Battery Energy Storage Safety in Residential Settings

A Fall 2021
Collaborative Project with
Arizona State University's
Project Cities & the
City of Peoria

Sustainable Cities Network

Arizona State University

Project Cities

PART 1:

Project and Community Introduction

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SUSTAINABLE DEVELOPMENT GOALS

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ACKNOWLEDGMENTS

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On behalf of the Julie Ann Wrigley Global Futures Laboratory, the Global Institute of Sustainability and Innovation, and the School of Sustainability, we extend a heartfelt thank you to the City of Peoria for enthusiastically engaging with students and faculty throughout the semester. These projects provide valuable real-world experience for our students and we hope that their perspectives shine light on opportunities to continuously improve Peoria's future livelihood and community well-being.

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To access the original student reports, additional materials, and resources, visit:
links.asu.edu/PCPeoriaSafeBatteryStorage21F

ABOUT PROJECT CITIES

The ASU Project Cities program uses an innovative, new approach to traditional university-community partnerships. Through a curated relationship over the course of an academic year, selected Community Partners work with Project Cities faculty and students to co-create strategies for better environmental, economic, and social balance in the places we call home. Students from multiple disciplines research difficult challenges chosen by the city and propose innovative sustainable solutions in consultation with city staff. This is a win-win partnership, which also allows students to reinforce classroom learning and practice professional skills in a real-world client-based project. Project Cities is a member of Educational Partnerships for Innovation in Communities Network (EPIC-N), a growing coalition of more than 35 educational institutions partnering with local government agencies across the United States and around the world.

ABOUT SUSTAINABLE CITIES NETWORK

Project Cities is a program of ASU's Sustainable Cities Network. This network was founded in 2008 to support communities in sharing knowledge and coordinating efforts to understand and solve sustainability problems. It is designed to foster partnerships, identify best practices, provide training and information, and connect ASU's research to front-line challenges facing local communities. Network members come from Arizona cities, towns, counties, and Native American communities, and cover a broad range of professional disciplines. Together, these members work to create a more sustainable region and state. In 2012, the network was awarded the Pacific Southwest Region's 2012 Green Government Award by the U.S. EPA for its efforts. For more information, visit *sustainablecities.asu.edu.*

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ASU Sustainable Cities Network
Arizona State University

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Sustainability through local action

ABOUT PEORIA

Ranked as the No. 1 place to live in Arizona by Money Magazine, the City of Peoria is currently home to over 191,000 residents. The City enjoys a reputation as a family-oriented, active community with an exceptional quality of life. Peoria entertainment and recreational amenities include attractions such as Lake Pleasant, trails, and community parks.

The City has also demonstrated a strong commitment to sustainability, as evidenced by its incorporation of LEED building design standards, a council-adopted Sustainability Action Plan, and the "Green Team" staff dedicated to managing organization-wide sustainability initiatives.

PEORIA TEAM

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Peoria is the place
World class ▪ Sustainable ▪ Future Ready

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February 28, 2022

Dear Peoria community members,

On behalf of the City of Peoria, we would like to express our appreciation to all who have been involved with Arizona State University's (ASU) Project Cities program. Over the last year, our staff has had the opportunity to collaborate with faculty and students across several academic programs, benefitting from their insights, ingenuity, and diverse perspectives on a number of projects. Many of these entailed public participation, and you may have met some of these engaging students at a community event, or completed a community survey.

Project Cities is one of several partnerships we enjoy with ASU, and part of our ongoing strategy to connect with community partners to leverage our resources as we address the many challenges facing local governments. Working with students at an undergraduate, graduate and capstone project level brings a fresh perspective and resourcefulness to complex issues. This partnership has resulted in extensive research, recommendations, and deliverables that take several key initiatives to the next level. These include our efforts around increasing transit ridership, community engagement strategies, historic preservation and innovative recycling methods. Through this partnership, we have developed an understanding of the feasibility of each initiative much more quickly than we could have without their collaboration.

The results provided on each project position us to serve our community with cost-effective and innovative programs in the interest of continuous improvement. The city has already begun to incorporate the students' deliverables into next steps in advancing these projects. We look forward to continuing this work on additional projects in the coming year with such talented students and faculty.

The City of Peoria appreciates the ongoing and growing relationship with Arizona State University and the many ways in which the alliance provides mutual value.

Sincerely,

Cathy Carlat, Mayor

Jeff Tyne, City Manager

Peoria, Arizona

Proud partner of

ASU Sustainable Cities Network

Arizona State University

Project Cities

Rio Vista Recreation Center

Demographics

total population: **190,985**

median age: **35**

highly skilled and educated workforce of 85,252

11,997 veterans live in Peoria

78% of residents are homeowners

median property value: **$399,025**

33% of residents hold a Bachelor's degree or higher

median household income: **$79,700**

Schools

#3 of 131 Best School Districts for Athletes in Arizona

#5 of 40 Best School Districts in Phoenix Metro Area

#7 of 130 Best School Districts in Arizona

The Peoria Unified School District consistently receives high ratings and offers signature programs such as the Career and Technical Education programs. Deer Valley Unified School District has two highly-rated K-8 schools within the city, including an Academy of Arts.

Peoria is also home to Huntington University, a liberal arts college offering digital media education in animation, broadcasting, film, graphic design and other digital media arts.

Leading industries

Peoria, Arizona is not just a scenic suburb of Phoenix, but also a thriving economic development hub with an educated workforce and high-end residential living. There are over 4,000 employers and more than 75,000 people employed within Peoria. Leading industries include health care and social assistance, retail trade, and finance and insurance. Highest-paying industries include utilities, manufacturing and public administration. Beyond these industries, Peoria works actively to attract businesses from aerospace and defense, film and digital media, technology and innovation, hospitality and tourism, and research and development. Peoria is the place for business owners, developers and investors.

Health Care & Social Work

10,905 employees

Retail Trade

10,628 employees

Finance & Insurance

6,574 employees

History

Founded in 1886 by Midwestern settlers, Peoria is nestled in the Salt River Valley and extends North into the foothills around Lake Pleasant. Beginning as a small agricultural town, the economy received a major boost when a railroad spur line was built along Grand Avenue. The construction of the Roosevelt Dam in 1910 secured a reliable water supply, attracting more settlers to the area and business endeavors to the town center. Peoria's economy continued to have an agricultural focus for decades. Continually growing, Peoria assumed city status in 1971 with a population of 4,792. It has since grown into a city with a population over 190,000, and is renowned for its high quality of life and recreational amenities.

Sustainability

Peoria has demonstrated leadership in municipal sustainability efforts through a wide range of actions. Listed below are some of the City's sustainability accomplishments.

