Public Interest Energy Research (PIER) Program
INTERIM PROJECT REPORT

HUMBOLDT COUNTY AS A RENEWABLE ENERGY SECURE COMMUNITY

Resource and Technology Assessment Report

DRAFT

Prepared for: California Energy Commission

Prepared by: Schatz Energy Research Center, Humboldt State University

SCHATZ ENERGY RESEARCH CENTER

MAY 2011

PIR-08-034

Prepared by:

Primary Author(s):
Jim Zoellick, Senior Research Engineer, SERC
Colin Sheppard, Research Engineer, SERC
Peter Alstone, Research Engineer, SERC

Also Contributing:
Andrea Alstone, Dr. Charles Chamberlin, Ruben Garcia, Dr. Steven Hackett, Dr. Peter Lehman, Eric Martin, Luke Schiedler, SERC

Schatz Energy Research Center
Humboldt State University
Arcata, CA 95521
707-826-4345
www.schatzlab.org

Contract Number: PIR-08-034

Prepared for:
Public Interest Energy Research (PIER)
California Energy Commission

# ACKNOWLEDGEMENTS

We would like to thank the staff and interns of the Redwood Coast Energy Authority and the Schatz Energy Research Center at Humboldt State University who participated in this study. We would like to thank the members of our Professional Advisory Committee who so generously donated their time and expertise to help ensure the results of this study are relevant and realistic. We would like to thank the many other technical advisors who we called upon during this study for technical guidance and assistance. We would like to thank Pacific Gas and Electric Company for their generous support of this project and for providing technical advice and data. Finally, we would like to thank the staff at the California Energy Commission for their generous support of this project.

Redwood Coast Energy Authority

Dana Boudreau
Matthew Marshall

Professional Advisory Committee

Obadiah Bartholomy, Sacramento Municipal Utility District
Don Dame, Northern California Power Agency
Easan Drury, National Renewable Energy Laboratory
Kirk Girard, County of Humboldt
Garvin Heath, National Renewable Energy Laboratory
Bryan Jungers, E Source
Tim Lipman, Transportation Sustainability Research Center, UC Berkeley
Bob Marino, DG Fairhaven Power
David Rubin, Pacific Gas and Electric Company
Sasha von Meier, Sonoma State University

Pacific Gas and Electric Company

Ashwini Mani
Marco Rios
Alison Talbott
Joscelyn Wong

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Humboldt County Renewable Energy Secure Community: Resource and Technology Assessment Report is an interim report for the Humboldt County Renewable Energy Secure Community: Planning for Renewable-based Energy Security and Prosperity in Humboldt County project (contract number PIR‐08‐034) conducted by the Redwood Coast Energy Authority. The information from this project contributes to PIER's Renewable Energy Technologies Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

This resource and technology assessment examines renewable energy development opportunities in Humboldt County, CA. The purpose of the work is to support the development of a strategic plan for the Humboldt County Renewable Energy Secure Community project. The study explores the viability of using local renewable energy resources coupled with energy efficiency and other enabling technologies to meet the majority of local electricity demand and a large portion of heating and transportation energy needs. A single-node energy dispatch model is developed and used to examine the temporal match between supply and demand. Numerous scenarios are evaluated based on their associated costs and their ability to meet energy demands and reduce greenhouse gas emissions. An optimization algorithm is employed to identify scenarios that can reduce greenhouse gas emissions at least cost. The study found that Humboldt County can meet the majority of its electricity demand and a large portion of its heating and transportation energy needs using local renewable resources while achieving a substantial reduction in greenhouse gas emissions at a modest cost increase. Key resources and energy technologies identified include biomass, wind, energy efficiency, electric vehicles and electric heat pumps. Other California communities can use the models and tools developed and lessons learned to further their sustainable energy and greenhouse gas reduction efforts.

Keywords: Renewable, energy, secure, community, RESCO, local, resource, technology, assessment, cost, greenhouse gas, strategic, plan, grid, integration, dispatch, model, optimization, fuel switching, electric vehicles, heat pumps, California, Humboldt

Please use the following citation for this report:

Zoellick, Jim, Colin Sheppard and Peter Alstone. (Schatz Energy Research Center, Humboldt State University). 2012. ***Humboldt County as a Renewable Energy Secure Community: Resource and Technology Assessment Report.*** California Energy Commission. Publication number: CEC-XXX-2012-XXX.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

The Humboldt County Renewable Energy Secure Community (RESCO) project is an exploratory study intended to evaluate renewable energy opportunities in Humboldt County, California and develop a strategic plan for their efficient and successful development. The stated goal of the Humboldt County RESCO project is to develop a strategic action plan for Humboldt County to develop its local renewable energy resources in an effort to meet 75 to 100 percent of local electricity demand, as well as a significant fraction of heating and transportation energy needs. A full range of resources and technologies are being considered that can meet the county's energy needs while maximizing environmental, economic, and social benefits. One key element of the Humboldt RESCO study, and the topic of this report, is an assessment of renewable energy resources and technology options.

Purpose and Objectives

The resource and technology assessment identified and explored the viability of using local renewable energy resources and demand-side energy technologies to efficiently meet Humboldt's renewable energy goals. A key issue was matching local electricity supply availability with demand profiles. If there was a temporal mismatch in supply and demand, then energy import/export capabilities, energy storage assets, and/or demand management technologies were required to maintain stability on the electric grid.

The viability of various options was assessed according to a number of criteria, including:

- Providing adequate energy supply to meet projected demand;
- Utilizing resource and technology options that are currently ready for commercial development;
- Utilizing options that will function acceptably with Humboldt County's local electricity grid;
- Providing cost-efficient energy services;
- Providing environmental benefits, including cost-efficient reductions in greenhouse gas emissions; and
- Providing local economic benefits in terms of jobs and economic output.

In addition, an effort was made to identify optimal combinations of various resource and technology options. The optimization analysis focused particularly on energy costs and greenhouse gas emissions.

Project Approach and Scope

A set of energy supply, demand management, energy import/export and energy storage scenarios were developed in an effort to meet the RESCO goal: provide at least 75 percent of local electricity demand and a significant portion of heating and transportation energy needs using local renewables. Key tasks included identifying energy resource and technology options, assessing energy demands, and analyzing the ability of the energy resources and technology options to meet project goals. The work included the development and use of a customized energy balance and optimization model called the Regional Energy Planning

Optimization (REPOP) model. The model is a single-node energy dispatch model that balances energy supply and demand on an hourly basis over a full year. It was used to assess the ability of various supply portfolios to adequately meet demand, the overall cost of the supplied energy, and the resulting greenhouse gas impacts.

An optimization algorithm was used to identify optimal supply mixes coupled with energy technology solutions for given scenarios. For one of the potential scenarios, PG&E staff conducted a steady state power flow analysis to assess associated impacts to the local electric grid and to identify required infrastructure upgrades.

The renewable energy supply options for Humboldt County that were considered in the study are wind, wave, biomass, solar, biogas, and run-of-the-river hydro. Imported power and power generated by the new PG&E Humboldt Bay Generation Station were also considered. The new PG&E plant consists of ten 1.6 MW natural gas fired internal combustion engine generators.

The demand-side technology options included energy efficiency and demand shifting, as well as fuel switching opportunities in the transportation and heating sectors. The technologies that enable fuel switching are electric vehicles (both plug-in hybrid and battery electric) for transportation and heat pumps for space and water heating. To help match energy supply to demand, centralized energy storage and transmission system capacity upgrades to the Humboldt electric grid were considered.

Hydrogen was considered as a means for powering the public transit fleet; it is another way to fuel-switch from gasoline and diesel to electricity. Also, the Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model was used to examine trade-offs between various forest biomass to transportation energy pathways. Biomass fired power plants coupled with electric vehicles were compared with several forest-based biofuel production pathways.

Conclusions and Recommendations

Humboldt County has a wealth of local renewable energy resources. It is geographically isolated and severely constrained with regard to energy transmission capacity in and out of the county. Nearly all of Humboldt County's transportation fuels and the majority of its heating fuels are imported. Given these circumstances, the key issues Humboldt County faces in meeting its energy goals are not related to the adequacy of local resources, but instead to the ability to develop these resources and the associated energy infrastructure needed to adequately serve demand with local renewable energy generation.

Key lessons learned in this study include the following:

- Humboldt County can meet 75 percent or more of its electricity needs and a large fraction of its heating and transportation demand using local renewable energy resources. This can result in a substantial reduction in greenhouse gas emissions and can be achieved at a modest cost increase.
- There are many possible resource and technology options to choose from, and a mixed portfolio of options will be more advantageous than any technology in isolation. Aggressive implementation of cost-effective energy efficiency opportunities should be a near-term pursuit. Biomass, wind, and small run-of-the-river hydroelectric energy sources should play a key supply-side role.
- The RESCO goal of meeting 75 percent or more of electric demand with local renewable resources may not be the best metric for measuring success. Instead of focusing on the percentage of *electric* energy demand served by local renewable resources, the authors

recommend the focus be on cost-effective options to decrease *overall* greenhouse gas emissions across the whole energy sector.

- Fuel switching to plug-in hybrid and battery electric vehicles in the transportation sector and to electric heat pumps in the heating sector has the potential to play a major role in realizing the RESCO vision. Fuel switching opportunities are critical to cost-effectively achieving large reductions in energy related greenhouse gas emissions. Without fuel switching, deep reductions in greenhouse gas emissions are infeasible.

- Humboldt County's RESCO goals can be achieved with only a modest cost increase. The majority of greenhouse gas reductions can be realized with only a 5 to 15 percent increase in overall energy costs, and beyond this level there are diminishing returns. With a cost increase of only 5 percent and a 40 percent penetration of electric vehicles and heat pumps, Humboldt County can achieve an 80 percent share of local renewable electricity and a 36 percent decrease in greenhouse gas emissions. Doubling the percentage cost increase to 10 percent can achieve a 95 percent share of local renewable electricity and a 43 percent decrease in greenhouse gas emissions.

- Distributed generation, like rooftop solar, can play a smaller but important role. These technologies can provide direct economic benefits to retail customers. In addition, they provide an active way for individuals and businesses to participate in the implementation of the RESCO vision. Appropriate levels of support for these technologies can help cultivate broad backing for the overall RESCO plan.

- A steady state power flow analysis conducted by PG&E indicates that substantial upgrades to the local transmission and distribution system will be required to accommodate large-scale development of local renewable energy sources.

- Energy storage will not likely play a significant role unless local renewable generation provides the vast majority (i.e., greater than 90 percent) of local electricity demand.

- Regarding pathways for the use of forest-based biomass to provide energy for the transportation sector, the Fischer-Tropsch biodiesel pathway compares favorably with the biopower to electric vehicles pathway, with both of these pathways achieving greater than 90 percent reduction in fossil fuel use and greenhouse gas emissions. The cellulosic ethanol pathway does not fare as well in comparison.

- Opportunities for further research include:
  - Review, refine and improve the Regional Energy Planning Optimization Program model, with subsequent adaptation of the model for use in another California community.
  - Identify and assess ways to cost-effectively and sustainably utilize forest fuel reduction material from remote locations as a fuel source.
  - Assess small hydroelectric opportunities and barriers in Humboldt County.
  - Conduct a more robust power flow analysis for the Humboldt area electric grid to include a transient stability analysis, as well as non-conventional means of meeting North American Reliability Corporation (NERC) reliability standards such as energy storage facilities or curtailment of generation.

- Conduct further research into the Fischer-Tropsch biodiesel forest-based biofuel pathway for using local biomass resources to meet transportation energy needs. Include further study into the cost and feasibility of this pathway.

- Benefits to California communities include:
    - Development of simulation models and planning tools for community energy and greenhouse gas reduction planning.
    - Lessons learned that can be applied to other communities.
    - A case study of how large percentages of local renewable resources coupled with the adoption of electric vehicles and heat pumps can lead to cost-effective reductions in greenhouse gas emissions and substantial local economic benefits.

CHAPTER 1: Introduction

1.1 Study Context

The Humboldt County Renewable Energy Secure Community (RESCO) study is a two-year planning study intended to evaluate renewable energy opportunities in Humboldt County and to develop a strategic plan for their efficient and successful development. The stated goal of the Humboldt County RESCO project is to develop a strategic action plan for Humboldt County to develop its local renewable energy resources in an effort to meet 75 to 100 percent of the local electricity demand as well as a significant fraction of heating and transportation energy needs. A full range of renewable resources is to be considered and a portfolio of supply and demand technologies is to be identified to best meet the county's needs and best capture associated environmental, economic, and social benefits.

One key element of the Humboldt RESCO study, and the topic of this report, is an assessment of resource and technology options. Additional elements of the study include an economic analysis, an assessment of development, financing and ownership options, an assessment of regulatory and political issues, and a stakeholder analysis. Key information obtained through these various work elements will be combined to inform the development of the Humboldt RESCO strategic plan. Separate study documents are being prepared for most of these key elements and a final report will integrate the full body of work.

1.2 Study Objectives

The purpose of this resource and technology assessment is to identify and explore the viability of using various integrated mixes of local renewable energy resources to meet most or all of Humboldt County's electricity needs and a significant portion of its heating and transportation energy needs in the year 2030. The viability of various options was assessed according to a number of criteria, including:

- Providing adequate energy supply;
- Utilizing resource and technology options that are currently ready for commercial development;
- Utilizing options that will function acceptably on Humboldt County's local electricity grid;
- Providing cost-efficient energy services;
- Providing environmental benefits, including cost-efficient reductions in greenhouse gas emissions; and
- Providing local economic benefits in terms of jobs and economic output.

The work documented in this report addresses all of these criteria. In addition, an effort was made to identify optimal combinations of various resource and technology options. The optimization analysis focused particularly on energy costs and greenhouse gas emissions. While local economic benefits were also considered, they are not discussed in this report. They are examined in detail in a companion document entitled *Humboldt County as a Renewable Energy Secure Community: Economic Analysis Report* (Schatz Energy Research Center, 2011).

1.3 Study Overview

The focus of this assessment is to identify a set of resources and technologies that efficiently meet Humboldt County's RESCO goals. This required the identification and assessment of local renewable energy resources along with key energy technology options that could help enable development of these resources. A key issue to be examined was the ability to match local energy supply and demand profiles. If there is a temporal mismatch in supply and demand then energy import/export capabilities, energy storage assets, and/or demand management technologies will be required to maintain stability on the electric grid.

Key tasks for this project included the identification of energy resource options, the identification of energy technology options, an assessment of energy demands, and an assessment of the ability of the energy resources and technology options to meet project goals. The assessment task involved the development and use of a custom energy balance and optimization model called the Regional Energy Planning Optimization Program (REPOP). The model is a single-node energy dispatch model that balances energy supply and demand on an hourly basis over a full year. This model was used to assess the ability of various supply portfolios to adequately meet demand subject to various constraints. In addition, the model was used to assess the overall cost of the supplied energy and the resulting greenhouse gas impacts. Finally, an optimization algorithm was used to identify the optimal supply mixes coupled with energy technology solutions.

In Chapter 2 the energy resource and energy technology options are identified, followed by a description of the energy balance model. In Chapter 3 the results of optimization modeling are presented, and in Chapter 4 overall conclusions are discussed.

1.4 Background

Humboldt County has an electrical system that is geographically isolated from the larger California grid. It has a small electrical demand (170 MW peak), and a wealth of local renewable energy resources, including wind, wave and biomass. The *Humboldt County Energy Element Appendices: Technical Report* (Schatz Energy Research Center, 2005) found that Humboldt County's renewable energy resources could potentially meet all of the county's energy needs for electricity, transportation, and heating. Local biomass fired generators already support a third of the local demand. In addition, there are currently numerous renewable energy projects being considered for development. The largest of these is the Shell Wind Energy Bear River Wind Power Project, with a proposed installed capacity of 50 MW. Also, Pacific Gas and Electric (PG&E) has recently re-powered a local natural gas fired power plant, and the new plant consists of ten 16-MW high efficiency engine generators that are ideally suited to following changes in the intermittent supply of renewable electricity.

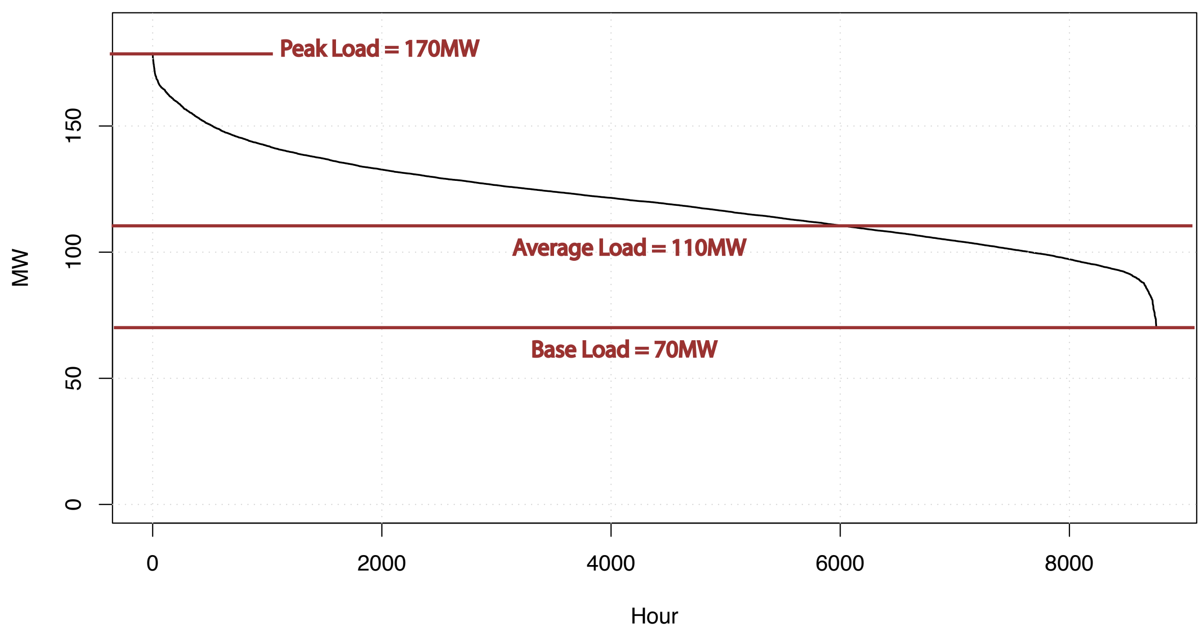
Humboldt County is geographically isolated and is almost an energy island. It has only one connection to the larger natural gas grid and four connections to the larger electric grid. The normally available capacity (approximately 60-70 MW) of the electrical transmission lines that connect Humboldt County to the larger grid is less than half of the County's 170 MW peak electrical demand. For this reason Humboldt County generates much of its own electricity. Although Humboldt County has a tremendous potential supply of indigenous renewable energy sources, it currently imports the majority of its energy in the form of natural gas and petroleum products.

1.4.1 Energy Use

In Humboldt County, energy is used as a transportation fuel and as electrical and heat energy in homes, businesses, industries, and agriculture. In 2008 it is estimated that Humboldt County's end-use energy consumption totaled about 18 trillion Btu's. Approximately half of the energy was used as a transportation fuel (gasoline and diesel), with large amounts also used to meet end-use electrical demands and end-use natural gas heating demands. Because of inefficiencies in the generation and transmission of electricity, the county's primary energy consumption totals about 25 trillion Btus. Primary energy sources were comprised mainly of natural gas, gasoline, diesel, and biomass (wood waste and firewood).

Humboldt County electricity use in 2008 totaled 990 GWh. This was used primarily in the residential, commercial, and industrial sectors. Lighting and refrigeration were the primary end-uses served in the residential and commercial sectors. The Humboldt area is winter peaking, with a peak demand of about 170 MW. Average demand is 110 MW, and baseload usage accounts for about 70 MW. Figure 1 shows a typical load duration curve for Humboldt County. Electricity use in Humboldt County increased by about 2.4 percent per year between 2004 and 2009.

Figure 1: Humboldt County 2008 Electricity Load Duration Curve



Source: Generated by Schatz Energy Research Center, data from PG&E.

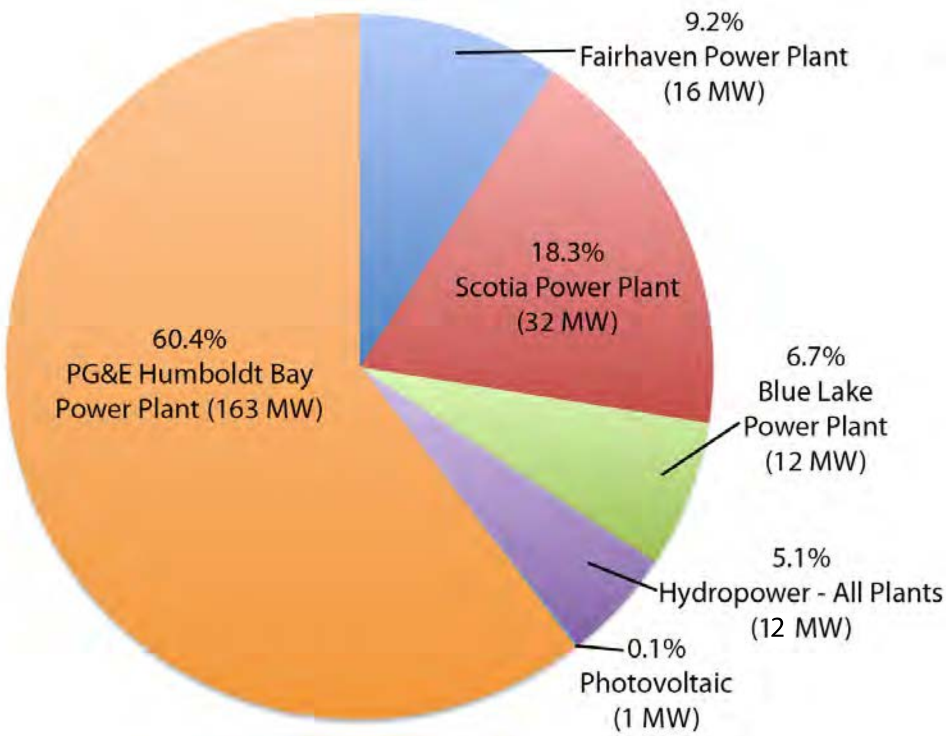
In Humboldt County, natural gas consumption in 2008 totaled an estimated 40 million therms. This usage does not include gas for producing electricity. More than half of the gas is consumed by the residential sector for home heating and cooking. The rest is consumed by the commercial, industrial, agricultural, and mining sectors.

Gasoline and diesel consumption in Humboldt County in 2008 was about 68 million gallons. The use of transportation fuels is closely linked to the number of vehicle miles traveled. Due to its rural nature, the county averages more vehicle miles traveled per capita than many more densely populated areas.

1.4.2 Energy Supply

The majority of primary energy used in Humboldt County is imported, with the exception of biomass energy. Essentially all of the county's transportation fuels are imported. Although the majority of electricity is generated in the county, a large portion of it is generated using natural gas. The county imports about 90 percent of its natural gas; the rest is obtained locally from fields in the Eel River valley. The county has the capability of generating all of its own electricity. In fact, in 2001 during the California electricity crisis, Humboldt County was a net exporter of electricity. Figure 2 shows an estimate of the breakdown of electricity sources serving Humboldt County in 2010. Three wood-fired power plants, Fairhaven, Scotia, and Blue Lake, provided 34 percent of the electrical energy needs. About 5 percent of electricity was supplied by small-scale hydropower (various plants each less than 3 MW). Finally, PG&E's Humboldt Bay Power Plant provided most of the remaining locally produced electrical energy.

Figure 2: Humboldt County 2010 Estimated Electricity Supply by Generator



Source: SERC Staff, 2011

1.4.3 Renewable Energy Resources

It has been estimated that the total electricity generation from local renewable resources could provide as much as 1500 MW of generating capacity and over 6000 GWh per year of electrical energy (SERC, 2005). This includes power primarily from waves, wind, and biomass, with smaller contributions from small hydroelectric and solar. This is over six times the county's current electricity consumption rate. However, there is considerable uncertainty about how much of these resources can realistically be developed. For example, over 75 percent of the estimated renewable electricity resource would come from wave power, a technology that is in its early stages of development and therefore unproven. Even for well proven resources like wind, solar, and hydropower, there are many potential barriers that could impede development, including high costs, regulatory hurdles, lack of financing, siting and transmission access issues, and lack of public support. Nonetheless, the potential of these local resources is large and offers significant economic development potential.

1.4.4 Energy Transmission Infrastructure

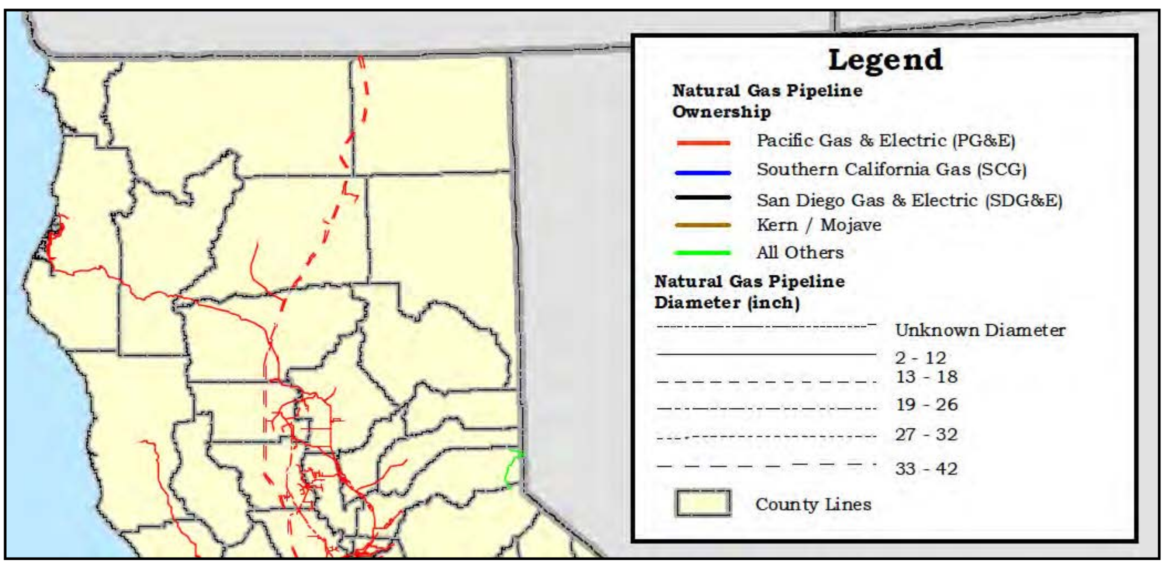
Humboldt County is remotely located at the end of the electrical and natural gas supply grids. PG&E owns the natural gas and electricity transmission and distribution systems in Humboldt County. There is one major natural gas supply line that comes from a compressor station in

Gerber in the Central Valley and follows a route roughly parallel to Highway 36 (Figure 3). This pipe is between two and 12 inches in diameter and according to PG&E is capable of transporting enough natural gas to meet current local needs. There are no gas storage fields in the local area, though there are some native gas fields in the Eel River Valley. It is estimated that approximately 65 to 70 percent of the households in Humboldt County have access to the natural gas grid (SERC, 2005).

