THESIS

THE VIABILITY OF VEHICLE TO GRID (V2G) INTERACTION FOR THE DEPARTMENT OF DEFENSE

Submitted by

Brian Dean Johnston

Department of Electrical and Computer Engineering

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2012

Master's Committee:

Advisor: Thomas H. Bradley

Anthony A. Maciejewski
Peter Young

ABSTRACT

THE VIABILITY OF VEHICLE TO GRID (V2G) INTERACTION

FOR THE DEPARTMENT OF DEFENSE

The Department of Defense, through a combination of mandated Executive Orders and voluntary energy saving goals has direction to achieve improvements in energy self-sufficiency onboard its major domestic bases. Two primary areas of interest are in the area of expanding use of collocated renewable energy production (Wind, Solar, Biomass), and the capability to operate at some level of capacity completely independent of commercial utility providers in an "islanded" microgrid condition. Reduced environmental impact and enhanced energy security are a proposed result of the achievement of these objectives.

Traditional power grids have only a negligible energy storage capability, so production must equal demand at all times. Energy production from renewable sources is intermittent and not subject to dispatch, so it requires smoothing to enhance its utilization and value. Vehicle to Grid (the use of vehicle energy storage as a grid resource) provides a technology which can mitigate the difficulties in integration of renewable power generation as well as provide collocated energy storage for a microgrid under islanded conditions. Military bases are equipped with extensive vehicle fleets for both operational support and logistics requirements. This report analyzes the potential benefit of electrifying this fleet of vehicle assets as V2G capable Battery Electric Vehicles (BEVs) or Plug-in Hybrid Electric Vehicles (PHEVs) to not only achieve energy savings with the vehicles themselves, but to concurrently achieve advances in the integration of collocated renewable resources as well as provide enhanced independent microgrid operation.

Previous studies have focused on V2G capability in terms of its application in the civilian sector. Primary measures of the effectiveness of V2G are availability, reliability, and commercial viability. These metrics focus the employment of V2G to primarily the Ancillary Services portion of the commercial power production market due to the difficulty in aggregating thousands of independently owned energy sources/sinks in a reliable and cost effective way. The military base environment provides a new and compelling use for V2G, in that individual vehicle assets are commanded operationally and therefore much easier to aggregate reliably. Also of interest is the requirement in an "islanded" scenario, where V2G might provide all the requirements of a full power grid including Base Load, Peak Load, and Ancillary Services reliably and with some level of improved capability over traditional power generation technologies such as backup diesel generation.

This study explores the viability of V2G as part of the DoD's operational and strategic energy initiatives. It provides a review of energy requirements for islanded operation on a typical military air base, proposes a model fleet of BEV/PHEV assets to attempt to meet those requirements, evaluates the operational and strategic value of the V2G system, and proposes an idealized Standard Operating Procedure (SOP) for the employment of those vehicles.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

The 2011 model year marked an historic milestone for the transportation system of the United States. For the first time in recent history, a mass produced Battery Electric Vehicle (BEV) was offered by a major automaker for outright sale to the American public in the form of the Nissan Leaf. This vehicle is the size of a conventional sedan and is powered strictly by electricity provided by the commercial grid and stored in a large bank of onboard Lithium Ion (Li-Ion) batteries. It provides the user over 100 miles of range at a fraction of the cost of conventional petroleum based fuels [1]. It also offers zero operational emissions. Other recent additions to the automobile consumer's choices are the Plug-in Hybrid Electric Vehicle (PHEV) GM Chevrolet Volt, and a PHEV variant of the already popular 2012 Toyota Prius. All of these vehicles rely on substantial electrical energy storage to increase their efficiency or provide propulsion outright. Previous analysis reveals that the average American vehicle only spends one hour a day in actual operation [2]. This has led to increased interest in employing the energy stored in this pool of battery assets to serve additional purposes when not required for actual transportation. This is the conceptual basis for Vehicle to Grid (V2G) interaction, where electrical energy flows bi-directionally between a parked automobile and the electrical power grid to which it is connected. Energy flows into the vehicle to charge the batteries when required, and also discharges from the vehicle when it is advantageous to the grid to do so.

Traditional power grids have negligible storage capability, so production must equal demand at all times. Energy production from renewable sources is often unreliable or poorly timed, so it requires smoothing to enhance its benefit. V2G interaction provides a technology which mitigates both the difficulties in integration of renewable power generation (with its dependencies on time of day and season), as well as providing collocated energy storage for a microgrid in the event of unplanned outages. Military bases are equipped with extensive vehicle fleets for both operational support and logistics requirements. The General Services Administration (GSA) is responsible for procuring more than $1 billion in vehicles and automotive services each year [3], of which domestic military bases make up a substantial component. There has also been significant growth in on-base renewable generation as part of the DoD's Net Zero Energy Installation (NZEI) program and other energy conservation measures.

The Federal Government is the largest consumer of energy in the US economy [4]. The Department of Defense is the largest energy user within the Federal Government consuming 93% of the annual fuel requirements [5]. The Department of Defense provides the ideal opportunity to employ energy saving technology and environmentally friendly practices, maximizing the effects through scale alone. In a nation which has been described by its own leadership as "Addicted to Oil", the dependence on fossil fuels has a substantial National Security component to be considered. To this end, the Defense Science Board Task Force was convened to evaluate the DoD Energy Strategy. Among a variety of missions assigned, the board was tasked to: Identify opportunities to reduce demand, identify opportunities to deploy renewable and alternative energy resources for facilities, and identify and recommend programs to reduce facility energy use. In February 2008 they released a report titled "More Fight – Less Fuel". Among their findings, a disturbing theme emerged:

> *"(The) DoD's key problem with electricity is that critical missions, such as national strategic awareness and national command authorities are almost entirely dependent on the national transmission grid. About 85% of the energy infrastructure upon which DoD depends is commercially owned, and 99% of the electrical energy DoD installations consume originates outside the fence. . . . In most cases, neither the grid nor on-base backup power provides sufficient reliability to ensure continuity of critical national*

priority functions and oversight of strategic missions in the face of a long term outage."[6]

The Task Force concluded that the DoD faces two primary energy challenges:

1. Unnecessarily high and growing fuel demand compromises operational capability and mission success;

2. Almost complete dependence of military installations on a fragile and vulnerable commercial power grid and other critical national infrastructure places critical military and homeland defense missions at an unacceptably high risk of extended disruption.[7]

The Task Force references the events surrounding Sept 11, 2001, massive blackouts in 2003 both domestically and in Europe, and Hurricane Katrina to emphasize their conclusions. Appendix G of their report details the implementation of microgrids to "island" those installations from external public utilities. Although it is classified, it is clear that this capability is highly sought after by the DoD.

Federal Mandate Compliance

The military also falls under the directives governing the Federal Government as a whole. The Department of Defense, through a combination of mandated Executive Orders and voluntary energy saving goals has direction to improve energy self-sufficiency and to decrease the environmental impact of its major domestic bases. Two primary areas of interest are expanding the use of collocated renewable energy production (Wind, Solar, Biomass), and to reduce the petroleum consumption and emissions of its fleet vehicles. Reduced environmental impact and enhanced energy security are a direct result of these interests. A list of the applicable directives is included in Table 1.

Table 1: Applicable Federal Directives

Title	Date of Release
Executive Order 13514 Federal Leadership in Environmental, Energy, and Economic Performance	October 5, 2009
Energy Independence and Security Act of 2007	December 19, 2007
Energy Policy Act of 2005	August 8, 2005
Secretary of the Navy Policy	October 14, 2009

The Federal Policy Goals established in these directives which directly apply to the implementation of Vehicle to Grid are:

1. *Reduce Vehicle Fleet Petroleum Consumption 30% by 2020 based on a 2005 baseline.*[8]

2. *Reduce GHG Emissions 28% by 2020 based on a 2008 baseline* [9].

3. *Optimize the number of fleet Alternative Fueled Vehicles* [10].

4. *Ensure that Renewable Energy Consumption by the Federal Government cannot be less than 7.5% after FY2013* [11].

These directives provide the metrics for V2G enabled vehicles in a non-islanded scenario. In normal operations, a V2G enabled fleet would meet all the transportation requirements of the existing petroleum powered predecessor system, but would do so at a significantly reduced requirement for petroleum and a reduced GHG output. They could also potentially enhance the efficacy of collocated renewable energy generation by providing energy storage during peak output. This is in keeping with the Task Force's first challenge: Reduce Fuel Demand. It does not however, justify implementation of V2G. This validates the replacement of conventional vehicles with a BEV/PHEV fleet whose energy is still supplied by a commercial utility supplemented with collocated renewable generation.

There is some potential for V2G to also provide financial incentive to the DoD installation as a public utilities customer in a non-islanded scenario. This would take the form of peak shaving in times of high demand and the potential to bid in the Ancillary Services market to provide Frequency Regulation or Spinning Reserve. The sizing of this fleet to meet the required reliability and contract size was studied thoroughly at Colorado State University [12] and validates the need for aggregation for V2G to be commercially viable. In the case of the DoD, the base itself would serve as the aggregator to optimize the ability to win contracts with the required reliability. In the author's opinion, this is a negligible benefit considering the operational limitations that would be imposed on the military vehicles and the potential for a reduced capacity for an emergent shift to an islanded microgrid. The real area of interest in V2G implementation for the DoD is in the "islanded" scenario, where the requirements and expectations for the technology change dramatically.

Grid Independence

It is the second of the Task Force's major energy challenges: Reduce Dependence on the Commercial Power Grid, where V2G interaction is of primary interest. In an islanded scenario, the installation is in effect, cut off from the commercial power grid which normally supplies electricity during day to day operation either voluntarily or due to a regional emergency. The installation must now operate at some desired (but reduced) capacity in order to accomplish its mission. With all generation now contained within the perimeter, the base must in effect become its own utility responsible for not only generating a subset of the Base Load, but also managing Spinning Reserve, Renewable Energy Smoothing and Ancillary Services. Two major programs are under development in the DoD to address this challenge directly, and V2G is planned for implementation in both.

SPIDERS **(S**mart **P**ower **I**nfrastructure **D**emonstration for **E**nergy **R**eliability and **S**ecurity)

As detailed in the SPIDERS Implementation Plan (Figure 1), the DoD has developed a stepwise program to demonstrate then deploy, islanded microgrids at domestic installations. It uses a traditional "Crawl, Walk, Run" approach with enhanced capability introduced in each phase for risk mitigation. The second "Walk" phase is to be implemented at Fort Carson, CO. It is planned for FY-12 funding and is currently up for proposal. It will incorporate five Smith Newton (80kWh) electric trucks to demonstrate a Vehicle to Grid capability, as well as a 2 MW photovoltaic (PV) array to increase the base's renewable and independent power generation. V2G implementation at Fort Carson can strictly be described as a demonstration however. The vehicle fleet of the base consists of over 500 vehicles of various size and missions, so five trucks would not provide the capacity to study the true effects of V2G on an islanded base. That study would most likely be accomplished at Camp Smith or later during a DoD-wide transition. It is the goal of this paper to determine whether V2G merits such consideration. When the National Renewable Energy Laboratory (NREL) performed an analysis of V2G in the case of Fort Carson, 75 Smith Newton and 18,000 Personally Owned Vehicles (POVs) were used to evaluate the V2G interaction with simulated normal and emergency load data. The SPIDERS program will be the first step in the verification of this analysis.

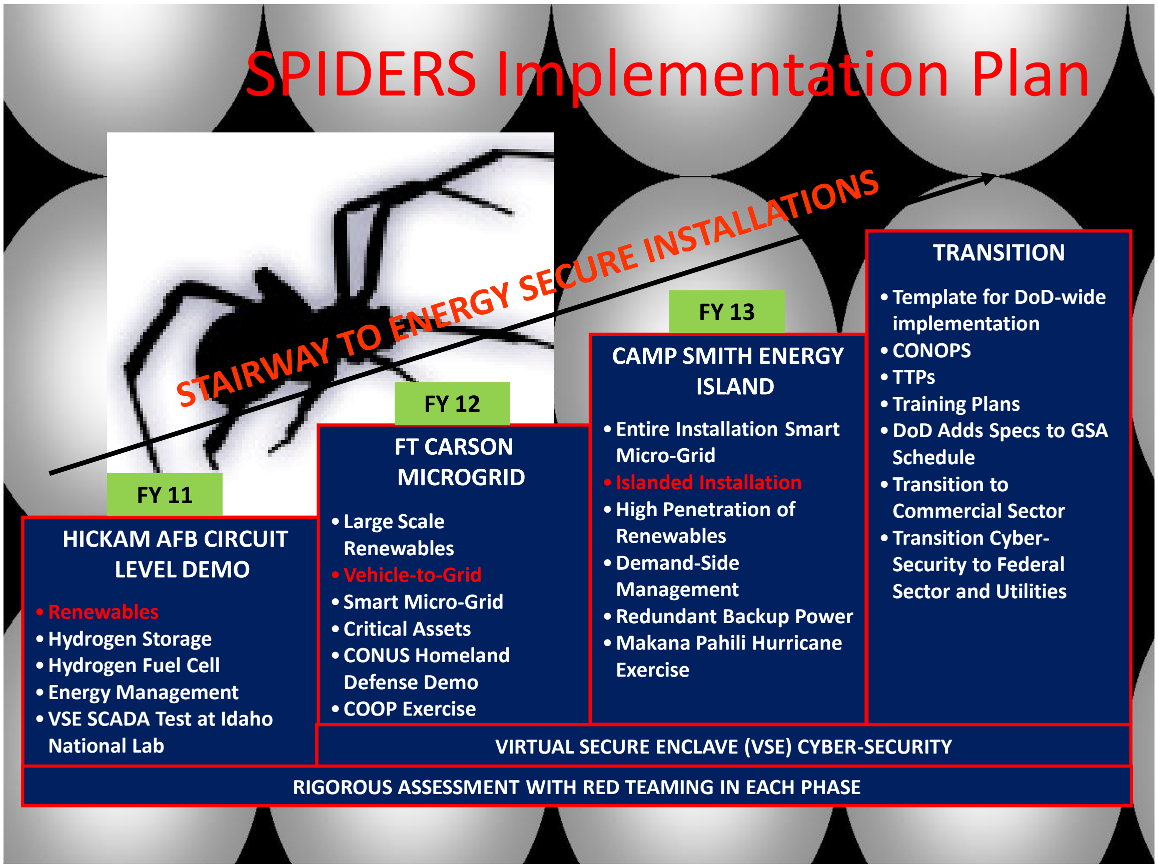

Figure 1: SPIDERS Implementation Plan [13]

Net Zero Energy Installations (NZEI)

The second DoD program with V2G components is the Net Zero Energy Installation (NZEI). Such a base is defined as:

> "A military installation that produces as much energy on-site from renewable energy generation or through the onsite use of renewable fuels, as it consumes in its buildings, facilities, and fleet vehicles."

The Army currently has 18 bases striving towards 2020 goals, of which Fort Carson is one [14].

Each of the bases in the program receives a NREL NZEI assessment to determine baseline energy usage of its buildings and vehicles, as well as its potential for energy conservation measures and renewable energy generation. This baseline will be used to judge

NZEI achievement as well as compliance with the Federal and DoD mandates for energy conservation measures. For the purposes of this thesis research, an actual DoD facility is studied and will be generically referred to as Military Air Base (MAB). The installation Mission Critical load data and transportation baseline used for analysis are actual, and were gathered from one of the military installations involved in the NZEI program. It has been sanitized to remove any operational vulnerability which might be exploited as a result of its publication.

CHAPTER 2 MOTIVATION FOR RESEARCH

There is ample motivation to research the viability of implementing V2G as it applies specifically to the Department of Defense. Certainly the DoD itself is interested in this capability as it has incorporated V2G into its own research as part of both SPIDERS and NZEI. There are several key areas which makes this research unique. The first of which is to explore an environment which utilizes controllable assets. The military application of V2G is markedly different from the civilian sector in that when required, all of the vehicles can be commanded to perform specific tasks. This includes time and location of charging (and discharging), State of Charge (SOC) management, desired cycle life, and daily mileage. Unlike an aggregated fleet of individuals whose behavior must be estimated and predicted, a fleet of military vehicles can be far more accurately directed for the desired effects. It does not require a probabilistic approach for optimization. The acquisition of V2G capable vehicles is also under precise control. Consumer preference must be predicted, while Defense Acquisitions is highly programmed and controlled.

Another motivation for research is that the DoD has already begun implementation and execution of a V2G system. This will provide an opportunity for data collection and real world analysis. While V2G will certainly be demonstrated, it is of interest to determine the scale with which it should be applied in follow-up phases of military microgrids. Vehicle to Grid systems have been demonstrated successfully on the small scale on numerous occasions by Kempton et al. and even the military itself, answering the question “Can it be done?”, but as no DoD installation (or any large civilian vehicle fleet/community) has a full scale V2G system in operation, the real question is “Should it be done?”

