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THESIS

**A COST-BENEFIT ANALYSIS OF THE SMART POWER
INFRASTRUCTURE DEMONSTRATION FOR ENERGY
RELIABILITY AND SECURITY (SPIDERS)**

by

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September 2012

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ENERGY RELIABILITY AND SECURITY (SPIDERS)**

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ABSTRACT

The Cost Benefit Analysis of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) at the Waste Water Treatment Plant (WWTP) located on Hickam AFB is a comprehensive analysis of the costs and benefits of an Energy Surety Microgrid (ESM) facility to the Navy. Along with the initial investment of \$5.2M, the increase or decrease of standard financial metrics becomes apparent to the lifetime costs associated with SPIDERS. This thesis attempts to construct a viable understanding of the potential savings and Return On Investment (ROI) that could be achieved, and how the recoupment of investment will unfold based on combinations of potential savings. Congressional legislation and Executive orders dictate the increased consumption and production of renewable energy by federal agencies. SPIDERS presents a strategy toward achieving these mandates, and Hickam AFB is well on its way to capitalize on this strategy. This thesis estimates those costs and benefits based on available data and assumptions, with a very optimistic approach to savings. Those estimates are discounted for time and shown in FY12K\$. The thesis then conducts sensitivity analysis around potential variations in the data to explore changes to savings and ROI.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACTD	Advanced Concept Technology Demonstration
COCOMs	Combatant Commanders
DoD	Department of Defense
DOE	Department of Energy
DON	Department of the Navy
DR	Demand Response
EMS	Energy Management System
EPA	Environmental Protection Agency
ESM	Energy Surety Microgrid
FY	Fiscal Year
HECO	Hawaiian Electric Company
IR	Internal Report
JCTD	Joint Capability Technology Demonstration
kW	Kilo Watt
MOU	Memorandum of Understanding
NAVFAC	Naval Facilities
NIST	National Institute for Standards and Technology
NPV	Net Present Value
PV	Present Value
RFD	Rapid Fielding Directive
ROI	Return On Investment
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
UPS	Uninterruptable Power Supply
UV	Ultraviolet
WWTP	Waste Water Treatment Plant

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EXECUTIVE SUMMARY

Everyone has the same problem when it comes to energy stability and savings. The Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) is a technological attempt to alleviate that problem, and at Hickam Air Force Base in Honolulu, HI, the Waste Water Treatment Plant (WWTP) is doing that with the implementation of SPIDERS.

The SPIDERS Joint Capability Technology Demonstration (JCTD) addresses four critical requirements needed to demonstrate enhanced electrical power surety for national security:

- Protecting mission critical assets from loss of power due to cyber attack
- Integrate renewable and other distributed energy generation concepts to power mission critical assets in time of emergency
- Sustain critical operations during prolonged power outages
- Manage installation electrical power and consumption efficiently, to reduce petroleum demand, carbon footprint, and cost (Ellman 2012)

The overall focus of SPIDERS is to prolong the time in which a facility can be without power and keep the mission critical loads safe. SPIDERS is currently being implemented on Hickam Air Force Base in Honolulu, HI. The current design is based on the Energy Surety Microgrid [™] (ESM), which has been developed by Sandia National Laboratories.

An ESM is a means of taking multiple energy sources, such as solar, wind, and battery power, and integrating them in a decentralized area near the point of use. In this case, the point of use would be the WWTP.

The ESMs allow for less reliability on diesel generated backup power through the use of renewable energy sources. ESMs allow for potential peak shaving, a process in which utility usage is managed in an efficient and effective manner to better utilize sources of power during peak hours.

With the implementation of SPIDERS only the new, primary 800kW diesel generator will be needed to operate the critical loads, thus saving diesel fuel and reducing the carbon footprint. There are two generators, an 800kW and 1600kW, having a 10,000-gallon diesel fuel storage tank that will last approximately 72 hours. Once the fuel is gone, the generators will stop running, thus creating more disaster and possibly dumping unsterilized wastewater into the ocean. The WWTP has an average throughput of 6 million gallons per day and during the rainy season that can reach as high as 30 million gallons per day. There is one uninterruptable system load, the ultraviolet (UV) treatment system, which does not have an uninterruptable power supply (UPS). With the implementation of SPIDERS, a UPS will be added, thus taking away the risk and fear associated with unsterilized wastewater escaping to the ocean.

I have developed cost estimates for the current WWTP system showing annual operating costs and potential savings incurred with the addition of SPIDERS. Additionally, I have developed estimates of the Return On Investment (ROI) with the implementation of SPIDERS and developed a plan for cost savings.

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To my daughters, Madison, Carson, and Rylee, thank you for supporting me, loving me, and keeping me grounded while I did my best at work. I hope by continuing my education and accomplishing my goals, you see that you can accomplish whatever you set your mind to. I will always remember these years and how much excitement you brought me everyday. I hope the example I set will forever remain in your minds. I love you girls with all my heart.

To my stepdaughters, Lauren and Anna Grace, thank you for being such sweet girls and keeping laughter in our home. You brighten my day with your enthusiasm for life and your eagerness to learn. I love you.

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I. INTRODUCTION

A. PURPOSE AND BACKGROUND OF THE STUDY

The United States consumed 3723.8 billion kilowatt hours of electricity in 2009. China, second in consumption, consumed only 470.2 billion kilowatt hours fewer (Barrientos 2012). The Department of Defense (DoD) is greater than 1.5% of national consumption, and is looking for ways to reduce energy consumption, maintain current energy grids, and allow for energy surety and security. The Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD) is an energy smart grid that will allow the DoD to harness renewable resources such as wind and solar power, energy surety and security by use of early warning power disruption alarms, and it provides the opportunity for the DoD to enter into service contracts with power providers and peak-shave using SPIDERS to sell back energy for more than it costs SPIDERS to produce.

The initial use of SPIDERS is to ensure the Waste Water Treatment Plant (WWTP) at Hickam Air Force Base, HI remains operational in the event of a power loss or disruption, keeping energy surety and security as the main focus. The expectation is that SPIDERS is a safer way of maintaining the mission critical load of the WWTP, rather than utilizing the current operation of dual generator use and inefficiency. By keeping the unsterilized water out of the environment in the event of a power outage and allowing for the use of one efficient 800kw diesel generator vice using two generators, SPIDERS will allow for a safer environment as well as fuel savings.

This research examines the DoD's proposed usage of SPIDERS, maintaining the WWTP online in the event of power loss, and how SPIDERS can be utilized to save money, fuel, and labor.

This study analyzes the cost and benefits of implementing SPIDERS and in doing so:

- Develops a Business Case for SPIDERS. The objective is to identify the cost benefits of SPIDERS. The goal is to provide the decision makers the financial information and alternatives to make better-informed decisions.

- Examines DoD’s proposed usage of SPIDERS and assists in understanding the incorporation of power saving agreements into DoD installations for future use.

As referenced in *SPIDERS microgrid project secures military installations*, published by Sandia National Laboratories, Stephanie Hobby states, “The main technical challenge of SPIDERS is integrating the use of diesel generators with renewable sources. This integration would help military installations drastically increase power reliability, decrease the need for diesel fuel, and reduce the carbon footprint”. Currently, when a power failure takes place on a military installation, individual buildings switch to backup diesel generators, which is limiting in many ways. Diesel generators may fail to start, and if the building’s backup power doesn’t start, then the building will have no power, as there are currently no means of accessing another building’s diesel generators. Most of the generators used are oversized for the load they would need to carry, thus the generators are operating in a less-than-optimal operating point, using excess fuel as a result and therefore increasing the carbon footprint (Hobby 2012).

The operational concern that underlies this study is how to ensure continued operation of the Waste Water Treatment Plant at Hickam Air Force Base, HI should they encounter a power outage or a need to take their facility off the power grid for events such as maintenance.

The following paragraphs describe the proposed operation of SPIDERS and the diesel generators at the WWTP in the event of a power loss or disruption. We also address a brief discussion of the President’s Operational Energy Strategy Implementation Plan and how SPIDERS can be linked to the improvements on DoD installations in accordance with this plan.

SPIDERS implements an Energy Management System (EMS) and the addition of several sectionalizing breakers on the current energy grid at Hickam Air Force Base, HI, so that when a power disruption is sensed on the grid, the WWTP operator will receive an alert on screen via EMS with the option to start SPIDERS or leave the system as is. These sectionalizing breakers will seclude the WWTP from the power grid, using the diesel generators to maintain power. Once the WWTP is stable with all electrical loads

online, the 1600kw generator is taken offline and the 800kw generator runs the mission critical WWTP using a mix of fuel and renewable energy resources such as wind and solar power, running at an efficient 50%-85% of max load (Stamp, et al 2011). Once the energy grid is stable and the power disruption is alleviated, SPIDERS will transfer the load of the WWTP back to the energy grid, resulting in zero downtime and mission criticality maintained. SPIDERS replaces the current 600kW generator with a larger more capable 800kW generator.

Figure 1 displays the Waste Water Treatment Plant diagram after the implementation of SPIDERS. The green section is the renewable generation station now in place at Hickam AFB, which incorporates wind and solar generation for renewable energy. The blue section is the Mamala Sub-Station that feeds the electrical grid and is located at Hickam AFB. The red section is the Waste Water Treatment Plant at Hickam AFB, showing the new 800kW diesel generator along with new isolation breakers and monitoring points.