The Humboldt area electrical grid covers about 3000 square miles and is connected to the bulk PG&E transmission system by four transmission circuits, each ranging from 31 to 115 miles in length (Figure 4 and Figure 5). Electricity imports are primarily transmitted through two 115kV circuits that come from the east at Cottonwood and follow a route roughly parallel to Highway 36 and Highway 299. Lower capacity circuits include a 60 kV circuit coming from the south at Bridgeville-Garberville (roughly parallel to Highway 101) and a second 60 kV line coming from Trinity County to the east that ties into the 115 kV lines. The total electrical transmission capacity into Humboldt County through the existing lines is 60 to 70 MW, less than half of the county's current peak demand. Therefore, local electrical generators are critical to meeting local electricity needs.

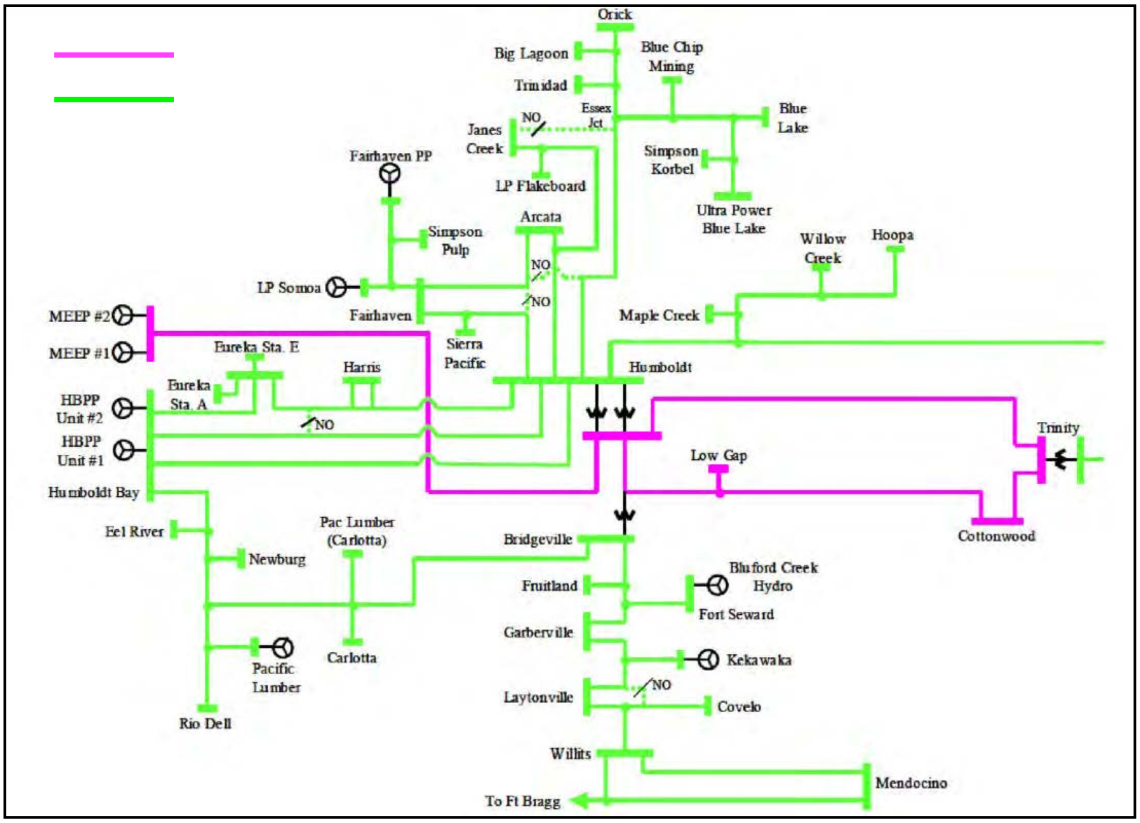
Humboldt County's connection to PG&E's larger electrical transmission grid serves many important functions. It supports wholesale market transactions and helps stabilize electricity prices, improves system stability and reliability, and provides additional voltage support. This connection allows electrical power to be imported, as well as exported.

Figure 3: Humboldt County Natural Gas Pipeline



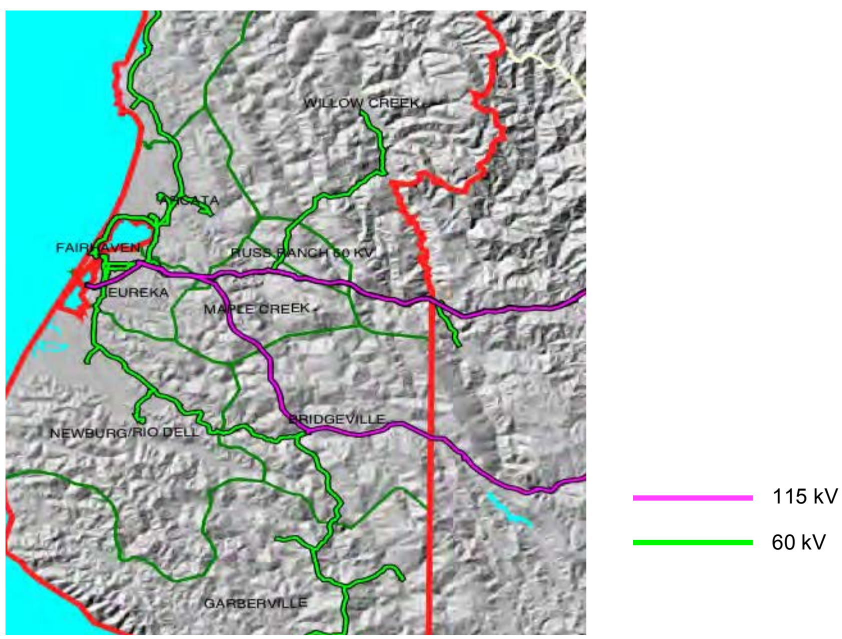
Source: Adapted from California Natural Gas Pipelines, California Energy Commission, Systems Assessment and Facilities Siting Division, Cartography Unit, http://www.energy.ca.gov/maps/natural_gas.html.

Figure 4: Humboldt Area Electricity Transmission Schematic



Source: Pacific Gas & Electric, 2005

Figure 5: Humboldt Area Electricity Transmission Map



Source: PG&E, undated.

CHAPTER 2: Approach

2.1 Overview

A resource and technology assessment was conducted to determine which local renewable energy resources and associated energy technologies can be used to meet Humboldt County's renewable energy goals. Accordingly, a set of energy resource, energy storage, and demand management scenarios were developed in an effort to provide at least 75 percent of local electricity demand and a significant portion of heating and transportation energy needs using local renewables. These scenarios were assessed for their technical feasibility according to their ability to meet projected energy demands in the year 2030. In addition, they were assessed based on their expected cost, greenhouse gas emission impacts, and economic impacts. For one potential scenario, PG&E staff conducted a steady state power flow analysis to assess associated impacts to the local electric grid and required infrastructure upgrades.

In Section 2.2 renewable energy resources in Humboldt County are identified and characterized, including an estimate of their available capacity. Energy technology options are identified and characterized in Section 2.3, the Regional Energy Planning Optimization (REPOP) Model is described in Section 2.4, and the Power Flow Analysis conducted in partnership with Pacific Gas & Electric Company is introduced in Section 2.5.

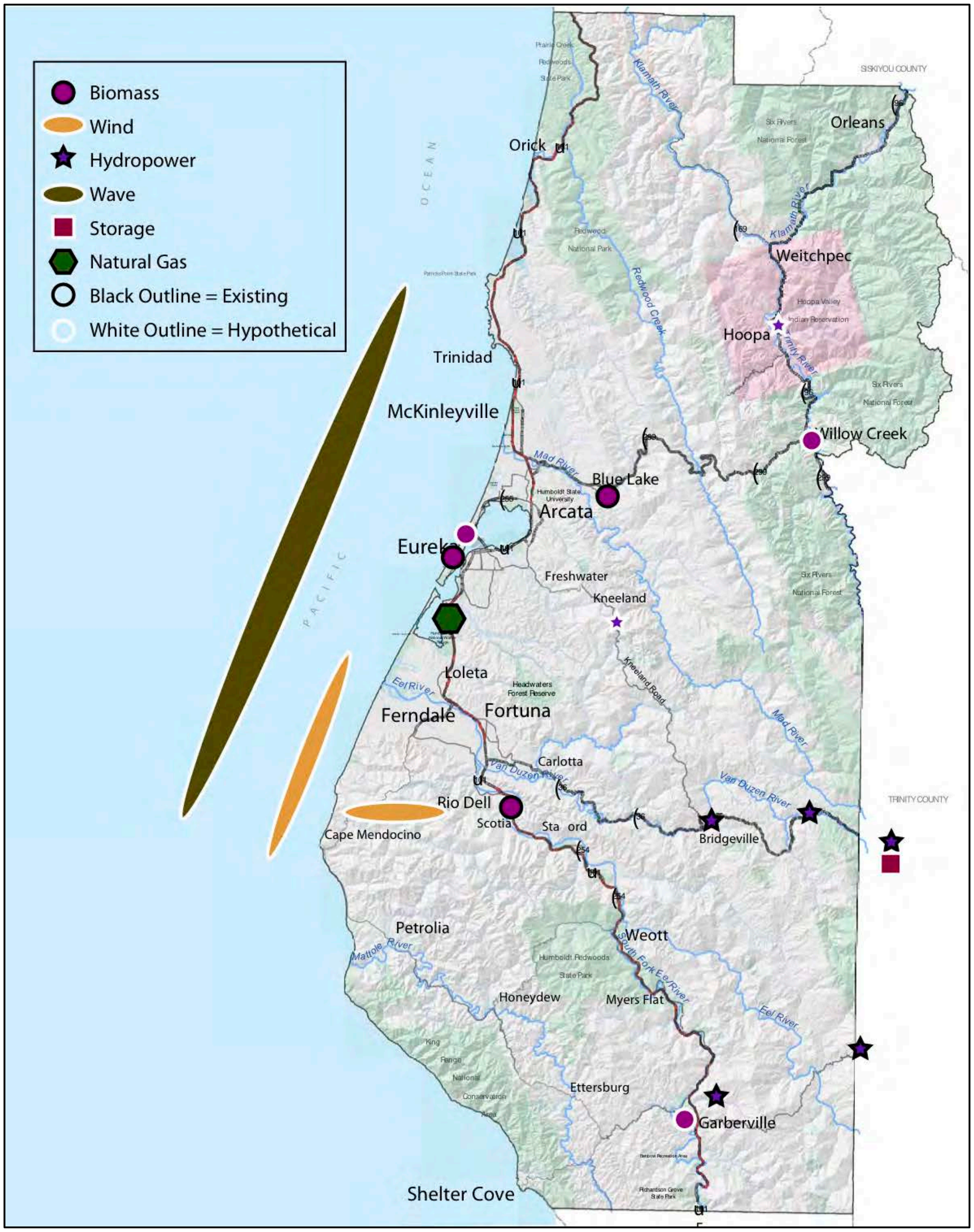
2.2 Energy Resource Options

Humboldt County is blessed with an abundant supply of renewable energy resources. Topping the list are wind, wave and biomass. In addition, run-of-the-river hydro and solar energy resources are also available in substantial quantities. To a lesser extent there are various biogas resources that can be accessed. Finally, Humboldt County possesses a significant supply of natural gas in Eel River Valley. Each of these resources is discussed briefly below. Figure 6 highlights existing as well as potential future sites for renewable electricity production.

2.2.1 Wind

Humboldt County's primary wind resource is located in the Cape Mendocino area. There is both a high quality onshore and offshore resource in this area. The onshore resource is rated at Class 5 or better and therefore exhibits good commercial potential. Shell WindEnergy, Inc. is currently pursuing the development of a 50 MW wind farm in this area on Bear River Ridge (Shell WindEnergy, Inc. 2007). It has been estimated that there is greater than 400 MW of onshore wind resource potential in this area (California Department of Water Resources, 1985). No other onshore geographic areas in Humboldt County exhibit potential for utility scale wind development. The maximum wind farm capacity examined in the REPOP Model was 250 MW. Offshore wind was not considered in the modeling analysis due to its inherent cost disadvantage compared to onshore development.

Figure 6: Existing and Potential Resources for Electricity Production in Humboldt County.



Source: SERC staff.

2.2.2 Wave

Currently, wave energy technologies are relatively immature. Nonetheless, there is tremendous wave energy potential worldwide and tremendous interest in the technology. In 2003 the California Energy Commission completed a study (California Energy Commission, 2003) that estimated the wave energy potential offshore from Humboldt County. Primary sites for the Humboldt County coastline north of Cape Mendocino (a 72 mile stretch) were estimated to have a total potential capacity of 3,900 MW. Primary sites for the southern Humboldt and northern Mendocino coastlines (an 81 mile stretch) were estimated to have a total potential capacity of 3,700 MW, approximately half of which falls within Humboldt County's coastline. A conservative estimate is that as much as 1,000 MW of this potential capacity could be developed (SERC, 2005). PG&E recently considered development of a 5 MW wave energy pilot project directly west of Humboldt Bay (PG&E, 2010a). Although this project has been suspended, future development of wave energy potential on the Humboldt County coastline continues to be a real possibility. The REPOP Model was used to examine the potential for wave energy development as large as 100 MW in capacity.

2.2.3 Biomass

The primary biomass resource in Humboldt County is forest biomass. Humboldt County is fortunate to have a tremendous forest resource base, with 1.9 million acres (65 percent private) of forested land covering more than 80 percent of the county's land area (Humboldt County, 2005). The timber harvest volume in Humboldt County in 2000 was 389,000 million board feet. This accounted for 20 percent of the timber harvest volume in the state, ranking Humboldt County as the number one county in the State with almost twice the harvested volume of second ranked Siskiyou County (Laaksonen-Craig, Goldman, and McKillop, 2003).

Humboldt County has historically obtained a large portion of its electricity from wood-fired, Rankine cycle steam power plants. Currently there are three operating wood waste-fired power plants in Humboldt County: the 28.8 MW Town of Scotia Company, LLC power plant (formerly Pacific Lumber), the 17.25 MW DG Fairhaven Power, LLC plant, and the 11 MW Blue Lake Power, LLC (formerly Ultrapower) power plant. The Fairhaven plant sells all of its electricity to PG&E under a long-term contract that extends to 2017. The Scotia plant provides electricity for the town of Scotia and the Humboldt Redwood Company sawmill, and excess electricity (approximately 80 percent of what is generated) is sold to PG&E under a long-term contract. Power from the Blue Lake power plant is sold under long-term contract to San Diego Gas & Electric Company. These three operating plants currently provide between a third and a half of Humboldt County's total electricity needs.

Biomass fuel currently comes from wood waste from mill operations and forest slash left over from timber harvest operations. Another potential source is residue from forest fuel reduction programs aimed at minimizing forest fire hazards. While most sources of sawmill waste are currently being utilized, there may be room for expansion of biomass power production if woody biomass from forest fuel reduction efforts can be economically utilized.

Our estimate of the available biomass resource comes from the findings of the California Biomass Collaborative (Williams, 2008), which was reported without modification from estimates developed by the California Department of Forestry and Fire Protection. The forest biomass available for fuel use in Humboldt County for the period 2007-2020 is estimated to be 1,314,000 bone-dry tons per year. This resource is distributed between forest thinnings (48 percent), forest slash (31 percent), and mill residue (21 percent). Logging slash comprises branches, tops and other materials left on the ground after harvest. Forest thinnings are non-merchantable materials removed during harvest activities and include understory brush, small diameter trees, and other material that cannot produce saw logs. Thinning is designed to reduce crowding and enhance overall forest health and fire resistance. Thinning resources exclude materials from forest reserves, stream management zones, coastal protection zones, and steeply sloped lands (greater than 30 to 35 percent slope). Sawmill residues are a by-product of milling operations and are already utilized for energy production or other non-energy uses. Williams estimates that Humboldt County forest biomass residues are capable of supporting 222 MW of electricity generation capacity. The maximum biomass capacity examined in the REPOP Model is 225 MW.

2.2.4 Hydro

There are currently six small hydroelectric facilities that serve Humboldt County (SERC, 2005). These facilities have a combined rated capacity of 11.5 MW. All but one of these, The Mathews Dam facility at Ruth Lake, are run-of-the-river systems. All of these systems are 5 MW or less in capacity and all of them sell power to Pacific Gas and Electric Company via long-term contracts. Although numerous other sites totaling about 60 MW in capacity have been identified for potential development of small, run-of-the-river hydroelectric power (Oscar Larson & Associates, 1982), very few sites have been developed. Likely barriers to small hydropower development include rigorous permitting requirements, remote site locations, and lack of economic viability. That said, significant potential for expansion of small hydropower exists in Humboldt County. A maximum biomass capacity of 38 MW of small hydroelectric power was examined in the REPOP Model.

2.2.5 Solar

Humboldt County is not well suited for large, utility-scale solar energy installations, including photovoltaic and concentrating solar thermal electric. The solar resource is not adequate to make such an installation economically viable, and there are few areas with large expanses of flat, available terrain. Most of the flat areas are in the foggy coastal parts of the county (near the Humboldt Bay and Eel River deltas), which are the population centers.

However, rooftop solar electric and solar hot water systems that serve individual facilities can be very appropriate in Humboldt County. In fact, on a per capita basis since 1998, the residents of Humboldt County have installed over twice as many grid-connected solar electric systems as the State of California as a whole. The total grid-connected capacity in 2010 was 1.44 MW for 428 systems (California Energy Commission, 2010a).

The average solar resource in the coastal areas of Humboldt County is 4.4 kWh/m2/day for a surface sloped at latitude (41°) and facing due south. A maximum cumulative solar electric system capacity of 10 MW was examined in the REPOP Model.

2.2.6 Natural Gas

There are natural gas deposits in Humboldt County in the Eel River basin. As of 2005 there were 38 producing wells and 15 shut-in wells in the county. Shut-in wells cannot produce gas at their existing depths and are sealed off in order to maintain the pressure on remaining deposits. Total net gas production in the county in 2003 was 1,040,000 MCF. The active gas wells are concentrated in the Tompkins Hill gas field, where there are 31 producing wells. In county production in 2003 was enough gas to supply approximately 11 percent of Humboldt County's total natural gas needs that year. The peak production for the Tompkins Hill field has passed. Current production rates are barely one half what they were in 1992 when net production was 1,930,000 MCF (thousand cubic feet) (California Department of Conservation, 2003). There were 10 new exploratory wells drilled in recent years in the Alton area where there are two new producing wells (Wheeler, 2005). The size of the natural gas reservoir in the Alton area is still unknown and data being collected is proprietary. All of the active gas wells in Humboldt County are dry gas wells and are not associated with oil deposits.

Natural gas is also supplied to Humboldt County via a gas transmission pipeline as discussed in Section 1.4.4.

2.2.7 Natural Gas Fired Power Plant

The Humboldt Bay Generating Station is a 163 MW power plant located on the eastern shore of southern Humboldt Bay in King Salmon. It is owned and operated by Pacific Gas and Electric Company and was first brought online in 2011. It consists of ten 16.3 MW natural gas fired engine generators made by Wartsila. The generators have an overall thermal efficiency rating of 45 percent. They are operated individually and can be used to closely follow changes in demand and changes in the supply of local intermittent renewable resources. They can be ramped up from a warm standby state to full power in 10 minutes. These generators are able to provide all of the local reserve capacity that is needed for the Humboldt Area. The Humboldt Bay Generating Station is included as one of the electricity supply resources in the REPOP Model.

2.2.8 Biogas

Additional sources of biomass-based fuel in Humboldt County include biogas from numerous resources. These include anaerobic digester gas from wastewater treatment plants and/or food waste digesters, landfill gas, and dairy biogas. These projects are not likely to make a large contribution toward meeting the county's electricity needs as the electricity production from all of these sources combined is unlikely to generate more than about 1 MW in the best of circumstances. Nonetheless, these projects are likely to be small-scale community based efforts that will have strong local support. As such, they represent some good potential near-term projects for the Humboldt RESCO strategic plan.

A food waste digester project currently being proposed by the Humboldt Waste Management Authority (HWMA) could generate up to 300 kW (Humboldt Waste Management Authority, 2010). The project would involve the creation of a local food waste collection program and would require strong participation from area restaurants, food vendors, and other food waste generators. Food waste would be digested adjacent to the Eureka wastewater treatment plant facility and digester gas would be added to the wastewater treatment plant's digester gas stream. Project benefits will include a reduction in the solid waste stream, monetary savings and greenhouse gas reductions in addition to renewable energy generation. Environmental documents for this project have already been completed and preliminary project development is underway. A pilot food waste collection program is being used to determine the cost of collection and the most efficient collection strategy, as well as to establish partnerships with commercial and industrial food waste generators. Additional work underway involves digester procurement, property rezoning, assessment of site suitability and negotiations for site control.

HWMA is also pursuing a landfill gas to energy project at the Cummings Road Landfill that could power a 250 kW generator. In April 2011, they released a Request for Proposals for the development of the landfill gas resource. In July 2011, the HWMA Board approved a contract with Flex Energy to develop the resource. This approval was subject to a number of contingencies, including clarifying the costs associated with interconnection to the electricity grid, site development, and permitting. Other contingency efforts include further evaluation of the landfill gas resource, assessment of system durability, and researching agreements for selling electricity and using the waste heat. Once these contingencies have been fully addressed the project economics will be reassessed and, provided the project is still cost-effective, the HWMA will proceed with the contract to install a Flex Energy Powerstation.

Regarding power generated from anaerobic digester gas from wastewater treatment plants, Humboldt County has four facilities that may be large enough to justify electrical power generators (SERC, 2005). The Eureka wastewater treatment plant already operates a 95 kW generator powered by anaerobic digester gas. Three additional wastewater treatment plants offer power production potential of 20 to 30 kW each and include the plants for the cities of Arcata, Fortuna and McKinleyville. Economic feasibility for each of these facilities is uncertain.

Finally, power generation from dairy biogas does not appear very promising for Humboldt County dairies because of their small size and pasture-based operations (Reis and Engel, 2003). If a biogas digester system were installed for a local dairy operation the typical generator size would likely be about 25 kW.

Note that these various biogas resources are not considered in the REPOP Model due to their small cumulative capacity.

2.2.9 Heating Fuels

Heating fuels in Humboldt County predominantly include natural gas (discussed in Section 2.2.6), propane, and firewood. All propane is trucked into the County. In 2003, an estimated 5.8 trillion Btus of heating energy were used in Humboldt County for space heating, water heating and other uses (SERC, 2005). Of this total, 85 percent was in the form of natural gas, 9 percent in the form or firewood, and the remaining 6 percent in the form of propane.

2.2.10 Transportation Fuels

Essentially all transportation fuels are in the form of diesel and gasoline and are imported into the county via barge to the Chevron petroleum terminal in the south end of Eureka. In 2003 nearly half of Humboldt County's end-use energy (8.52 trilling Btu's) was used in the form of gasoline and diesel fuels. This amounted to 54.6 million gallons of gasoline and 16.8 million gallons of diesel fuel (SERC, 2005).

2.3 Energy Technology Options

In order to effectively integrate large-scale development of renewable energy resources into the Humboldt County electric grid it is anticipated that the addition of various energy technologies may be necessary or desirable. For example, energy storage may be required to buffer intermittent renewables. Similarly, growth in local electric demand can be used to absorb additional generation from local renewable resources. In particular, fuel switching in the transportation sector by converting to electric vehicles and in the heating sector by converting to electric heat pumps may prove beneficial in reducing greenhouse gas emissions while also making use of local renewable energy sources.

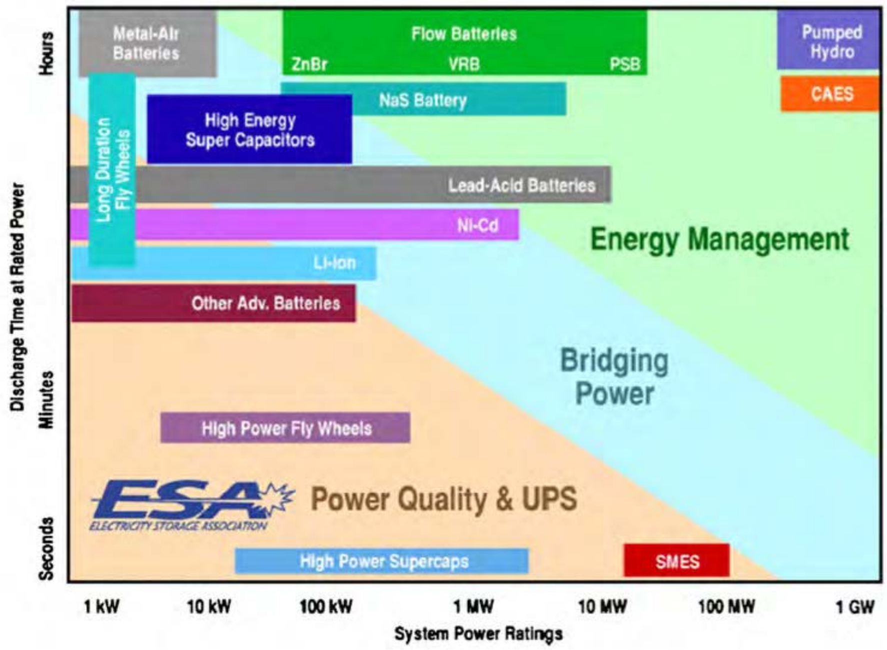
This section of the report identifies and describes various energy technology options that have been considered as part of the Humboldt RESCO study. Where detailed analyses were required to develop the required input to the REPOP Model, a summary of the information is presented here and greater detail is provided in associated appendices.

2.3.1 Energy Storage

A significant challenge to achieving high penetrations of renewable energy on the electric grid can be the variable and intermittent nature of some renewable resources. For example, solar and wind energy cannot be dispatched to match fluctuating demands, but instead must be utilized when available. A mismatch between the availability of these resources and the demand for electricity can result in supply deficits or surpluses that cannot be used. Energy storage provides a solution to this issue by decoupling the timing of resource availability from resource use, allowing electric power to be stored and released when needed.

Initial simulations of high levels of renewable energy penetration in Humboldt County suggest that energy spillage due to surplus intermittent renewable energy may occur frequently throughout the year. The term "spillage" refers to available renewable electricity that cannot be used due to a lack of adequate demand and capacity for export. This curtailed power is estimated to range from about 5 MW to 20 MW for durations of two to three days at a time. This suggests the need for an energy storage solution with a capacity of 240 MWh to 1440 MWh. As shown in Figure 7, pumped hydroelectric energy storage, compressed air energy storage (CAES) and various battery energy storage technologies are suitable for energy storage applications requiring these power and stored energy characteristics. The REPOP Model considered a maximum charge/discharge capacity of 25 MW and a maximum energy storage capacity of 18 GWh (enough energy to discharge for 30 days) at a cost of 1.25 million $/MW of capacity. These assumptions are based on data associated with pumped hydroelectric storage. See Appendix D.2.2 for a full discussion of the storage technology assessment as well as the treatment of energy storage in the REPOP Model.

