery world.[10] SPS will begin to cultivate a relationship with EV recycling companies, such as Retriev Technologies and the Kinksbury Brothers recycling facility,[11] Initially, we will seek to form a partnership to ensure both proper EOL disposal of spent LiBs, as well as price stability for the cost of recycling. As LiB recycling centers become more prevalent, we will reevaluate the need for such a partnership against the prospect of simply searching for the lowest cost provider of recycling services.

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Photo: YouTube

Section 5: Environmental Benefits

- The MoonLite is charged with grid electricity, which emits about half as much CO_2 per kilowatt-hour, compared to typical diesel generators used for events

- Over the course of its life, one MoonLite can displace up to 16 metric tons of CO_2 emissions, equivalent to taking 3.5 passenger vehicles off the road for an entire year

- The MoonLite extends the useful life of lithium-ion batteries, the production of which negatively impacts both the environment, as well as human health

As discussed in Chapter 4, the MoonLite has a number of environmental benefits, which add to our value proposition. Namely, because the MoonLite can decrease, and in some cases eliminate, the need for fossil fuel generators at event, we are displacing generator power with cleaner grid electricity. This results in lower CO_2 emissions, and we quantify this for a typical use case here. In this chapter, we aim to quantify these reductions based on typical use cases, as described to us by event professionals.

In addition to reducing CO_2 emissions, the MoonLite also extends the useful life of lithium-ion batteries. While this does not displace new lithium-ion batteries, as the MoonLite does not serve as a substitute for any products using new batteries, it is still worth looking at the environmental impacts of lithium-ion battery production.

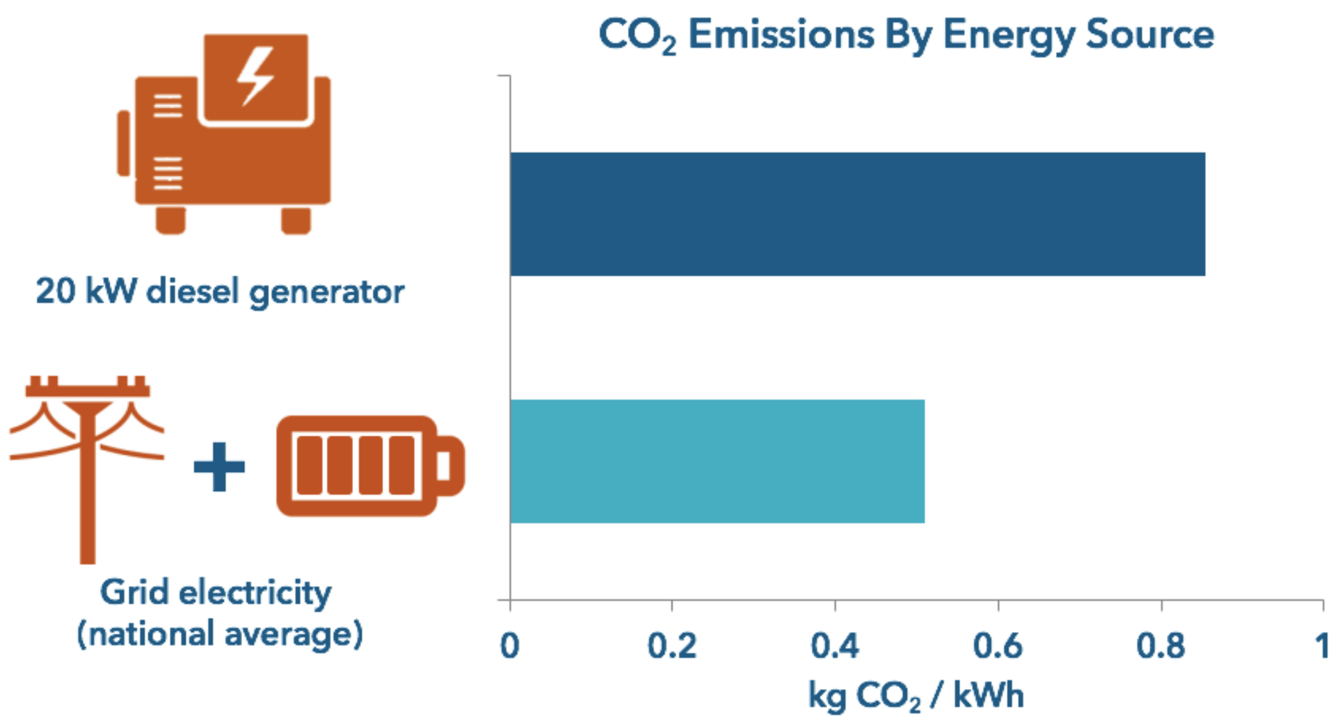

Figure 14 CO_2 emissions (kg CO_2 / kWh) from the national average grid electricity mix as compared to a 20 kW diesel generator.

Case study of a typical event

Though power needs vary by event, the event professionals we spoke to described a typical generator they use as a 20-kilowatt, diesel unit. Ideally, the generator runs at around ¾ capacity, which ensures that it both has enough power capacity to comfortably handle short-term spikes in power demand, while also running at optimal fuel efficiency. For our case study, we used the specifications for a 20kW MultiQuip DCA20 generator[1] to estimate fuel consumption and power output over the course of a typical 8-hour event.

We assume that the event professional replaces 65,000 lumens of traditional incandescent lights (about 4.5 kW) with 10 highly-efficient 100-watt LED MoonLites, operated at half brightness, which provides approximately 65,000 lumens.

This reduces generator load by 4.5 kW, and would thus allow the event professional to downsize from a 20kW unit to a 14kW unit, like MultiQuip's DC15A series,[2] which burns less fuel per hour (Table 3).

Table 6 Fuel savings and avoided CO_2 emissions for a typical 8-hour event when downsizing from a 20kW to a 14kW diesel generator

Generator size	Fuel consumption @ ¾ load (gal / hr)	Fuel use (gal / 8 hr event)	CO_2 emissions (kg CO_2)
20kW	1.26	10.1	102.5
14kW	0.8	6.4	65.1
Savings		**3.7**	**37.4**

Downsizing from a 20kW generator to a 14kW unit would thus save 3.7 gallons of diesel fuel, and avoid just over 37 kgs of CO_2 emissions, based on a diesel fuel emissions factor of 10.17 kg CO_2 per gallon, obtained from the Energy Information Administration (EIA).[3]

The grid electricity used to charge the MoonLites, however, is not without associated emissions. We used the average emissions factor for U.S. grid electricity, to factor back in CO_2 emissions associated with charging the MoonLite. We used the Environmental Protection Agency's Power Profiler Tool[4] to obtain the national average grid mix, and used emissions factors from the EIA for common power sources[5] to determine that grid electricity has 0.51 kg of CO_2 emissions per kilowatt-hour (kWh).

Ten MoonLites running at half brightness for eight hours will consume 5.5 kWh of grid electricity, after accounting for efficiency losses due to battery degradation and losses in charging. This means that the grid electricity used to charge the ten MoonLites accounts for 2.8 kg of CO_2 emissions. Subtracting this from the avoided CO_2 emissions in Table 3, that means that our net avoided CO_2 emissions per eight-hour event is 34.6 kg.

Lifetime avoided CO_2 emissions

Our case study assumed that MoonLites are replacing incandescent lights powered by a generator. Yet not all events use generators. Our customer research found that 41% of event professionals use generators for all of their events, while 36% use generators "sometimes", and 23% rarely or never use generators. Assuming that those who responded "sometimes" use generators at 30% of their events, that gives us an average of approximately 50% of events that use generators.

For events that run on venue power, we again assume ten MoonLites at half brightness replace 4.5 kW of incandescent ambient lights, and calculate emissions reductions as a function of reducing the use of grid electricity. In this case, the incandescent lights would have estimated emissions of 19.49 kg CO_2 for an 8-hour event. Again subtracting the 2.8 kg CO_2 from electricity used to charge the MoonLites, we see a total reduction of 16.7 kg CO_2, or 1.67 kgCO_2 per MoonLite.