- Incorporation of LEED building design standards
- Appointment of a full-time city staff member who manages and coordinates sustainability initiatives
- Sustainable urban planning practices including open space planning and water management principles
- Sustain and Gain: Facebook page and brochures keep residents up to date on city sustainability efforts and ways to get involved
- Water Conservation Program: free public classes, public outreach at city events, and water rebate incentives for residents
- Council-Adopted Sustainability Action Plan: this strategic planning document, in its second iteration, ensures city departments are developing sustainability-oriented goals, tracking success metrics, and encouraging cross-communication in the preparation of Sustainability Update presentations made to the Peoria City Council on an annual basis
- Sustainable University: courses and workshops to empower residents to make small changes that make Peoria a better place to live; topics covered include residential solar, gardening, composting and recycling

Awards and recognition

- Number One City to Live, Work and Play in 2021 *(Ranking Arizona)*
- Received three Crescordia awards by Arizona Forward at the annual Environmental Excellence Awards in 2016
- 12th City for Green Space in the U.S. in 2019 *(Wallethub)*
- Top 15 Safest Cities in the U.S. 2017-2019 *(Wallethub)*
- 6th Wealthiest ZIP Code in 2020 *(Phoenix Business Journal)*
- Top 50 Hottest Hoods in 2018 *(Phoenix Business Journal)*
- 10th Best City to Raise a Family in 2018 *(Wallethub)*
- Top 100 Golf Course in U.S. 2017-2019 *(Golf Digest)*

Lake Pleasant

1886 — **2020**

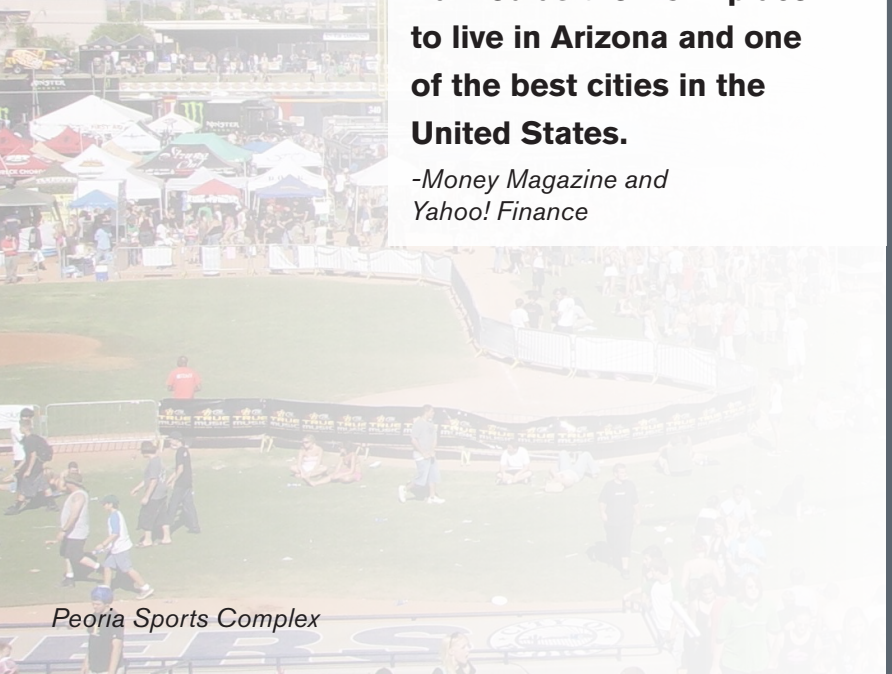
- **1889** — Peoria founded by William J. Murphy
- **1889** — First school district formed
- **1919** — Chamber of Commerce organized
- **1954** — Assumed city status with a population of 4,792
- **1954** — Peoria incorporated
- **1971** — Centennial celebration
- **1977** — Brewers spring training begins at Greenway Sports Complex
- **1986** — Theater for the Performing Arts and Rio Vista Recreation Center opened
- **1994** — Peoria Sports Complex opened
- **2007** — 20-year extension spring training agreement with San Diego Padres and Seattle Mariners
- **2012** — Selected as site of new $70M health clinic for Maricopa County Integrated Health System
- **2017**

Livability

Peoria is renowned as a great place to raise a family and start a career. A plethora of local amenities and attractions contribute to Peoria's livability. Beyond the tourist attractions of Spring Training and Lake Pleasant, the City offers many community facilities and recreational opportunities for all ages and interests such as an extensive public park system and annual community events. Peoria's dedication toward livability is also evident in the City's latest General Plan which addresses sustainable water use, housing, public services and more.

Ranked as the No. 1 place to live in Arizona and one of the best cities in the United States.

-Money Magazine and Yahoo! Finance



Peoria Sports Complex

Peoria strives to uphold these six major livability priorities in order to maintain an exceptional quality of life for its citizens:

- Arts, Cultural and Recreational Enrichment
- Economic Prosperity
- Smart Growth
- Superior Public Services
- Healthy Neighborhoods
- Integrated Transportation

Community Facilities

- Peoria Community Center
- Rio Vista Recreation Center
- Peoria Sports Complex
- Peoria Center for the Performing Arts
- 39 neighborhood parks
- 2 libraries
- 3 swimming pools
- 5 golf courses
- 9 lighted multi-purpose ball fields
- 15 tennis courts

Lake Pleasant

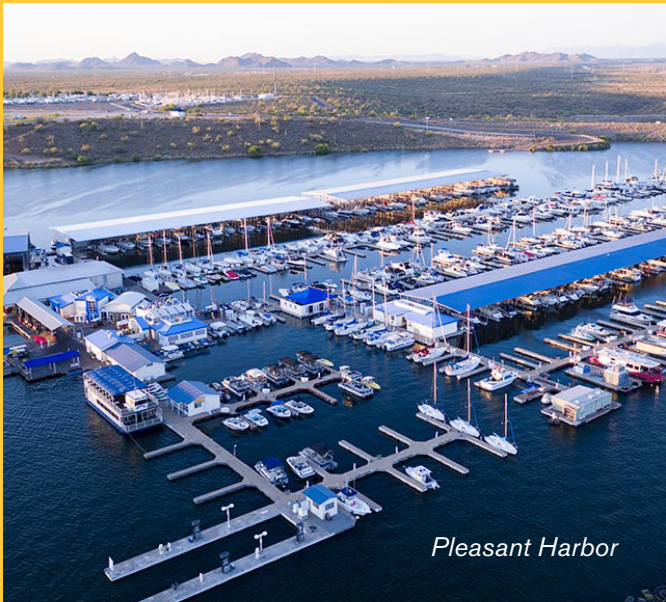
Urban ecology, ecotourism and recreation

Peoria is surrounded by the natural beauty of the Sonoran Desert and is home to Lake Pleasant, a 23,000-acre park and major recreational asset to the North Valley. The transient Agua Fria River and New River flow through Peoria, as do a multitude of washes and creeks. Most notable perhaps is Skunk Creek — known for the recreational trails running alongside it — which forges a connection between Peoria and Glendale. Northern Peoria is home to beautiful mountains and buttes including Sunrise Mountain, Calderwood Butte and Cholla Mountain.

Boasting over 300 days of sunshine annually, Peoria's ecotourism opportunities are a steady industry for residents and visitors. The City features over 60 miles of trails for walking, biking and horseback riding, as well as 570 total acres of accessible park land.