Figure 7: Distribution of energy storage technologies as a function of field application.



Source: Electricity Storage Association (2010)

2.3.2 Fuel Switching - Transportation

2.3.2.1 Electric Vehicles

Electric drive vehicles have the potential to substantially displace gasoline and diesel demand with the use of cleaner, locally generated electricity. Compared to conventional gasoline and diesel, which is entirely imported, the majority of electricity consumed in Humboldt County is generated by local natural gas and biomass fired power plants. Studies indicate that electricity generation from fossil fuels such as natural gas and even coal is cleaner than the combustion of gasoline and diesel (EPRI, 2007). Moreover, electricity generated from local renewable sources can further reduce GHG emissions. Electric drive vehicles represent a fuel switching option that can reduce GHGs and allow greater use of local renewable energy resources.

The term electric vehicle (EV) is used throughout this report to refer to both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). Electric vehicles can derive part or all of their propulsion power from electricity stored in an on-board rechargeable battery. This has two primary benefits: electricity can be generated domestically and an electric motor is more energy efficient than an internal combustion engine.

PHEVs incorporate a drive train architecture that includes both an internal combustion engine (ICE), powered by gasoline or diesel, and an electric motor. A PHEV can be propelled by its ICE, its electric motor, or a combination of the two. The vehicle's all-electric range refers to the number of miles that can be traveled using only electricity from a single battery charge while in charge-depleting mode. For travel beyond a PHEV's electric range, the vehicle operates in charge-sustaining mode and is powered by its ICE. Depending on PHEV architecture, some driving events, such as aggressive acceleration, may cause the vehicle to simultaneously demand power from both its electric motor and ICE (blended-mode). Examples of PHEVs include the Chevrolet Volt and Toyota Prius Plug-In, with advertised all-electric ranges of 40 miles (PHEV-40) and 13 miles (PHEV-13), respectively. PHEVs provide a flexible alternative to conventional vehicles because they can meet the typical energy required for daily commuting with electricity, while relying on gasoline for extended travel.

In contrast to a PHEV, a BEV is solely propelled by an electric motor and powered by electricity, with no reliance on an ICE. A BEV generally has a larger battery capacity since its travel distance is limited to the energy available in a single battery charge. The Nissan Leaf is a BEV with an advertised all-electric range of 100 miles. While a BEV's lack of an ICE makes it a zero emissions vehicle (ZEV), it is reliant on the development of a rich charging infrastructure for extended travel and to reduce consumer "range anxiety."

To assess the potential impacts of electric vehicles in Humboldt County, the literature was consulted and a technical assessment was conducted. Only light duty conventional vehicles (that is, vehicles classified as autos or light trucks by the California Department of Motor Vehicles) fueled by gasoline were considered for replacement by an electric vehicle. Key tasks included establishing a baseline, projecting the future adoption of electric vehicles, characterizing vehicle performance, and estimating vehicle charging power requirements. The methodology and results are described in detail in Appendix A. An economic benefit/cost analysis was also conducted as part of the RESCO study and is presented in SERC (2011).

2.3.2.2 Hydrogen Vehicles

Another way of meeting transportation energy demands with local renewable energy resources is to produce hydrogen fuel. The most likely hydrogen production pathway would be electrolysis utilizing local renewable electricity. This fuel could then be most efficiently utilized in hydrogen fuel cell vehicles. This pathway would directly compete with the electric vehicle pathway, as the local renewable electricity could be used to either charge electric vehicle battery packs or produce hydrogen. In this regard, EVs have numerous advantages over hydrogen fuel cell vehicles. EVs are currently becoming commercially available, whereas hydrogen fuel cell vehicles are still several years away from commercial release. EVs are likely to be cheaper than hydrogen fuel cell vehicles, at least in the near-term. EVs make more efficient use of the available renewable electricity (plug-to-wheel efficiency for a modern EV, like the Nissan Leaf, is likely to be about 0.24 kWh/mi compared to a hydrogen fuel cell vehicle running on electrolytic hydrogen at 1.0 kWh/mi.) And finally, the infrastructure requirements for hydrogen production and fueling are likely to be somewhat more demanding than the required electrical system infrastructure upgrades required to support EVs. For all of these reasons hydrogen fuel cell vehicles were not considered in the REPOP model.

There are, however, market niches where hydrogen fuel cell vehicles may out-compete EVs. These include vehicle applications that demand long distance driving. For example, the Toyota Highlander Fuel Cell Hybrid Vehicle advanced (FCHV-adv) has a range of 400 miles compared to the Nissan Leaf BEV with a range of only 100 miles. In addition, fuel cell vehicles can be refueled in a few minutes, not the hours that are required to recharge an EV battery. Most major car companies (Toyota, Honda, GM, Hundai, and Daimler) have major fuel cell vehicle programs.

Fuel cell vehicles also outperform EVs in heavy-duty vehicle applications, like for transit buses. All electric vehicles are not being proposed for full-size transit applications, whereas hydrogen fuel cell buses are being successfully used in these applications. The Humboldt RESCO study examined the use of hydrogen fuel cell powered transit buses. This is a niche application that accounts for about 1.5 percent of the county's diesel fuel consumption. The analysis considered the development of hydrogen infrastructure capable of handling 10 to 100 percent of transit needs and examined the resulting cost and greenhouse gas emission implications. It was assumed that hydrogen fuel would be generated via electrolysis. Details for the methodological approach are given in Appendix B.1 and the results of this analysis are presented in Section 3.3.

2.3.2.3 Forest-based Biofuels

Humboldt County has a tremendous forest biomass energy resource. Currently a large portion of this resource is used to fuel steam-fired power plants, thereby generating electricity. If the use of this resource were expanded, a portion of the added electricity could be used to charge electric vehicles. However, an alternate pathway for using forest biomass energy resources to power the transportation sector would be to produce forest-based biofuels. Two forest-based biofuel options are cellulosic ethanol and Fischer-Tropsch biodiesel. These alternate pathways were explored and compared with the biopower to electric vehicle pathway in terms of energy efficiency and greenhouse gas emissions using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. GREET is a software tool developed by Argonne National Laboratory to fully assess the lifecycle, or well to wheels (WTW) energy and emission impacts of various vehicle and fuel combinations. GREET calculates total energy consumption, GHG emissions (CO_2, CH_4, N_2O), and criteria pollutant emissions (VOCs, CO, NO_x, PM10, PM2.5, and SO_x). This analysis was conducted independent of the REPOP Model optimization exercise.

To conduct the fuel pathway comparison, the spreadsheet-based version of the GREET model was used as opposed to the graphical user interface version. This allowed for more control over a wider range of model parameters and visibility of underlying model calculations. Default GREET parameter values were assumed during model runs with a few exceptions, which are listed in Appendix B.2.3, **Error! Reference source not found.**. These parameters were updated primarily to specify a common biomass feedstock (forest residue) for all fuel pathways and to reflect Humboldt County's electricity generation mix. Ethanol yield via fermentation was also updated according to the literature since a comment in the GREET model explained that the default value was not well researched and should not be used.

A complete description of the technical assessment of electric vehicles can be found in Appendix A. For comparison to biofuel conversion processes, it was assumed that all marginal electricity required to power EVs would come from the combustion of biomass. From a greenhouse gas perspective, electricity generated from sustainable biomass harvesting is generally considered to be carbon neutral, and it is treated as such in this analysis. Electric vehicle emissions directly depend on vehicle type (PHEV or BEV), its all-electric range, and the generation source of its electricity. The average daily distance traveled per vehicle in Humboldt County is approximately 30 miles. A PHEV with a lower all-electric range (for example PHEV 10) will consume more gasoline and emit more GHG emissions than a PHEV with a higher all-electric range (for example, PHEV 40). A BEV is a zero emissions vehicle when powered by biomass generated electricity.

The two forest-based biofuel options examined in this study are Fischer-Tropsch biodiesel and cellulosic ethanol, as these technologies are the most effective at utilizing lignocellulosic biomass. In Humboldt County it is estimated that lignocellulosic feedstocks, those derived from woody biomass in the forestry sector, account for 94 percent of the technically available biomass (Williams et al., 2007). See Appendix B.2 for a detailed description of these technologies; the results of the analysis are summarized in Section 3.4 and presented in detail in Appendix B.2.3.

2.3.3 Fuel Switching - Heating

Another area where fuel switching can be used to replace the consumption of imported fossil fuels with the use of local renewable energy sources is in the space heating sector. Currently the majority of energy used for space heating in Humboldt County, over 80 percent, comes from natural gas (Schatz Energy Research Center, 2005). A smaller portion comes from propane (approximately 9 percent), with the remainder coming from firewood. With large-scale renewable electricity development in Humboldt County, a portion of this heating energy demand could be served using renewable electricity and electric heat pumps. Heat pumps are devices that utilize an electrically driven vapor-compression refrigeration cycle (like a refrigerator or air-conditioner) to move heat from a colder reservoir to a warmer reservoir.

When using heat pumps for space heating applications heat is either moved from the outside air (an air source heat pump) or from the ground (a ground source heat pump) to the interior conditioned space. The efficiency of a heat pump can be expressed as the coefficient of performance (COP), which is the ratio of useful heat moved into the conditioned space to the amount of electrical energy required to move the heat. A typical air source heat pump has a COP of about 3, whereas a typical ground source heat pump has a COP of about 4.

This study employed a highly conservative approach in estimating the cost of switching from natural gas furnaces to heat pumps. The total cost for heating service in Humboldt County was assumed to include the cost of fuel plus the installed cost of a geothermal heat pump system. This assumption neglects the fact that air source heat pumps, which cost considerably less than ground source units, are generally more appropriate in Humboldt County due to the mild climate (CEC 2010b). In addition, the cost of replacing existing natural gas heating equipment was ignored. This implies the that there will be an early replacement of the natural gas heating equipment as opposed to a replace of the equipment at the time of failure. Finally, a coefficient of performance of 3 was used in the analysis, which is a conservative performance estimate. Ground source heat pumps generally have a coefficient of performance of about 4 (USDOE 2010). The lower coefficient of performance results in more electricity consumed and therefore greater cost to meet a given heating demand.

2.3.4 Energy Efficiency

Improvements in energy efficiency can substantially reduce energy demand in Humboldt County. While there are no detailed Humboldt County specific estimates of energy efficiency potential and associated costs, there is a wealth of literature at the state level. The most recent and authoritative of these reports is the *California Energy Efficiency Potential Study* by Itron, Inc. (2008).

The Itron (2008) study quantifies yearly (2007-2026) energy savings potential and associated costs by investor owned utility service territory, California Energy Commission climate zone, consumption sector, building type, end-use category, fuel type (electricity or natural gas), and efficiency measure type. The sectors and end-use categories included in the analysis can be seen in Table 1. Each end-use category is comprised of a number of efficiency measures that provide energy savings above a common base technology.

The Itron (2008) study assessed statewide technical, economic and market potential for energy efficiency measures. This study considers only market potential and examines a range of incentive levels, starting with a base incentive and increasing up to the full measure cost. The total savings potential from the statewide study was scaled to Humboldt County with adjustments for climate zone, population and total county energy consumption. Details of the energy efficiency analysis are described in Appendix C.

2.3.5 Smart Grid and Demand Response

Smart grid technologies can provide for two-way communication over the electrical grid, thereby allowing for control of appliances at customers' homes and businesses. Smart grid technology will be critical to allow intermittent renewable energy resources to charge electric vehicles, generate hydrogen fuel for vehicles, and charge heat pump thermal storage systems. As such, smart grid technology can play a significant role in the context of Humboldt County's renewable energy future. As of March 2012 PG&E has installed almost 98,000 electric and gas smart meters in Humboldt County, which accounts for 89% of eligible meters (PG&E, 2012).

By 2030 the smart grid will likely provide mechanisms to induce consumers (residential, business, and industrial) to curtail or shift electricity demand at critical times based on price signals. There are numerous programs being studied and pilot tested currently, with "critical peak pricing" being the framework in California (Goldman, Hopper, Bharvikar, Neena, & Cappers, 2007). Table 2 contains a summary of demand response studies for California. Based on the range of estimates from those studies and with an assumption that Humboldt County is typical in the California context, it is reasonable to expect up to 10-15 percent of peak electricity demand can be curtailed or shifted to a later time with appropriate program design and supporting technology. A maximum of 10 percent load curtailment and 6 percent load shifting were assumed in the REPOP Model.

Table 1: Sectors and End-uses Included in Analysis

End-Use	Description
Residential Electric	
HVAC	High efficiency central and room air conditioners, heat pumps, whole house fans, windows, infiltration control and attic and wall insulation
Lighting	Compact fluorescent lamps and hardwired fixtures, LED exit signs, occupancy sensors, photocells, T8 linear fluorescents, and torchieres
Water Heating	Water heaters, low-flow showerheads, faucet aerators, high efficiency clothes washers, dishwashers, and pipe wrap
Miscellaneous	One-and two speed pool pumps, high efficiency refrigerators and refrigerator and freezer recycling
Residential Gas	
HVAC	High efficiency gas furnace, attic and window insulation, infiltration control, and duct repair
Water Heating	Water heaters, low-flow showerheads, faucet aerators, pipe wrap, clothes washers, and dishwashers
Commercial Electric	
HVAC	High efficiency air conditioning, chillers, chiller tune-up, motors, and DX tune-up
Lighting	Compact and efficient linear fluorescent lamps and hardwired fixtures, HIDs and metal halides, LED exist signs, time clocks, occupancy sensors, and photocells
Refrigeration	Controls, infiltration barriers, compressors, fan motors, and night covers
Food	Holding cabinet, steamer, high efficiency ovens
Miscellaneous	Copy machines, high efficiency computers, and vending machine controls.
Commercial Gas	
HVAC	Boilers and high efficiency furnaces
Food	High efficiency steamers, ovens and fryers
Water Heating	Water heaters, boilers, circulation pump time clocks, and clothes washers
Miscellaneous	High efficiency water heating boilers, water heaters, and pool heaters

Source: Itron (2008)

Table 2: Demand response studies focused on California

Reference	Study Type	Sector	Notes	Percentage reduction (%)
Herter and Wayland (2010)	Pilot study	Residential	483 California households in 2004; critical peak pricing	5.1% (avg.) 1.9-10% depending on climate and housing type.
Goldman et al (2007)	Mixed	Commercial / Industrial	Economic model to estimate C&I demand response in CA; multiple mechanisms studied	0-5% depending on customer size and program type.
Brattle Group et al. (2009)	Economic Model	All	Nationwide study with state highlights; multiple mechanisms included in estimates (parallel programs).	6.1% (BAU) 6.5% (expanded BAU) 12.6% (achievable) 17.3% (full participation)
Piette et al (2006)	Pilot Study	Commercial	18 facilities with automated demand response.	8% coincident reduction.

Source: SERC staff.

2.3.6 Upgrades to Electrical Transmission System

One alternative for enabling the large-scale development of renewable energy resources in Humboldt County may be to upgrade the capacity of the transmission lines that serve the county, thereby allowing excess renewable power to serve loads in other geographic regions of the state. The current transmission infrastructure has four circuits that connect Humboldt to the greater California grid. These circuits include two 115kV lines from Cottonwood to the east, one 60kV line from Trinity to the east and one 60kV line from Laytonville to the south (PG&E 2005). The combined thermal limit to the export (or import) of power over these circuits is 80-167MVA. The range of limits is due to a combination of real-time factors such as weather and congestion outside of Humboldt. In addition, the power factor over the system is less than unity, which means that the exportable real power is less than the capacity of the lines. In addition, there must be redundancies in the system to ensure reliable operation of the Humboldt area grid. Accurately estimating all of these factors at the hourly time resolution of the energy balance model was beyond the scope of this study. The authors therefore make the conservative assumption that there is currently a 60MW limit to the real power that can be exported or imported from/to Humboldt County during any hour of the year. Consultation with PG&E staff has confirmed that a normal operating capacity of 60-70 MW is reasonable. The authors considered an expansion of the capacity of the transmission system serving Humboldt County of up to 200 MW in the REPOP Model.

2.3.7 Distributed Generation and Combined Heat and Power

Distributed generation has been defined by the California Energy Commission as electricity production of a capacity of 20 MW or less that is on-site or close to a load center and is interconnected to the utility distribution system (CEC 2007). Typical distributed generation technologies include photovoltaics, small wind, small biomass, and small combined heat and power (CHP) or small cogeneration. The Humboldt RESCO optimization analysis considered distributed photovoltaics, along with small biomass and small hydro. However, the representative small biomass and small hydro projects considered may not meet the California Energy Commission's definition of distributed generation because they may not be located on-site or close to a load center and may interconnect to a substation at a transmission level voltage (likely 60 kV).

With regard to small, distributed generation that is connected on-site at distribution level voltages, it is not expected that these facilities will contribute a large portion of the Humboldt County electricity supply. For example, while the REPOP model simulations did consider distributed photovoltaic capacity up to 10 MW, it was found not to be economically preferable compared to other available renewable resources. Other distributed generation opportunities that might meet the California Energy Commission's definition include small wind and small biomass facilities, though it is not expected that there will be a large number of opportunities for these technologies to be connected at the distribution level.

Finally, combined heat and power opportunities may play a role. While these opportunities were not examined as part of the RESCO analysis, it is recommended that they be included in the strategic plan and be studied in the future. One key resource for this further study is the Pacific Clean Energy Application Center sponsored by the U.S. Department of Energy[1]. Another key resource is a recent consultant report prepared for the California Energy Commission that quantifies the long-term market penetration potential for combined heat and power (ICF International, Inc., 2010). Prime opportunities for CHP include commercial and industrial applications where substantial thermal energy is required. These include hospitals, jails, colleges, large office buildings, casinos, supermarkets, and commercial and industrial processes. CHP systems are typically sized to meet the heating load.

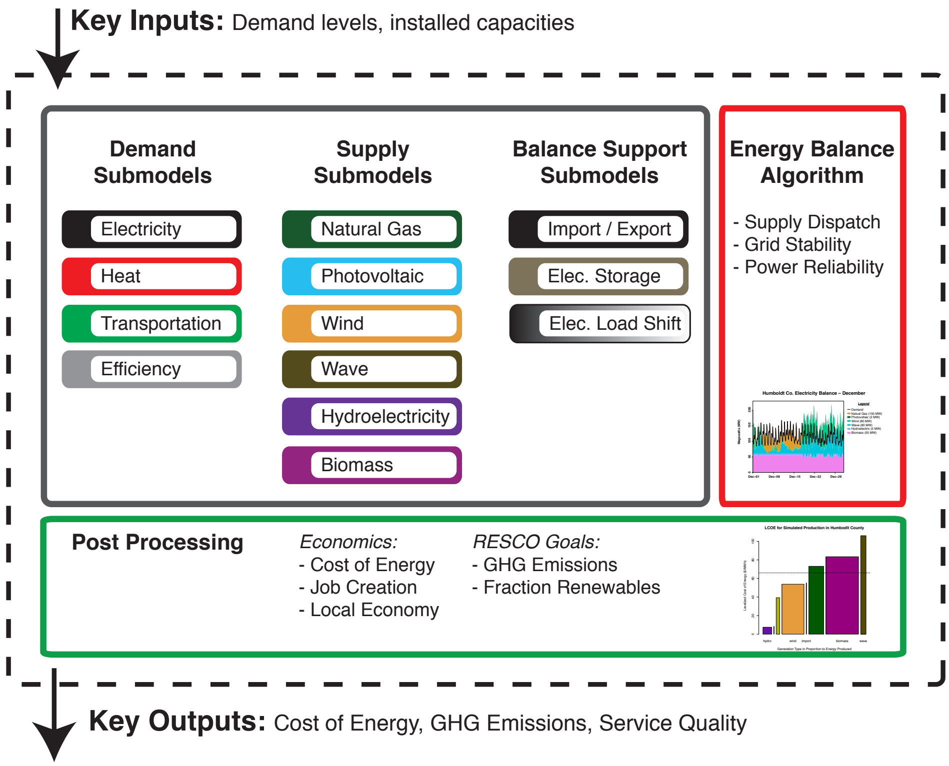
Regardless of whether the distributed generation opportunities in Humboldt County fit the California Energy Commission's definition and regardless of whether they can meet a large portion of the local electrical demand, the authors feel that distributed generation can still play an important role in Humboldt County's RESCO plan. Small, distributed projects are one key way that local residents and businesses can directly participate in implementing the RESCO vision. This can play an important role in building community support for the goals of the greater community, and therefore is expected to be a significant part of the Humboldt County RESCO strategic plan.

2.4 Energy Balance Model Methodology

This section describes the Regional Energy Planning Optimization (REPOP) Model. The REPOP model includes an energy balance model and an optimization algorithm that wraps around the energy balance model. See Section 2.4.11 for a description of the optimization algorithm. The energy balance model is made up of a combination of submodels that characterize supply and demand for energy, an algorithm that dispatches supply to meet demand, and post processing algorithms that serve to summarize a model run. Figure 8 depicts how these algorithms work together to model energy production and consumption. A portfolio, or combination, of generation capacities and demand levels is defined as the input to the model. Outputs from the model summarize the resulting energy costs, greenhouse gas emissions, economic impacts and service quality associated with the supply and demand portfolio used to serve Humboldt County's energy needs for one year. Each of the submodels is briefly described below. Details on the individual submodels and the team's background research that informed their creation are included in Appendix D and in other sections that describe the technologies in question.

[1] http://www.pacificcleanenergy.org

Figure 8: Regional Energy Planning Optimization Model



Source: SERC staff.

2.4.1 Supply Modeling

To the extent that data allow, the energy balance model simulates the availability of electricity from the following sources on an hourly time scale: natural gas, biomass, wind, wave, hydropower, solar PV and import from outside the county. Each source is assigned a maximum power output capacity along with a distribution of availability for each hour of the year (that is, at a given hour some percentage of the total capacity is available).

For the intermittent resources (wind, wave, solar, and hydro), the hourly availability is based on observed or derived data that are representative of the resource in the geographic region where it is currently or is likely to be developed (for example, wind resource near Cape Mendocino, wave power off of Humboldt Bay). For the natural gas power plant, the full net capacity of the plant is assumed to be available. For the biomass power plants, the hourly availability is based on a time series model designed to reproduce key operational characteristics observed at a local power plant. For a detailed description of each of the supply submodels, including a listing of technical and economic assumptions, see Appendix D.1.

2.4.2 Demand Modeling

Humboldt County residents' demand for energy falls generally in three categories, classified by the general end-use: electricity-driven services, heat, and transportation. The demand submodels in the energy balance model consider the three end-use categories separately with a goal of developing estimates for hourly demand for electricity and daily estimates for liquid and gaseous fuels.

Of all the "fuels", electricity is the most flexible; people in Humboldt County use electricity to saw logs, communicate using modern media, light their homes, and for a myriad of other purposes. With enabling technologies electricity can be used to meet demand in the other end-use categories. Fuel switching from liquid or gaseous fuels to electricity for heating and transportation is a key phenomenon the model is designed to study. Table 3 summarizes the type of fuels considered in each end-use category. Note that electricity shows up in each.

Table 3: End-use energy categories and fuel types included in demand estimates

End-Use	Energy and Fuel Types				
Electricity Services	Electricity				
Heat	Electricity	Natural Gas	Propane (LPG)	Kerosene	Wood
Transportation	Electricity	Gasoline	Diesel	Biofuels	

Source: SERC staff.

2.4.2.1 Demand Submodel Framework

The following submodels were used to develop estimates of demand for energy in Humboldt County.

Heating

The monthly demand for heat (for space heat, hot water, and cooking) is estimated for each end-use sector based on natural gas billing data, information on natural gas market share by sector, and estimates of the baseline efficiency of existing heating equipment and appliances. The monthly heat demand estimates are parsed into the hours of each month using typical load profiles for non-weather related end-uses (hot water and cooking). For space heating, a weather-sensitive end-use, the hourly parsing was based on results from a set of DOE-2[2] energy models that represent typical building types in Humboldt County. The hourly demands for heat, weather-related or not, are then satisfied using a fleet of equipment and appliances. The fleet characteristics reflect the existing equipment stock as well as improvements associated with energy efficiency upgrades. By varying the model constraints it is assumed that from 0 to 38 percent of the space heating and hot water heat demand currently being met with natural gas furnaces can be met with electric heat pumps. The output from the heating submodel is an hourly demand for electricity and monthly demands for other heating fuels. The implementation of efficiency measures is accounted for as described below.

Transportation

The overall annual demand for transportation fuels and electricity for charging vehicles is based on methods presented in Appendix A. Baseline gasoline and diesel demand is based on annual vehicle miles traveled and fuel consumption data. Electricity demand is parsed into an hourly demand profile using a mix of typical daily load profiles from NREL (Parks, Denholm & Markel, 2007) with 60 percent lower demand on the weekends than the weekdays. The output from the transportation submodel is hourly demand for electricity and monthly demands for other fuels. Only automobiles and light duty trucks (under 3000 lbs) are included in the analysis.

---

[2] DOE-2 is a widely used and accepted freeware building energy analysis program that can predict energy use for all types of buildings. See www.doe2.com.

Energy Efficiency Programs

The overall impact from efficiency programs is calculated in terms of avoided electricity and natural gas demand. Supply curves for efficiency improvements are based on the base, mid, and full incentive scenarios as described in Appendix C. The net impact of electricity and gas energy efficiency measures is defined in terms of the fraction of the maximum efficiency potential that is captured. Those impacts are then distributed into the hours of the year proportional to the hourly load (that is, greater impact at peak times, less impact at off-peak).

Electricity

The demand for electricity is estimated by modifying the current-day electricity demand on an hourly basis. First, the existing electric heat demand (that is, mainly resistive heat) is subtracted so the data represent "non-heat" electricity demand. The demand is further reduced according to the level of efficiency program implementation. Finally, the additional electric demand from electric vehicles and heating systems is added to arrive at a "corrected" electricity demand dataset. The corrected dataset is then linearly modified to reflect population growth (described in Appendix D.3.1).

2.4.3 Stochastic Analysis

Electricity demand, as well as electricity supply from intermittent renewable resources like wind, wave and solar all exhibit some randomness. At any given point in time there might be excessive peak demands that are coincident with severe low points in the availability of intermittent renewables. Analyzing the overall reliability of the electricity grid based upon a small number of simulation years can lead to biased results. In order to avoid this potential bias and capture the probability of these rare events, the model is designed to be stochastic. For some submodels (such as electricity demand or wind), time series are randomly drawn from a pool of source data to simulate a given year. For the biomass submodel, a time series model is developed that synthesizes hourly availability for the plants. The full details of these stochastic models are described in Appendix D.1.

2.4.4 Demand-side Management

The model includes a provision for electricity demand curtailment and shifting as a demand response when demand outstrips the available supply. For three types of demand ("typical" electricity, electric heat, and electric vehicle charging) there are three parameters that determine the degree and flexibility of demand response: curtailment fraction, shift fraction, and shift half-life. The curtailment fraction is the absolute fraction of peak demand that can be shed. The shift fraction is the fraction that can be shifted to a later time, and the half-life determines the "decay rate" of the shifted energy (that is, how much of the pent-up demand dissipates over time). For transportation demand, there is a provision to replace any curtailed electricity with gasoline while accounting for the gasoline engine efficiency of PHEVs. Based on the background research presented in Section 2.3.5 above, the parameters shown in Table 4 were used in the model.