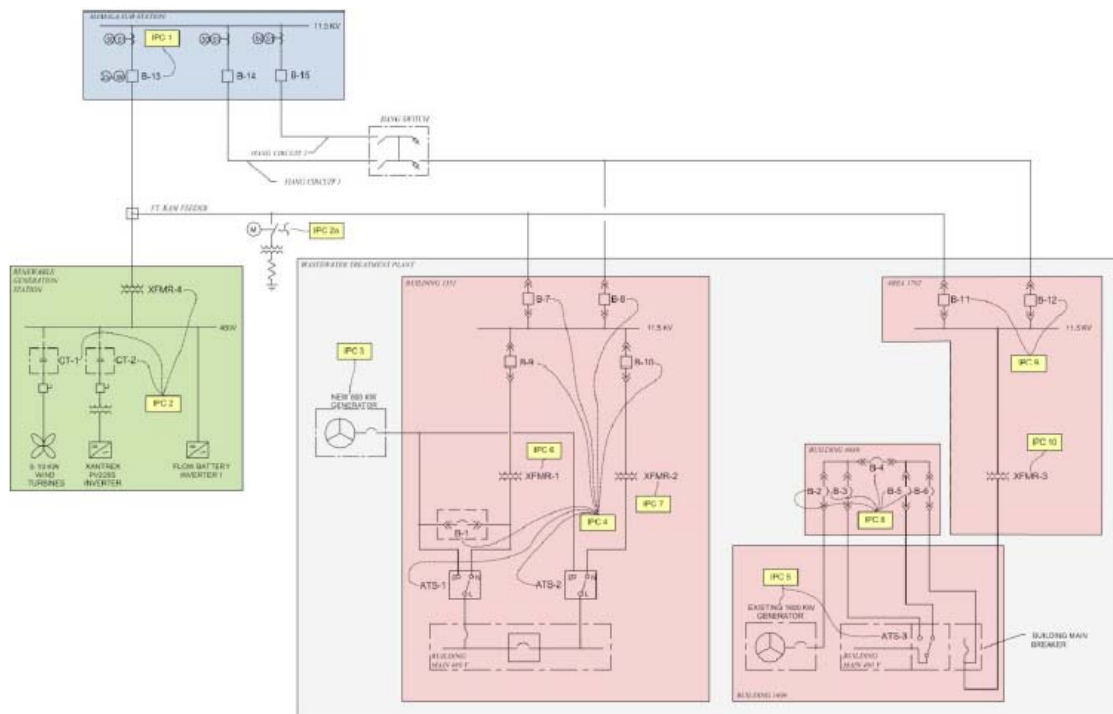


Figure 1. Waste Water Treatment Plant Diagram with SPIDERS, (From Burns & McDonnell Design Update March 2012)

The use of SPIDERS, as identified in this study, has broad significance, leading the way for DoD installations to research and work toward the changes outlined in President Obama’s Operational Energy Strategy Implementation Plan, released March 2012. The Operational Energy Strategy Implementation Plan serves as a roadmap to transform the way the DoD uses energy in military operations (Compton 2012). In the implementation of SPIDERS, Hickam AFB, HI will save on fuel consumption, reduce carbon emissions, and provide the DoD the option to enter into service agreements with Hawaiian Electric Company (HECO). These service agreements would be the largest of the savings applications, possibly several hundreds of thousands of dollars per year. Last year USPACOM spent \$368.5 million for energy at its Air Force installations in Hawaii, Japan, and Korea (Kiser 2012). SPIDERS implementation at these facilities could drastically reduce yearly power spending and allow the savings to be re-allocated to other areas of need, such as ships or aircraft.

B. LITERATURE REVIEW

We review five articles and one energy blog below, which discuss the importance of smart grid use and the associated benefits.

In *Smart Grid Could Reduce Emissions By 12 Percent*, published by Pacific Northwest National Laboratory (PNNL), Anne Haas states that “using smart grids could decrease carbon emissions and electricity use by at least 12% by 2030” (Haas 2010). There is a direct link between new technology and reduced carbon emissions, and these new technologies could make new energy programs affordable. The article makes two key points with regard to smart grids:

- “The U.S. could, with 100 percent full deployment of the smart grid, reduce the carbon emissions by 442 million metric tons per year, or equal to 66 coal power plants’ worth of emissions. That is equal to roughly enough electricity to power 70 million homes” (Haas 2010).
- Rob Pratt, PNNL Research Scientist, states, “making the grid smart is making the grid more efficient and accommodating for renewable energy sources, and, by doing this, enabling cuts to the carbon emitted while producing electricity” (Haas 2010).

Although researches between emissions and smart grids have been separate studies, both fields are trying to take stake in the future of energy. Mike Davis, PNNL associate laboratory director for Energy and Environment, states that “reducing our dependence on foreign oil and reducing our carbon footprint can be profitable and go hand-in-hand” (Haas 2010). These two mutually support each other and are thought to be profitable.

Smart grids have two types of impacts: direct and indirect.

- In a direct impact, the means to reduce electricity and CO₂ emissions when a smart grid is in place are visible and seen by the user. In order to be considered a direct impact, the savings must be produced from means used and the smart grid itself.
- In an indirect impact, the costs saved can then be turned into carbon savings by reinvesting those savings in carbon reduction technology, which is being considered in a later phase of SPIDERS.

The importance of direct and indirect impacts is their roles in the reduction of carbon emissions plus the potential increase in renewable sources. Once the infrastructure for the smart grid is purchased, it can be used so that additional future benefits can be provided at a marginal, if any, cost. The information provided in this review shows the importance of new energy sources and how these new technologies can effect carbon emissions, such as SPIDERS.

In *A Rose by Any Other Name: The Struggle to Define and Value Energy Security*, published by The Department of Defense (DoD) Energy Blog, Dan Nolan discusses the importance of the smart grid and its implementation and how the civilian sector and government are coming together for a common cause, that of constant access to secure energy. “Without a smarter grid, there is no real energy security” (Nolan 2012) because there is no resistance to outside influences and no real time way to detect if outside sources are tampering with the energy grid. The DoD has identified the importance of smart grids with the efforts from SPIDERS, and other microgrid projects, and recognizes the need for more reliable energy sources.

In *SPIDERS microgrid project secures military installations*, published by Sandia National Laboratories, Stephanie Hobby discusses that “SPIDERS is the first major

project under a Memorandum of Understanding (MOU) between Department of Energy (DoE) and DoD to accelerate joint innovations in clean energy and national energy security” (Hobby 2012). The objective of SPIDERS is on-base energy generation and reliable delivery when needed. If the instance arises where power is lost or disrupted, SPIDERS can deliver back up power to the mission critical loads, such as the WWTP on Hickam AFB, HI.

SPIDERS is facing the challenge of incorporating renewable sources of wind and solar power into the microgrid. These renewables will run in parallel with the back up generators, reducing diesel fuel consumption and carbon emissions. This new technology has the ability to change the way the DoD provides essential power to mission critical loads on its installations.

In *Why the Military’s Smart Grid Battle Plan Could Ignite a Victory For All of Us*, published by Smart Grid News.com, Liz Enbysk details the driving force behind smart grid initiatives on military installations, less dependence on oil. U.S. Sen. Mark Udall quotes Admiral Mike Mullen, former chairman of the Joint Chiefs of Staff, as stating “energy needs to be the first thing we think about, before we deploy another soldier, before we build another ship or plane” (Enbysk 2011).

In order to become more self-sufficient, the DoD must invest in technologies that improve energy efficiency, such as microgrids. “An Energy Surety Microgrid has been developed by Sandia National Laboratories for use by the military with hopes of the civilian sector using it in later endeavors. The Pentagon is making plans to decrease energy consumption by a third at military bases by 2020 and to have renewable energy sources account for 25% of energy used by 2025” (Enbysk 2011). The information presented in this review shows how the DoD is working with the civilian sector, Sandia National Laboratories to be specific, in forging new technologies to reach the goals set for 2025.

The article *GE to Transform U.S. Military Base into Smart Grid Model*, published by Transmission and Distribution World, discusses smart grids and their uses by the military. “GE is focusing toward the objectives of increasing energy security, efficiency,

and encouraging cleaner alternative energy at U.S. military bases, and they were awarded \$2 million in federal stimulus funding from the U.S. DoD for a smart grid demonstration project at Twenty-nine Palms Base, CA” (Holman and McMurray 2009). The grid will allow for the incorporation of renewable resources, such as solar energy, to help meet electricity demand while reducing carbon emissions.

As stated in the article, “according to the 2009 Defense Appropriations Act, U.S. military installations consumed 3.8 billion kWh of electricity last year (2008), enough to power 350,000 households in the U.S” (Holman and McMurray 2009). Since DoD installations either receive power from electric grids or locally by means of generators, the smart grid proposal by GE will offer a means to effectively and efficiently control where the power is received from and how it is managed.

C. PROBLEM STATEMENT

The WWTP at Hickam Air Force Base, HI has two diesel generators for backup power in the case of power loss or disruption. When that loss happens, both of the generators, one 600kw and one 1600kw, are placed online in order to run the WWTP load. Both operate inefficiently due to the small load being carried by each, thus using more fuel and releasing greater carbon emissions than would be with SPIDERS installed. Problems with the current WWTP system are the inefficiency of running two diesel generators, the Ultraviolet (UV) treatment system not having an Uninterruptable Power Supply (UPS), and the high rate of fuel consumption (Ellman 2012).