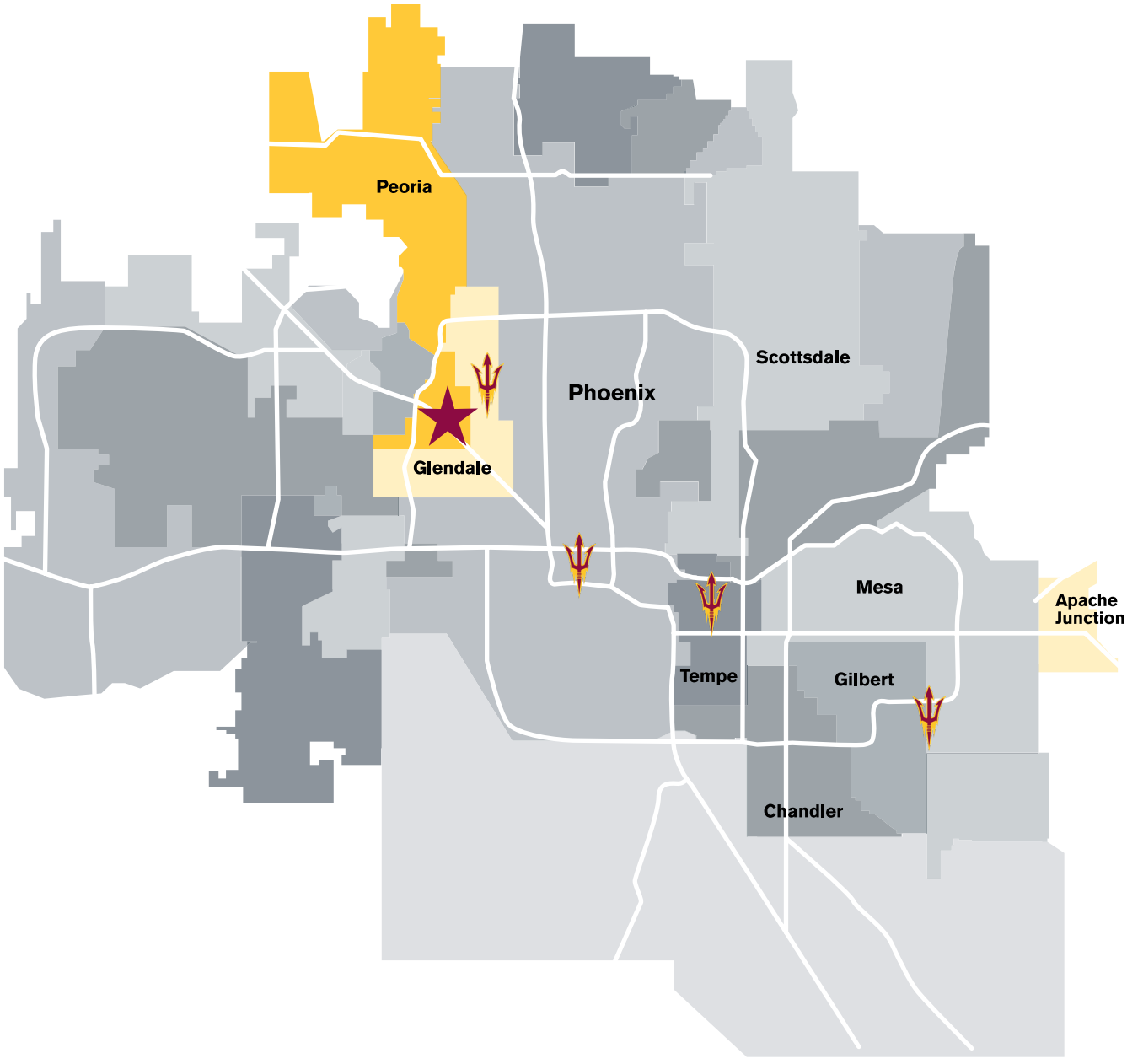
Lake Pleasant Regional Park contains a full-service marina, providing opportunities for water-oriented recreation such as kayaking, water skiing and even scuba diving. Visitors can also go horseback riding, take gliding lessons, hike, camp and more.

Skunk Creek



Pleasant Harbor

MAP OF PROJECT CITIES PARTNER COMMUNITIES IN THE GREATER PHOENIX METROPOLITAN AREA



Peoria City Hall

ASU campus

The following report summarizes and draws highlights from work and research conducted by capstone student Justin Zysk in PAF 509 Public Affairs Capstone, for the Fall 2021 partnership between ASU's Project Cities and the City of Peoria.

To access the original student reports, additional materials, and resources, visit:

links.asu.edu/PCPeoriaSafeBatteryStorage21F

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EXECUTIVE SUMMARY

As one of the fastest-growing cities in Arizona, the City of Peoria and its municipal services strive to be at the forefront of providing excellent care to its residents, and Peoria's Fire-Medical Department is no exception. As one of the few agencies to be accredited by the Center for Public Safety Excellence, Inc. (CPSE), Peoria's Fire-Medical has been awarded for its excellence in providing emergency and medical services to its residents.

Figure 1 *Peoria Fire Department #1, by Google Maps*

Lithium-ion battery storage systems come with their own challenges regarding fire safety. Following a lithium-ion battery energy storage system explosion in Surprise, Arizona, in 2019, several of Peoria's firefighters were injured due to the explosion. The incident highlighted the need to review battery storage safety codes and educational programs thoroughly.

As part of Malcolm Goggin and LaDawn Lingard's **PAF 509: Public Affairs Capstone**, Master of Public Administration student Justin Zysk completed his culminating experience with Peoria's Fire-Medical Department. In an effort to better equip Peoria's Fire-Medical Department for future incidents, the project focuses on the safety concerns surrounding battery storage systems and how to educate Peoria's residents and first responders about safe battery storage practices. Three research questions guided the research:

- How can Peoria improve its current battery storage protocols based on case studies and best practices around the nation?
- What city codes are in place at other agencies regarding safe battery storage?
- Are there any educational programs in place in cities that the City of Peoria can adapt?

In partnership with ASU Project Cities, the capstone research seeks to provide Peoria's Fire-Medical with recommendations to update its city code publications related to safe battery storage. The student conducted a literature review of battery storage concerns and presented foundational knowledge about the various battery storage types. By reviewing battery storage and education best practices from other cities, the student poses several recommendations aim to empower Peoria's firefighters with fire safety knowledge to ensure a safer residential and work environment.

With a surge in lithium-ion battery use in residential settings, being proactive about battery storage safety will be paramount for Peoria's first responders and residents. Through regular maintenance of Peoria's fire codes, and regular trainings, the City of Peoria can take proactive steps to ensure the safety of its residents and first responders.