Table 4: Demand-side Management Factors

Sector	Curtailment Fraction	Shift Fraction	Shift Half-life
"Typical" electricity	10%	2%	12 hours
Electric heat	10%	2%	6 hours
Electric vehicles	6%	6%	10 hours

Source: SERC staff.

2.4.5 Long-term Demand Forecasting

Forecasts of future energy demand in the year 2030 are entirely based on population growth projections. See Appendix D.3.1 for a detailed discussion of the population growth model and assumptions.

2.4.6 Energy Balancing

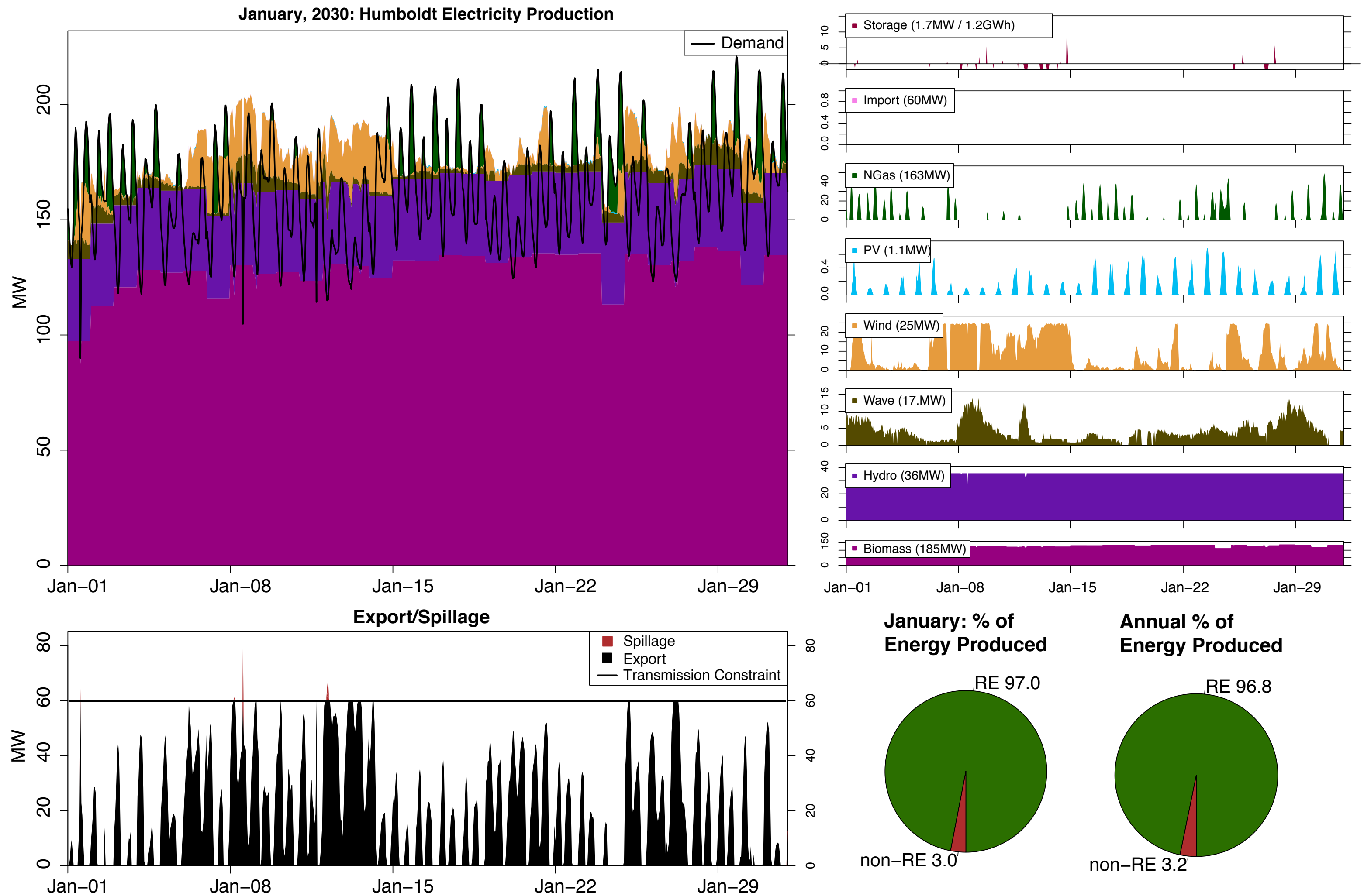
The authors developed an hourly model to balance the local supply and demand for electricity. Resources are dispatched based on an assigned priority, where renewable resources are utilized first, followed by the fossil fuel power plant and then import from outside the County. A reserve requirement must be met every hour of the year (see section 2.4.7 for a description of reserve capacity). Excess power from renewable generators can be exported up to the capacity limit of the transmission system.

The model employs an algorithm that steps through each hour of the year and dispatches resources to meet the electricity demand. A simplified formulation of the energy balance algorithm follows:

1. Always meet the reserve requirement.
2. Meet demand with available supply in order of priority.
3. Export excess power from renewable generators.

A full description of the energy balance algorithm is provided in Appendix D.4. Figure 9 shows the results of the energy balance algorithm for the month of January in an example simulation.

Figure 9: Example Results from Energy Balance Algorithm



Top left: Model demand (black line) and supply from various generators (color shaded regions) for a simulated month. Top right: Electricity supply by individual generator, colors in these plots match colors in top left panel. Bottom left: Electricity exports and energy spillage (available power that is not consumed or exported due to insufficient demand/transmission capacity). Bottom right: Fraction of renewable energy (RE) and non-renewable energy (non-RE) for the month and the entire year of the example simulation.

Source: SERC Staff

2.4.7 Reserve Capacity Requirements

Reserve capacity on the electricity grid is necessary to accommodate unforeseen fluctuations in demand as well as supply. In order to adequately evaluate renewable energy development scenarios, it is important that reserve requirements are accounted for. Reserve capacity is associated with uncertainty. If grid operators know exactly what the demand will be in the future, no reserve is necessary. In reality, operators can only estimate or forecast the future demand and available intermittent renewable power capacity, and therefore need enough reserve to cover any error in their forecasts.

To model the reserve capacity needed in any hour of the year, the authors conducted an analysis of the uncertainty associated with hour-ahead forecasts of demand, wind power production, and wave power production. A persistence forecasting method was used where the assumed demand or intermittent power production in the next hour was equal to that in the current hour. In reality, grid operators can employ a multitude of forecasting techniques that produce results far more accurate than with persistence forecasting. The persistence forecast method was employed as a highly conservative measure of the uncertainty associated with demand and production. A more complete description of the methodology used for estimating hourly reserve capacity is provided in Appendix D.2.3.

2.4.8 Energy Storage

One alternative to increasing transmission capacity in and out of the county is to develop local energy storage capacity. Like increased transmission, local storage capacity introduces flexibility into the electric grid. In reality, a storage facility would likely operate to maximize revenue. However, the authors lack the detailed price and contracting data necessary to accurately model purchasing costs and revenues from a storage facility. Therefore, the facility is assumed to operate in a manner intended to achieve the overall goals of this study, namely, serving local electricity demand with local renewable energy. To this end, the overall operational strategy is aimed at enhancing system flexibility for the Humboldt County grid.

The energy storage submodel requires specification of the following energy storage system parameters: nameplate power capacity (MW), energy capacity (MWh), round trip efficiency (percent), decay rate (percent/hr), and percent usable capacity (percent). These parameters can be defined for any storage technology (for example batteries, compressed air, pumped hydro). See Appendix D.2.2 for a description of how these parameters are used in the storage model.

During model development, the authors experimented with various control strategies for charging and discharging storage. Ultimately, a strategy was employed that allows the storage facility to act as a mechanism for both absorbing excess renewable energy and filling supply deficits when demand outstrips generation capacity. The storage operation strategy maintains a target state of charge (in the model the target is 50 percent) by using the following decision rules:

- Discharge to help meet demand; the priority of storage as a generator is set below that of all other generators including import.
- If not discharging to help meet demand, discharge if the state of charge of the system is above the target state of charge and if doing so will displace natural gas and/or import. In other words, the storage facility does not export power and therefore will not discharge if there is enough renewable energy to satisfy demand.
- If not discharging, charge anytime there is available capacity (that is the capacity not serving load, exporting, or in reserve) and the state of charge is below the target.

The effect of these decision rules is the facility moves toward the target state of charge when possible and remains there in "standby mode". Because the facility has spare charging and discharging capacity, it can respond to either type of contingency when needed.

2.4.9 Operational Constraints

The electric grid is a highly dynamic and complex machine that must be operated and maintained to rigorous standards in order to provide the high degree of safety and reliability demanded by end-users. In addition, power exchange on the electric grid is the physical manifestation of a dynamic and complex economic market containing myriad agents with various roles and interests at stake. A truly accurate model of the electric grid in Humboldt County would need to suitably capture most of the detail associated with the physical and economic forces at play in the system. Unfortunately, such a sophisticated modeling exercise is beyond the scope of this study. The model therefore contains the following simplifying assumptions with respect to operational and contractual constraints on the electric grid.

- All generators can be curtailed any hour of the year by any amount (with biomass power as an exception, see next bullet).
- Biomass power plants can only be curtailed by 10 percent of the available capacity in a given hour. In part, this constraint reflects the contractual obligation that some local biomass power plants have to meet or exceed an 80 percent capacity factor for certain qualifying months of the year (Marino, 2010). Additionally, this requirement ensures biomass generation will be online every hour of the year, which is used as partial justification for ignoring issues with transient stability (see next bullet).
- The impact of asynchronous generators on transient stability is ignored in this study. This choice is based on the fact that firming generators (biomass and natural gas power plants) are always online in the model simulations. In a majority of this study's results over 50 percent of instantaneous generation is always from firming sources, and in the worst scenario, firming sources account for at least 18 percent of generation. Based on a literature review of the impact of a high penetration of wind on electric power systems (NREL 2008, EWEA 2005), the authors feel confident that these penetrations of non-firming resources are technically achievable, though regulatory and economic challenges may need to be overcome.
- Ramping capabilities of load following generators (natural gas, biomass, and hydropower) are assumed sufficient to follow the combined load and intermittent supply fluctuations from hour to hour (and within the hour).

2.4.10 Post Processing

When the energy balance model completes a one-year simulation of the Humboldt area energy supply and demand, the result is an account of the energy dispatched to meet electricity demand for every hour of the year along with an accounting of transportation and heating fuels consumed. These results are post processed to quantify the technical, economic, and environmental implications of the simulated portfolio. The following sections summarize these calculations and their associated assumptions and justifications.

2.4.10.1 Cost Accounting

A proper evaluation of any energy generation portfolio must include an estimate of the associated costs. For a detailed description of the assumptions and sources used in the lifecycle cost analysis, see SERC (2011). The following description explains how a simplified lifecycle cost analysis is conducted at the conclusion of each run of the energy balance model. The objective of this calculation is to summarize all of the cost implications of a given scenario into a single number that makes it easy to compare portfolios against each other.

To encapsulate the total cost of servicing the energy demand for Humboldt County, the annualized life cycle cost for each technology is calculated individually and then summed together. The annualized life cycle cost is the present value of the project life cycle cost divided by the project lifetime. Dividing by the lifetime normalizes the cost of each technology to a single year allowing all of the technologies and their varied lifetimes to be combined. The following formula is used to estimate the annualized cost of each technology:

$$C_{annual} = \frac{C_{overnight} + \sum_{t=0}^{n-1} \left[\frac{C_{fixed} + C_{variable}}{(1+d)^t} \right]}{n}$$

Where C_{annual}, $C_{overnight}$, C_{fixed}, and $C_{variable}$ are respectively the annualized cost, up front capital cost, annual fixed costs, and annual variable costs of a particular technology, n is the lifetime of the project in years, and d is the discount rate. All costs are in present value terms. Values for the overnight, fixed, and variable costs used for each technology are tabulated in Appendix D.6. Finally, the following list highlights some of the key assumptions made in the cost accounting:

- All cost data are based on present-day (2010) estimates, no technology learning curves are assumed.
- Costs of existing generation capacity are included in the supply estimates.
- Transportation costs include vehicle costs (both conventional and electric vehicles) in addition to fuel and maintenance costs.
- Heating sector costs include the capital cost of installing heat pumps but neglect the cost of existing infrastructure.
- All fuel costs are based on a retail rate.

2.4.10.2 Greenhouse Gas Accounting

In post processing, GHG emissions are estimated for all uses of energy simulated in the model. Table 5 lists the conversion factors used in this analysis along with data sources. The emission calculations are accomplished by multiplying the appropriate emissions factor by the amount of energy consumed for each technology.

Table 5: Greenhouse gas emissions factors used in the model.

Fuel Type / Generator	Factor (units)	Data Source
Gasoline	97.8 (gCO_2e/MJ)	Well to wheels emission factor from CARB (2009)
Wood (for heating)	0 (gCO_2e/MJ)	SERC staff assumption
LPG	63.7 (gCO_2e/MJ)	Emissions factors from IPCC: http://www.ipcc-nggip.iges.or.jp
Fuel Oil	77.6 (gCO_2e/MJ)	
Natural Gas (for heating)	56.4 (gCO_2e/MJ)	
Electricity Imports into Humboldt	362.7 (gCO_2e/kWh)	E3 GHG Tool for Buildings In California: http://www.ethree.com
PG&E Humboldt Bay Natural Gas Power Plant	450 (gCO_2e/kWh)	Engine manufacturer brochure: http://www.wartsila.com/en/Home
PV, Wind, Wave, Hydropower	0 (gCO_2e/kWh)	SERC staff assumption
Biomass Power	6 (gCO_2e/kWh)	Pellissier (2010); Marino (2010) based on observed usage of natural gas co-firing at Fairhaven power plant.

Source: SERC staff.

Biomass power production from forest-based biomass is considered carbon neutral, with the exception being the use of relatively small amounts of natural gas for co-firing. This is consistent with current California energy and climate policy, as well as policies at the national and international level. The authors acknowledge that this is a complex topic that is currently being more heavily scrutinized, and that all sources and pathways for biomass energy production should not be considered carbon neutral. It is expected that this policy debate will become better understood and hopefully largely resolved in the near future.

The general consensus regarding where this policy debate is headed seems to be that it depends on how the forest biomass is generated (Bracmort 2011). If standing timber is being removed to fuel power plants, it may not be considered carbon neutral. If forest residues are being used, it more likely can be considered carbon neutral. Current California policy is to view biomass energy production from forest residues (mill waste, slash, thinnings and fuel reduction) as carbon neutral, and the authors expect that this will continue to be the policy well into the future (Pellissier 2010). The current biomass energy plants in Humboldt County and the possible future expansion of biomass energy as outlined in this study fit within this definition of carbon neutral biomass energy derived from forest biomass residue.

2.4.10.3 Fraction of Energy From Renewables

The authors developed two metrics to quantify the fraction of energy supplied by renewables for a particular portfolio. The first metric is referred to as "the fraction of electricity met by renewables." This metric considers only the electricity sector and ignores issues of power contracting and ownership. In other words, regardless of who ultimately pays for the electricity, renewable power produced in Humboldt County is assumed to count toward the county's renewable portfolio. In addition, power exports are ignored, so the metric represents just the fraction of local electricity demand met by renewable sources.

The second metric is referred to as "the fraction of total primary energy met by renewables." This metric is an attempt to quantify the penetration of renewable energy across all sectors of the energy economy: electricity, transportation, and heating. To formulate such a metric, a series of design choices were made to put these various forms of energy usage on equal footing. The energy balance model produces estimates of demand for fuels in the transportation and heating sectors, not demand for energy service. In order to avoid the complex calculations necessary to estimate the actual energy service demanded in the electricity sector, demand for electricity is instead converted into an estimate of the primary energy necessary to serve the electric load. Therefore, energy in all three sectors is expressed as primary energy and is comparable.

Another complication arises, however, with regards to renewable electricity that is not generated by thermal power plants (PV, wind, hydro, and so forth.). If the primary energy associated with these resources is assumed to be equal to the delivered energy, then their contribution to the overall fraction of renewables is dramatically underweighted compared to thermal sources like biomass. One kWh of biomass energy would have ~5.8 times more weight than 1 kWh of wind energy because the dimensionless heat rate for biomass is ~5.8. To address this issue, a heat rate is applied to non-thermal renewable generators despite the fact that there is no physical justification for doing so. The authors acknowledge that this choice may be controversial, but the ultimate goal is to fairly characterize the proportion of energy supplied by renewables, regardless of which type of renewable generator is involved.

The heat rate used is a weighted average of the annual local thermal generating grid mix. For example, if natural gas and biomass are the only two thermal generation types in a scenario and they produce 0.25 and 0.75 TWh of power in a year, then the heat rate applied to the non-thermal generators is the weighted average of the natural gas and biomass heat rates in proportion to their annual production.

Once energy in the electricity sector is converted into primary form, then an overall metric is calculated by dividing the sum of primary energy from renewable sources by the overall primary energy across all sectors. For reporting purposes, the metric is also disaggregated by sector (electric, transportation, heating). To do this, the renewable fraction of all primary energy for electricity is first calculated. Then that primary energy (and its associated division between renewable and non-renewable sources) is redistributed back to the transportation and heating sectors in proportion to the fraction of the delivered electricity that served those respective demands. It should be noted here that greenhouse gas emissions are not redistributed in an analogous manner when reported as disaggregated results. The reported emissions from the electricity sector include emissions due to electricity used for transportation and heating.

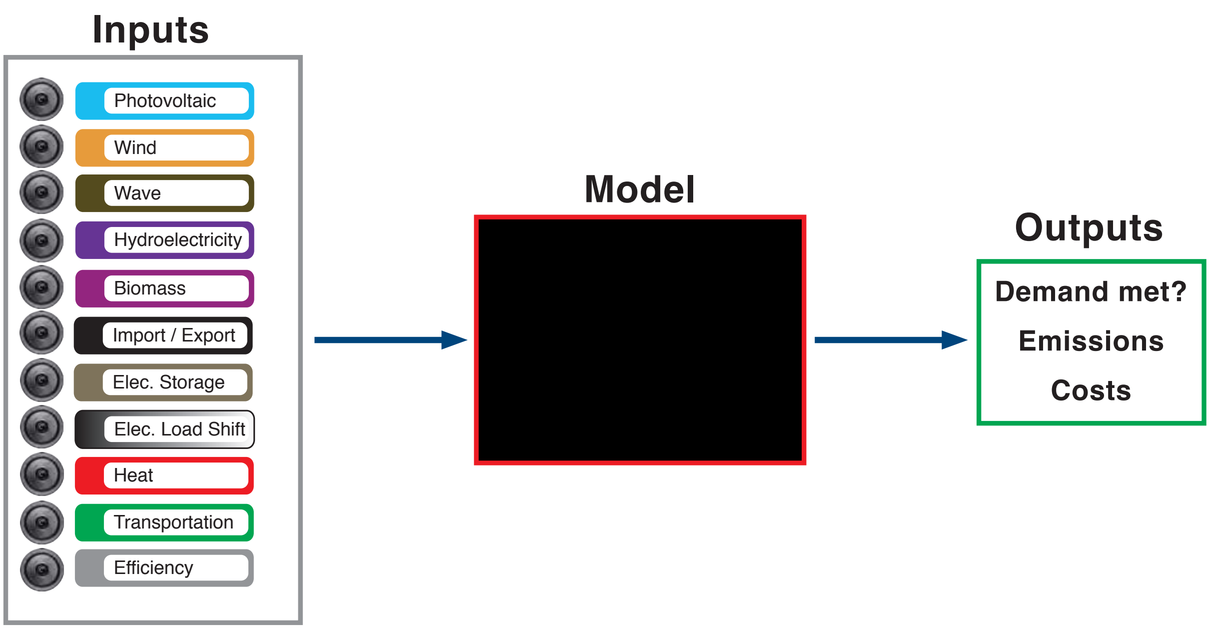
2.4.11 Model Application – Optimization

The overall goal of the Humboldt RESCO technology and resource assessment is to explore the range of supply and demand options available for increasing the use of local renewable energy sources. Ultimately, the authors' results and conclusions should help inform the creation of a strategic plan for moving Humboldt County toward a more sustainable and secure energy future.

With this goal in mind, the research team chose to apply the model in the context of various optimization problems. Optimization can provide answers to specific questions common to long term planning. For example, what portfolio of supply and demand options provides the maximum reduction in greenhouse gas emissions given a certain constraint on the overall cost? This section summarizes the methodological approach used to pose and answer these types of questions while employing the energy balance model.

The energy balance model is capable of simulating the County's energy sector for a year at the hourly timescale. The key inputs to the model include installed energy system capacities (including existing and new capacity), as well as the penetration of demand-side programs and fuel switching technologies (Figure 10). The key outputs are service reliability, the total cost of energy, and the greenhouse gas emissions associated with the scenario.

Figure 10: Black box representation of the energy balance model for the purpose of system optimization.



Source: SERC staff.

The optimization process involves iteratively updating the inputs to the model in order to achieve a desired outcome in the outputs. The desired outcome is referred to as the objective, and it usually involves minimizing or maximizing the value of an output. Constraints can be placed on the permissible values of both the inputs and the outputs, thereby keeping the range of explored options and outcomes within realistic bounds.

2.4.11.1 Optimization Problem Formulation

Optimization is used to find the portfolio(s) that satisfy various problem formulations, such as:

- Minimize GHG emission without increasing cost above a certain threshold; require that demand is met 99.9 percent of the year, or
- Minimize cost of energy but levy a price per ton of CO_2e emitted; require that demand is met 99.9 percent of the year.

Differential Evolution is the optimization algorithm employed in the analysis. Differential Evolution is a metaheuristic global optimization technique, also called a "direct search" approach, developed by Rainner Storn and Kenneth Price. See Appendix D.5 for a description of the technique and its advantages over other common optimization approaches.

The following descriptions introduce the problem formulations explored through optimization.

Business-as-Usual (BAU)

In this report, the business-as-usual scenario represents the energy sector in Humboldt County in the year 2030 assuming that no new generation is developed, no energy efficiency programs are enacted beyond the current base levels, and there is no fuel switching in the heating and transportation sectors. Many of the results in this analysis are reported relative to the business-as-usual scenario (e.g. the costs or the emissions associated with a scenario are usually reported as a percentage of business-as-usual).

Greenhouse Gas Minimization (GHG)

The minimization of GHG emissions is the primary problem formulation explored through system optimization. The formulation is subject to the following two constraints: (1) System reliability must be 99.9 percent, (2) Total annualized cost cannot exceed a prescribed level. The result of this optimization represents the portfolio that achieves the greatest emissions reductions at a given cost. It is useful to note that the result of this problem formulation should be identical to the result of the inverse formulation: minimize total cost with an upper constraint on GHG emissions. Indeed, the authors have verified that the optimal portfolio is the same regardless of which problem formulation is used.

To explore the relationship between cost and the emissions associated with optimized portfolios, the optimization is conducted multiple times with varying constraints on cost, including a scenario where cost is not constrained at all. Taken together the results represent points on a Pareto optimality frontier. Because the outputs of interest are costs and emissions, the frontier is a curve in the two-dimensional cost/emissions space. Any point along the curve represents the optimal emissions reductions possible for a given cost.

Cost Minimization

The secondary problem formulation is a cost minimization with a 99.9 percent system reliability constraint. The optimization is solved multiple times, with a successively higher price levied on every ton of CO_2e emitted in the scenario. The solutions to this optimization also form a curve in the same two-dimensional cost/emissions space, though this curve represents the cost and emissions associated with the least cost portfolio at a given price on GHG emissions. This allows us to investigate the implications of carbon pricing policies that may occur at the state and/or federal levels.

2.4.11.2 Constraints on Inputs

There is an important difference between constraints placed on the outputs of the model (cost and emissions) and constraints placed on the inputs themselves (installed capacities, penetration of electrified heating and transport). The problem formulation descriptions in Section 2.4.11.1 focus on output constraints. For all of the optimizations conducted, there are also constraints on the inputs. The constraints are based on author's estimates of the technical limits to development of each technology in Humboldt County by 2030. Table 6 lists the limits used in the analysis.

Table 6: Decision variables used in the optimizations and their corresponding boundary constraints.

Decision Variable	Lower / Upper Limit of Installed Capacity (includes existing and new capacity)
Wind Capacity (MW)	0 / 250
Wave Capacity (MW)	0 / 100
Biomass Capacity (MW)	61 / 225
Hydropower Capacity (MW)	11 / 38
Solar PV Capacity (MW)	1.1 / 10
Import/Export Transmission Capacity (MW)	60 / 200
Storage Capacity (MW)	0 / 25
Efficiency Program Level (0 = Base, 100 = Full)	0 / 100
Electrified Vehicle Penetration (% of registered vehicles)	0 / 38
Penetration of Heat Pumps (% of residential & commercial natural gas furnaces)	0 / 38
Demand Response (% of max potential or ~12% of peak load)	0 / 100

Source: SERC staff.

2.5 Power Flow Analysis – Impacts to the Local Electric Grid

Simulations using the REPOP model identified opportunities for substantial development of renewable energy projects on the Humboldt area electric grid. Before any new generators are added to the grid, however, interconnection studies will need to be performed to identify required transmission and distribution system upgrades. To develop a preliminary assessment of the need for infrastructure upgrades, the Humboldt RESCO study engaged the services of project partner and local investor owned utility Pacific Gas and Electric Company (PG&E).

PG&E's Interconnected Grid Planning group conducted an interconnection feasibility study to evaluate the transmission impacts of a representative scenario for future renewable energy development in Humboldt County. The objectives of the study were to identify:

- Transmission system impacts caused solely by the addition of the proposed renewable energy development;
- System reinforcements necessary to mitigate any adverse impacts of the proposed renewable energy development under various system conditions; and
- Facilities required for system reinforcements with a non-binding good faith estimate of cost responsibility.

The study examined transmission facilities within PG&E's Humboldt and North Coast Areas. The study assumed a projected year 2030 winter peak electric loading condition of 223 MW and included nine proposed new generation facilities in Humboldt County with a total generation output of 253 MW. Table 7 lists the proposed new generation facilities, their locations, and their proposed points of interconnection while Figure 11 shows the geographic dispersion of these facilities.