The inefficiency encountered when both generators are operated to maintain the electrical load of the WWTP causes increased fuel consumption, degrades the diesel generators themselves, and creates excess carbon emissions. The fuel tanks that supply the diesel generators are able to hold enough fuel for only 72 hours of operation without the implementation of SPIDERS. Once that fuel is depleted, the generators will shut off if power has not been restored to the electrical grid, and the WWTP will spill unsterilized wastewater into the environment.

The UV treatment system does not have an UPS. A complete power loss to the system, or if the backup generators run out of fuel, will cause the WWTP to shut down,

spilling unsterilized wastewater into the ocean. The result of such a spill would not only have a negative impact on the environment, but also poses the threat of possible Environmental Protection Agency (EPA) fines of up to \$50,000 per day per event. The implementation of SPIDERS and the associated UPS provide a means for avoiding these spills and EPA fines.

In the current configuration, if the WWTP experiences a power loss situation, both backup generators start and maintain the load of the WWTP with the 600kW generator operating at 30% efficiency, causing higher than optimal fuel consumption. The same is true for the 1600kW generator, operating at 25% efficiency in the current system configuration, causing higher than optimal fuel use. (Stamp, et al 2011) These backup generators operate off the same fuel tank that has the fuel capacity for only 72 hours of operation. With the implementation of SPIDERS, diesel generator efficiency can be attained, and the operational time can be extended well beyond the 72 hours, providing security that the WWTP will remain operable while power is being restored.

To address energy security concerns and meet legislative mandates, the DoD is aggressively seeking on-installation renewable energy projects. This thesis focuses on one part, SPIDERS Phase One, of Joint Base Pearl Harbor-Hickam's overall renewable energy strategy. SPIDERS is a project which integrates new and existing fossil backup generation, renewable energy, energy storage, and demand management for secure backup power and cost savings (Ellman 2012).

II. BACKGROUND

A. JOINT CONCEPT TECHNOLOGY DEMONSTRATION PROGRAM (JCTD)

An accelerated pace in technology development, and tight budget constraint have fostered the need for a DoD program to get much-needed new technologies, to keep up with new initiatives and changes of DoD policy, into the hands of DoD installations. The Advanced Concept Technology Demonstration (ACTD) was designed in 1994 to fill this role, but our forces now operate in a joint environment, thus creating the JCTD process.

According to the JCTD website, the Joint Capability Technology Demonstration program (JCTD) directly addresses Joint, Coalition, and/or Interagency capability needs expressed by Combatant Commands (COCOMs). COCOMs utilize the JCTD Program as a primary means to rapidly develop, assess, and transition needed capabilities. Due to the invaluable partnerships with resource sponsors and companies that strive for innovation, the JCTD program has been able to intensify its value to the COCOMs (Department of the Navy 2012).

The JCTDs are meant to meet the needs of the DoD and deliver a product for evaluation and testing. The OSD Rapid Fielding Directorate (RFD) works with the Joint Staff to manage the Joint Capability Technology Demonstration (JCTD) Program. The JCTD program provides the funding for the quick progress and evaluation of the advanced technology needs, based on the Joint War Fighting Requirements and COCOMs priorities.

The JCTD website also states that the program has assisted in numerous joint military and interagency operations, such as Operation Enduring Freedom, Operation Iraqi Freedom, and Operation United Response in Haiti. Due to the significance of the program and the large coalition participation, the U.S. has had successful past collaborations and expects to have successful future endeavors with the United Kingdom, Canada, Australia, the Republic of Korea, and the Republic of Singapore (Department of the Navy 2012).

B. PROPOSED SPIDERS INITIATIVES

SPIDERS JCTD addresses four initiatives to protect the mission critical WWTP. These four initiatives are protection of mission critical assets from power loss, integration of renewable and other distributed generation electricity to power mission critical assets in times of emergency, sustainment of critical operations during prolonged power outages, and management of installation electrical power and consumption efficiently to reduce fuel demand, carbon footprint, and cost. The initiatives are supported by the technology design concept of SPIDERS to ensure decreased fuel demand, operate efficient diesel generators, reduce the carbon footprint, and lower operational costs. These initiatives are discussed in the following paragraphs with a brief description and status of implementation procedures.

1. Protect Mission Critical Assets from Power Loss

a. Description

This initiative protects the mission critical asset, the WWTP, from prolonged periods of power loss that could result in the release of unsterilized wastewater to the bay, leading to environmental damage, large amounts of paperwork, and possible fines. Currently, diesel generators provide backup power protection from the occurrence of power loss or outage. Figure 2 shows the current system configuration of the WWTP. It details the renewable sources, the original HRS Circuit connecting the Mamala Substation to the Vehicle Maintenance Building, and the Hiang Circuit connecting the Administration Building, both of which will go away with SPIDERS and allow for complete isolation of the WWTP.

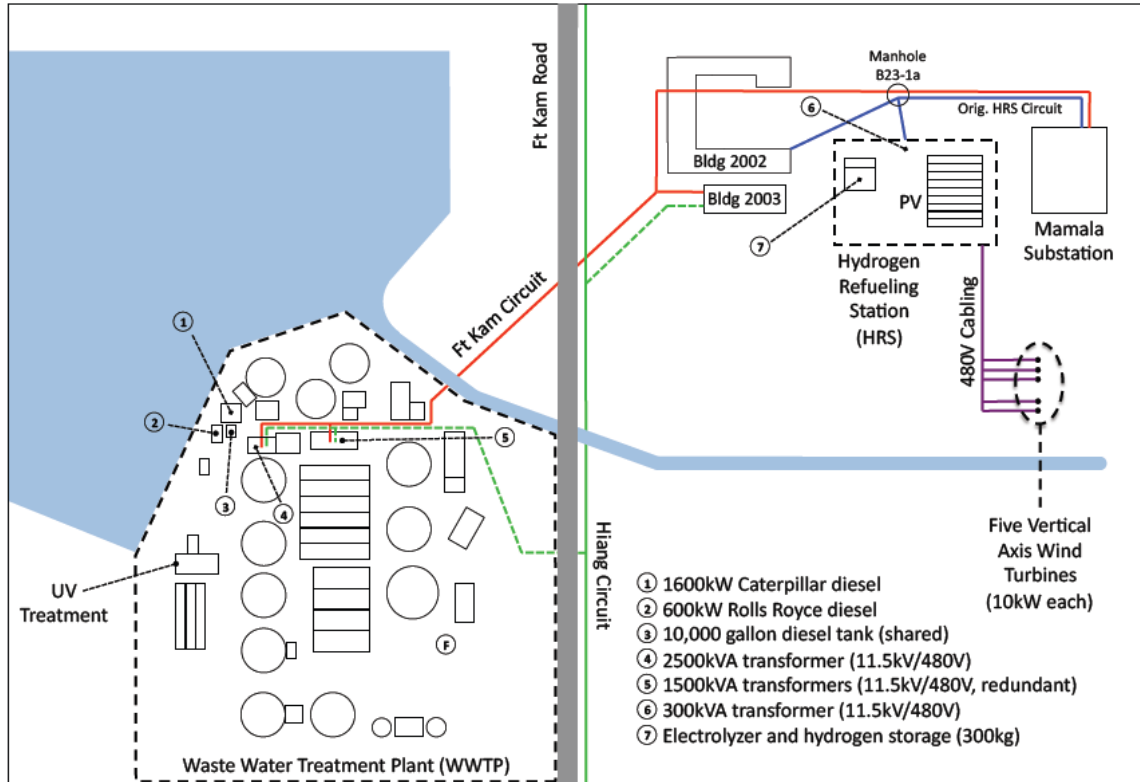


Figure 2. Current WWTP system and hydrogen refueling station located at Hickam AFB, (From Ellman SPIDERS CONOPS 2012)

The WWTP has several deficiencies that are being addressed by SPIDERS:

- The generators can each only power a section of the WWTP, which makes redundancy impossible in the case of generator failure.
- The UV system has no UPS, which leads to the release of unsterilized wastewater when power loss occurs.
- The WWTP currently does not have a means of remote monitoring or control.
- When losses of power or electrical surges occur, equipment breakers are constantly tripping causing damage to equipment (Ellman 2012).

In order for this vital asset to remain protected during power loss or disruption, some key changes must take place to the current electrical grid for the WWTP. The diesel generators, renewable energy assets, and energy storage devices must be linked together in an isolated microgrid that would be able to power the entire WWTP. In order to accomplish this, there must be reconfiguration of the electrical grid and equipment.

Figure 3 shows the proposed changes to the WWTP incorporating the 800kW diesel generator and the UPS for the UV treatment plant.

