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# Alternative Energy Sources for MoDOT

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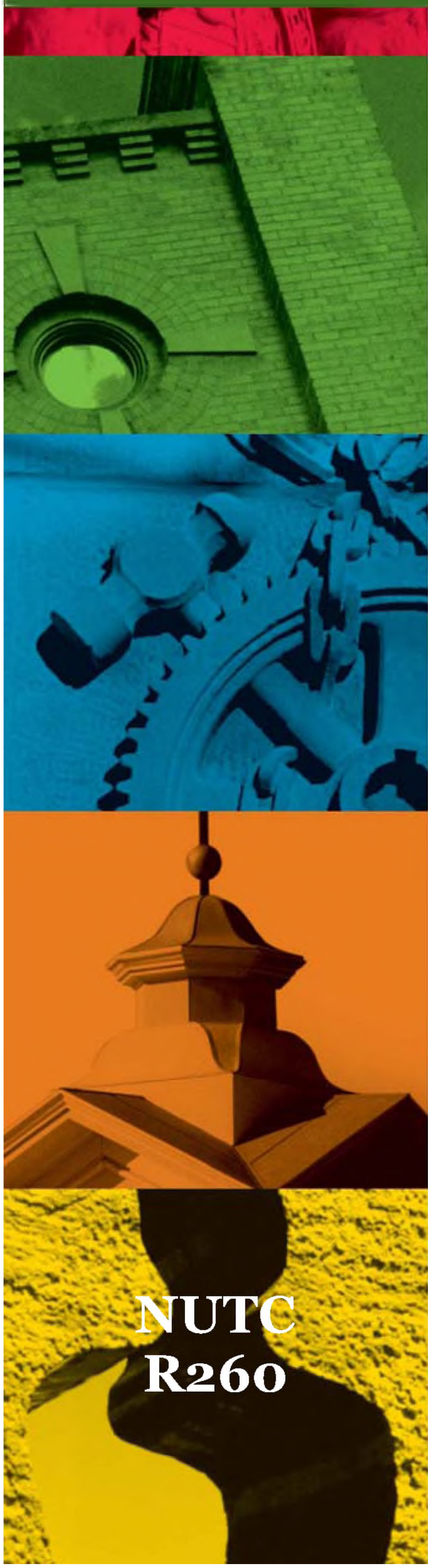
# Center for Transportation Infrastructure and Safety

Missouri S&T




# Alternative Energy Sources for MoDOT

by

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## Executive Summary

Missouri faces significant challenges related to environmental quality, changes in energy markets, and evolving public interests. Practices for alternative energy have drawn significant research attention in recent years. Missouri has a strong foundation suitable for leadership in alternative energy sources, including industrial, governmental, and academic expertise. MoDOT has committed to developing an efficient roadmap to successfully make the critical transition to the use of alternative energy sources. To better address this commitment and deliver tangible "Environmentally Responsible" results, MoDOT aims to develop applicable strategies to implement alternative energy in various areas. Not only will these applications be environmentally friendly but, in some cases, they may be technically and economically superior to traditional strategies.

In that regard, the objective of this project was to investigate environmentally friendly alternative energy sources that could be used by MoDOT in various areas, and to develop applicable and sustainable strategies to implement those energy sources. Specifically, the project conducted a thorough investigation of potential alternative energy sources that could be used by MoDOT, identified the various application areas in which the alternative energy may be appropriate, created an appropriate cost-effectiveness and financial feasibility analysis framework as a function of electric utility rates and potential rate increases, as well as analyzed various financing mechanism such as public-private partnerships, and developed detailed and applicable strategies that will guide the implementation of the selected energy sources based on appropriate technology feasibility analysis, as well as address technological issues and risk mitigation.

It is recommended that MoDOT pursue the use of alternative energy sources in four main areas:

1. Wastewater Treatment,
2. LED Roadway Lighting,
3. Miscellaneous Energy Savings Projects, and
4. Renewable Solar/Wind Installations.

These recommendations highlight suitable near-term initiatives for MoDOT, based not only on payback period, but on the technical and economic feasibility of potential sources/applications, as well as risk mitigation, financing mechanisms, and near-term actions with potential economic development benefits.

