SOLAR IN A BOX: CASE STUDY
HENDERSON, PERTH, WESTERN AUSTRALIA

Introduction

In the pursuit of sustainable and resilient energy solutions, testing commenced in early November 2023 on an innovative Solar in a Box System at a test site in Henderson, South Australia. This cutting-edge system seamlessly integrates solar technology, Vanadium Redox Flow Batteries (VRFB), and Mint Energy's Graphene Supercapacitor Battery Banks to create a robust and reliable power solution. The Graphene Supercapacitors are a crucial part of this system, ensuring continuous system functionality and enhancing energy reliability.

This case study explores the synergies and performance dynamics of these advanced components, offering insights into the future of sustainable energy infrastructure utilizing graphene-based energy storage systems.

Project Overview

The Solar in a Box system was deployed and tested in Henderson, Western Australia as part of a green energy initiative. The Australian Central Government provided research and development funding for the project.

The primary objective of testing was to analyze the Solar in a Box system's efficiency in providing continuous and reliable power in Western Australia's specific climatic and geographical conditions. This included evaluating its adaptability to fluctuations in solar availability, resilience in extreme temperatures, and seamless integration within the existing energy infrastructure.

The fast deployment and retractable nature of the Solar in a Box system proved instrumental during the initial setup, requiring only 4-5 hours to become operational. The container, housing PV Solar Energy, Vanadium Redox Flow Batteries (VRFB), Graphene Supercapacitor Battery Banks, and an Advanced Energy Management System (A-EMS), was strategically positioned to maximize solar exposure.

The system's performance was monitored, focusing on key metrics including power output, energy storage and release efficiency, and adaptability to varying solar conditions. The VRFBs and supercapacitor banks were tested for temperature resilience and overall reliability.

The Solar in a Box system exhibited commendable performance throughout the testing phase. The PV Solar Energy Container consistently delivered up to 100KW 3-phase output, with an average daily yield of 528 kWh, showcasing its reliability in Western Australia's climate. The VRFBs and supercapacitor banks demonstrated durability, and the A-EMS seamlessly orchestrated the hybrid system, optimizing energy usage.

One of the standout features was the system's adaptability and resilience. It’s ability to operate directly with diesel generators and function seamlessly in a full hybrid system, showcases its versatility in meeting energy demands under various scenarios. The system's ability to operate without climate control in extreme temperatures underscores its suitability for deployment in diverse environments.

The Solar in a Box system's successful testing in Henderson, Western Australia, positions it as a promising solution for sustainable and reliable energy needs. Its compact design, rapid deployment, integration of advanced energy storage technologies, and the efficient orchestration through the A-EMS make it a robust contender for diverse applications, from remote locations to urban settings.

Key Demonstration Points

PV Solar Fuel Saving

By utilizing the Diesel Generator to supply baseload power, the system operates at the minimum capacity required while considering spinning reserve (typically 20-30% capacity). During daylight hours, solar energy is harnessed to directly fulfill 25-70% of the operational load demand, leading to a substantial reduction in diesel consumption. The system further exemplifies sustainability by supplying 20-50% of the total energy needed annually through solar power.

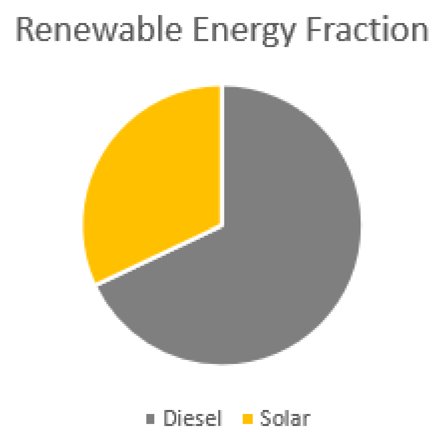

Diagram 1.1: PV Solar System - Renewable Energy Breakdown

Full Hybrid System Operation

As a full hybrid solution, the batteries take charge of providing baseload power, tapping into the full generation capacity of solar energy during peak production. Notably, the system stores excess solar energy for nighttime usage, ensuring continuous power supply. The Diesel Generator seamlessly integrates into the system's operation, running on demand during times of high load demand or unfavorable weather conditions. This strategic utilization of the Diesel Generator serves the dual purpose of supplying load and charging batteries when solar energy availability is limited. The system supples 50-90% of the total energy demand annually through solar power, showcasing its capacity to operate efficiently in diverse scenarios.