Using our assumption of 50% of events running on generators and 50% on venue power, we get a blended average for emissions reductions by one MoonLite over an 8-hour event of 2.57 kgCO_2. Over the course of a MoonLite's 50,000-hour life, that equates to about 16,000 tons of avoided CO_2 emissions. This is roughly equivalent to the annual emissions of 3.5 typical passenger vehicles.[6] For

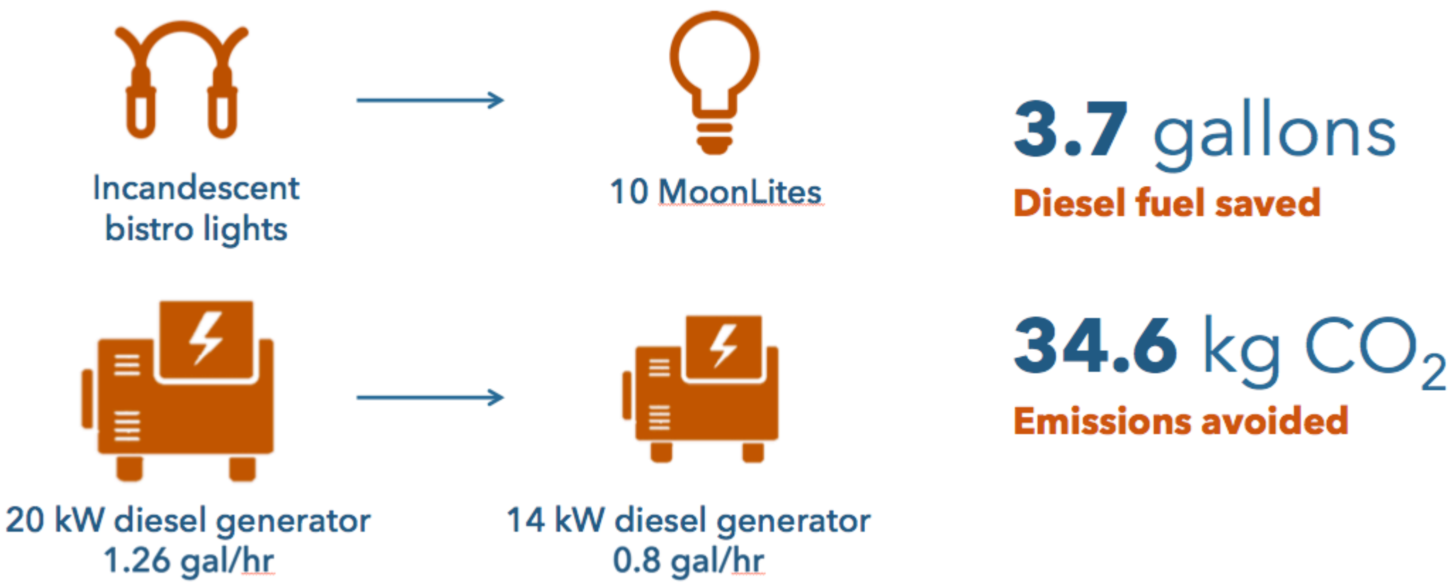

Figure 15 Estimated diesel fuel savings and avoided CO_2 emissions for an 8-hour event using MoonLites

more detailed description of CO_2 emissions reduction calculations, see Appendix 1.

Environmental impacts of lithium-ion batteries

Production of lithium-ion batteries is resource intensive, with negative impacts on both the environment around mining areas, as well as human health.

Today, most lithium mining occurs in South America or Africa, although larger deposits have been found in other regions of the globe.[7] The cheap refining of lithium begins by pumping lithium brine from terrestrial sources into evaporation ponds like those seen in the Andes and Tibet.[8] Due to this open air extraction technique, the surrounding populations can suffer health impacts from associated hydrochloric acids, creating volatile gasses and causing adverse effects on the ground water.

Child labor is also an issue in some regions producing minerals that end up in lithium-ion batteries. In 2010, 51% of the world's cobalt supply originated from the Democratic Republic of the Congo (DRC); of that global stock, one quarter was associated with virgin battery production.[9] In the DRC, child labor is of exceptional concern: one estimate claims that minerals needed for one EV battery requires 104 minutes of underage work.[10]

While we are not displacing the use of new lithium-ion batteries, we are extending the useful life of already existing batteries, creating less incentive for unnecessary new battery production.

Endnotes for Section 5

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[10] Ibid.

Section 6: Next Steps

- We will further refine our value proposition and product design through continued customer interviews and demonstrations.

- We will secure seed funding to obtain the staff and resources necessary for an initial production run of 250 units. This will include applying to incubators and excelerators, as well as meeting with venture capitalists and raising funds.

- We will continue to look for opportunities beyond event lighting where cables-free lighting can address a customer pain point, while reducing environmental impact. We see areas parallel to the events industry, such as hotels, restaurants, and even home use, being viable markets for entrance.

Appendix 1 - Detailed environmental benefit calculations

Avoided CO_2 emissions per event

Equation 1 shows how we estimate CO_2 emissions reductions from replacing incandescent lights powered by a diesel generator with MoonLites charged with grid electricity.

$$\textbf{Equation 1}\ (Avoided\ fuel\ burn\ x\ Fuel\ emissions\ factor) - (Grid\ electricity\ emissions) = Avoided\ CO_2\ emissions\ per\ event$$

For our case study, we assumed 10 MoonLites, running at roughly half brightness, replace 4.5 kW of incandescent lights. The incandescent lights are powered by a typical 20kW diesel generator, operating at ¾ load.[1] Reducing the load by 4.5 kW allows for downsizing to a 14 kW diesel generator. Representative models from MultiQuip have the fuel burn rates shown in Table 7 below, and diesel fuel emits 10.17 kg CO^2 per gallon.[2]

Table 7 Fuel use for an 8-hour event for a 20 kW and 14 kW diesel generator

	Power (kW)	Fuel use (gal/hr)	Fuel use for 8-hour event (gal)
MultiQuip 20 kW generator			
Full load	20	1.62	12.96
¾ load	15	1.26	10.08
½ load	10	0.94	7.52
¼ load	5	0.67	5.36
MultiQuip 14 kW generator			
Full load	14	1.09	8.72
¾ load	10.5	0.8	6.4
½ load	7	0.64	5.12
¼ load	3.5	0.41	3.28

[1] We assume the generator runs at ¾ load, as this is when generators operate most efficiently

[2] U.S. Energy Information Administration. *Frequently Asked Questions: How much carbon dioxide is produced per kilowatthour when generating electricity with fossil fuels?* Retrieved from: https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11

We can solve for the first term from equation 1 as follows:

$$(10.08\ gal - 6.40\ gal)\ \text{x}\ \frac{10.17\ kg\ CO_2}{gal} = 37.44\ kg\ CO_2$$

We then solve for the second term, to determine emissions associated with the grid electricity used to charge the MoonLites. We assume 10 MoonLites run at 55% brightness, as this supplies an equivalent amount of brightness, in terms of lumens, as 4.5 kW of incandescent lights. We also assume 25% energy loss due to efficiency loss in charging, and battery degradation, meaning that, on average, 1.25 kW of electricity is consumed in delivering 1 kW of electricity for lighting. Over an 8-hour event, this means a total energy consumption of:

$$\frac{0.1\ kw}{MoonLite}\ x\ 10\ MoonLites\ x\ 0.55\ brightness\ x\ \frac{8\ hrs}{event}\ x\ 1.25\ efficiency\ factor = \frac{5.5\ kWh}{event}$$

Finally, we use the national average for grid mix from the EPA Power Profiler tool, and EIA emissions factors, as described in Section 5, to determine associated CO_2 emissions (Table 8).

$$\frac{5.5\ kWh}{event}\ x\ \frac{0.51\ kg\ CO_2}{kWh\ grid\ electricity} = 2.81\ kg\ CO_2$$

This gives us a net avoided CO_2 emissions per 8-hour event of:

$$34.44\ kg\ CO_2 - 2.81\ kg\ CO_2 = 34.63\ kg\ CO_2$$

Because this scenario assumes 10 MoonLites are used, this translates to 3.46 kg CO_2 avoided per MoonLite, per event.

Lifetime avoided CO_2 emissions

To determine lifetime avoided emissions for one MoonLite, we assume that they replace generator-powered lights 50% of the time, and incandescent lights running on venue power the other 50% of the time. In the case where MoonLites replace venue-powered lights, we calculate the emissions associated with the grid electricity used to power these lights, similar to how we did for the MoonLite above. We assume 4.5 kW of lights, running for 8 hours, consuming a total of 36 kWh of electricity. The emissions associated with this electricity are:

$$\frac{36\ kWh}{event}\ x\ \frac{0.51\ kg\ CO_2}{kWh\ grid\ electricity} = \frac{18.36\ kg\ CO_2}{event}$$

So, net avoided CO_2 emissions for an 8-hour event where MoonLites displace venue-powered incandescent lights is:

$$18.36\ kg\ CO_2 - 2.81\ kg\ CO_2 = 15.56\ kg\ CO_2$$

Or, 1.56 kg CO_2 per MoonLite, per event.