KEY STUDENT RECOMMENDATIONS

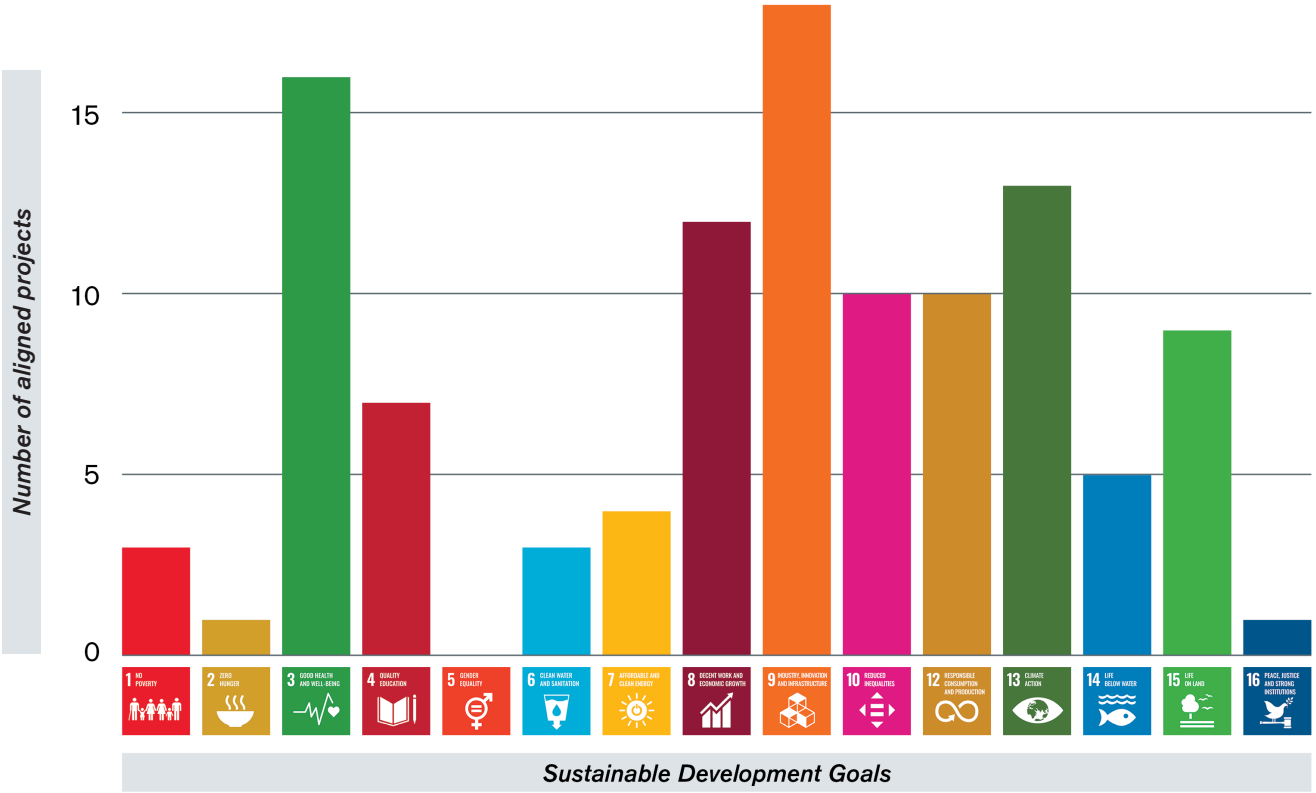
Recommendations for battery energy storage system safety	Read more
Maintain and update city code publications on a yearly basis to ensure compliance with the National Fire Protection Association.	pp.32-34
Consult with the National Fire Protection Association for regular updates to Peoria's fire codes. Consider regularly updating and reviewing Peoria's codes.	pp.32-34
Consult with external training providers to facilitate expert driven safety training, particularly in the use of BESS, for the firefighters of Peoria.	pp.32-34
Develop a physical battery energy storage system training aid, which can be housed in the Peoria fire department facilities for regular training purposes.	pp.32-34

CITY OF PEORIA PROJECTS: ALIGNMENT WITH THE UNITED NATIONS' SUSTAINABLE DEVELOPMENT GOALS

As the leading international framework for sustainable decision-making, the 17 Sustainable Development Goals (SDGs) lay out a path for partnerships toward global peace and prosperity. The SDGs provide a set of goals and metrics for project impact to be measured, offering an illustration of the benefits experienced by the cities, towns, and students who participate in a Project Cities partnership. For details on the SDGs, visit **sdgs.un.org/goals.**

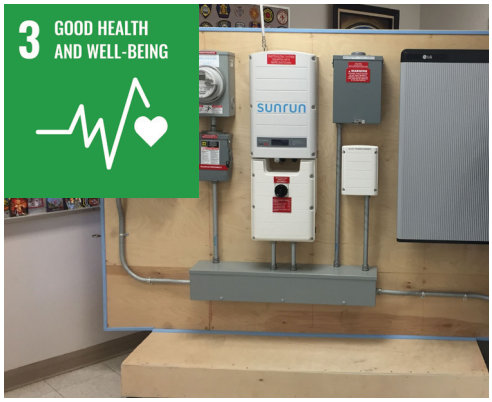
Every project in the PC program aligns with SDGs 11 and 17.

The figure below illustrates SDG project alignment throughout the City of Peoria's partnership with Project Cities, through the Fall 2021 semester.



TOP THREE GOALS ADDRESSED IN THE FOLLOWING REPORT

This capstone project provides foundational knowledge around safety aspects of battery energy storage systems that is relevant to residential or commercial settings. The research is used to provide city code and educational initiative recommendations for the City of Peoria to consider alongside its goal to maximize safety protocol for battery energy storage.



Goal 3: Good Health and Well-Being

"Ensure healthy lives and promote well-being for all at all ages."

Enhancing safety protocols around battery energy storage increases the well-being of area residents, utility workers, and first responders that may encounter with the systems.

Goal 7: Affordable and Clean Energy

"Ensure access to affordable, reliable, sustainable and modern energy for all."

Minimizing risk factors and increasing safety measures can help make solar power more feasible and attractive to implement in residential as well as commercial locations.

Goal 9: Industry, Innovation and Infrastructure

"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation."

Reducing risks of battery energy storage accidents helps protect valuable infrastructure while boosting the safety of a viable clean energy source.

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PART 2:

Safe Battery Energy Storage Systems in Residential Settings

MUNICIPAL CODE UPDATES AND EDUCATIONAL EFFORTS TO ADDRESS BATTERY STORAGE SAFETY CONCERNS

PAF 509: PUBLIC AFFAIRS CAPSTONE

SCHOOL OF PUBLIC AFFAIRS

FACULTY: MALCOLM GOGGIN & LADAWN LINGARD

CAPSTONE STUDENT: JUSTIN ZYSK

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INTRODUCTION

A critical incident in Surprise, AZ, in 2019 resulted in several firefighters being seriously injured and raised questions regarding the safety of solar energy storage and the implications that might have in the residential setting for the City of Peoria and the Peoria Fire Department. By reviewing academic literature and seeking out local and national best practices, Peoria has taken steps to ensure it is prepared for similar incidents and have leveled themselves with some of the most stringent states' compliance measures. With that said, there is still some room for improvement. Training is a crucial component of preparedness, and as a result, it is recommended that Peoria's Fire-Medical supplement its current training with the S.A.F.E. program discussed in this paper. It is also recommended that an annual review of the newly implemented fire codes complies with the National Fire Protection Agency's (NFPA) codes surrounding solar energy systems. This paper also concludes that the type of batteries used are often just as much, if not more, of a safety problem as the battery energy storage systems used. A considerable amount of residential fires and damage is caused more often by solar panels than the battery unit, which is an important finding given the research problem.

Figure 1 *Battery energy storage at a solar farm*

Background

Arizona Public Service, referred to as APS, is an alternative energy source company that harnesses solar energy and converts it to electric power. Nearly three million Arizona residents rely on APS for their residential and business power needs (Arizona Public Service, 2021).