Once V2G is in place on an installation, there are many other considerations as to how it should be operated. There is also an operational component to a V2G enabled transportation system which must be explored in order to provide decision makers with better tools for implementation and use. The Base Commander who wants to optimize Expeditionary Power for example might manage the fleet SOC at the upper end of its capacity. In a different scenario, the vehicles may be kept fully depleted on a Friday in order to capture collocated renewable energy generated over a holiday weekend. There are also dramatically different requirements when connected to the public utility and when completely islanded. The system could not only be expected to provide transportation and Ancillary Services, but might also be used to meet Base Load for brief periods, or provide Spinning Reserve to conventional backup generators.

The DoD application of V2G also requires an evaluation of the metrics. In this environment, what are the best measures of V2G success? The metrics for V2G in the civilian application revolve around finances, not capability. If the civilian vehicle owner does not earn a financial dividend from participating in V2G, it is unlikely he will accept higher incremental cost, or the potential for reduced vehicle Utility Factor. In the military application, there are multiple possible alternative measures of success. These include: compliance with directives, collocated renewable smoothing, elimination of redundant power generation/storage for islanding, reduced distribution infrastructure, and Expeditionary Power potential. Although cost is certainly considered, new capability is also of interest.

Chapter 3 RESEARCH QUESTIONS AND HYPOTHESES

In order to focus the investigation, a series of research questions and hypotheses were developed. Each question aids in developing a systematic method to determine the critical performance metrics of a V2G enabled transportation system, while the hypotheses state the expected performance of the system. They are listed below with no particular priority placed on their order:

Research Questions

1. The Department of Defense is under directive to implement energy saving measures and satisfy performance metrics with specific milestones and baselines. Is Vehicle to Grid (V2G) a valid technology to achieve any or all of the four major performance indices mandated by these directives?

2. What are the characteristics of a V2G enabled system which justifies its implementation regardless of cost effectiveness, ability to comply with mandates, or any other limitations?

3. Under an "islanded" scenario, what are the capabilities of a V2G enabled system?

4. What are the key components of a Standard Operating Procedure (SOP) to govern the daily use and emergent deployment of V2G assets?

Hypotheses

1. V2G provides advantages over a system utilizing traditional power generation (Diesel, CNG) and a non-V2G electric vehicle fleet.

2. V2G enhances firming of on-base renewable energy assets, particularly in an "islanded" scenario.

3. While V2G may not be the most cost effective method to operate Mission Essential loads, in an islanded scenario it provides new capabilities for the leadership during Emergency Operations.

4. In non-islanded operations, V2G enabled vehicles are an effective means for complying with applicable Federal Policy Mandates concerning energy conservation, fossil fuel substitution, and GHG reduction.

CHAPTER 4 BOUNDARY CONDITIONS

It is important to establish boundary conditions to scope this research to an appropriate scale. These boundary conditions are listed below:

1. *Consider only Non-Tactical vehicles for their V2G capability*.

The federal mandates are restricted to fleet vehicles, not tactical ones. While the DoD certainly has interest in applying fuel conservation and environmental standards to combat vehicles, it is much more practical to determine the most effective measures with commercial fleet vehicles (which have a relatively fast and low cost acquisition timelines) and then apply the technology to combat vehicles later. Fleet vehicles are also held to a much lower standard for operating envelope and durability in line with other Commercial Off- The-Shelf (COTS) products utilized by the DoD. This makes them more suited for developmental research.

2. *Personally Owned Vehicles (POVs) are not included in the V2G fleet composition.*

The NREL study into V2G application as part of NZEI at Fort Carson [15] assumes that the commuter fleet of vehicles will make up the bulk of the assets and energy available for V2G (see Figure 2). A Bass Diffusion Model was used to estimate the acceptance of the BEV/PHEV by the military and civilian workforce, resulting in 18,000 vehicles by 2030. The NREL model is not of interest to the investigation in this thesis in that: 1) POVs are not truly commandable by military leadership, so a probabilistic approach is required to describe their behavior. 2) In an islanded condition, there is likely to be a dramatically reduced POV population. 3) Consumer acceptance of PHEV/BEV is overestimated. At the time of this writing, GM has halted production of the Volt at 7,500 cars [16], and Nissan has only produced 27,000 Leafs [17] worldwide. DoD acquisition of AFVs is predictable and directed, the consumer's much less so. The large energy storage capacity illustrated in the middle of the day is unlikely to be available.

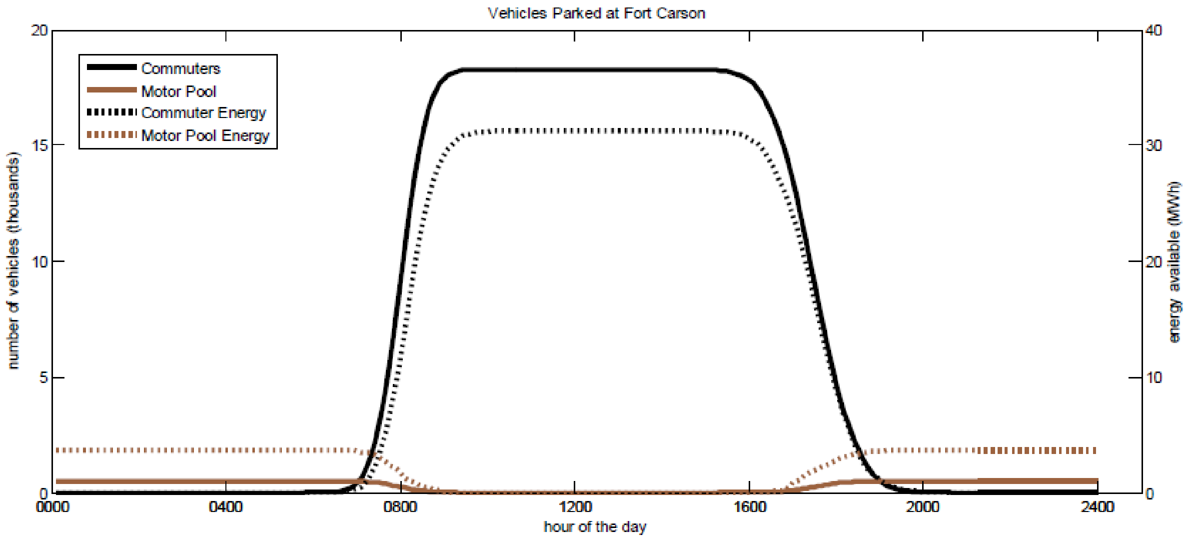

Figure 2: Commuter and fleet vehicles available at Fort Carson during weekdays [18]

3. Only Mission Critical loads are studied

The MAB data applied to study power and energy scale and behavior only includes the Mission Critical loads of the installation. It is likely that in the event of an islanded scenario, demand would be restricted to these loads until the conventional grid is restored, at least until highly developed microgrids are widely deployed in the DoD.

4. The islanded condition is the focus for V2G evaluation.

The behavior of a V2G enabled system is of most interest when low cost energy from the public utility is not available. In normal operation, the vehicle fleet would most likely operate as PHEV/BEVs connected to conventional power generation from outside the installation. In this non-islanded condition there would be minimal V2G interaction with the public utility except if Ancillary Services contracts are being bid. The one circumstance where non-islanded performance of the system is of interest is when petroleum substitution and GHG emissions are evaluated. The target of the federal mandates to reduce the environmental impact of fleet vehicles concerns daily operations, not the emergent operation associated with an islanded condition. Backup generator emissions during islanding are not included in the calculations for GHG and fossil fuel usage. It is assumed that leadership will waive increased environmental impact during emergency operation.

5. E85 and Biodiesel vehicles do not actually meet the intent of the mandates for fossil fuel substitution and are not included in this analysis in terms of optimizing compliance with those mandates.

The DoD currently maintains a large fleet of Flex Fuel (FFV) and Biodiesel capable vehicles, and claims 100% credit for petroleum substitution. This premise underestimates the actual petroleum use by 15% in the case of E85 and 80% for the B20 typically utilized. The life cycle petroleum usage of these fuels is also not considered. Numerous energy surveys of installations also reveal that E85 and Biodiesel are not readily available, even if the vehicles are capable. It is my contention that the use of electricity for fuel substitution is the true intent of the mandates and an optimized fleet including other AFVs not be considered for minimization of emissions or optimizing AFV utilization.

CHAPTER 5 RESEARCH PLAN

In order to effectively understand and quantify the behavior and performance of a V2G enabled fleet, a series of research tasks was developed. These tasks fall into the broad categories of: understanding the power requirements of the installation during islanding, quantifying the power and energy storage capacity of the V2G fleet, and comparing the capability of the fleet with system requirements and performance metrics of mandated policy. The analysis and results of each task appear in Chapter 6. The research tasks were:

A. Analyze and collate MAB load data to determine the characteristics and demand of an actual major installation in an islanded condition.

B. Establish a BEV/PHEV transportation fleet based on the existing MAB assets. Substitute the 2012 Toyota PHEV Prius, 2012 Chevy Volt, 2012 Nissan Leaf, and Smith Newton electric truck (80 kWh) as applicable to model the capability and cost.

C. Determine actual annual fleet vehicle energy usage and characterize the type of daily/annual operation.

D. Calculate petroleum saving by substituting BEV/PHEVs for the existing fleet.

E. Establish renewable energy generation based on existing/planned DoD assets and MAB environmental data.

F. In an islanded condition, determine the V2G energy storage capabilities for on base renewable generators.

G. In an islanded condition, determine the validity (if any) of utilizing V2G to replace or smooth conventional power generation.

H. Identify SOP components for the V2G system.

I. Employ a GREET Analysis of the representative V2G System during normal operations to evaluate GHG and other emissions.

CHAPTER 6 ANALYSIS AND RESEARCH RESULTS

This chapter will evaluate each of the tasks established in the research plan and provide the analysis and results to determine the viability of a V2G system as it would be deployed at an actual military air base.

A. Analyze and collate MAB load data to determine the characteristics and demand of an actual major installation in an islanded condition.

Data from a domestic Military Air Base (MAB) was evaluated to provide realistic energy and power requirements to apply to a V2G system in an islanded condition. To summarize, the data consisted of 305 days of observations at 15 minute intervals of the Mission Critical loads. The demand is the sum of the 4 feeders and 41 individual loads, and due to minimal system impedance, can be treated as a single load. It is assumed that none of the existing backup capability was being utilized during the observations, and that the data is considered to be "Normal Operations." It is also assumed that these loads would not change in the event of Emergent Operations or as a result of islanding. Unfortunately, this assumption deviates from expected system behavior in the event of an actual deployment of an islanded microgrid. Installation Operational Tempo (OPTEMPO) would most likely increase during microgrid operations, and the probability of three days of "Holiday Routine" would approach zero. This phenomenon would likely result in increased demand on the Mission Critical loads. The data does provide real world insight into the magnitude and variation of the loads across a single day, a work week, and with respect to seasonal variation. The relative OPTEMPO and other external factors such as weather at the installation during the observation period when compared to other years are unknown.

The data was incomplete in that it did not cover an entire year, so it was manipulated to make it easier to evaluate. The first two days of observations were removed, so that the first data point would coincide with 0001L on an assumed Sunday. The last 23 days of data was removed, so that the data could be parsed into ten, four week long months. In this way, the data is sanitized, as it does not coincide directly with a given calendar month or day. Although the actual season where the data begins is not published, it is assumed to be summer. Peak loads tend to revolve around additional air conditioning requirements, and these are observed in the early months of the data. The missing months would therefore coincide with springtime. This is a period of neither high nor low extremes, and is therefore of limited interest for system design and evaluation. The partial data for this period was analyzed and no atypical or peaking behavior was observed. Figure 3 illustrates the weekly energy requirements determined by integrating the power observations using the MATLAB “trapz” function.

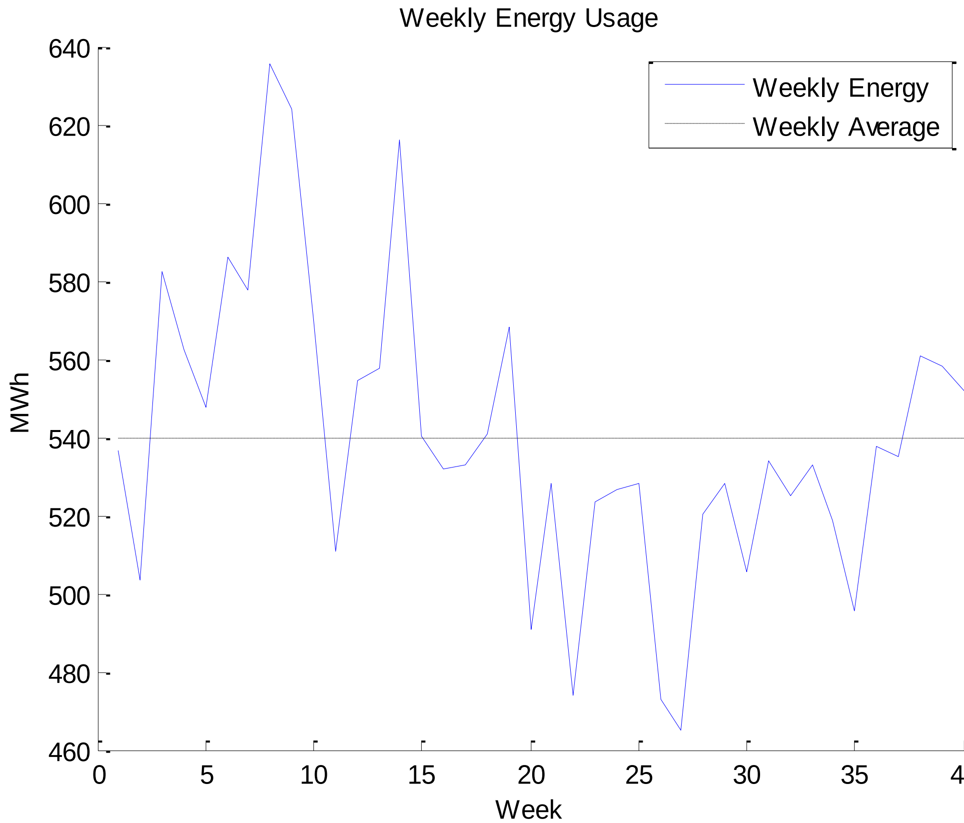

Figure 3: MAB Weekly Energy Usage on MC Loads

In publishing Requests for Information (RFIs) to implement microgrids, the DoD has demonstrated interest in a 2 week capability for islanding an installation, with the expectation of shorter periods being more likely [19]. Clearly the design of such a system for MAB should focus on Weeks 8/9 for determination of the maximum desired capability, and weeks 26/27 for establishment of the minimum requirements. These define the Weeks of Interest for this thesis. The behavior of the system during these weeks of interest is portrayed in Figures 4-6.