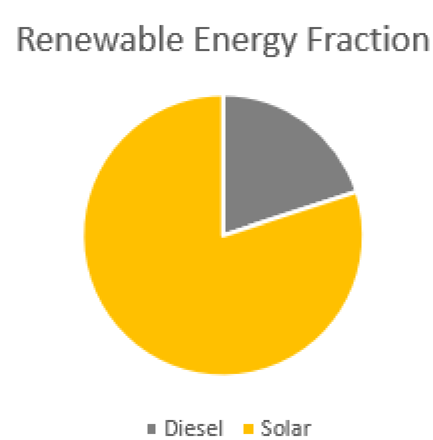

Diagram 1.2: Full Hybrid System - Renewable Energy Breakdown

These key demonstration points highlight the Solar in a Box system's operational efficiency, fuel-saving capabilities, and adaptability to a variety of conditions. The system not only optimizes the use of renewable energy sources but also ensures a reliable and continuous power supply, making it a versatile solution for addressing the evolving energy needs of different environments and industries.

Goals

1. **Performance Evaluation**
   Assess the Solar in a Box system's performance under real-world conditions, focusing on power output, energy storage efficiency, and adaptability to varying solar conditions.
2. **Environmental Suitability**
   Determine the system's resilience in the specific climatic and geographical conditions of Henderson, Western Australia, including its ability to operate in extreme temperatures and fluctuations in solar availability.
3. **Operational Efficiency**
   Evaluate the operational efficiency of the PV Solar Energy Container, Vanadium Redox Flow Batteries (VRFB), Graphene Supercapacitor Battery Banks, and Advanced Energy Management System (A-EMS) in a comprehensive hybrid system.
4. **Adaptability and Versatility**
   Assess the system's adaptability and versatility by examining its performance in various scenarios, such as operating directly with diesel generators and functioning within a full hybrid system.
5. **Cycle Life and Longevity**
   Analyze the cycle life and longevity of critical components, including VRFBs and supercapacitor banks, to ensure their durability and reliability over an extended period.
6. **Orchestration by A-EMS**
   Evaluate the efficiency of the Advanced Energy Management System in orchestrating the hybrid system, optimizing energy usage and ensuring seamless interaction between different energy components.
7. **Scalability and Applicability**
   Explore the scalability and applicability of the Solar in a Box system, considering its potential deployment in diverse environments, from remote locations to urban settings.
8. **Documentation for Future Implementation**
   Provide comprehensive documentation of the testing process, results, and key findings to serve as a reference for future implementations and improvements to the Solar in a Box system.
9. **Demonstrate Sustainability and Reliability**
   Showcase the system's sustainability and reliability, highlighting its potential to revolutionize energy infrastructure and provide a scalable, adaptable, and resilient power solution for the future.
10. **Inform Decision-Making**
    Offer valuable insights to stakeholders, policymakers, and decision-makers involved in the adoption of alternative energy systems, aiding informed decision-making and potential scaling of the Solar in a Box technology.

Location: Henderson, Western Australia

Image 1: Live Demonstration Plant, AMC Henderson, Perth, WA

Testing an alternative energy system in Henderson, Western Australia, holds several practical and strategic advantages.

I. **Harsh Environmental Conditions**
Henderson, Western Australia, experiences challenging environmental conditions, including high temperatures. Testing the Solar in a Box system in such an environment allows for evaluating its performance under extreme weather conditions, ensuring its resilience and reliability in areas with similar climates worldwide.

II. **Isolated and Remote Areas**
Henderson is situated in a region with remote and isolated areas, where access to traditional power infrastructure may be limited. Implementing alternative energy systems like Solar in a Box in such locations helps address energy needs in off-grid or hard-to-reach areas, providing a sustainable and reliable power source.

III. **Energy Independence**
Henderson's testing of Solar in a Box contributes to the exploration of energy independence. By relying on solar power, this alternative energy system reduces dependence on traditional energy sources, offering a sustainable solution that aligns with global efforts to transition towards cleaner and more renewable energy options.

IV. **Hybrid Energy Systems**
Henderson's unique testing environment allows for the examination of the Solar in a Box's compatibility within a full hybrid energy system. This includes integrating solar power with diesel generators in order to showcase the system's adaptability and its ability to provide continuous energy in various scenarios.

V. **Grid-Stabilization**
Henderson's testing ground offers an opportunity to assess the Solar in a Box system's potential in grid-stabilization efforts. As the region continues to explore and expand its

renewable energy portfolio, understanding how alternative systems contribute to stabilizing the power grid becomes increasingly valuable.

VI. **Local Energy Needs**
Testing in Henderson allows for a tailored assessment of how well Solar in a Box meets the specific energy needs of the local community and industries. This ensures that the alternative energy system is not only sustainable but also aligned with the demands of the region.

VII. **Data for Scaling**
Gathering data on the performance of Solar in a Box in Henderson provides valuable insights for potential scaling. Understanding its effectiveness in this real-world setting informs decisions on whether and how to implement similar systems on a larger scale, both regionally and globally.