This work assists in developing a framework/roadmap for alternative energy in Missouri that is likely to advance alternative energy programs in Missouri. This final project report includes:

- a comprehensive literature review that provides background information, validates research efforts, and imparts best practice knowledge,

- a thorough investigation of potential alternative energy sources, *as well as unique applications*, that could be used by MoDOT,
- appropriate cost-effectiveness and financial feasibility analysis, and
- applicable strategies to implement alternative energy including detailed implementation plans and technological instructions, *including financing mechanisms*.

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## 1.0 Introduction

Global environmental challenges such as climate change and carbon emissions have raised people's concerns about current energy consumption and their awareness of renewable and sustainable energy sources. Although a complete transformation from a fossil-fuel-dependent economy to a clean-energy one still looks like a long battle ahead, research and practices for alternative energy have been under way and have drawn enormous attention. Alternative resources have long been experimented with and utilized as clean and sustainable alternative energies. MoDOT has been committed to engaging in environmentally friendly innovative technologies and practices. To better address this commitment and deliver the tangible result of "Environmentally Responsible", MoDOT is aimed at developing applicable strategies to implement alternative energy in various areas.

This report assists in developing a framework/roadmap for alternative energy in Missouri based on the technical and economic feasibility of potential sources/applications. This final report provides a comprehensive literature review that provides background information, validates research efforts, and imparts best practice knowledge, a thorough investigation of potential alternative energy sources, as well as unique applications, that could be used by MoDOT, appropriate cost-effectiveness and financial feasibility analysis, and applicable strategies to implement alternative energy including detailed implementation plans and technological instructions, including financing mechanisms and risk mitigation. The report is organized around the following four tasks.

Task 1: Literature Review and Best Practices (Section 2.0)

Task 2: Investigation of Potential Alternative Energy Sources/Applications (Section 3.0)

Recommendations for Alternative Energy Projects (Section 4.0)

Task 3: Cost-Effectiveness and Financial Feasibility Analysis (Section 5.0)

Task 4: Implementation Strategies and Procedures (Section 6.0)

## 2.0 Literature Review and Best Practices

During the past decades, approaches have been used to encourage the application of alternative energy. Many of these have failed because of the lack of a real marketplace, shifts in government policies, and/or a relative lack of interest. Lessons learned with respect to previous alternative energy technologies, as well as other technologies may be used to provide recommended best practices for alternative energy strategies. Task 1 completed an in-depth study of past and existing programs to determine technology status at the time of introduction, strategies used for the introduction of the technology, consumer behavior and attitudes, as well as industry participation or lack thereof, impact of infrastructure availability, including environmental benefits/impacts, cost-effectiveness of the program (investment vs. market success/failure), description of challenges/solutions, major achievements of the programs or justification for lack of success, and financial status and competitiveness. The literature from both academic and implemented programs is used to:

- provide lessons learned and best practices related to alternative energy programs,

- identify unique opportunities for alternative energy sources and applications,
- estimate data for technical and economic feasibility analysis, and
- recommend strategies for successful implementation.

Sources of literature included academic, governmental, and industrial technical publications and reports, as well as databases maintained by appropriate entities. Some initial sources of information are provided in Table 1.

Table 1 Data Sources

| **Source** | **Reference/Website** |
|---|---|
| Database of State Incentives for Renewable Energy (DSIRE) | http://www.dsireusa.org/ |
| National Association of State Energy Offices (NASEO) | http://www.naseo.org/ |
| DOE - Energy Efficiency & Renewable Energy (EERE) | http://www.eere.energy.gov/ |

Other sources include federal agencies such as the Department of Agriculture (http://www.usda.gov), Department of Energy (http://www.doe.gov), Department of Transportation (http://www.dot.gov), Environmental Protection Agency (http://www.epa.gov), as well as State agencies such as the Missouri Department of Natural Resources (www.dnr.mo.gov/).

A listing of relevant literature and documentation related to alternative energy projects is provided later. Literature was reviewed in order to establish relevant projects, policies, and contacts. It is important to note that, while the focus is related to providing recommended opportunities to MoDOT, it is the opinion of the investigators that analyzing applications of alternative energy outside of transportation will lead to unique solutions. Thus, the project addressed all aspects of the alternative energy. From the literature review, a project/contact list was developed for development of best practices, as well as for source/application identification. Special attention was paid to those projects that have direct implications on the on-going study.