Table 7: New Generation Sources Considered in Interconnection Feasibility Study

Technology	Max MW	Location Description	Proposed Point of Interconnection
Wind	50	Bear River Ridge	Rio Dell Substation 60 kV Bus
Wind	75	Bear River Ridge	Rio Dell Substation 60 kV Bus
Biomass	40	Samoa	Fairhaven Substation 60 kV Bus
Biomass	15	Willow Creek	Willow Creek Substation 60 kV Bus
Biomass	15	Garberville	Garberville Substation 60 kV Bus
Hydro	8	Maple Creek	Maple Creek Substation 60 kV Bus
Hydro	5	Hoopa Valley	Hoopa Substation 60 kV Bus
Storage – Pumped Hydro	15	Ruth Lake	Low Gap Substation 115 kV Bus
Wave	30	Samoa	Fairhaven Substation 60 kV Bus
Total	**253**		

Source: PG&E, 2011

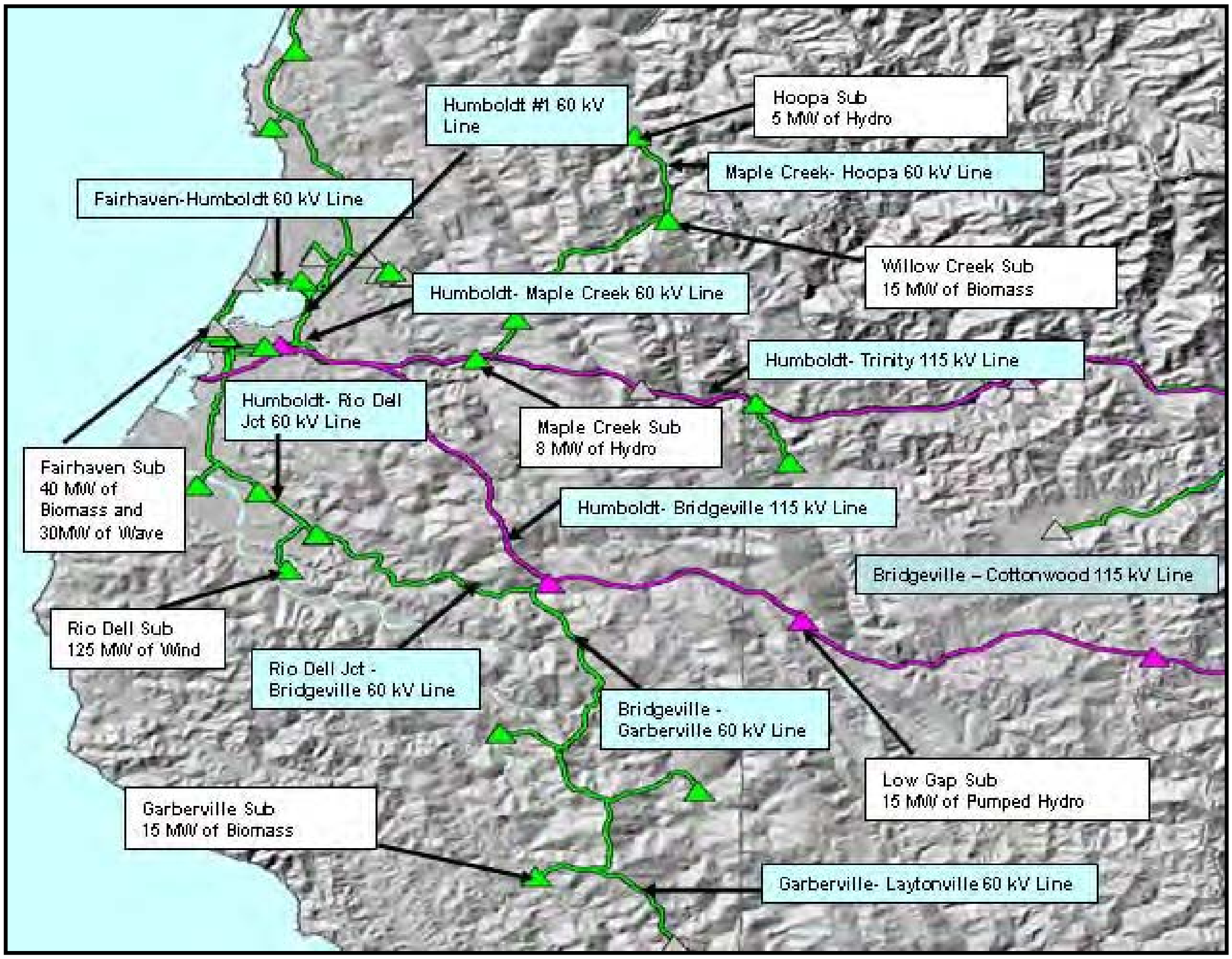
The interconnection study took into account the planned generating facilities in PG&E's service territory that are in the California Independent System Operator (CAISO) Generation Interconnection Queue in the Humboldt and North Coast Areas. In addition, all CAISO approved PG&E transmission projects in the area that will be operational by 2020 were also included.

The power flow analysis was performed to ensure that PG&E's transmission system remains in full compliance with North American Electric Reliability Corporation (NERC) reliability standards. Where a NERC reliability deficiency resulted due to the interconnection of the new generators, PG&E identified the problem and developed appropriate transmission solutions to comply with NERC reliability standards.

Two power flow base cases were used in the analysis. These included a winter peak base case and an off-peak base case, representing extreme loading and extreme generation conditions, respectively. Additional analyses were not possible within the scope of the Humboldt RESCO study. Consequently, it is important to note that this is a preliminary analysis, and the results of this study do not provide any guarantees about the ability of the system to function properly during times, seasons and situations not studied.

The base cases were used to simulate the impact of the proposed renewable energy projects during normal (CAISO Category "A") operating conditions as well as during single (CAISO Category "B") and selected multiple (CAISO Category "C") contingency conditions. In addition, CAISO Category "B" and "C" contingencies were analyzed to identify reactive power deficiencies. For a full description of the PG&E interconnection study plan see Appendix E.

Figure 11: Location of New Generation Facilities and Interconnection Points.



Source: PG&E, 2011.

CHAPTER 3: Outcomes

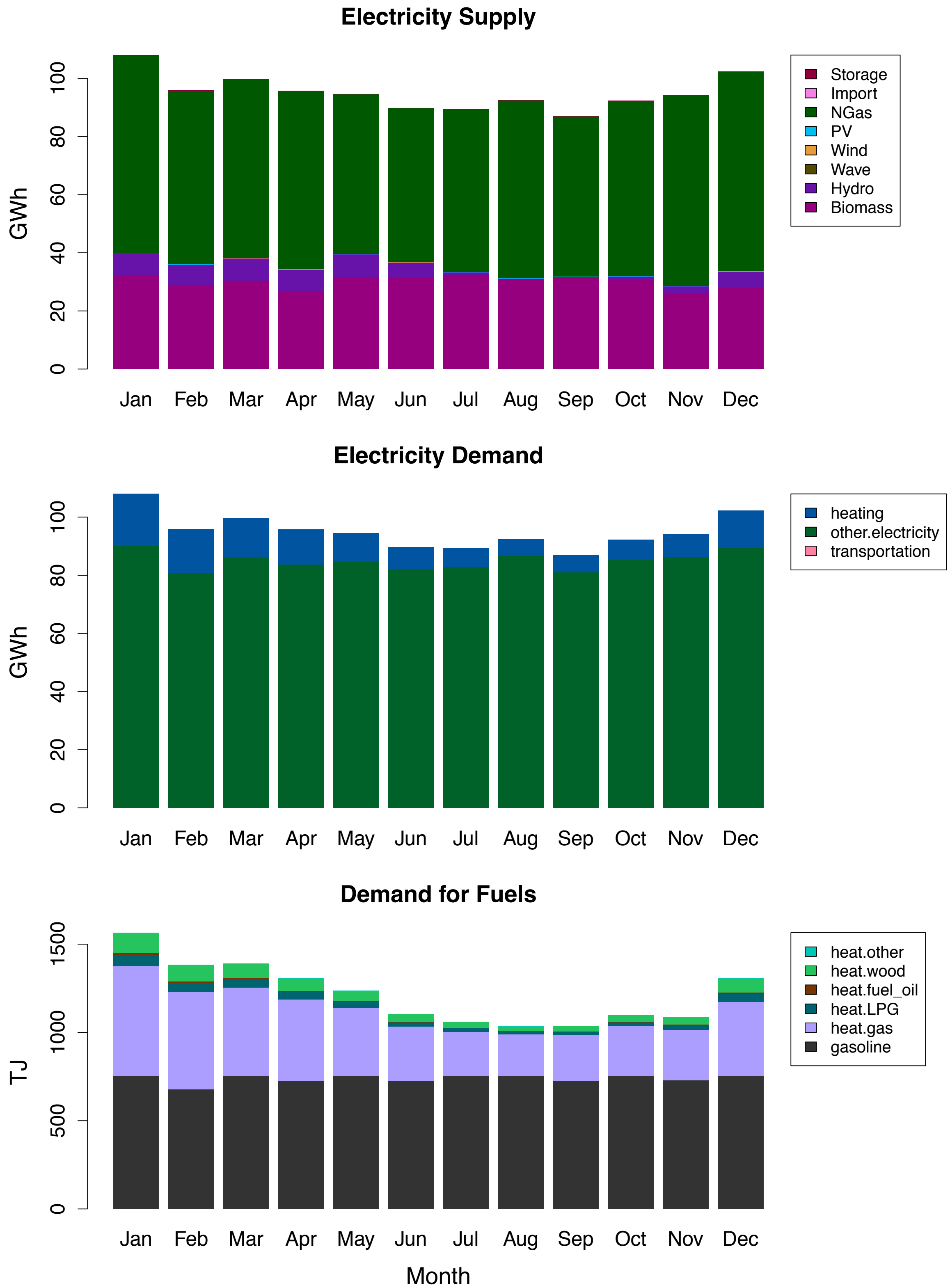
The Humboldt RESCO resource and technology assessment involved the development and use of the Regional Energy Planning Optimization Model. Chapter 3 reports on the results of the REPOP model simulations. A key focus of the work examined the trade-offs between energy costs and greenhouse gas emissions for various renewable energy resource and technology portfolios. In addition, the outcomes of multiple REPOP model sensitivity analyses are reported. Finally, results are presented for the electric grid power flow analysis, the hydrogen fuel cell bus analysis, and the forest-based biofuels analysis.

3.1 Energy Modeling Results

3.1.1 Business-As-Usual

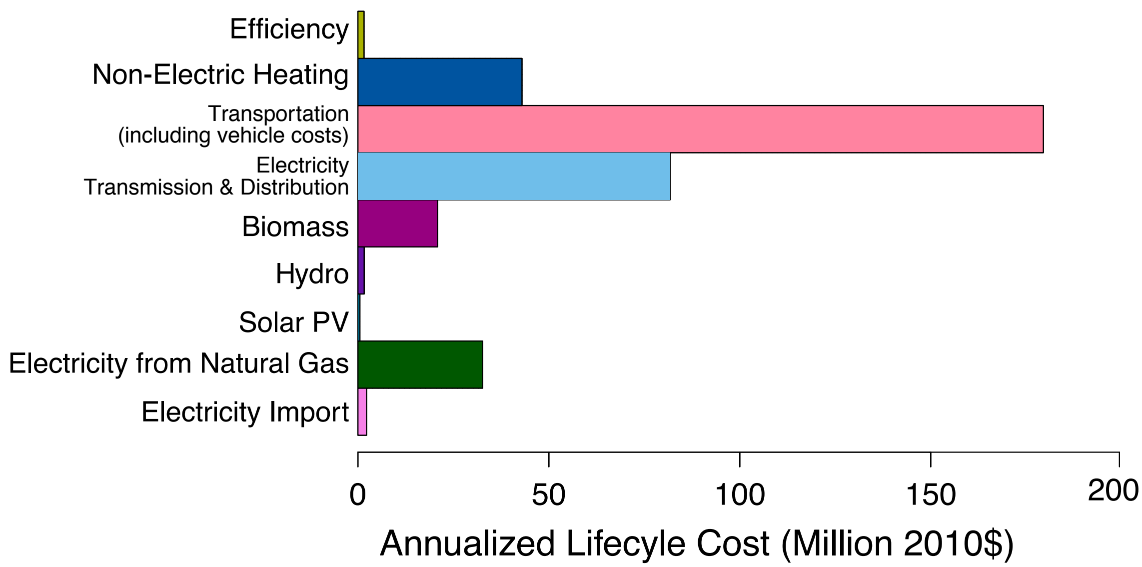
The energy demand and supply results determined by running the energy balance model for the business-as-usual, projected 2030 scenario are presented in Figure 12. The supply of electricity is dominated by natural gas (65 percent) and biomass (30 percent). Likewise, natural gas and gasoline fuels dominate the energy supplied to the heating and transportation sectors, respectively. The total annualized lifecycle cost associated with the business-as-usual scenario is $364M and the total GHG emissions are 1500 kilotonnes CO_2e. Figure 13 reports the costs and emissions associated with business-as-usual disaggregated by technology and fuel type.

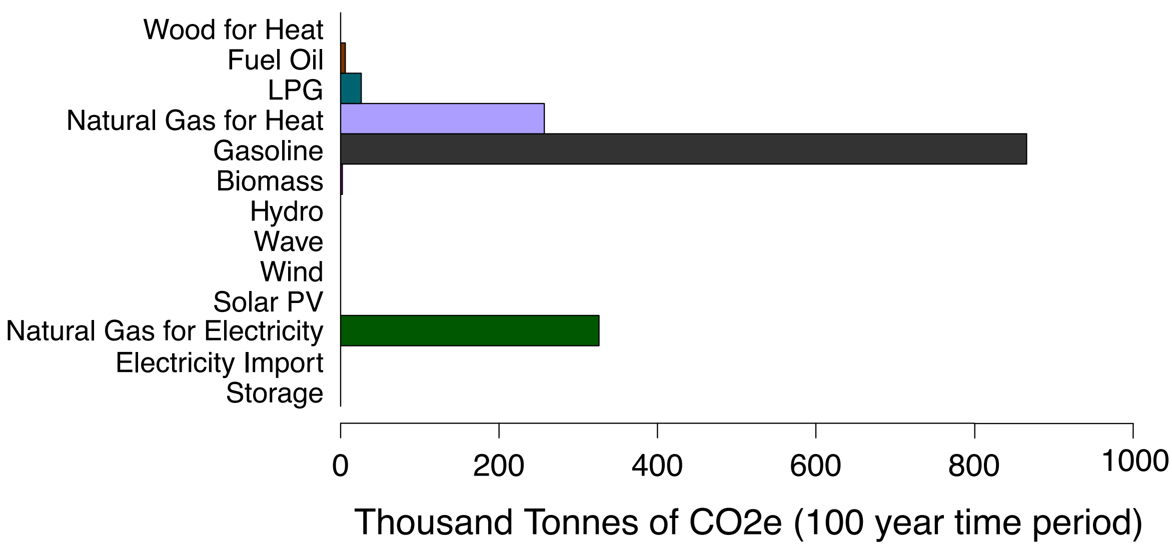
Figure 12: Business-as-usual 2030 energy supply and demand by month.



Source: SERC staff.

Figure 13: Annualized lifecycle retail costs (top) and annual greenhouse gas emissions (bottom) for business-as-usual 2030 Humboldt County energy needs.



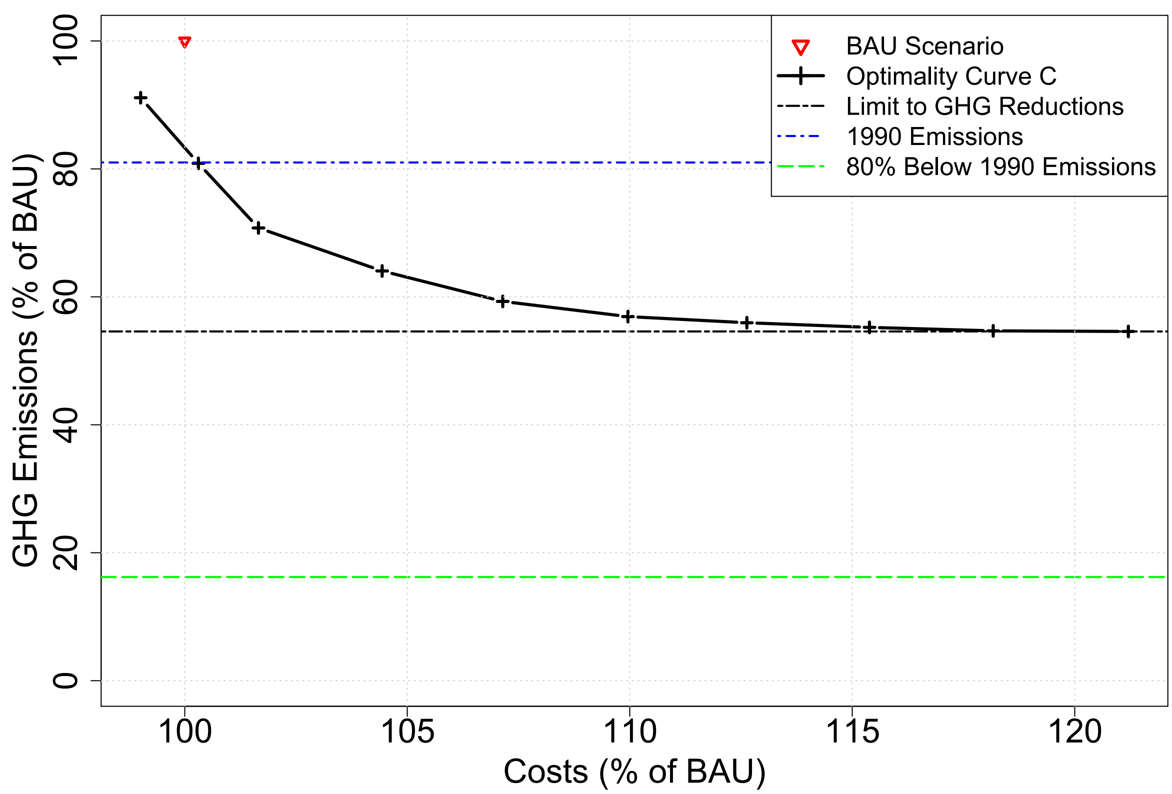


Source: SERC staff.

3.1.2 Greenhouse Gas Minimization

Given the default constraints on the decision variables (Table 6), a series of optimizations were conducted to produce the optimality curve in Figure 14. The curve represents the emissions reductions achievable at a given cost and is referred to as "Curve C" for reasons explained in Section 3.1.5. The leftmost point on the curve indicates that a 9 percent reduction in greenhouse gas emissions is possible with a 1 percent *decrease* in costs below business-as-usual. As costs increase, more and more emissions reductions are achievable, but with decreasing returns on investment. The dashed black line indicates the limit for reduced emissions. This represents the result of an optimization where emissions were minimized with no cost constraint, and therefore represents the technical limit to reducing emissions given the decision variable constraints in Table 6. The dashed blue line represents 1990 greenhouse gas emission levels, and the dashed green line represents an 80 percent reduction in greenhouse gas emissions below 1990 levels.

Figure 14: Optimality curve (Curve C) for the default emissions minimization problem formulation (minimize emissions with various cost ceilings).



BAU stands for "business-as-usual."

Source: SERC staff.

The optimal scenarios associated with a subset of the points on Curve C are summarized in Figure 15. For each scenario, the sub-plots show the installed capacities of the generators, the percent penetration of the demand decision variables, and the proportion of electricity demand met by each generator (with efficiency counting as a generator). The error bars on the bar plots indicate the range of values found by the differential evolution algorithm that equally satisfy the problem formulation. In other words, different variations on a scenario all result in essentially the same overall costs and emissions.

Energy efficiency is maximized in all scenarios, which is consistent with the fact that efficiency measures have a negative lifecycle cost. Hydropower capacity is also maximized in every scenario, indicating that it is the least cost generation technology capable of reducing overall emissions. The capacities of PV and transmission for import/export are minimized in all scenarios, reflecting the fact that their relative costs are extremely high compared to all of the other decision variables.

Generally, as the cost constraint is increased on the optimization, two strategies are simultaneously employed to achieve the lowest GHG emissions possible. These strategies are: (1) increasing the capacity of renewables on the electric grid and (2) fuel switching in the transportation and heating sectors.

However, unexpected results emerge as the cost constraint is progressively relaxed. The capacities of wind and biomass do not exhibit monotonic behavior. Below approximately 102 percent of the business-as-usual cost, wind is favored over biomass in the optimal portfolio. As more money is spent, wind increases in capacity and biomass essentially stays at business-as-usual levels. But at 105 percent of business-as-usual costs, biomass capacity becomes favored over wind. Both technologies are present in each solution, but wind capacity is low (~25MW) and biomass capacity dominates the portfolio. Finally, as the cost constraint continues to relax, wind capacity increases and plays a significant role in the solution along with biomass. This phenomenon is discussed below.

3.1.3 Marginal Cost of Greenhouse Gas Abatement

The tradeoff in dominance of wind versus biomass (described above, Section 3.1.2) can be confirmed and partially explained by estimating the marginal cost of abatement of each technology at every point on the curve. This estimation is made by the following methodology:

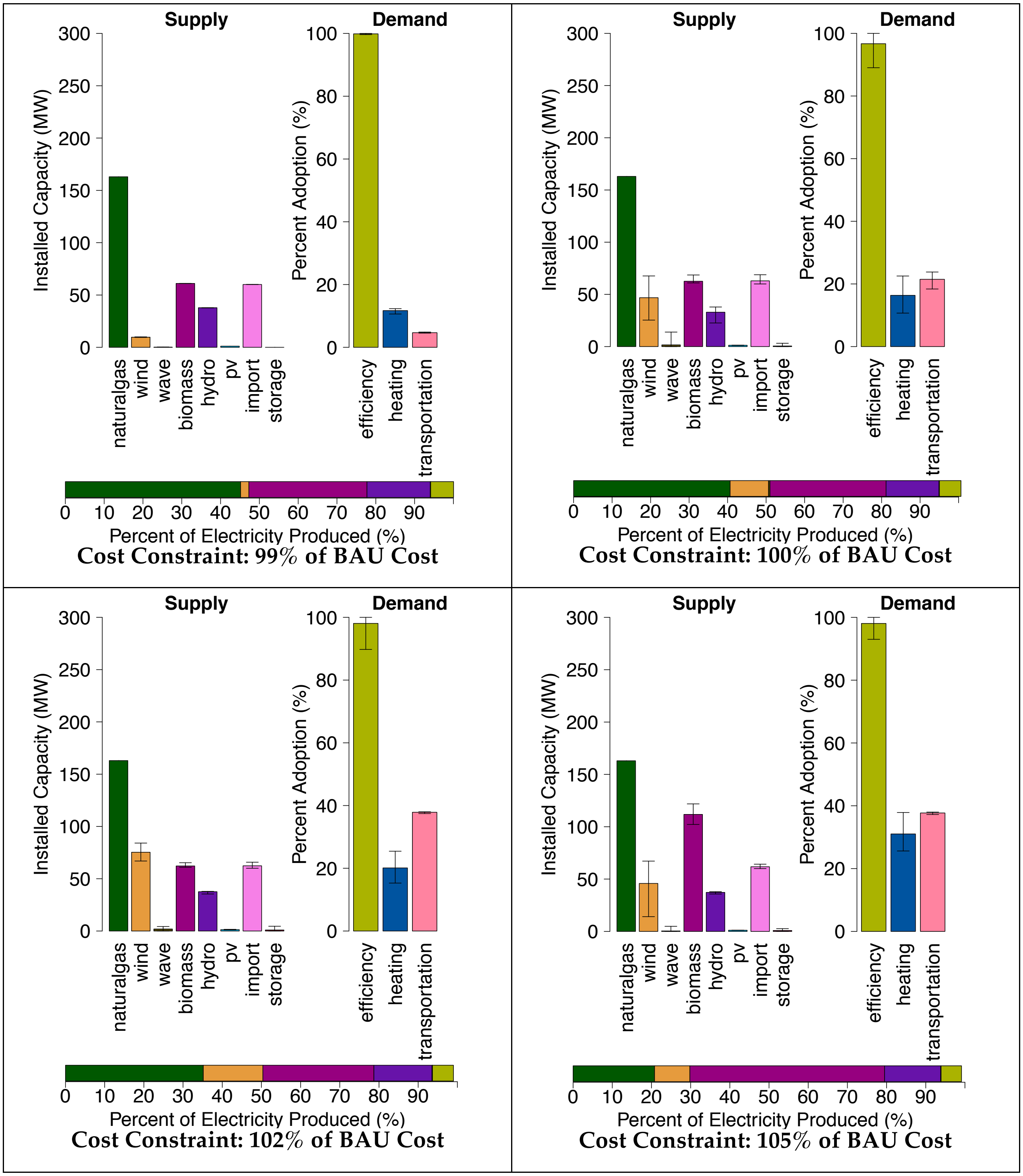
For each point on the curve:

- Run the energy balance model for the optimal portfolio associated with the point.
- Run the simulation four more times, varying the capacity of wind and biomass by +/-10 percent each (while holding all other parameters constant).
- Divide the change in emissions by the change in total cost for both biomass and wind; this is the estimate of the marginal cost of abatement.

The result of this analysis is plotted in Figure 16. Consistent with the results in Figure 15, the marginal cost of abatement of wind is lower at the left end of the optimality curve, but biomass has a lower marginal cost of abatement over the middle region. Finally, there is a region on the right side of the curve where wind again is the lower cost alternative.

While it is illustrative to compare wind and biomass in this manner, it should be stressed that this cannot be considered a full explanation of the unexpected behavior. As the cost constraint is relaxed the impact of all the decision variables, both individually and in combination, ultimately dictates the optimal portfolio.