This allows us to calculate lifetime avoided emissions as follows:

$$\left(\frac{3.46\ kg\ CO_2}{generator\ event}\ x\ \frac{1\ event}{8\ hours}\ x\ \frac{50{,}000\ hours}{Life\ of\ 1\ MoonLite}\right) x\ 0.5 + \left(\frac{1.56\ kg\ CO_2}{venue\ power\ event}\ x\ \frac{1\ event}{8\ hours}\ x\ \frac{50{,}000\ hours}{Life\ of\ 1\ MoonLite}\right) x\ 0.5 = \frac{\mathbf{15,683\ kg\ CO_2}}{\mathbf{Life\ of\ 1\ MoonLite}}$$

Sensitivity to grid mixes

We can extend this analysis to other grid mixes, to see how sensitive these benefits are to local electricity mix. We use Santa Barbara, CA, with high penetration of clean energy sources, as our “clean” scenario, and Charleston, WV, with a high proportion of coal, as our “dirty” scenario. According to the EPA Power Profiler tool, these two cities have the grid mixes shown in Table 8 below.

Table 8 Grid mixes and associated CO_2 emissions - National Average; Santa Barbara, CA; Charleston, WV

National Average

Energy Source	Proportion of mix	Emissions (kg CO_2e / kWh)	Contribution (kg CO_2 / kWh)
Non-hydro renewables	0.08	0.00	0.00
Hydro	0.08	0.01	0.00
Nuclear	0.17	0.00	0.00
Oil	0.07	0.74	0.05
Natural Gas	0.29	0.55	0.16
Coal	0.31	0.97	0.30
Emissions (National Average)			**0.51**

Santa Barbara (Zip Code 93110)

Energy Source	Proportion of mix	Emissions (kg CO_2e / kWh)	Contribution (kg CO_2 / kWh)
Non-hydro renewables	0.19	0.00	0.00
Hydro	0.08	0.01	0.00
Nuclear	0.09	0.00	0.00
Oil	0.00	0.74	0.00
Natural Gas	0.63	0.55	0.34
Coal	0.00	0.97	0.00
Emissions (Santa Barbara, CA)			**0.35**

Charleston, WV (Zip Code: 25301)

Energy Source	Proportion of mix	Emissions (kg CO_2e / kWh)	Contribution (kg CO_2 / kWh)
Non-hydro renewables	0.03	0.00	0.00
Hydro	0.01	0.01	0.00
Nuclear	0.20	0.00	0.00
Oil	0.01	0.74	0.00
Natural Gas	0.11	0.55	0.06
Coal	0.65	0.97	0.63
Emissions (Charleston, WV)			**0.69**

A dirtier grid mix actually leads to greater reductions in CO_2 emissions, while a cleaner mix leads to slightly attenuated reductions (Table 9). These results suggest that, while grid electricity in places like southern California has only half the CO_2 emissions of diesel fuel, the real driver of emissions reductions is the decrease in total energy consumption through use of energy-efficient LED lights.

Location	Grid mix emissions (kg CO_2 / kWh)	Avoided CO_2 emissions / 8-hr event on generator power (kg CO_2)	Lifetime emissions reductions per MoonLite (kg CO_2)
Santa Barbara, CA	0.35	35.51	14,433
Charleston, WV	0.69	33.64	17,089
National Average	0.51	34.63	15,683

Appendix 2 - Detailed financial model calculations and assumptions

Cost inputs	
Used battery price ($/kWh)	$80
Charger	$80
BMS	$20
Housing	$60
LED light	$210
Breaker	$19
Voltage regulator	$11
Wire	$0.66
Construction cost	$150
Warehouse rent escalator	10%
COGS deescalator	10%
Liability Insurance (annual)	$50,000.00
Cost of end-of-life disposal	$75.00
Marketing (% of gross revenues)	15%

Company size and general model inputs	
Discount rate	10%
Annual sales escalator: Y1 - Y5	125%

Power (kW)	Capacity (kWh)	# of units	Sale price
0.1	1.67	250	$1,250

Costs	0			1			2			3			4			5		
	Number	Unit cost	Total	Number	Unit cost	Total	Number	Unit cost	Total	Number	Unit cost	Total	Number	Unit cost	Total	Number	Unit cost	Total
Raw inputs																		
Used batteries	250	$ 133	$ 33,333	562	$ 120	$ 67,440	1264	$ 107	$ 134,827	2844	$ 93	$ 265,440	6399	$ 80	$ 511,920	14397	$ 67	$ 959,800
Charger	250	$ 80	$ 20,000	562	$ 72	$ 40,464	1264	$ 64	$ 80,896	2844	$ 56	$ 159,264	6399	$ 48	$ 307,152	14397	$ 40	$ 575,880
Battery Management System	250	$ 80	$ 20,000	562	$ 72	$ 40,464	1264	$ 64	$ 80,896	2844	$ 56	$ 159,264	6399	$ 48	$ 307,152	14397	$ 40	$ 575,880
Housing/UI	250	$ 60	$ 15,000	562	$ 54	$ 30,348	1264	$ 48	$ 60,672	2844	$ 42	$ 119,448	6399	$ 36	$ 230,364	14397	$ 30	$ 431,910
LED light	250	$ 210	$ 52,500	562	$ 189	$ 106,218	1264	$ 168	$ 212,352	2844	$ 147	$ 418,068	6399	$ 126	$ 806,274	14397	$ 105	$ 1,511,685
Breaker	250	$ 38	$ 9,500	562	$ 34	$ 19,220	1264	$ 30	$ 38,426	2844	$ 27	$ 75,650	6399	$ 23	$ 145,897	14397	$ 19	$ 273,543
Voltage regulator	250	$ 22	$ 5,500	562	$ 20	$ 11,128	1264	$ 18	$ 22,246	2844	$ 15	$ 43,798	6399	$ 13	$ 84,467	14397	$ 11	$ 158,367
Wire (12 gauge)	250	$ 66	$ 16,500	562	$ 59	$ 33,383	1264	$ 53	$ 66,739	2844	$ 46	$ 131,393	6399	$ 40	$ 253,400	14397	$ 33	$ 475,101
Construction	250	$150	$ 37,500	562	$135	$ 75,870	1264	$120	$ 151,680	2844	$105	$ 298,620	6399	$90	$ 575,910	14397	$75	$ 1,079,775
R&D																		
Electrical Engineer - initial design	160	$ 50	$ 8,000															
Full-time staff																		
Chief Executive Officer (CEO)	0.25	$ 110,000	$ 27,500	0.25	$ 110,000	$ 27,500	0.25	$ 110,000	$ 27,500	0.25	$ 110,000	$ 27,500	0.25	$ 110,000	$ 27,500	1	$ 110,000	$ 110,000
VP of Sales and Marketing	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	1	$ 85,000	$ 85,000
Chief Technology Officer (CTO)	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	0.25	$ 85,000	$ 21,250	1	$ 85,000	$ 85,000
Technician	0	$ 50,000	$ -	1	$ 50,000	$ 50,000	1	$ 52,500	$ 52,500	2	$ 55,125	$ 110,250	2	$ 57,881	$ 115,763	3	$ 60,775	$ 182,326
Customer Service Rep	0	$ 50,000	$ -	1	$ 50,000	$ 50,000	2	$ 52,500	$ 105,000	3	$ 55,125	$ 165,375	4	$ 57,881	$ 231,525	5	$ 60,775	$ 303,877
Employee benefits			$ 17,500			$ 42,500			$ 56,875			$ 86,406			$ 104,322			$ 191,551
Overheads																		
Office/warehouse (monthly lease)	12	$ 12,500	$ 150,000	12	$13,750	$ 165,000	12	$ 15,125	$ 181,500	12	$16,638	$ 199,650	12	$18,301	$ 219,615	12	$20,131	$ 241,577
Utilities																		
Warehouse operations (kWh)	12	$ 400	$ 4,800	12	$ 400	$ 4,800	12	$ 400	$ 4,800	12	$ 400	$ 4,800	12	$ 400	$ 4,800	12	$ 400	$ 4,800
Insurance																		
Liability	1	$ 50,000	$ 50,000	1	$50,000	$ 50,000	1	$ 50,000	$ 50,000	1	$50,000	$ 50,000	1	$50,000	$ 50,000	1	$50,000	$ 50,000
Start-up costs	1	$ 10,000	$ 10,000															
Patents & legal fees																		
Marketing																		
Ads/Tradeshows		$46,875	$46,875		$95,795	$95,795		$195,868	$195,868		$400,639	$400,639		$819,488	$819,488		$1 676,138	$1,676,138
Capital expenditures																		
Battery tester	1	$ 25,000	$ 25,000															
End-of life disposal	250	$ 75	$ 18,750	562	$ 68	$ 37,935	1264	$ 60	$ 75,840	2844	$ 53	$ 149,310	6399	$ 45	$ 287,955	14397	$ 38	$ 539,888
Total Costs			$ (610,758)			$ (990,565)			$ (1,641,117)			$ (2,907,375)			$ (5,126,004)			$ (9,512,096)
PV of Costs			$ (610,758)			$ (900,514)			$ (1,356,295)			$ (2,184,354)			$ (3,501,130)			$ (5,906,263)