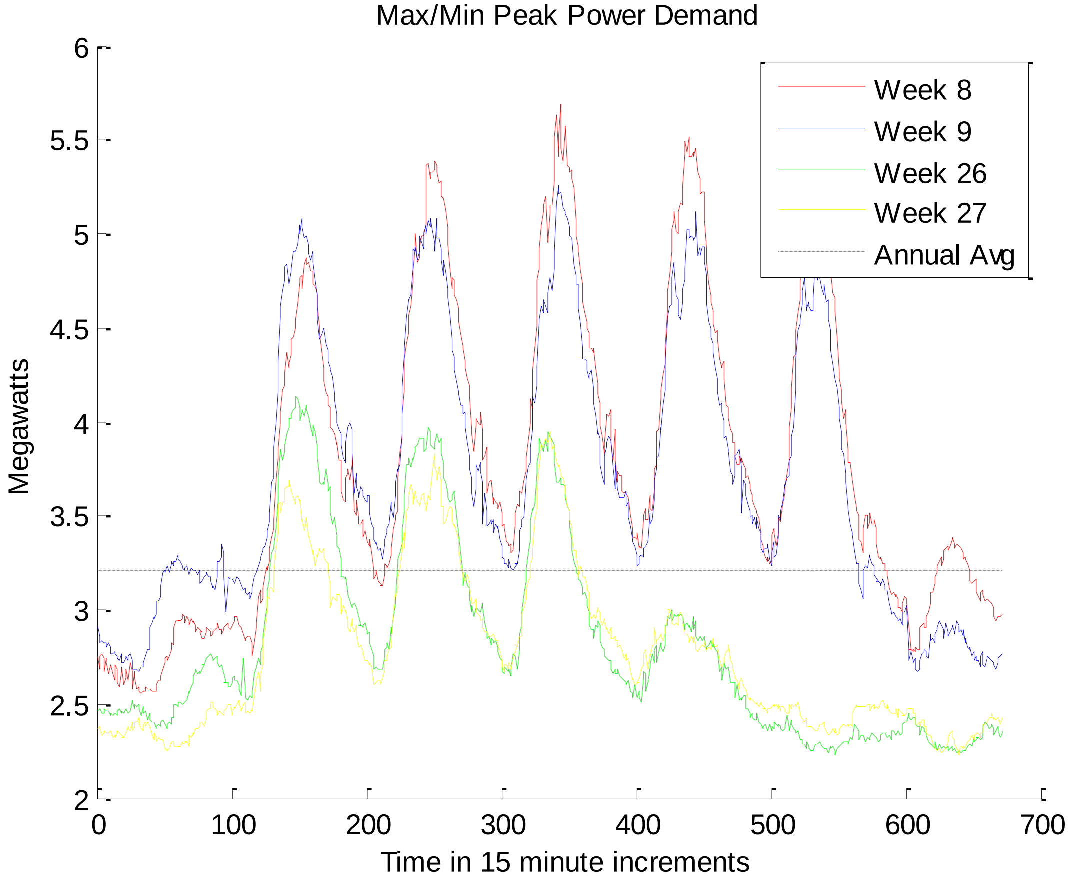

Figure 4: MAB Power Demand on Weeks of Interest

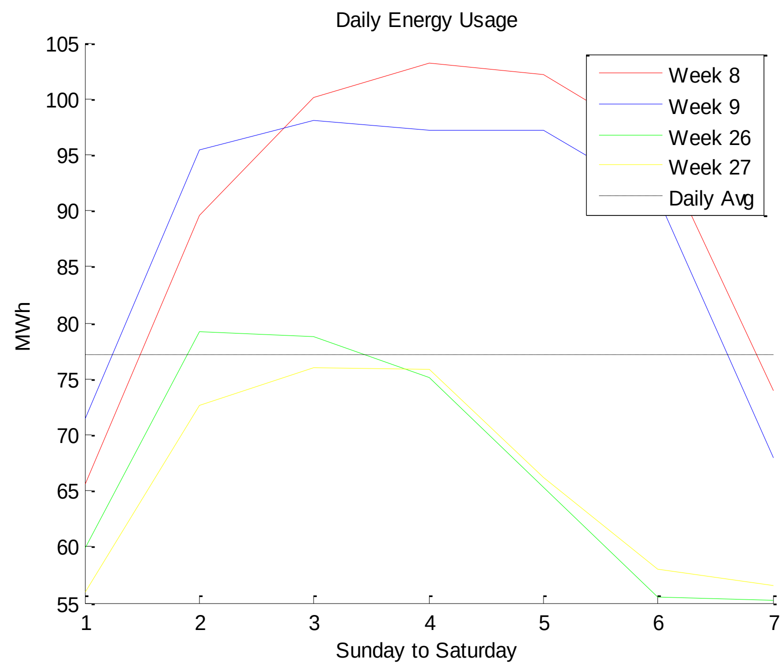

Figure 5: MAB Daily Energy Required during Weeks of Interest

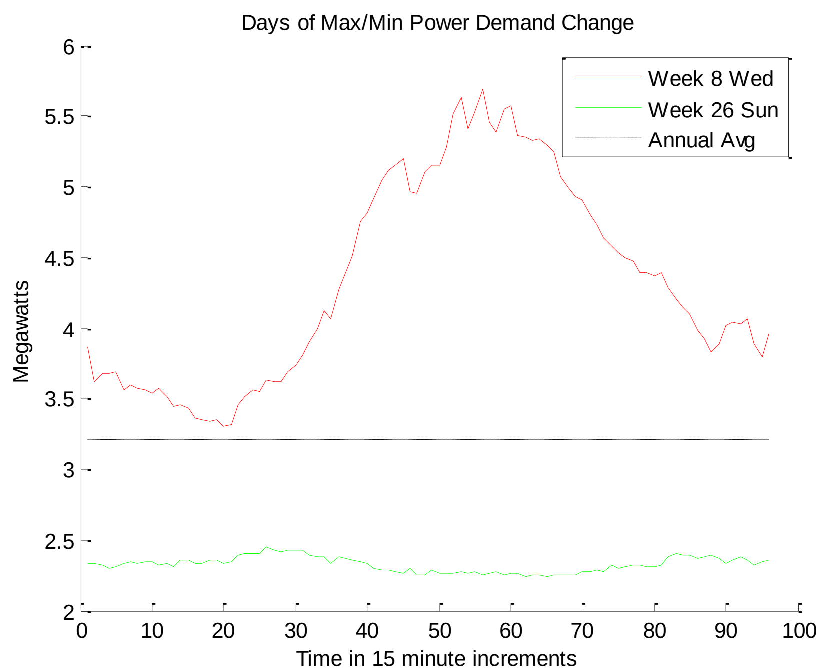

Figure 6: MAB Extreme Days of Power Demand Change

Load Synthesis:

Maximum Demand on the Microgrid

- Maximum power and energy requirements for a two week period are Weeks 8/9
- Peak power demand was 5.7 MW occurring @ 2pm on Wed, Week 8
- Week 8 was the maximum weekly energy required (630 MWh). It also contains the annual peak power demand (5.7 MW), the maximum daily change in power demand (2.4 MW), and the maximum daily energy required.
- Week 9 was the penultimate energy use week (618 MWh) and makes up the remainder of the upper extreme 2 week period.
- An apparent working weekend connects Weeks 8/9.
- Maximum energy usage for a single day of the week never occurred on a weekend.
- Maximum energy usage for a single day was most likely on a Thursday (14 of 40 weeks).

Minimum Demand on the Microgrid

- Minimum energy demand for a 2 week period occurred during Weeks 26/27
- This period was two consecutive 3.5 workday weeks (Thu half day/Fri off)
- Week 27 had the minimum weekly energy usage (461 MWh).
- Week 26 had the second lowest energy usage (469 MWh) and makes up the lower extreme 2 week period.
- Minimum daily power demand change for the weeks of interest occurred in Wk 26 (209kW).
- Minimum power demand for the minimum energy weeks was 2.6 MW occurring @ 815am on Sun, Week 27.

- Minimum energy usage for a single day of the week only occurred on a weekday twice (once Monday, once Friday, probable holidays)
- Minimum energy usage for a single day was most likely on a Sunday (26 of 40).
- Absolute minimum power demand for the data was during Week 32 (2.22 MW). This week is not of interest as the energy and power deltas are in no other way extreme.

Average Demand on the Microgrid

- Average Power Demand was 3.2 MW from data.
- Average Energy for a week was 540 MWh.
- Average Energy for a day is 77 MWh

Load Results:

The load data can be characterized as follows:

- The Mission Critical loads follow distinct patterns in terms of Time of Day, Day of the Week, and by Season. The power demand peaks in early afternoon on weekdays and is substantially lower at night. Power demand is notably lower on weekends/holidays and the demand is relatively constant throughout these off days. Demand is much higher in summer and can be associated with daytime air conditioning. Minimum annual requirements occur around the winter holiday season.
- 5.8 MW of power generation on base would be required to meet islanded demand without additional load shedding. No less than 2.3 MW of generation is required at all times. An average of 3.2 MW is required throughout the observed data.

- For a study of performance for a 2 week islanded operation, the data from Weeks 8/9 should be the focus for maximum performance. Weeks 26/27 defines the minimum performance requirement.
- The 60 days of incomplete or omitted observations does not likely constitute a period which is critical to design or analysis of a V2G system.

B. Establish a BEV/PHEV transportation fleet based on the existing MAB assets. Substitute the 2012 Toyota PHEV Prius, 2012 Chevy Volt, 2012 Nissan Leaf, and Smith Newton Electric Truck (80 kWh) as applicable to model the capability and cost.

Summaries of the existing Conventional Vehicles (CVs) and the fuel usage for MAB and Fort Carson were published in the NREL NZEI assessments as the transportation baseline of each installation. The existing CV fleet for MAB consisted of 262 vehicles powered by gasoline, compressed natural gas (CNG), and diesel/biodiesel (B20). A total of 175,500 gallons of petroleum based fuel is available to be displaced by the V2G fleet annually [20]. What is noteworthy about MAB Table 2 is that there are 102 Flex Fuel Vehicles (FFV) capable of using E85, but these vehicles were being operated on gasoline not ethanol during the 2008 baseline The NREL report cites a lack of E85 availability which may have been remedied since. In later GHG analysis it will be assumed that these vehicles were being operated on gasoline, not as AFVs. In terms of mandate compliance, FFVs are considered a 100% replacement for petroleum, as are Diesels operated on B20. It begs the question of how these vehicles are being reported up the Chain of Command. The Fort Carson fleet is twice as large, consisting of 520 vehicles (Figure 9.) consuming 276,500 gallons distributed as illustrated in Figure 10 [21].

Table 2: MAB Conventional Fleet Vehicles and Fuel Usage [22]

Vehicle Fuel Type	Number of Vehicles	Fuel Used (gallons)
E85 Flex Fuel	102	0
Gasoline	102	89,500
CNG	53	45,000
Diesel	5	31,000 Biodiesel (B20) 10,000 Conventional
TOTAL	**262**	**175,500**

Table 3: Fort Carson Conventional Fleet Summary 2009 [23]

Vehicle Type	Gasoline	Diesel	E85	CNG	Hybrid	Total
Van	83	3	50	29	-	165
SUV	10	-	80	-	32	122
Pick-up	51	24	38	11	-	124
Sedan	-	-	21	-	6	27
Bus	-	32	-	-	-	32
Heavy Truck	-	11	-	-	-	11
Ambulance	-	5	-	-	-	5
Other	24	10	-	-	-	34
Total	168	85	189	40	38	520

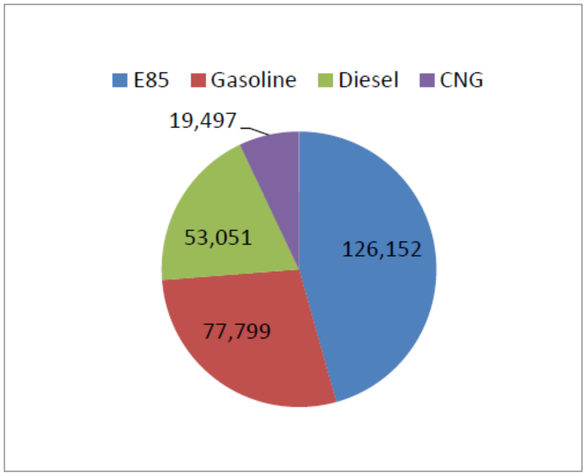

Figure 7: Fort Carson Fleet Fuel Use Estimates (gals) [24]

What is not known for either of these representative CV fleet, is the actual fleet make up in terms of individual vehicle make/model, fuel economy, or annual mileage. NREL has reported that MAB ". . . uses its fleet of vehicles for ground maintenance, security and other purposes. The majority of the vehicles are pickup trucks or sport utility vehicles."[25] For the purpose of the V2G analysis, an average fuel economy of 10 mpg was assigned to determine the required miles needed to meet the annual operational demands of the vehicles. This fuel economy was selected based on the vehicle types found in the inventory at Fort Carson which is also made up almost exclusively of large trucks, vans, and SUVs. It is also likely that for the most part these vehicles are being operated in a manner best represented by the "City" type of drive cycle. It can be assumed that the MAB fleet would be comprised of similar types of vehicles.

Also unknown was the actual operational requirements of each vehicle. As there are no large scale production PHEV variants of an SUV or pickup truck for example, it is assumed that one of the V2G enabled sedans or trucks would be able to perform the desired mission of the existing CV. This would most likely include passenger transport, security patrols, delivery of large loads, or other logistics services. It is important to note that this report investigates strictly fleet vehicles, not tactical ones. The circumstances are extremely rare that anything but moderate on road use is required of these vehicles, and if it were a tactical vehicle could be assigned the mission. NREL reported:

> *"Given the relatively small number of sedans in the fleet, there may be an opportunity to downsize to smaller more fuel efficient vehicles and move away from large pickups and SUVs where the mission does not dictate a need for these larger vehicles. If there are instances where a vehicle is used primarily for passenger transportation, a small sedan may well meet the fleet needs*."[26]

This underlines that a transition to a fleet with vehicles similar to those assigned in the following analysis would be desirable in any case.

It is the primary focus in assigning a representative V2G enabled fleet that such vehicles are actually available and in large scale production, not prototypes or concept cars. In this way, the actual power and energy capacity of the vehicles is known as well as their performance using standard EPA fuel economy and emissions testing. The vehicles selected were the 2012 Toyota PHEV Prius (PHEV10), the 2012 GM Chevrolet Volt (PHEV35), the 2012 Nissan Leaf (BEV), and the Smith Newton Electric Truck (BEV). Each of these vehicles can be purchased in the open market in large quantity if desired. With the exception of the PHEV Prius, all appear on the GSA approved vehicles list making them available for purchase by federal agencies. The conventional Prius is already GSA approved and it is anticipated that the PHEV variant, currently in its introductory year, will soon follow.

Representative V2G 2012 Production Vehicles

Figure 8: Toyota PHEV Prius

<u>PHEV</u>

2012 Toyota PHEV Prius

3.5 kWh usable Battery Capacity

3.3 kW Power

6 mi electric range

87 MPGge

Unlimited total range

$ 30,721

Figure 9: Nissan Leaf

BEV

2012 Nissan Leaf

19.2 kWh usable Battery Capacity

6 kW Power

73mi electric range

99 MPGge

$ 35,439

Figure 10: Smith Newton (80kWh)

BEV

2012 Smith Newton (80kWh)

64 kWh usable Battery Capacity

20 kW Power

47mi electric range

19 MPGge

$ 139,754

V2G capability for any proposed fleet of production vehicles is strictly notional at this time even though small scale demonstrations have been performed. When discussing current models, none are actually V2G enabled as they sit on the showroom floor. In fact, use of the vehicle as a power source voids the conventional warranty. Bidirectional capability requires either onboard or fixed Electric Vehicle Support Equipment (EVSE) to convert their DC battery capacity into useable AC power which could then be integrated with a conventional grid. This equipment is already being developed in Japan for use with the Leaf (Figure 8). Since this is fairly mature technology, the advertised 6 kW rating was utilized to represent the power capability of the Nissan BEV.

Figure 11: Nissan Power Control System (6 kW through CHAdeMO compliant connector) [27]

To assess the power output potential of the two PHEVs, only the listed charging capacity was utilized as potential for output since the required EVSE does not yet exist. Level 2 charging of Volt and Prius is restricted to:

240 VAC * 16A* 85% charger efficiency = 3.3kW

The Smith Newton Electric Truck is expected to have a Level 3 charging capability for fleet use. Level 3 standards are still being developed and apply to charging power greater than 20kW. This value was assigned the Newton for its notional power output capability.

V2G enabled vehicles in the future will most likely have increased power output potential restricted only by the discharge limitations of their batteries and the nature of their connection to the grid. Currently the J1772 connection is limited to 19.2 kW (240V AC level 2) and the CHAdeMO is limited to 62.5 kW [28] (DC Fast Charge). The SAE is currently developing new standards for each which would increase these available outputs with a combo plug to 90 kW (200-450V DC Level2) [29]. This would dramatically increase the power potential for a V2G enabled system.

In terms of energy storage, many previous analyses utilize the nameplate capacity of the vehicle battery. This is an overstatement of the usability for application in V2G systems because the available energy from a battery is limited by manufacturer's state of charge limitations. For example, the GM Volt allows only 10.4 kWh of the 16 kWh nameplate capacity to be used, thereby reducing battery degradation, and Nissan does not recommend charging if the battery SOC is greater than 80%, and does not recommend discharge below 10% SOC. In this study, usable battery energy was defined at 80% of nameplate capacity for the Prius, Leaf, and Newton and the published 10.4 kWh capacity was used for Volt.

Two fleet compositions were considered for the analysis. A summary of the capabilities of each is listed in Table 4 and Table 5. Calculations used to derive these tables are included in Appendix A. The Mixed Fleet replaces the existing CV assets with equal quantities of all the representative V2G vehicles. This provides increased flexibility. Able to operate on gasoline as well as electricity, they have unlimited range if fuel is available and could be utilized for missions outside the installation perimeter even in the event of large scale power failure. They could also operate as mobile generators in a limited capacity if the situation dictated. This flexibility comes at the price of decreased storage capacity, decreased power output, and potential for reduced petroleum replacement credit and increased GHG emissions.

Table 4: Mixed PHEV/BEV Fleet Capability

Vehicle Type	Vehicles Quantity	Power	Energy Capacity	All Electric Range	GSA Cost [30]
PHEV Prius	65	3.3 kW	3.5 kWh	6 mi	$30,700
GM Volt	65	3.3 kW	10.4 kWh	35 mi	$37,400
Nissan Leaf	65	6 kW	19.2 kWh	73 mi	$35,400
Smith Newton	65	20 kW	64.0 kWh	47 mi	$139,700
Fleet Totals	**260**	**2.1 MW**	**5.9 MWh**	**10,500 mi/day**	**$15,800,000**

The second fleet is made up of strictly of EVs. This would be the fleet that would maximize the potential for V2G interaction as it has the largest energy storage capacity, largest power output, as well as the greatest all electric driving miles available.

Table 5: All EV Fleet Capability

Vehicle Type	Vehicles Quantity	Power	Energy Capacity	All Electric Range	GSA Cost
Nissan Leaf	130	6 kW	19.2 kWh	73 mi	$35,400
Smith Newton	130	20 kW	64.0 kWh	47 mi	$139,700
Fleet Totals	**260**	**3.4 MW**	**10.8 MWh**	**15,600 mi/day**	**$20,500,000**

Vehicle Fleet Results

The mixed PHEV/BEV fleet of 260 vehicles would provide 5.9 MWh of energy storage and 10,500 daily all electric miles assuming once daily charging. At its maximum power output, this system could provide 2.1 MW for 2 hours 47 minutes (or 2 MW for 2hr 57min). This would come at a cost of $15.8 million in vehicles alone, not including operating costs or additional electrical infrastructure.