Henderson, Western Australia provides a real-world environment to evaluate performance, address unique challenges, and contribute to the ongoing transition toward sustainable and resilient energy solutions.

Components

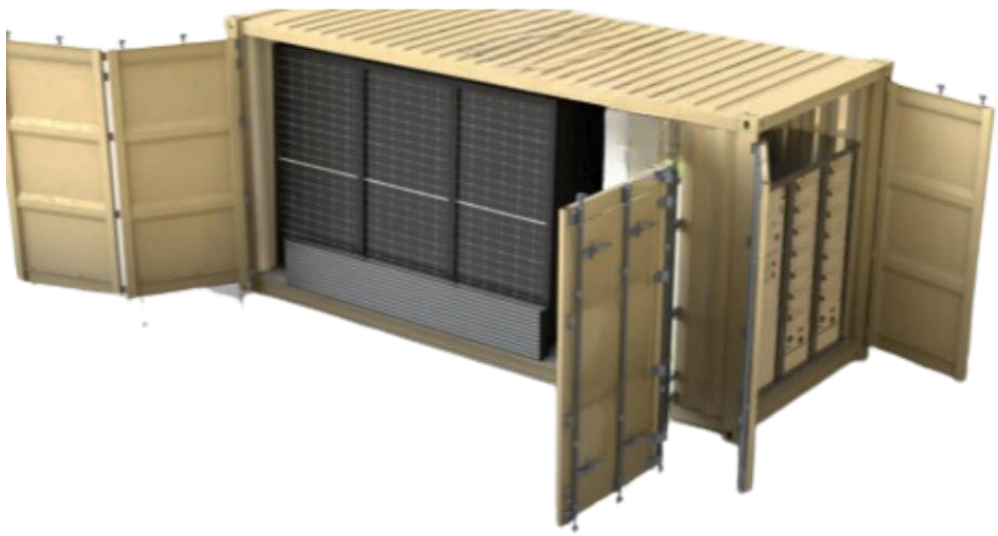

Image 2.1: Solar In A Box

I. **PV Solar Energy Container**
The PV Solar Energy Container represents the cornerstone of the energy system, offering fast deployment and flexibility. With a remarkable initial setup time of just 4-5 hours, this easy-to-install container delivers 110 KWP power, providing up to 100KW 3-phase output. Its adaptability is demonstrated by an average daily yield of 528 kWh, with fluctuations corresponding to seasonal variations. Operating seamlessly with both diesel generators and within a full hybrid system, this container ensures continuous energy supply even in the absence of ideal solar conditions.

Image 2.2: Solar In A Box - Deployed

II. **Vanadium Redox Flow Battery (VRFB)**

The Vanadium Redox Flow Battery boasts 40KW power and 200kWh energy capacity. With a service life of 20,000 cycles or a minimum of 20 years, the VRFB ensures long-term reliability. Notably, it requires no climate control in ambient temperatures below 50 degrees Celsius, making it well-suited for a variety of environments. With a high recycle value at the end of its life and fire-risk-free operation, the VRFB stands as a robust and sustainable energy storage solution. These batteries are configured across six inverters to manage the charge and discharge processes.

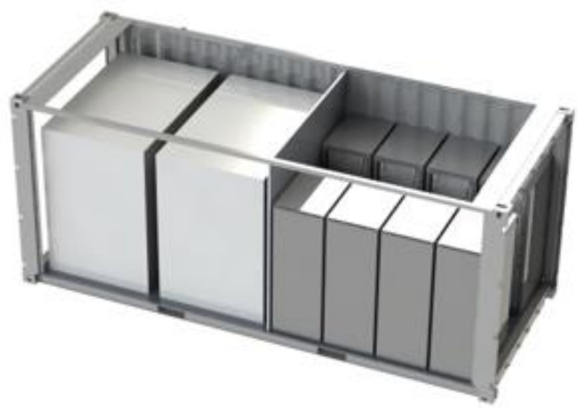

Image 2.3: Battery Banks

III. **Graphene Super Capacitor Banks**

The Graphene Super Capacitor Banks contribute to the energy system with 72KW power and 36kWh energy capacity. Similar to the VRFB, these banks have a service life of up to 20,000 cycles or a minimum 20 years and require no climate control in ambient temperatures under 40 degrees Celsius. With no fire risk and a focus on longevity, these capacitor banks enhance the overall reliability and safety of the energy infrastructure. Like the Vanadium Redox Flow Battery, these are configured across six inverters to manage the charge and discharge processes.