Revenue	0			1			2			3			4			5		
	Number	Price	Revenue	Number	Price	Revenue	Number	Price	Revenue	Number	Price	Revenue	Number	Price	Revenue	Number	Price	Revenue
Sales																		
18 W / 300 Wh (10 hr. duration)	250	$ 1,250	$ 312,500	562	$ 1,250	$ 702,500	1264	$ 1,250	$ 1,580,000	2844	$ 1,250	$ 3,555,000	6399	$ 1,250	$ 7,998,750	14397	$ 1,250	$ 17,996,250
Total revenue			$ 312,500			$ 702,500			$ 1,580,000			$ 3,555,000			$ 7,998,750			$ 17,996,250
PV of revenue			$ 312,500			$ 638,636			$ 1,305,785			$ 2,670,924			$ 5,463,254			$ 11,174,255

Appendix 3: Technical Literature Review

Introduction

As climate change becomes a growing political and economic concern, public and private sectors alike are looking toward sustainable and innovative technologies that will reduce our dependence on nonrenewable energy sources. This is leading to a massive shift in societal power consumption, particularly in terms of energy and transportation.

Traditional energy sources, such as oil and gas, are becoming increasingly outdated, while renewable methods of power generation, like solar, wind, and hydropower, are slowly gaining traction. In tandem, the use of high capacity batteries to store renewables or be utilized as a substitute for fuel-powered generation is becoming a popular method of energy efficiency and savings.

In particular, lithium ion batteries are gaining traction in the energy world. However, as more technologies adopt these batteries, such as EV development and industrial-scale energy storage, a slew of new issues and unknown impacts begin to arise.

Sunset Power Solution aims to reuse these lithium ion batteries once they are no longer viable in their primary, power-heavy use cases. However, understanding the product itself and the surrounding industries is integral in order to recognizing the direct and indirect value propositions of such a business plan.

Historically speaking, the battery industry is not known for fast-paced innovation. In 1859, the first rechargeable battery was invented using a lead-acid chemistry; nickel-cadmium became widely available nearly a century later, and both are still commonly used to this day.[3] Although these batteries propelled electric innovation forward, they were not powerful or efficient enough to make significant progress. For decades, chemists struggled to find cheaper and more powerful options that were safe enough for use by the general public. That's why, when Sony introduced the first commercially-available and rechargeable lithium-ion battery (LiB) in 1991, the development was unprecedented in the mobile power industry.[4] Lithium-ion was lauded for its substantial energy density and flexible chemistry. Still, this does not mean there is no room for improvement in LiB development.

All batteries produce electricity as a result of electrons flowing from a negatively charged end (the anode), through an electrolyte fluid, to a positively charged end (the cathode). A particular concern with lithium ion is that it loses capacity over time as a result of metallic lithium build-up at the anode in a process known as "lithium plating", which inhibits electron flow.[5] Under normal use cases, LiBs experience a linear loss in capacity with respect to discharge cycles until they decrease to about 80% of their original capacity. At this point, they may experience accelerated nonlinear aging. Factors that lead to earlier onset of nonlinear aging include: rapid charging, large changes in voltage related to maximum charging and complete discharge, and extreme low and high temperatures.[6,17] Yet despite these concerns, lithium ion batteries continue to dominate the market in capacity, power, and reliability.

Impact on the EV Market

Lithium-ion technology was first used in mobile phones, laptops, and smaller electronics, however the electric vehicle (EV) industry is where LiBs truly left their mark. In 2009, Tesla released the Roadster -- the first EV powered by a lithium-ion battery and fully highway-legal.[7] Now, less than a decade later, LiBs are cheaper, lighter, and more powerful than ever. Manufacturers are able to design vehicles with a range of over 200 miles at an accessible price for many middle-class consumers. In March, 2016, Tesla made another unprecedented move in the automotive industry by announcing the Model 3, an EV with a reported range of 215 miles on a single charge, at a price of $35,000, before incentives.[8] Chevrolet soon followed with the all-battery

[3] http://batteryuniversity.com/learn/article/lead_based_batteries
[4] "In Search of the Perfect Battery." *The Economist.* Print. March 6th 2008. Retrieved from: http://www.economist.com/node/10789409
[5] Technische Universitaet Muenchen. "Lithium-ion batteries: Phenomenon of 'lithium plating' during the charging process observed." *ScienceDaily*. Science Daily. 3 September 2014. Retrieved from: www.sciencedaily.com/releases/2014/09/140903105638.htm
[6] Schuster et al. (2015) Nonlinear aging characteristics of lithium-ion cells under different operational conditions. *Journal of Energy Storage*. Vol. 1. Pp. 44 - 53.
[7] https://cleantechnica.com/2015/04/26/electric-car-history/
[8] "Model 3" Tesla Motors. 2016. Retrieved from: https://www.tesla.com/model3

Bolt, packing an estimated range of 238 miles and starting at a price of $37,495.[9] Taking only federal tax credits into consideration, costs can be subsidized by up to $7,500, dropping the price of both vehicles to under $30,000 across the nation.[10]

Since the introduction of the Roadster in 2009, EV sales have grown steadily with the exception of one year.[11] In

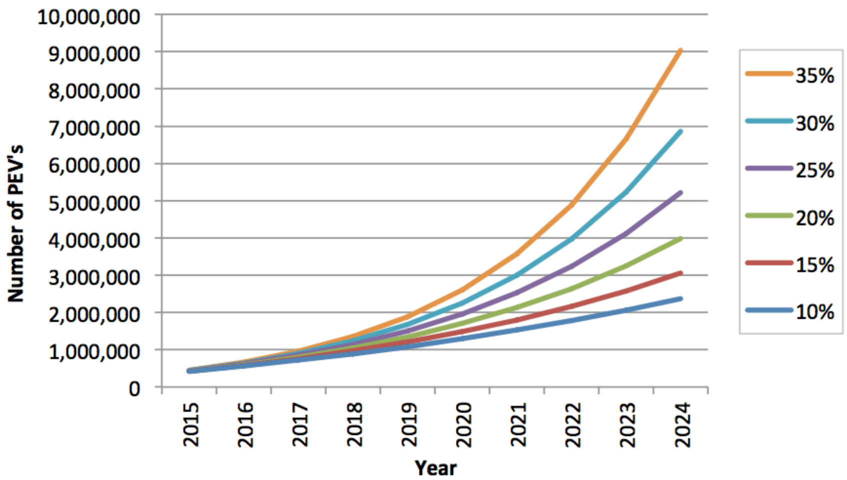

Figure 16: Global PEV sale predictions by growth rate. Image courtesy of the Electric Vehicle Transportation Center, Electric Vehicle Sales for 2014 and Future Projections Report

2015, EV sales in the US reached just over 100,000 units, representing a 17% decline from 2014. While some industry experts attribute this slump to the low price of gasoline[12], others believe that buyers interested in purchasing EVs are waiting for the all-electric Model 3 and Bolt to become available in 2017.[13]

With less than ten years of data available for analysis, EV growth estimates vary widely. However, there is nearly unanimous agreement that the industry will continue to see an upward trend. The Energy Information Administration (EIA) sets a low estimate for 2020 sales in the US at 449,000 units, while Deutsche Bank estimates that as many as 4 million units may sell annually by 2020. A 2013 study from the Florida Solar Energy Center (FSEC) projected cumulative 10-year EV sales for the period from 2013 to 2023 to be between 1.8 and 7.3 million.[14] Coming full circle, the FSEC study also recognized a number of studies that assume a 20% growth in EV sales, which corresponds closely to the EIA's lowest sales estimate.