The all EV fleet of 260 vehicles would provide 10.8 MWh of energy storage and 15,600 daily all electric miles assuming once daily charging. At its maximum power output, this system could provide 3.4 MW for 3 hours 11 minutes (or 2 MW for 5hr 24 min). This would come at a cost of $20.5 million in vehicles alone.

C. Determine actual annual fleet vehicle energy usage and characterize the type of daily/annual operation.

In this section, the transportation baseline data is used to determine the operational requirements of the vehicle fleet and gain insight into the daily operations of the individual vehicles. An estimated average fleet fuel economy is used based on the composition of the existing CV fleet. Of interest is whether a V2G fleet can meet the transportation requirements of the existing fleet, and whether enough additional battery capacity exists to allow them to perform as viable energy storage. Using the following equations to determine the daily mileage requirement:

$$D_{yr} = F_{tot} * MPG_{avg} \ / N$$

$$D_{day} = D_{yr} /365$$

At MAB, the CV fleet provides:

$$F_{tot} = 175{,}500 \text{ gal/yr}$$
$$MPG_{avg} = 10 \text{ mi/gal}$$
$$N = 262 \text{ vehicles}$$

$$\mathbf{D_{day} = 18.4 \text{ mi/vehicle/day}}$$

At Fort Carson the CV fleet provides:

$$F_{tot} = 276{,}500 \text{ gal/yr}$$
$$MPG_{avg} = 10 \text{ mi/gal}$$
$$N = 520 \text{ vehicles}$$

$$\mathbf{D_{day} = 14.6\ mi/vehicle/day}$$

A PHEV/BEV Mixed fleet would provide:

$$\mathbf{D_{day} = 40.3\ mi/vehicle/day} \quad \text{(all electric miles, once daily charging)}$$

An EV fleet would provides:

$$\mathbf{D_{day} = 60.0\ mi/vehicle/day} \quad \text{(all electric miles, once daily charging)}$$

Depending on vehicle class, an annual utilization rate for federal fleet vehicles of 7,500 to 12,000 mi/yr is recommended (20.5-32.9 mi/day) [31]. In their NZEI assessment, NREL reported that Fort Carson vehicles are waived from this recommended utilization down to a 3,600 mi/yr reduced utilization rate due to the operational nature of their mission. Even with the reduced expected utilization, 33% of the vehicles drove even less, and have low annual odometer readings due to infrequent use or short driving distances.

Vehicle Usage Results:

These calculations show that the fleet vehicles of these two installations are highly underutilized for transportation purposes. While this is indicative of inefficiency in a conventional vehicle fleet, it actually improves the viability of a V2G transportation system. The V2G fleet provides up to 3 times the average daily requirement for mileage on a single charge. The results of this analysis indicate:

- Both the Mixed fleet and the All EV fleet can meet the daily average distance requirements for transportation assets without using gas and without recharging.
- V2G vehicles can be kept at low states of charge, ready to perform energy storage and still meet the operational transportation commitments.
- The all electric range of the PHEV Prius is below the average daily requirement. The Prius is therefore less useful as a V2G asset when assuming once daily charging. It

would still be able to complete all the missions utilizing conventional gasoline, but at reduced efficiency. If it is to be used at all, it should be applied to a mission where it is usually driven short distances and it could be recharged frequently. A flightline crew service vehicle would be such an application.

- With such limited driving distances required, the Utility Factor of the PHEV/BEV fleet is very high.
- The excess range available in the V2G assets would provide a substantial quantity of energy to the grid or an ability to store it depending on operational requirements and the user's desires.

D. Calculate petroleum savings available through substituting BEV/PHEV for the existing fleet.

This research task seeks to calculate the petroleum savings available to the MAB through the electrification of the on-base vehicle fleet. In general, fleet electrification has been shown to reduce the petroleum consumption of a fleet relative to conventional vehicles [32]. The degree of petroleum reduction available at this MAB with the fleet characteristics proposed in Research Task B will be quantified by modeling the anticipated vehicle usage, charging behavior, and petroleum content of electricity for both PHEVs and EVs.

Petroleum Usage/Savings Calculations:

In both the US average mix and the CA mix of power generation, petroleum-derived electricity makes up less than 1% of all electricity production. Therefore for this study, petroleum reduction figures do not account for the petroleum used to generate electricity. With this assumption, there is no petroleum consumed in fueling and operating the BEV. This is not the case for the PHEV. If the mission exceeds the all-electric range of the vehicle, or if a mission is required when the vehicle is at a low state of charge, petroleum would be required to complete that mission albeit at a much reduced rate of consumption when compared to the CV. The Chevy Volt operates at 37mpg combined in charge-sustaining mode, and the PHEV Prius at 50mpg. Even operating on gasoline alone, both vehicles could reduce petroleum consumption by 30% over the existing 10mpg average CV fleet, in compliance with the Federal Mandates.

As petroleum usage for a PHEV is dependent on both SOC management and driving behavior, it is important to understand how the vehicles are being driven each day. Concerning SOC management, once daily charging is assumed because this is a worst case evaluation. In the V2G implementation, the vehicle would potentially be charging much more frequently but may be required to discharge as well so the once daily charge accounts for this potential SOC variability. Predicting driving behavior is also difficult as the distance required for each particular trip can result in dramatically different fuel economy. In an effort to predict this, Utility Factor is applied to estimate the petroleum usage. For fleet vehicles, the SAE J2841 Utility Factors for City driving are applied as these more closely approximate the way in which military fleet vehicles are operated on a daily basis. The SAE J2841 utility factor is shown in Figure 9. The utility factor represents the ratio of the number of miles driven under charge-depleting mode to the total number of miles driven by a vehicle fleet. The J2841 UF is derived from the driving habits of the US light-duty vehicle fleet as measured by the 2001 National Household Transportation Survey (NHTS).

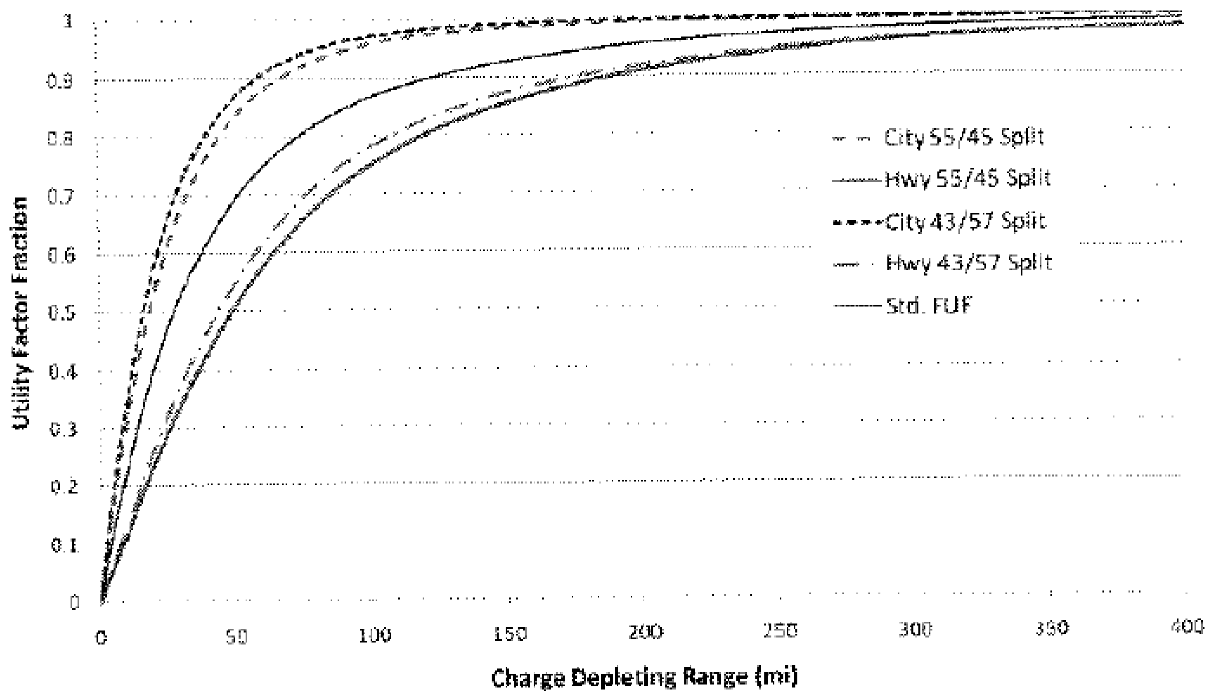

Figure 12: SAE J2841 Utility Factors [33]

The J2841 method yields a UF of 0.17 for a PHEV(5) and 0.722 for a PHEV(35) on the 55% City / 45% Highway profile [34]. Based on these assumptions regarding vehicle usage, the annual petroleum usage can be calculated as:

Annual miles per vehicle type * (1-UF) / Mpg = Annual gallons

For the PHEV Prius, the annual gasoline consumption can be calculated as:

439,000 mi/yr * (1-.170)/50mpg = 7287 gallons

For the Volt, the annual gasoline consumption can be calculated as:

439,000 mi/yr * (1-.722)/37 mpg = 3298 gallons

For PHEV Prius, a higher fraction of the annual of annual vehicle miles require gasoline since it has a much smaller electric range.

Petroleum Usage/Savings Results:

The Mixed fleet would consume 10,585 gallons of fuel annually, or 6% of the Baseline CV fleet. The EV fleet would completely eliminate petroleum consumption for vehicle operation. It is also interesting to determine what the minimum number of conventional vehicles replacements are required to comply with the Executive Order. For a 30% petroleum reduction at MAB a total of 52,650 gallons would need to be displaced annually. Each vehicle averages 670 gal/yr, indicating that the MAB petroleum consumption goals could be accomplished by replacing 79 CVs with EVs.

In summary, the petroleum saving by electrifying the MAB fleet regardless of its composition easily meets the targets for petroleum replacement. By converting less than 25% of the vehicles to EVs, the DoD would be able to meet its goal, but that would come at a much reduced potential for V2G viability due to a marked decrease in potential energy storage.

E. Establish renewable energy generation potential based on existing/planned DoD assets and MAB environmental data.

The goal of this research task is to understand the timing and quantity of renewable energy resources at the subject installation. Due to its higher availability and penetration of renewable energy, Southern California was selected to represent the location of MAB. Data from San Diego was utilized to model PV performance for this analysis. According to the NREL assessment, there is poor potential for wind power at MAB, so it is not considered in the analysis. This is due to a lack of natural resource and the operational difficulties of operating air search RADARs and wind turbines simultaneously. No wind power generation exists or is planned. This is regrettable in terms of the V2G application. Wind power generation often occurs at night, when vehicle use is minimal and charging opportunities are improved. Wind is also far less predictable than other renewable and would benefit more from the smoothing that V2G could provide.

According to the desired microgrid capability for MAB, a 3 MW of Landfill Gas Generator is planned as part of the renewable energy generation capability. This generator provides consistent power to the installation either in an islanded or non-islanded condition [35].

The potential for solar power generation is high at MAB. An analysis of available energy was performed based on arrays which either exist, or are planned for the installation by 2020. The total planned PV assets for MAB are 2.3 MW [36].

Using the NREL PV Watts v2 online tool, the PV annual energy production for 2.3 MW at MAB is 3405 MWh/yr. The data generated by PV Watts and utilized for the PV potential calculations is attached as Appendix B. Concerning the magnitude of the PV assets, the following was determined [37]:

Table 6: PVWatts modeled solar PV energy production at MAB

Average Modeled Solar AC Power Production	3405 MWh / 365 days	9.3 MWh / day
Peak Monthly Solar AC Power Production (August)	309 MWh / 31days	10.0 MWh / day
Minimum Monthly Solar AC Power Production (December)	239 MWh / 31 days	7.7 MWh / day

As would be expected, there is seasonal variation in PV output, with the maximum occuring in summer, and the minimum occuring in winter. The variation at MAB is not as extreme as can be expected in other part of the country. This can be attributed to sea level elevation, and proximity to the ocean, as well as its geographic location. This is beneficial to developing a V2G system which can be used throughout the year.

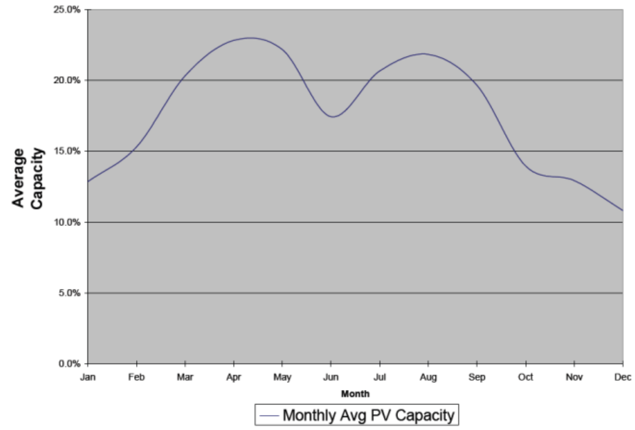

Figure 13: MAB Solar Potential based on Season [38]

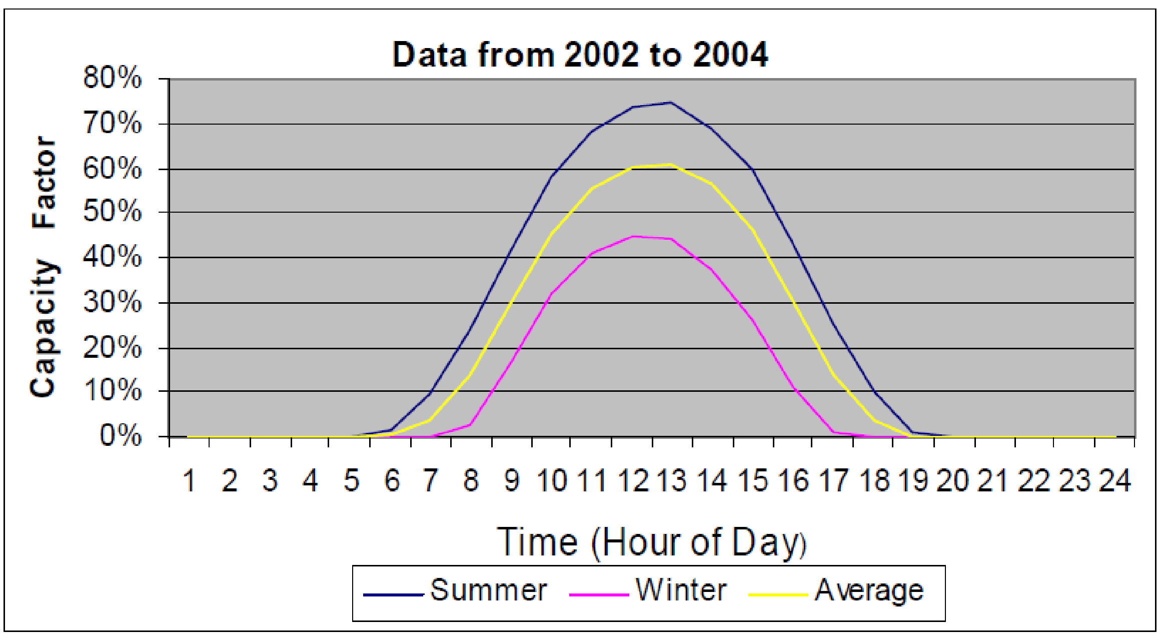

Figure 14: MAB Solar Potential based on Time of Day [39]

Concerning the time of day potential for PV, the results from the Renewable Energy Study Group were applied to the MAB nameplate PV capacity. Figure 11 depicts the maximum Energy demand day (which occurred in summer) and the minimum energy demand day (which occurred in winter) and the PV daily potential during those seasons.

