Residential Energy Storage Solution to Address Renewable Energy Shortcomings

A Technical Report
presented to the faculty of the
School of Engineering and Applied Science
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by

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with

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____

Approved: ____________________________________ Date ______________________
James Groves, Department of Engineering and Society

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Overview

This project was undertaken with the goal of developing an energy storage system that could promote resilience and independence from failures of the electrical grid. Stakeholders benefiting from this include consumers victim to blackouts, solar panel companies, finance companies, and utilities. This storage system could be charged either via personal solar cells, or from the electrical grid itself. One of the primary use cases in mind when developing this project was electrical blackouts that occur in California. If homeowners had these systems, they would be able to continue life as normal for a certain amount of time while the storage system supplied their electrical demands. The team ultimately selected a battery as the storage system. Requirements and specifications that were focused on for the battery were defined as cycle life (lifetime), efficiency, cost, and environmental impact.

The totality of research for the solar storage technology solution can be divided threefold: finances, materials, and the system. Each of these categories has utilized extensive STEM knowledge from each of the team members, each with different areas of expertise. These three different pieces of the project were mutually dependent on one another. The algorithm's design was strongly tied to the finances section. The algorithm had to know how to behave in order for the homeowner to qualify for certain incentive programs. The finances were very dependent on the battery as well. Depending on the materials and specification of the battery, the price point changes. A change in price point affects who can afford the battery. Cost was the unifying factor that united the system, the materials, and the financing.

The design of the system was intentionally flexible. For this reason, the battery storage system is not only viable for a certain area or set up. It can either be attached to solar cells, or directly to the grid. The battery can be charged in a variety of special modes to help take advantage of whatever incentives may be applicable for the region that a given customer lives in as well.

Applications to STEM

Financial

The financial aspect of the solar storage technology solution takes advantage of various aspects of data and risk analysis as well as rudimentary modeling skills. In addition, simple concepts such as return on investment (ROI), interest, and payment sheets. Developing this financial model is important in understanding the value for the customer in acquiring a solar storage system. By creating a report of revenues and expenses, we are more able to compare the costs and benefits of the system. However, the team first needed to better understand the current market for solar storage and how other companies afford the costs involved to produce a solar storage technology as well as understanding the generation of cash flows between the company, consumers, and third parties. Using data analysis to better convey the risks and appropriate modeling concepts. The use or attempted use of stakeholders were contacted in an attempt to understand more in depth the finances and technologies in relation to the solar industry. These stakeholders include a solar finance firm that must remain anonymous and Argonne, an emissions and science lab in Charlottesville.

Materials

The materials aspect of the solar storage technology solution is directly related to important concepts in fundamental engineering background knowledge. Utilizing knowledge about material properties to understand the differences between the battery types is crucial to determining a valid solution. Understanding energy, power, capacity, and other units and what they mean in terms of the battery performance is important as well to accurately comparing and choosing the storage solution. Additionally, knowledge about materials on the micro and nano level is needed to understand scientific articles relevant to comparing and researching battery types and technologies.

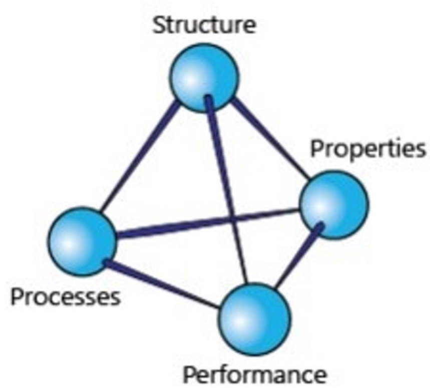


Fig 1. Materials science tetrahedron

Our application utilizes a core concept in materials science, the materials science tetrahedron. This concept relates structure, processes, properties, and performance, which are interrelated and contribute simultaneously to a successful product. These faucets relate directly to battery technologies. Properties such as electrochemical and mechanical properties are critical to the effectiveness of the battery which affects performance. The structure of the battery on the macro, micro, and nano level are also crucial to various necessary aspects of the battery such as efficiency, cost and environmental impact. The crystal structure of varying materials plays a significant role in the overall battery's properties and performance. The performance of the battery is a product of the properties and processes to fabricate it, which directly connects to this project's design specifications.

Courses such as Materials Science Investigations; Thermodynamics and Kinetics of Materials; Materials for Electronic, Optical, and Magnetic Applications; Materials Processing; and Introduction to Sustainable Energy Systems have all contributed to this knowledge and aided in prototyping, testing, and eventually coming to a conclusion on our final product. Concepts in these courses such as electron transport aided in background knowledge of how batteries operate on a nanoscale level and furthermore how different materials and crystal structures affect this to influence efficiency. Understanding of thin film and materials processing techniques was crucial to determining techniques needed to improve efficiency and deciding which processes would be more beneficial to our application versus others. From a sustainability standpoint, understanding lifecycle analysis data was invaluable to analyzing different environmental impacts on various battery materials and eventual determination of a battery type.

Algorithm

For the design of the algorithm, a number of the core classes from the UVA CS and the larger UVA Engineering school curriculum was pulled from. For the platform that would be hosting the algorithm, experiences in Engr 1620 were useful. In Engr 1620, students learned how to program RaspberryPi in python, and a RaspberryPi was, not coincidentally, the platform we selected to control the charging of the battery. Also, the teamwork approach to complex problem solving is taught in this class. By identifying relative strengths in the group, and allowing people to play to their own, optimal results can be achieved.

Experiences from other Python based classes such as CS 1110, where the fundamentals of how to problem solve in Python are taught, was also invaluable. In CS 1110, conditionals and if else statements are the major focus. Later in the year more advanced paradigms like loops are introduced. Upper level classes like Algorithms were useful when it came to designing the algorithm itself. In these classes, students are taught logically how to think through problems, and consider all possible inputs, and then figure out how to make sure these result in the desired outputs. Learning how to do REST calls in Ecommerce Technologies was also a useful skill, and was directly helpful when plugging into the WattTime API.

Prototyping and Testing

Finance

Introduction to Finance

The financial section covers the different factors of cost related to producing a battery as well as the incentive programs that aid in reducing the cost of the battery for both the consumer and the production company. First, the total cost of a battery will be calculated by using credible sources, relating it to our model – a 65kWh Lithium-Iron-Phosphate battery. After finding the initial cost of production for our model, the coverage of all incentive programs will follow. These will be broken down into eligibility incentives, performance-based incentives, and other rebates, giving a good idea of the market price. Afterward, a general timeline of the flow of cash for the customer will be described so as to better conceptually understand the timing of the incentives.

Evolution of Finances

The financial system is largely confounded in the collection of information. Throughout the course of the collection of information, the majority of research has been through the collection of information. As this process has progressed, the display of information has become clearer. The information later displayed is the full concentration of knowledge that has been learned throughout the previous year, collected of the course of the school year. The evolution of the financial model is more the display of information rather than an evolution. Overall, the collective information is shown throughout the course of the paper.

Final Costs for the System

The costs for solar storage can be broken down into two consistent categories: soft costs and hardware costs. Hardware costs are simply the cost of resources to manufacture the battery – essentially the materials of the battery itself. Soft costs are non-material related costs pertaining to the development of the battery – licensing, initiation fees, partnerships for software and system development, etc. Below is an in depth look at the intricacies of soft costs in solar storage as an industry, followed by a comparison of our project to the industry's costs.

Soft Costs

Soft costs can be broken down into a multitude of categories, all of which will be explored. These categories are: Engineering, Procurement and Construction (EPC), Developer, Debt Fees, Professional Services, and Additional Transaction Fees.
All of this follows a 2012 solar storage cost analysis. Battery costs are introduced on a cost-per-watt basis, so that if the battery itself carries a higher capacity, the cost is adjusted accordingly.

EPC Installer

EPC services are those dealing with the physical battery and focus on the technology and the "how" to construct the battery all without the inclusion of the cost of the actual hardware. The averages for this category is as follows:

EPC Installer (engineering, procurement, and construction) –
- SG&A (selling, general and administrative): $.19/W
- Direct Costs: $.15/W

Developer Costs

The developer produces the software that controls the capacity, output and other factors pertinent to the battery. Typically, the system can be automated using this system using priority queuing, and the costs of the software and the personnel are involved in this sense. The averages for developer costs are as follows:

Developer –

SG&A: $.76/W
Direct Costs: $.24/W

Debt Fees

Debt fees are pretty self-explanatory. They are simply the accumulation of debt in terms of interest or other styles of accruement during the payment to specific companies or other credit holders:

Debt Fees (for developer) – $.05/W

Professional Services

Professional Services would be professional labor mainly for the purpose of installing the battery in a home or business. They are as follows:

Professional Services – $.04/W

Additional Transaction Fees

Other fees can include litigation or scribes when writing contracts. This can also include transportation or storage fees for inventory as well. Other fees are as follows:

Additional Transaction Fees – $.12/W

Hardware Costs

In general, the total cost of the actual hardware is based on the same 2012 cost analysis as the soft costs. There can vary based on the specific materials used, but for simplicity at this moment, our team has used the industry average for this purpose. The most common battery for solar storage at this point in time is the Lithium-ion battery, and even that is a generic term. By using a Lithium-Iron-Phosphate battery, our costs will be different from the industry average. But without real research and development, the industry average is our starting point. The average total cost for the storage system is **$2.92/W**.

Total Cost

By adding together all factors listed above, the total cost of development, it costs an average total of $4.47/W for the construction of a battery, according to the report, with no margin included.

Table 1. Cost factors for Solar Storage System

Cost Factors	Cost
EPC Installer	SG&A: $.19/W Direct Costs: $.15/W
Developer	SG&A: $.76/W Direct Costs: $.24/W
Debt Fees (for developer)	$.05/W
Professional Services	$.04/W
Additional Transaction Fees	$.12/W
System	$2.92/W
Total Cost	$4.47/W

Using our battery metrics, under this assumption, a 65 kW battery for the average company would be **$290,550.**

However, that price is met under the assumption of hiring separate entities to finish tasks. Our group will be self-reliant in those aspects, meaning all costs associated with the developer will be nullified and the cost of EPC and transaction costs would dramatically decrease. Instead of $4.47/W, the cost for our group would be an estimated $3.28/W (subtract $1.00/W for developer and $.19/W for EPC Installer's SG&A) – **$213,200** per 65kW battery.

This being said, since 2012, the cost of solar storage has dropped by 76% (*Mai*). By cutting all costs without weight to a specific factor, the predicted current cost of our battery is: $213,200*(1-.76) = **$51,168**.

Incentives

Using the incentive programs discussed earlier – SGIP, ITC and MACRS – there is ample opportunity for manufacturers and consumers alike to save money. For our team, there are two types of incentives in which we are interested: eligibility incentives and Performance Based Incentives (PBIs). Eligibility incentives are simple in that by simply being located in a specific geographic location, having a specific income, etc., one can use the incentive. PBIs are based on the performance of the solar system and each program has nuanced performance metrics.

Eligibility Incentives

While the PTC, ITC and MACRS are more related to buy-back rates, credit rates and tax deductions, the SGIP works on both eligibility incentives and PBIs. For our initial targeted market (rural-suburbia in California), the generally accepted upfront coverage for the SGIP is about 50%. At 50%, the upfront cost for our consumer would be **$25,584.** The following is a chart of yearly payment information, assuming a 50% coverage of upfront costs, for a 10-year payment plan, with a 3.99% interest rate:

Loan	25584				
r	3.99%				
n	10				
payments/yr	12				
Monthly Payment	$258.90				
Year	ADS	Interest	Principal	Balance	PMTS Left
0				25584	120
1	$3,106.85	$982.23	$2,124.62	$23,459.38	108
2	$3,106.85	$895.89	$2,210.96	$21,248.42	96
3	$3,106.85	$806.04	$2,300.81	$18,947.61	84
4	$3,106.85	$712.54	$2,394.31	$16,553.30	72
5	$3,106.85	$615.24	$2,491.61	$14,061.69	60
6	$3,106.85	$513.99	$2,592.86	$11,468.83	48
7	$3,106.85	$408.62	$2,698.23	$8,770.60	36
8	$3,106.85	$298.97	$2,807.88	$5,962.72	24
9	$3,106.85	$184.86	$2,921.99	$3,040.73	12
10	$3,106.85	$66.12	$3,040.73	$0.00	0

Fig 2. Yearly payment information

It includes the Annual Debt Service (ADS), which is the annual amount paid by the consumer, the amount of interest and principal remaining on the loan, the remaining balance, as well as the remaining payments (PMTS).

If the battery fails to meet any of the performance metrics, the baseline monthly payment for consumers is **$258.90**.

PBIs

Again, the SGIP will be the main program relating to PBIs due to its structure in comparison to other programs. For the SGIP, its PBI pertains specifically to the solar storage output capabilities and can be viewed in the following chart:

Energy Storage Incentive Calculation

Combining both incentive reductions produces:

>4-6 hours	25%	12.5%	6.25%
>2-4 hours	50%	25%	12.5%
0-2 hours	100%	50%	25%
	0-2 MWh	>2-4 MWh	>4-6 MWh

Both types of incentive reductions apply if the project has a duration longer than two hours AND an energy capacity greater than 2 MWh.

Fig 3. SGIP Incentive
https://www.selfgenca.com/home/resources/ ->SGIP Incentive Examples

The nuance is that the battery must be capable of outputting 10kW in order to receive financing. The standards of production incentive rate are at 100% for 0-2 hours of use, and as hours of production increase, the incentive decreases for the remaining hours (think like our tax system). So, let's use the battery our team has developed with the SGIP standard $50/Wh rate – 65kWh, so 13 hours at a 5 KW output.

First 2 hours: 10,000 Wh * $.50/Wh = **$5,000**
Second 2 hours: 10,000 Wh * $.50/Wh * 50% = **$2,500**
Third 2 hours: 10,000 Wh * $.50/Wh * 25% = **$1,250**
Remainder of time: no incentive

Total incentive: **$8,750**

This is just an example, but using our battery with a 65kWh system, this is very much a possibility. In order to maximize the total incentive, we would have to minimize hours of use to a 2-hour system, giving us a total incentive of:

65,000 Wh * $.50/Wh = **$32,500**

However, this would not be conducive to the purpose of our battery for long period sustainable use during a rolling or sudden blackout. That's why I recommend the top example with a 13 hour system.

If we want to target those that need day-long support for medical reasons, then a 24-hour use battery incentive would like:

65kWh
2.708 kW, 24 hours

First 2 hours: 5,417 Wh * $.50/Wh = **$2,708**
Second 2 hours: 2,708 Wh * $.50/Wh * 50% = **$1,354**
Third 2 hours: 2,708 Wh * $.50/Wh * 25% = **$677**

Total Incentive: **$4,739**

These examples show one reasonable case as well as the two extreme cases for the output capabilities of the battery. Below is a one-way sensitivity analysis that shows all possible incentives for the battery output in terms of the hour of duration, in increments of two:

1-2 hours	100%	watt	65000
3-4 hours	50%	rate	0.5
5-6 hours	25%		
	Hour of Duration	Incentive	
	2	$32,500.00	
	4	$24,375.00	
	6	$18,958.33	
	8	$14,218.75	
	10	$11,375.00	
	12	$ 9,479.17	
	14	$ 8,125.00	
	16	$ 7,109.38	
	18	$ 6,319.44	
	20	$ 5,687.50	
	22	$ 5,170.45	
	24	$ 4,739.58	

Fig 4. Sensitivity analysis of PBIs

Other Incentive Programs

Other incentive programs do not directly benefit income/cost of the battery or are dependent on the utility company provided. Starting with the ITC, it allows homeowners and business owners to deduct a certain percentage of the cost of the battery from their taxes (*Matasci*). The specific percentages are:

2020 – 26% of total cost
2021 – 22% of total cost
2022 and thereafter – 10% of total cost

The MACRS is another tax-deductible program that works in tandem with the ITC. It allows for the remainder of the solar cost to be deducted from the tax basis. For example, if filing in 2020, the homeowner deducts 26% of the cost of solar. The homeowner can then deduct the remaining 1- (26%/2) or 87% of the cost from their tax basis for the given year (*Depreciation of Solar*). This will vary from person to person, but is beneficial to potential consumers.