Image 2.4: Graphene Power Rack Module

Image 2.5: Stacked Graphene Power Rack Modules

IV. **Advanced Energy Management System (A-EMS)**

The Advanced Energy Management System serves as the orchestral conductor of this comprehensive energy system. Operating within a full hybrid system and orchestrating multiple generation sources, the A-EMS facilitates a seamless integration of renewable energy and diesel backup. Its functionalities include baseload 24-hour solar power, supplementary diesel generator operation for fuel efficiency, peak shaving, and grid-stabilization (not demonstrated at Henderson). This sophisticated system ensures optimal performance and adaptability to varying energy demands.

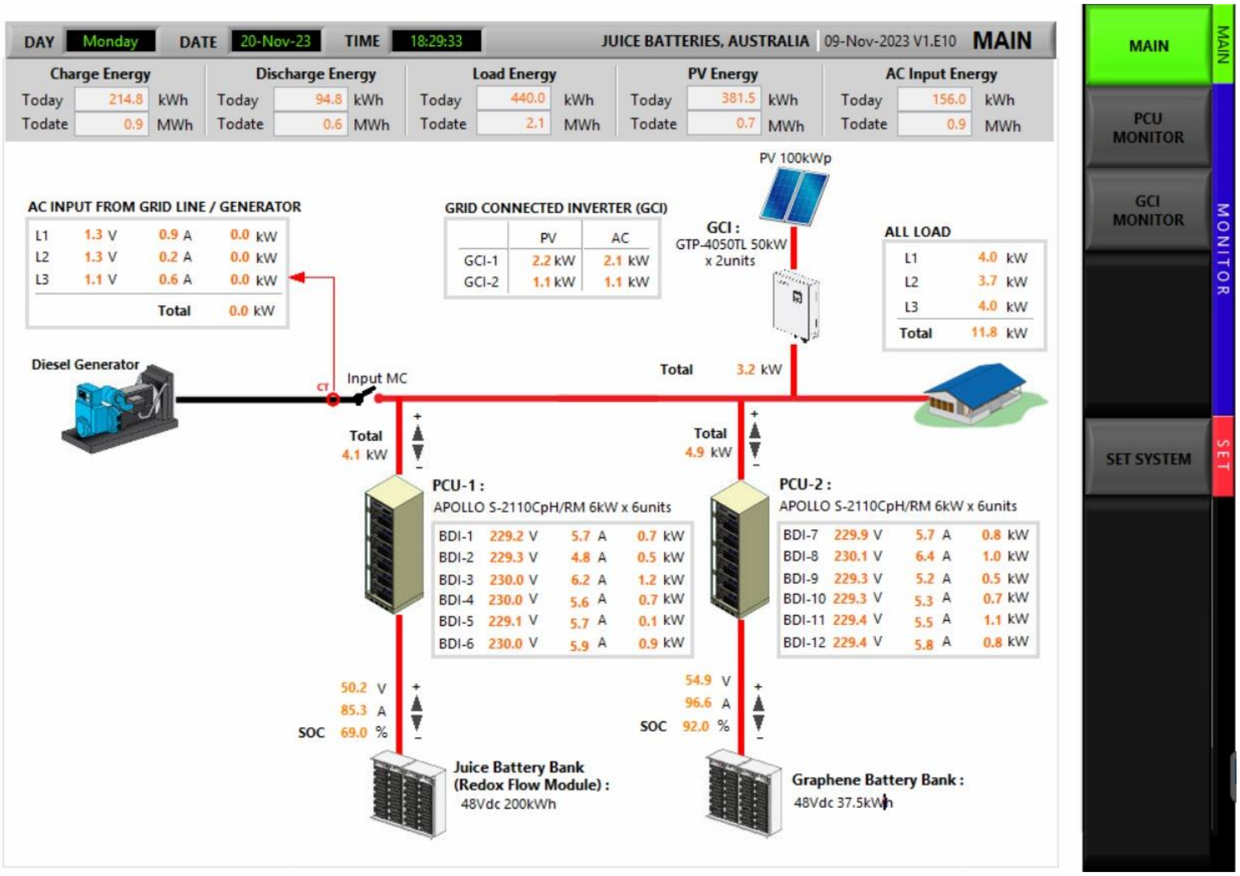

Image 2.6: A-EMS System

The integration of a compact, easily deployable design, Vanadium Redox Flow Batteries (VRFB), graphene supercapacitor battery banks, and an Advanced Energy Management System (A-EMS) in an energy system offers a suite of technical advantages that collectively contribute to enhanced efficiency, reliability, and adaptability.

Graphene Supports the System

In the pursuit of optimizing energy storage and addressing the inherent limitations of Vanadium Redox Flow Batteries (VRFB), the integration of graphene emerges as a game-changing solution. While VRFBs are renowned for their reliability and long service life, they are characterized by a relatively slow response time. To address this inherent drawback, the incorporation of graphene, known for its exceptional conductivity and rapid charge/discharge capabilities, proves instrumental.