To provide electric power to its customers 24 hours a day, seven days a week, APS needs to have the ability to store its excess energy for use at a later time. For this reason, APS owns and operates three large-scale battery system storage facilities located in various Arizona cities; Buckeye, Surprise, and Punkin Center (Arizona Public Service, n.d.). The storage of any form of energy requires the use and implementation of safe storage protocols and risk-mitigating systems. If an issue arises where a first responder response is required, it is also imperative to have safe response protocols available in order to protect responding personnel from injury.

On April 19th, 2019, the battery storage facility in Surprise, Arizona, experienced an internal equipment failure and required a fire response from the Peoria Fire Department in line with mutual aid agreements with Surprise, Arizona. The equipment failure and several other contributing factors led to nine first responders being injured, four of which were seriously injured. According to the final technical analysis and recommendations report conducted by DNV GL Energy Insights, there were a total of five contributing factors that led to this critical incident. The first factor was the internal battery failure which resulted in a cascading effect of issues. Three of the four remaining contributing factors highlighted inadequacies in the safety measures within the storage facility itself. The fifth and final contributing factor to this critical incident was the lack of an appropriate emergency response plan given the circumstances (DNV GL Energy Insights USA Inc., 2020).

Figure 2 *Bank of electric batteries in a residential home used in conjunction with a solar energy system or for backup power*

Purpose of study

Due to the critical incident discussed above, the Peoria Fire Department has become concerned about the implications of battery energy storage systems (BESS) in a residential setting. Much has changed since this incident in solar energy; however, there is still some room for improvement. The purpose of this study will be to provide the City of Peoria with any relevant recommendations that address their concerns regarding BESS safety and risks in a residential setting.

Importance of the study

For several years, smaller, more compact battery storage packs have been available for residential use for storing solar power. Some of the concerns expressed by Peoria first responders were the lack of homeowner knowledge about solar energy battery storage packs and the need for a drastically different response approach to a battery failure in a residential setting versus an isolated battery storage facility in the middle of the desert. Chief Ruiz, the Fire Chief for the Peoria Fire Department, said, "you can't just let a residential battery unit burn until it can't burn any longer because of the proximity to other structures" (B. Ruiz, personal communication, September 8, 2021).

Comparing and contrasting best practices and operating procedures with those of the City of Peoria and the Peoria Fire Department should provide alternative or more comprehensive measures to add to the existing two-page publication adopted by the Peoria Fire Department since this incident. At the end of this project, the client will receive key findings and recommendations that the city and fire department should consider to prevent a similar incident in the residential setting.

RESEARCH METHODS

The student guided their research in order to answer three key research questions:

1. How can Peoria improve its current battery storage protocols based on case studies and best practices around the nation?
2. What city codes are in place at other agencies regarding safe battery storage?
3. Are there any educational programs in place in cities that the City of Peoria can adapt?

As this is a research-driven project, the bulk of this project included an extensive review of the literature. This paper has highlighted several sources, discussing various aspects of safety related to lithium-ion batteries (LIB) and battery energy storage systems (BESS). In addition to academic and scientific literature, the research process will also include literature analyzing codes, ordinances, and training programs. These play a key role in identifying what others are doing in the industry and can be of value to the City of Peoria and the Peoria Fire Department as they show potential model behavior and best practices.

An active recall was immediately discovered while looking into the research of residential BESS incidents. As a result of five reported incidents, this led to the recall of the LG Chem “RESU10H” Lithium-Ion Residential Energy Storage System Batteries. These five reported incidents would have been ideal for case studies because this unit is used mainly in a residential setting. The information, albeit limited, stated that although no loss of life occurred, a wide range of damage was reported. Several avenues of gaining access to the details of these five reports surrounding the recall were attempted but were unsuccessful.

Limitations of methods chosen

As with any research project or major project in general, inherent and unforeseen limitations and challenges arise throughout the process. One of the major methods of gathering information regarding this research project was the goal of using case studies relevant to residential BESS issues. Despite a thorough search of public records and academic research, there was very little literature regarding fires or safety concerns directly resulting from a BESS in the residential setting. The research showed that the overwhelming majority of fires or safety concerns happened to be the result of the solar panels and the electricity that they collect and transfer. During the research phase of residential case studies, it was discovered that there is an active recall of LG Chem “RESU10H” Lithium-Ion Residential Energy Storage System Batteries. This was the only research finding that linked solar BESSs to safety incidents. Based on what little public information was available surrounding this recall, it was found that there were five incidents regarding this particular product causing a range of damage from minor to severe. Since this was an active recall, the only way to obtain any information regarding those five specific cases was to file an official Freedom of Information Act Request directly with the United States Consumer Product Safety Commission (CPSC). It took several weeks, but the expeditious request and the information request were denied, citing the active nature of the investigation and recall. The denial resulted in not being able to obtain any specific information surrounding the five cited incidents of the recall.

FINDINGS & ANALYSIS

Foundational knowledge

The purpose of this section is to lay basic groundwork for the capstone topic subject matter. This section is not intended to be exhaustive or completely comprehensive, nor is it designed to provide an in-depth scientific understanding of BESS or LIB. This section is simply to lay a basic foundation of a solar system more generally, explain a bit about the components and function of the BESS, and then a brief introduction to a few types of batteries seen in solar energy systems.

Foundational solar energy system knowledge

The technical term for a solar energy system is photovoltaic, or PV for short. Refer to Figure 3 below for a basic-level depiction of a solar system in the residential setting.