Timeline

The various types of incentives can cause confusion as to when the funding will be received by the consumer. All directly monetized incentives – eligibility and performance based – will be included at the initial point of sale, thus deducting the price closer to market price: $17,459. From there, the consumer will begin making monthly payments upon the point of installment for 10 years. At the end of each year, during tax season, the consumer can then use the other incentive programs like the ITC and MACRS to deduct their annual debt service from their taxes. Any other reductions from cost (electric costs from the grid, etc.) would be the sole responsibility of the consumer.

Total Costs

When deciding the hours of duration – or the discharge period – of the battery the figure, it is important to understand the funding it will receive as well as the overall objective of our battery project. Due to the dramatically increased cost of production, the 24-hour long duration battery was not feasible as a market solution. When doing this, it seems most reasonable to consider a 14-hour battery as the optimal solution. This means the total PBI will be **$8,125**. An idea of our battery's cost for the consumer would then be:

Loan	17459				
r	3.99%				
n	10				
payments/yr	12				
Monthly Payment	$176.68				
Year	ADS	Interest	Principal	Balance	PMTS Left
0				17459	120
1	$2,120.17	$670.29	$1,449.88	$16,009.12	108
2	$2,120.17	$611.37	$1,508.80	$14,500.32	96
3	$2,120.17	$550.06	$1,570.12	$12,930.20	84
4	$2,120.17	$486.25	$1,633.92	$11,296.28	72
5	$2,120.17	$419.85	$1,700.32	$9,595.96	60
6	$2,120.17	$350.75	$1,769.42	$7,826.54	48
7	$2,120.17	$278.85	$1,841.32	$5,985.22	36
8	$2,120.17	$204.02	$1,916.15	$4,069.07	24
9	$2,120.17	$126.15	$1,994.02	$2,075.05	12
10	$2,120.17	$45.12	$2,075.05	$0.00	0

Fig 5. Payment plan with all Incentive funding received

This leads to a very reasonable $176.68 per month for the consumer over a 10-year period. The reason for the 10-year period is due to the expected lifespan of the battery. With an expected lifespan of more than 10 years, it is reasonable to end the payment plan before the usable cycle of the battery is complete. This is all also under the assumption that there is no a 0% down payment. By incorporating a down payment, the monthly payment cost would go down a significant amount.

The culmination of the financial plan produces a reasonably priced monthly payment plan for a designated 10-year period, which is shorter than other significant purchases like a car or house. Taking into account the challenges of development: producing an effective battery, developing a system and understanding the market, the financial model puts all of these together to succinctly and effectively describe these aspects to the potential consumers.

Challenges

Moving forward, the largest issue we still need to tinker with is: if homeowners will live there for only a handful of years, how do they continue paying?

Some of these problems may be self-resolving. In terms of homeowner payment, solar panels and storage instantly appreciate the value of the home, plus they are entitled to 26% back in tax deductions. IF the homeowner is to sell their house, they could already make more profit to offset the costs of the solar storage. Even if they are paying the cost of the battery over a long period, it would be worth it. It is possible to transfer the title of the battery to the next homeowner so that they will be the ones to continue payment. There is also the possibility of simply leasing the battery, then properly restoring, repurposing or disposing of the batteries ourselves so as to ensure proper treatment.

Algorithm

Introduction to the System

Solar Storage is an already-implemented technology used to store and hold energy received from solar panels for an extended period of time. The need for such use has greatly increased as solar panels have become more commonplace and self-attained energy has become of a necessity, given rolling blackouts and power outages in California (discussed previously).

This being said, the actual solar storage technology must be innovated in order to accommodate the growing needs of the general public. Our project is to research and implement possible improvements to existing technologies, namely in the topics of cost, environmental impact, lifespan, and overall system function.

Rudimentary Solution Concept

The basic solution that the team produced is as follows:

a. The Selected Region – California. Place of high interest, with mandated solar systems on new developments and highly funded incentive programs for solar storage.

b. Battery Type – Lithium Iron Phosphate (LFP) battery with a capacity of 65kWh. It has effective and sufficient efficiency during charge and discharge periods. The materials used are more common and less ecologically harmful than other materials commonly used in batteries – namely cobalt. The lifespan of a LFP battery can be up to 10,000 cycles in comparison to 500 cycles for a Lithium-ion battery.

c. Financial Modeling – A fixed payment plan that works in accordance with the many incentive programs to limit the overall cost. Low interest rates due to the high likelihood of repayment with incentives.

d. System – The system used with the solar battery is a programmed algorithm with priority queues that the client chooses with either an app or a panel device installed in the home.

Understanding the Finances

There are a number of inputs necessary to determine the payment plan and payment price.

1. The first aspect is the initial price point of the battery (P_i). This means determining production cost of the battery and the profit margin per battery.
2. After finding that specific price point, the next concept is the collection of incentive subsidies for a specific client. There are two ways in which the funds from the incentive programs are given.
    1. Pre-installation allocation (A_1) – there are qualifications that a client must meet that are more rigid in structure (i.e. low income, living in a certain region, etc). If these qualifications are met, the client receives the subsidy to buy the solar storage system.
    2. Post-installation allocation (A_2) – the client must keep the solar + storage system running with certain standards based on emissions, kWh used and other performance-based metrics. After the allotted time period, if those standards are kept, the client will receive the subsidy, in the sense of a monthly rebate.
3. The third factor is the interest (r) and payment length (n) in order to determine the fixed payment amount. Once the pre-installation allocations are received, they can be cut from the initial price to find a total loan amount(L).

The final monthly payment (M) amount would look similar to such:

L=Pi-A1

Year	Amount	Payback
1	M=[L/(n*12)]*[1+(r/(12)]	
2	M=[L/(n*12)]*[1+(r/(12)]	A2
3	M=[L/(n*12)]*[1+(r/(12)]	A2
4	M=[L/(n*12)]*[1+(r/(12)]	A2
...	...	...
n	M=[L/(n*12)]*[1+(r/(12)]	A2

Fig 6. Final monthly payment amount

In general, this kind of payment plan would apply to any type of client – residential, commercial or industrial. The nuance would be with contracted work with companies. For example, Acme Real Estate Company could have a contractual agreement to use our solar storage batteries for all new housing developments in a given development. The only difference would be that the batteries are essentially bought in bulk. Instead of having *n* payment plans for the *n* housing developments, they would simply combine and pay for the batteries under one payment plan, using the same method as above or by paying it forward as a 100% down payment.

Interest Rates

Generally, interest rates vary based upon type of loan, credit score of the individual (or the rating of the company), and the economic situation. With the use of state and federal funding, the likelihood of repayment increases exponentially. In fact, the government debt on the loan is considered sovereign debt and is essentially risk-free with 100% guarantee of repayment.

Finding Incentive Programs

In the state of California, there are hundreds of possible incentive programs and funding opportunities as well regulations and mandates to follow. The simplest way to find these is by using a program database. The best database we have found so far is DSIRE, which has consolidated all state and federal funding programs into one website (website link is in the citations). There is a filtering system on the website to limit the programs specifically to solar for a certain region (county, city, precinct, etc.). It is regularly updated, so someone would be in charge of manually checking for updated or out of date program listings.

Other Financial Costs

The other general costs include general and unsecured fixed and variable costs like leasing for production and inventory, utilities, the cost of development for the system algorithm, and research and development to produce the prototype. In general, these are considered overhead and will be accounted for with inclusion to the profit margin. The cost of development of the system algorithm could slightly alter the initial battery price slightly, depending on the software necessary to do so. The research and development can often be funded for projects such as these.

Designing the Algorithm

There are a number of factors to consider when designing the algorithm that controls the charging and discharging of the battery. We are primarily considering the California market, so in addition to nationwide incentive programs, state incentive programs will also come into play. We selected Python as the language of the algorithm due to the speed of development in Python, and that it runs natively on many controllers such as Raspberry Pi.

Self-Generation Incentive Program

One of California's green investment incentive programs is called the Self Generation Incentive Program (SGIP).

> "California's **SGIP rebate** is one of the best incentives in the country for homeowners who want to install a home battery with their solar panels. The Golden State already leads the country in solar energy – it has more solar capacity than any other state in the U.S., and nearly six times more solar than number-two state Arizona. Now, California is becoming a leader in energy storage. Thanks to the Self-Generation Incentive Program (SGIP) you can get a rebate for most or all of your solar battery installation in California, and it's about to become a lot easier for homeowners to access. Here's everything you need to know about the SGIP rebate."

If the battery is connected to solar cells versus if it is just connected to the grid will have a large impact on how the algorithm is run. There is currently a requirement in California that all new house construction must have solar installed as well. This requirement will make installing a battery to be more attractive. To take full advantage of SGIP, the battery storage system must be charged by at least 75% from the solar cells. This means that if a homeowner wants to take advantage of SGIP, the algorithm must know this and monitor how much it powers the battery from the grid verses from the solar cells.

Investment Tax Credit

Another large incentive program that homeowners may want to take advantage of is the Federal Investment Tax Credit (ITC). The ITC allows homeowners to write off on their taxes investments they made in their property that enhance sustainability. The qualifications for taking advantage of the ITC are less stringent than SGIP. To qualify for the ITC, the homeowner must have the battery connected to solar cells, and more than 50% of the battery's charge must come from these cells. Homeowners may want the algorithm to allow them to qualify for the ITC, but not care about SGIP. An example of a customer like this would be a homeowner outside the California market. If the homeowner is in Nevada, it does not matter to qualify for SGIP because they cannot take advantage of it in the first place.

Time of Charge

Another thing to consider for how the algorithm is written is what time to charge the battery at, when charging from the grid:

> "Now that you understand all this (right?), you might be interested in an even more accurate way to determine the best time to charge your EV. Instead of looking at the emissions that are **on** the grid at a given time, you look at the emissions that **would be added** to the grid if you were to plug in your car. These are called "marginal emissions." They sound a bit finicky, but they reflect how the grid actually works, so it's important to use them for policies or technology that would impact electricity demand at scale. Stay tuned to learn more. In the meantime, consider midday charging!"

The time of day that the battery is charged can have a large impact on the sustainability of the battery. For obvious reasons, there is a greater abundance of solar power during the day than at night, and consequently charging batteries at night can have a negative environmental impact, because the electricity comes from less sustainable sources such as fossil fuels. There has recently been a requirement added to SGIP that to take full advantage of the rebate, the homeowner must be able to demonstrate that the battery has reduced the production of greenhouse gasses.

WattTime:

Fortunately, there is an API that can help with this problem. The API is published by the Rocky Mountain Institute and called WattTime:

> "With WattTime, energy customers have the freedom to choose the power they consume for the first time, signaling a true paradigm shift in clean energy access. This is made possible by WattTime's software that automatically tracks the actual emissions impacts associated with electricity use—both in real time and with ahead-of-time predictions—enabling us to use and charge devices and appliances at times when our electricity is the cleanest."

When charging a battery with WattTime, there is a 32% reduction in emissions, and only a .1% increase in price (Watttime). This would be a very helpful tool in the California market, when you need to demonstrate that the battery had a net positive environmental impact. Also, even outside the California market, this may have a strong appeal to customers due to how much it reduces emissions for such a small change in price.

Public Safety Power Shutoffs:

Another important thing to consider is if Public Safety Power Shutoffs (PSPS) are going into effect:

> "For public safety, it may be necessary for us to turn off electricity when gusty winds and dry conditions, combined with a heightened fire risk, are forecasted. This is called a "Public Safety Power Shutoff" or "PSPS." While customers in high fire-threat areas are more likely to be affected, any of PG&E's more than five million electric customers could have their power shut off. This is because the energy system relies on power lines working together to provide electricity across cities, counties and regions."

When PSPSs occur, there is usually a 48 hour notice given to homeowners. A main draw of having a large home battery is resilience during times like this. It is important for the algorithm to be aware when a PSPS is upcoming, so it can change how it is charging. It is important for the battery unit to be as full as possible before the PSPS occurs, so that the house can sustain itself for the maximum amount of time. During these events, the algorithm would want to do whatever is necessary to get to full, even if that means that it pulls much more from the grid than it is supposed to. The system will just need to track how much it pulls from the grid, and then in the future it can charge more from solar cells until it meets the SGIP requirements again.

Time of Use Pricing:

Time of use pricing is becoming increasingly popular in California:

> "If you are able to manage your energy habits, one of our Time-Of-Use plans may be the best fit for your home. Rates on a TOU plan are based on the time of day and the season. TOU plans can help you manage your energy costs. By taking advantage of lower rates during off-peak and super off-peak periods, you can avoid higher weekday rates when energy resources are in demand."

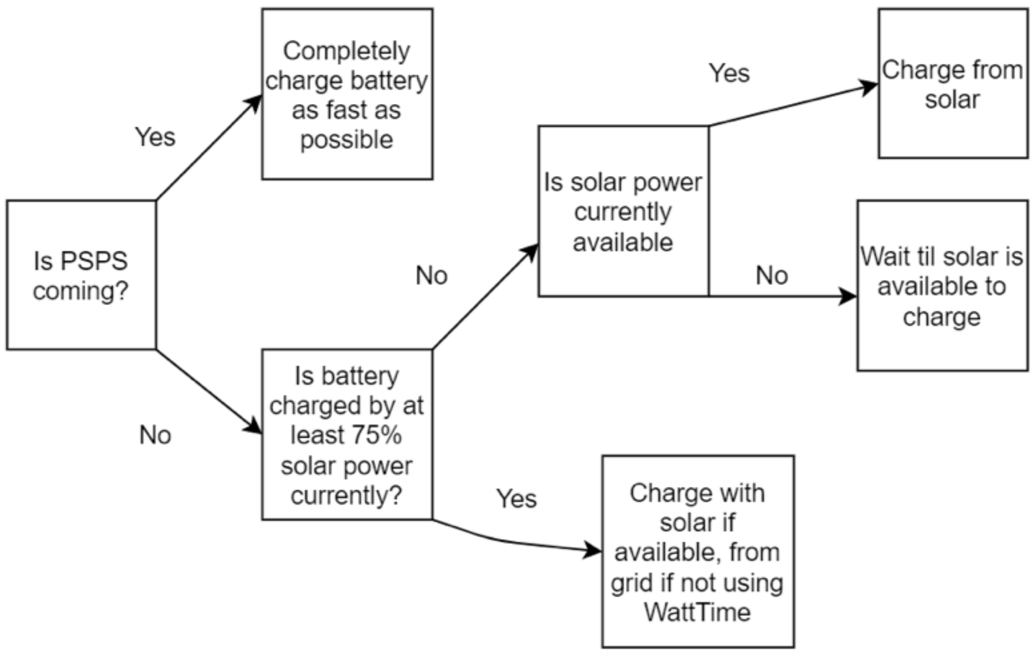
Having storage could allow for charging the batteries when the price is cheaper, and discharging / consuming the battery when power is more expensive. Time of use pricing also helps to round off peak demand, allowing for less peaker plants to be needed due to the total amount of energy being needed at one time is lower.