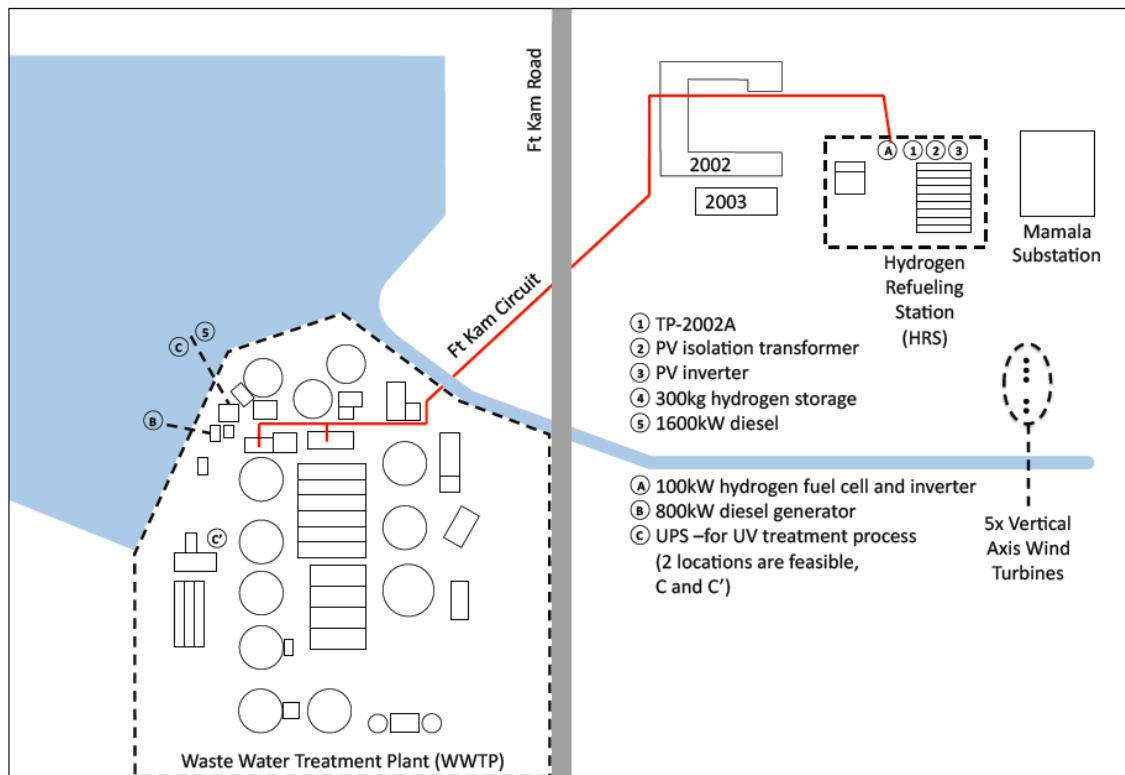


Figure 3. WWTP with SPIDERS recommended equipment, (From Sandia Report SPIDERS Project: Hickam AFB Preliminary Design Summary October 2011)

b. Status

As of September 5, 2012, the concrete foundation for the 800kW generator has been poured and grounded. The UPS has been successfully installed and is awaiting operational testing scheduled for the first week of October 2012.

2. Integrate Renewable and Other Distributed Generation Electricity to Power Mission Critical Assets in Times of Emergency

a. Description

Renewable sources aid in the reliability and security of energy by providing efficient means of generating and using this energy (United States Senate for Nevada 2012). SPIDERS provides the WWTP the capability to isolate the WWTP from the electrical grid by incorporating wind and solar power, and creating a reliable energy environment. The new, isolated, reliable environment within SPIDERS has a greater generating capacity of energy than the current system that runs generators on diesel fuel in an emergency. The new environment also has greater flexibility, creates redundancy, and ensures energy for mission critical loads is available. Without the incorporation of these renewable sources, there is the risk of losing all energy in times of emergency. Renewables in SPIDERS helps to address an identified deficiency with the current system at the WWTP.

- Currently, solar and wind power are automatically disconnected during a power loss and therefore do not contribute to extending the length of time that the WWTP can operate without power.

In order to combat this deficiency, the proposed changes are as follows:

- SPIDERS will link the diesel generators, renewable energy sources of wind, solar, and the stored energy flow battery in an isolated microgrid, shielding the WWTP from any further power problems until power to the energy grid is restored.

- SPIDERS will incorporate the use of solar and wind renewable energies and the stored energy flow battery for full time employment.

b. Status

As of September 5, 2012, three of the five wind turbines have been installed and all solar panels are incorporated for the renewable station. Awaiting approval from HECO for interconnect agreements for testing scheduled to begin in November 2012.

3. Sustain Critical Operations During Prolonged Power Outages

a. Description

The WWTP is the major mission critical load for Hickam AFB, and power loss or disruption can have negative consequences. The focus of SPIDERS is to enable the isolation of the WWTP and to sustain operations using the WWTP's own energy sources, whether stored renewables or diesel back up, in the event of prolonged outages. Sustainment is also aided by efficient equipment, which SPIDERS uses to provide power to the WWTP, by means of diesel generators and reducing diesel fuel consumption. The reduction in diesel fuel consumption also diminishes the logistical problem of refueling during prolonged outages.

b. Status

SPIDERS is not yet operational, so there is no status. The renewable sources are being incorporated into the current system and the replacement of the 600kW diesel generator is undetermined. Current plans call for test and evaluation in September. It is unclear that this timeline will be met.

4. Manage Installation Electrical Power and Consumption Efficiently to Reduce Fuel Demand, Carbon Footprint, and Cost

a. Description

The goal of this initiative is the reduction in cost of operations at the WWTP, extension of the time of operations while not connected to the electrical grid, and the integration of renewable power generation systems to meet government mandates. There are two underlying objectives that must be met.

- During operations while isolated from the electrical grid, the most efficient mix of energy sources must be used to increase operational longevity while decreasing fuel usage.
- While in normal operations and connected to the electrical grid, carbon emissions and operational costs must be reduced by incorporating renewables and monitoring via EMS.

b. Status

Due to SPIDERS not being up and operational, these objectives are not met at this time. This could be presented in a follow on study.

C. BENEFITS OF THE PROPOSED SPIDERS INITIATIVES

In the following paragraphs, we present the benefits of SPIDERS and United States Pacific Command J81 Joint Innovation and Experimentation Division's efforts to meet legislative mandates, goals set forth by DoD installations, and efforts to reduce carbon footprint and costs.

1. Energy Reliability

There is a need for reliable, uninterrupted electricity at Hickam AFB WWTP. The facility is capable of handling 13 million gallons of wastewater per day, and on an average day will process 5.5 million gallons (Naval Facilities Engineering Command (NAVFAC Hawaii) 2011). Increasing on-site energy through renewables and a microgrid concept such as SPIDERS, reduces risk of power loss because it provides a steady source of energy availability and there is no delay in the switch from normal power to back up power.

2. Energy Efficiency

In order for the WWTP to operate efficiently, the 600kW diesel generator must be replaced in addition to incorporating renewable resources. The inefficiency of the status quo is due to the power required to operate all the loads, or equipment, of the WWTP. Due to the load being just over the capacity of the 600kW generator and under the desired operating capacity of the 1600kW generator, both the 600kW and 1600kW generators are necessary to provide backup power, which in turn causes inefficient operations at 30%–50% of the capacity of the generators (Stamp, et al 2011). When the 600kW generator is replaced, the 800kW generator will be able to provide power to all loads of the WWTP without the addition of the 1600kW generator needed for use, other than initial startup to transfer loads. While this is one of the first proposed steps of SPIDERS to maintain mission criticality, it also aids in efficient operations of the WWTP when power loss occurs. The EMS that SPIDERS incorporates will allow for monitoring and managing of the microgrid and its equipment, and also allow the WWTP to implement energy efficient practices and procedures. The replacement of the 600kW generator will allow for less of a carbon footprint and reduction in fuel consumption.

3. Energy Supply Security

Natural disasters, terrorism, and other risks have exposed vulnerabilities in energy supplies. SPIDERS implements several designs to ensure the appropriate level of security is maintained or improved. Specific examples of design securities implemented by SPIDERS are:

- Secure network design
- Network communications security
- Strong access authorization/authentication
- Secure log in
- Network intrusion detection system

New DoD directives are in progress of approval for proper management and oversight of the microgrids like SPIDERS. Currently, The National Institute for Standards and Technology (NIST) Internal Report (IR) 7628 – Guidelines for Smart Grid

Cyber Security is being used as the basis for identifying which DoD instructions to apply to a microgrid control system (Stamp, et al 2011).

4. Energy Sustainability

In order for energy to be deemed sustainable, it must meet current needs without compromising the needs of future generations or their ability to meet those needs. The DoD is placing heavy emphasis on renewable sources of energy, notably DoDINST 4170.11 Installation Energy Management, stating that the DoD will invest in cost effective renewable energy sources and energy efficient facility designs and regionally consolidate Defense requirements to aggregate bargaining power to achieve better energy deals (Department of Defense 2009). Besides generation and storage, the DoD has plans and programs to conserve energy. SPIDERS creates a more efficient environment by operating the diesel generators efficiently, causing less wear and tear on the generators, therefore prolonging the life of this equipment. With the implementation of EMS, equipment monitoring and management can make for an improved use of the critical loads and equipment, which aids in efficiency and longer life cycles of mission critical loads.

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III. COST ESTIMATES FOR HICKAM AFB WWTP

A. METHODOLOGY

This chapter provides the methodology used in the cost and benefits calculations, as well as in the sensitivity analysis. All results are in FY12\$K.

Electricity and fuel are the variables that drive savings and return on investment since we are sure that we can harvest these savings. The realization of labor costs, on the other hand, is more problematical, so we treat them separately.

SPIDERS initial investment is estimated at \$5,200K, which includes Research and Development, Procurement, and Operation and Sustainment costs for the testing and evaluation phase. The Present Value (PV), cumulative Net Present Value (NPV), and Return On Investment (ROI) were calculated for a baseline 30-year time horizon with a discount factor of 2%.

For sensitivity analysis, Table 1 shows the variables and their values.

	BASE	MINIMUM	MAXIMUM
ELECTRICITY(kW)	4,157,567	4,157,567	4,157,567
FUEL (price/gal)	\$4.69	\$4.22	\$5.16
LABOR (# released)	0	0	1 person
INVESTMENT (\$FY12)	\$5.2M	\$5.2M	\$10.4M
TIMELINE (years)	30	10	30
Discount Factor	2%	1%	5%

Table 1. SPIDERS sensitivity analysis for input values.