The utilization of graphene in conjunction with VRFB technology serves to manage critical moments of peak load efficiently. In scenarios where the energy demand experiences sudden spikes, such as during peak usage hours or when powering inductive loads, graphene's swift response time becomes paramount. This dynamic integration ensures that the energy storage system can promptly deliver the required power, mitigating the challenges associated with slow response rates inherent in traditional VRFBs.

In the context of off-grid systems, where self-sufficiency and reliability are paramount, the introduction of graphene proves indispensable. Off-grid systems often encounter fluctuating energy demands and intermittent power generation from renewable sources. Graphene's ability to handle sudden and intense energy requirements positions it as an ideal component in maintaining a consistent and reliable power supply.

Without graphene's rapid response capabilities, a system relying solely on VRFBs would necessitate a significantly larger battery capacity – up to five times more. By incorporating graphene, the system achieves enhanced efficiency without the need for excessive battery expansion, optimizing both performance and cost-effectiveness.

This synergy between VRFB technology and graphene represents a forward-thinking approach to energy storage in off-grid environments. It not only addresses the limitations of VRFBs but also paves the way for more responsive, adaptable, and efficient energy storage solutions. As industries continue to embrace renewable energy and off-grid independence, the integration of graphene into energy systems could drive the evolution of energy storage technologies.

Data

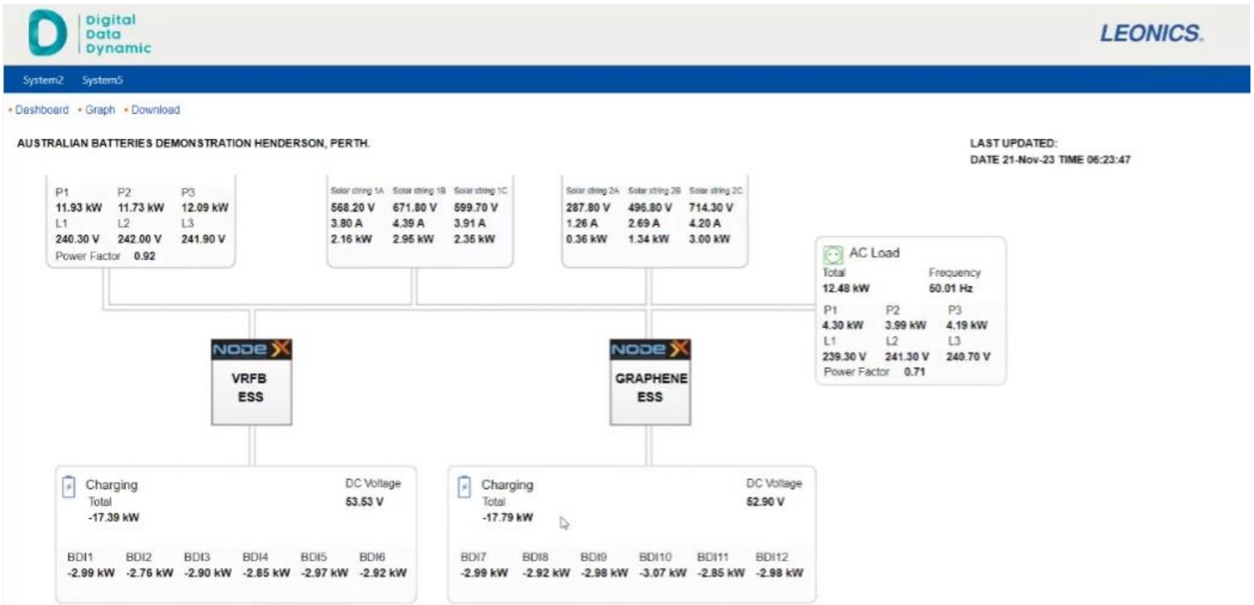

Image 3.1: Dashboard - Charging Batteries on 18 kW

Image 3.2: Graph Data – Day 20

System Advantages

The adoption of containerized energy solutions presents a paradigm shift in the energy landscape, offering significant economic and practical advantages that redefine the traditional notions of energy infrastructure.

I. **Cost-Effective Civil and Site Works**
   Containerized energy solutions reduce the cost of site preparations. These systems require nothing more than an open flat area, eliminating the need for complex and expensive

infrastructure modifications. The simplified installation process contributes to substantial cost savings, making the technology financially attractive for various applications.