Other Considerations:

Some people may want to have explicit control over the battery. They may want to set an amount that the battery is always charged above in case of an unexpected emergency. It may be more worth it to some people to know that their battery is alway at least 70% charged than to let the battery get down to 15% charge because the algorithm controlling the flow of electricity is doing time of use pricing optimizations. These factors lead us to 8 different algorithms.

Algorithm 1:

SGIP, ITC, Plug into WattTime



For the first algorithm option, this would be for someone who wants to take advantage of both the SGIP and ITC incentives. This customer would also be concerned about the environment and not strictly finances if they elect to use WattTime as well. WattTime provides a nice benefit for consumers because it makes it easier to demonstrate that the battery system had a net positive impact on sustainability. When applying for SGIP, the homeowner receives half of the funds they are eligible for simply for investing in battery storage that connects to solar cells. In order to receive the second half of the benefit, they must demonstrate that the charging of the cells came 75% from the solar cells, and that the investment in the battery had a net environmental good. If the battery was pulling from the grid when the power is least sustainably produced, this becomes harder to do. So WattTime offers the convenient benefit of dropping emissions by 32% when used. When the homeowner qualifies for SGIP, they automatically qualify for ITC as well, because all ITC requirements are covered and then some in SGIP.

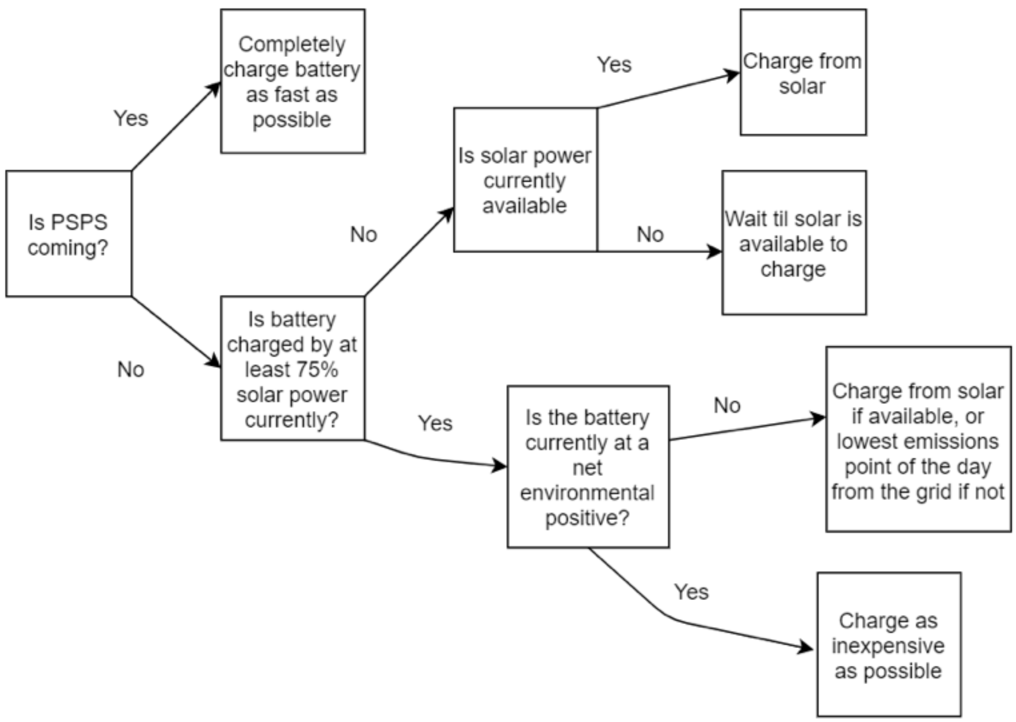
The code for the first algorithm is:

```
global grid_charge
global solar_charge
average = .5
global grid_minutes
global solar_minutes

def grid_minute():
  grid_minutes =+ 1

def solar_minute():
  solar_minutes += 1


# upcoming_psps is a boolean variable passed in that indicates if a
# public safety power shut off is coming so the battery needs to
# completely charged for resilience

# charge_percent is a float variable that reflects the current amount
# the battery has been charged by solar, for SGIP it needs to be charged
# at least 75% by solar, so we track this and use it to make decisions accordingly

# local_solar is a boolean saying if there is solar being produced on the
# roof at the time

# watt_time is a float variable that reflects the amount of energy
# being produced by the grid that is sustainably produced

def sgip_itc_watttime(upcoming_psps, charge_percent, local_solar, watt_time):

  #when a psps is upcoming, charge as fast as possible
  while (upcoming_psps):
    solar_charge = False
    grid_charge = True
    grid_minute()

  # check if charging percent is below .75, if so then charge with solar
  while (charge_percent <= .75):
    if (local_solar):
      grid_charge = False
      solar_charge = True
      solar_minute()
    else:
      grid_charge = False
      solar_charge = False

  # if above .75, charge with solar if available, grid if not
  while (charge_percent > .75):
    if (local_solar):
      grid_charge = False
      solar_charge = True
      solar_minute()
    else:
      solar_charge = False
      # check watt_time to see if it is better than average charging conditions
```

```
if (watt_time > average):
    grid_charge = True
    grid_minute()
```

Algorithm 2:

SGIP, ITC



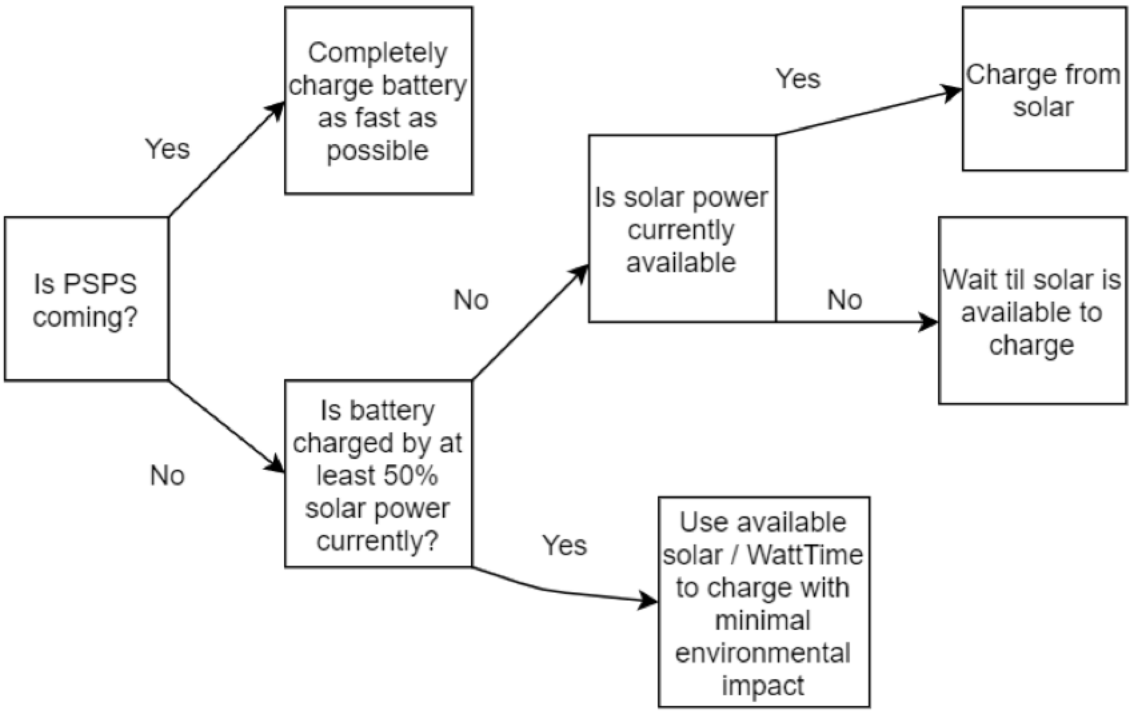
This option of the algorithm would be for consumers in the California market that want to take advantage of both SGIP and ITC. For this consumer, the most important thing is saving money, and not reducing their environmental impact. The algorithm is still constantly monitoring, and making sure that the battery has a net positive impact, because this is one of the requirements to take full advantage of that. However, once all the minimum requirements are met, the algorithm will do what it takes to maximize the savings of the homeowner. This may include looking at time of use pricing, and charging during off peak hours (midnight to 4am) and charging when power is least sustainably produced. Although one of our goals as a company is to promote sustainability, we feel it is important to remember this battery system will still have a net positive environmental impact, and it is important to give the consumers the freedom to make their own decisions.

The algorithm for this is:

```python
def sgip_itc(upcoming_psps, charge_percent, local_solar, net_good):

    #when a psps is upcoming, charge as fast as possible
    while (upcoming_psps):
        solar_charge = False
        grid_charge = True
        grid_minute()

    # check if charging percent is below .75, if so then charge with solar
    while (charge_percent <= .75):
        if (local_solar):
            grid_charge = False
            solar_charge = True
            solar_minute()
        else:
            grid_charge = False
            solar_charge = False

    # if above .75, charge with solar if available, grid if not
    while (charge_percent > .75):
        if (local_solar):
            grid_charge = False
            solar_charge = True
            solar_minute()
        else:
            solar_charge = False
            # check to make sure the charging is a net environmental good
            if (net_good == True):
                grid_charge = True
                grid_minute()
```

Algorithm 3:

ITC, WattTime



In this case, the consumer wants to take advantage of the ITC and WattTime, but not SGIP. There are several reasons this case could arise. If our company offered a variety of battery types, and some of them did not have a cycle efficiency of 75%, then those batteries are not eligible for SGIP funding. Also, maybe this consumer is in a market other than California, so using SGIP is not an option. It is also possible that the consumer has already claimed the maximum benefit from SGIP, so no longer needs to keep following the rather strict rules to qualify. In this scenario, the battery is still connected to WattTime, so when the battery is charging from the grid, it is minimizing the emissions that are being released. The battery is making sure to charge at least 50% from the connected solar cells, because this is the requirement for the ITC funding. In the scenario that a Public Safety Power Shutoff occurs, the battery will get as close to full charge as it can before the event occurs, regardless of if that means drawing more that 50% of its charge from the grid.

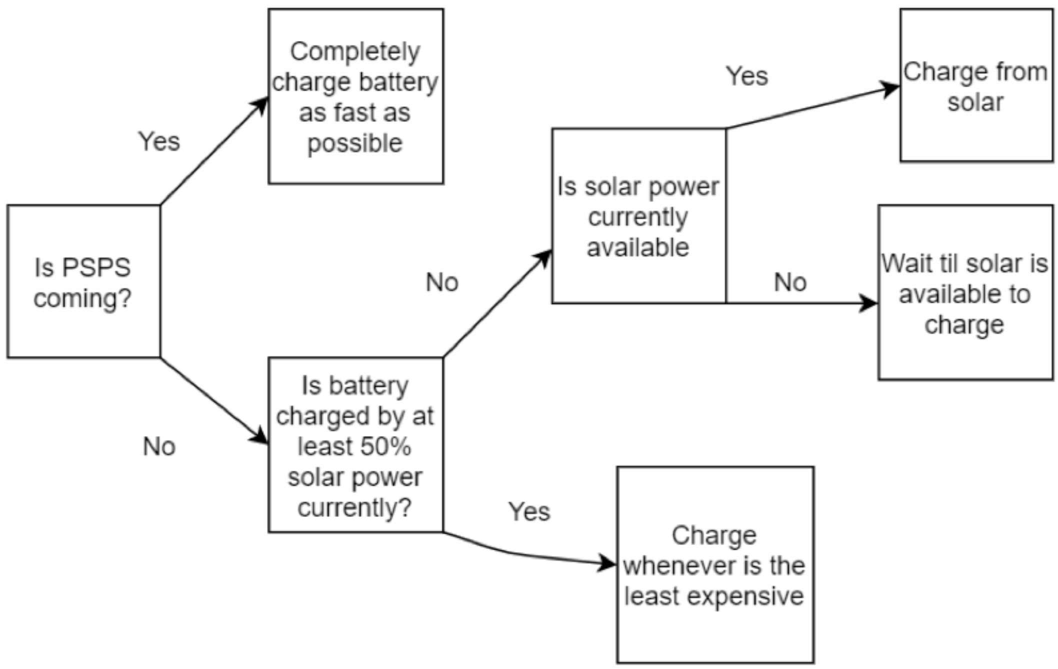
The algorithm for this would be:

```
def itc_watttime(upcoming_psps, charge_percent, local_solar, watt_time):
```

```
#when a psps is upcoming, charge as fast as possible
while (upcoming_psps):
    solar_charge = False
    grid_charge = True
    grid_minute()

# check if charging percent is below .75, if so then charge with solar
while (charge_percent <= .5):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        grid_charge = False
        solar_charge = False

# if above .75, charge with solar if available, grid if not
while (charge_percent > .75):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        solar_charge = False
        # check watt_time to see if it is better than average charging conditions
        if (watt_time > average):
            grid_charge = True
            grid_minute()
```

Algorithm 4:

ITC



In this option, the consumer is primarily concerned about saving money. In order to qualify for the ITC, the consumer only needs to connect the battery to solar cells, and have 50% of the charge for the battery come from these cells. Other than that, this battery will charge whenever it is least expensive. For charging the battery, the least expensive way to do that will always be solar, unless there is not a surplus of solar. If the house needs all the solar, but the battery needs to charge, the battery will need to draw power from the grid. If time of day pricing is a thing in the region, the algorithm will charge at whatever time of day is cheapest. If time of day pricing is not a factor, the battery can charge whenever. The level of charge that the battery is kept at can be determined by the homeowner. Some homeowners may want to set a minimum level that the battery never decreases past, unless there is a power outage. Other customers may want to algorithm to behave in whatever way saves them the most money. It largely depends on whether the consumer is more interested in resilience (in which case they need the battery charged in the event of an emergency) or if the battery is for saving money (in which case the charge level can get low and it is not an issue).