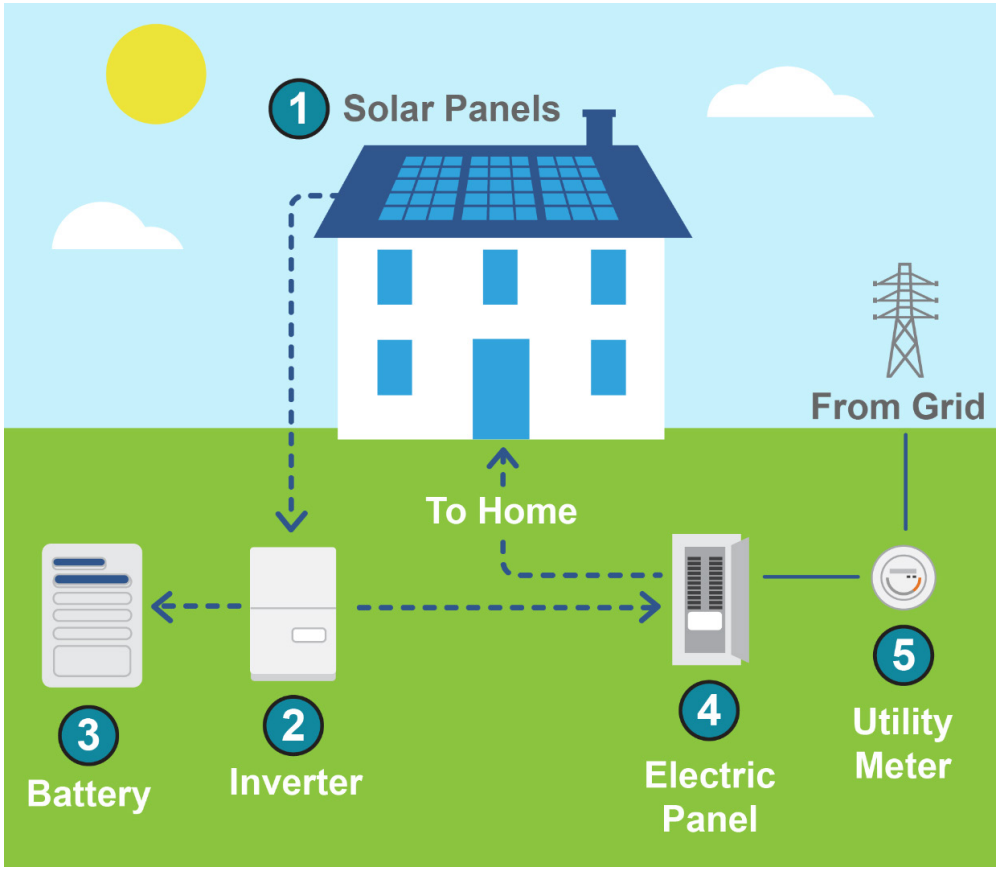

Figure 3 *Residential solar system basic diagram, by Sun Run*

As shown in Figure 3, the panels on the roof collect solar energy, and that energy is transferred to an inverter. The job of the inverter is to convert the power into the correct current for use in the home. From the inverter, the energy goes to the electrical panel and the battery at the same time. The power not used for supplying electricity to the house by way of the electrical panel is sent to the battery storage unit for later use. Figure 4 below shows a real-world example of a solar system inside a residence.

Figure 4 *Installed residential solar battery system, by Brian Wolfson*

All of the main electrical components are found on the right side of the picture, and this particular setup has two separate battery storage units that are found on the left side. There are setups installed inside the residence, like the one pictured above, and there are setups installed outside. An external setup can be either installed directly to the house's exterior or in a separated storage shelter.

Use of battery energy storage systems

The primary function of the BESS is simply to store excess solar energy for use at a later time. With the push for more renewable and lower emission styles of energy, solar energy has become quite popular in the United States, especially in the west, where Arizona is located, and available sunlight is abundant. With an average of 300 or more days of sun, Norman (2020), states like Arizona, and cities like Phoenix, in particular, have seen a rise in solar energy use in both commercial and residential settings over the years (Borst, 2020, para. 5). Furthermore, states like California have mandated through the use of state building codes that all houses newer than the year 2020 be powered by solar energy (Norwood, 2018). As such, solar is the way of the future, and with that comes a greater need to fully understand the various systems, components, and implications, both positive and negative.

The BESS really only comes into play when the sun is set, and the solar panels are no longer actively gathering solar energy. The energy collected is stored in the BESS unit throughout the day and becomes available during night-time hours. Sometimes consumption during the day outweighs the energy collection amount, and then energy will be pulled from the battery storage units.

Battery types

A few types of batteries can be used as a storage unit in a solar system. The four most frequent types are lead-acid, nickel-cadmium, flow, and lithium-ion. Lithium-ion will be the focus since that is the type most often seen in a residential setting and led to the APS incident in 2019. LIBs are used in many everyday items such as computers and cellphones. Their wide use and availability, coupled with some highly touted benefits, make them the "go-to" battery type for BESSs.

Literature review

The purpose of this section is to examine existing literature in order to apply what others have found about the problem posed in this capstone project.

Safety concerns

There is countless research into the safety concerns that BESSs and LIBs pose. With the use of these systems in a residential setting, the risks are far greater than a remote and uninhabited large-scale energy storage facility. According to Chen et al., (2021), internal makeup, the surrounding environment, and externally applied factors of a battery have a lot to do with the product's safety (Chen et al., 2021, p.83). Some of these elements are easier to control than others. The placement and surroundings of a BESS are fully within the control of the installation expert and resident. However, controlling the internal makeup and some externally applied forces might not be as easily controlled. Based on the available literature, some of the most notable safety concerns worth mentioning are pictured in Figure 5.

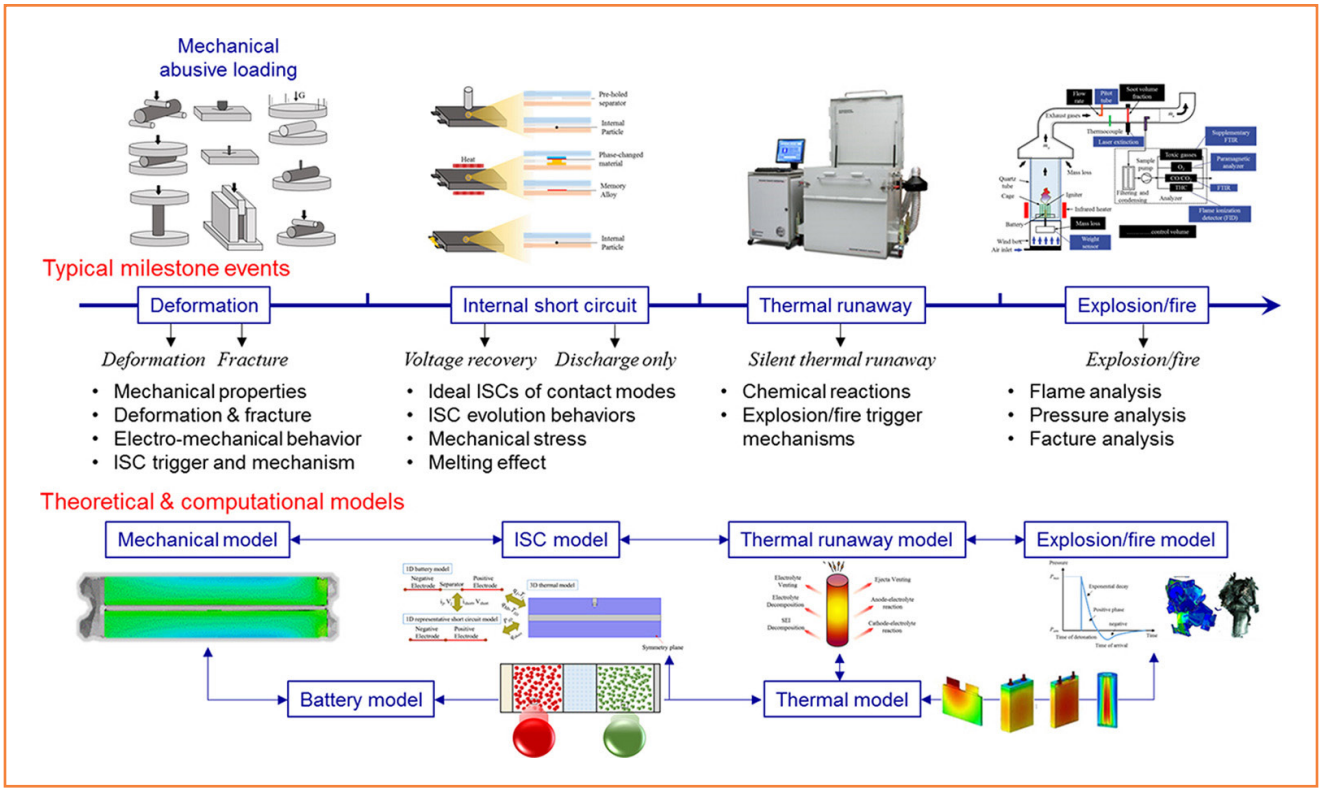

Figure 5 *Battery failure progression diagram, by Liu B. et al., 2020*

Battery failures typically result from things such as overheating (Liu, P. et al., 2020 & Wang, H. et al., 2021), abusive loading (Liu, B. et al., 2020), and accidents, disasters, and inadequate control systems (Chen et al., 2021, p.85). Figure 6 below shows a flowchart of how the latter three failures progress from initiation to a potentially disastrous outcome.