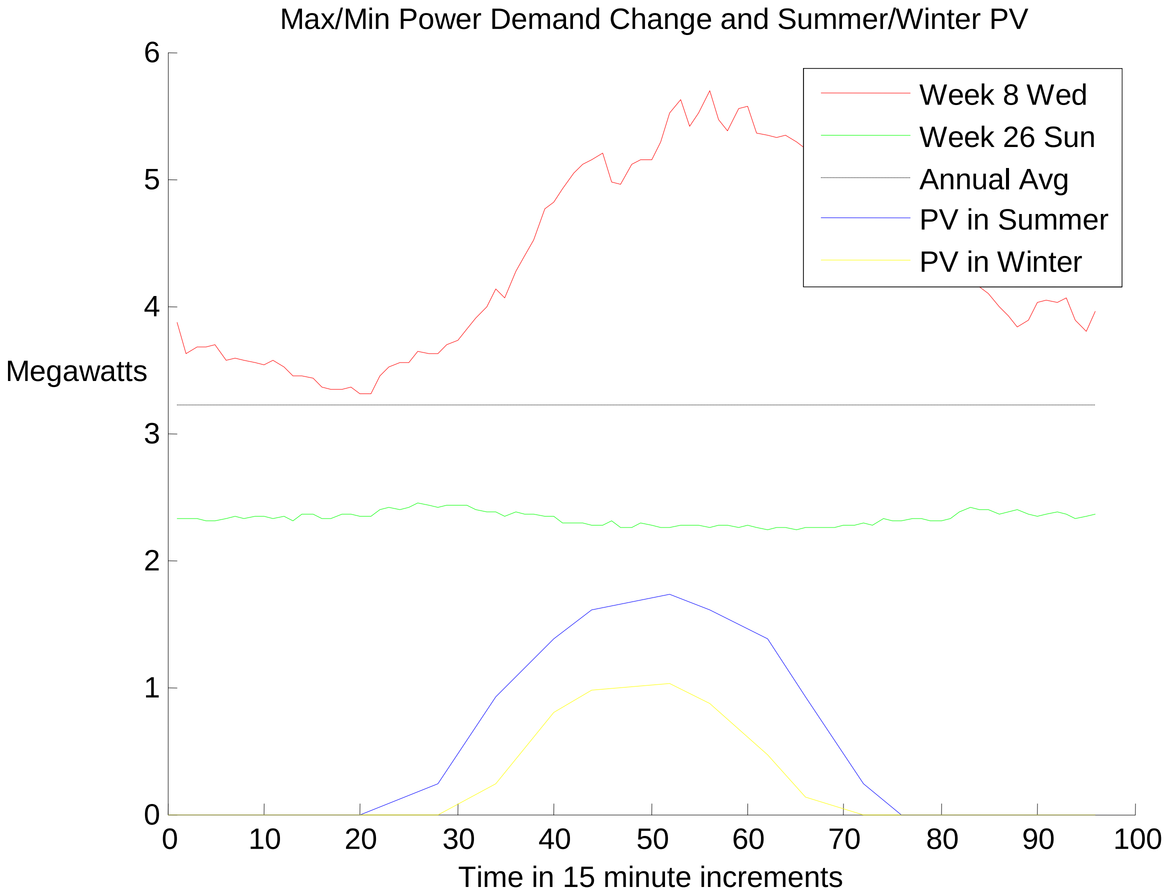

Figure 15

The following observations can be made:

- Solar daily potential is highest when the daily power demand is the highest during normal workdays (1300L). It also has maximum seasonal potential when seasonal demand is the highest (late summer).
- PV power never exceeds the power the fleet of vehicles could accept if they were all plugged into the microgrid. Max PVout is 1.7 MW in summer, while Max V2Gin is 2.1MW for PHEV/BEV mixed fleet, and 3.4 MW for the all EV fleet.
- The daily PV power maximum would coincide with maximum vehicle usage on weekdays, so potential for charging (and discharging) would be reduced.

- The V2G fleet is most available to supply energy when PV is not available. (1900L-0600L). This is a positive attribute of the V2G system.
- PV never meets the baseload requirements for the Mission Critical loads. Other power generation will be required such as conventional or biomass generation during an islanded condition.
- MAB has a 3 MW Landfill Gas generation system. If this system is in operation, PV would often be in excess when compared to the average and lower extreme power requirements. This energy could be stored with V2G enabled vehicles then discharged later when demand exceeds 3MW.
- The month of June warrants more detailed study due to increased demand and decreased PV due to Marine Layer weather phenomenon.

Renewable Generation Results

This analysis shows that there is considerable power and energy provided by renewables at MAB. The usefulness of V2G to store this energy is sub-optimal because the best time of day for charging or helping to meet peak demand by discharging occurs when the demand for driving the vehicles is also highest. On days like the summer weekdays in Week 8, PV would be best utilized to peak shave since it coincides with peak demand. If PV assests were increased in the future to a point where they exceed the baseload or peak load of the microgrid, a V2G enabled fleet might be able to store this additional energy for later use. If 3 MW of Landfill Gas generation coincidental with PV is assumed, the V2G system could be utilized to capture the PV energy that would then be in excess. This would likely occur on weekends and holidays when demand is low and vehicle availability is increased.

F. In an islanded condition, determine the V2G energy storage capabilities for on base renewable generators.

The objective of this task is to determine the capability of the V2G system to store available renewable energy when detached from the commercial grid. During normal operations, excess power is returned to the grid as a negative load. This would not be possible in the islanded condition. In a microgrid, renewable sources form an important asset for supplying the Mission Critical loads. This enhances the Energy Security of the system. Desired capability would be to store all the energy available during the day through vehicle charging, then discharge it in times of reduced PV availability (night for example). Energy storage for the Landfill Gas generator is also of interest. This system produces 3 MW which is often more that the daily peak for the Mission Critical loads on winter days and weekends.

Energy Storage Calculations:

From previous tasks it was determined that:

Peak Solar Energy (Aug)	10.0 MWh/day
Winter Solar Energy (Dec)	7.7 MWh/day
Energy Capacity for the All EV fleet	10.8 MWh
Energy Capacity for PHEV/BEVfleet	5.9 MWh

Concerning Landfill gas:

3 MW * 24 hours	72 MWh /day Production Capacity
Annual Average	77 MWh /day (5 MWh required)
Daily Average Week 27	66 MWh /day (6 MWh excess)

Energy Storage Observations:

1. The V2G fleet can easily handle the peak output power of the PV Array up to its 1.7 MW maximum output during charging

2. The energy capacity calculation for the fleet assumes 80% of the nameplate battery capacity is useable. If the All EV fleet began a summer day at 20% SOC and was never driven, it could barely store all the PV energy available. The Mixed fleet could not during any season.

3. In most scenarios, due to low mileage requirements and expected SOC for vehicle utilization for transportation, the fleet will not be able to store all available PV energy.

4. The more the fleet is driven, the more it can accept PV energy if more than once daily charging is utilized. The average MAB vehicle is driven 18.4 miles/day. This represents:

PHEV Prius (6mi electric)	-306% SOC (Three full cycles on the battery, no gas) or
	-100% SOC (One cycle, up to 0.4 gallons gas)
Volt (35mi electric)	-53% SOC (no gas even w/ once daily charge)
Leaf (73mi electric)	-25% SOC
Newton (47mi elctric)	-39% SOC

This shows that it is not likely that (except for Prius) transportation demands will discharge the fleet for optimal energy storage of renewables in most circumstances. Energy will acrue, reducing storage capacity unless it is discharged as V2G relatively frequently.

5. There is opportunity for the V2G system to absorb excess Landfill Gas energy on minimum demand days, or supply it when Landfill Gas does not meet demand (most of the time).

Energy Storage Results:

The results of this task are that although there is sufficient energy available from renewable sources at MAB, the V2G enabled fleets studied do not have sufficient battery capacity to store all of it and then return the energy later during times of low output. Extremely active V2G control will be required with proactive charge/discharge to the grid to adequately capture excess PV energy when it exists and manage the vehicles SOC. Without frequent discharge to the grid the V2G storage limit would quickly be reached. The benefit of V2G over a long weekend when vehicle availibility is high is limited by the storage capacity of the V2G battery fleet and the fact that the Mission Critical demand and actual propulsion requirements for the vehicles are reduced during these periods. There is a likelihood that all vehicles will reach 100% SOC with PV energy still available, even in winter. With no other way to store energy in an islanded condition, the V2G vehicles should be used to the maximum extent possible to optimize the renewables. This would take the form of hourly (or even minute by minute) smoothing of the energy to transform the PV assets into a Managed Generation resource rather than a large pool of energy to be "saved for a rainy day."

G. In an islanded condition, determine the validity (if any) of utilizing V2G to replace or smooth conventional power generation.

As the previous tasks have shown, collocated renewable generation is unable to meet the Mission Critical load demands at all times, even when PV and Landfill Gas generation are combined. The V2G fleet is unable to fill this shortfall due to insufficient total battery capacity. It follows that conventional power generation will be a requirement within the installation perimeter. Previous studies at Colorado State University explored various conventional generation possibilities centered around 3 (2 MW) Diesel or Natural Gas generators [40]. PV and V2G were not considered in that study. This research task examines the impact V2G might have in supplementing those assets.

Baseload

The energy storage capacity of the V2G fleet makes its contribution to replacing baseload limited in effectiveness. With an average daily requirement for 77 MWh of energy required to run the Mission Critical loads, the EV fleet would quickly be depleted. The entire fleet could be utilized to meet the minimum demands for all the Mission Critical loads on an off day, or replace a single conventional generator for a few hours. This would be a short term or emergent capability (under a generator casualty condition, etc). The one exception is during operation on the Landfill Gas (LG) system when less than 3MW are required. The LG system is optimized in a high output steady state condition, and has a slow response rate. V2G could capture the excess energy when required and also provide demand smoothing. As storage for the excess energy during periods of low demand for extended periods however, the V2G fleet is just too small. In a matter of hours, the fleet would reach 100% SOC. For baseload, V2G would not be a likely replacement for conventional generators, as a two week desired islanding capability requires a more capable steady state generation solution.

Smoothing of Renewables

V2G has valuable capability in this area. It is highly desireable to convert both Wind and PV power into a Managed Generation source rather than an uncontrolled negative load for applying various control strategies. V2G is best applied to smoothing the variability in renewables generation and peak shaving/valley filling the demand, rather than storing the energy for later (more than a few hours) as the storage capacity is still too small to be of great value. The entire fleet starting at minimum SOC can store about the amount of energy produced by PVduring a single day. Even though demand for this energy decreases overnight, the fleet would would be completely depleted long before sunrise. This is not the desired condition to meet the following day's transportation requirements. Wind power increases V2G viability in terms of timing in that it is potentially available at night when vehicle availability is high, transportation needs are low, and power demand is lower and less variable. An installation with high wind penetration would be better served by V2G than one which relies primarily on PV (like MAB). The V2G assets are more ideally sized to capture energy during variable wind gusts, or supply energy when the sun briefly goes behind a cloud and this should be the primary application.

Uninterupted Power Supply

V2G would not serve as a legitimate UPS for several reasons. First, a certain number of vehicles would be required to be connected to the grid (with a specific SOC) at all times in order to provide adequate power and energy to Mission Critical equipment. This would reduce their operational effectiveness for transportation. Secondly, the control system required to detect a power casualty and activate/aggregate the vehicles energy storage for discharge in a timely fashion would be too complex. It would require activation in fractions of seconds and such a control system and strategy does not currently exist in the COTS arena. This is theoretically possible, but not a near term capability.

Ancillary Services/ Spinning Reserve

This area has been studied at length for the public utility application [41] and is a valid use for V2G enabled vehicles. In the islanded condition, MAB would still require all the components of a public utility to manage its conventional power generation. The CSU study of proposed microgrid operations at MAB found:

> *"The second approach is to augment the natural gas engines with a small, but fast, asset which will support frequency, and possibly voltage, during transient conditions. Several asset architectures for this purpose have been proposed, and several have been deployed. One approach utilizes a "secondary load controller" – a fast-acting resistive load bank. The load bank normally operates at ½ load* [42]*."*

V2G enabled vehicles could perform this function in place of an additional generator with high speed response that is operating below its optimal load. The V2G fleet can be aggregated to provide both frequency control and spinning reserve and the installation itself would function as the aggregator. It is interesting to note that in terms of reliability, an islanded V2G system would not have to meet the same criteria for a public utility which would just shop elsewhere for these services if desired performance is not met. The military vehicles can also be directed to connect to the grid to perform these services, so probability is removed from predicting vehicle availability. This means far less vehicles are required to be aggregated to reach a desired level of system performance.

Blackstart

It is anticipated that the DoD will utilize a Blackstart to transition from normal operation to that of an islanded microgrid. During this procedure almost the entire Mission Critical load is de-energized and then generation is brought online and the loads are powered back up. There is significant transient behaviour associated with this process, and V2G could play a beneficial role, especially when landfill gas is utilized. In <u>Design and Analysis of Blackstart Sequences for a Notional Microgrid</u> the authors found:

> "*Since the landfill gas machines are not capable of providing disturbance response, the microgrid cannot be operated using these generators alone. Some 'swing'*

capacity must be on-line. Therefore, two possibilities must be considered for successful microgrid operation:

1) *During low load periods, additional load must be added to microgrid, possibly from a non-critical feeder."*

And:

> *" It is therefore necessary to plan for sufficient diesel capacity to carry all load – particularly during blackstart or other critical periods – and then utilize the landfill gas machines to reduce fuel consumption when sufficient load is available to safely unload one (in rare cases, two) of the diesels."* [43]

In both of these scenarios, V2G could provide benefit either by providing a flexible load for disturbance response, or by providing a short term power source to unload a Diesel generator in order to bring the landfill gas generation online.

Expeditionary Capability

A final area where V2G might augment or replace conventional power generation is in the area of Expeditionary power supply. During emergency operations there may be a requirement to provide a mobile power source either outside the perimeter, or within it in the case of infrastructure damage. V2G can provide a self propelled and scalable power supply which can be deployed very quickly. Using the Nissan Power Control System, a Leaf can provide 6 kW of power (enough to supply a small house) for up to 2 days [44]. A Smith Newton could triple this capability. At some level these assets can be aggregated, providing a tactical power solution to the Base Commander with preexisting assets.

H. Identify Standard Operating Procedure (SOP) components.

This research task identifies the major areas to be considered in establishing how the V2G system should be operated in both normal and islanded conditions. Depending on the nature of the emergency and the desires of the Base Commander, this system could be deployed in a myriad of configurations. Each of these topics merits further research to optimize the system for that scenario.

In Normal Operation:

1) *SOC Management for Transportation.* For normal operations, SOC would be managed to meet the transportation requirements of the vehicle fleet. This could be at high SOC to optimize potential for travel, or something lower to meet expected mileage and allow energy storage potential. A minimum SOC would be established to meet transition to islanded expectations.

2) *Off Peak Charging*. If the installation receives incentivized electricity rates, charging could be directed to save money. Most of the vehicles have an excess of daily electric range, so charging time and timing can be optimized for cost.

3) *Aggregation for Carbitrage or Ancillary Services contracts.* The installation could conceivably aggregate and bid these contracts at the 1MW level desired by public utilities. If this was desired, a procedure would need to be put in place to assure vehicle availability and manage SOC to provide the requisite level of reliability.

4) *Using V2G to Peak Shave and reduce utilities cost.* Directed charging and discharging has the potential to shift the base's peak demand and decrease its magnitude during normal operations. The increased electricity cost of electrifying the V2G fleet could be recouped by optimizing the timing of when electricity is required. Discharging the vehicles on Summer afternoons would exemplify this procedure.

5) *SOC management for planned or emergent islanding.* In the event of a planned transition to microgrid operations such as a drill or impending utilitity malfunction, the SOC of the vehicles can be adjusted to increase their value to the system. This procedure would direct charging/discharging to meet the assigned islanded V2G role in advance. Charging to 100% SOC to maximize baseload capability is an example.

6) *Mission Assignment to optimize vehicle efficiency/Mission completion*. If the V2G fleet utilizes PHEVs, it is important to assign the correct vehicle to the mission in order to minimize its use of petroleum or maximize its total range if that is a priority. A matrix of missions and vehicle options would be included so that a Prius would not be assigned to a 50 mile daily commute, and a Leaf would not be sent to another base 200 miles away.

A different set of procedures would be employed for the islanded condition. Depending on the role desired for the V2G system, various SOC management and charging/discharging strategies would be employed. Areas of interst include:

1. *Vehicle V2G Mission Options.* During islanded operation transportation usage of V2G vehicles could be directed to maximize specific capabilities. They might be minimized to reduce the load on conventional generation, or maximized to provide energy storage potential.

2. *Baseload.* Although the capability to replace baseload is limited, it does exist. In the event of a single generator casualty, V2G could be used for several hours until repairs are effected.

3. *Blackstart*. V2G can be applied during Blackstart procedures both as an energy source or as a sink to manage transient conditions. It could also be used to provide high speed reponse when landfill gas is the primary generation. When transition to island condition is expected, SOC can be adjusted to optimize the desired capability (not necessarily 100% SOC).

4. *Smoothing of Renewables.* This is a primary mission for the V2G system during an islanded condition. Vehicles would be positoned to charge from and discharge to supplement renewable generation. This allows better utilization of those resources as a managed resource.

Limited storage of this energy is also possible, especially in the case of nighttime wind power. This procedure would also allocate a percentage of the fleet for power services as well as those for transportation to produce the desired effect.

5. *Expeditionary Capability.* To provide mobile power generation a high SOC would be employed to maximize vehicle range and energy/power output.

6. *Ancillary Services*. To maintain appropriate AC power for the installation, vehicles would be assigned to provide Frequency Regulation, Spinning Reserve and Peak Power. For Regulation, SOC would be managed at approximately 50% to provide both up and down capability. Spinning Reserve and Peak Power assets would be kept at high SOC and allocated depending on required output.

It is obvious that a Standard Operating Procedure would have to be tailored to each individual installation. This would take into account the expected Mission Critical Loads, the size and type of back-up generation, and the size and make up of the vehicle fleet. There would also be analysis required to determine the best mission for V2G power depending on the primary and secondary missions of the installation. While the core component listed above would form the core of the document, a large degree of specialization would be required to make it truly effective.