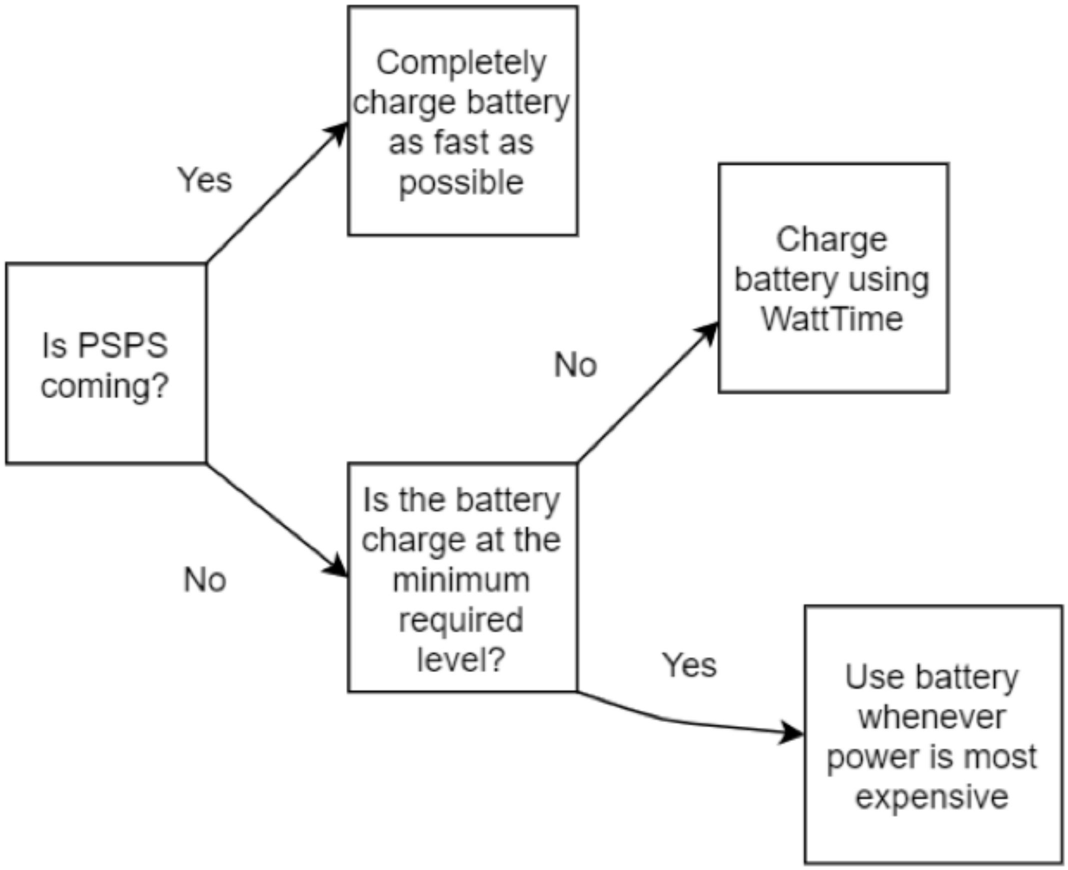
The algorithm for this would be:

```
def itc(upcoming_psps, charge_percent, local_solar, watt_time):

  #when a psps is upcoming, charge as fast as possible
  while (upcoming_psps):
```

```
    solar_charge = False
    grid_charge = True
    grid_minute()

# check if charging percent is below .75, if so then charge with solar
while (charge_percent <= .5):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        grid_charge = False
        solar_charge = False

# if above .75, charge with solar if available, grid if not
while (charge_percent > .75):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        solar_charge = False
        grid_charge = True
        grid_minute()
```

Algorithm 5:

WattTime



This algorithm could be used for clients who lack solar cells, but want home battery storage and to help the environment. The lack of solar cells to connect to means that the client is neither the ITC nor SGIP. Having a battery is still a good option even without the solar connection, due to the resilience it provides. If you have a battery, you do not need a generator that likely burns diesel and is bad for the environment. Having local battery storage also allows the homeowner to save money by taking advantage of time of use pricing. Also, once homeowners have extracted all the value possible from SGIP and ITC, they may elect to have their systems to behave in this way to start maximizing their savings. This option is not completely focused on savings however. In this case, the consumer still is electing to use WattTime when charging their battery. Although only a slight increase in expenses, this is a large benefit in emissions reductions.

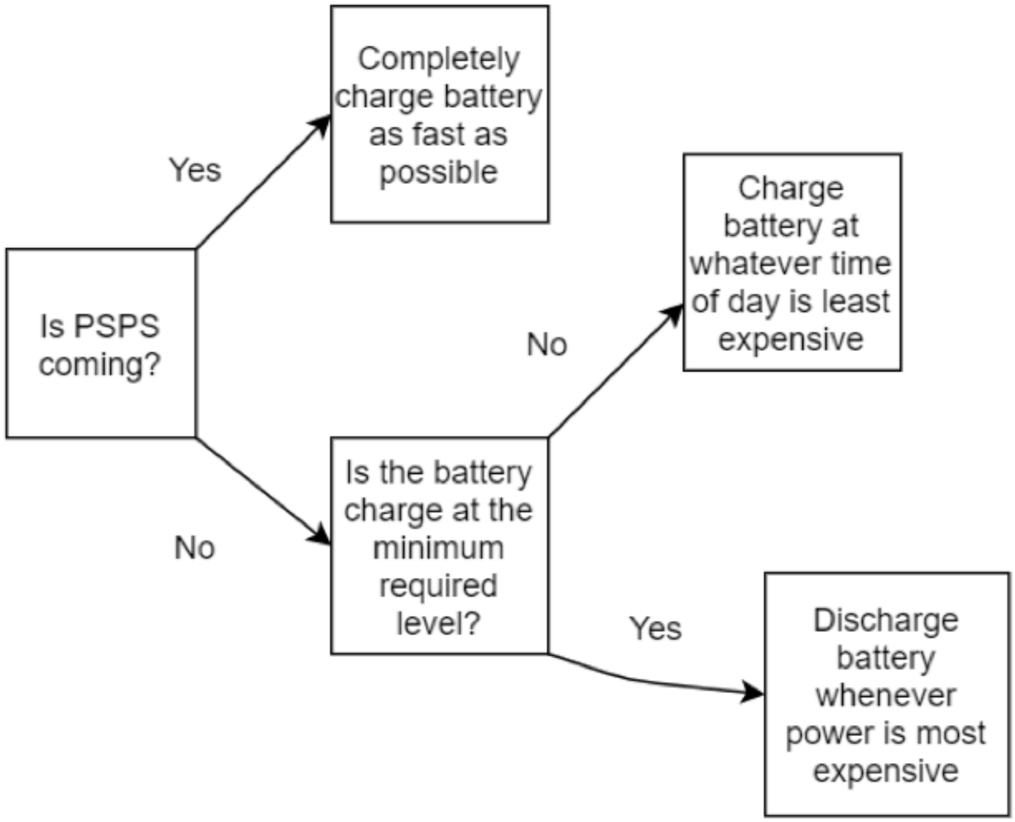
The algorithm for this would be:

```
def watttime(upcoming_psps, charge_percent, local_solar, watt_time):
```

```
#when a psps is upcoming, charge as fast as possible
while (upcoming_psps):
    solar_charge = False
    grid_charge = True
    grid_minute()

if (local_solar):
    grid_charge = False
    solar_charge = True
    solar_minute()
else:
    solar_charge = False
    # check watt_time to see if it is better than average charging conditions
    if (watt_time > average):
        grid_charge = True
        grid_minute()
```

Algorithm 6:

Savings Mode



In this case, the consumer's goal is to maximize savings. This could be a homeowner who is looking for resilience, or someone who already maxed out the benefits of the ITC and SGIP for their home. In this scenario, the customer opted not to use WattTime, meaning environmental impact likely is not a priority for them. The main factor that would affect this algorithm is if the consumer set a level that they want the battery always to be charged at when the power is not shut off. If resilience is the motivation for the consumer, then they likely will set a higher percent of desired power. If savings is more of a concern, then it is less likely that will be set. It is worth noting that in California, the utility gives heads up when they can, but sometimes the power is shut off unexpectedly. The company may not have had time to warn people, or a bad storm may have knocked over power lines. The higher the floor is set for minimum power level, the more resilient the homeowner will be to unexpected phenomena.

The algorithm for this would be tailored and would need the user to input what they desire the charge percentage to come from the grid. In the algorithm below, "user_desired_cp" represents this. The algorithm is:

```
def custom(upcoming_psps, charge_percent, user_desired_cp, local_solar, watt_time):
```

```
#when a psps is upcoming, charge as fast as possible
while (upcoming_psps):
    solar_charge = False
    grid_charge = True
    grid_minute()

# check if charging percent is below the user desired charge percentage
while (charge_percent <= user_desired_cp):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        grid_charge = False
        solar_charge = False

# if above .75, charge with solar if available, grid if not
while (charge_percent > user_desired_cp):
    if (local_solar):
        grid_charge = False
        solar_charge = True
        solar_minute()
    else:
        solar_charge = False
        grid_charge = True
        grid_minute()
```

The final option would be “manual mode.” In this option, the homeowner would have explicit control over what the battery is doing. They could set times to charge and discharge, how much power to draw, and where to draw it from, and also the minimum charge level for the battery.

The algorithm will be controlled by an app that the homeowner uses. On the app the homeowner will be able to see metrics about the system. The app will display much money the battery has saved them in electricity costs. They can see the charge level of the battery, and also give the algorithm explicit instructions regarding how and when to charge. The manual mode of charging would be controlled through the app, or the homeowner could select any of the six preprogrammed tracks described earlier. Also, if we identify more tracks or incentive programs that we could code to make the consumers' life easier, these could be pushed to the app and the homeowner could use one of those instead. We verify that the algorithm works as expected by creating test data for the algorithm to work on and ensuring that the outcome is what was expected.

Materials

Determining Battery Type

Battery Type Requirements and Parameters

Requirements were set in order to specify what battery type was best. For residential energy storage, the main specifications looked at were the lifetime of the battery / cycle life (how long the battery lasts), the efficiency, power output, and energy density (how much and how well the battery holds charge), the cost, the safety, and the environmental impact.

Environmental impact is a broad term, looking at a lifecycle analysis approach, this includes GHG emissions from manufacturing and production as well as the effects of the acquisition of the battery materials on both the environment and on humans. Mining of materials can have huge impacts on surrounding communities both in an economic sense, these towns and villages are often very poor and the miners get low pay, and in a health sense, many of these materials are toxic and lead to health problems. Considering all of these factors in order to make a battery type decision would be difficult as some of the "types" of impacts are hard to quantify. Therefore, the focus of the environmental impact of a battery type will be toxicity of the materials.

For our solution selection process, the parameters most critical for residential battery storage are efficiency, lifetime, cost, and environmental impact. Efficiency of the battery is defined as the ratio of energy retrieved from the battery to the energy provided.

Current Commercialized Battery Types

As population and urbanization increase, the demand for electricity grows and with it, electricity generation. Currently, fossil fuels dominate this but renewable energy is rising to mitigate climate change and environment deterioration. Primary challenges with renewable energy resources are the intermittency of the power supply. This can be dealt with by energy storage systems, storing energy to ensure the stability of electricity distribution. The main technologies used today for residential and community use are lithium ion batteries, sodium-based batteries, and flow batteries. Various parameters, requirements, and specifications were set in order to conclude which battery type is best for our application. Analysis was done on the different battery types and through research and a decision matrix, our battery type was chosen.

Flow

Flow batteries include a wide range of technologies, however for residential applications the predominant type is zinc-bromine. One of the core advantages to flow batteries in comparison to lithium-ion or lead-acid is that they have a 100% depth of discharge, meaning that it can be completely discharged without any degradation to the battery over multiple cycles. Additionally, the main battery component material, the zinc-bromine liquid, is a flame retardant making the battery very safe. Due to the separation of components in the battery, there is no change for thermal runaway or fires (SolarQuotes, 2019). However, they do suffer from corrosion issues and formation of dendrites which reduce performance (Akinyele et al., 2017). Flow batteries can also be made in a modular system which can increase their energy capacity (RedFlow, 2017).

The zinc-bromine battery is very environmentally friendly compared to other battery types. The materials used in these batteries are easily recyclable such as polyethylene plastic and aluminum. Additionally, the battery materials, namely the electrolyte, are nontoxic, especially compared to the use of cobalt in some derivatives of lithium-ion batteries (RedFlow, 2017).

Flow battery specs vary from manufacturer to manufacturer but some general numbers are as follows: cycle life from 2,500-3,000 (Akinyele et al., 2017), energy density of 30-50 Wh/kg (Akinyele et al., 2017), and a price point of $870/kWh (SolarQuotes, 2019).

Sulfur based

Sodium-based batteries use salt—sometimes saltwater—to produce nontoxic, long-duration power. Salt-based cells can be completely drained to zero charge without damaging the system. Lithium-ion batteries, in comparison, always require some charge or they will fail. Sodium batteries are not flammable or explosive (as long as other materials are not added to the chemistry), making them highly safe, and can function in a wide temperature range (Pickerel, 2018). However, these are a relatively new technology and as such do not have as much of a market share as existing technologies (EnergySage, 2019).

Sodium-based batteries don't contain heavy metals, relying instead on saltwater electrolytes. While batteries that use heavy metals, including lead acid and lithium ion batteries, need to be disposed of with special processes, a saltwater battery can be easily recycled. Materials such as cobalt and nickel can pose toxicity risks in both mining and disposal while saltwater is an abundant resource with little to no health or environmental impacts in disposal (EnergySage, 2019).

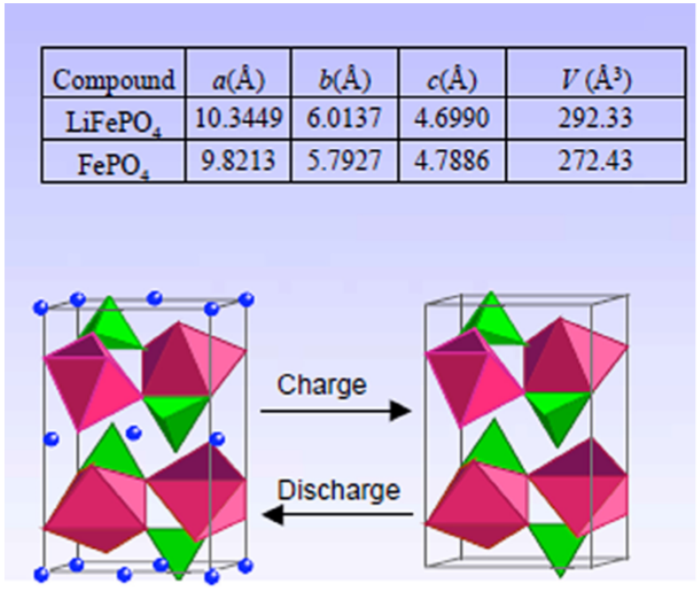
Sodium-based battery specs depend on the manufacturer but some general numbers are: cycle life of 2,000-3,000, energy density of 100 Wh/kg, and a price point of $570/kWh (WebSolarSupplies, 2019).

Lithium-ion

Lithium-ion batteries are the most common for residential energy storage and are characterized by the transfer of lithium ions between electrodes during charge and discharge cycles. The cathode within the battery is made of different materials, often nickel, manganese, and cobalt, to increase desirable material properties such as efficiency and stability. Lithium-ion batteries have a strong foothold in the market and benefits include long cycle life, high charge and discharge efficiency, and good safety (Pickerel, 2018).

Lithium-ion batteries often use scarce metals in the cathode to improve efficiency, however these resources are in finite supply which poses a problem in sustainability of the battery. One of the most common metals used in lithium-ion batteries is cobalt, which has an additional problem of

being toxic and hence the use of this metal is detrimental to the environment and to humans in mining and makes disposal of the battery problematic (Oliveira et al., 2015).
Lithium-ion batteries have a wide range of specs depending on the cathode material, however general consensus is that lithium-ion batteries as a whole have a much lower price point than other technologies on the market, have good cycle life, and are ~90% efficient.



Compound	a(Å)	b(Å)	c(Å)	V (Å^3)
$LiFePO_4$	10.3449	6.0137	4.6990	292.33
$FePO_4$	9.8213	5.7927	4.7886	272.43

Fig 7. Working mechanism of Li-ion batteries (Satyavani, 2016).