The review of best practices for alternative energy programs began by reviewing other State programs. The Database of State Incentives for Renewable Energy (DSIRE) is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. DSIRE provides summary maps, summary tables, and a library of documentation with search mechanisms. In addition, The National Association of State Energy Offices (NASEO) provided contact information for state energy offices, which, along with individual State DOTs, was used as initial sources for strategies related to alternative energy programs.

**2.1 Use of Alternative Energy in Transportation Survey**

The Missouri S&T research team attended the 2010 Annual Meeting of American Association of State Highway and Transportation Officials (AASHTO) Research Advisory Committee/Transportation Research Board (TRB) State Representatives in Kansas City, Missouri from July 26-29. The participants included approximately 150 research decision-makers, including national research leaders from the TRB, universities and independent researchers. The team met with DOT officials from different states and collected information on various renewable energy projects deployed in their state. The meeting provided an excellent opportunity to learn what other states have been doing to improve the transportation sector and the areas which they are trying to improve using renewable energy sources. It also helped to gain insight on the different issues faced by the Department of Transportation for deployment of renewable energy sources. The team also distributed a link to a 21-question online questionnaire to solicit information about the different alternative energy and energy efficient projects deployed in transportation sector by different agencies/organizations. The survey was designed to solicit input primarily from state DOTs as a mechanism for determining "best practices" and evaluating the current level of use for alternative energy technologies in transportation organizations. The survey and its results are provided in Appendix A. The following section is a brief discussion about the survey and its results.

The survey received a total of 36 responses including responses from 19 different State DOTs. Additional respondents include people from consultants, universities, and other state and federal agencies. More than 51% of the respondents had more than 10 years of experience in the transportation sector and included people from administration, research and development, academia, engineering, fleet managers, building and construction, information technology/MIS, etc. 72% of the survey takers responded that their agency/organization had installed or were planning to install alternative energy projects, (Figure 1) signifying the importance of renewable energy sources in transportation.

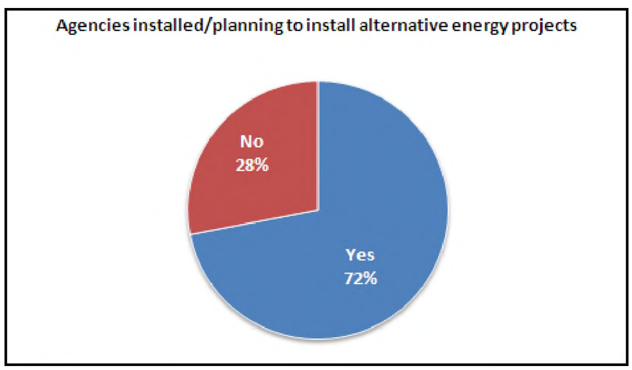


Figure 1. Alternative energy sources in transportation

For making recommendations on implementation strategies of alternative energy sources at MoDOT, it was important to learn where the state DOTs deployed their alternative energy projects. The survey showed two main areas using alternative energy sources, (i) fleet vehicles (56% of responses) and (ii) office buildings (52% of the responses) (Figure 2). Other areas include maintenance facilities and welcome centers/rest areas, traffic management/logistics, traffic signals, etc.