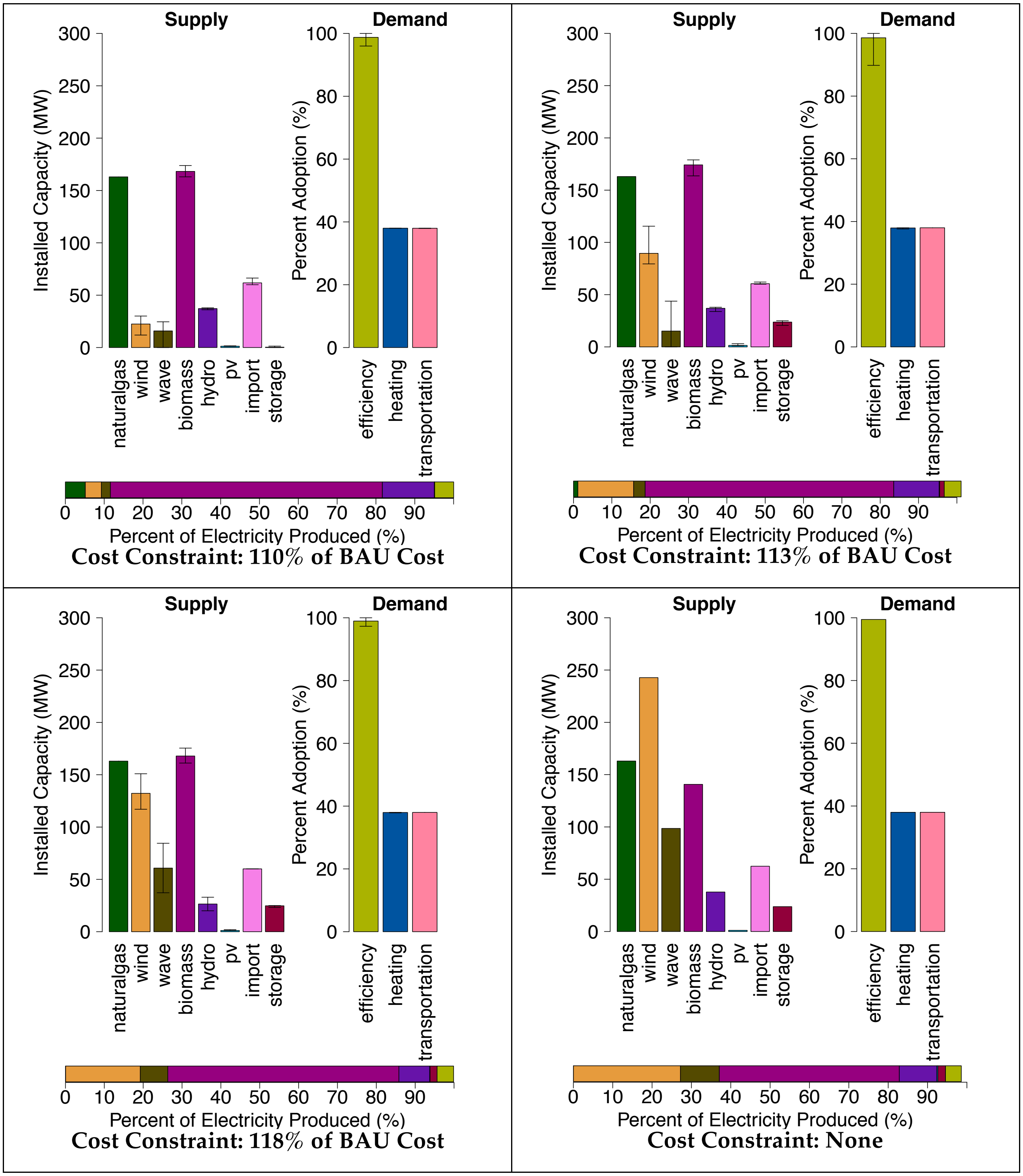
Figure 15: Portfolios from optimality curve C



Installed capacities of generators (top left), penetration levels associated with efficiency and load building (top right), and the proportion of the electricity produced by each generator (efficiency is treated as a generator in this context). Colors in the grid mix bar match those in the upper plots and are in the same order from left to right. The "error bars" associated with the decision variables represent the range of values observed in the converged generation of particles as solved by the differential evolution algorithm. BAU stands for "business-as-usual."

Source: SERC staff.

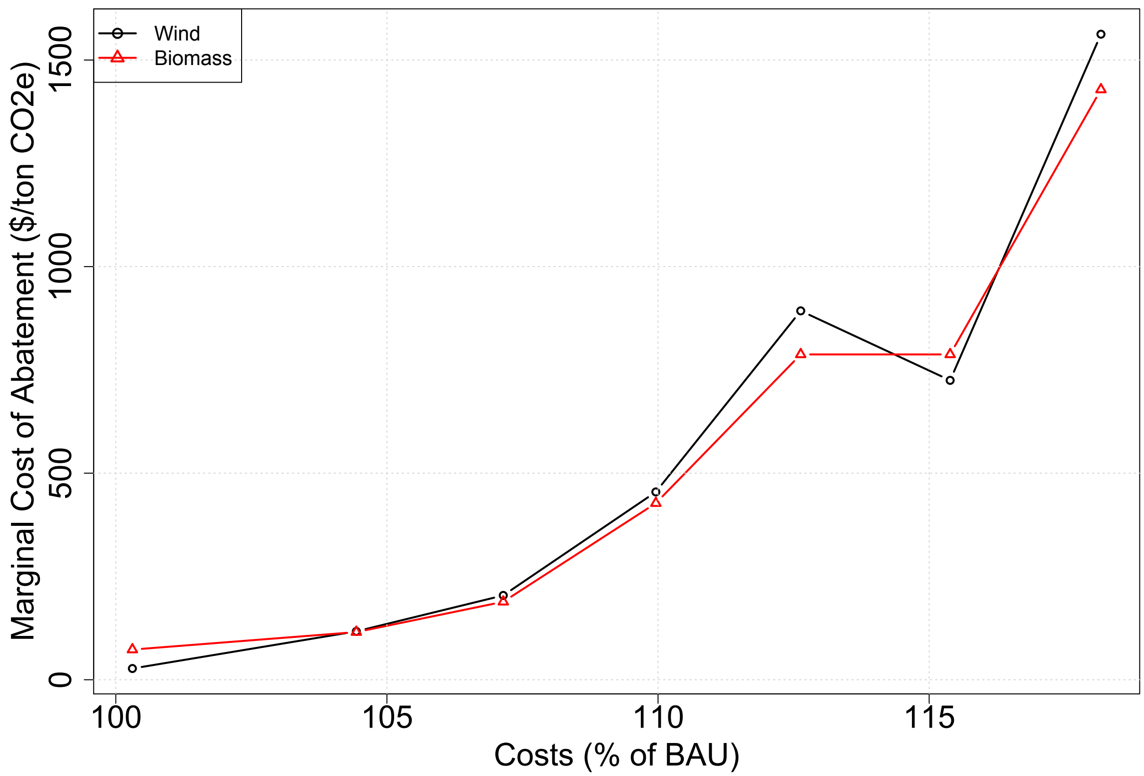
Figure 17 (continued): Portfolios from optimality curve C



Installed capacities of generators (top left), penetration levels associated with efficiency and load building (top right), and the proportion of the electricity produced by each generator (efficiency is treated as a generator in this context). Colors in the grid mix bar match those in the upper plots and are in the same order from left to right. The "error bars" associated with the decision variables represent the range of values observed in the converged generation of particles as solved by the differential evolution algorithm. BAU stands for "business-as-usual."

Source: SERC staff.

Figure 16: Marginal cost of greenhouse gas abatement for wind and biomass at several locations along optimality Curve C.



BAU stands for "business-as-usual."

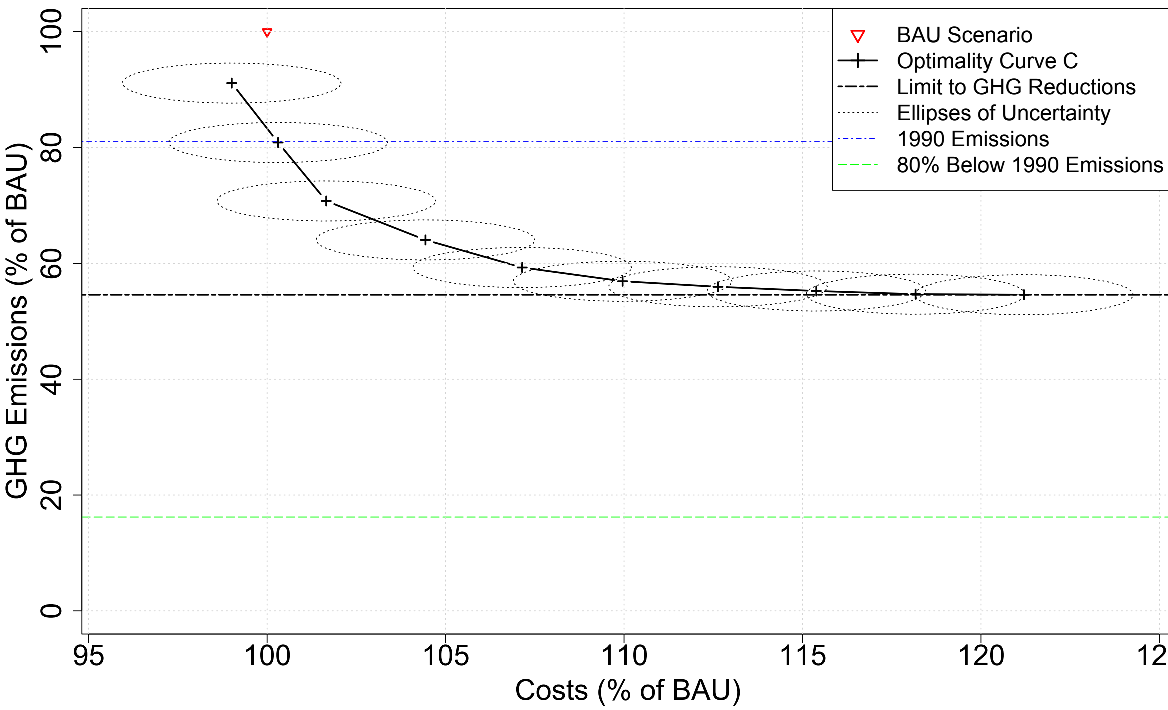
Source: SERC staff.

3.1.4 Error Analysis

To examine the uncertainty associated with these results, the authors conduct a Monte Carlo error analysis. A point on the optimality curve serves as the base scenario for the error analysis. The fourth point from the left was chosen, which roughly corresponds to a 5 percent increase in costs above business-as-usual. The energy balance model is then run 500 times. Before each run, all of the technical and economic parameters in the model (Table 8, 60 parameters in all) are modified by a random amount (no more than +/-10 percent of the original) based on a random draw from a uniform distribution. For discrete inputs (for example what year of source data to use in the wind submodel), one of the possible discrete values is randomly selected with equal probability. The total annualized cost and greenhouse gas emissions are calculated for each model run and the resulting distribution is used to create the ellipses in Figure 17. The axes of the ellipses represent +/- two standard deviations of the resulting values for costs and emissions associated with the 500 model runs.

The distributions from which parameter values are selected in a Monte Carlo error analysis are usually based on prior knowledge about the uncertainty of each parameter. Due to the large number of parameters and the lack of data necessary to confidently characterize their uncertainty, the authors chose to vary all parameters +/- 10 percent. In reality, the uncertainty may be much less than 10 percent for some parameters and somewhat greater for others.

Figure 17: Error analysis for optimality Curve C



Ellipses of uncertainty are based on a Monte Carlo error simulation where all model inputs and parameters are varied +/-10%; the axes of the ellipses represent +/- two standard deviations of the resulting values for costs and emissions. BAU stands for "business-as-usual." Note that axis scales are not equivalent, variability in the cost and emissions dimensions are approximately equal.

Source: SERC staff.

Table 8: Model parameters varied in the Monte Carlo error analysis.

Discount Rate	Import Heat Rate
GHG Emissions Price	Natural Gas Power Plant Heat Rate
Population Growth Rate	Wave Capacity
Efficiency Program Level	Wave Source Data Year
Heat Pump COP	Wind Capacity
Heat Pump Penetration	Wind Source Data Year
PEV Penetration	Wind Source Data Location
Demand Response Capacity	Natural Gas Power Plant Costs (Capital, O&M, Fuel, and Life Time)
Conventional Vehicle Costs (capital, O&M, fuel, and equipment life time)	Biomass Costs (Capital, O&M, Fuel, and Life Time)
PEV Vehicle Costs (capital, O&M, and equipment life time)	Heating Fuel Costs (fuel oil, gas, LPG, wood)
Storage Power Capacity	Heat Pump Costs (Capital, O&M, and Life Time)
Storage Energy Capacity	Hydropower Costs (Capital, O&M, and Life Time)
Storage Target State of Charge	Transmission/Distribution Costs (Capital, O&M, and Life Time)
Biomass Capacity	PV Costs (Capital, O&M, and Life Time)
Biomass Min Turndown Factor	Storage Costs (Capital, O&M, and Life Time)
Biomass Availability Capacity Factor	Wave Costs (Capital, O&M, and Life Time)
Hydropower Capacity	Wind Costs (Capital, O&M, and Life Time)
Import Capacity	

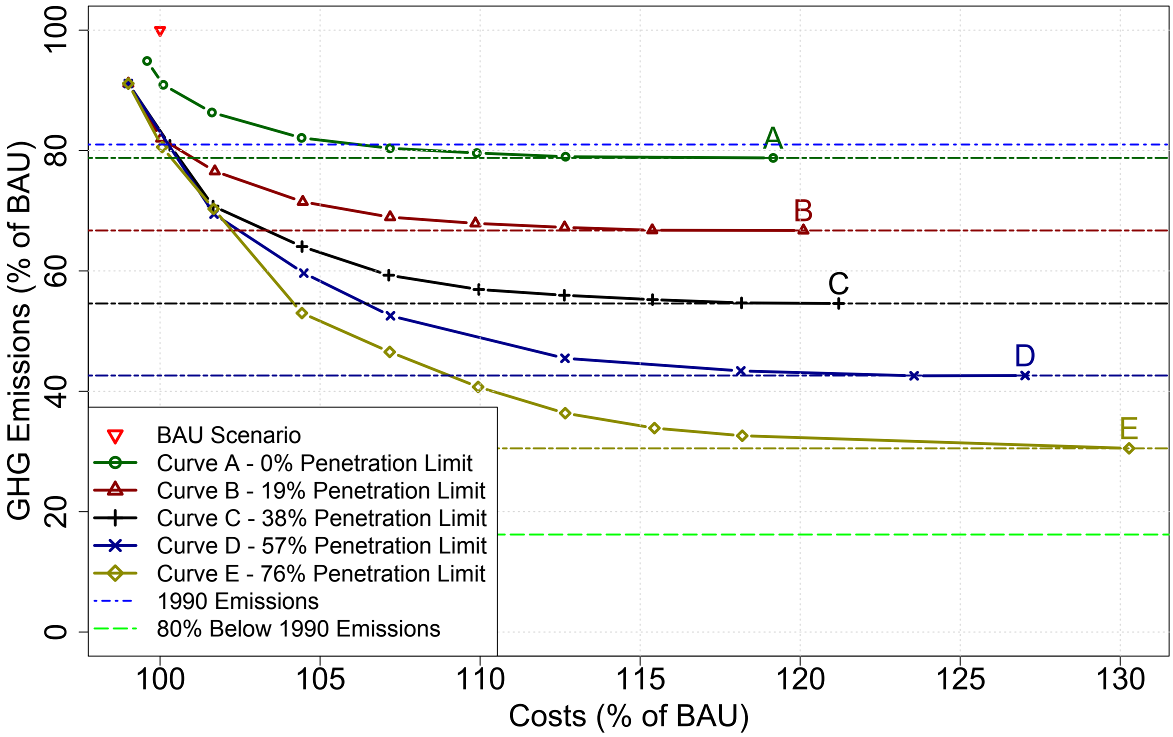
Source: SERC staff.

3.1.5 Effect of Changes in Heat Pump and Electric Vehicle Penetrations

The Monte Carlo error analysis only demonstrates the model sensitivity to input parameters. The constraints imposed on the decision variables can have an impact on the results as well. In particular, the limits on the penetration of electric vehicles and heat pumps in the transportation and heating sectors have a dramatic effect on the emissions reductions that can be realized. To examine this effect, the authors conducted additional optimizations varying the limits on those two decision variables. The resulting optimality curves are plotted in Figure 18. The optimality curves identified as A through E correspond to electric vehicle and heat pump penetration limits of 0 through 76 percent, respectively. It is important to note that the authors do not consider curves D and E to be realistically achievable penetration levels for Humboldt County by the year 2030. Nevertheless, those scenarios were included in the analysis to examine the sensitivity of model results to that constraint.

There is a clear linear relationship between the emission reduction limit associated with each curve (represented by the horizontal line at the curve's asymptote) and the limit on electric vehicle and heat pump penetration. For every 5 percentage point increase in the penetration limits, the emission reduction limit decreases by about 3 percentage points.

Figure 18: Optimality curves with varying limits on the penetration of electric vehicles and heat pumps.



Each curve has a corresponding horizontal line indicating the emissions reduction limit at that penetration level. BAU stands for "business-as-usual."

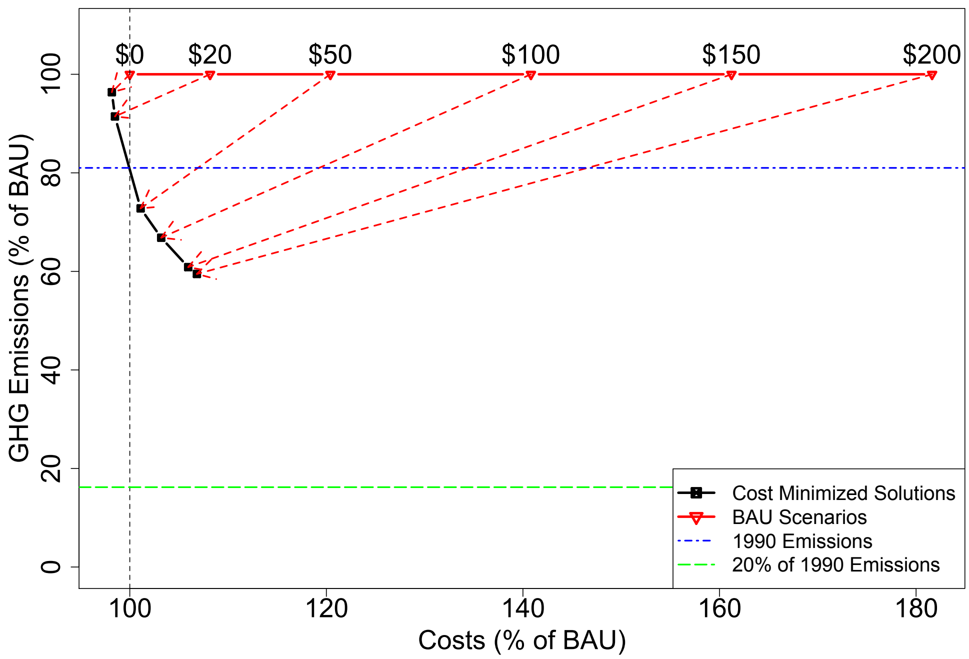
Source: SERC staff.

3.1.6 Cost Minimization

Like with the greenhouse gas minimization analysis (Section 3.1.2), the default set of decision variable constraints (Table 6) is again used for the cost minimization exercise. The optimization algorithm finds the lowest cost portfolio that serves Humboldt County's energy needs. The process is repeated for progressively higher prices levied on a ton of CO_2e emitted. Figure 19 presents the results of the optimizations. It is clear from these results that business-as-usual is not the economically optimal scenario, even with no price on carbon. As the price increases, the difference in cost between business-as-usual and the economically optimal scenario increases dramatically. Concurrently, the emissions associated with the economically optimal scenario decrease as carbon intensive technologies are more extensively displaced. The sensitivity of emissions to the price on carbon is very high for the first $50 per ton, but the subsequent reductions quickly decrease as the price increases thereafter.

An unexpected result of this optimization can be seen when the cost minimization curve in Figure 19 is plotted on the same axes as curve C from the emissions minimization analysis (Figure 20). The curves are essentially identical in the overlapping regions. The differences between the curves are well within the region of uncertainty discussed in Section 3.1.4. This suggests that the end result is the same whether a cost constrained emissions reduction strategy or a purely economic optimization strategy is pursued in the context of a price on carbon.

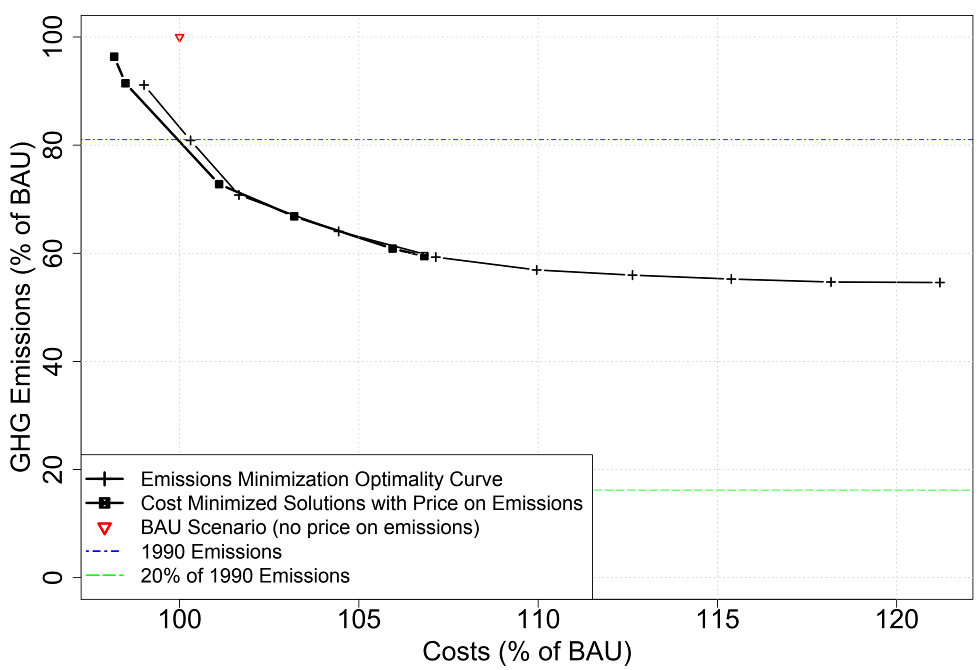
Figure 19: Cost minimization solutions (black squares) and business-as-usual (BAU - red triangles) with various prices levied on GHG emissions.



BAU stands for "business-as-usual." Prices have units of 2010$ / tonne CO2e.

Source: SERC staff.

Figure 20: Emissions minimization optimality curve and cost minimization curve with price on emissions.



BAU stands for "business-as-usual."

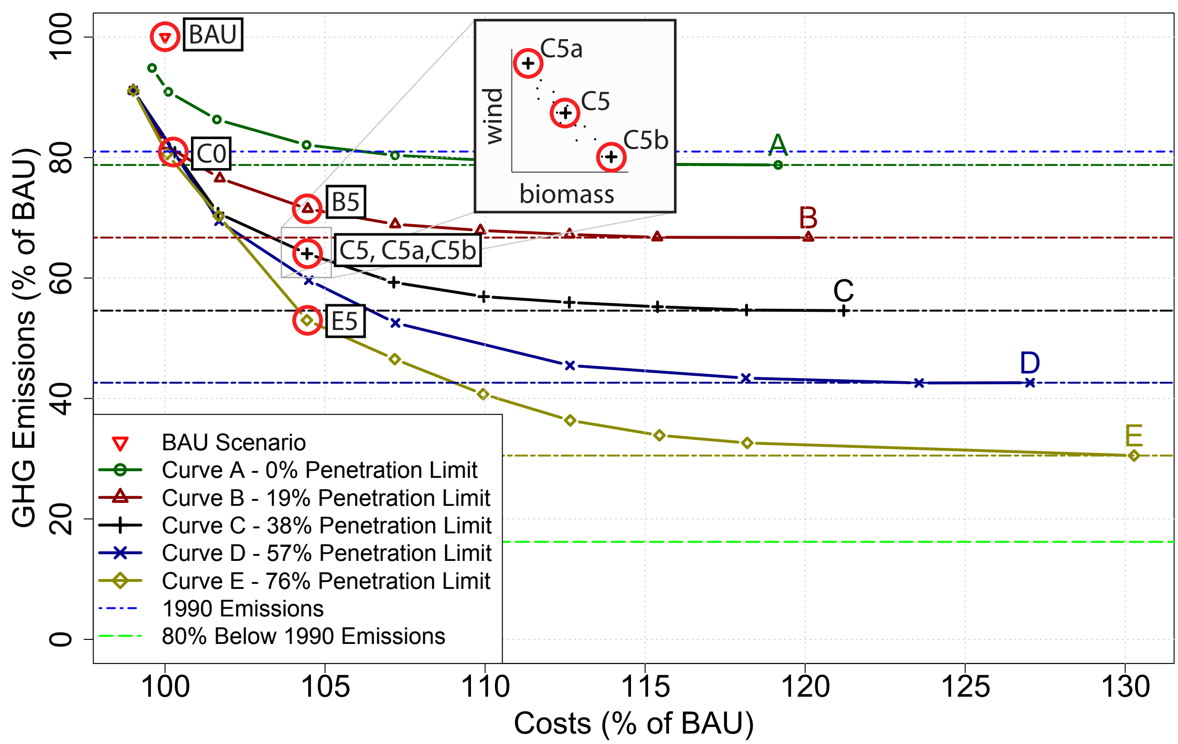
Source: SERC staff.

3.1.7 Preferred Scenarios

The authors selected seven scenarios to be subjected to a detailed economic analysis as reported in *Humboldt County as a Renewable Energy Secure Community: Economic Analysis Report* (Schatz Energy Research Center, 2011). These scenarios are noted in Figure 21. The naming scheme consists of an upper case letter, a number, and an optional lower case letter. The upper case letter refers to the optimality curve from which the scenario was chosen, the number represents the cost of the scenario (where x means x percent above business-as-usual cost), and the lower case letter distinguishes among multiple portfolios that have essentially the same values of costs and emissions.

These scenarios were chosen because they represent a wide range of GHG reduction potential at a reasonable increase in cost (5 percent or less). Scenarios C0 and C5 allow for a contrast between two points on the same optimality curve but with different cost constraints. To investigate the impact of electric vehicle and heat pump penetration limits, scenarios B5, C5, and E5 were chosen. Curve E represents a penetration limit of 76 percent, which the authors do not consider to be realistically achievable for Humboldt County by the year 2030. Nevertheless, that scenario is included to examine the model sensitivity to that constraint. Finally, scenarios C5, C5a, and C5b are located at essentially the same point on the optimality curve, but they explore the tradeoff that exists between wind and biomass. Among these three C5 scenarios, wind varies between 14 to 67 MW and biomass varies between 102 to 122 MW. Table 9 provides a listing of summary metrics associated with all seven scenarios.

Figure 21: Annotated optimality curves of scenarios to be examined in further detail.



BAU stands for "business-as-usual."

Source: SERC staff.

Table 9: Summary metrics for the scenarios chosen for further economic analysis.

Scenario	Cost M$/yr (% BAU)	Emissions kilotonnne CO2e/yr (% BAU)	% Renewables of Electricity Delivered	% Renewables of All Primary Energy
BAU	364 (100%)	1470 (100%)	36%	31%
C0	364 (100%)	1190 (81%)	57%	44%
B5	380 (105%)	1050 (71%)	87%	62%
C5,C5a,C5b	380 (105%)	940 (64%)	78%	62%
E5	380 (105%)	780 (53%)	60%	55%

BAU stands for “business-as-usual.”

Source: SERC staff.

3.1.8 Percent Renewables as a Poor Metric of Success

As stated in Section 1.1, the goal of the Humboldt County RESCO project is to develop a strategic plan for Humboldt County to develop its local renewable energy resources in an effort to meet 75 to 100 percent of the local electricity demand, as well as a significant fraction of heating and transportation energy needs. This goal was chosen as a proxy for achieving various benefits associated with the development of local renewable energy resources. Desired local benefits include reduction of greenhouse gas emissions, creation of local jobs and economic stimulus, reduced economic leakage associated with energy purchases, greater local control of energy supply and demand, greater stability in energy prices, and greater reliability and sustainability in local energy supply.

With regard to greenhouse gas reductions, it was expected that an increase in the use of local renewable energy resources would directly correlate to a reduction in greenhouse gas emissions. While this does hold true to an extent, it was found that obtaining the most cost-efficient reduction in greenhouse gas emissions does not directly correlate to an increase in the fraction of electricity generated from renewable sources. In retrospect, setting goals for meeting a specified portion of energy demand using local renewable energy resources may not be the best metric, especially if the most cost-efficient reductions in greenhouse gas emissions are desired. In this section, these complex results are explored further.