Battery Type Selection: Lithium-ion

From analysis of the current frontrunners in the energy storage market, for this project's application the battery type of choice was determined to be lithium-ion. Due to the strong foothold in the energy market and the vast amount of research currently being done on how to improve lithium-ion batteries, lithium-ion batteries have the greatest chance for a lower cost and relatively easy commercialization. While it does pose environmental risks more than sodium-based or flow batteries, increasing technological advances are lessening lithium-ion's impact.

Determining Li-ion Variation Type

Lithium-ion Variation Type Requirements and Parameters

Lithium-ion batteries have varying specs dependent on the cathode material; hence it is prevalent to specify the requirements and parameters to be analyzed in comparing different lithium-ion variations. Parameters such as cost, efficiency, lithiation / delithiation capacity, energy density, power output, safety, and environmental impact are all important in deciding a cathode material. Energy density is an important material property for batteries, but it is more relevant to EVs, since the weight-to-power ratio is much more crucial than for residential applications. For this project's application the main focus will be on efficiency, cost, cycle life, and environmental impact.

Current Commercialized Lithium-ion Variation Types

The most common cathode materials for lithium-ion batteries currently on the market are Lithium-Manganese-Oxide (LMO), Lithium-Nickel-Manganese-Cobalt-Oxide (NMC), Lithium-Nickel-Cobalt-Aluminum-Oxide (NCA), and Lithium-Iron-Phosphate (LFP). Specifications vary with each cathode material, each having benefits and downfalls.

Lithium-Manganese-Oxide (LMO)

LMO batteries have fast-charging properties and increased thermal stability since there is no cobalt. These batteries are entering the residential energy storage market because they're a safer alternative to cobalt batteries and can be optimized for longevity and high energy capacity (Pickerel, 2018). They have relatively low cycle life (300-700), moderate energy density (100-150 Wh/kg), a moderate price point and safety, and good environmental impact due to the lack of toxic materials (Battery University, 2019).

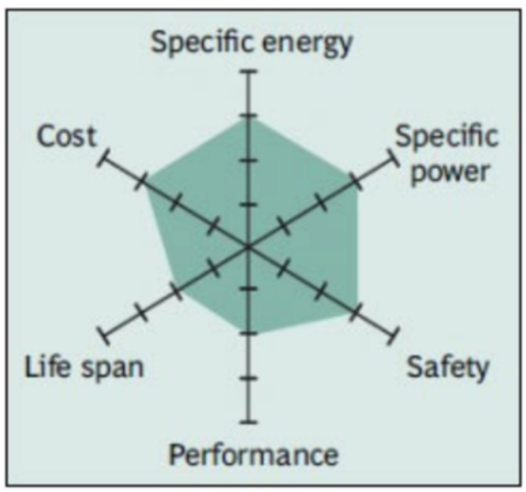


Fig 8. LMO property comparison (Battery University, 2019)

Lithium-Nickel-Manganese-Cobalt-Oxide (NMC)

NMC batteries are a popular chemistry within the lithium-ion category. LG Chem, Tesla, and Panasonic make residential batteries with NMC chemistries. The combination of nickel and manganese provides these batteries with high specific energy and stability. Their use of cobalt, though, increases the risk of thermal runaway (Pickerel, 2018). NMC batteries have a cycle life of 1,000-1,500, energy density of 150-220 Wh/kg, a price point of about $420/kWh, moderate safety, and poor environmental impact due to the use of cobalt (Battery University, 2019).

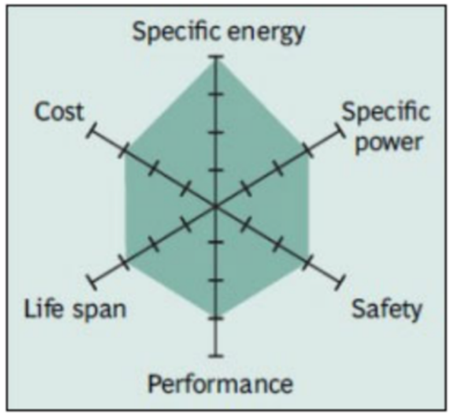


Fig 9. NMC properties comparison (Battery University, 2019)

Lithium-Nickel-Cobalt-Aluminum-Oxide (NCA)

NCA batteries are a relatively new chemistry and act similarly to NMC-based systems. The addition of aluminum provides the batteries with more stability (Pickerel, 2018). NCA batteries have a cycle life of 500-1000, energy density of 200-260 Wh/kg, a price point of about $350/kWh, moderate to poor safety, and poor environmental impact due to the use of cobalt (Battery University, 2019).

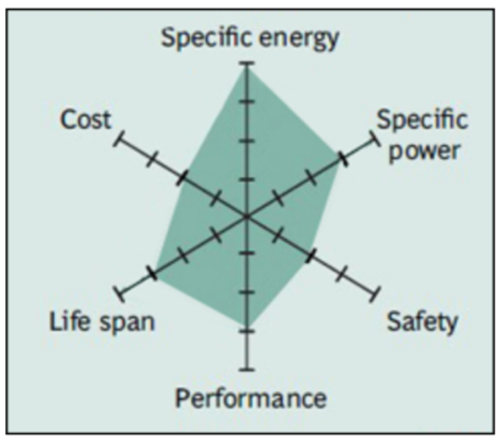


Fig 10. NCA properties comparison (Battery University, 2019)

Lithium-Iron-Phosphate (LFP)

LFP batteries use iron phosphate to increase safety and thermal abilities while also experiencing a long cycle life. Since they generate little heat, these batteries don't require ventilation or cooling, so they can be installed in more unique, indoor applications (Pickerel, 2018). Additionally, they boast increased environmental friendliness and safety. Although the cost is currently higher than other technologies, it is decreasing due to increased presence on the market. LFP batteries have a cycle life of 2000+, energy density of 90-120 Wh/kg, very high safety, and low environmental impact (Battery University, 2019).

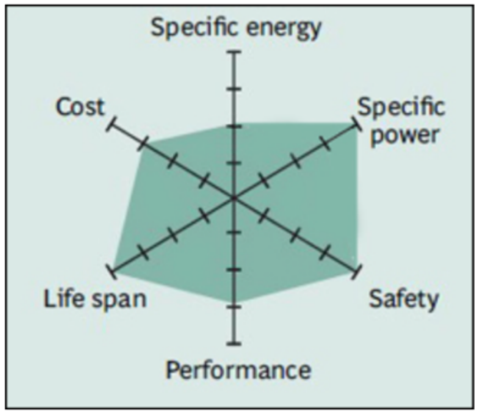


Fig 11. LFP properties comparison (Battery University, 2019)

Lithium-ion Variation Type Selection: Lithium-Iron-Phosphate (LFP)

In comparing various parameters between lithium-ion variants, the best candidate for this project's application is the lithium-iron-phosphate (LFP) battery. Due to its low environmental impact comparatively to other cathode materials as well as its potential for low costs due to the availability of its materials, a lithium-ion battery with a LFP cathode stands out as a better choice than other technologies. It has a long cycle life, increased efficiency, and good safety. While it does not have the same stronghold in the market as cobalt-based cathodes, it is commercialized and is becoming increasingly competitive with existing technologies.

Table 2. Lithium-ion Variants Decision Matrix

	Cost	Cycle life	Efficiency/power/energy density	Safety	Environmental impact	Total Score
Requirement Weight ->	0.15	0.2	0.25	0.2	0.2	**1**
LMO	-	-	-	-	-	
Ability to Deliver	6	4	5	7	7	
Weight * Ability	0.9	0.8	1.25	1.4	1.4	**5.75**
NMC	-	-	-	-	-	
Ability to Deliver	6	7	9	6	3	
Weight * Ability	0.9	1.4	2.25	1.2	0.6	**6.35**
NCA	-	-	-	-	-	
Ability to Deliver	8	6	9	4	4	
Weight * Ability	1.2	1.2	2.25	0.8	0.8	**6.25**
LFP	-	-	-	-	-	
Ability to Deliver	4	9	7	9	9	
Weight * Ability	0.6	1.8	1.75	1.8	1.8	**7.75**

Introduction to the Battery Materials

For our application, the best battery for residential use is a lithium-ion battery variant, lithium-iron-phosphate (LFP). This type of battery uses a lithium-iron-phosphate cathode in a typical lithium-ion battery configuration. The cathode material is very important to the battery's performance, safety, cost, and environmental impact.

Technical Overview

LFP is part of a class of cathodes that use polyanions $(XO_4)^{3-}$ (X = S, P, Si, As, Mo, W) which occupy lattice positions and increase cathode redox potential while also stabilizing its structure. LFP is known for its thermal stability and high power capability. In LFP, Li^+ and Fe^{2+} occupy octahedral sites, while P is located in tetrahedral sites in a slightly distorted hexagonal close-packed (HCP) oxygen array (Nitta et al., 2015).

Specifications

LFP batteries use iron phosphate to increase safety and thermal abilities while also experiencing a long cycle life. Since they generate little heat, these batteries don't require ventilation or cooling, so they can be installed in more unique, indoor applications (Pickerel, 2018). Additionally, they boast increased environmental friendliness and safety. Due to the internal chemistry, there is little chance for thermal runaway making the battery very safe. LFP batteries have a cycle life of 2000+, energy density of 90-120 Wh/kg, very high safety, and low environmental impact (Battery University, 2019).

The cycle life of a LFP battery is determined by the degradation rate during repeated charge/discharge cycles, which is influenced by many factors. The charge/discharge processes produce interphase boundaries with different lattice parameters. The volume change of lattice between LFP and fully delithiated FP is enough that often microcracks are formed after repeated charge/discharge cycles. This phenomenon is the major degradation mechanism for the LFP cathode and determines cycle life. There are many technologies to reduce it such as selecting materials to serve as solute on cation sites to reduce the volume change (Nishijima, 2014).

Anode Materials

Anode materials in lithium-ion batteries vary but the technologies that are currently in place and commercialized are graphitic and hard carbon anodes, lithium-titanium-oxide anodes, and conversion material anodes. LFP batteries currently on the market use these, the choice of anode to pair with the LFP cathode depends on the manufacturer.

Graphitic and Hard Carbons

The carbon anode has been prevalent for over 20 years and continues to be the anode of choice for many manufacturers. Carbon has the combined properties of low cost, abundant availability, low delithiation potential vs Li, high Li diffusivity, high electrical conductivity, and relatively low volume change during lithiation/delithiation. Thus, carbon has an attractive balance of low cost, moderate energy density, power density, and cycle life compared to other intercalation-type anode materials. Graphitic carbons can achieve close to theoretical charge capacity but don't combine well with a very common electrolyte which causes it to lose capacity. Hard carbons are much less susceptible to degradation as graphitic carbons are and they have reduced volume expansion which yields a high capacity high cycle life material. However, exposed plane edges reduce coulombic efficiency (Nitta et al., 2015).

Lithium-Titanium-Oxide (LTO)

LTO allows the combination of superior thermal stability, high rate, relatively high volumetric capacity, and high cycle life. However, the cost of Ti is quite high, the cell voltage is reduced, and it has a lower capacity. LTO is considered “zero strain” meaning it has only a very slight change in volume which results in a high rate and high stability. LTO is extremely safe because its high potential prevents Li dendrite formation however it does suffer from surface reactions which can limit its cycle life. Overall it does not have a particularly high Li diffusivity or electrical conductivity but is a good material for low-energy high-power high-cycle-life batteries (Nitta et al., 2015).

Conversion Materials – Alloying Materials

Elements which electrochemically alloy and form compound phases with Li can have extremely high volumetric capacity but are notorious for their large volume change upon lithiation which can cause particles to fracture and lose electrical contact, increasing loss of Li inventory. Alloying anodes generally suffer from short cycle life due to increasing cell impedance. There are techniques to mitigate this including electrolyte additives or adding a carbon shell. Si has received the most attention due to its low average delithiation potential, very high volumetric capacity, abundance, low cost, chemical stability, and non-toxicity. Other elements are of interest, Sn, Ge, Ga, Zn, Cd, and Pb are a few, each with benefits and downfalls. Common cons include the element being expensive, prone to fracturing, or being toxic (Nitta et al., 2015).

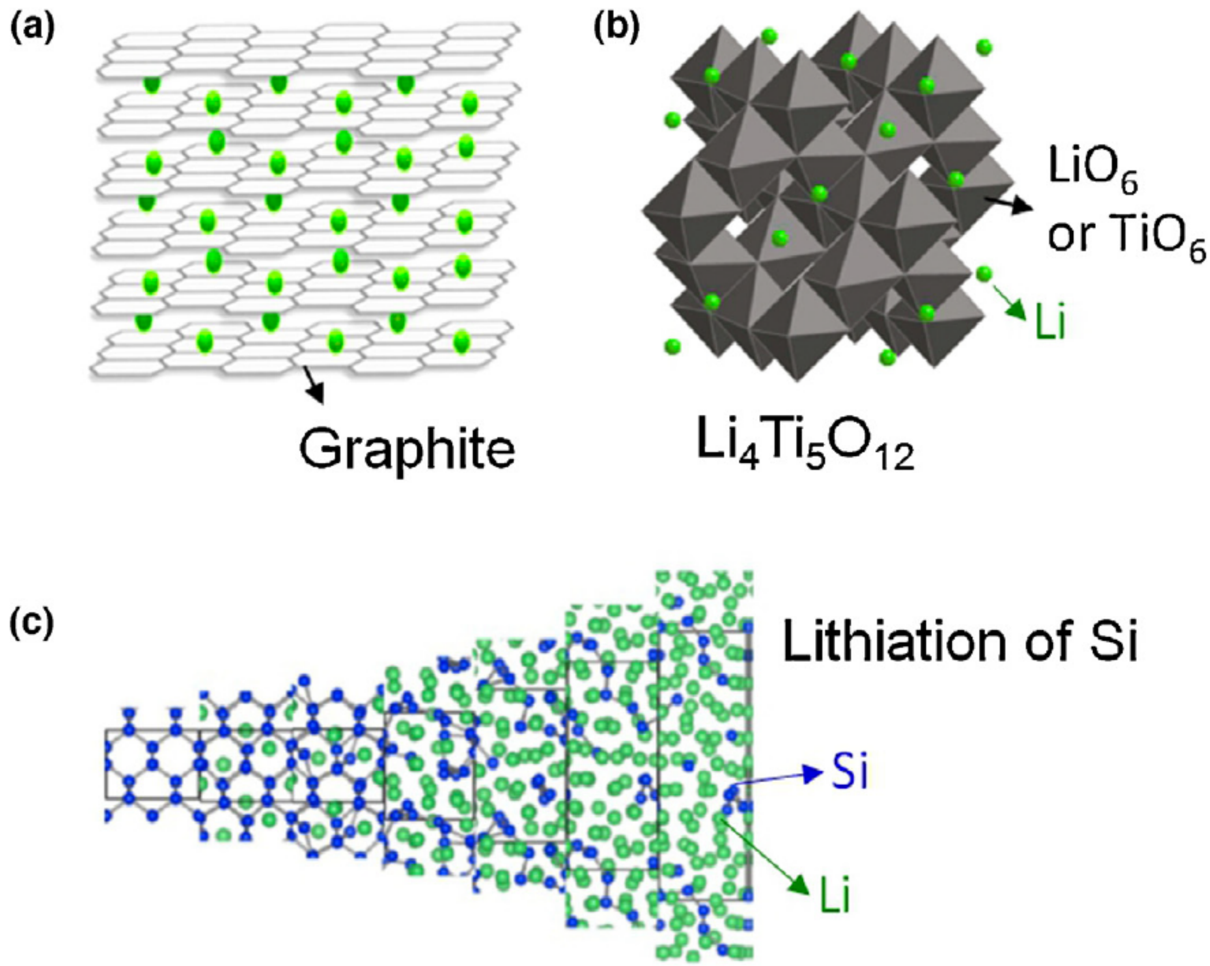


Fig 12. Crystal structures of (a) lithiated graphite, (b) lithium titanate (LTO), and (c) silicon during lithiation (Nitta et al., 2015).