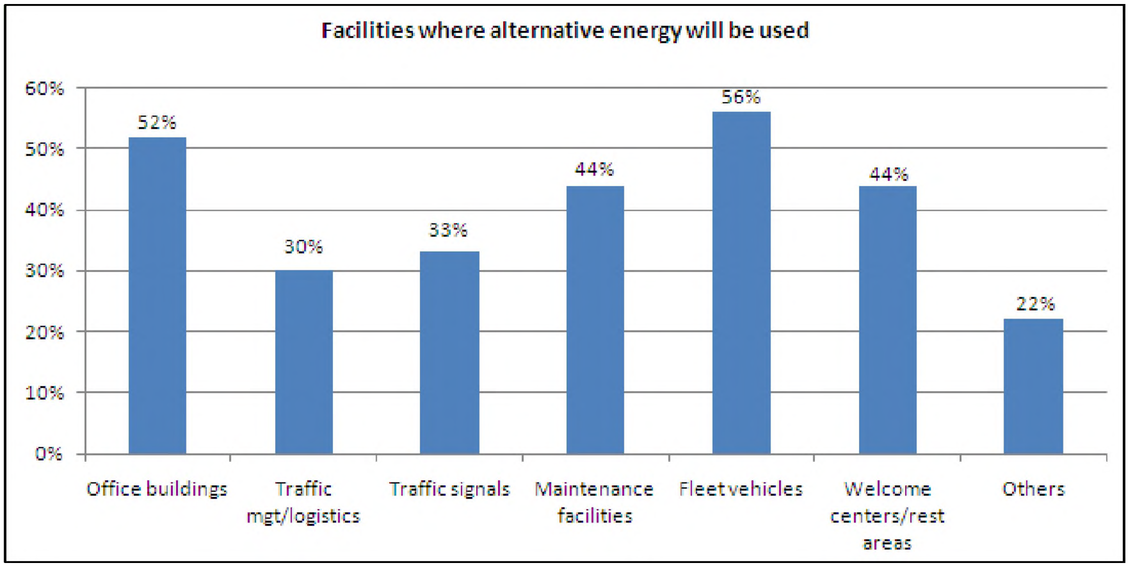


Figure 2. Facilities where alternative energy will be deployed

The survey asked about the different types of alternative energy sources used to identify the alternative energy trends and projects in the transportation sector (Figure 3). Projects using solar energy were the most common, followed by alternative fuel vehicles and wind energy. Other alternative technologies used at the DOT facilities included geothermal energy, fuel cells, waste water treatment, biomass, hybrid vehicles, etc.

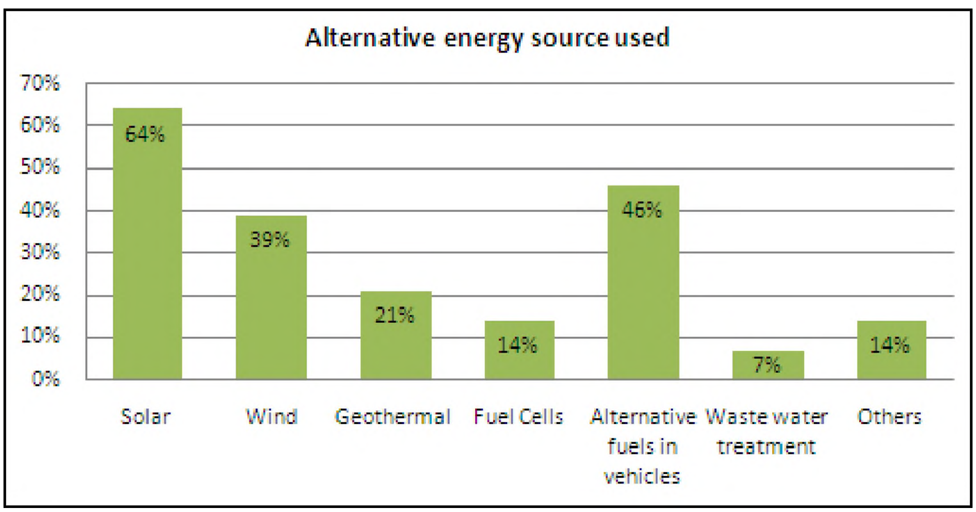


Figure 3. Alternative energy used at different DOT facilities

From the previous two results, it is evident that one of the main areas of alternative energy usage at state DOTs is fleet vehicles. The survey shows that the major alternative fuel used in fleet vehicles are CNG, ethanol, biodiesel, and other alternative fuels (Figure 4).