B. BASE CASE COST ELEMENTS

The following paragraphs discuss the WWTP base case operational costs for electricity and fuel, with and without SPIDERS. Labor savings were not included for the base case but are discussed later.

1. Predicted Electrical Costs with Status Quo

The base electrical demand for Pearl Harbor and Hickam AFB, from FY11 WWTP records at Public Works Pearl Harbor Naval Base, is 4.15M kW. Since HECO charges \$0.20/kWh, the status quo electricity costs is \$835.6K per year.

2. Predicted Electrical Costs with SPIDERS

The electricity costs of the WWTP with SPIDERS were calculated by subtracting the estimated electricity savings achieved by implementing Demand Response (DR) contracts through HECO from the status quo estimates. DR contracts pay/credit \$5 for each kWh of electricity not used. We estimate 10hrs/day of savings, based on DR “windows of opportunity” from the HECO DR website, which is \$20K per year under the DR contract provisions. Estimated yearly electricity cost incurred by implementing SPIDERS is the difference between status quo and SPIDERS savings, \$835.6K-20K= \$815.6K.

3. Predicted Fuel Costs with Status Quo

Debra Urasaki of the Hickam AFB WWTP provided estimated diesel generator operating hours, fuel costs for the DoD, and consumption rates. The predicted fuel costs for the status quo were calculated using the number of estimated operating hours for the 600kW and 1600kW diesel generators multiplied by the current price per gallon of fuel for DoD of \$4.69. The status quo yearly maintenance hours per diesel generator is 56, and the estimated operating hours in the event of power loss is 5 hours per diesel generator. The estimated operating hours in the event of power loss was estimated based on the WWTP logs, which were visually inspected by Debra Urasaki for outages in the past 2 years. These records indicate 2 outages, for a total 5 hours of operation. The 600kW diesel generator consumes 50 gallons per hour and the 1600kW uses 120 gallons per hour giving us an estimated cost for fuel during power outages of \$4k/year. The total fuel cost for the status quo is then estimated at \$48.6K.

4. Predicted Fuel Costs with SPIDERS

Fuel costs for the WWTP with SPIDERS were calculated by estimating the operating hours in the event of power loss for the 800kW diesel generator. We use the 800kW generator because it will be able to operate the full load of the WWTP on its own after all critical loads have been started, and those loads transferred that were started by the 1600kW generator, since the 1600kW diesel generator will only operate to start and then transfer certain critical loads. As per Cummings 800kW diesel generator specs, the 800kW diesel generator has an estimated consumption rate of 58 gallons per hour; therefore the estimated operating cost during power loss is \$1.2K. The yearly maintenance hours were reduced by 50%, as an assumption that there will be fewer preventative maintenance checks due to a new diesel generator. Therefore the estimated fuel cost for maintenance is \$44.8K, and the total fuel cost for SPIDERS is \$24.3K.

5. Predicted Labor Costs with Status Quo

Debra Urasaki of Hickam AFB WWTP provided the labor force data and labor costs for estimation purposes only. Estimated WWTP hourly labor costs, including fringe and benefits, are \$83.06. For a labor force of 19 personnel (13 day shift, 6 night shift), this is an annual cost of \$3.6M.

6. Predicted Labor Costs With SPIDERS

In the base case for labor, it is assumed that there are no labor savings incurred with SPIDERS, as there has been no evidence to date that SPIDERS will reduce the amount of personnel required to operate the WWTP. We know from the labor figures above that 1 man-year costs \$166.4K.

C. PREDICTED SAVINGS WITH SPIDERS

The following tables summarize the NPV of savings, identified in the paragraphs above, using a discount factor of 2%.

1. Estimated Electricity Savings

Annual Electricity Savings (FY12\$)	Total NPV Savings @ 10 Yrs (FY12\$)	Total NPV Savings @ 20 Yrs (FY12\$)	Total NPV Savings @ 30 Yrs (FY12\$)
\$19.6K	\$180.3K	\$328.2K	\$449.6K

Table 2. Estimated cumulative NPV electricity savings from SPIDERS

2. Estimated Fuel Savings with SPIDERS

Case	Annual Fuel Savings (FY12\$)	Total NPV Savings @ 10 Yrs (FY12\$)	Total NPV Savings @ 20 Yrs (FY12\$)	Total NPV Savings @ 30 Yrs (FY12\$)
Base	\$23.4K	\$214.8K	\$391.0K	\$535.5K
Best	\$26.0K	\$249.2K	\$474.8K	\$679.0K
Worst	\$20.5K	\$166.1K	\$268.1K	\$330.7K

Table 3. Estimated cumulative NPV fuel savings from SPIDERS

3. Estimated Labor Savings with SPIDERS

Case	Annual Labor Savings (FY12\$)	Total NPV Savings @ 10 Yrs (FY12\$)	Total NPV Savings @ 20 Yrs (FY12\$)	Total NPV Savings @ 30 Yrs (FY12\$)
0 Personnel	\$0	\$0	\$0	\$0
1 Personnel	\$169.3K	\$1,551.8K	\$2,824.9K	\$3,869.3K
2 Personnel	\$338.7K	\$3,103.7K	\$5,649.9K	\$7,738.6K
3 Personnel	\$508.1K	\$4,655.6K	\$8,474.8K	\$11,607.9K

Table 4. Estimated cumulative NPV labor savings with SPIDERS

D. TOTAL SAVINGS WITH SPIDERS

The total savings from SPIDERS, including electricity, fuel, and possible labor savings, are discussed in the following paragraphs. Graphical representations are provided to show the base case, best-case, and worst-case scenarios.

1. Electricity and Fuel Savings

Table 5 presents the cumulative NPV 30-year electricity and fuel savings at the WWTP due to SPIDERS, as a function of price of fuel, discount factor, initial investment, and the cumulative savings.

Scenario	Fuel (price/gallon)	Discount Factor	Investment FY12\$K	Savings (FY12\$K)
Base	\$4.69	2%	\$5,200	\$1,013
Best	\$5.16	1%	\$5,200	\$1,232
Worst	\$4.22	5%	\$10,400	\$656

Table 5. Cumulative 30-year NPV savings incurred at WWTP with SPIDERS by scenarios with fuel, discount factor, and investment shown for each case

It is clear from the Table 5 that the savings from electricity and fuel alone are not enough to provide a positive ROI in the 30-year evaluation period. In order for there to be a positive ROI, there must be labor savings, and these are discussed in the following section. Figure 4 shows that savings from electricity and fuel do not reach the investment costs of \$5.2M in 30 years, so the ROI is not positive unless potential labor savings are incurred.

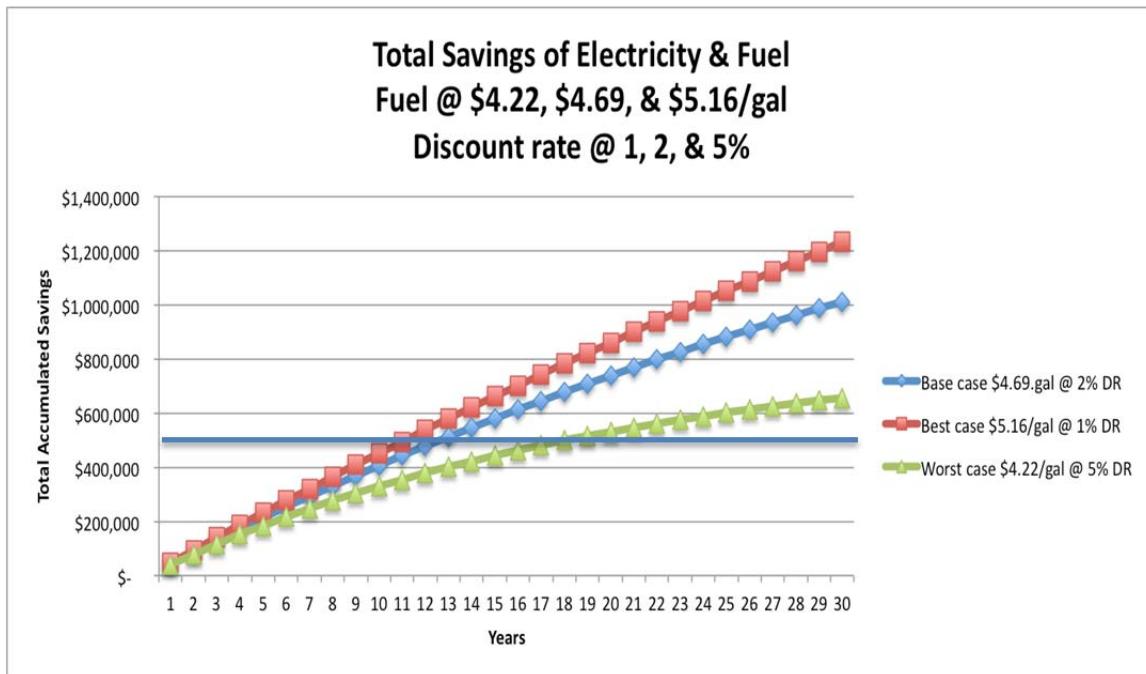


Figure 4. Cumulative annual electricity and fuel savings for base, best, and worst case scenarios