Environmental Impact and Lifecycle Analysis

One of the many advantages of a lithium-iron-phosphate battery versus other types of lithium-ion batteries is its very low environmental impact. LFP batteries contain no cobalt which in itself lends itself to be much more environmentally friendly than the majority of batteries on the market currently. Cobalt-based cathodes, which make up a significant portion of the battery market, are problematic in many ways despite their strong foothold in the market. Cobalt is a toxic material and as such poses many risks, for both humans and the environment. Additionally, mining cobalt is dangerous and fraught with human rights violations since the majority of cobalt is extracted from the Congo under hazardous conditions and often illegal circumstances. Iron and phosphate, two materials key to a LFP battery, are widely abundant, much more so than cobalt, and do not rely on a sole country for the majority of its extraction. These materials and their mining have much less potential for harming humans as well as the environment.

From a purely materials perspective, LFP batteries are advantageous due to their lack of toxic materials. This makes disposal easier and less impactful on ecosystems and water supply. Cobalt leaks in the environment can have devastating impacts on surrounding communities and habitats, making LFP materials extraction, with no toxic materials, desirable. The extraction of LFP materials doesn't pose a risk of contamination since the materials don't pose a serious safety risk to humans.

As seen in Fig 7., which details the lifecycle analysis of lead-acid batteries (LAB), lithium-manganese batteries (LMB), and lithium-iron-phosphate batteries (LIPB), lithium-iron-phosphate batteries had a lower environmental impact than the other two in every category (Wang, 2017).

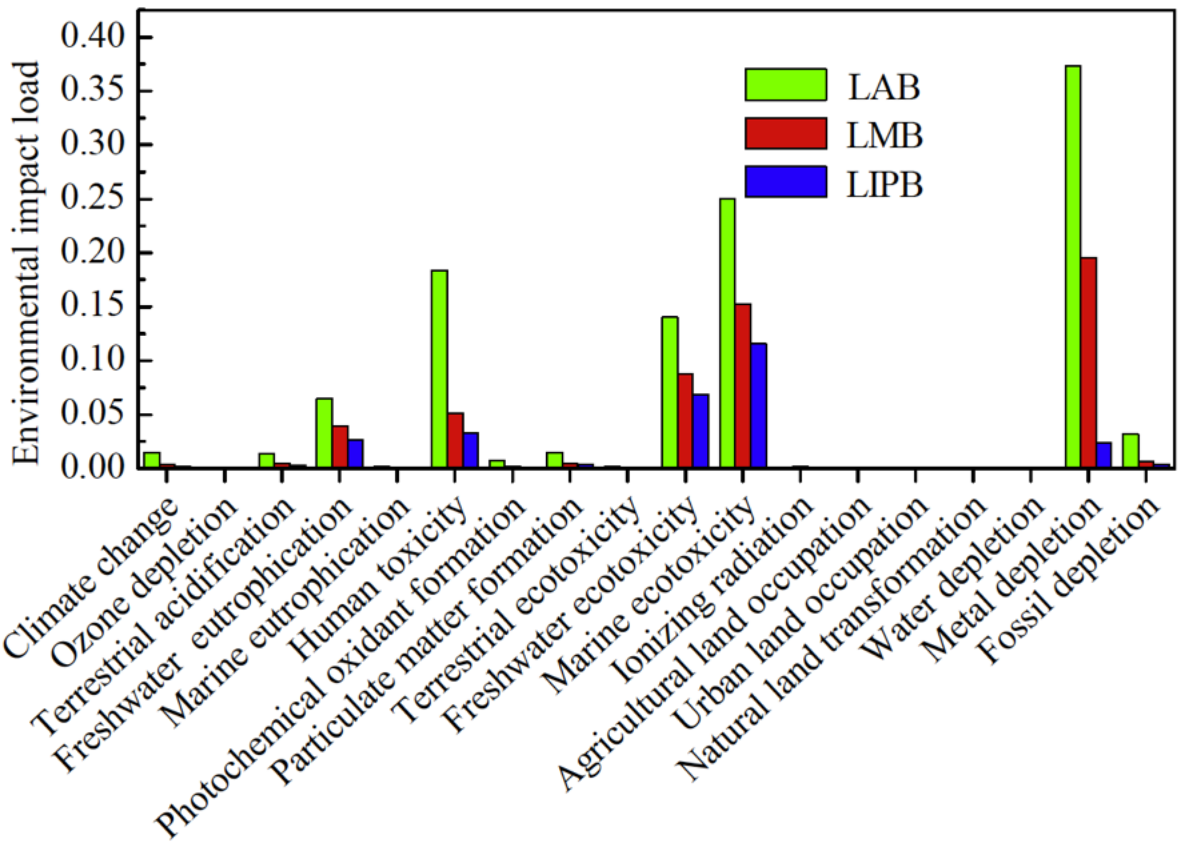


Fig 13. Normalized effect results of lifecycle analysis of LAB (lead acid battery), LMB (lithium manganese battery), and LIPB (lithium iron phosphate battery) (Wang, 2017).

The raw materials and their impacts which are involved in a battery are not the only measure of environmental impact. Production and manufacturing of battery components is energy intensive and as such has great influence on harmful emissions into the environment. The cathode materials have significant contributions to total battery energy and environmental impacts, therefore the focus in assessing environmental impacts are centered around the type of cathode present in a battery. A lifecycle analysis on the energy consumption to produce various types of batteries demonstrated that a battery with a LFP cathode showed the lowest energy needed for production. The low energy cost of producing a LFP battery showcases its low environmental impact as well as potential for decreased cost. Additionally, in a cradle-to-gate emissions analysis, LFP demonstrated very low impacts especially compared to cobalt-based batteries (Dunn et al., 2015).

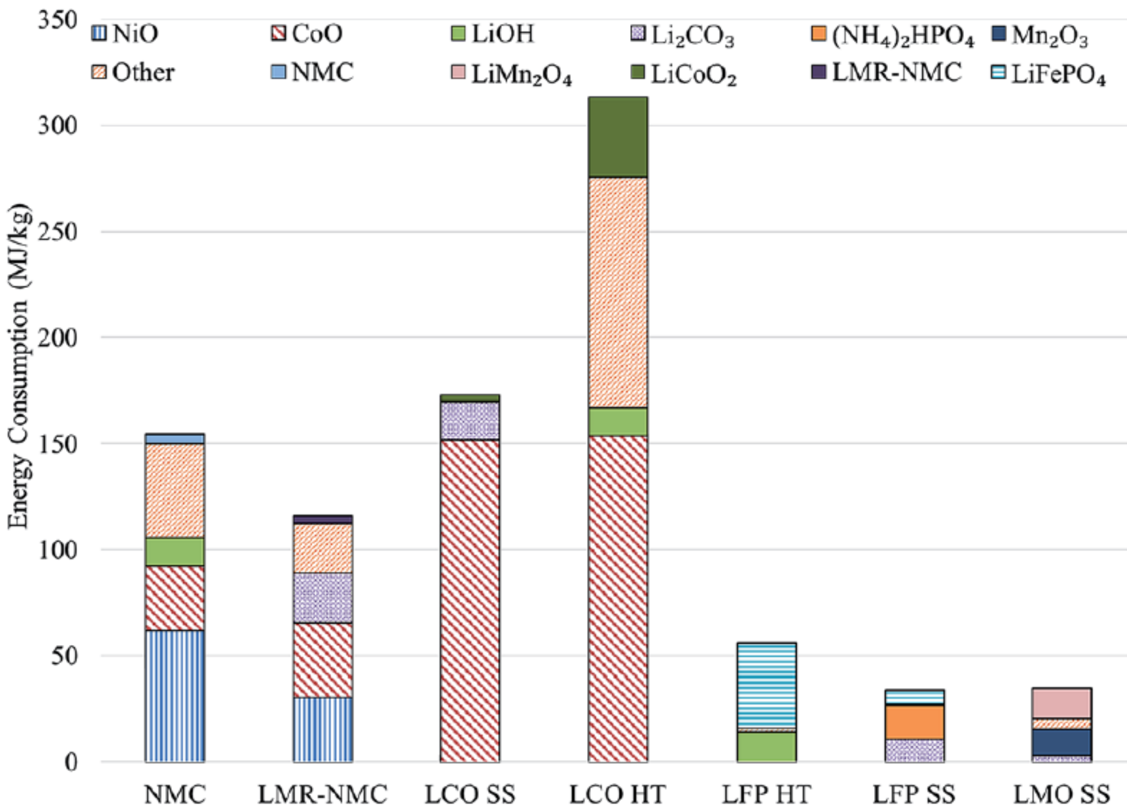


Fig 14. Cradle to gate energy consumption for different cathode materials (Dunn et al., 2015).

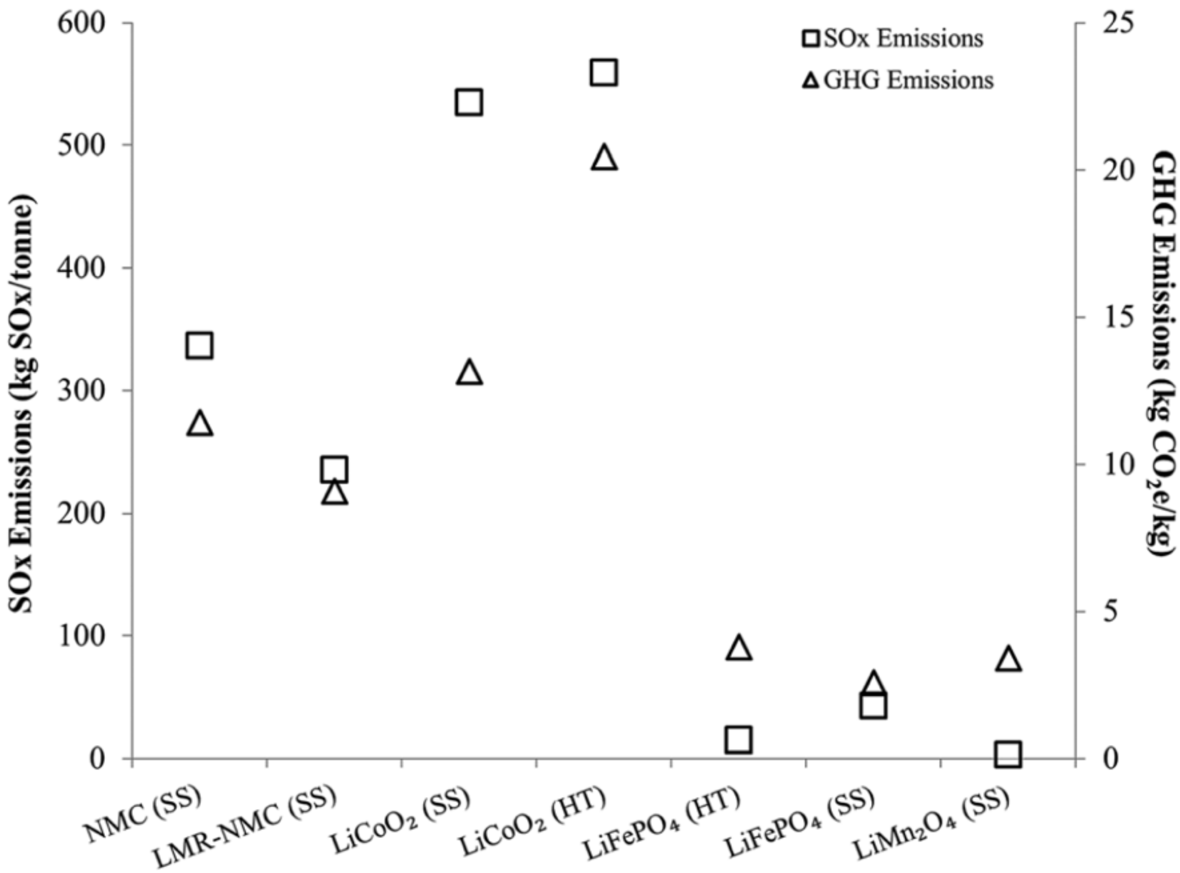


Fig 15. Cathode material cradle-to-gate GHG and SO_x emissions (Dunn et al., 2015).

Cost and Market Analysis

Costs

In terms of costs, lithium-iron-phosphate has shown the greatest potential for cost reduction in residential energy storage use. This is due to a variety of factors.

The cost of a battery can be divided into three categories: material costs, labor costs, and overhead costs and profits. From various market reports it has been determined that material costs are the largest contributor to the overall cost, making up about 60% of the total cost of a battery (Qnovo, 2016). Therefore, for this cost analysis the focus will be on the materials.

The material costs are further broken down by the components of the battery; the cathode, the anode, the electrolyte, the separator, and other materials. The cathode is the greatest contributor to the overall materials cost due to its importance to the function of the battery and the (often) costly materials needed to produce it (Qnovo, 2016).

For lithium-ion batteries made with cobalt based cathodes, as used in the Tesla Powerwall, the price of raw cobalt is a crucial factor in the price of the cathode and hence the battery. Production and manufacturing add to this cost which in turn raise the price for consumers. Cobalt is a rare metal and is in limited supply, which increases the price and will only get worse as time goes on.

Lithium-iron-phosphate’s materials are abundant, more so than competing lithium-ion variants, which drives the cost of the battery down significantly. As seen in Fig 10, LFP’s materials, iron (Fe) and phosphate (P and O), have a greater abundance than other variants’ materials such as cobalt (Co), nickel (Ni), and manganese (Mn). The availability of the materials is also related to the cost. Fig 10 also shows the price of the elements per pound. Iron, one of the main components of an LFP battery, is of significantly lower cost than other elements used in competing lithium-ion batteries; iron has a price range of 0.1-0.25 $/lb whereas cobalt and nickel have ranges of 10-25 $/lb and 5-15 $/lb respectively (Nitta et al., 2015). These material costs show how LFP has tremendous potential for cost reduction in batteries.

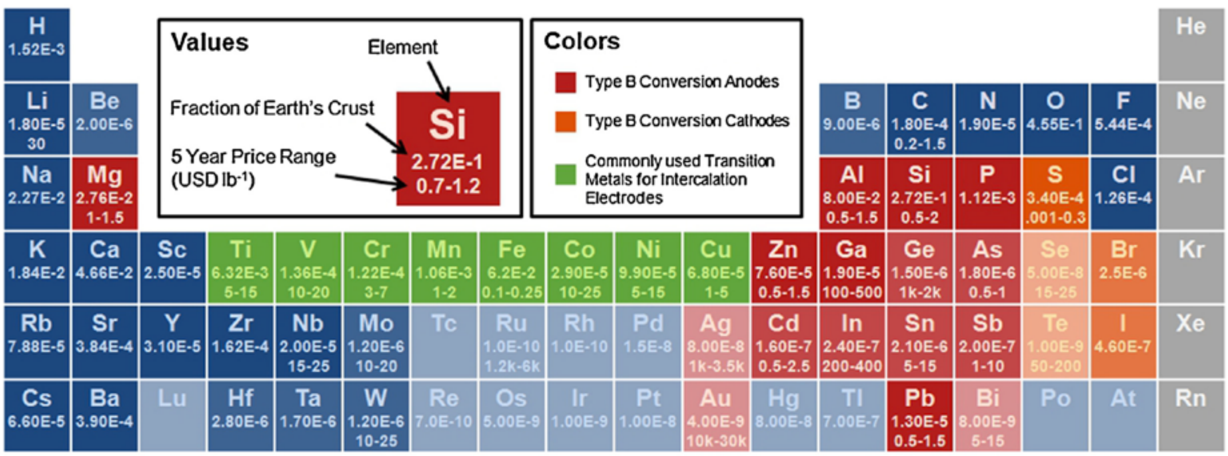


Fig. 16. Availability of elements that may host Li as electrodes (Nitta et al., 2015).