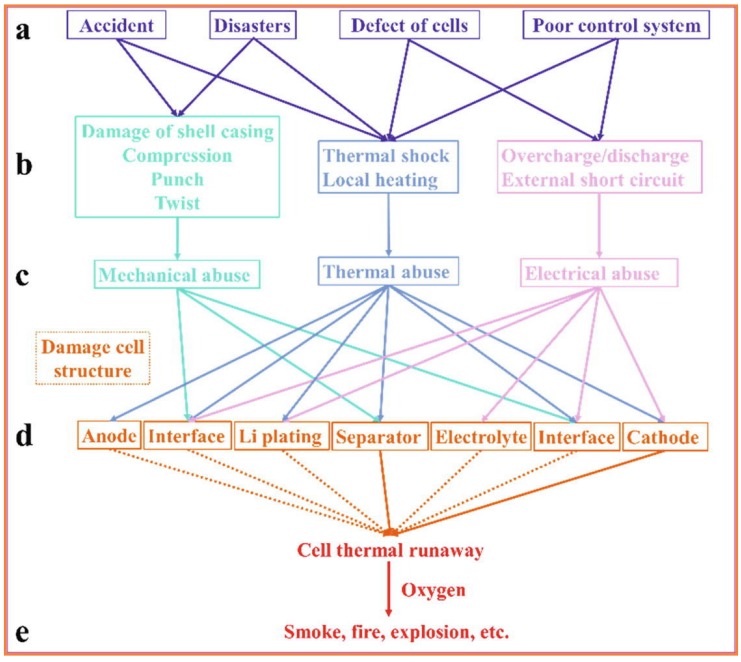

Figure 6 *Battery failure flowchart, by Chen et al., 2021*

Thermal runaway

According to Liu et al., (2020), "thermal runaway is a major battery failure mode, wherein exothermic reactions go out of control due to an increase in temperature" (p.1). If left unmitigated or unchecked, it can spiral out of control and propagate to nearby cells and batteries (Zalosh et al., 2021). Thermal runaway is extremely dangerous because not only is it the catalyst for the issue spreading, but it is also the cause of the toxic chemical release. See Figures 7 and 8 below for a visual of the thermal runaway. As the temperature rises, so too does the hazard level.

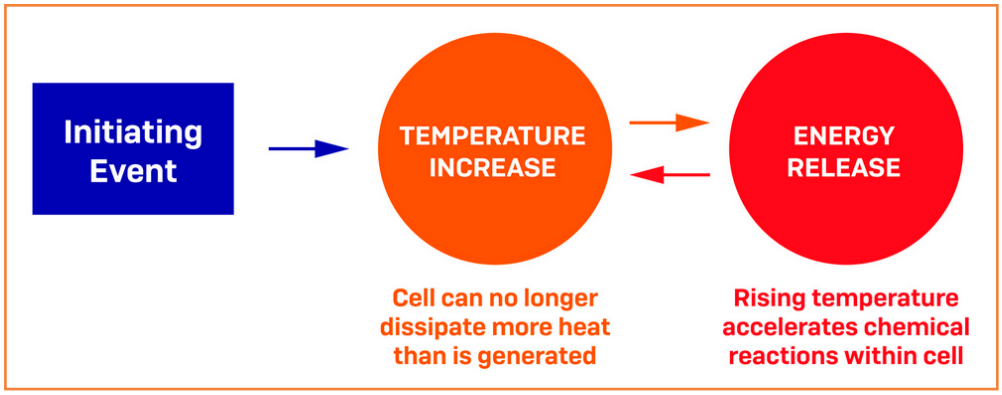

Figure 7 *Thermal runaway visualization, by Rokion*

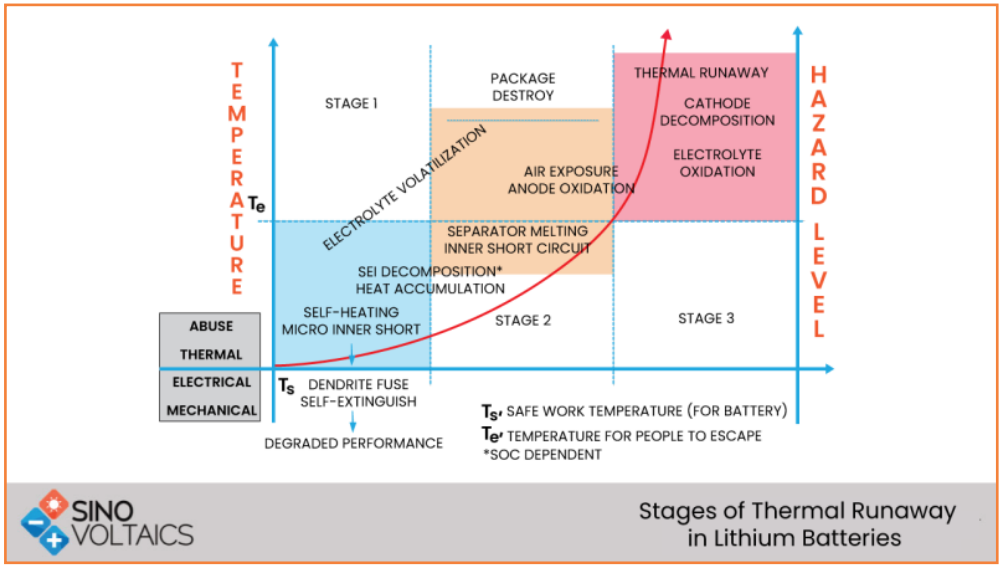

Figure 8 *Depiction of thermal runaway in relation to temperature and hazard level, by Sinovoltaics*

Once a certain temperature is reached the internal energy created cannot stay contained and is released in the form of gasses, heat, and fire. This process is important to understand because a residential structure is home to more combustible items than a large-scale BESS facility. Ensuring that all possible preventative measures are implemented could help mitigate or eliminate the risk such a failure could pose.

Summary

Research behind the hazards of LIBs is plentiful. Most available studies focus on large-scale BESSs, such as the one that exploded in Surprise, Arizona, in 2019. However, there seems to be a gap when it comes to residential BESSs. Whether discussing a cellphone or a solar storage battery, the elements, failures, and hazards of a LIB are essentially the same. The lack of public, academic literature could lead to thinking that residential BESSs are safer than the LIBs that go in a computer or an electric vehicle. The reality is they pose the same threat in terms of failures and have higher risk due to human habitation and proximity to other structures, which means a higher potential for catastrophic outcomes.

Findings

Research Question 1:

How can Peoria improve its current battery storage protocols based on case studies and best practices around the nation?