2. Electricity, Fuel, and Labor Savings

The best-case scenario involves the annual savings from electricity and fuel, as well as the potential annual labor savings from SPIDERS. The annual savings from electricity and fuel total \$45.2K for the best-case scenario, and with the addition of the potential annual labor savings, the total annual savings are \$211.6K for 1 person released from the payroll. For each additional person released from payroll, an additional \$166.4K will be added to the annual savings. Figures 5–7 show the cumulative NPV base-case, best case, and worst-case scenarios with sensitivity of labor for 1–3 personnel released from the payroll. We see from these figures with the incorporation of labor savings, depending on the number of personnel released from the payroll, that the initial investment could be recouped within the 30-year time-horizon. For example, with 1 person released from the payroll, in the base case, we have a payback period of 31 years, as shown in Figure 5.

a. Cumulative Annual Savings for Electricity, Fuel, & Labor with 1 Person Released from Labor

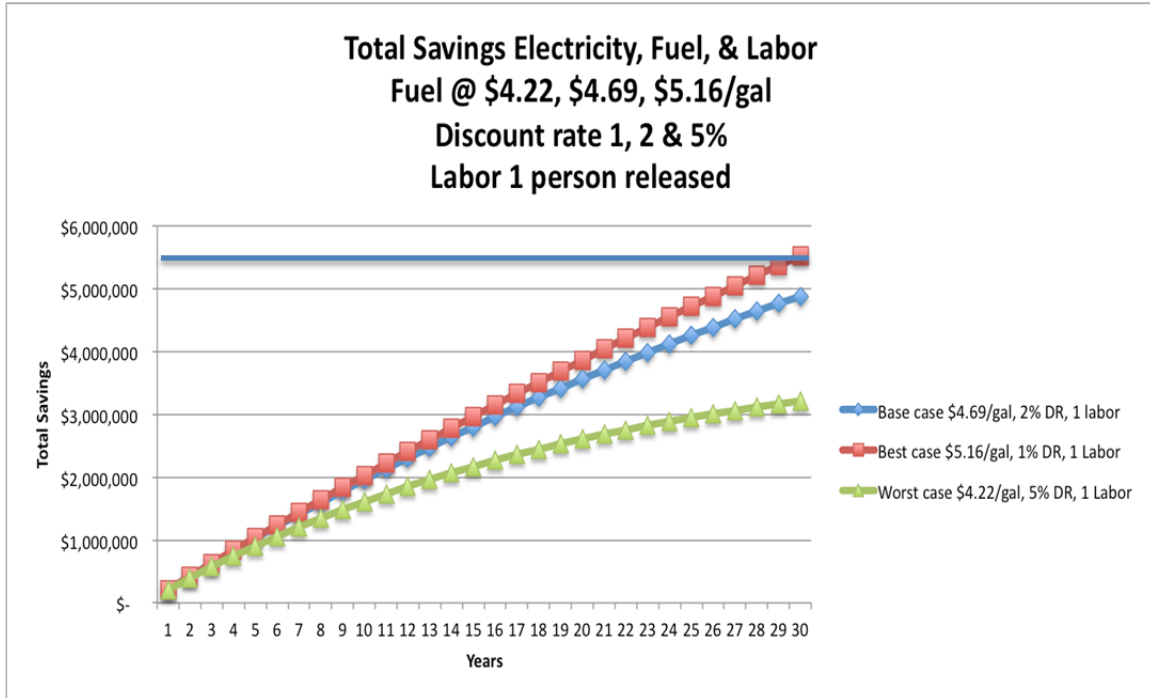


Figure 5. Cumulative annual electricity, fuel, and labor savings of 1 person released from the WWTP payroll for base, best, and worst case scenarios

b. Cumulative Annual Savings for Electricity, Fuel, & Labor with 2 Personnel Released from Labor

In Figure 6, the base case with 2 personnel released from the payroll has a payback period of 16 years.

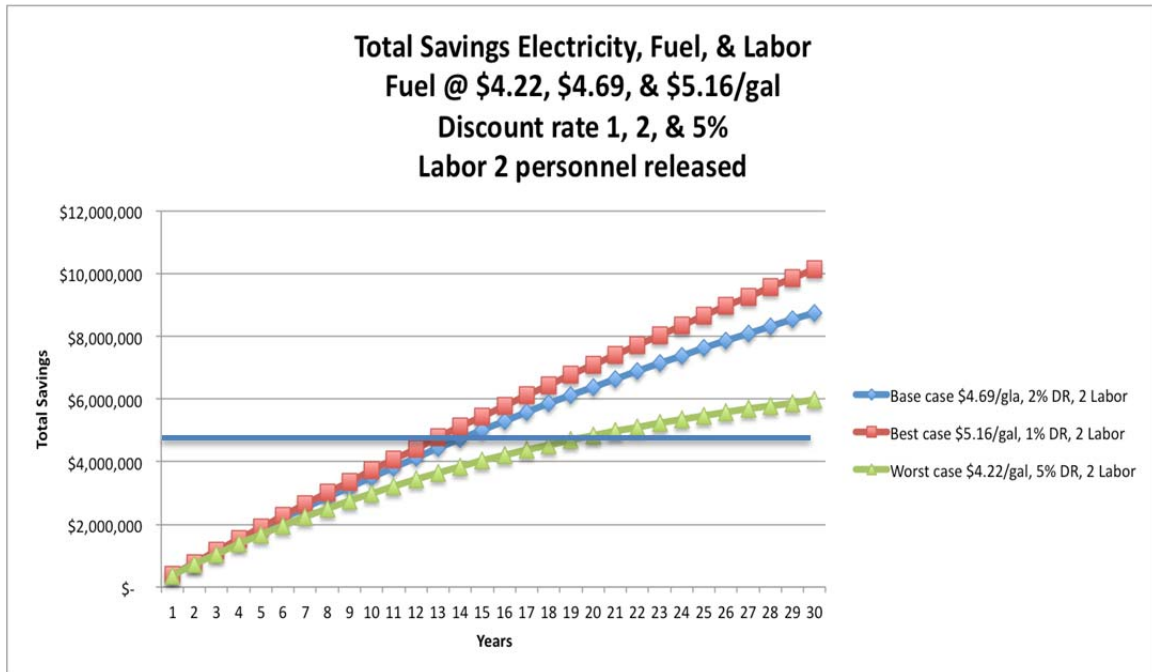


Figure 6. Cumulative annual electricity, fuel, and labor savings of 2 personnel released from the WWTP for best, base, and worst-case scenarios.

c. Cumulative Annual Savings for Electricity, Fuel, & Labor with 3 Personnel Released from Labor

In Figure 7, we see the base case with 3 personnel released from the payroll has a payback period of 11 years.

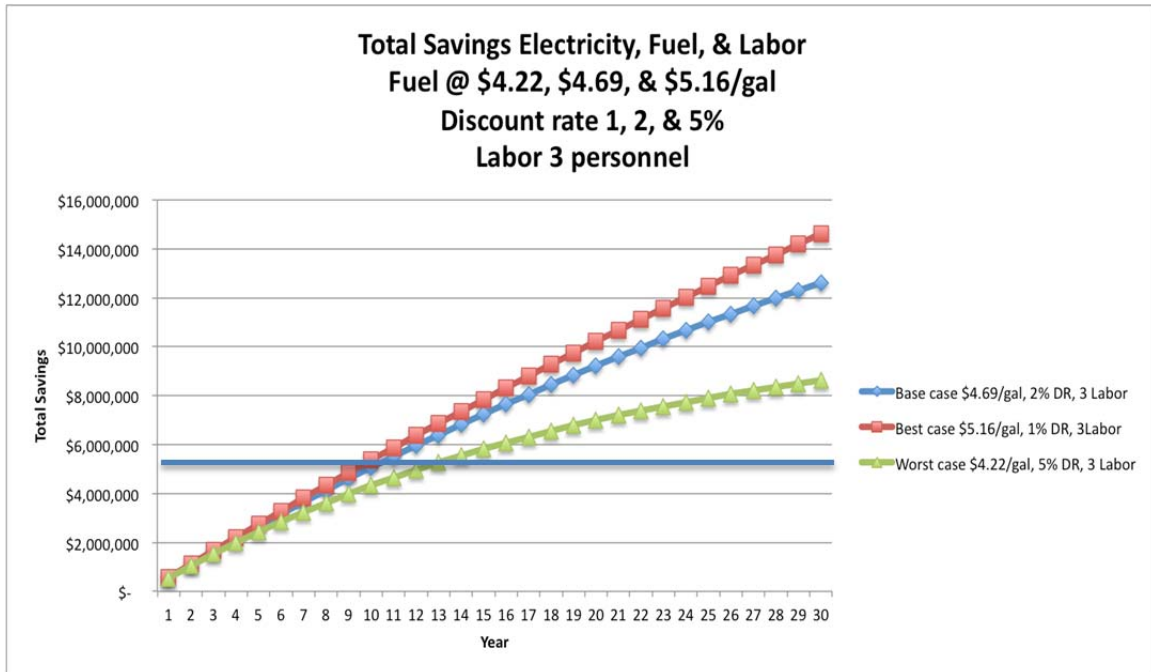


Figure 7. Cumulative annual electricity, fuel, and labor savings of 3 personnel released from the WWTP for best, base, and worst case scenarios

E. SENSITIVITY ANALYSIS OF THE RETURN ON INVESTMENT WITH SPIDERS

There were no scenarios that provided a positive ROI involving only electricity and fuel. For ROI to be positive, the potential labor savings have to be incorporated. So, we identify combinations of electricity, fuel, and labor savings that lead to a positive ROI.