Raw material prices have a large and direct impact on the complete costs of lithium-ion batteries and as such it is prevalent to examine historical information and current developments regarding overall supply. Political instability, depletion of resources, or the occurrence of monopolies can create supply risk and strongly affect cost stability. Demand for cobalt is predicted to increase in the coming years which is troubling due to its extraction process. Two-thirds of the world’s supply of cobalt is sourced from the Democratic Republic of the Congo, a politically unstable and corrupt country that uses child labor and environmentally damaging methods of extraction and processing. The country also plans on doubling its tax on cobalt in the coming years, further influencing and increasing the price of cobalt-based batteries on the market (Wentker, 2019).

Table 3. Relevant raw material prices over time (Wentker, 2019).

Raw Material	Average 2011	Average 2017	Average 2018 (Jan–Oct)	March 2018 Price Peak[1]
Li_2Co_3	4.37	9.32	16.50	-
Cobalt	43.29	38.24	80.49	95.50
Nickel	25.88	11.24	8.93	13.32
Manganese	3.93	1.89	2.06	-
Iron	0.19	0.08	0,06	-
Aluminum	2.71	1.77	1.89	2.06

With the increasing depletion of cobalt supply, the price will continue to rise and this gives LFP technology a chance to overtake cobalt-based batteries as a more price competition option for residential storage use. Price forecasts for major batteries currently on the market shows the LFP has the greatest potential for cost reduction (Renard, 2014). This is partly because of the materials aspect, more abundant and less expensive elements, but also partly due to increasing research and development of LFP technologies, which increase its prevalence and further push it into the market. The longer LFP continues to stay on the market, the cost is driven lower which is telling for continued commercialization of the technology.

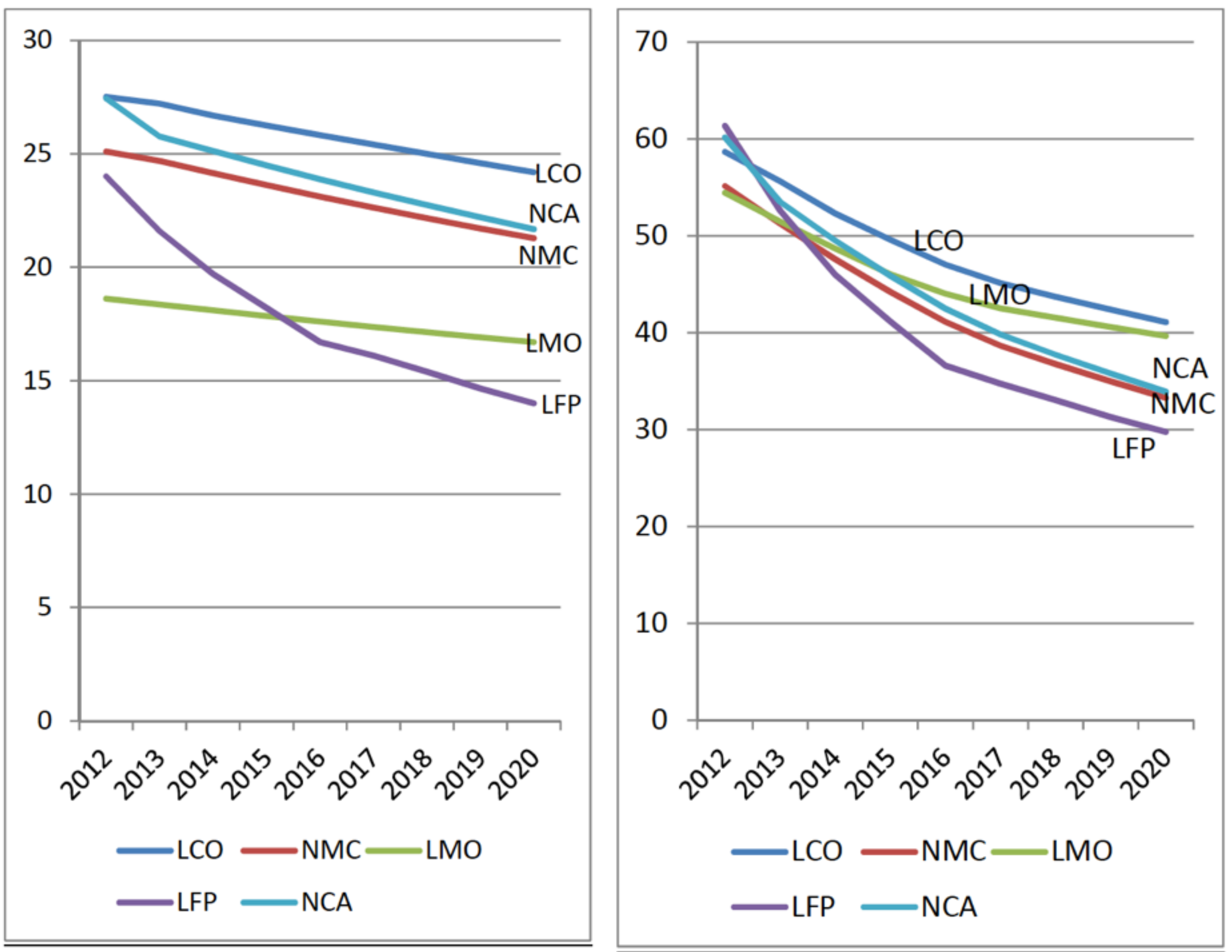


Fig 17. Cathode price forecast in $/kg (left) and $/kWh at pack level (right) (Renard, 2014).

In a simulation done by A. Jaiswal in 2017, LFP was shown to have had the second lowest (by a very small margin) total net present cost (TNPC). TNPC was defined as the present value of the cost of the PV panel and battery over the 20-year lifetime. This demonstrates yet again that LFP has cost reduction potential especially since other technologies use increasingly scarce materials.

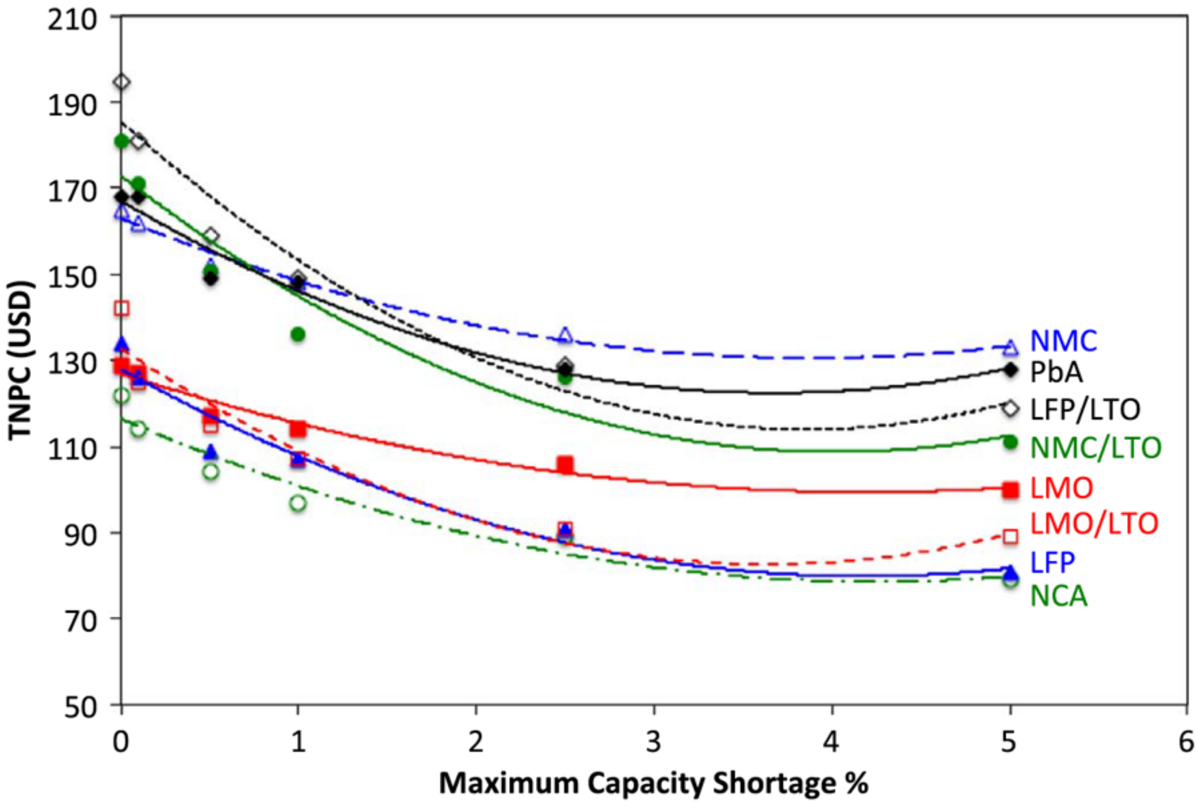


Fig 18. Relationship between TNPC and maximum capacity shortage of SHLS (Solar Home Lighting System) with different battery chemistries (Jaiswal, 2017).

Market

In terms of the current market of LFP batteries, there are quite a few companies manufacturing these types of batteries. Prices range from $1,000 to $10,000 depending on the company and product capacity (SolarQuotes, 2020). Table 4 details current companies selling LFP batteries, their prices, and a few key specifications. In many cases the price of the LFP batteries are competitive and comparable to the Tesla Powerwall, one of the most common residential batteries. This shows the increased presence of LFP batteries on the market and how decreasing costs are proving to make LFP batteries competitive and upcoming as the next major battery type.

Table 4. Price and spec comparison of current LFP batteries on the market (SolarQuotes, 2020).

Product Name	Price excl. installation (Estimated Retail pricing in USD using 1 AUD = 0.63 USD)	Usable Storage Capacity	Power	Round Trip Efficiency
BYD B Box Pro 13.8	$6,048	13.8 kWh	12.8kW	≥95.5%
Dyness Powerbox	TBD	9.6kWh	4.8kW	TBD
Fronius Solar Battery	$12,555.90	9.6kWh	4kW steady	>90%
GenZ 48V 3kWh	$2,173.50	2.25kWh (per module)	3kW	96%
Growatt GBLI6531	TBD	6 kWh	4.2kW	TBD
PowerPlus Energy LiFe Premium Series	$2,236.50	2.64kWh	3.3kW	>96%
Pylontech US2000B	$1,259.37	2.16kWh	2kW continuous per module (stacks with each additional module)	TBD
fronius Solar Battery	$2,961	3.4kWh (or 2.75kWh if you are cycling at 80% DoD as per warranty document)	1.5kW steady (48v version) 0.75kW stead (24v version)	98%
Soltaro 2	$1,071	1.8kWh	2kW per module	97%
Soltaro 4.5	$2,646	4.05kWh	4.5kW per module	97%
Sonnenbatterie Eco 9.43	$10,395	13.5kWh	3.3kW	95%
Trinabess Powercube	$6,167.70 (includes $346.50 charge for extended Powerbox battery inverter warranty)	8.64kWh	3kW steady	94%
Alpha-ESS Storion SMILE 5 – 5.5kWh	$5,696.46	5.5 kWh	2.8kW nominal output	92%
Alpha-ESS Storion SMILE 5 -11kWh	$8,814.96	11 kWh	4.6kW nominal output	92%
Alpha-ESS Storion SMILE 5 -16.5kWh	$10,848.60	16.5 kWh	4.6kW nominal output	92%
Enphase AC Battery	$1,260 (fully installed)	1.2kWh	260W per battery (stacks with each additional battery)	96%
All-in-One Soltaro 5kw / 4.5kWh	$4,504.50	4.05kWh	5kW Steady, 15.5kW Peak (100ms)	97%
All-in-One Soltaro 5kw / 9kWh	$7,245	8.1kWh	5kW Steady, 15.5kW Peak (100ms)	96.5%
All-in-One Soltaro 5kw / 13.5kWh	$9,450	12.15kWh	5kW Steady, 15.5kW Peak (100ms)	96%
QCells Q.HOME	TBD	10.8kWh	4.6kW	95%
Redback SH5000 + BE13200	TBD	Modular, up to 11.9kWh	5kW	90% Typical
Senec.HOME V3 Hybrid	TBD	9 kWh	3 kW charge, 3.5 kW discharge	TBD

Future Technologies

LFP Cathode with Sulfur Doped Porous Carbon Anode

Porous carbons have similar Li storage capacities but lower cost and better structural and chemical stability. Compared to other porous carbons, sulfur (SPC) shows the best performance in terms of delithiation capacity, has a high volumetric storage capacity, enhances conductivity, and almost no capacity decay. S doping can improve electrochemical kinetics allowing faster Li diffusion and quicker charge transfer at the electrolyte / electrode interface. SPC/LFP battery has high reversible capability, good cycling stability, increased capacities, and improved SOC (amount of deliverable capacity at any instant) (Sun et al., 2016).

Improving Electrochemical Performance of LFP Cathode

Carbon coating

This emerging technology enhances the electronic conductivity by introducing conductive additives (coating carbon through the synthesis of LFP/C composite or dispersing copper, silver, etc. into the solution during synthesis). Carbon coating has an improvement to practical specific capacities approaching the theoretical value at room temperature. It enhances the particle electronic conductivity, avoids the aggregation of nanoparticles, and provides passages for Li-ions. Conductive carbon is homogeneously dispersed in the cathode to promote conductivity (Satyavani et al., 2016; Wang, 2014). This can significantly improve the efficiency of LFP batteries.

Reduction of particle size

This technique consists of adding metal oxide additives to control the particle size and to grow homogeneous LFP nanoparticles by optimizing the synthesis conditions to tailor the morphology and texture. Observed capacity loss of LIB upon cycling is known to result from utilization of large particles constrained by their small surface area and from the diffusion limit of Li ions through the decreasing LFP interfaces. To improve rate capability, it is needed to minimize particle size and increase surface area. The nanostructured LFP is beneficial when high rates of charge-discharge are used (Satyavani et al., 2016).

Doping with cations supervalent to Li^+

In this method, the anode is selectively doped with cations supervalent to Li. Low level doping with supervalent ions into Li site increases electronic conductivity by a factor $>10^8$. Various dopants increased specific capacity, electronic conductivity, decreased resistance, enhancing reversible capacity at high charge-discharge rates. Cation substitution could result in enhancement of high current rate performance of LIB and a reduction in polarization (Satyavani et al., 2016).