I. Employ a GREET analysis of the representative V2G System during normal operations to evaluate GHG and other emissions.

In this research task, the open source GREET toolset developed by the Argonne National Laboratory is used to determine both the petroleum replacement potential and the effects on GHG emissions (both upstream and downstream) when conventional vehicles are replaced with EVs and PHEVs. This forms the measure of effectiveness for the V2G system in meeting federal mandate. Although the GREET model only approximates the vehicles selected for this thesis, it gives the reader a good idea as to the nature and scale of the effects of electrifying the fleet. Three tools were employed to quantify the effects on the Well to Pump (WTP) (production of the fuel required), the Vehicle Cycle (production of the vehicle) and the Vehicle Operations Cycle (the actual operation of the Vehicle).

The first analysis employed the GREET Mini Tool (a subset of GREET1_2011). This gives a Rough Order of Magnitude (ROM) as it is not readily adjusted to specific variables. Using the GREET defaults with both the US average and CA mixes for electricity production and corn based E85 yields the following results:

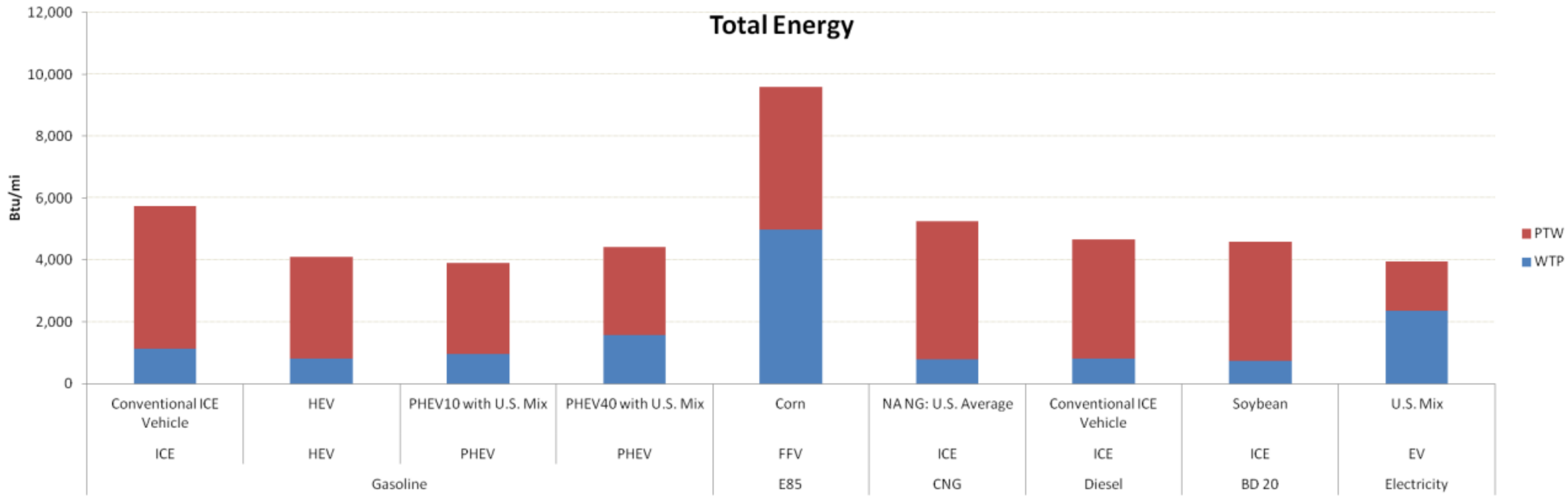

Figure 16: Total Energy

GREET Mini-Tool (US Mix)

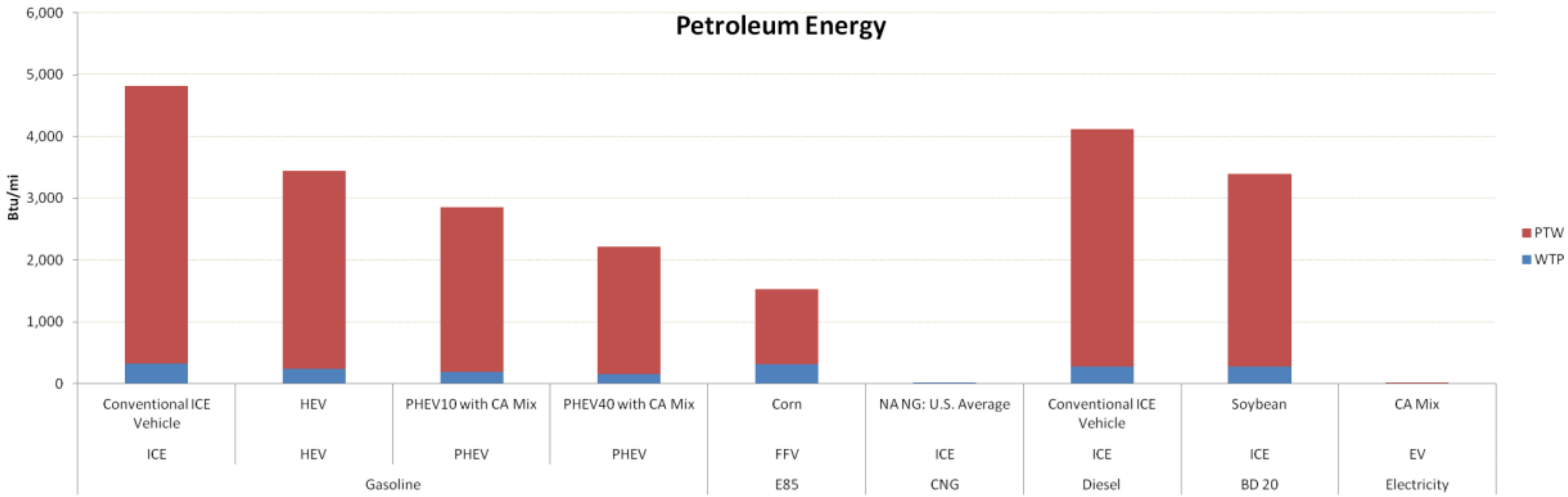

Figure 17: Petroleum Energy

GREET Mini-Tool (CA Mix)

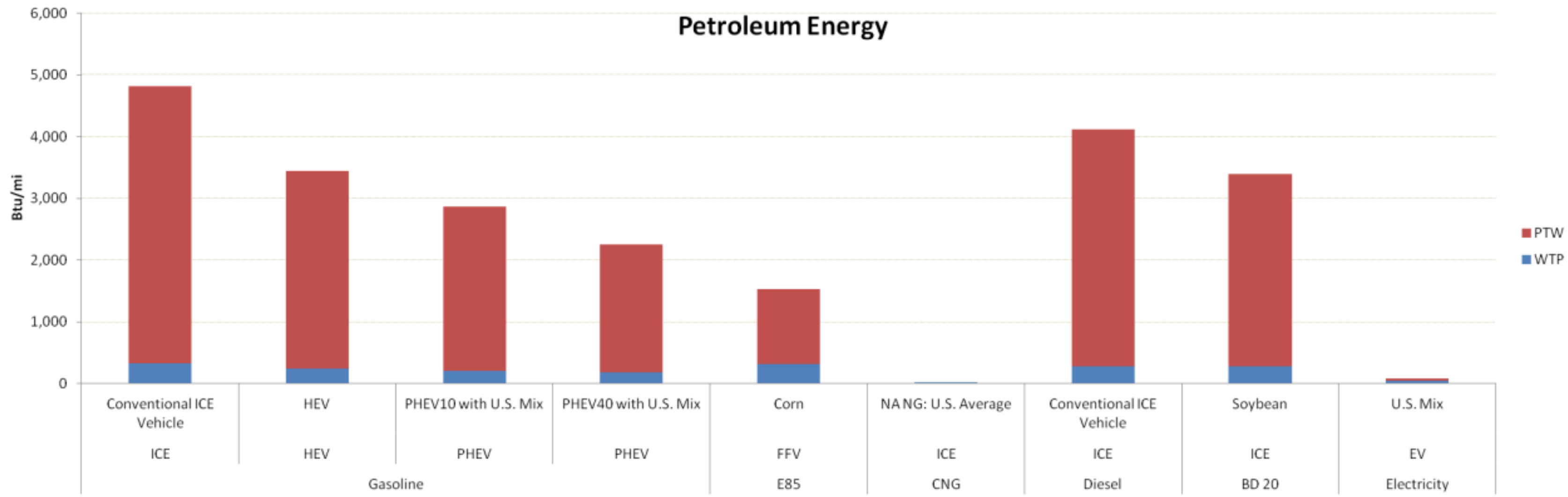

Figure 18: Petroleum Energy

GREET Mini-Tool (US Mix)

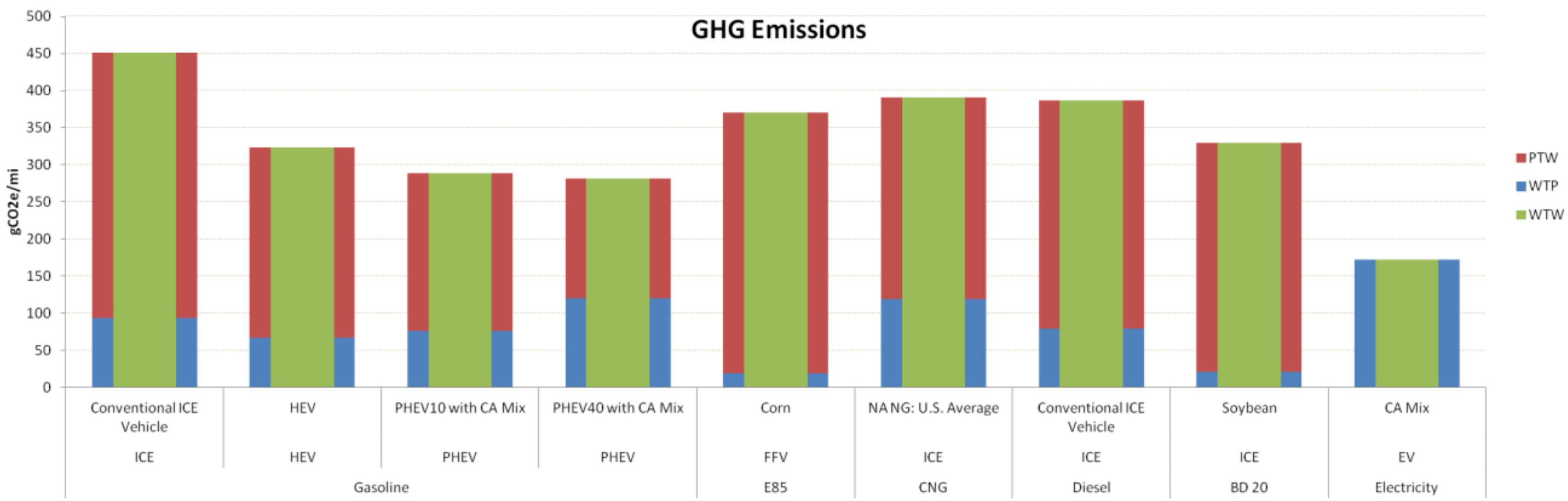

Figure 19: GHG Emissions

GREET Mini-Tool (CA Mix)

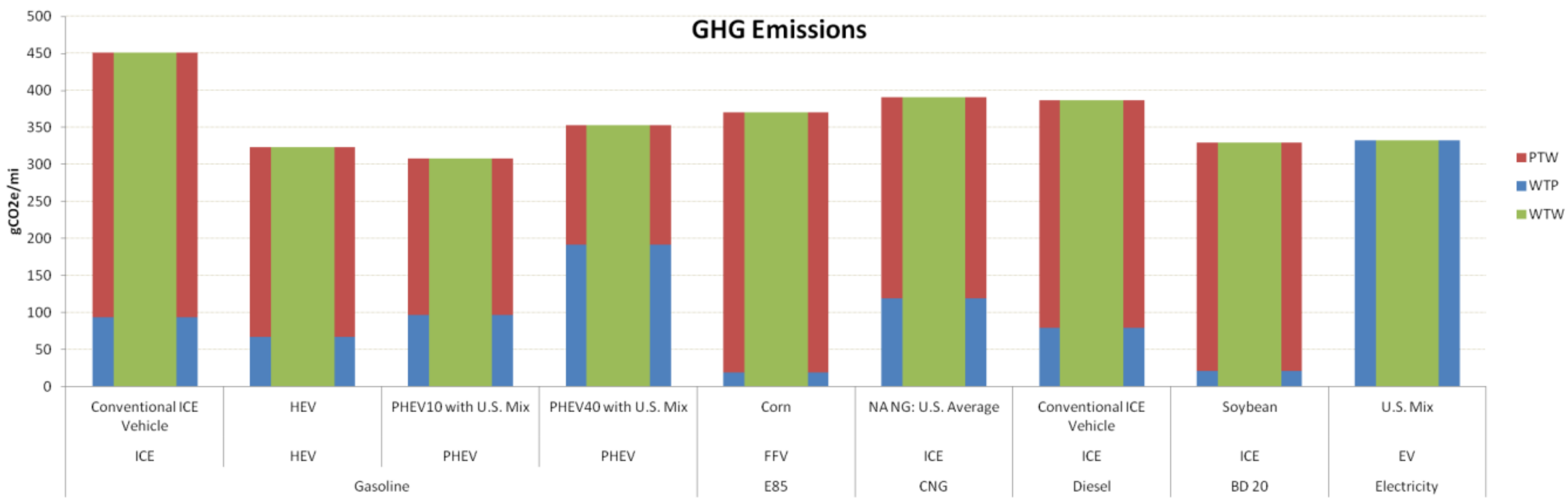

Figure 20: GHG Emissions

GREET Mini-Tool (US Mix)

This first cut gives the reader the impression that Electric Vehicles, and to a lesser extent PHEVs are the ideal solution for Petroleum replacement and GHG reduction especially when operated on electricity produced with the California mix of fuels which substantially reduces coal and increases renewable energy fractions. It shows that EVs are superior to both the E85 and CNG Alternative Fuel vehicles currently being implemented at MAB to comply with mandates. Also of interest is the Total Energy required for WTW use of E85. It would appear that a V2G system is the perfect answer to the Federal mandates. The first analysis is not the whole picture however.

A second level analysis utilized the full GREET1_2011. Highlight of the full analysis are included as Appendix C. Results of the Passenger Car analysis are shown in Figure 14 and Figure 15. Federal Mandate items are highlighted in green. Areas where the AFVs performed worse than the baseline CV are printed in red.

GREET1_2011 **Passenger Cars (PHEV10)** **US Mix for Electricity Production**

	EtOH FFV: E85, Corn	Grid-Independent SI HEV: CG and RFG	Grid-Connected SI PHEV: CG and RFG	CIDI Vehicle: Conventional and LS Diesel	CIDI Vehicle: BD20	Electric Vehicle
Total Energy	70.6%	-28.6%	-32.7%	-18.6%	-19.8%	-28.7%
Fossil Fuels	-36.6%	-28.6%	-33.6%	-15.9%	-28.5%	-35.9%
Coal	359.2%	-28.6%	319.9%	-26.8%	3.4%	2958.0%
Natural Gas	178.5%	-28.6%	-18.9%	-22.0%	-20.9%	88.3%
Petroleum	-68.2%	-28.6%	-40.9%	-15.0%	-29.9%	-98.2%
CO2 (w/ C in VOC & CO)	-28.7%	-28.6%	-32.4%	-14.1%	-27.5%	-23.8%
CH4	53.6%	-29.1%	-26.0%	-20.7%	-27.6%	31.9%
N2O	834.8%	-9.2%	-21.8%	-26.9%	17.1%	-74.7%
GHGs	-16.2%	-28.4%	-32.0%	-14.5%	-27.0%	-22.5%
VOC: Total	29.1%	-29.8%	-40.8%	-62.6%	-54.1%	-90.0%
CO: Total	2.0%	-0.5%	-17.2%	-84.4%	-84.2%	-97.6%
NOx: Total	53.4%	-24.1%	-25.9%	-12.5%	-11.9%	-3.5%
PM10: Total	160.8%	-15.9%	57.0%	-12.7%	-4.4%	626.9%
PM2.5: Total	85.7%	-16.1%	14.5%	-9.7%	-4.5%	272.3%
SOx: Total	104.8%	-28.6%	26.6%	-23.5%	-19.6%	474.3%
VOC: Urban	-6.6%	-29.9%	-41.9%	-65.4%	-66.4%	-98.8%
CO: Urban	-0.3%	-0.2%	-17.2%	-85.0%	-85.1%	-99.2%
NOx: Urban	-11.6%	-20.1%	-27.9%	-4.1%	-7.8%	-49.2%
PM10: Urban	-18.0%	-8.4%	-13.7%	-2.3%	-6.5%	-34.0%
PM2.5: Urban	-19.4%	-9.4%	-17.3%	-1.0%	-5.6%	-49.4%
SOx: Urban	-35.2%	-28.6%	0.4%	-21.8%	-32.9%	252.3%