1. Predicted Electricity and Labor Savings Incurred With SPIDERS

One combination of potential savings incurred with SPIDERS is electricity and labor savings, under the pessimistic assumption that there are no savings incurred for fuel. As shown in the previous paragraphs, the potential estimated electricity savings is \$20K per year. The addition of each person released from payroll adds an additional \$166.4K to the total and the results are shown in Figures 8–10 for 1, 2, and 3 personnel. We see from these figures, except for Figure 8, that ROI becomes positive during the 30-year time-horizon with the incorporation of labor savings.

a. SPIDERS ROI Assuming 1 Labor Person Released from Payroll at the WWTP and Electricity Savings

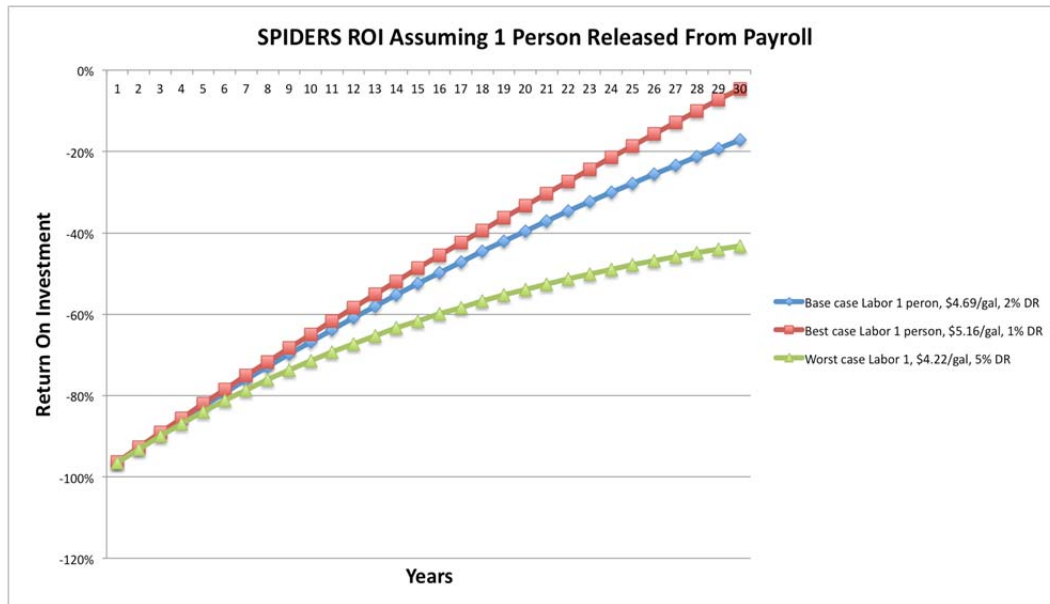


Figure 8. SPIDERS ROI with 1 labor person released

b. SPIDERS ROI Assuming 2 Labor Personnel Released from Payroll at the WWTP and Electricity Savings

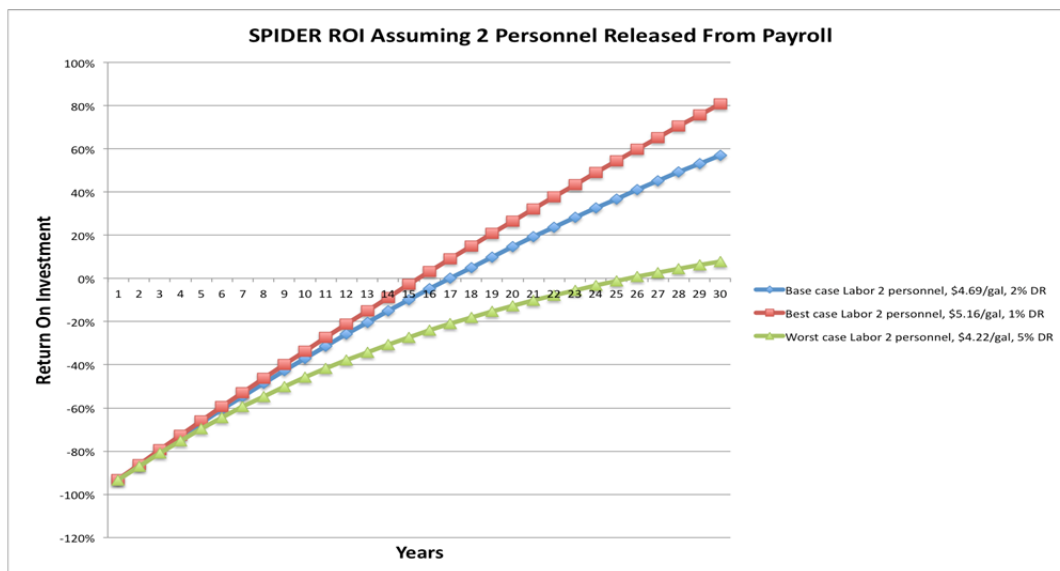


Figure 9. SPIDERS ROI with 2 labor personnel released

c. ***SPIDERS ROI Assuming 3 Labor Personnel Released from Payroll at the WWTP and Electricity Savings***

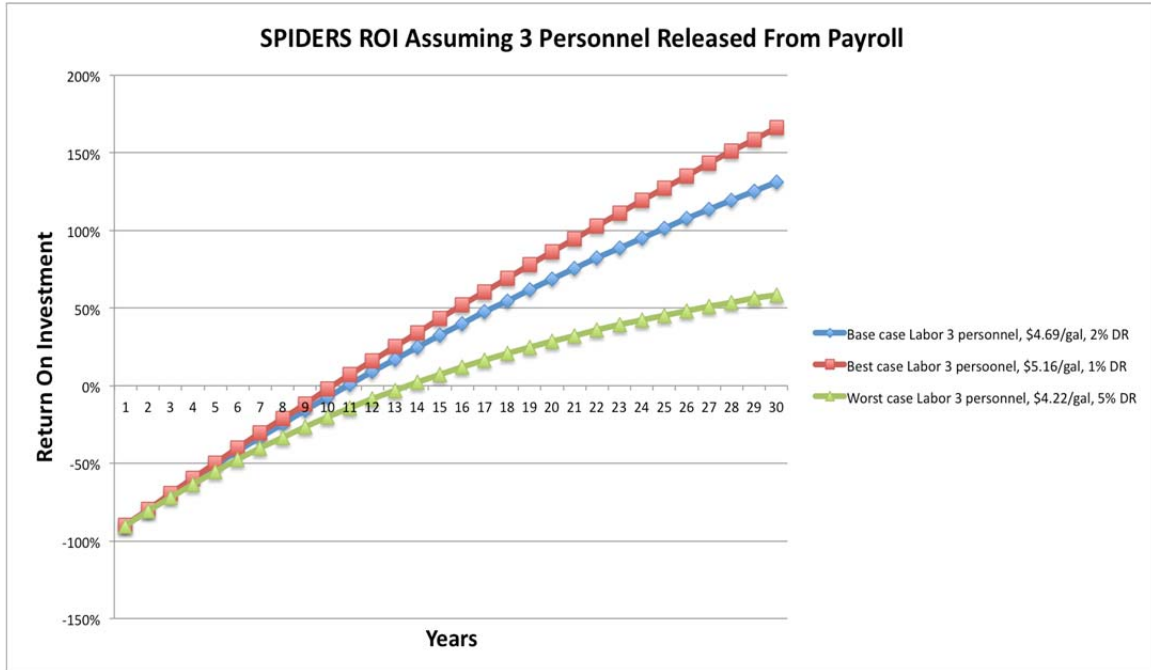


Figure 10. SPIDERS ROI with 3 labor personnel released

2. **Predicted Fuel and Labor Savings Incurred with SPIDERS**

The last combination of potential savings incurred with SPIDERS is fuel and labor savings, under the assumption that there are no savings incurred for electricity if the WWTP either is not allowed to participate in, or opts out of, DR contracts. Figures 11-13 show the ROI with SPIDERS assuming fuel and labor savings with 1, 2, and 3 personnel released from the payroll. We see that ROI becomes positive, except for Figure 11, with the addition of labor savings.

a. SPIDERS ROI Assuming 1 Labor Person Released from Payroll at the WWTP and Fuel Savings

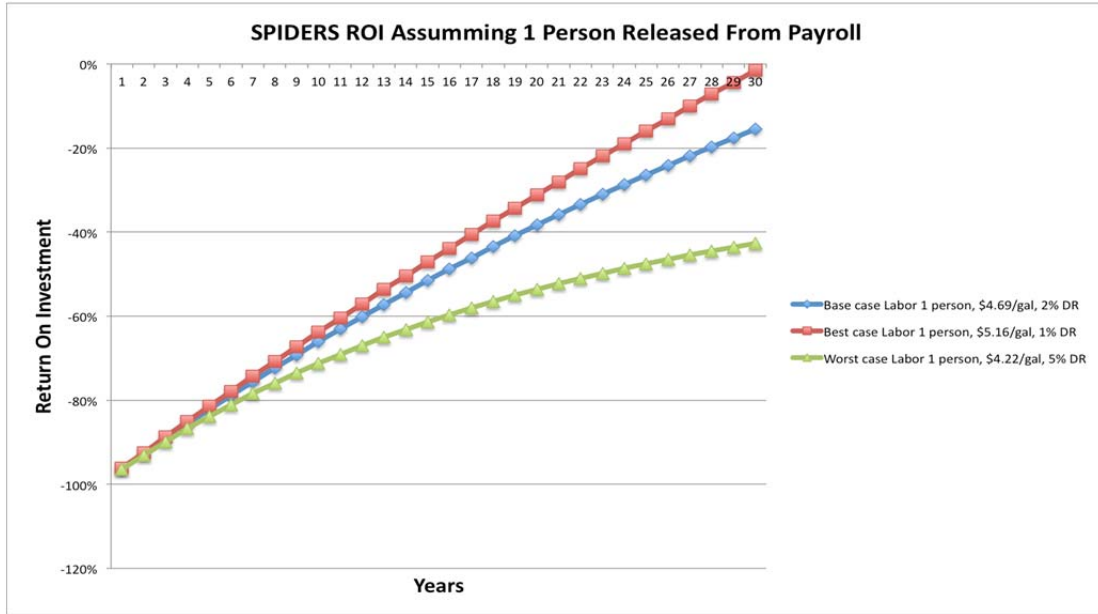


Figure 11. SPIDERS ROI with 1 labor person released

b. SPIDERS ROI Assuming 2 Labor Personnel Released from Payroll at the WWTP and Fuel Savings