II. **Plug & Play Architecture for Rapid Deployment**
A standout feature of containerized energy solutions lies in their Plug & Play architecture, facilitating swift deployment. The low cost of installation and commissioning is a direct result of the system's ability to seamlessly integrate with existing infrastructure. This accelerated deployment ensures that energy solutions can be operational in minimal time, making them particularly advantageous for projects with time-sensitive requirements.

III. **Scalability and Modularity**
Containerized systems offer unparalleled flexibility with easy expansion through the addition of more modules. This modular approach allows for the customization of energy solutions based on evolving needs. Whether for a small-scale deployment or a large-scale energy project, the ability to scale the system ensures that energy infrastructure grows in tandem with demand.

IV. **Re-deployable and Tradeable Asset Modules**
One of the transformative advantages of containerized energy solutions is the shift from renewable energy being a permanently installed and fixed asset to becoming a re-deployable and tradeable asset. This dynamic feature allows organizations to relocate assets based on changing energy demands or trade them in if they are no longer required, promoting resource optimization and sustainability.

V. **Turtle Mode for Extreme Weather Resilience**
The inclusion of a "Turtle Mode" in containerized energy solutions showcases a commitment to resilience in the face of extreme weather conditions. In areas prone to severe weather events, solar arrays can be quickly retracted into the container, preventing direct damages and reducing insurance premiums. This adaptive capability ensures that the energy infrastructure remains robust and operational even in regions with a high risk of adverse weather.

The advantages of containerized energy solutions extend beyond traditional energy infrastructure models. The low-cost installation, scalability, re-deployability, and resilience to extreme weather make these systems a transformative force in the pursuit of cost-effective, adaptable, and sustainable energy solutions. As the energy landscape evolves, containerized energy solutions emerge as a pivotal component, reshaping the way we approach and deploy power infrastructure.

Economic Performance Analysis

The economic performance of the Solar in a Box system was analyzed in comparison to a typical diesel-powered off-grid mining exploration camp. The baseline scenario considers an annual energy demand of 240,000 kWh, a service life of 10 years for the assets, realistic maintenance costs, scrap/recycle values, and an annual inflation rate of diesel costs set at 4%.

In the first scenario, we simulate the economic performance of the conventional diesel-powered operation. This serves as a benchmark for comparison. The analysis includes comprehensive assessments of initial setup costs, ongoing operational expenses, and the total cost of ownership over the 10-year lifespan. By factoring in maintenance costs, fuel expenses with an annual 4% inflation rate, and potential resale values, we establish a baseline for evaluating the economic sustainability of traditional diesel-powered solutions.

In the following sections, we present the economic performance of Solar in a Box through two distinct system options. These simulations showcase the cost-effectiveness and financial viability of transitioning from traditional diesel to a more sustainable energy solution. The analyses include considerations for initial setup costs, operational savings, and potential long-term return on investment. Special attention is given to the adaptability of Solar in a Box, its resilience under diverse conditions, and the potential for reduced reliance on volatile diesel costs.

This economic performance analysis provides a comprehensive overview of Solar in a Box's potential to revolutionize the energy landscape in off-grid mining exploration camps. By scrutinizing key economic indicators and comparing them to conventional diesel-powered operations, we aim to demonstrate the financial advantages, operational efficiency, and long-term sustainability inherent in the adoption of Solar in a Box technology.

Economic Performance of Diesel Generator Plant

I. **System Overview**
The diesel generator plant consists of three units of 63 kVA diesel generators. This traditional power system is evaluated over a 10-year operational period, considering the total cost of operation, the levelized cost of electricity, CO2 emissions, and the renewable energy share.

II. **Total Cost of Operation (10 Years)**

The diesel generator plant incurs a total cost of operation over the 10-year period amounting to 1,602,043.00 AUD. This includes expenses related to fuel, maintenance, and other operational considerations. Understanding the full economic impact over this timeframe is crucial for assessing the viability of traditional diesel-powered solutions.

III. **Levelized Cost of Electricity**

The levelized cost of electricity is a key metric, revealing the average cost of producing electricity over the plant's operational life. For the diesel generator plant, this cost is calculated at 0.67 AUD/kWh. This metric serves as a benchmark for comparing the economic competitiveness of alternative energy solutions, such as Solar in a Box, in providing power to off-grid mining exploration camps.

IV. **CO2 Emissions (10 Years)**

An important aspect of the economic analysis is the environmental impact, measured through CO2 emissions. Over the 10-year span, the diesel generator plant is estimated to generate 1,787 tons of CO2 emissions.

V. **Renewable Energy Share**

The diesel generator plant operates with a renewable energy share of 0%, indicating its reliance solely on non-renewable fuel sources. This metric highlights the lack of sustainability and environmental responsibility inherent in traditional diesel-powered solutions.