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9 "The All Electric 2017 Bolt EV". Chevrolet. 2016. Retrieved from:http://www.chevrolet.com/bolt-ev-electric-vehicle.html
10 O'Dell, J. (14 April 2016) Electric Vehicle Tax Credits: What you need to know. *Edmunds*. Retrieved from: https://www.edmunds.com/fuel-economy/the-ins-and-outs-of-electric-vehicle-tax-credits.html
11 http://insideevs.com/monthly-plug-in-sales-scorecard/

12 Hull, D. (January 6, 2016) "Plug-in Electric Autos Left Behind in Record U.S. Year". *Bloomberg Technology*. Retrieved from: https://www.bloomberg.com/news/articles/2016-01-06/plug-in-electric-vehicles-left-behind-in-u-s-autos-record-year
13 "Electric Car Sales Up 10% in 2016". *EVObsesion*. April 9, 2016. Retrieved from:http://evobsession.com/electric-car-sales-up-10-in-us-in-2016/
14 http://evtc.fsec.ucf.edu/reports/EVTC-RR-01-14.pdf

Impact on the Energy Storage Market

LiBs are also being used extensively in grid-based energy storage systems (ESS).[15] ESSs are stationary banks of batteries tied to the electric grid that can be charged or discharged at various times, depending on the ESS owner's needs. "Behind-the-meter" (BTM) systems sit behind a utility customer's electricity meter, and are employed in a variety of ways to reduce the customer's electricity bills. "Front-of-the-meter" (FTM) systems are generally larger battery banks, on the order of 0.5 megawatts to 20 megawatts, and are used by utilities to either regulate transient anomalies in grid voltage, or in lieu of bringing additional power plants online to meet short-term (2-4 hour) peak energy demand.

Concurrent with the EV market, the energy storage industry is experiencing rapid growth. Greentech Media, a leading industry research body, estimates that the US will add an additional 15.4 gigawatt-hours of energy storage to the grid in the period from 2016 to 2021.[16] The vast majority of this will be LiB systems, with a battery capacity equivalent to nearly 257,000 of Tesla's currently available Model S cars, which come standard with a 60 kWh battery pack.

15 "Applications of Energy Storage Technology" *Energy Storage*. Energy Storage Association. 2016. Retrieved from: http://energystorage.org/energy-storage/applications-energy-storage-technology

16 GreenTech Media Research. (2016). U.S. Energy Storage Monitor: Q2 2016

Battery potential after EV use

As LiB-powered EVs continue to grow in popularity, questions surrounding end-of-life potential begin to arise. In the 1990s, car manufacturers became interested in lithium ion battery technology, leading the U.S. Advanced Battery Consortium (USABC) to establish standards for BEV battery performance.[17] USABC defines a battery as having reached "end of life" (EOL) in an EV application when delivered capacity is less than 80% of its rated capacity.[18]

Since commercial EV adoption is an extremely new phenomenon, real-time data is meager; current studies are based on predictive modeling and lead to varied results. However, general consensus holds that after about 8-10 years, or 100,000 miles, LiBs will deteriorate to a point that they are no longer viable for use in EVs and will need to be replaced.[19] Yet these same studies, such as one presented in 2013 at the National Meeting and Exposition of the American Chemical Society, also found that 70-80% of the original capacity still remains at this point. This means an influx of retired batteries will soon be available for secondary uses that require less power capacity. Navigant Research, a leading research organization in the energy industry, estimates that by 2035, there will be 11GWh of second-life LiB power from EV applications.[20] For perspective, this is enough capacity to meet the annual energy use for just over 1,000 US households.[21] In the Journal of Power Sources, researchers Jeremy Neubauer and Ahmad Pesaran note that second-life battery use could be economically valuable to the EV/PHEV industry by offsetting the high initial cost of purchase.[22]

Post-industrial scale energy use

LiBs are also switched out of grid storage applications when they've degraded to a certain point. However, there is scant literature or popular media detailing the scale or remaining capacity in these batteries. Overall, research points to two potential outcomes for post-primary use battery disposal: Direct recycling or secondary reuse.

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17 Wood et al. (2011) Investigation of battery end-of-life conditions for plug-in hybrid electric vehicles. *Journal of Power Sources*. Vol. 196. Pp. 5147-5154.
18 FEV North America. (2015) Battery Durability in Electrified Vehicle Applications: A Review of Degradation Mechanisms and Durability Testing. Draft Report prepared for the Environmental Protection Agency.
19 http://www.forbes.com/sites/peterdetwiler/2014/03/18/the-afterlife-for-electric-vehicle-batteries-a-future-source-of-energy-storage/#43b522653d17
20 Navigant Research. (2016). Annual Capacity of Lithium Ion Batteries for Plug-in Electric Vehicle Second-Life Stationary Energy Storage Is Expected to Reach 11 GWh by 2035. [Press Release] Retrieved from: https://www.navigantresearch.com/newsroom/annual-capacity-of-lithium-ion-batteries-for-plug-in-electric-vehicle-second-life-stationary-energy-storage-is-expected-to-reach-11-gwh-by-2035
21 EIA. How much electricity does an American Home Use? Retrieved from: https://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3
22 http://www.sciencedirect.com/science/article/pii/S0378775311012377

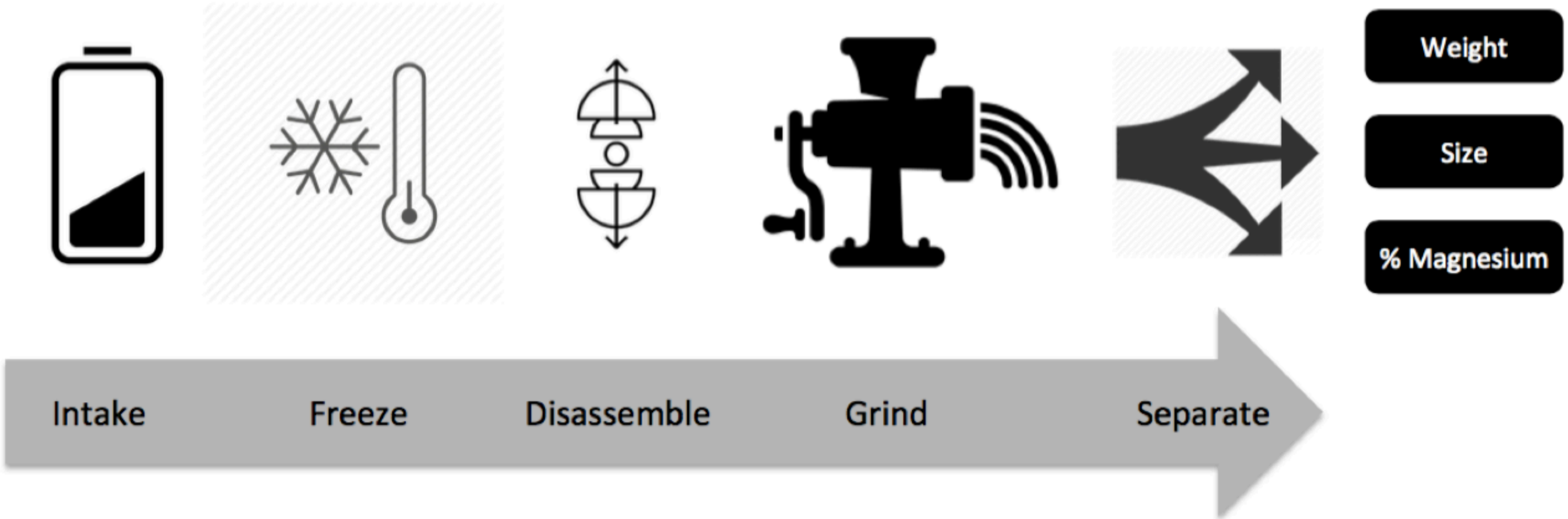

Figure 17: Visualization of battery recycling waste stream.

Recycling Capabilities and Expectations

Taking the aforementioned industrial growth predictions into account, researchers are working to assess management needs for these partial-use batteries. In the study "A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles," lead author Kirti Richa estimates a baseline of 1.9 million battery packs will enter the market annually by 2040.[23]

However, estimates for the total number of wasted battery packs per year could potentially range from 0.83 to 2.87 million. This means a cumulative outflow of 30 billion individual cells could require end-of-life management in less than three decades, requiring significant recycling and reuse mechanisms.[24]

Currently, all batteries are considered hazardous waste and must be recycled. Batteries that are intended for disposal may not be brought to a landfill, instead they must be taken to a universal waste handler or authorized recycling facility.[25] While a recognized standard exists for lead-acid car battery recycling, there is no current equivalent for lithium-ion chemistries. As mentioned, this technology is relatively new in the battery world, and extremely recent on the large scale of EV use.