Based on the research of this topic, the most notable finding through literature search is that the BESS, in general, is not a specific threat to the safety of residential structures and their inhabitants as compared to the other solar system components used. The larger safety concern related to the BESS is based more on the type of battery used. This is not to say that other battery types do not have safety concerns; however, LIBs are more widely known to cause issues. Research shows that LIBs, if not properly maintained and cared for, will break down internally and set off a cascading progression of dangers, leading to serious and potentially disastrous outcomes.

As discussed earlier, thermal runaway is the key component to the issue growing to levels of potential danger. Considering the research, directing the recommendations to mitigate these findings is the best course of action. Avoiding circumstances that lead to the failure stage of thermal runaway in a LIB will drastically reduce the risk involved in housing a BESS within a residential structure and go a long way to ensuring the safety and sustainability of storing solar energy for the future use.

Research Question 2:

What city codes are in place at other agencies regarding safe battery storage?

There has certainly been a lot of progress made in terms of safety measures and precautions prior to and as a result of the APS facility incident and other similar incidents. However, there is always room for improvement. As part of this project, research was undertaken on the most recent fire codes as set by the National Fire Protection Agency (NFPA) (International Code Council, 2017). Prior to the APS incident, energy storage system (ESS) fire codes were not present in the City of Peoria fire codes. Furthermore, a national fire code section dedicated to energy storage was not even added to the International Fire Code (IFC) national standards until 2018 (ICC, 2017). As a result of the APS incident in 2019, the City of Peoria and several local cities in Arizona implemented fire codes specific to energy storage systems. Regarding this, the City of Peoria has done an excellent job in ensuring their codes are directly in line with the published version at that time; however, this version is now obsolete with the introduction of the 2021 version, which addresses some additional information items related to ESSs. Peoria's fire codes are also in line with even the most stringent codes found in the state of New York (NYS, 2020). This action is certainly a huge step in the right direction in mitigating similar incidents.

Research Question 3:

Are there any educational programs in place in cities that the City of Peoria can adapt?

Since information, knowledge, and technology adapts as time progresses, it is important to ensure the training used in order to prepare employees for situations is as up to date, comprehensive, and accurate as possible. With this said, another key finding from the research on this topic is a free training program, Solar and Fire (S.A.F.E) based out of Las Vegas run by a now-retired Las Vegas Fire Department Fire Captain. This is a mobile training program in which the creator will come to you and put on a class. The class provides valuable information about the uses of solar energy systems in both commercial and residential settings, visual training aid as depicted in Figure 9 for hands-on learning, and expert-level knowledge regarding safety concerns and how to approach them if the situation arises. This training option is one of the only local, cost-effective, and expert-led training programs that came about through research.

RECOMMENDATIONS

In leveraging literature review and available information, several opportunities are recommended for ensuring safety as it relates to BESS, specifically in the residential setting.

Regular updates

Maintain an up to date and comprehensive city code publication. Since the implementation of such a code is still fairly new, it can be easy to neglect its update. Since the NFPA works to update these codes on their end, typically every three years, the fire codes related to energy storage systems and solar systems must be assessed and updated accordingly. As stated earlier, Peoria has effectively implemented codes that are in line with most other municipalities, including the most stringent New York City, however, it is now important to maintain them since a lot can change in a three-year span. Peoria's city codes are based on the IFC 2018 version, but this is no longer the current version. The 2021 version has since been released with some noteworthy changes. Among other changes, the 2021 version further refined the ESS code section to include new technologies and applications as well as mentioning proper commissioning and decommissioning protocols (ICC, 2020). It is recommended to apply the 2021 version changes to the City of Peoria Chapter 9 fire codes.

S.A.F.E. training

Although training material is utilized within the Peoria Fire Department to ensure maximum knowledge of BESSs, it is recommended to seek outside consultation for a comprehensive and expert-level training regimen. This training would be a great supplement to any and all current training provided to the firefighters of Peoria. Inquiries about training can be sent to solarandfireeducation@gmail.com.

BESS training aid

In continuing with the training aspect of preparedness, it is recommended to consider building a training aid as pictured in Figure 9 to house at the department for training purposes. The BESS training setup gives a hands-on experience in a controlled and non-stressful setting, and is more accessible than having to schedule a S.A.F.E. training class. Figure 9 depicts the training aid used for S.A.F.E. training classes.

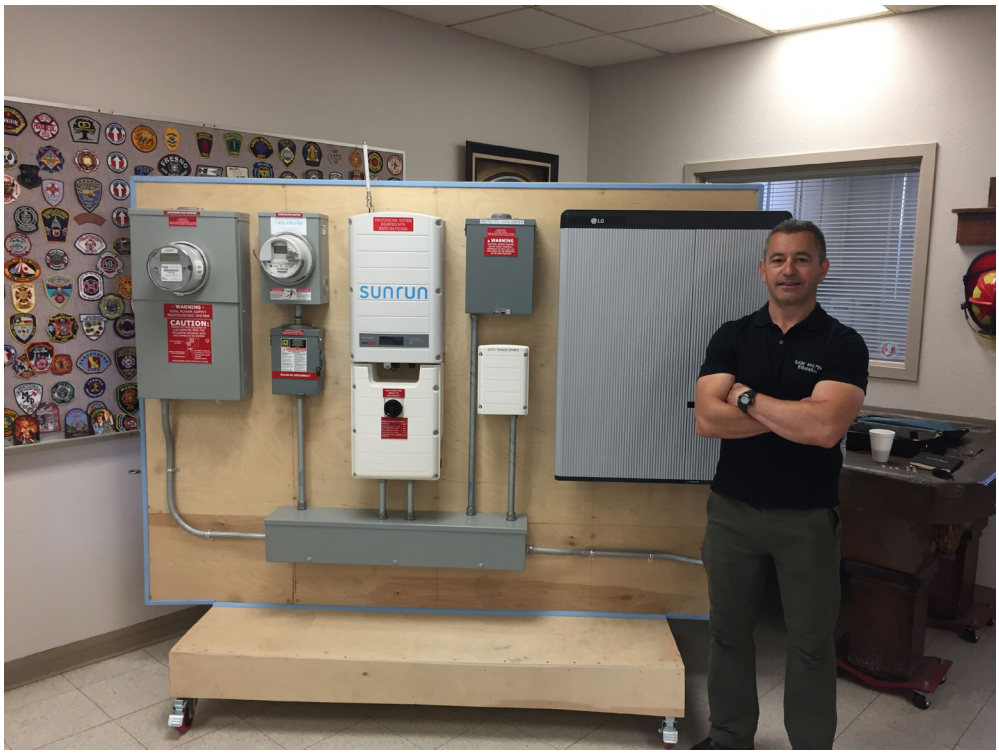

Figure 9 *BESS training aid, by Robert Birt*

CONCLUSION

As the research has concluded, the safety concern regarding residential BESSs goes much deeper than simply storing solar energy. The biggest component to safety concerns is housed in the type of battery used and ensuring it is maintained properly. Due to the internal chemical instability of a LIB, it is widely known that LIBs pose a greater risk of failure leading to damage than some of the other battery types. This is not to say that all LIBs are faulty and will lead to catastrophic failure, but it should be noted that LIBs have a higher propensity to have adverse effects if internal failure is reached. This means that the proper precautions need to be taken, a greater understanding of the battery and its operational makeup needs to be considered, and appropriate and intentional training of first responders is critical.

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