The economic performance evaluation of the diesel generator plant provides critical insights into the financial and environmental implications of traditional power systems. Comparing these metrics with alternative energy solutions, particularly the Solar in a Box solution, allows for informed decisions that align with both economic prudence and environmental sustainability in off-grid mining exploration camps.

Economic Performance of Small Solar Energy Container with Fuel Save Controller

I. **System Configuration**
The Small Solar Energy Container with Fuel Save Controller includes 3 Units of 63 kVA Generators and 1 10' Solar PV Container (60 KWP) equipped with a Fuel Save Controller.

II. **Total Cost of Operation (10 Years)**
The Small Solar Energy Container with Fuel Save Controller demonstrates a favorable economic profile, with a total cost of operation estimated at 1,317,923.67 AUD over a 10-year period. This comprehensive assessment encompasses initial setup costs, ongoing operational expenses, and maintenance, providing valuable insights into the system's economic impact.

III. **Levelized Cost of Electricity**
The system achieves a competitive levelized cost of electricity at 0.55 AUD/kWh. This metric signifies the cost-effectiveness of producing electricity over a 10-year operational life of the

Small Solar Energy Container. It positions the system as a financially viable alternative, particularly when compared to traditional diesel-powered solutions.

IV. **CO2 Emissions (10 Years)**
Over the 10-year span, the Small Solar Energy Container is estimated to produce 1,444 tons of CO2 emissions. The Fuel Save Controller ensures optimal fuel utilization, contributing to lower CO2 emissions and aligning with sustainability goals.

V. **Renewable Energy Share**
The system incorporates a commendable renewable energy share of 31.9%, predominantly sourced from solar energy. This integration aligns with a commitment to sustainable practices, reducing dependence on non-renewable resources and showcasing a responsible approach to power generation.

VI. **Total Savings (10 Years)**
The Small Solar Energy Container with Fuel Save Controller offers significant total savings amounting to 284,119.73 AUD over a 10-year period. These savings encompass reduced operational costs, fuel expenses, and maintenance expenditures, reinforcing the system's economic advantage and financial prudence.

VII. **Total CO2 Savings (10 Years)**
In tandem with economic savings, the system achieves a notable reduction in CO2 emissions, saving a total of 343 tons over the 10-year span.

The economic performance analysis of the Small Solar Energy Container with Fuel Save Controller positions it as an economically sound and environmentally responsible solution. With a focus on renewable energy integration, fuel efficiency, and substantial cost savings, this system stands as a compelling choice for off-grid applications, offering a harmonious blend of financial prudence and environmental responsibility.

Future of Energy in Australia

The future of energy in Australia is increasingly leaning towards a distributed energy system. Australia has abundant renewable energy resources, including solar, wind, and hydropower. A distributed energy system allows for the effective harnessing of these resources, promoting a shift away from centralized fossil fuel-based power generation. As the country seeks to reduce its carbon footprint and meet sustainability goals, distributed renewable energy installations become crucial components of the energy mix.

Distributed energy systems enhance grid resilience and reliability. By dispersing power generation across various locations, the impact of disruptions is minimized. This approach reduces vulnerability to single points of failure and enhances the overall stability of the energy grid. Decentralized systems can better withstand extreme weather events, natural disasters, or technical failures.

Distributed energy empowers consumers to become more self-reliant and less dependent on centralized utilities. Through the use of solar panels, battery storage, and other distributed technologies, individuals and businesses can generate, store, and manage their own energy. This shift towards energy independence provides greater control over energy costs and supply, fostering a sense of empowerment among consumers.

Advances in technology, particularly in the field of energy storage and smart grids, make distributed energy systems more feasible and efficient. Battery storage allows for the storage of excess energy generated during peak times for use during periods of high demand or when renewable sources are not actively producing energy. Smart grids enable better coordination and communication between distributed energy resources, optimizing their performance.