Design in Detail

Selecting Battery Type

Initial design metrics and standards were rudimentary in their specificity. Understanding the appropriate materials for the solar battery depended on the research and weighing the most important aspects of the battery itself. These metrics were defined as: cycle life, efficiency, cost, and environmental impact. Upon comparing these metrics to different battery types, it was determined that a lithium-ion battery would be best suited to our application. Furthermore, additional in-depth research concluded that the lithium-ion variant best suited for the residential solar storage technology would be lithium-iron-phosphate. This battery met the most important aspects, and so it was the technology we chose to implement. LFP demonstrated superior properties to other variants in terms of reversible capacity and a long cycle life due to the crystal structure containing Li and Fe in octahedral sites. With further analysis it was confirmed that the battery met requirements and specifications.

Since the commercialization of lithium-ion batteries, cathode materials have always been important, the most research of which are cobalt-based. These are problematic due to their negative environmental impact due to toxicity, cost, safety concerns due to thermal runaway, and degradation of lifetime and cycling ability. LFP has exceptional price reduction potential due to its low material cost, non-toxicity, and environmental benignity.

Table 5. Comparison of the properties of different cathodes (Satyavani, 2016).

Property	$LiAl_{0.05}Co_{0.15}Ni_{0.8}O_2$	$LiCoO_2$	$LiMn_2O_4$	$LiFePO_4$
Avg. voltage (V)	3.65	3.84	3.86	3.22
Theo. capacity (mAh g^{-1})	265	274	117	170
True density (g cm^{-3})	4.73	5.05	4.15	3.60
Specific energy (Wh kg^{-1})	219.8	193.3	154.3	162.9
Energy density (Wh L^{-1})	598.9	557.8	418.6	415.0
Materials' cost	1.628	1.824	1.159	1.219
Energy cost (Wh $US\$^{-1}$)	6.08	5.05	5.97	6.31

From these analyses, it was concluded that the best residential energy storage battery solution is a lithium-iron-phosphate battery because of its low environmental impact, lowering cost with increasing commercialization, safety benefits, long cycle life, and overall potential for improvement with incoming future technologies.

Selecting Incentive Programs For the Algorithm

There are five different incentive programs outlined below. They are the Self Generation Initiative Program (SGIP), Federal Investment Tax Credit, Modified Accelerated Cost Recovery System (MACRS), a California specific incentive model, and finally Section 179 Bonus and Depreciation. Two of these incentive programs are specific to California. However, that is our initial target market, so are applicable. Something good about this variety of incentive programs is that they are not mutually exclusive. You can take advantage of several simultaneously, so we do not need to target only one of these programs. Some of the incentives are decreasing in the future however. For example, the Federal Investment Tax Credit in 2022 will provide ⅓ the benefit it did in 2019. Some of the programs are specifically for battery storage, others are for the combination of solar and battery. They are all explored in depth below.

Self Generation Incentive Program (SGIP):

Can it be used just for batteries: Yes

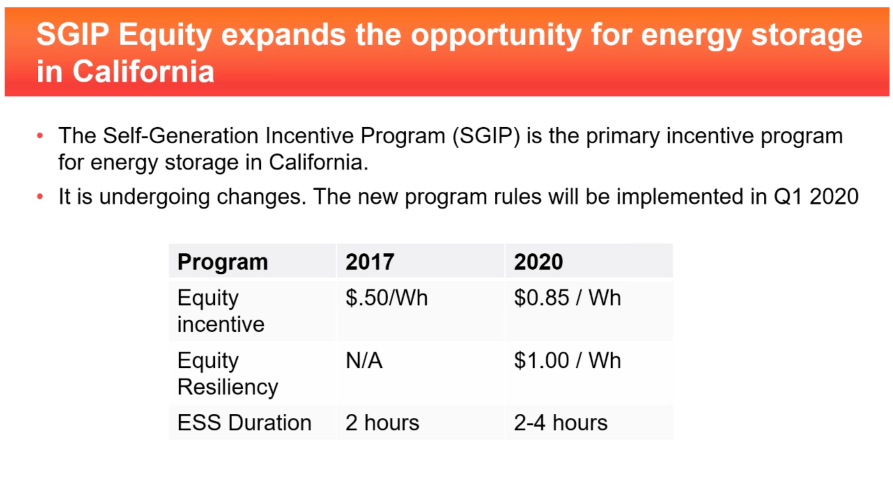
The California Public Utilities Commission's (CPUC) Self-Generation Incentive Program (SGIP) provides incentives to support existing, new, and emerging distributed energy resources. SGIP provides rebates for qualifying distributed energy systems installed on the customer's side of the utility meter. Qualifying technologies include wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems.

Provides additional benefits for low income communities:

CPUC Decision 17-10-004 created the SGIP Equity Budget, which will be implemented beginning with Step 3. This Equity Budget will be allocated 25% of SGIP funds already allocated for energy storage projects, and will provide incentives for customer-sited energy storage in disadvantaged communities and low-income communities in California. For a map of these areas, please click here (any shaded area is eligible). Customers eligible for Equity Budget incentives include non-profits, small businesses, educational institutions and governments.

Customers in low-income housing may also access Equity Budget incentives and are eligible even if they do not reside in a disadvantaged community or low-income community. For more information on the Equity Budget, please consult this press release.

Specific relief for people in fire zones:
SGIP in specific areas can cover even more of the cost of batteries. The California Public Utilities Commission approved changes (PDF) late last week to the Self-Generation Incentive Program, the state's premier behind-the-meter battery incentive program. Among them is a $100 million carve-out for vulnerable households and critical services in Tier 2 and Tier 3 "high fire threat districts," offering incentives that could pay for nearly all of a typical residential battery installation, according to the CPUC analysis. - Sept 17, 2019



Program	2017	2020
Equity incentive	$.50/Wh	$0.85 / Wh
Equity Resiliency	N/A	$1.00 / Wh
ESS Duration	2 hours	2-4 hours

Fig 19. SGIP Equity changes [Ben Lack]

Federal Investment Tax Credit (ITC):

Can it be used just for batteries: Kind of
Battery systems that are charged by a renewable energy system more than 75% of the time are eligible for the ITC, currently 30% for systems charged by PV and declining to 10% from 2022 onward. Battery systems that are charged by a renewable energy system 75%–99.9% of the time are eligible for that portion of the value of the ITC. For example, a system charged by renewable energy 80% of the time is eligible for the 30% ITC multiplied by 80%, which equals a 24% ITC instead of 30% (the tax credit is vested over 5 years, and recapture can apply in unvested years if the percentage of renewable energy charging declines). Battery systems that are charged by renewable energy systems 100% of the time on an annual basis can claim the full value of the ITC.

Can it be used by either individuals or businesses? Both

The Federal Investment Tax Credit allows both tax paying citizens and businesses to recoup part of the cost of solar and battery installations when paying their taxes. As explained above, the individual/business can recoup 30% of the cost of solar installation, or some percentage of what it cost to install a battery system charged off solar. The way it works is when paying federal taxes, the business/individual subtracts the amount of the installation multiplied by the appropriate expense from their amount due. Nonprofits cannot take advantage of this incentive because they do not pay taxes.

How is it changing?
Currently, people who take advantage of the Federal Investment Tax Credit can recoup 30% of their costs for installing solar. By 2022, this amount will decrease to 10%. See the graph below for what will happen year by year.

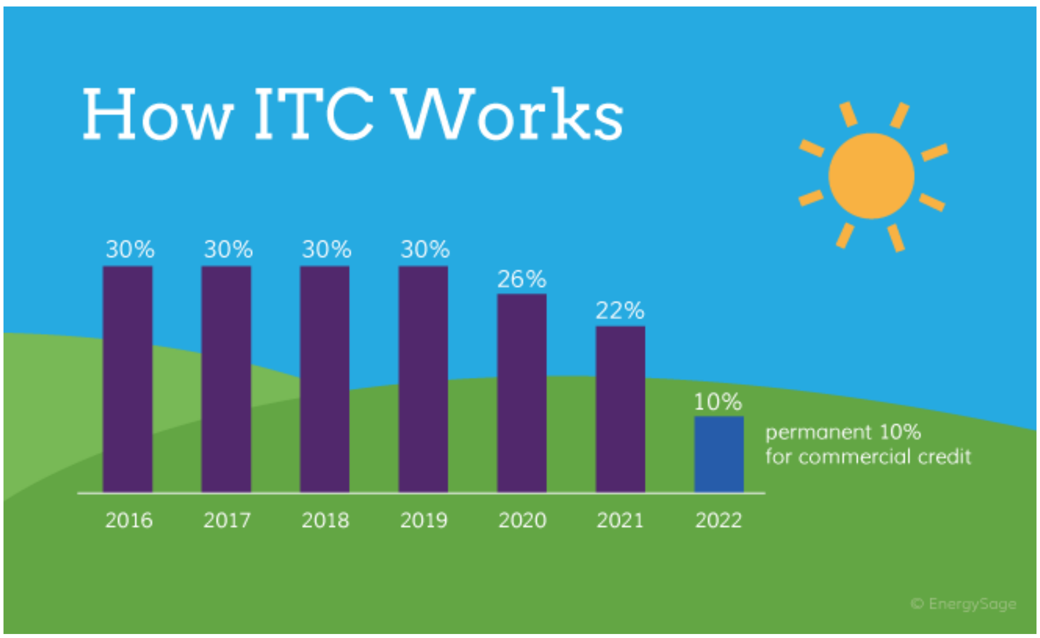


Figure 20. ITC

Modified Accelerated Cost Recovery System (MACRS):

Can it be used just for batteries: Yes
Without a renewable energy system installed, battery systems for businesses are eligible for the 7-year MACRS depreciation schedule: an equivalent reduction in capital cost of about 25% (*Assumes a 35% federal tax rate and 10% discount rate.*). The same benefit applies to battery systems installed along with a commercial renewable energy system if the battery is charged by the renewable energy system less than 50% of the time.

Can it be used by either individuals or businesses? Both

The U.S. tax code allows for a tax deduction for the recovery of the cost of tangible property over the useful life of the property. The Modified Accelerated Cost Recovery System (MACRS) is the current depreciation method for most property. The market certainty provided by MACRS allows businesses in a variety of economic sectors to continue making long-term investments and has been found to be a significant driver of private investment for the solar industry and other energy industries. Individuals are also allowed to take advantage of MACRS to recover costs associated with installing batteries.

California Specific Depreciation:

Can it be used by either individuals or businesses? Only Businesses
Under California tax law, businesses are allowed to depreciate certain equipment purchases – including both solar PV installations and on-site battery storage.
Using the 10-year straight-line method, the equipment depreciation is deductible and allows for recovery of the business expense total cost over a 10 year period for the business renewable energy investment purchase.

Other incentives:

The Sales and Use Tax Exemption for Electric Power Generation and Storage Equipment is a welcome addition to the other incentives available in the Golden State. That means you can pocket the extra 7.25% state sales tax you would normally pay when you buy a home solar system and battery.
Homeowners understand the value of property tax exemptions, so it's good news that California is offering a tax exemption for residential solar systems until the end of 2024. And since purchased solar systems may increase the value of your home by up to $15,000 on average, you'll get even more bang for your buck if you decide to move.
Some municipal utilities like Sacramento Municipal Utility District (SMUD)7 offer solar rebates based on the estimated performance of the home solar system. Go Solar California lists electric companies that provide solar panels and/or solar battery storage incentive programs.

Section 179 Bonus and Depreciation:

Can it be used by either individuals or businesses? Only Businesses
According to the Internal Revenue Code, Section 179, and the IRS's bonus depreciation regulation, companies are allowed to deduct the cost of projects that improve their businesses. Although technically not a typical solar "incentive," these deductions can help shorten the payback period of your clean investment. Whereas a standard commercial solar installation might take 7 years to pay for itself, adding in these deductions means you can typically break even in under 5 years.
So for incentive programs to target, because we are focusing on residential storage, we should target SGIP and MACRS. We could also target the ITC provided that the battery would be

mainly charging from solar cells. Many of the California specific programs and also the Section 179 incentive are for businesses. If we choose to market this to small businesses as well as individuals this could be useful.

Financial Model

The financial model of the project was dependent on: customer feasibility, company financial sustainability, market capitalization potential, exterior support, and revenue opportunity, all of which carried equal weight. The use of incentive programs dramatically decreases the cost of producing a battery, but understanding how to utilize the incentives became the driving force in deriving the financial model, keeping in mind a long-term storage and energy usage solution. Our initial idea was a battery with the capabilities of a 24-hour long duration, providing the possibility of day-long service to the homeowners.

Loan	17459				
r	3.99%				
n	10				
payments/yr	12				
Monthly Payment	$176.68				
Year	ADS	Interest	Principal	Balance	PMTS Left
0				17459	120
1	$2,120.17	$670.29	$1,449.88	$16,009.12	108
2	$2,120.17	$611.37	$1,508.80	$14,500.32	96
3	$2,120.17	$550.06	$1,570.12	$12,930.20	84
4	$2,120.17	$486.25	$1,633.92	$11,296.28	72
5	$2,120.17	$419.85	$1,700.32	$9,595.96	60
6	$2,120.17	$350.75	$1,769.42	$7,826.54	48
7	$2,120.17	$278.85	$1,841.32	$5,985.22	36
8	$2,120.17	$204.02	$1,916.15	$4,069.07	24
9	$2,120.17	$126.15	$1,994.02	$2,075.05	12
10	$2,120.17	$45.12	$2,075.05	$0.00	0

Fig 21. Payment plan with all Incentive funding received

Design Thinking Reflection

Mark- Overall I enjoyed the design thinking process and thought it was quite useful. I liked at the beginning of the year when we read the articles from the Stanford Design school. The iterative process of starting with a holistic view of the problem, and then drilling down and researching more and more until finding an optimal solution makes intuitive sense. Identifying potential solutions, and then choosing the most viable based on a weighting of a variety of factors seems interesting. I do think however, that while design thinking has its place, it's not a panacea and can stifle creativity. A large portion of it is interviewing experts and hearing what people want. This limits creativity. Henry Ford is famous for saying, “if I asked people what they wanted they would have said faster horses,” and there is a great deal of truth to that. When an inventor has an inspiration for a terrific idea, sometimes they need to change the market to get buy in. So overall I had a positive experience with design thinking, but think like all processes it has its limitations.

Marin- The design thinking process was a very refreshing way to look at designing products and generating concepts. I did not know many of the techniques it took to come to a conclusion about an idea and completing a final design. Coming into the project I believed that a concept was generated by independent thinking, so it was interesting to learn all the different concrete steps it took to arrive at a final concept design. The intensive research simply into the problem, not even the solution, was surprising to me but helped a lot in the end. Understanding the entirety of the problem before coming up with solution ideas was a new concept for me but very useful going into the future. There were times that I wanted to jump right into a solution but in the end it was necessary to take the steps and define the problem first. Additionally, researching in depth and doing analysis on not only technical details but economic data as well was new to me but very intriguing and gave me a new perspective on the big picture approach it takes to solve a problem.

Jesse- The design thinking process was extremely intriguing for me.There were definitive and imperative steps necessary to put together a legitimate prototype, many of which I did not know. The implementation of very thorough research naturally gave us perspective on what was necessary and capable of entering and staying in the market. Refining the matters in which we know as well as enhancing them through steady research, internal thinking, and the outreach to other parties such as experts, gave us the ability to move forward. The biggest downside to design thinking is the limitation to creativity. There were times in which I felt the only path to take was innovating a current technology instead of creating something entirely new. Ultimately, there are positives in the process of thinking, especially in the aspect of thoroughness, but there are some cons in outside the box thinking.

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