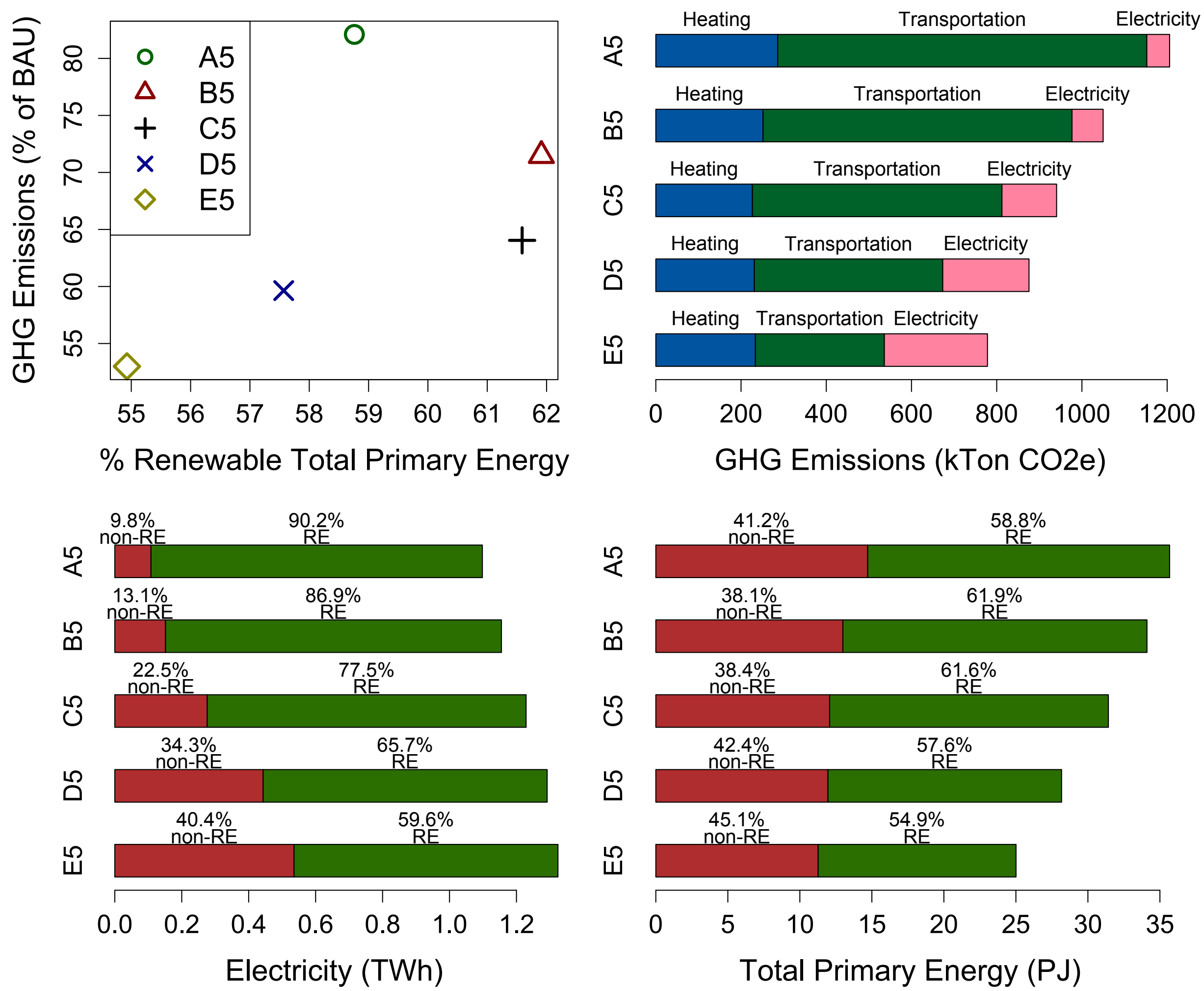
The results in Table 9 indicate the percent renewable energy serving the electricity grid and overall primary energy. The results, however, are not intuitive. One’s expectation may be that the fraction of renewables on the grid would need to increase in order to decrease GHG emissions. Or if the fraction of renewables on the grid doesn’t increase, at least the fraction of total primary energy from renewables must increase in order to see a decrease in emissions. In Table 9, the equal cost scenarios from different curves (B5, C5, and E5) indicate that both percent renewable metrics decrease as the emissions decrease.

The explanation for this behavior is illustrated in Figure 22. This figure presents several results from scenarios A5, B5, C5, D5, and E5 simultaneously. The top left panel shows the relationship between emissions and the percentage of total primary energy from renewables. The top right panel contains GHG emissions for the heating, transportation, and electricity sectors. Note that the emissions from heating and transportation exclude emissions from electrified technologies. The bottom left and bottom right panels show how delivered electricity and total primary energy are distributed between renewables and non-renewables, respectively. The horizontal axes of the bottom bar plots are in units of annual energy (TWh and PetaJoules [PJ], respectively) in order to highlight how both total energy and the fraction of renewables change from scenario to scenario.

From point A5 to E5, the maximum allowable penetration of electric vehicles and heat pumps increases. As heating and transportation fuels are switched to electricity, there is a steep decrease in emissions associated with those sectors as well as overall emissions. The increase in emissions from the electricity sector from point A5 to E5 (Figure 22, top right panel) are due to increases in electricity demand and also to a decrease in the fraction of renewables on the electricity grid (bottom left panel). All five of these scenarios have the same cost, and there is an expense associated with fuel switching. This means the greater the level of fuel switching, the less money there is to invest in renewable power generation. This behavior can be seen by the decreasing size (from top to bottom) of the green portion of the bars in the center panel of Figure 22. At the same time, there is also a general increase in the fraction of all primary energy from non-renewables from point to point (with an exception between A5 and B5). But even though the fraction of non-renewables is increasing, the overall non-renewable energy use is decreasing. This is due to the fact that electrified vehicles and heat pumps are substantially more efficient than their conventional alternatives, thereby consuming less primary energy. The net effect is that the absolute quantity of non-renewable primary energy decreases from scenario A5 to E5 as shown by the red bars in the bottom right panel of Figure 22. Along with this decrease in consumption of non-renewable fossil fuels comes a decrease in greenhouse gas emissions.

If the goal is to reduce GHG emissions at a reasonable cost, then it is clear that metrics such as the fraction of renewables on the electricity grid or of overall energy are misleading measures of success. Conversely, if the primary goal is to maximize the fraction of renewables, then it should be acknowledged that this would not necessarily translate into the most efficient reduction of GHG emissions. Traditionally, studies of renewable energy focus exclusively on the electricity grid where an increase in the fraction of renewables on the system will result in reduced emissions (assuming constant demand). When fuel switching is treated as an option in accomplishing the GHG minimization goal, that relationship unravels and metrics quantifying the fraction of renewables should not be taken as indicators of success.

Figure 22: Comparison of scenarios from different optimality curves of equal cost



Comparison in terms of emissions vs. percent renewables of total primary energy (top left), emissions from heating transportation and electricity sectors (top right), percent renewables of electricity delivered (bottom left), and percent renewables of total primary energy (bottom right).

Source: SERC staff.

3.1.9 Additional Sensitivity Analyses

The authors conducted additional analyses to investigate whether certain omissions or assumptions may have had a meaningful impact on the optimization model results. In these additional sensitivity analyses, the omission of demand response as a decision variable and the use of overly conservative heat pump costs were examined. The following describes the impact of these actions on the model results.

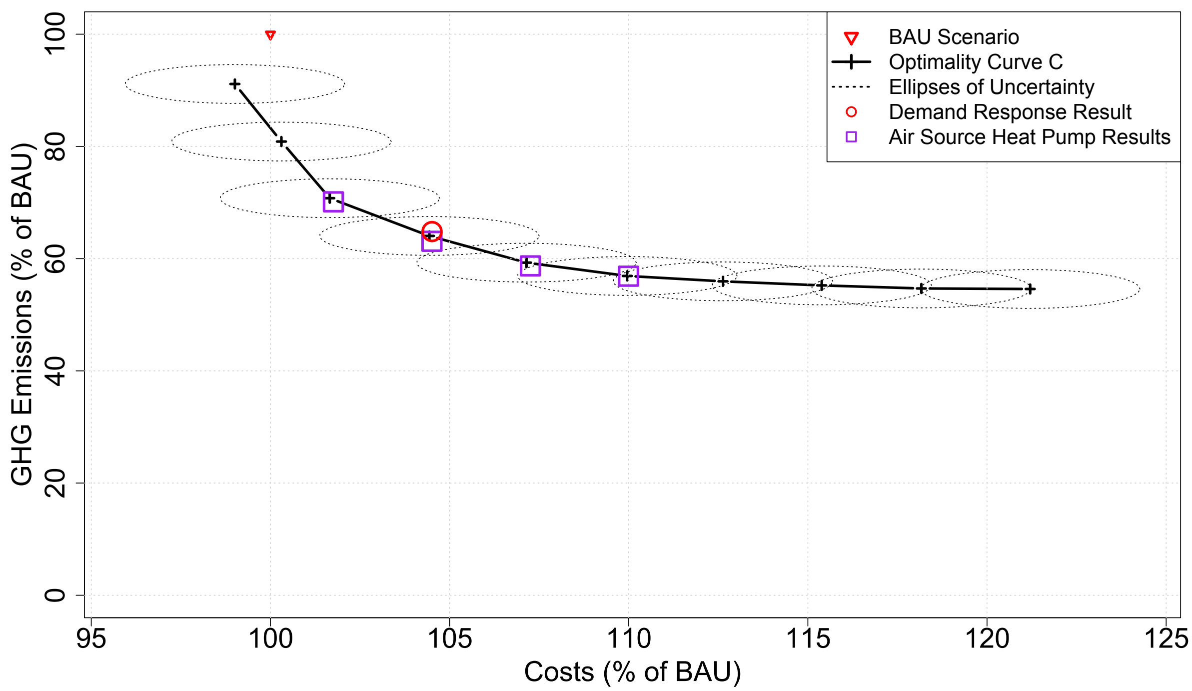
3.1.9.1 Demand Response

The demand response submodel is computationally intensive because it requires running the energy balance algorithm twice. It effectively doubles the length of a model run. At the same time, including demand response as a decision variable in the optimization has a negligible impact on the final results (Figure 23). This lack of impact is not surprising given that even without the development of new generation, there is already plenty of spare capacity in the Humboldt electric power system. This is true even with substantial load growth due to aggressive adoption of electric vehicles and heat pumps (i.e., 38% penetration). It is therefore rare when supply cannot meet demand, which is the circumstance when demand response becomes valuable. In order to reduce computation time, the authors excluded demand response as a decision variable in the optimizations.

3.1.9.2 Heat Pump Cost

The cost data used for heat pumps is a highly conservative overestimate. In order to assess the impact of this issue on the optimization results, the authors conducted several optimizations with a modified cost assumption based on the cost of air source heat pumps instead of geothermal heat pumps. Figure 23 demonstrates that the differences in outcomes are small relative to the general uncertainty of the overall results.

Figure 23: Alternative optimization results compared to the original optimality curve C



Demand response is included as a decision variable (red circle) or air source heat pump cost data are used instead of geothermal (purple boxes).

Source: SERC staff.

3.2 Power Flow Results

The results of the interconnection study conducted by PG&E identified a large number of CAISO Category A, Category B, and Category C violations associated with the Humboldt County RESCO renewable energy development scenario that was analyzed. These CAISO violations indicate conditions on the Humboldt area electric grid that could result in power supply and/or power quality problems. Given the number of violations identified, it was clear that a plan for mitigation must be investigated. PG&E developed three alternative plans for system upgrades that would correct the violations. In addition, PG&E provided non-binding, good-faith estimates of the cost of each alternative. For the full report, see Appendix F. The following summarizes PG&E's findings and discusses the implications for the overall Humboldt RESCO study.

3.2.1 Grid Limitations and Necessary Upgrades

As noted by PG&E (Appendix F), the electricity transmission system in Humboldt County is composed primarily of 60 kV circuits, which were designed to provide power to a geographically sparse population. The system is adequate for serving the local load, but would quickly become overloaded if mid to large generation capacity were added throughout the system. Adding 253 MW of renewable generation, as was analyzed, will require substantial upgrades to the transmission system in order to meet federal reliability standards. Table 10 summarizes three alternative upgrade plans investigated by PG&E.

Table 10: Transmission system upgrade alternatives developed by PG&E to mitigate development of 253 MW of renewable generation.

Alternative	Description	Non-binding, Good-faith Cost Estimate
1 - Reconductoring, Voltage Support and Transformer Upgrades only	Leaves voltage of the system as is but increases the capacity of transmission circuits to allow increased power flow.	$944 million
2 - Voltage Conversion, Reconductoring and Transformer Upgrades only	Convert some 115 kV transmission out of Humboldt to 230 kV. Convert several intra-county circuits from 60 kV to 115 kV.	$1002 million
3 - Build New DCTL 230 kV Line and Reconductor only	Convert circuits to 230 kV to substantially increase power flow from Rio Dell out of the County.	$260 million

Alternative 1 involves increasing the capacity of existing transmission lines through reconductoring, transformer upgrades, and the addition of voltage support. This alternative would not involve any voltage conversion (i.e. replacing transmission lines with new circuits at higher voltage levels). This alternative is relatively expensive because the number of system upgrades is large. This alternative is not recommended by PG&E as it is very costly and does not improve system reliability. In fact, according to PG&E, it could make the system operation more vulnerable to failures.

Alternative 2 focuses on increasing the voltage of selected transmission lines to increase the capacity of the system. The circuits identified for improvement include the export lines connecting Humboldt to Cottonwood and several other lines throughout the Humboldt Bay area and the southern end of the County. This alternative also requires extensive upgrades and is very costly.

Alternative 3 involves essentially one system upgrade, the conversion of the entire pathway between Rio Dell and Cottonwood to 230 kV. This alternative is designed to provide access to the greater California grid for the large capacity of wind power (125 MW) that was analyzed in the hypothetical development scenario. At $260 million, this alternative is the least expensive by a factor of 4, however, it is a custom solution and may not be suitable for a renewable portfolio that involves less wind development and greater development of other resources in other locations. On the other hand, the substantial difference in cost between alternative 3 and the other alternatives highlights the importance of a planning process capable of anticipating the location and extent of all (or most) of the new generation capacity. If generation projects are planned one at a time, in isolation, then alternative 1 may be the most likely pathway toward accommodating future projects. However, if project planning is coordinated across the county, there could be opportunities for substantial overall savings.

3.2.2 Study Implications and Limitations

The roughly $1 billion cost for alternatives 1 and 2 may appear to be prohibitive and unrealistic. However, if a 40-year economic lifetime is assumed for the infrastructure and O&M costs are considered negligible, then these alternatives would have a lifecycle cost of about $25 million per year (assuming a 7 percent discount rate), which is approximately 7 percent of the total business-as-usual lifecycle cost for energy services in Humboldt County. It is important to note that the power flow study was not completed until after the completion of the REPOP modeling analysis presented in this report. Therefore, the cost results presented throughout this report do *not* include the costs of transmission system upgrades necessary to accommodate high penetrations of renewable resources. In the worst cases, the cost figures would increase by only 5 to 10 percent (with respect to business as usual) to account for transmission system upgrade costs.

While this cost underestimate is not negligible, the authors believe that a full inclusion of transmission upgrade costs would not appreciably change the overall conclusions of this study, namely, that substantial development of local renewable energy resources is both technically possible and economically feasible. It should also be noted that some or all of these system upgrades could count as "network upgrades" under the California Independent System Operators (CAISO) Tariff. While project developers are responsible for covering the upfront cost of network upgrades, they are repaid for the upgrades in the first few years of the project. This means the entire rate base, not just project developers or the citizens of Humboldt County, would share the economic burden of the upgrades.

Furthermore, the authors believe that the methodological approach PG&E is required to follow to satisfy national reliability requirements is excessively conservative and may substantially overstate the need for system upgrades. The problem is that the analysis is based on a worst-case scenario that assumes *every* proposed generator (including the energy storage facility) in Humboldt County is producing electricity at full capacity. Essentially, the grid is assumed to be entirely unmanaged. This approach ignores legitimate and potentially cheaper solutions to reliability concerns such as using energy storage facilities as load (instead of generation) or curtailing generators during periods of excess power on the system. For example, the REPOP model assumes that most generators – especially the 163 MW natural gas power plant – can be curtailed when the total potential for power production exceeds the demand and ability to export.

The North American Electric Reliability Corporation (NERC) is the entity ultimately responsible for reliability standards on the grid. As stated in a recent report (NERC, 2009), NERC is well aware of these and other important issues relevant to the interconnection of variable power sources. They are currently working on solutions to the transmission planning process that will facilitate, rather than hinder, the rapid development of renewable power sources. Assuming the planning process is amended in the future, it is reasonable to assume that the upgrade cost estimates discussed above represent an absolute upper limit to the cost of accommodating renewable energy development in Humboldt County.

Another aspect that should be considered in the context of significant upgrades to the Humboldt area transmission and distribution system is the possibility of creating a community scale microgrid in Humboldt that can operate independent from the statewide electric grid if necessary. While alternative 3 is clearly the cheapest option for overcoming the grid reliability problems associated with large-scale renewable energy development in Humboldt, it would likely not lead to a functioning microgrid. For this reason, an upgrade plan more like alternatives 1 and 2 might be preferred if microgrid functionality is desired.

3.3 Hydrogen Transit Results

Results of the hydrogen fuel cell bus analysis are given in Table 11 below. The largest cost for a hydrogen transit system is associated with the buses themselves. The cost of a hydrogen fuel cell bus (even assuming the cost decreases significantly as they become commercial) is 25 percent higher than the current cost of a new hybrid diesel bus. The initial cost of required fueling infrastructure is also high, almost $800,000 for a small hydrogen system and over $3 million for a full hydrogen transit system. These initial costs would likely be the biggest hurdle to developing a hydrogen powered transit system. As a revenue negative system (mass transit system do not generally bring in enough revenue to be self supporting; they rely on governments to make up the cost difference to provide a service seen as a public good), Humboldt Transit Authority would need to find outside funding to pay the initial costs.

Annual operating costs for a hydrogen transit system are higher than for a diesel-based system. Both fuel costs and operations and maintenance costs are higher on a per mile basis for a fuel cell bus than a diesel bus. However, as fuel cell bus technology matures operations and maintenance costs will likely decrease and fuel economy will likely increase, resulting in lower operating cost. The cost of hydrogen fuel will also decrease if the energy required to generate and compress hydrogen decreases. This will happen as manufacturers make equipment more efficient, which they are already doing in response to the growing interest in hydrogen fuel.

Transitioning to a hydrogen transit system would decrease carbon dioxide emissions, but at a high cost. A full hydrogen system would result in a 32 percent decrease in CO_2 emissions at a 21 percent increase in cost compared to business-as-usual. A system with 10 percent of the miles travelled fueled by hydrogen would result in 3 percent decrease in CO_2 emissions at a 2 percent increase in cost. This corresponds to costs ranging from $1,700 to $2,000 per ton of avoided CO_2 emissions. This is significantly higher than the current price of CO_2 (approximately $20 per ton in European markets) and most projections of the future price of CO_2.

Table 11: Results of Hydrogen Transit Analysis

H_2 Penetration	BAU	10%	15%	25%	50%	75%	100%
Diesel cost ($/year)	$682,527	$614,275	$1,062,500	$937,500	$625,000	$312,500	$0
Diesel cost ($/mile)	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55
Hydrogen ($/kg)	N/A	$9.89	$9.42	$9.05	$8.76	$8.67	$8.62
Hydrogen ($/mile)	N/A	$1.27	$1.21	$1.16	$1.13	$1.12	$1.11
Annual costs diesel fleet	$5,720,027	$5,148,025	$4,862,023	$4,290,020	$2,860,014	$1,430,007	$0
Annual costs H_2 fleet	N/A	$712,831	$1,057,948	$1,748,182	$3,473,766	$5,199,351	$6,924,935
Annual total costs (H_2 and Diesel)	$5,720,027	$5,860,855	$5,919,971	$6,038,202	$6,333,780	$6,629,358	$6,924,935
Total costs ($/mile)	$4.58	$4.69	$4.74	$4.83	$5.07	$5.30	$5.54
% of BAU Cost	100%	102%	103%	106%	111%	116%	121%
Annual CO_2 emissions (lbs CO_2)	4,329,173	4,189,692	4,119,952	3,980,471	3,631,768	3,283,065	2,934,363
CO_2 emissions (% of BAU)	100%	97%	95%	92%	84%	76%	68%
Fleet average CO_2 emissions (lbs/mile)	3.46	3.35	3.30	3.18	2.91	2.63	2.35
Cost of avoided CO_2 ($/lbs CO_2 avoided)	N/A	$1.01	$0.96	$0.91	$0.88	$0.87	$0.86
Cost of avoided CO_2 ($/t$CO_2$)	N/A	$2,019	$1,911	$1,825	$1,760	$1,739	$1,728
Capital costs (not including buses)	N/A	$781,970	$922,173	$1,202,581	$1,903,600	$2,604,619	$3,305,638
Number of H_2 buses	N/A	3	5	9	17	26	34
Cost of hydrogen buses	N/A	$2,568,493	$3,852,740	$6,421,233	$12,842,466	$19,263,699	$25,684,932

Source: SERC staff.

Because of uncertainty in the variables used for this analysis, it is instructive to perform a sensitivity analysis. A sensitivity analysis explores how the results change as the input variables change. The authors performed a sensitivity analysis focusing on four variables: the fuel economy of the hydrogen buses, the cost of electricity, the amount of energy required to generate and compress hydrogen, and the price of diesel fuel. Because of the high costs found in the initial analysis, these variables were only changed in a way that would make the results more cost-effective. The results were compared to the base case results from the original analysis. Table 12 shows the parameter values used in the original analysis (base case) and the optimistic values used for the sensitivity analysis.

Table 12: Variables used in Hydrogen Bus Sensitivity Analysis

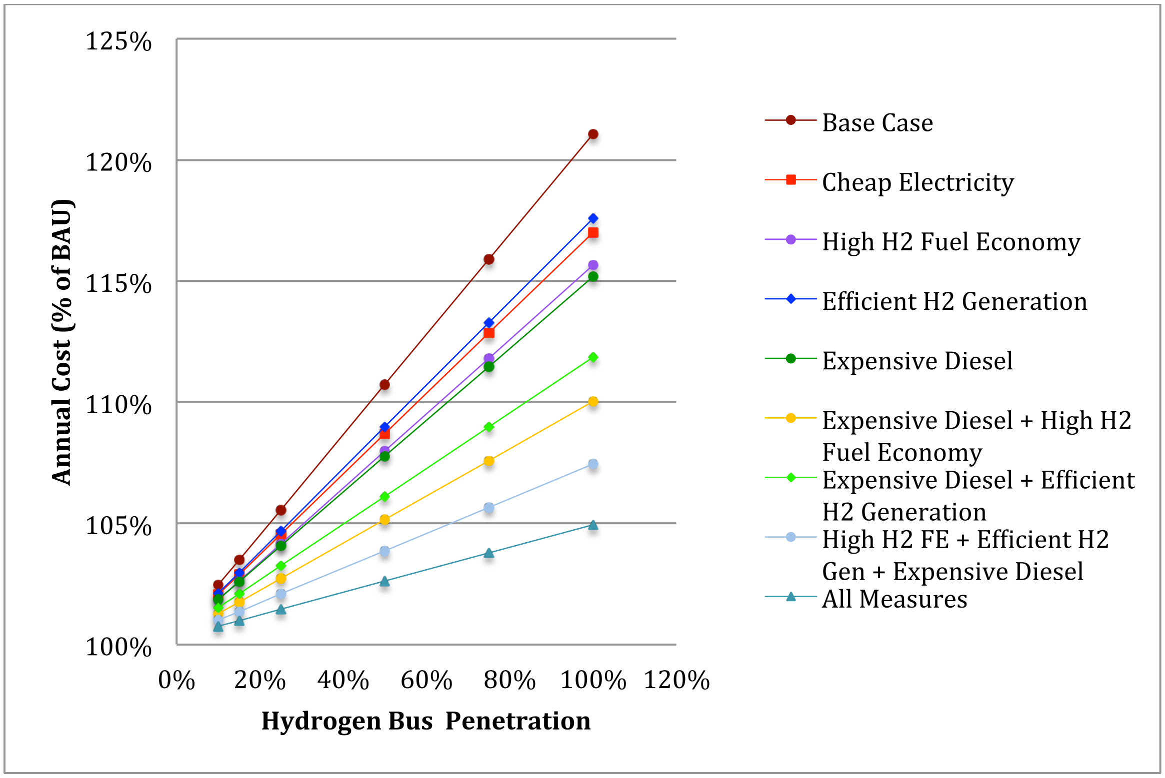
Variable	Base Case Value	Optimistic Value
Cost of Electricity ($/kWh)	0.124	0.100
Fuel Economy of H_2 Bus (Miles/kg H_2)	7.77	10
H_2 generation Energy (kWh/kg H_2)	60	50
Cost of Diesel ($/gallon)	3.5	5

Source: SERC staff.

Changing any of the variables decreases the operating costs of the hydrogen transit, but no one variable reduces the cost to BAU. Increasing the cost of diesel gas has the greatest impact. When the cost of diesel is increased to $5 per gallon, the cost of the hydrogen system is 15 percent higher then BAU for the full hydrogen scenario. If measures are combined there is a greater impact on the cost. Using the optimistic values for all the variables results in a cost that is 5 percent higher than BAU. Figure 24 shows the results from all the scenarios investigated in the sensitivity analysis.

The cost of diesel fuel is the most volatile variable in this analysis, so an analysis was performed to estimate the cost of diesel that allows a hydrogen transit system to break-even with BAU. This again excluded initial capital costs. For the smallest hydrogen system (10 percent penetration), diesel fuel would need to cost $10.72 per gallon, whereas a full hydrogen system would require a diesel price of $9.68 per gallon to break-even. While these numbers represent a several fold increase in the price of diesel fuel, they are not out of line with prices elsewhere in the world. As of March 2011 the price of diesel in the United Kingdom is around $8.25 per gallon and oil prices are rising due to unrest in Northern Africa.

Figure 24: Results of Hydrogen Bus Sensitivity Analysis



Source: SERC staff.

This analysis shows that creating the infrastructure for a hydrogen transit system is expensive and does not provide an economic benefit. Funding would need to be found for the initial costs of the fueling infrastructure and the fuel cell buses. If only the costs associated with fuel and operations and maintenance are considered, it could be economically feasible if the fuel economy of the buses increased, electrolysis and compression becomes more efficient, and the cost of diesel fuel increases. Increases in hydrogen bus fuel economy seem likely as the technology matures. Electrolyzer and compressor manufacturers are making their products more efficient in response to consumer demand, largely driven by the renewable energy sector. There is also precedent for rising gas prices. It would take some combination of all these factors for a hydrogen transit system to become economically viable in Humboldt County.