Figure 21

GREET1_2011 Passenger Cars (PHEV10) CA Mix for Electricity Production

	EtOH FFV: E85, Corn	Grid-Independent SI HEV: CG and RFG	Grid-Connected SI PHEV: CG and RFG	CIDI Vehicle: Conventional and LS Diesel	CIDI Vehicle: BD20	Electric Vehicle
Total Energy	69.8%	-28.6%	-34.4%	-18.6%	-19.8%	-42.5%
Fossil Fuels	-38.9%	-28.6%	-36.1%	-15.8%	-28.6%	-57.3%
Coal	740.3%	-28.6%	180.9%	-36.5%	48.7%	1781.2%
Natural Gas	178.8%	-28.6%	-2.3%	-22.0%	-20.9%	228.9%
Petroleum	-68.3%	-28.6%	-41.1%	-15.0%	-29.9%	-99.7%
CO2 (w/ C in VOC & CO)	-31.9%	-28.6%	-36.8%	-14.0%	-27.7%	-61.6%
CH4	51.9%	-29.1%	-24.5%	-20.7%	-27.8%	44.4%
N2O	836.3%	-9.1%	-22.3%	-26.9%	17.2%	-78.8%
GHGs	-19.2%	-28.4%	-36.2%	-14.4%	-27.2%	-58.1%
VOC: Total	28.9%	-29.8%	-41.2%	-62.6%	-54.2%	-93.4%
CO: Total	1.9%	-0.5%	-17.3%	-84.4%	-84.2%	-98.1%
NOx: Total	50.6%	-24.0%	-32.1%	-12.3%	-11.8%	-56.1%
PM10: Total	151.5%	-13.5%	-4.0%	-10.7%	-2.5%	90.1%
PM2.5: Total	75.0%	-15.0%	-16.4%	-8.6%	-3.6%	2.7%
SOx: Total	88.8%	-28.6%	-26.0%	-23.6%	-20.4%	28.4%
VOC: Urban	-6.6%	-29.9%	-41.8%	-65.4%	-66.4%	-98.5%
CO: Urban	-0.3%	-0.2%	-17.2%	-85.0%	-85.1%	-99.1%
NOx: Urban	-13.4%	-20.0%	-30.4%	-4.0%	-7.8%	-71.3%
PM10: Urban	-18.6%	-8.4%	-14.5%	-2.3%	-6.5%	-41.4%
PM2.5: Urban	-19.9%	-9.3%	-17.8%	-1.0%	-5.6%	-54.2%
SOx: Urban	-57.7%	-28.6%	-33.9%	-21.7%	-34.6%	-38.6%

Figure 22

GREET Default Assumptions (Passenger Car):

CV 23.7 mpg

CIDI 28.4 mpg

FFV 23.7 mpg

CIDI (B20) 34.1 mpg

HEV 33.2 mpg

BEV 80.6 mpg

PHEV 48.3 mpgge CD/ 35.1 mpg CS (11.2 mi all electric, 26% CD, 74% CS)

GREET Analysis:

- Much like in the GREET Mini tool, the EV has superior performance for lowering Petroleum consumption and GHG emissions.
- All of the AFVs considered are improvements over the baseline CV utilizing only those metrics.
- The petroleum use of the CV is replaced by increases in Coal and Natural Gas usage for PHEV/EVs. Not all bad, as these are domestic products and still increase Energy Security.
- There is a dramatic increase in Particulate Matter and SOx emissions of the EV especially when being operated on the US mix of electricity production. This is a result of the increase in Coal utilization. For the US mix there is actually an increase in Urban SOx by 252%. This is a particularly bad side effect.
- E85 suffers from similar increases in emissions other than GHGs, and even has some notable increases in other emissions such as N2O and CH4 as a result of the agricultural process.
- Using the CA mix dramatically improves the performance of the PHEV/EV due to reduced coal and increased renewable percentages.
- Much improved performance of the Grid Connected PHEV in terms of both petroleum replacement and GHG when the PHEV35 (Volt) is introduced. It performs equally with CV on SOx emissions.
- The improvements of EVs over CVs increases as the size of the vehicle increases. This would be considerable for the Smith Newton.

A third analysis was required to answer the question: "Does the manufacture of the EV's battery and other components have an impact upstream on the metrics of interest?" This is described as Vehicle Cycle emissions and is estimated using GREET 2.7. The results are also included in Appendix C. The inputs to this model were the actual weight of the Nissan Leaf with the actual weight of the battery for the EV, and minus the weight of the battery for a CV. Remaining components remained at the GREET defaults. For the manufacturing of the vehicle, the EV showed increased environmental impact when compared to the CV in the Vehicle Cycle:

Table 7: Vehicle Cycle Results

Total Energy (34%)	The Vehicle Cycle is 8% of the CV's Total Energy required
Petroleum (3%)	The Vehicle Cycle is 2% of the CV's total Petroleum consumed
GHG (37%)	The Vehicle Cycle is 8% of the CV's total GHGs produced
SOx (65%)*	The Vehicle Cycle is 50% of the CV's total SOx produced

* The production of copper requires a variety of Sulphur compounds, and this is a likely cause of this side effect of electrifying the installation vehicle fleet. The effects would be even more substantial if EVSE and other V2G infrastructure are taken into account.

GREET Results:

1. Concerning Federal Mandates, the EV is the best choice for an AFV which displaces Petroleum and minimizes GHGs. In a non-islanded condition, a V2G vehicle would behave similarly.

2. Outside of Federal Mandate, there are negative environmental consequences of substituting PHEV/BEV for CVs including increased PM and SOx emissions.

3. Regional differences in how electricity is produced play an important role in how effective V2G will perform in terms of the environment. This is a key to making V2G truly environmentally friendly.

4. V2G is more effective than E85 which has substantial penalty in spite of perceived gains in terms of Petroleum displacement

5. While there are increased upstream impacts in producing EVs themselves, they do not impact the viability of EVs in complying with the Federal Mandates.

Chapter 7 SUMMARY OF RESULTS

Upon completion of the research tasks of the previous chapter, a summary of the results, and review of the research questions and hypotheses to ascertain the viability of a vehicle to grid system in a DoD application reveals:

1. *The Department of Defense is under directive to implement energy saving measures and satisfy performance metrics with specific milestones and baselines. Is Vehicle to Grid (V2G) a valid technology to achieve any or all of the four major performance indices mandated by these directives?*

When compared to metrics concerning reduction of petroleum consumption, reductions in GHG emissions, and increased deployment of Alternative Fuel Vehicles, a system of V2G enabled vehicles is highly effective. This is largely due to the fact that it electrifies the fleet not due to the V2G capability itself.

The Electric Vehicle completely replaces petroleum in the Vehicle Operations cycle and even though it still requires gasoline, the Plug-in Hybrid Electric Vehicle uses its electric components for dramatic increases in efficiency over conventional vehicles, especially in short range applications. This occurs whether these vehicles are connected to the grid or not. This comes with negligible increases in the petroleum required to produce the electricity itself. An additional benefit is that PHEVs and EVs replace petroleum with coal, natural gas, and renewable energy, all of which are domestically produced substitutes. This increases Energy Security. While there would be an increase in petroleum use by the V2G system during islanding, but this would still be far less consumption than a CV fleet. This constitutes an emergent condition however, and is not the focus of the federal mandates.

Concerning GHG emissions, a V2G fleet meets the mandated targets. This comes at potentially increased emissions in other areas and is highly dependent on the makeup of the public utilities electrical mix. When one evaluates V2G strictly in terms of the GHG effects, it can be described as compliant with the goals of the mandates.

A V2G enabled fleet optimizes the use of Alternate Fuel Vehicles. Like no other form of AFV, the vehicles not only provide the desired level of transportation and reduced environmental impact, but they also provide additional capability as a result of their bidirectional grid interaction. All other choices strictly convert fuel into vehicle miles and usually less efficiently than an EV. The DoD is going down the wrong path w/ E85. Even if V2G is not implemented, serious consideration should be given to at least electrifying the vehicle fleet.

By these results, one hypothesis is confirmed. In non-islanded operations, V2G enabled vehicles are an effective means for complying with applicable Federal Policy Mandates concerning energy conservation, fossil fuel substitution, and GHG reduction.

While V2G has some positive benefit on smoothing renewable energy generation, it is not enough to justify the technology in its own right. A V2G system does not encourage increased penetration of renewable sources because it is not scalable in kind. The fleet of vehicles is already too large compared with transportation requirements and too small in terms of energy storage capability. Increased renewable penetration should occur because it is more sustainable and secure, but not because a V2G system is in place. The hypothesis that V2G enables enhanced firming of on-base renewable energy assets, particularly in an “islanded” scenario is only partially validated. The potential to effectively smooth renewable energy generation is highly dependent on its type and size. V2G is far more effective for smoothing wind power and when renewable generation exceeds the base or peak load of the Mission Critical loads. Neither of these are the case at MAB nor Fort Carson. Also the perception that

V2G could smooth renewable over a series of days or even overnight is flawed, the storage capacity is just too small. V2G could work to dampen PV for passing clouds, but not cloudy days.

2. What are the characteristics of a V2G enabled system which justifies its implementation regardless of cost effectiveness, ability to comply with mandates, or any other limitations?

A V2G enabled system has several characteristics which increase both the capability of the transportation system and the backup power generation of the installation. These include: improved vehicle efficiency, decreased pollution, enhanced energy security, and improved electrical energy storage. It is difficult to state that they justify the implementation of such a system however. Given the limited actual storage capacity and power output, the increased costs in terms of both monetary cost and system complexity the hypothesis that V2G provides advantages over a system utilizing traditional power generation (Diesel, CNG) and a non-V2G electric vehicle fleet is not valid. A detailed cost analysis of conventional power generation to supply backup power and its associated cost and limitations would likely show it to be simpler to operate, less complex and easier to scale appropriately than a V2G system.

3. Under an "islanded" scenario, what are the new capabilities of a V2G enabled system?

There are three new capabilities of a V2G system available in an islanded scenario. The first is an ability to store energy in electrical form at all times. This is unique as there is negligible storage on the commercial power grid or a military microgrid as they exist today. This storage capability although modest in size does provide the installation with more flexibility in how it manages its power supply especially during microgrid operation. Although a fixed battery bank could save the same purpose, it lacks the second characteristic of a V2G system: Mobility. The V2G system of energy storage is self propelled and can be repositioned as required either in an Expeditionary fashion or simply to circumvent power distribution casualties. Finally, a V2G system is flexible and easily dispatched. The behavior of the system can be adjusted to suit the mission requirements quickly. Although the magnitude of the power supply and energy storage is quite modest, the ways in which this energy can be used is limitless. By these standards, the hypothesis that while V2G may not be the most cost effective method to operate Mission Essential loads, in an islanded scenario it provides new capabilities for the leadership during Emergency Operations is validated.

4. What are the key components of a Standard Operating Procedure (SOP) to govern the daily use and emergent deployment of V2G assets?

The procedures governing how a V2G system is operated are integral to the maximization of system performance. Pro-active management of vehicle's State of Charge, location and timing of charging / discharging, and vehicle-appropriate mission assignment are the key to proper operation of the system in both normal and islanded operations. Advanced planning concerning what the desired use for the power is in various configuration must also be addressed required to ensure that the V2G system is being used to its highest potential. With the flexibility designed into this power source comes a much increased attention to HOW the system is operated.

In summary, the answers to these questions reveal that a Vehicle to Grid transportation system is viable when implemented on a domestic military air base. The capabilities of this system are much more limited than was previously anticipated however. The V2G system is not an unlimited way to store excess energy, nor provide it at will during emergencies. Understanding the scale of this asset and proper implementation of its capabilities are the key to its future deployment.

Chapter 8 CONCLUSIONS

This thesis has defined and completed a series of tasks to address the primary research challenges associated with the role of vehicle to grid in meeting the requirements of Department of Defense objectives including environmental and energy policies. This thesis has developed a model DoD fleet with the understanding that the commercial introduction of electric and plug-in HEV vehicles has now occurred, and these vehicles will be the basis of DoD acquisitions for a V2G capable electrified fleet. This thesis has characterized the actual mission critical load profile associated with a real world DoD installation. This thesis has integrated a time-resolved model of renewable energy generation on a military air base to determine the role of renewable energy generation in meeting the required loads in an islanded condition.

This work is novel in that it is the first documentation of the real-world scale of a prospective V2G equipped installation inclusive of actual mission critical load data, actual production vehicle V2G capabilities, and an actual on-base vehicle fleet.

The results of this study show that V2G fleet is no more effective than an electrified vehicle fleet in meeting federal policy goals. The scale of V2G is not large enough to provide additional petroleum or GHG reduction relative to an electrified vehicle fleet. V2G does not enable the employment of renewable energy generation because the storage capacity of the V2G fleet is not compatible with the large magnitude of energy generated and consumed at the base. V2G has no impact on the quantity of renewable energy consumed at the installation.

In terms of meeting the DoD interest in energy security and microgrids, V2G does have some role and capabilities that are not available from a non-V2G capable electrified vehicle fleet. This thesis has shown that for the MAB considered, the size of the vehicle fleet, the type and timing of the mission critical loads, and the energy storage capacity of production EV/PHEVs are not compatible with a V2G system whose purpose is provide islanded energy storage. For this MAB under an islanded condition, the scale of available V2G is only large enough to provide hourly-type renewable energy firming to a collocated renewable generator or to provide spinning reserve to conventional generation.

Future Work

Future work associated with these research efforts would include some validation of the capability of conventional BEVs/PHEVs to actually perform V2G with the vehicle capabilities proposed in this thesis. This thesis has also not considered the economic costs and benefits that might be associated with V2G. The economics of V2G-capable fleets should be compared to those of stationary battery energy storage, and conventional power generation. Future work should also determine the capability of V2G to engage in expeditionary power generation and storage as well as its application to tactical vehicles.

REFERENCES

[1] Nissan Leaf Range Calculator available at:
http://www.nissanusa.com/leaf-electric-car/range?next=ev_micro.section_nav.
[2] Kempton, W, "Vehicle to grid power implementation: From stabilizing the grid to supporting large scale renewable energy", Journal of Power Sources, Dec 2004, p 2.
[3] Automotive Fleet, "Smith Electric Vehicles Awarded GSA Schedule", Jan 28, 2010, available at:
http://www.automotive-fleet.com/Channel/fuel-management/News/Story/2010/01/Smith-Electric-Vehicles-Awarded-GSA-Schedule.aspx?prestitial=1
[4] White House Press Release, "President Obama signs an Executive Order Focused on Federal Leadership in Environmental, Energy, and Economic Performance", Oct 5, 2009, available at: http://www.whitehouse.gov/the_press_office/President-Obama-signs-an-Executive-Order-Focused-on-Federal-Leadership-in-Environmental-Energy-and-Economic-Performance
[5] Colonel Gregory J. Lengyel, USAF, The Brookings Institution, "Department of Defense Energy Strategy", Aug 2007.
[6] Defense Science Board Task Force on DoD Energy Security, "More Fight – Less Fuel," February 2008.
[7] Ibid.
[8] President of the United States, EO 13514, "Federal Leadership in Environmental, Energy, and Economic Performance", Oct 5, 2009, Sect 2iii.
[9] Ibid.
[10] Ibid.
[11] Energy Policy Act of 2005, "EPAct 2005", Sect 203.
[12] Quinn, C., Zimmerle, D., and Bradley, T.H. "The effect of communication architecture on the availability, reliability and economics of plug in hybrid vehicle-to-grid charging," Journal of Power Sources Volume 195, Issue 5, 1 March 2010, Pages 1500-1509.
[13] Beary,W. et al, "SPIDERS", ICSJWG Spr 2011, Slide 8. Available at: http://www.govenergy.com/2010/Files/Presentations/Energy%20Security/Energy%20Security%20S4%20-%20Roley.pdf www.
[14] U.S. Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), "Army Identifies Net Zero Pilot Installations," April 20, 2011, Press Release No. 319-11, Available at: http://www.defense.gov/releases/release.aspx?releaseid=14420.
[15] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations", Oct 2011, Appendix A.
[16] Bunkley, N., New York Times, "GM Again Pauses Production of Chevy Volt", Mar 2, 2012, available at: http://www.nytimes.com/2012/03/03/business/gm-suspends-production-of-chevrolet-volt.html
[17] Blanco, S., Autobloggreen, "Carlos Ghosn: 27,000 Nissan Leafs sold worldwide; many, many more to come", Apr 4, 2012 available at:
http://green.autoblog.com/2012/04/04/carlos-ghosn-27-000-nissan-leafs-sold-worldwide-many-many-mor/
[18] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations", Oct 2011, Appendix A, p.113
[19] Request for Information, MCAS Miramar Microgrid, 2011, available at: https://www.neco.navy.mil/necoattach/N6247312C3801Final_Microgrid_RFI.pdf