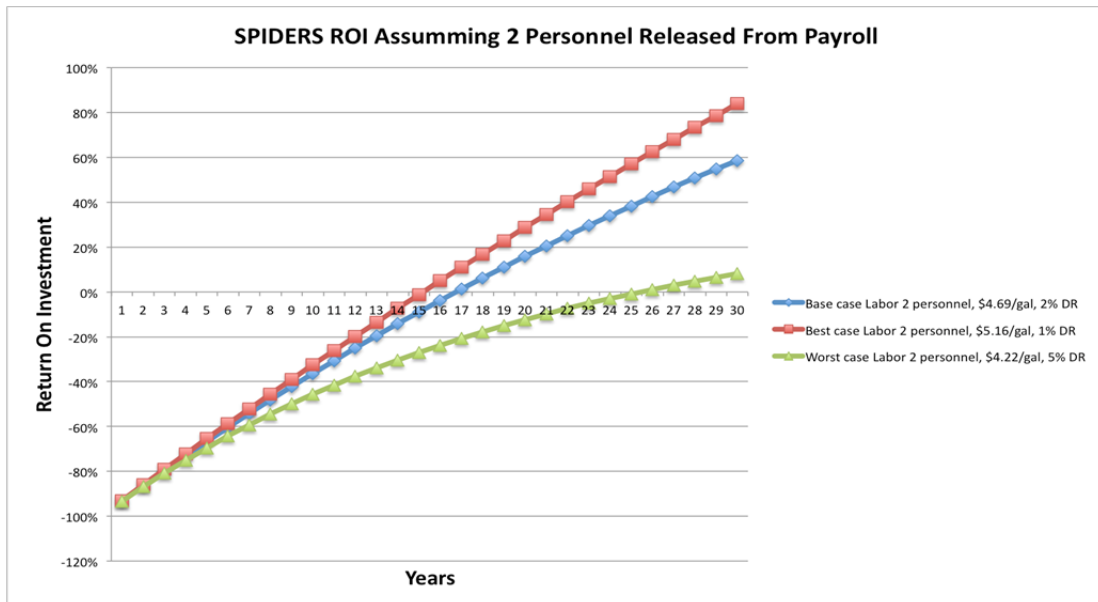


Figure 12. SPIDERS ROI with 2 labor personnel released

c. ***SPIDERS ROI Assuming 3 Labor Personnel Released from Payroll at the WWTP and Fuel Savings***

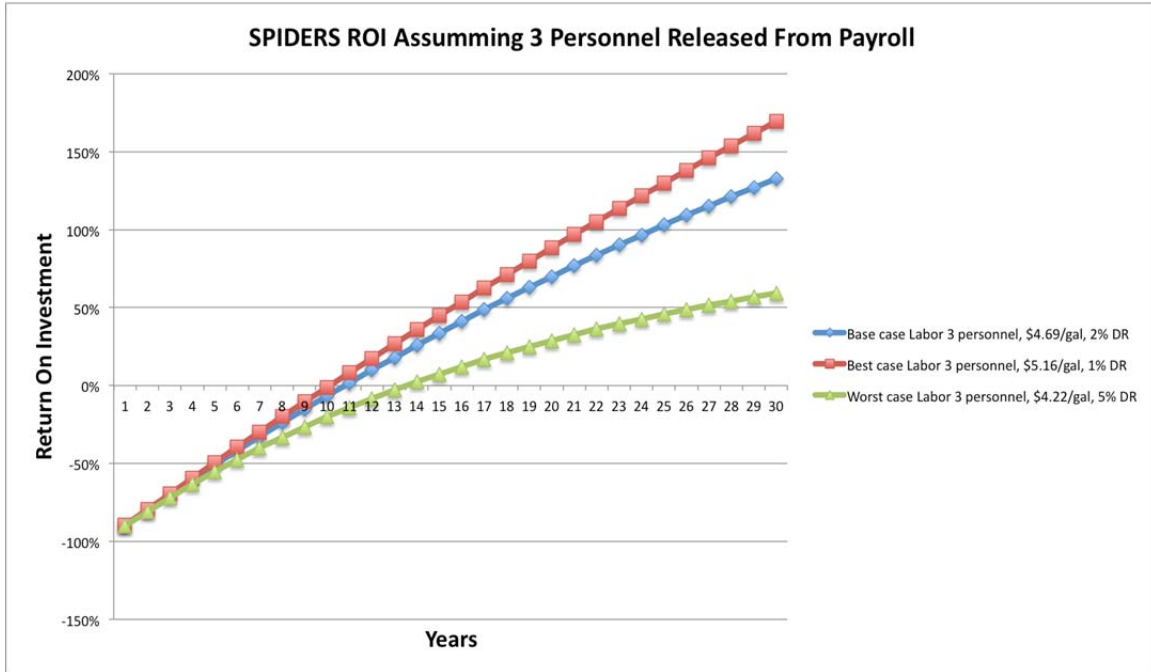


Figure 13. SPIDERS ROI with 3 labor personnel released

F. SENSITIVITY ON INVESTMENT COSTS

Many projects overrun their investment cost estimates in the investment phase. We analyze the impact of ROI if SPIDERS experiences this, considering a base case cost of \$5.2M and an overrun case of \$10.4M. The previous analysis showed that electricity and fuel savings were insufficient to recoup the investment at the \$5.2M level. It is clear that the same can be said for the \$10.4M case. Table 5 presents the break-even year and ROI at 30 years for initial investments of \$5.2M and \$10.4M. We see from Table 5 that until 2 personnel are released from the payroll, the break-even year is non-existent and the ROI remains negative regardless of investment.

Labor Cut	Break-Even Yr \$5.2M	Break-Even Yr \$10.4M	ROI @ 30-Yr \$5.2M	ROI @ 30-Yr \$10.4M
0	N/A	N/A	-78%	-90%
1	N/A	N/A	-6%	-53%
2	16	N/A	68%	-16%
3	11	24	142%	21%

Table 6. Labor sensitivity presenting cases of zero personnel cut from labor force to 3 personnel cut from labor force, break-even years for initial \$5.2M invested and assumed max of \$10.4M invested, and ROI at 30 years for both investment

IV. CONCLUSION

When measured against standard financial metrics, the proposed Hickam AFB SPIDERS microgrid represents a poor business decision by the United States Navy compared to the status quo. The annual savings of electricity and fuel never recoup the investment of \$5.2M, so without incurring potential labor savings, there will never be a recoupment of investment, much less a positive ROI.

However, based on existing legislative mandates, proposed reductions in carbon emissions, reduction in fuel demand, and maintaining a reliable source of energy, the Hickam AFB SPIDERS microgrid represents a good business decision by the United States Navy. A SPIDERS microgrid could store enough electricity to ensure zero down time for the WWTP well beyond the initial 72 hours allocated by the diesel fuel tanks used by the status quo.

A. RECOMMENDED FUTURE STUDY

This thesis analyzed the first phase of SPIDERS, which focuses on the WWTP at Hickam AFB. Phase Two of SPIDERS intends to focus on the cyber security aspect of SPIDERS, vehicle-to-grid integration, and Homeland Defense at Fort Carson, Colorado. Phase Three will be the first two phases tied together for a completely independent energy island at Camp Smith, HI.

One issue not analyzed in this thesis is the monetizing of carbon emission savings. This means developing a dollar-value per metric ton of carbon dioxide emitted per year, also known as the “social cost of carbon”. One could first monetize the carbon emissions of the status quo, then adjust the electrical demands at the WWTP via use of SPIDERS, and compare the carbon emissions. With monetization, this data could be used to forecast the amount of carbon emissions per critical load, and allow future reductions in carbon emissions, as well as identifying which equipment contributes heavily to these emissions.

Other possible benefits not explored in this thesis that may have an effect on the value of renewable energy projects for military installations include the economic benefit

of the establishment of green jobs, the economic benefit of potential carbon emission cost avoidance, and the benefits of contributing to Hawaii's' Renewable Portfolio Standard goal of 40% by 2030 (U.S Department of Energy 2003).

Another possible benefit not addressed in this thesis is the Hawaii Clean Energy Initiative goal of 70% clean energy by 2030, with 30% coming from efficiency measures, and 40% coming from the locally generated renewable sources (Hawaii Powered) This initiative could possibly be examined in other states, such as Colorado, where the next phase of SPIDERS will be incorporated.

A future business case study may analyze the possibility of multiple SPIDERS microgrids across DoD installations, monetizing the overall cost-benefits to the DoD, and determining if a commercial off-the-shelf product could be produced to provide such capabilities.

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