3.4 Forest-based Biofuels Results

Section 2.3.2.3 (Forest-based Biofuels) and Appendix B.2 (Forest-based Biofuels Assessment) laid out two primary alternatives for utilizing the forest biomass resource in Humboldt County to power vehicles: (1) combustion of biomass for electricity generation to power electric vehicles and (2) production of biofuels through biochemical, thermochemical, and Fischer-Tropsch conversion processes. Based on these two alternatives, five related fuel pathways (Table 13) were developed and assessed using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET).

Table 13: Description of fuel pathways modeled in GREET.

Fuel Pathway	Description
Baseline: CG and RFG for CVs	Conventional and reformulated gasoline are used to fuel spark ignition conventional vehicles
E85 (gasification) for FFVs	A gasification based process is used to produce ethanol from forest biomass; ethanol is used to fuel spark ignition flex-fuel vehicles
E85 (fermentation) for FFVs	A fermentation based process is used to produce ethanol from forest biomass; ethanol is used to fuel spark ignition flex-fuel vehicles
FTD100 for CIDIVs	The Fischer-Tropsch process is used to produce Fischer-Tropsch Diesel from forest biomass; FTD is used to power compression-ignition direct-injection vehicles
CG/RFG and Electricity for SI PHEVs	Conventional/reformulated gasoline and electricity from the combustion of forest biomass are used to power spark ignition plug-in hybrid electric vehicles
Electricity for BEVs	Electricity from the combustion of forest biomass is used to power battery electric vehicles

Source: SERC staff.

Per mile lifecycle energy and GHG impacts of each fuel pathway considered are shown in Table 14. Lifecycle impacts for vehicles are often referred to as well-to-wheels (WTW) impacts, though in the case of biomass the "well" is the forest. Relative to the baseline, all three of the biofuel scenarios are more energy intensive, with the fermentation based ethanol pathway requiring the most energy (83 percent more than the baseline). Meanwhile, the PHEV and BEV pathways reduce energy use by 12 percent and 15 percent, respectively. All pathways significantly reduce fossil fuel use and GHG emissions relative to the baseline. BEVs have the largest impact, reducing fossil fuel use and GHGs by 95 percent and 92 percent, respectively, followed by the FTD pathway, which results in reductions of 92 percent and 91 percent. The smallest impact, though still significant, is made by the PHEV pathway with a 47 percent reduction in fossil fuels and 46 percent reduction in GHGs. Clearly all of these fuel and vehicle combinations have the potential to drastically reduce transportation sector GHG emissions. The costs associated with the development of each fuel and vehicle pathway is an important criterion by which to further assess these options. A comparative lifecycle benefit/cost analysis should be conducted. Such an analysis is carried out for PHEVs and BEVs in Section 2.4 (Transportation Cost Analysis) of the RESCO Economic Analysis Report (SERC, 2011). A comparable lifecycle benefit/cost analysis should also be conducted for the identified biofuel pathways to further assess these options.

Appendix B.2.3 contains more detailed well-to-wheels (**Error! Reference source not found.**) and well-to-pump (**Error! Reference source not found.**) results for each fuel and vehicle pathway.

Table 14: Well-to-Wheels total energy, fossil fuels, and GHG emissions for several pathways

Fuel Pathway	Total Energy (BTU/mi)	Relative to Baseline	Total Fossil Fuels (BTU/mi)	Relative to Baseline	GHGs (g/mi)	Relative to Baseline
Baseline: CG and RFG for CVs	5279	0.0%	4909	0.0%	405	0.0%
E85 (gasification) for FFVs	6557	24.2%	1794	-63.5%	149	-63.2%
E85 (fermentation) for FFVs	9684	83.4%	1050	-78.6%	111	-72.5%
FTD100 for CIDIVs	7367	39.5%	398	-91.9%	36	-91.0%
CG/RFG and electricity for SI PHEVs	4655	-11.8%	2594	-47.2%	219	-46.0%
Electricity for BEVs	4483	-15.1%	226	-95.4%	33	-91.7%

Percent change is relative to a baseline of conventional vehicles fueled with conventional and reformulated gasoline.

Source: SERC staff.

CHAPTER 4: Conclusions and Recommendations

4.1 Conclusions

The overall goal of the technical and resource assessment was to explore the range of supply and demand options available for increasing Humboldt County's energy security through the development of local renewable energy resources. The research team developed and employed a custom energy balance and optimization model called the Regional Energy Planning Optimization (REPOP) model. It was used to assess resource and technology portfolios based on criteria, including the overall cost of supplied energy and greenhouse gas impacts. The results of this resource and technology assessment will inform the development of the Humboldt RESCO strategic plan.

4.1.1 Key Findings

Humboldt County has a wealth of local renewable energy resources. It is geographically isolated and severely constrained with regard to energy transmission capacity in and out of the county. Nearly all of Humboldt County's transportation fuels and the majority of its heating fuels are imported. Given these circumstances, the key issues Humboldt County faces in meeting its energy goals are not related to the adequacy of local resources, but instead to the ability to develop these resources and the associated energy infrastructure needed serve local demand with local renewable energy sources.

Key lessons learned in this study include the following:

- Humboldt County can meet 75 percent or more of its electricity needs and a large fraction of its heating and transportation energy demand using local renewable energy resources.
    - This can result in a substantial reduction in greenhouse gas emissions (e.g., a 35 percent reduction below business-as-usual, which is equivalent to about a 20 percent reduction below estimated 1990 emissions levels).
    - This can be achieved at a modest cost increase (approximately 5 percent above business-as-usual), with greater reductions possible at higher cost.
- There are many possible resource and technology options to choose from, and a mixed portfolio of options is likely more advantageous than any technology in isolation. Aggressive implementation of cost-effective energy efficiency opportunities should be a near-term pursuit. Biomass, wind and small run-of-the-river hydroelectric energy sources should play a key supply-side role.
- The RESCO goal of meeting 75 percent or more of electric demand with local renewable resources may not be the best metric for measuring success. Instead of focusing on the percentage of *electric* energy demand served by local renewable resources, the authors recommend the focus be on cost-effective options to decrease *overall* greenhouse gas emissions across the whole energy sector.
- Fuel switching to plug-in hybrid and battery only electric vehicles in the transportation sector and to electric heat pumps in the heating sector has the potential to play a major role in realizing the RESCO vision. Fuel switching opportunities are critical to cost-effectively achieving large reductions in energy

related greenhouse gas emissions. Without fuel switching, deep reductions in greenhouse gas emissions are infeasible.

- Humboldt County's RESCO goals can be achieved with only a modest cost increase. The majority of greenhouse gas reductions can be realized with only a 5 to 15 percent increase in overall energy costs, and beyond this level there are diminishing returns. With a cost increase of only 5 percent and a 40 percent penetration of electric vehicles and heat pumps, Humboldt County can achieve an 80 percent share of local renewable electricity and a 36 percent decrease in greenhouse gas emissions. Doubling the percentage cost increase to 10 percent can achieve a 95 percent share of local renewable electricity and a 43 percent decrease in greenhouse gas emissions.

- Distributed generation, like rooftop solar, can play a smaller but important role. These technologies can provide direct economic benefits to retail customers. In addition, they provide an active way for individuals and businesses to participate in the implementation of the RESCO vision. Appropriate levels of support for these technologies can help cultivate broad backing for the overall RESCO plan.

- A steady state power flow analysis conducted by PG&E indicates that substantial upgrades to the local transmission and distribution system will be required to accommodate large-scale development of local renewable energy sources. The most cost-effective plan for these upgrades would likely involve an area-wide planning approach that simultaneously considers multiple projects. If instead a project-by-project approach is taken, a less optimal piecemeal solution is likely to result. It is also important to note that "non-standard" approaches to maintaining grid stability, such as curtailing generation, should be considered in the analysis. Finally, transmission planning should also consider the possibility of creating a community-scale microgrid in Humboldt that can operate independent of the statewide grid if necessary.

- Energy storage will not likely play a significant role unless local renewable generation provides the vast majority (i.e., greater than 90 percent) of local electricity demand.

- Regarding pathways for the use of forest-based biomass to provide energy for the transportation sector, the Fischer-Tropsch biodiesel pathway compares favorably with the biopower to battery electric vehicle pathway, with both of these pathways achieving greater than 90 percent reduction in fossil fuel use and greenhouse gas emissions. The cellulosic ethanol pathway does not fare as well in comparison, though it does beat out the plug-in hybrid electric vehicle pathway.

4.1.2 Modeling Results

4.1.2.1 Business-as-Usual

If there is no further development of clean energy alternatives in Humboldt County, model estimates for the business as usual scenario in 2030 show an electric supply dominated by power from the natural gas fired PG&E Humboldt Bay Generating Station (65 percent) and existing biomass power plants (30 percent). In the business-as-usual scenario the energy supply for the heating and transportation sectors will continue to be dominated by fossil fuels in the form of natural gas (75 percent) and gasoline (100 percent). Transportation fuels will continue to dominate annual energy costs, and transportation fuels and natural gas usage will drive greenhouse gas emissions to 1500 kilotonnes of CO_2e per year (25 percent greater than 1990 levels). Clearly the business-as-usual scenario will not improve local energy sustainability, but instead will exacerbate the environmental problems associated with the current energy system while maintaining Humboldt County's exposure to fuel scarcity and price volatility.

4.1.2.2 Clean Energy Development

Humboldt County possesses ample renewable energy resources to meet the majority of its electricity demands and a large portion of its transportation and heating energy needs. Modeling results have shown that key local renewable energy resources include biomass, wind, and hydropower. In addition, while biomass resources can provide baseload electric power and intermittent renewables like wind and solar can provide as-available power, PG&E's new natural gas fired engine generators at the Humboldt Bay Generating Station can provide load following capability to fill the gaps when demand peaks or power from intermittent renewables fluctuates. Not surprisingly, modeling results indicate that all cost-effective energy efficiency measures should be implemented as this is the most inexpensive way to provide energy services and reduce greenhouse gas emissions.

In the transportation and heating sectors, fuel switching from fossil fuels (petroleum and natural gas) to electricity via the adoption of electric vehicles and heat pumps enables greater development of local renewable electricity sources while also deeply reducing fossil fuel use and associated greenhouse gas emissions. Perhaps more importantly, it has been shown that the adoption of electric vehicles and heat pumps can allow for a more cost-effective reduction in greenhouse gas emissions than to simply focus on renewable electricity supplies. This leads to a conclusion that the initially stated RESCO goal of meeting 75 percent or more of electric demand with local renewable resources may not be the best target for environmental and economic reasons. Instead of focusing on the percentage of electricity served by local renewable resources, the research team suggests it is better to focus on the most cost-effective ways to decrease greenhouse gas emissions, which would include aggressive adoption of electric vehicles and heat pumps in addition to the development of local renewable energy supplies. Furthermore, without fuel switching in the heating and transportation sectors it has been shown that only a 20 percent reduction in greenhouse gas emissions is achievable regardless of the level of renewable energy development. Clearly the adoption of electric vehicles and heat pumps is critical to achieving greenhouse gas reduction goals.

The results of this analysis indicate that the ambitious development of local renewable energy resources and the adoption of electric vehicles and heat pumps would make great strides toward meeting renewable energy and climate action goals, and that this can be achieved at a modest cost increase. In fact, the optimization modeling shows that the majority of greenhouse gas reductions are realized with only a 5 to 15 percent increase in overall energy costs, and that beyond this level there are diminishing returns. With a cost increase of only 5 percent and a 40 percent penetration of electric vehicles and heat pumps, Humboldt County can achieve an 80 percent share of local renewable electricity and a 35 percent decrease in greenhouse gas emissions compared to business-as-usual. Doubling the allowable cost increase to 10 percent can achieve a 95 percent share of local renewable electricity and a 45 percent decrease in greenhouse gas emissions. In addition, as documented in *Humboldt County as a Renewable Energy Secure Community: Economic Analysis Report* (Schatz Energy Research Center, 2011), aggressive development of local renewable energy sources would also create a substantial number of permanent local jobs and significantly stimulate the local economy by reducing the economic leakage associated with energy dollars leaving the county.

Small-scale distributed generation technologies (defined here as <5 MW generators connected to the distribution system at or very near to the load) did not play a major role in the RESCO modeling effort. The only technology fitting this description that was modeled was rooftop solar photovoltaic systems. Given that Humboldt County does not have a robust solar resource in the Humboldt Bay area where the population is centered (i.e., approximately 4 peak sun hours per day on average) and rooftop solar is the most expensive generation technology that was considered, solar photovoltaic systems did not play a significant role in the optimal mixes of generation resources. Nonetheless, solar and other distributed generation technologies can play an important role in the Humboldt RESCO plan. They are technologies that can provide direct economic benefits to retail customers. In addition, they provide an active way for individuals and businesses to participate in the implementation of the RESCO vision. In this way they can empower people and help generate broad support for the overall RESCO plan.

With a current peak load of 170 MW and an average load of about 110 MW, the normal transmission capacity of 60 to 70 MW between Humboldt County and the rest of California poses a severe constraint on the operation of the local electric grid. Clearly a large portion of Humboldt County's electrical power must be generated locally. In addition, there are serious limitations to the amount of excess renewable generation (e.g., from intermittent wind facilities) that could be exported. With large increases in local renewable electricity generation this could require that local renewable capacity be curtailed during high generation and/or low demand situations. However, this analysis found that an increase in transmission capacity is neither necessary nor cost-effective in pursuing Humboldt RESCO goals assuming sufficient local demand is built by fuel switching in the heating and transportation sectors. Current transmission capacity was essentially found to be adequate as increases in the transmission capacity were never a part of the optimal solutions found by the REPOP model.

Energy storage was also examined as a way to minimize the curtailment of local intermittent renewable generation during high generation, low demand situations. However, like with transmission capacity, energy storage was not shown to play a significant role. For example, in the scenario with 38 percent penetration of electric vehicles and heat pumps, energy storage only became a part of the optimal solution when local renewable generation provided greater than 95 percent of electricity demand. Nonetheless, three energy storage technologies were identified that could be implemented in Humboldt County: pumped hydro, compressed air, and batteries. Of these, pumped hydro appeared to be the most cost-effective provided it turns out to be politically and technically viable.

A steady state power flow analysis conducted by PG&E indicates that substantial upgrades to the local transmission and distribution system will be required to accommodate large scale development of local renewable energy sources as suggested by this study. These upgrades will be required to ensure that PG&E's transmission system remains in full compliance with North American Electric Reliability Corporation (NERC) reliability standards.

Finally, two pathways were examined for the use of forest-based biomass to provide energy for the transportation sector. One pathway included the production of biopower and subsequent charging of electric vehicles, whereas the alternate pathway involved the production of forest-based biofuels, either cellulosic ethanol or Fischer-Tropsch biodiesel, to be used in internal combustion engine vehicles. The use of Argonne National Laboratory's GREET model was used to compare these pathways and the results indicate that the Fischer-Tropsch biodiesel pathway compares favorably with the biopower to battery electric vehicles pathway, with both of these pathways potentially achieving greater than 90 percent reduction in fossil fuel use and greenhouse gas emissions. The cellulosic ethanol pathway did not fare as well, though it did outperform the plug-in hybrid electric vehicle pathway.

4.2 Recommendations

The results and conclusions from this study will help inform the creation of a long-term Humboldt County RESCO strategic plan to move toward a more sustainable and secure energy future. The RESCO study seeks to achieve benefits including reductions in greenhouse gas emissions, job creation and economic stimulus, and greater local control of energy decisions. Key recommendations to be drawn from this work include:

- The results of the Humboldt RESCO resource and technology assessment should be used to inform the development of the Humboldt County RESCO Strategic Plan.
- The goals of the Humboldt County RESCO Strategic Plan should focus on the most cost-effective way to achieve greenhouse gas emission reductions in combination with the development of local renewable energy resources. Meeting a certain percentage of electricity demand using local renewable resources should not be the primary goal.
- Elements of the RESCO Strategic Plan should include:
    - Aggressive pursuit of cost-effective energy efficiency opportunities.
    - Development of new biomass, wind and small hydroelectric generating facilities.
    - A focused effort to encourage adoption of electric vehicles and heat pumps.
    - Appropriate levels of support for distributed generation, like rooftop solar, as a means of engaging and garnering community backing for the overall RESCO vision.

4.3 Suggestions for Further Study

While the Humboldt RESCO resource and technology assessment study was comprehensive in its scope, it was by no means exhaustive. Opportunities for further research include:

- Further review and refinement of the assumptions used in the Regional Energy Planning Optimization model.
- Improvements or added capabilities to the Regional Energy Planning Optimization model.
- Identifying ways to cost-effectively and sustainably utilize forest fuel reduction material from remote locations as a fuel source for biopower or biofuel production.
- A biomass fuel availability assessment that estimates the technical, economic and achievable quantity of biomass fuel that can be successfully utilized for

renewable energy generation. This should include an assessment of various fuel sources, including material from both public and private timber lands, as well as waste materials generated during timer harvests (slash), fuel treatments, and thinning of stands. The estimate of "achievable" quantities should include impacts associated with community acceptance.

- A life-cycle assessment of greenhouse gas emissions associated with biomass power should be conducted and the assumption that biomass energy is climate neutral should be examined.
- An assessment of small hydroelectric opportunities and barriers.
- Adaptation of the Regional Energy Planning Optimization model for use in another California community.
- A more robust power flow analysis to include a transient stability analysis, as well as examination of non-conventional means of meeting North American Electric Reliability Corporation (NERC) reliability standards (e.g., through energy storage facilities or flexible contracting arrangements with curtailment).
- Further research into the Fischer-Tropsch biodiesel forest-based biofuel pathway for using local biomass resources to meet transportation energy needs. An examination into the cost and feasibility of this pathway is needed.

4.4 Benefits to California

While the focus of this study was to provide guidance to Humboldt County, the tools developed and lessons learned can provide substantial benefit to communities throughout California and beyond. Some of the benefits to other communities include:

- Development of simulation models and planning tools for community energy and greenhouse gas reduction planning.
- Lessons learned that can be applied to other communities.
- A case study of how large percentages of local renewable resources coupled with the adoption of electric vehicles and heat pumps can lead to cost-effective reductions in greenhouse gas emissions and substantial local economic benefits.
- Using Humboldt County as a test case for operating an electric grid with high fractions of renewable energy generation.
- Additional products from the RESCO study will include a regulatory and policy guide for local government officials, a strategic planning document for the development of local renewable energy resources, and a RESCO planning workbook that will document RESCO planning activities and make them easily accessible to other communities.

CHAPTER 5: References

Bracmort, Kelsi (2011). *Is Biopower Carbon Neutral?* Congressional Research Service, R41603. January 25, 2011.

California Air Resources Board (2009). *Detailed California-Modified GREET Pathway for California Reformulated Gasoline (CaRFG*). Release Date: January 12, 2009. Downloaded Sep. 2010. http://www.arb.ca.gov/fuels/lcfs/011209lcfs_carfg.pdf

California Department of Conservation (2003). "2003 Annual Report, Production and Reserves," Division of Oil, Gas and Geothermal Resources.

California Department of Water Resources (1985), "California Wind Atlas," prepared for the California Energy Commission, Contract Number P-500-82-044.

California Energy Commission (2003). "California Ocean Wave Energy Assessment, Volume 1, Draft," August 2003.

California Energy Commission (2007). *Distributed Generation and Cogeneration Policy Roadmap for California*, Staff Report, March 2007.

California Energy Commission (2010a). *California Solar Photovoltaic Statistics and Data*, http://www.energyalmanac.ca.gov/renewables/solar/index.html [Accessed June 6, 2010].

California Energy Commission (2010b). *Geothermal or Ground Source Heat Pumps*. http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html [Accessed November 2010].

Chi-Jen, Y.; Williams, E. (2009). "Energy Storage for Low-Carbon Electricity." Duke University Climate Change Policy Partnership. http://www.nicholas.duke.edu/ccpp/ccpp_pdfs/energy.storage.pdf

Deane, J.P., Gallachoir, B.P. O, & McKeogh, E.J., (2010). Techno-economic review of existing and new pumped hydro energy storage plant. *Renewable and Sustainable Energy Review* 14(2010) 1293-1302

Energy Information Agency, Annual Energy Outlook 2011, Energy Generating Capacity http://www.eia.gov/analysis/projection-data.cfm#annualproj [Accessed April 7, 2011]

Electricity Storage Association. Accessed December 2010 at http://www.electricitystorage.org/site/home/

Electric Power Research Institute (2003). *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications.*

Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2003. 1001834.

European Wind Energy Association (2005). "Large scale integration of wind energy into the European power supply: analysis, issues and recommendations. " Technical report published December, 2005. http://www.ewea.org/index.php?id=1965.

Goldman, C., N. Hopper, R. Bharvirkar, B. Neenan, and P. Cappers (2007) *Estimating Demand Response Market Potential among Large Commercial and Industrial Customers: A Scoping Study.* Lawrence Berkeley National Laboratory report LBNL 61498.

Humboldt County, California (2005), *Humboldt 21st Century Natural Resources and Hazards Report*. http://www.planupdate.org/meetings/natl_res/nr_report.asp. [Accessed March, 2005].

Humboldt Waste Management Authority (2010). *Humboldt Food Waste Digester Project Summary*. http://www.hwma.net/index.php?a=foodwaste. [Accessed June, 2010].

ICF International, Inc. (2010). *Combined Heat and Power Market Assessment.* Prepared for California Energy Commission. CEC-500-2009-094-F. April 2010.

Iowa Stored Energy Park Project (2011). Economics Study Summary. http://www.isepa.com/index.asp [Accessed April 7, 2011].

Itron. 2008. *California Energy Efficiency Potential Study.* CALMAC Study ID: PGE0264.01.

Itron (2005) *2004-2005 Database for Energy Efficiency Resources (DEER) Update Study: Final Report*. http://www.deeresources.com [Accessed August 12, 2010].

Laaksonen-Craig S., Goldman G., and McKillop W (2003). "Forestry, Forest Industry, and Forest Products Consumption in California," University of California, Division of Agriculture and Natural Resources, 2003, ANR Publication 8070.

Marino, Bob (2010), Power plant production for DG Fairhaven Power LLC. Furnished personally by Bob Marino, General Manager.

National Geographic News (2010) "Texas Pioneers Energy Storage in Giant Battery." March 25, 2010. http://news.nationalgeographic.com/news/2010/03/100325-presidio-texas-battery/ [Accessed December 2010].

National Renewable Energy Laboratory (2008). "Impacts of Large Amounts of Wind Power on Design and Operation of Power Systems; Results of IEA Collaboration." Conference Paper: NREL/CP-500-43540. June 2008.

North American Electric Reliability Corporation (2009). "Accommodating High Levels of Variable Generation to Ensure the Reliability of the Bulk Power System." Special Report: April, 2009. http://www.nerc.com/filez/ivgtf.html [Accessed August 2011].

Oscar Larson & Associates (1982). *An Analysis of Small Hydroelectric Planning Strategies*. Prepared for: Humboldt County Board of Supervisors, May, 1982.

Pacific Gas and Electric (2005). *Humboldt Long Term Transmission Assessment: Final Study Report*. Technical report prepared by Electric T&T Engineering, February, 2005.

Pacific Gas and Electric Company (2010a). Draft Pilot Project License Application, Humboldt WaveConnect™ Project, Federal Energy Regulatory Commission Docket No. P-12779.

Pacific Gas and Electric Company (2012). Email correspondence with Ivan Marruffo, Senior Account Reprsentative, March 15, 2012.

Parks, K., P. Denholm, and T. Markel (2007). *Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory.* National Renewable Energy Laboratory Publication number: NREL/TP-640-41410.

Pellissier, Dan (2010). Letter to Ms. Lisa Jackson, Administrator, U.S. Environmental Protection Agency. Re: Docket Number EPA-HQ-OAR-2010-0560, Call for Information: Information on Greenhouse Gas Emissions Associated with Bioenergy and Other Biogenic Sources. September 13, 2010. Includes attachment with comments from the California Air Resources Board, the California Department of Forestry and Fire Protection, and the California Energy Commission.

Reis A. and Engel R (2003). "Feasibility Study on Implementing Anaerobic Digestion Technology on Humboldt County Dairy Farms," Schatz Energy Research Center, Humboldt State University, Arcata, CA, June 1, 2003. Prepared for Humboldt County Economic Development Office.

Schatz Energy Research Center (2011). *Humboldt County as a Renewable Energy Secure Community: Economic Analysis Report.* Public Interest Energy Research Program Interim Project Report. Prepared for: California Energy Commission, April 2011.

Succar, S., & Willams, R. H. (2008). *Compressed Air Energy Storage: Theory, Resources, and Applications for Wind Power*

USA Today. July 5, 2007. "New battery packs powerful punch." http://www.usatoday.com/money/industries/energy/2007-07-04-sodium-battery_N.htm [Accessed December 2010]

U.S. Department of Energy (2010). *Geothermal Heat Pumps – Product Information Spreadsheet*. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640 [Accessed November 2010].

Williams, R.B., B.M. Jenkins, and M.C. Gildart (2007). *Ethanol Production Potential and Costs from Lignocellulosic Resources in California*. Department of Biological and Agricultural Engineering, University of California, Davis, May 2007.

CHAPTER 6: Glossary

BAU	Business-as-usual
BDT	Bone dry ton
BEV	Battery electric vehicle
CAES	Compressed air energy storage
CDD	Cooling degree-day
CG	Conventional gasoline
CH_4	Methane
CHP	Combined heat and power
CIDIV	Compression-ignition direct-injection vehicle
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CZ	Climate zone
DHW	Domestic hot water
EF	Energy factor
EPRI	Electric Power Research Institute
EREV	Extended range electric vehicle
EV	Electric vehicle
FFV	Flex fuel vehicle
FTD	Fischer-Tropsch diesel
GHG	Greenhouse gas
GREET	Greenhouse gases, regulated emissions, and energy use in transportation
H2	Hydrogen
HDD	Heating degree-day
HTA	Humboldt Transit Authority
HVAC	Heating, ventilation and air conditioning
HWMA	Humboldt Waste Management Authority
ICE	Internal combustion engine

IOU	Investor owned utilities
LPG	Liquefied petroleum gas
N2O	Nitrous oxide
NaS	Sodium sulfur
NO_x	Nitrogen oxides
NRDC	Natural Resource Defense Council
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
PHES	Pumped hydroelectric energy storage
PHEV	Plug-in hybrid electric vehicle
PM10	Particulate matter with a diameter less than or equal to 10 micrometers
PM2.5	Particulate matter with a diameter less than or equal to 2.5 micrometers
PV	Photovoltaic
RE	Renewable energy
REPOP	Regional energy planning optimization program
RESCO	Renewable energy secure community
RFG	Reformulated gasoline
SCG	Southern California Gas Company
SDG&E	San Diego Gas & Electric Company
SEC	Southern California Edison
SEER	Seasonal energy efficiency ratio
SERC	Schatz Energy Research Center
SIPHEV	Spark ignition plug-in hybrid electric vehicle
SO_x	Sulfur oxides
TRC	Total resource cost
VOCs	Volatile Organic Compounds
WTW	Well-to-wheels
ZEV	Zero emission vehicle