Due to these growing pains, few facilities are equipped to properly recycle lithium-ion batteries. As a portion of waste handlers who are universally equipped to dispose of lithium-ion cells, only two, in all of the United States, have the capacity to recycle lithium-ion EV batteries on a commercial scale: Kinksbury Brothers and Retrieve Technologies, formerly known as Toxco, are therefore the only available recycling mechanism for all end-of-life EV batteries in the nation.[26]

Beyond the lack of infrastructure, chemical makeup is another complicating factor for lithium-ion battery disposal. A variety of lithium chemistries exist, and each individual EV manufacturer uses a slightly different process. These different metal materials must be separated from each other during the recycling process.[27] The chemical composition of cathodes also vary, resulting in differing valuations for the recycled materials. For example, lithium manganese oxide (LiMnO) waste streams are currently valued at an estimated $860 per ton. However, due to the high price of cobalt, lithium cobalt oxide (LiCoO) waste streams are valued at more than $8,000 per ton.[28] By comparing these valuations, researchers have found that lithium itself is not exceptionally

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[23] Richa, et. al. "A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles," *Resources Conservation and Recycling*; 83:63–76. February 2014. Retrieved from https://www.researchgate.net/publication/259995076_A_future_perspective_on_lithium-ion_battery_waste_flows_from_electric_vehicles

[24] Richa, et. al.

[25] http://www.calrecycle.ca.gov/reducewaste/Batteries

[26] http://www.calrecycle.ca.gov/Archive/IWMBMtgDocs/mtgdocs/2007/06/00022190.pdf

[27] Gaines, Linda. "The future of automotive lithium-ion battery recycling: Charting a sustainable course" *Sustainable Materials and Technologies*. December 2014.

[28] Wang, Xue, "Managing End-of-Life Lithium-ion Batteries: an Environmental and Economic Assessment" (2014). Thesis. Rochester Institute of Technology.

valuable as part of the LiB recycling process compared to the associated metals.

Methodology

In order to properly recycle batteries, facilities must first "deactivate and discharge" them by deep-freezing. This minimizes risk of a chemical reaction that may occur once the battery is opened. The batteries are then disassembled into single components and shredded, often with a high pressure hammer. Once the mechanical separation is complete, materials are sorted according to physical properties, such as weight, size and level of magnetism.[29]

However, a recent study conducted by Lux Research found that until packaging and external factors become more economically viable, recycling second-life batteries is a better option than reuse.[30] This research was done in particular reference to home energy storage systems, and not commercial-scale generator substitute or alternative wireless products. This opens up a platform to investigate a variety of alternative use-cases compared to recycling.

[29] Engel, Jan, "Development Perspectives of Lithium-Ion Recycling Processes for Electric Vehicle Batteries" (2016). Open Access Master's Theses. Paper 905.

[30] http://www.luxresearchinc.com/news-and-events/press-releases/read/recycling-not-reuse-better-choice-batteries-retired-electric

Predictive Potential

Despite aforementioned concerns over economic viability for home energy storage and nonlinear aging after 80% capacity, a number of studies have demonstrated technical and economic viability for second-life lithium ion batteries. These studies focus primarily on reuse for grid-based energy storage. In 2013, researchers at UC Davis explored the technical feasibility of such an application, finding that retrofitting second-life LiBs to store energy from a photovoltaic system was both simple and effective.[31] In this experiment, the research team used 135 second-life lithium ion phosphate ($LiFePO_4$) battery cells to form a 13.9 kWh battery pack. The pack was charged from a photovoltaic solar array, and effectively delivered over 10 kWh per day over a 198 days.

In another study, researchers at the University of Waterloo found that second-life LiBs with 80% capacity could be repurposed for grid storage and only sustain an additional 15% loss of capacity over a 10-year time period.[32] However, this process is labor intensive, as the repurposing involves disassembly and testing of the used battery modules, eliminating those that show signs of leakage or high internal impedance. The modules selected for high reuse viability are then repackaged and fitted with new wiring and control systems. Additionally, related studies found that use of second-life LiBs for grid storage could include significant environmental benefits, as long as systems were charged with renewable energy during off-peak hours and subsequently deployed as a substitute for natural gas power plants during times of peak electricity demand.[33]

Current Use Cases

Over the last few years, a few companies are already developing commercial products utilizing second-life LiBs. One is FreeWire Technologies, a startup that focuses on energy storage and delivery systems by repurposing second-life LiBs into two product lines: The Mobi Charger, a mobile EV charging system, and the Mobi Gen, a mobile diesel generator substitute product.[34] FreeWire has been conducting a pilot project for over two years at LinkedIn's Mountain View campus, with cloud-based statistics and usage measurements. This is the only commercially-available real-life data on second-life battery use, which will soon be used for studies based on non-predictive analysis.

[31] Tong et al (2013) Off-grid photovoltaic vehicle charge using second life lithium batteries- An experimental and numerical investigation. *Applied Energy*. Vol. 104. Pp. 740-750.
[32] Ahmadi, L. et al. (2014) Energy efficiency of Li-ion battery packs re-used in stationary power applications. *Sustainable Energy Technologies and Assessments*. Vol. 8. Pp. 9-17.
[33] Ahmadi et al. (2014) Environmental feasibility of re-use of electric vehicle batteries. *Sustainable Energy Technologies and Assessments*. Vol. 6. Pp. 64-74.
[34] Product Series. *FreeWire Technologies*. Retrieved from: http://www.freewiretech.com/

Another commercial use for a second-life LiB product is being done by EvGo, an EV charging company. They are partnering with BMW to use second-life LiBs from the i3 line of HEV sport-utility vehicles for stationary storage at DC fast-charging stations. The storage system is designed to reduce the total coincident power being drawn from the grid when multiple vehicles are hooked to a charging station, in an effort to reduce "demand charges"[35] paid by EvGo. Their pilot project at the San Diego State University campus won an Innovation Award at the 2016 Energy Storage North America conference.[36]

In a similar vein, GreenCharge Networks has partnered with Nissan to use second-life LiBs from Nissan's Leaf line of HEVs as low-cost, BTM energy storage.[37]

<u>Concerns</u>

Common issues with the reuse of second-life LiBs include the time and labor involved with repurposing the batteries, and losses in peak performance.[38] Additionally, the rapidly declining price of new LiBs[39] brings into question the actual cost-saving potential of using second-life LiBs.

35 "Demand charges" are a typical part of a commercial customer's electric utility bill. As opposed to an *energy* usage charge, which is a $/kWh rate, demand charges are generally a fixed $/kW charge that is set by the customer's peak *power* use during the billing cycle.

36 EVgo Wins Energy Storage North America 2016 Innovation Award. (2016 October 11) EVgo Latest News. *EVgo*. Retrieved from: https://www.evgo.com/about/news/evgo-wins-energy-storage-north-america-2016-innovation-award/

37 Nissan, Green Charge Networks Turn 'Second-Life' EV Batteries Into Grid Storage Business. (2015 June 15) *GreenTech Media*. Retrieved from: https://www.greentechmedia.com/articles/read/nissan-green-charge-networks-turn-second-life-ev-batteries-into-grid-storag

38 Recycling EV Batteries More Cost-Competitive Than Using For Home Energy Storage. (2016 November 24) *CleanTechnica*. Retrieved from: https://cleantechnica.com/2016/11/24/recycling-ev-batteries-makes-sense-using-home-energy-storage-lux-research-echoes-tesla-cto-jb-straubel/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+IM-cleantechnica+%28CleanTechnica%29

39 http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-technology-charges-ahead

Second Life vs. New LiB

Compared to the limited capacities of repurposed LiBs, the power potential and capacity of virgin batteries allow them to power multiple applications in a cost effective and efficient manner. From very small electronics to grid scale utility energy storage, LiBs have enhanced the performance of nearly all digital applications[40] in which they are utilized, as well as increasing renewable energy storage and easing grid intermittency concerns.

LiB vs. Other Chemistries

Although particular chemical makeup of individual cells varies performance between batteries, the average LiB can reach over 1000 deep cycle charges.[41] Compared to the lead acid batteries of the past, LiB technology has seen a four-fold increase in energy density, and significantly extended the battery material life. Additionally, newer batteries have removed many of the toxic components associated with lead acid.[42]

In order to reach new performance specifications, battery technology has moved away from lead acid as the standard and pushed towards lithium (Li) as the average-use standard bearer. Current compositions of Li-based batteries incorporate cobalt, manganese, phosphate, and nickel.[43] While the difference in mixture can provide better performance, cheaper materials, or longer life, it's the end application which usually dictates the ideal composition.