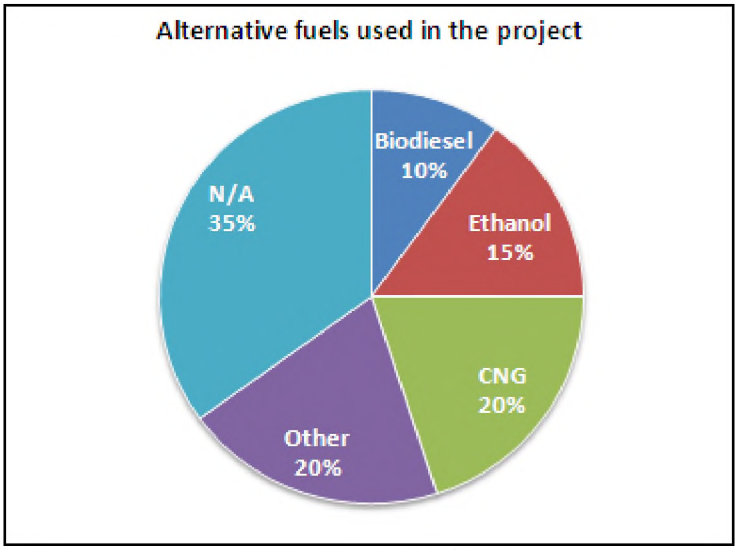


Figure 4. Alternative fuel used

Apart from investigating the alternative energy projects at different DOT facilities, it was also crucial to gather information on their energy efficient and sustainable projects. 89% of the respondents said their agency/organization had deployed or was planning to deploy projects that increase energy efficiency in office buildings, traffic management, maintenance facilities, etc. (Figure 5).

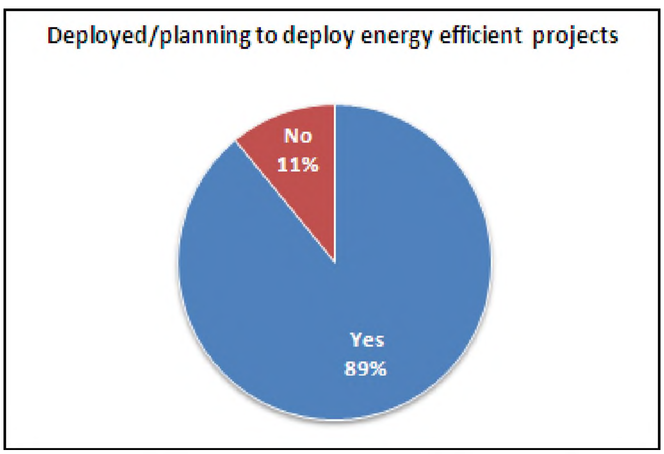


Figure 5. Deployed / planning to deploy energy efficiency projects at DOT facilities

Location of energy efficient projects at different DOT sites was determined. The responses show that office buildings are the major facility where sustainability and energy efficiency systems are being deployed. Maintenance facilities, welcome centers / rest areas, and traffic signals were also apt locations for energy efficient systems (Figure 6).

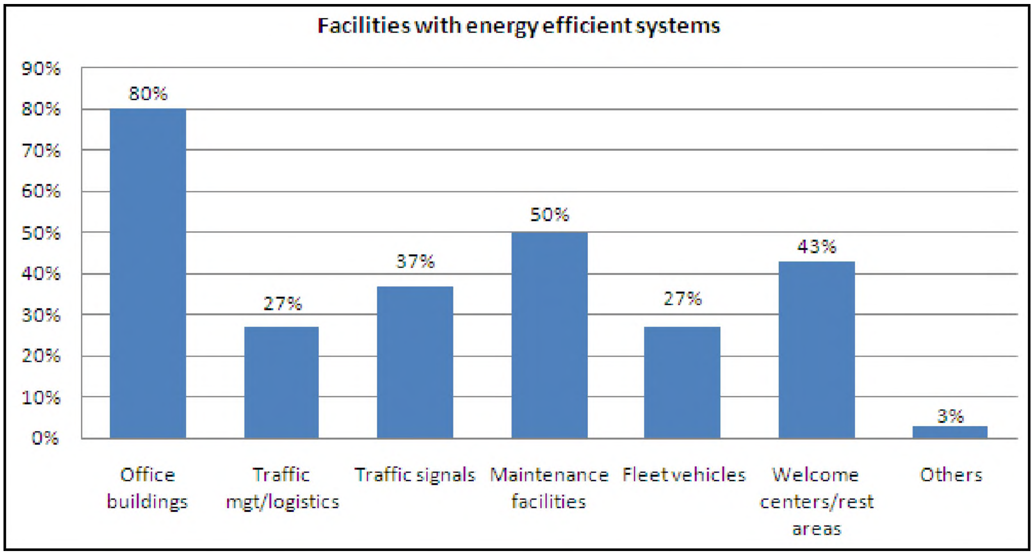


Figure 6. Facilities with energy efficiency systems

State DOTs have implemented many energy efficient and sustainable projects for saving energy. From (Figure 7), it can be clearly seen that lighting is the most widespread area for energy efficient systems. This includes the use of LED lighting for traffic signals, high efficiency lighting, and intelligent lighting systems for office buildings and other facilities. Other energy efficient and sustainable systems installed include high efficiency HVAC systems, intelligent systems, green roofs, rain water collection, better windows and insulation.