[20] NREL, "Targeting Net Zero Energy at MCAS Miramar: Assessment and Recommendations, Dec 2010, p 15.
[21] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations", Oct 2011, p 79.
[22] NREL, "Targeting Net Zero Energy at MCAS Miramar: Assessment and Recommendations, Dec 2010, p 15.
[23] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations", Oct 2011, p 79.
[24] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations, Oct 2011, p 80.
[25] NREL, "Targeting Net Zero Energy at MCAS Miramar: Assessment and Recommendations, Dec 2010, p 17.
[26] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations, Oct 2011, p 80.
[27] Nissan News Release, "Nissan Unveils New Power Supply System Through Nissan LEAF", Aug 2, 2011, available at: http://www.nissan-global.com/EN/NEWS/2011/_STORY/110802-01-e.html.
[28] Nissan News Release, "Nissan Introduces Quick EV Charger", May 21,2010 available at: http://www.nissan-global.com/EN/NEWS/2010/_STORY/100521-01-e.html.
[29] SAE Hybrid Committee, "SAE Charging Configurations and Ratings Terminology" ver. 031611, 2011.
[30] PHEV Prius is not yet available to the GSA. Invoice cost determined by Edmunds was substituted.
[31] NREL, "Targeting Net Zero Energy at Fort Carson: Assessment and Recommendations", Oct 2011, p 80.
[32] Bradley, T.H., Frank, A.A., "Design and of Plug-in Hybrid Electric Vehicles," Sustainable and Renewable Energy Reviews, 2009. Available at: http://www.engr.colostate.edu/~thb/Publications/Design%20Development%20and%20Sustainability%20impacts%20assessments%20for%20PHEVs_FINAL.pdf
[33] SAE J2841, "Utility Factor definitions for PHEVs using travel survey data", Sep 2010, p13
[34] SAE J2841, "Utility Factor definitions for PHEVs using travel survey data", Sep 2010, p42
[35] Request for Information, MCAS Miramar Microgrid, 2011, available at: https://www.neco.navy.mil/necoattach/N6247312C3801Final_Microgrid_RFI.pdf
[36] NREL, "Targeting Net Zero Energy at MCAS Miramar: Assessment and Recommendations, Dec 2010.
[37] Month of June warrants more detailed study due to increased demand and decreased PV due to Marine Layer weather phenomenon. This information appears in Figure 10, but is not reflected in the PV Watts modeling. A possible cause is that MAB is located far enough inland to avoid this degradation.
[38] San Diego Regional Renewable Energy Study Group, "Potential for Renewable Energy in the San Diego Region", Aug 2005, p 15.
[39] San Diego Regional Renewable Energy Study Group, "Potential for Renewable Energy in

[40] San Diego Regional Renewable Energy Study Group, “Potential for Renewable Energy in the San Diego Region”, Aug 2005, p 15.
[41] Natarajan, Zimmerle, Cale, “Design and Analysis of Blackstart Sequences for a Notional Microgrid,” unpublished manuscript, Colorado State University, 2012.
[42] Quinn, C., Zimmerle, D., and Bradley, T.H., "An evaluation of state-of-charge limitations and actuation signal energy content on plug-in hybrid electric vehicle vehicle-to-grid reliability and economics," IEEE Transactions on Smart Grid - Special Issue on Transportation Electrification and Vehicle-to-Grid Applications VOL. 3, NO. 1, Mar 2012.
[43] Natarajan, Zimmerle, Cale, “Design and Analysis of Blackstart Sequences for a Notional Microgrid”, unpublished manuscript, Colorado State University, 2012.
[44] Nissan News Release, “Nissan Unveils New Power Supply System through Nissan LEAF”, Aug 2, 2011, available at: http://www.nissan-global.com/EN/NEWS/2011/_STORY/110802-01-e.html.

APPENDIX A Vehicle Fleet Data

Mixed PHEV/BEV Fleet Summary

Vehicle	Quantity	Battery Capacity (kWh)	Total Capacity (MWh)	Power Output (kW)	Total Power Out (MW)	Power Input (kW)	Total Power In (	Range when Full (	Available Vehicle Miles (Mi)	Invoice	GSA Price	Total Cost	Incremental Cost	MPGge
2012 Toyota PHEV Prius (PHEV 15)	65	3.5	0.23	3.30	0.21	Level 2		6	390	$30,721	30,721	$1,996,865	N/A	87
2012 GM Chevy Volt (PHEV 40)	65	4.0	0.26	3.30	0.21	Level 2		35	2,275	$37,579	$37,370	$2,429,050	$22,234	94
2012 Nissan Leaf EV	65	19.2	1.25	6.00	0.39	Level 2		73	4,745	$33,707	$35,439	$2,303,535	$20,303	99
2012 Smith Newton	65	64.0	4.16	20.00	1.30	Level 3		47	3,055	$123,600	$139,754	$9,084,010	N/A	19
Total	**260**		**5.90**		**2.12**		**0**		**10,465**			**$15,813,460**		
									Annual Electric Miles Available					
									3,819,725					
									Avg Daily Electric Miles Available					
									10,465					
			Chevy Volt 16kWh, 10.4 usable, 12kWh NREL				Volt Power 240A/16A = 3.84 kW, 7.7kW NREL							
			Nissan Leaf 24kWh,25kWh NREL				Leaf Power 240A/16A = 3.84kW, limited to 3.3kW by BMS, 6.6 expected, 6kW from Nissan Power System, 7.7kW NREL							

All EV Fleet Summary

Vehicle	Quantity	Nameplate Capacity	Actual Capacity (kWh)	Fleet Capacity (MWh)	Power Output (kW)	Fleet Power Out (MW)	Power Input (kW)	Electric Range (Mi)	Available Vehicle Miles (Mi)	Invoice	GSA Price	Total Cost	MPGge
2012 Toyota PHEV Prius (PHEV 15)	0	4	3.5	0.0	3.30	0.0	Level 2	6	0	$30,721	N/A	$0	87
2012 GM Chevy Volt (PHEV 40)	0	16	10.4	0.0	3.30	0.0	Level 2	35	0	$37,579	$37,370	$0	94
2012 Nissan Leaf EV	130	24	19.2	2.5	6.00	0.8	Level 2	73	9,490	$33,707	$35,439	$4,381,910	99
2012 Smith Newton	130	80	64.0	8.3	20.00	2.6	Level 3	47	6,110	$123,600	$139,754	$16,068,000	19
Total	**260**			**10.8**		**3.4**		**161**	**15,600**			**$20,449,910**	
									Annual Vehicle Miles Available				
									5,694,000				
									Avg Daily Miles Available				
									15,600				
			Chevy Volt 16kWh, 10.4 usable (GM), 12kWh NREL			Volt Power 240A/16A = 3.84 kW (.85 charger eff) = 3.3kW							
			Nissan Leaf 24kWh,25kWh NREL			Leaf Power 240A/16A = 3.84kW, limited to 3.3kW by BMS, 6.6 expected, 6kW from Nissan Power System							

APPENDIX B PV WATTS v2 Results

"PVWATTS v.2: AC Energy and Cost Savings"
"Station Identification"
"Cell ID:","0174365"
"State:","California"
"Lat (deg N):" XXXXX
"Long (deg W):", XXXXX
"PV System Specifications"
"DC Rating:","2300.0 kW"
"DC to AC Derate Factor:"," 0.770"
"AC Rating:","1771.0 kW"
"Array Type: Fixed Tilt"
"Array Tilt:"," 32.7"
"Array Azimuth:","180.0"
"Energy Specifications"
"Cost of Electricity:","17.3 cents/kWh"
"Results"
"Month", "Solar Radiation (kWh/m^2/day)", "AC Energy (kWh)", "Energy Value ($)"
1, 4.94, 255622, 44191.93
2, 5.40, 250447, 43297.28
3, 5.78, 296433, 51247.34
4, 6.19, 303544, 52476.69
5, 6.27, 316469, 54711.16
6, 6.01, 291916, 50466.44
7, 6.24, 307552, 53169.59
8, 6.31, 308998, 53419.57
9, 6.20, 295812, 51139.98
10, 5.55, 279121, 48254.44
11, 5.27, 260303, 45001.18
12, 4.65, 238598, 41248.82
"Year", 5.74, 3404814, 588624.25

APPENDIX C   Additional GREET Analysis

GREET1_2011   Passenger Cars (PHEV35)   CA Mix for Electricity Production

Utilize Chevy Volt (PHEV35)

GREET defaults 24.7 mi all electric, 70.2 mpg CD, 26.5 mpg CS

	EtOH FFV: E85, Corn	Grid-Independent SI HEV: CG and RFG	Grid-Connected SI PHEV: CG and RFG	CIDI Vehicle: Conventional and LS Diesel	CIDI Vehicle: BD20	Electric Vehicle
Total Energy	69.8%	-28.6%	-27.9%	-18.6%	-19.8%	-42.5%
Fossil Fuels	-38.9%	-28.6%	-33.6%	-15.8%	-28.6%	-57.3%
Coal	740.3%	-28.6%	678.2%	-36.5%	48.7%	1781.2%
Natural Gas	178.8%	-28.6%	77.2%	-22.0%	-20.9%	228.9%
Petroleum	-68.3%	-28.6%	-50.0%	-15.0%	-29.9%	-99.7%
CO2 (w/ C in VOC & CO)	-31.9%	-28.6%	-35.9%	-14.0%	-27.7%	-61.6%
CH4	51.9%	-29.1%	5.2%	-20.7%	-27.8%	44.4%
N2O	836.3%	-9.1%	-38.1%	-26.9%	17.2%	-78.8%
GHGs	-19.2%	-28.4%	-34.4%	-14.4%	-27.2%	-58.1%
VOC: Total	28.9%	-29.8%	-54.1%	-62.6%	-54.2%	-93.4%
CO: Total	1.9%	-0.5%	-43.9%	-84.4%	-84.2%	-98.1%
NOx: Total	50.6%	-24.0%	-34.4%	-12.3%	-11.8%	-56.1%
PM10: Total	151.5%	-13.5%	28.6%	-10.7%	-2.5%	90.1%
PM2.5: Total	75.0%	-15.0%	-6.4%	-8.6%	-3.6%	2.7%
SOx: Total	88.8%	-28.6%	-0.4%	-23.6%	-20.4%	28.4%
VOC: Urban	-6.6%	-29.9%	-56.3%	-65.4%	-66.4%	-98.5%
CO: Urban	-0.3%	-0.2%	-44.3%	-85.0%	-85.1%	-99.1%
NOx: Urban	-13.4%	-20.0%	-41.3%	-4.0%	-7.8%	-71.3%
PM10: Urban	-18.6%	-8.4%	-20.6%	-2.3%	-6.5%	-41.4%
PM2.5: Urban	-19.9%	-9.3%	-26.7%	-1.0%	-5.6%	-54.2%
SOx: Urban	-57.7%	-28.6%	-26.4%	-21.7%	-34.6%	-38.6%

	EtOH FFV: E85, Corn	Grid-Independent SI HEV: CG and RFG	Grid-Connected SI PHEV: CG and RFG	CIDI Vehicle: Conventional and LS Diesel	Electric Vehicle
Total Energy	69.8%	-23.1%	-33.3%	-18.6%	-45.6%
Fossil Fuels	-38.9%	-23.1%	-35.0%	-15.8%	-59.6%
Coal	740.3%	-23.1%	178.8%	-36.5%	1681.7%
Natural Gas	178.8%	-23.1%	-1.7%	-22.0%	211.5%
Petroleum	-68.3%	-23.1%	-40.0%	-15.0%	-99.7%
CO2 (w/ C in VOC & CO)	-31.9%	-23.1%	-35.8%	-14.0%	-63.6%
CH4	51.8%	-22.9%	-23.1%	-20.9%	36.5%
N2O	1114.6%	-9.8%	-26.5%	-35.9%	-73.2%
GHGs	-19.2%	-23.0%	-35.3%	-14.4%	-60.2%
VOC: Total	29.2%	-15.6%	-33.5%	-57.8%	-93.8%
CO: Total	2.6%	-25.9%	-42.1%	-91.7%	-97.5%
NOx: Total	38.1%	-22.5%	-35.8%	-8.9%	-68.7%
PM10: Total	170.1%	-12.2%	-5.8%	-9.3%	88.8%
PM2.5: Total	78.3%	-12.6%	-18.9%	-4.6%	-6.2%
SOx: Total	88.8%	-23.1%	-25.1%	-23.6%	21.6%
VOC: Urban	-6.2%	-15.3%	-33.9%	-60.4%	-98.6%
CO: Urban	-0.4%	-26.0%	-42.3%	-92.6%	-98.8%
NOx: Urban	-8.3%	-22.2%	-37.4%	-1.9%	-83.2%
PM10: Urban	-21.8%	-7.9%	-18.9%	1.2%	-53.6%
PM2.5: Urban	-21.2%	-8.0%	-21.9%	5.3%	-65.0%
SOx: Urban	-57.7%	-23.1%	-32.9%	-21.7%	-41.8%

Assumptions:

CV	15.0 mpg
CIDI	18.0 mpg
FFV	15.0 mpg
CIDI (B20)	18.0 mpg
HEV	19.5 mpg
BEV	53.9 mpg
PHEV	30.3 mpgge CD/ 20.9 mpg CS (17.1 mi all electric, 36% CD, 64% CS)

GREET 2.7 Results   Examine Vehicle Cycle (Manufacturing) Impact of V2G

Gasoline Vehicle: CG and RFG, Conventional Materal

Item	Btu/mile or grams/mile				Percentage of each stage		
	WTP	Vehicle Cycle	Vehicle Operation	Total	WTP	Vehicle Cycle	Vehicle Operation
Total energy	1,231	563	4,908	6,701	18.4%	8.4%	73.2%
Fossil fuels	1,122	526	4,806	6,454	17.4%	8.1%	74.5%
Coal	198	198	0	396	50.1%	49.9%	0.0%
Natural gas	456	214	0	671	68.0%	32.0%	0.0%
Petroleum	468	114	4,806	5,387	8.7%	2.1%	89.2%
CO2 (VOC, CO, CO2)	83	42	377	501	16.5%	8.4%	75.2%
CH4	0.534	0.073	0.015	0.621	85.9%	11.7%	2.4%
N2O	0.006	0.000	0.012	0.018	31.0%	2.6%	66.4%
GHGs	98	44	381	522	18.7%	8.4%	72.9%
VOC: Total	0.134	0.205	0.180	0.520	25.8%	39.5%	34.6%
CO: Total	0.070	0.212	3.745	4.027	1.7%	5.3%	93.0%
NOx: Total	0.233	0.068	0.141	0.443	52.7%	15.5%	31.8%
PM10: Total	0.054	0.072	0.029	0.155	34.8%	46.7%	18.5%
PM2.5: Total	0.021	0.029	0.015	0.065	32.5%	44.6%	22.9%
SOx: Total	0.116	0.122	0.006	0.245	47.6%	49.9%	2.5%
VOC: Urban	0.076	0.113	0.112	0.302	25.3%	37.6%	37.1%
CO: Urban	0.019	0.002	2.329	2.350	0.8%	0.1%	99.1%
NOx: Urban	0.051	0.007	0.088	0.145	35.1%	4.6%	60.3%
PM10: Urban	0.009	0.001	0.018	0.028	31.9%	5.2%	62.9%
PM2.5: Urban	0.005	0.001	0.009	0.015	34.2%	5.8%	60.0%
SOx: Urban	0.035	0.011	0.004	0.050	70.4%	22.0%	7.6%

EV, Conventional Materal

Item	Btu/mile or grams/mile				Percentage of each stage		
	WTP	Vehicle Cycle	Vehicle Operation	Total	WTP	Vehicle Cycle	Vehicle Operation
Total energy	1,570	855	2,134	4,558	34.4%	18.7%	46.8%
Fossil fuels	1,505	778	2,134	4,417	34.1%	17.6%	48.3%
Coal	304	332	0	635	47.8%	52.2%	0.0%
Natural gas	1,177	328	2,134	3,640	32.4%	9.0%	58.6%
Petroleum	24	118	0	142	16.9%	83.1%	0.0%
CO2 (VOC, CO, CO2)	234	67	0	301	77.7%	22.3%	0.0%
CH4	0.768	0.110	0.000	0.878	87.5%	12.5%	0.0%
N2O	0.001	0.001	0.000	0.002	56.8%	43.2%	0.0%
GHGs	253	70	0	323	78.3%	21.7%	0.0%
VOC: Total	0.026	0.205	0.000	0.232	11.3%	88.7%	0.0%
CO: Total	0.062	0.241	0.000	0.303	20.6%	79.4%	0.0%
NOx: Total	0.153	0.096	0.000	0.249	61.5%	38.5%	0.0%
PM10: Total	0.081	0.105	0.021	0.207	39.2%	50.9%	9.9%
PM2.5: Total	0.041	0.040	0.007	0.088	46.7%	45.0%	8.3%
SOx: Total	0.125	0.346	0.000	0.471	26.6%	73.4%	0.0%
VOC: Urban	0.004	0.114	0.000	0.118	3.3%	96.7%	0.0%
CO: Urban	0.022	0.002	0.000	0.024	89.7%	10.3%	0.0%
NOx: Urban	0.037	0.008	0.000	0.045	81.6%	18.4%	0.0%
PM10: Urban	0.019	0.001	0.013	0.032	57.8%	2.7%	39.5%
PM2.5: Urban	0.018	0.000	0.005	0.023	78.7%	1.9%	19.4%
SOx: Urban	0.016	0.015	0.000	0.031	50.2%	49.8%	0.0%