One of the biggest benefits of LiBs is the inherent lack of discharge memory.[44] When batteries are improperly recharged before a complete discharge of the battery cells through frequent recharging, they have a tendency to lose charging capacity. This phenomenon is primarily responsible for the shortened lifespans of early stage nickel cadmium and nickel–metal hydride batteries. Due to this common phenomenon, early adopters are prone to questioning the capacity retention of new battery technologies, like lithium ion. This translates into a significant consumer obstacle for the EV industry, as range anxiety and charging habits can be huge deterrents for buyers.[45]

[40] http://electronicdesign.com/power/understanding-lithium-batteries-portable-electronics

[41] "Characterization of commercially available lithium-ion batteries" Bradley A. Johnson, Ralph E. White. Center for Electrochemical Engineering, Department of' Chemical Engineering, University (South Carolina, Columbia, SC 29208, USA; revised 11 March 1997

[42] Arnold, Craig B. Canarella, John. Krieger, Elena M. "A comparison of lead-acid and lithium-based battery behavior and capacity fade in off-grid renewable charging applications" *Elsevier*. September 2013.

[43] "Lithium ion battery production" Antti Väyrynen, Justin Salminen. European Batteries Oy, Karapellontie 11, 02610 Espoo, Finland

[44] "Characterization of commercially available lithium-ion batteries" Bradley A. Johnson, Ralph E. White. Center for Electrochemical Engineering, Department of' Chemical Engineering, University (South Carolina, Columbia, SC 29208, USA; revised 11 March 1997

[45] Hurdle, John. "Toward a Cure for Range Anxiety." *The New York Times*. Published February 11, 2013

The most popular chemistries for current batteries and their uses are seen in the following table:

Chemical name	Material	Abbreviation	Short form	Notes
Lithium Cobalt Oxide Also Lithium Cobalate or lithium-ion-cobalt)	$LiCoO_2$ (60% Co)	LCO	Li-cobalt	High capacity; for cell phone laptop, camera
Lithium Manganese Oxide Also Lithium Manganate or lithium-ion-manganese	$LiMn_2O_4$	LMO	Li-manganese, or spinel	Most safe; lower capacity than Li-cobalt but high specific power and long life. Power tools, e-bikes, EV, medical, hobbyist.
Lithium Iron Phosphate	$LiFePO_4$	LFP	Li-phosphate	
Lithium Nickel Manganese Cobalt Oxide, also lithium-manganese-cobalt-oxide	$LiNiMnCoO_2$ (10–20% Co)	NMC	NMC	
Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$ 9% Co)	NCA	NCA	Gaining importance in electric powertrain and grid storage
Lithium Titanate	$Li_4Ti_5O_{12}$	LTO	Li-titanate	

Table 1: Common chemistries for lithium-ion batteries and their differentiating use-cases. Image courtesy of Battery University.[46]

[46] http://batteryuniversity.com/learn/archive/the_high_power_lithium_ion

Corporate Manufacturing Development

Asian countries, particularly Japan, are quickly becoming leaders in LiB production.[47] Companies like Sony, Sanyo Electric, Matsushita Electric Industrial, Moli Energy, and A&T Battery quickly capitalized on the growth of power storage. During the 1990s, the massive export of Japanese electronics helped fuel the promotion of virgin battery demand, competition and storage research.

Production Sources

The costs of extraction, production and retail costs of battery manufacturing have decreased substantially as lithium ion cell types continue to be refined,[48] making them extremely attractive for investors and bulk buyers. As mentioned earlier, Sony's first commercial cell offering established a new market for these powerful batteries. The initial cost point for these batteries was affordable to some, but still significantly more expensive than cheaper and less powerful options. The race to decrease costs while scaling up production has become one of the greatest obstacles for the lithium ion battery manufacturing industry.[49] Still, with a lithium ion battery performance of 130 Wh/kg with over 1000 discharge cycles, high energy demanding devices like cell phones and mobile computers have become increasingly more powerful and reliable.[50]

Costs of Mining and Manufacturing

Today, most lithium mining occurs in South America or Africa, although larger deposits have been found in other regions of the globe.[51]

Economic Costs

Currently, the most cost effective mining processes pump lithium brine from terrestrial sources into evaporation ponds like those seen in the Andes and Tibet.[52] Due to solar evaporation, the initial cost of refining lithium products is extremely low. This cost structure is carried through the refining process into further steps, such as transportation and production.

Safety Costs

However, this commonly-used open air extraction technique is high risk in terms of the environmental and human health.

[47] http://asia.nikkei.com/Business/Trends/Makers-boosting-production-of-Li-ion-battery-materials

[48] "Characterization of commercially available lithium-ion batteries" Bradley A. Johnson, Ralph E. White. Center for Electrochemical Engineering, Department of' Chemical Engineering, University (South Carolina, Columbia, SC 29208, USA; revised 11 March 1997

[49] Deng, Da. "Li-ion batteries: basics, progress, and challenges". Energy Science & Engineering Journal. 23 September 2015.

[50] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100033740.pdf

[51] http://investingnews.com/daily/resource-investing/energy-investing/lithium-investing/lithium-producing-countries/

[52] "The time dimension and lithium resource constraints for electric vehicles" Duncan Kushnirn, Bjo¨rn A. Sande´n. Environmental Systems Analysis, Energy and Environment, Chalmers University of Technology, Go¨teborg 412 96, Sweden

The use of hydrochloric acid in barren toxic zones, like those around Atacama in South America, is extremely volatile. By moving these processes to more westernized, populated areas, remediation efforts and processes may increase costs for these extraction steps.

Conflict Minerals and Metals

During the overall lithium ion battery development process, other input material considerations become part of the overall manufacturing process. In the DRC, cobalt mining connected to lithium battery development have sparked global controversy around "conflict minerals" beyond the traditional flight against conflict diamonds.

In 2010, 51% of the world's cobalt supply originated from the DRC; of that global stock, one quarter was associated with virgin battery production.[53] Child labor is of exceptional concern: one estimate claims that three minutes of child labor is associated with each laptop made with a cobalt-based lithium battery. Hybrid vehicle batteries are significantly more labor-intensive, as one EV battery requires 104 minutes of underage work.[54]

Political instability and oppression propagate this continued use of child and undervalued labor. Current wages at some of the most prolific mines, like those in Katanga, offer unstable jobs with daily wages equivalent to $3 per day for some of the riskiest roles, like diggers.[55]

Complexities Within the System

Despite the hardships associated with conflict metal mining, these operations can bring financial stability or advancement for many locals involved in the exploration and extraction processes. In Katanga alone, artisanal mining provides around 60,000 locals with jobs surrounding the operations.[56]. During the exploration phase for new mines, international investors may offer healthcare and educational incentives to gain access to these reserves.

Though clearly controversial, introducing western education and healthcare to impoverished communities has led to higher standards of living, and corporate social responsibility (CSR) initiatives have made major headlines, specifically in relation to the mining sector.

As these practices become mainstream, smaller villages and underrepresented populations are beginning to expect better treatment during extraction work. According to

[53] "Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo" Nicolas Tsurukawa, Siddharth Prakash, Andreas Manhart. Öko-Institut e.V. Freiburg Head Office. Freiburg, November, 2011.

[54] "Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo" Nicolas Tsurukawa, Siddharth Prakash, Andreas Manhart. Öko-Institut e.V. Freiburg Head Office. Freiburg, November, 2011.

[55] "Corporate social responsibility in the mining industry: Perspectives from stakeholder groups in Argentina" Diana Mutti, Natalia Yakovleva, Diego Vazquez-Brust, Martı́n H. Di Marco. Elsevier Resource Policy 37 (2012) Journal homepage: www.elsevier.com/locate/resourpol

[56] "Corporate social responsibility in the mining industry: Perspectives from stakeholder groups in Argentina" Diana Mutti, Natalia Yakovleva, Diego Vazquez-Brust, Martı́n H. Di Marco. Elsevier Resource Policy 37 (2012) Journal homepage: www.elsevier.com/locate/resourpol

stakeholder theory, explained by J. E. Post,[57] firms are responsible for delivering benefits to not only shareholders or customers, but those impacted by mining activities, such as locals. This responsibility extends to "environmental deterioration, social vulnerability and inequality." Focus in alleviating the detrimental effects of mining must further progress to combat the negative aspects associated with immediate job growth in a culture that may not be ready for western ideals.

Despite the above social developments, negative impacts of child labor, prostitution and immigrant labor forces can lead to tearing the societal fabric of these isolated communities. With the increase of immediate "wealth" to these poor districts, outlets for spending come with very little oversight. Due to the culture of the mining sites and the assignment of higher paying jobs to men, prostitution rings and other options tailored to men's money exist with very little regulation. In Africa, many migrants and former soldiers working in mines spread HIV quicker than in populations not involved in mining. As artisanal mining represents 2.4% of Congolese GDP, the scope of this phenomenon is not limited to specific mines.[58]

<u>Market Impacts</u>

Mining efforts and predictions of remaining lithium stock have recently become an important topic surrounding further developing energy storage technologies and market prices overall. At current rates, the market assumes underground mining recovers 50% of energy utilized. However, other, more dangerous mechanisms (such as the lower cost open pit methods) are thought to recover 75% of energy consumed. Markets have equated lithium trends to copper, which has seen recently seen fluctuating prices with an overall upward trend.[59]

An increase in the price of lithium could significantly impact the overall storage market, thereby affecting the technology and electric vehicle transportation sectors. In certain situations, the cheapest labor solution cannot keep the price as low as the market would deem profitable. In those scenarios, the miners may face lower wages and overall health as in the case of mines in the Democratic Republic of the Congo (DRC). These particular mines have caused outrage and political strife with conflict minerals associated with lithium based products.