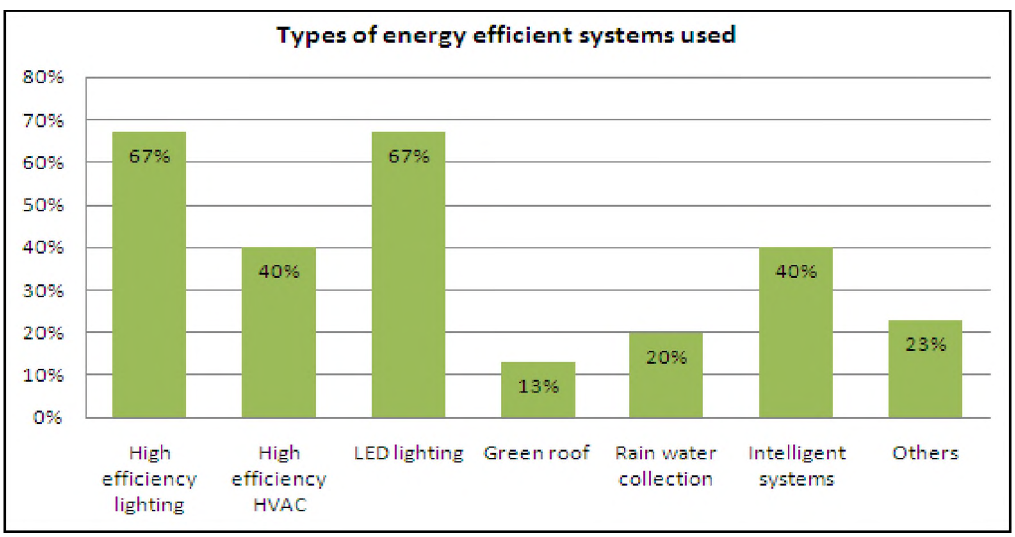


Figure 7. Types of energy efficiency systems used

To understand the difficulties in deploying alternative energy programs, the survey asked for the most significant obstacles that state DOTs faced during their projects. Initial cost and funding was the main obstacle for 70% of the respondents and some of them overcame it by obtaining matching funds from utilities, grants, and through annual energy savings. Legal hurdles, intermittent nature of renewable energy sources were some of the other obstacles they faced. When asked for recommendations for increasing the amount of alternative energy sources in transportation, respondents expressed the need for more grants/federal assistance, investment in R&D, encouragement for energy efficiency at DOT facilities, and development of LEED standards for transportation. Major achievements of the programs were energy savings, petroleum displacement, and cost savings/revenue from renewable energy sources.

### 2.2 Other Meetings and Workshops

In addition to policy analysis by the investigators, workshops (including topical presentations by industry, users, and scientists/engineers) establishment of working groups, and scenario development were used to analyze gathered information and develop strategy. Stakeholder meetings have taken place to discuss possible implementation strategies and procedures. These meetings, some of which were discussed earlier include:

1. Transportation Engineers Association Meeting – March 18, 2010, Branson
2. AASHTO/RAC Meeting – July 26-28, 2010, Kansas City
3. MoDOT Facilities Managers Meeting – August 3, 2010, Jefferson City
4. Tour of City of Rolla Wastewater Facilities – August 30, 2010, Rolla

From these meetings, it is evident a comprehensive program will be required to address MoDOT's need for alternative energy sources/applications. The comprehensive program will help prioritize projects both in the short-term and long term, while balancing financial and environmental issues.