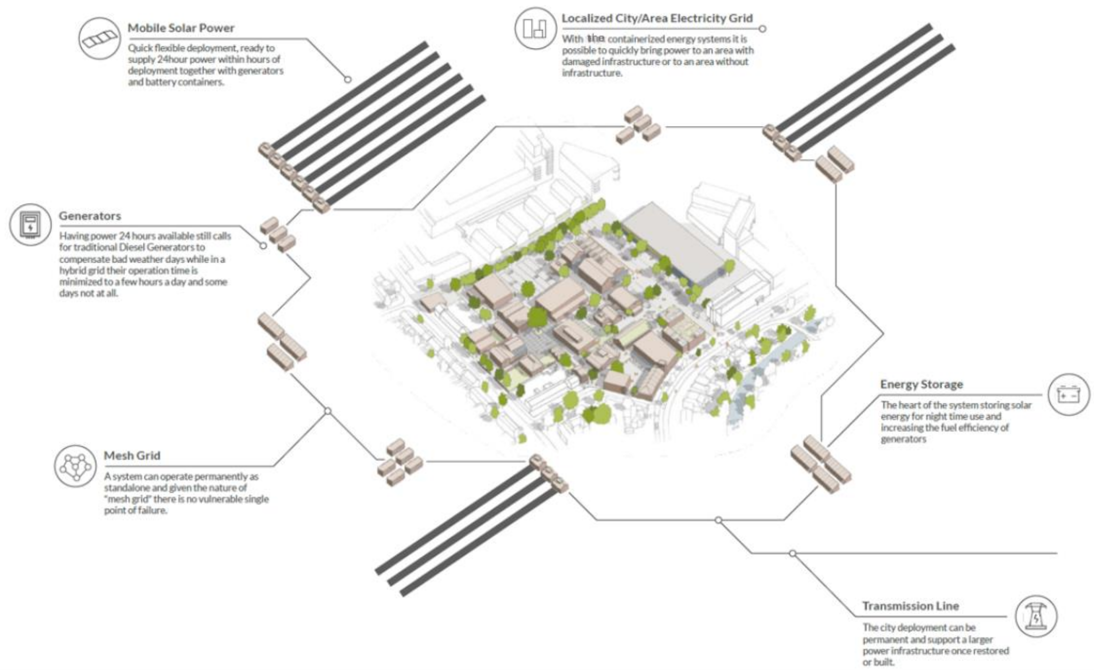

Diagram 2.1: Distributed Energy in Australia

Distributed energy systems offer economic advantages, both for individual consumers and the broader economy. By encouraging the adoption of rooftop solar panels, for example, Australians can benefit from reduced electricity bills and potential revenue through feed-in tariffs. At a larger scale, decentralized energy can stimulate economic growth by fostering innovation, creating jobs, and attracting investments in the renewable energy sector.

The distributed energy model aligns with Australia's commitment to environmental sustainability. Utilizing renewable energy sources at the point of consumption helps reduce greenhouse gas emissions and mitigate the impacts of climate change. By encouraging the widespread adoption of distributed renewable energy systems, Australia can contribute to global efforts to transition towards a low-carbon economy.

Distributed energy systems encourage community engagement and participation. Community-owned renewable energy projects, local microgrids, and shared energy resources promote a sense of community involvement and responsibility. This model not only fosters collaboration but also strengthens the resilience of local communities against disruptions in the broader energy network.

The future of energy in Australia is increasingly distributed to capitalize on renewable resources, enhance grid resilience, provide energy independence, leverage technological advancements, deliver economic benefits, promote environmental sustainability, and foster community engagement. This shift aligns with global trends towards a more decentralized and sustainable energy landscape.

Conclusion

In the dynamic landscape of energy infrastructure, containerized energy solutions represent a transformative shift towards efficiency, adaptability, and sustainability. The multifaceted advantages of this innovative approach have redefined traditional paradigms, offering a compelling vision for the future of energy deployment.

The low-cost requirements for civil and site works, coupled with the Plug & Play architecture enabling rapid deployment, showcase a commitment to economic viability. These containerized systems provide a cost-effective solution, eliminating the need for extensive infrastructure modifications and accelerating the timeline from installation to operation.

Scalability and modularity emerge as cornerstones of flexibility, allowing energy solutions to seamlessly evolve with changing demands. The ability to expand with additional modules and capacities ensures that the technology remains agile, catering to projects of varying scales and complexities.

A groundbreaking aspect of containerized energy solutions is their transition from fixed assets to re-deployable and tradeable modules. This dynamic feature aligns with the evolving needs of industries, allowing for asset relocation based on demand shifts or trading in modules that are no longer essential. This adaptability not only optimizes resource usage but also fosters a sustainable approach to energy infrastructure.

The incorporation of "Turtle Mode" exemplifies a commitment to resilience in the face of extreme weather events. The quick retraction of solar arrays into the container mitigates direct damages and reduces insurance premiums in high-risk regions. This adaptive capability ensures that energy infrastructure remains operational and robust, even in the harshest environmental conditions.

In essence, the containerized energy solutions presented in this case study represent a pivotal advancement in the energy sector. Their transformative advantages extend far beyond conventional models, offering a blueprint for cost-effective, scalable, and resilient energy deployment. As industries increasingly embrace sustainability and adaptability, containerized energy solutions will stand at the forefront, shaping a future where energy infrastructure is not only functional but also agile and environmentally conscious. This case study illuminates a path towards a more dynamic and responsive energy landscape, where innovation and practicality converge for a sustainable and efficient future.