[57] **Tom Donaldson and Lee E. Preston, "The Stakeholder Theory of the Corporation: Concepts, Evidence and Implications,"** ***The Corporation and Its Stakeholders*****, 1998, , doi:10.3138/9781442673496-011.**

[58] "Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo" Nicolas Tsurukawa, Siddharth Prakash, Andreas Manhart. Öko-Institut e.V. Freiburg Head Office. Freiburg, November, 2011.

[59] https://www.linkedin.com/pulse/status-lacks-copper-pcb-raw-material-nancy-zhou

Generators, which are classified by the EPA as non-road engines together with recreational vehicles, such as snowmobiles and all-terrain-vehicles, are regulated by strict EPA emissions standards. Second-life batteries have the potential to replace many generators currently utilized in the U.S. Below are a number of the concerns surrounding fuel-powered energy generation.

Exhaust

The impact of generator exhaust on air quality is significant: All non-road engines accounted for 9% of the United States' hydrocarbon (HC), 4% carbon monoxide (CO) and 3% nitrous oxide (NOx) emissions.[60]

In 2002, the EPA set regulations to reduce all emissions from non-road engines by at least 57 percent. Current regulations state that all diesel, gasoline and gas powered generators may not emit more than 4.4 g CO/ kWh, 2.7 g HC/ kWh and 2.7 g NOx/ kWh. In relation to a 25kW generator running for 8 hours, this would result in a cap of 880g of CO and 540g of both HC and NOx emissions. The EPA also regulates the useful life of generators, which is limited to either 7 years or 5,000 hours.[61]

In addition to air pollution, generators are known to disturb residents and businesses with high levels of noise pollution. Generators emit at least 100 dB of noise, which is approximately twice the volume of a regular conversation.[62] Studies show that exposure to increased noise disturbs sleep and causes daytime sleepiness, which directly affects work performance and productivity. Additionally, extensive noise pollution can cause hypertension, cardiovascular disease and impair cognitive performance in school children.[63]

Comparison to Grid Electricity

Battery-powered generator substitutes rely on grid generation, a power source which also contributes to diminished air quality. California has one of the cleanest energy portfolios in the United States[64] due high use of renewables and low power production from coal plants.

The following figure shows relative life cycle emissions in grams of CO2e/ kWh for various energy sources.

[60] http://www.cpower.com/pdf/infosheets/27.pdf
[61] https://www.dieselnet.com/standards/us/nonroad.php

[62] Ernst, Liz. "Emergency Generator Noise is a Growing Problem" *Acoustiblok*. December 2011
[63] Basner M, Babisch W, Davis A, et al. Auditory and non-auditory effects of noise on health. *Lancet*. 2014;383(9925):1325-1332. doi:10.1016/S0140-6736(13)61613-X.
[64] http://www.huffingtonpost.com/2014/11/20/the-best-and-worst-states_0_n_6134960.html

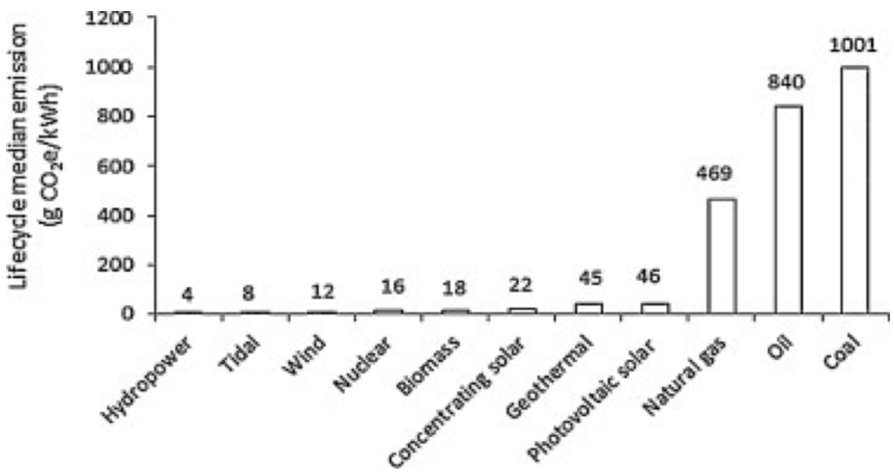

Figure 18: Emission production by power source. Retrieved from "Emissions from tropical hydropower and the IPCC"

According to EGRID data, each MWh of electricity produced emits an average 288 Kg of CO2 equivalent (EPA 2012), which translates to 288 g of CO2 emissions per kWh of electricity.

<u>Lifetime emissions from fossil fuel production</u>

In order to understand the full environmental impact of fuel-power generation compared to second-life battery storage of grid-based energy, a lifecycle assessment must be conducted. This allows researchers to analyze the cradle-to-grave environmental impacts of comparative products. A metric called well-to-wheels (WTW) is utilized to determine emissions and effects of various fuels. This encompasses the entire process, from the extraction of crude resources to end-use.

The Bakken play in North Dakota is a common source of national crude extraction, and therefore useful in LCA. WTW diesel production from the Bakken play causes 93.2 grams of CO2 equivalent per million Joules (MJ) of diesel emission, with 146.5 MJ per gallon of diesel fuel.[65] At an average of 1 gallon of fuel per hour for a diesel generator running for 8 hours, 109 kg of CO_2 would be emitted:

Equation 1: Measurement of CO2 emissions from diesel consumption.

93.2 g CO2e x 146.5 MJ x 8 hrs = 109,230g CO2e = 109 kg CO2e

[65] Brandt, Adam R. Yeskoo, Tim. McNally, Scott. Vafi, Kourosh. Kai, Hao. Wang, Michael Q. "Energy Intensity and Greenhouse Gas Emissions from Crude Oil Production in the Bakken Formation: Input Data and Analysis Methods" Prepared for Systems Assessment Group, Energy Systems Division Argonne National Laboratory.

WTW gasoline production from the Bakken play emits 94.6 grams of CO2 equivalent per MJ.[66] At an average of 1 gallon of fuel per hour for a gasoline generator running for 8 hours, and 131.8 MJ of emissions per gallon of automotive gasoline, 100 kg of CO_2 would be emitted:

Equation 2: Measurement of CO2 emissions from diesel consumption.

94.6g CO2e x 131.8 MJ x 8 hrs = 99,746g CO2e = 100kg CO2e

Extraction for natural gas and petroleum differ from the above. Data from the Marcellus shale, one of the largest and most studied fracking sites in the U.S., shows that life-cycle emissions of 1 kWh of natural gas equivalent release 466 g CO2e. These include emissions from extraction, transportation and use phase. Laurenzi & Jersey's results regarding these emissions are similar to Fearnside's calculations of 469 g CO2e/ kWh.

[66] Brandt, Adam R. Yeskoo, Tim. McNally, Scott. Vafi, Kourosh. Kai, Hao. Wang, Michael Q. "Energy Intensity and Greenhouse Gas Emissions from Crude Oil Production in the Bakken Formation: Input Data and Analysis Methods" Prepared for Systems Assessment Group, Energy Systems Division Argonne National Laboratory.

Conclusion

Despite a plethora of research continuously done on power, batteries and related energy generation sources, information surrounding second-life battery impacts are exceptionally lacking. As the EV market is just beginning to burgeon, second-use case data for batteries is weak, leading scientists to conduct studies on predictive and hypotheticals. The depth of uncertainty in this arena has lead to a number of intriguing hypotheses; however, much of the data is contradictory and ultimately meaningless until we garner real-life understanding of how battery performance will deplete over time.

Additionally, momentum around lithium ion battery improvement is creating an extremely sensitive and uncertain model for predictive growth. Many researchers are also switching their sights to other game-changing technologies that could displace LiBs, such as supercapacitors[67], fuel cells, and other potential innovations.

Sunset Power Solutions is heavily investigating the most pragmatic and economically viable solutions for second-life lithium ion batteries. As new research continues to be published, the team plans on integrating these findings into development of an environmentally and economically value proposition.

[67] http://news.mit.edu/2016/supercapacitor-made-without-carbon-1010