Missouri S&T coordinated a meeting (held at MoDOT Organizational Results on November 15) with MoDOT leadership to provide information on the benefits of a comprehensive Energy Management Plan using a Plan-Do-Check-Act methodology found in The American National Standard, ANSI/MSE 2000:2008 *Management System for Energy and the Environmental Protection Agency's (EPA) Guidelines for Energy Management*. An Energy Advisor from EPA Region 7 also attended to provide ideas for funding and recognition programs if MoDOT chooses to engage in a comprehensive plan that will demonstrate a reduction in Greenhouse Gas Emissions. Background information was provided on the Energy Management Initiative between Missouri S&T, Region 7 EPA, and Siemens Energy & Environmental Solutions that provided educational workshops, technical support, and recognition for 8 Missouri communities. Detailed information about Energy Savings Performance Contracting as an opportunity to provide a turn-key energy savings program to MoDOT with funding provided through MoDOT's energy savings was presented, along with information on Intelligent Transportation Systems, traffic management, and innovative street and traffic lighting technologies that could provide comprehensive energy savings as well as improved operations and lower operational costs.

## 3.0 Investigation of Potential Alternative Energy Sources/Applications

Department of Energy - Office of Energy Efficiency & Renewable Energy (EERE) provided a starting point for investigation of potential energy sources and applications. The data center contains a number of links to related sites, studies, and other analysis tools/methodology. Specifically, the site has information related to advanced vehicles and fuels, basic sciences, biomass, buildings, computational science, concentrating solar power, electric infrastructure systems, energy analysis, geothermal, hydrogen and fuel cells, renewable resource maps and data, photovoltaics, and wind.

Sources and applications were selected to build upon MoDOT's Being Green at MoDOT initiative[1], as well as to directly contribute to the "Environmentally Responsible" Tracker[2] measures, particularly related to clean air, fuel consumption, recycled/waste material, and wetlands.

### 3.1 Sources

Missouri has advantages that distinguish it from other states and can be leveraged to create business and energy-related opportunities. Further, Missouri can play an active role in national alternative energy discussions and planning. Among these are ongoing efforts related to transportation fuels, such as biofuels, ethanol, natural gas and hydrogen, as well as multimodal transport capabilities to distribute the regionally produced fuels. Missouri has significant opportunities to utilize clean and sustainable energy derived from solar, wind, geothermal, nuclear, hydrogen, and natural gas. In addition, Missouri has unique opportunities to harness and utilize hydro-kinetic energy from Missouri's many rivers and streams.

The Missouri University of Science and Technology (Missouri S&T) team investigated a variety of environmentally friendly alternative energy sources that could be used at various MoDOT facilities. These alternate energy sources include solar, wind, and geothermal energy and other alternative energy applications including fuel cells and alternative fuel for vehicle applications.

*Solar Energy (Figure 8)*

Use of active and passive solar is another alternative energy option and one MoDOT is already using. Active solar Photovoltaics is a technology that converts radiant light energy to electricity. Photovoltaic (PV) cells are the basic building blocks of this energy technology. Sunlight is the most common source of the energy used by PV cells to produce an electric current. It takes just a few PV cells to produce enough electricity to power a solar calculator. For more power, cells are connected together to form modules. Modules are connected to form arrays, and arrays can be interconnected to generate electricity for a large load, such as a group of buildings.

Passive solar energy uses the direct heat from the sun to change temperature. This type of energy is most often used to heat water. The sun also provides natural light which reduces the need for electricity to power lighting. MoDOT has successfully used solar power to generate power for digital signs, and

[1] http://www.modot.mo.gov/goinggreen/index.htm
[2] http://www.modot.mo.gov/about/documents/Tracker_PDF_July09/chapter10.pdf

recently added arrays to a new building. Solar technologies investigated include photovoltaic cells, concentrating solar power technologies, and low temperature solar collectors (Table 2).

Table 2. Solar Technologies

| Technology | Description |
| --- | --- |
| Photovoltaic Cells | Photovoltaic cells convert solar radiation to electricity and are usually made of semiconductors such as crystalline silicon, cadmium telluride, or other thin-film materials. |
| Concentrating Solar Power | Concentrating solar power technologies use lenses or mirrors to concentrate the sun's heat energy on to a collector which produces electricity via a steam turbine or heat engine driving a generator. |
| Low Temperature Solar Collectors | Low-temperature solar collectors absorb the sun's heat energy and are used directly for heating hot water or space heating. |

These technologies could be used to produce "renewable and green" power by optimizing systems for installation at different MoDOT facilities. These technologies may not be feasible at all MoDOT facilities since systems often require a large surface area to collect the solar energy; economic feasibility of using this technology can be evaluated on a case-by-case basis. Potential applications include providing power and hot water to rest areas, offices, garages, other facilities, and charging plug-in hybrid vehicles.

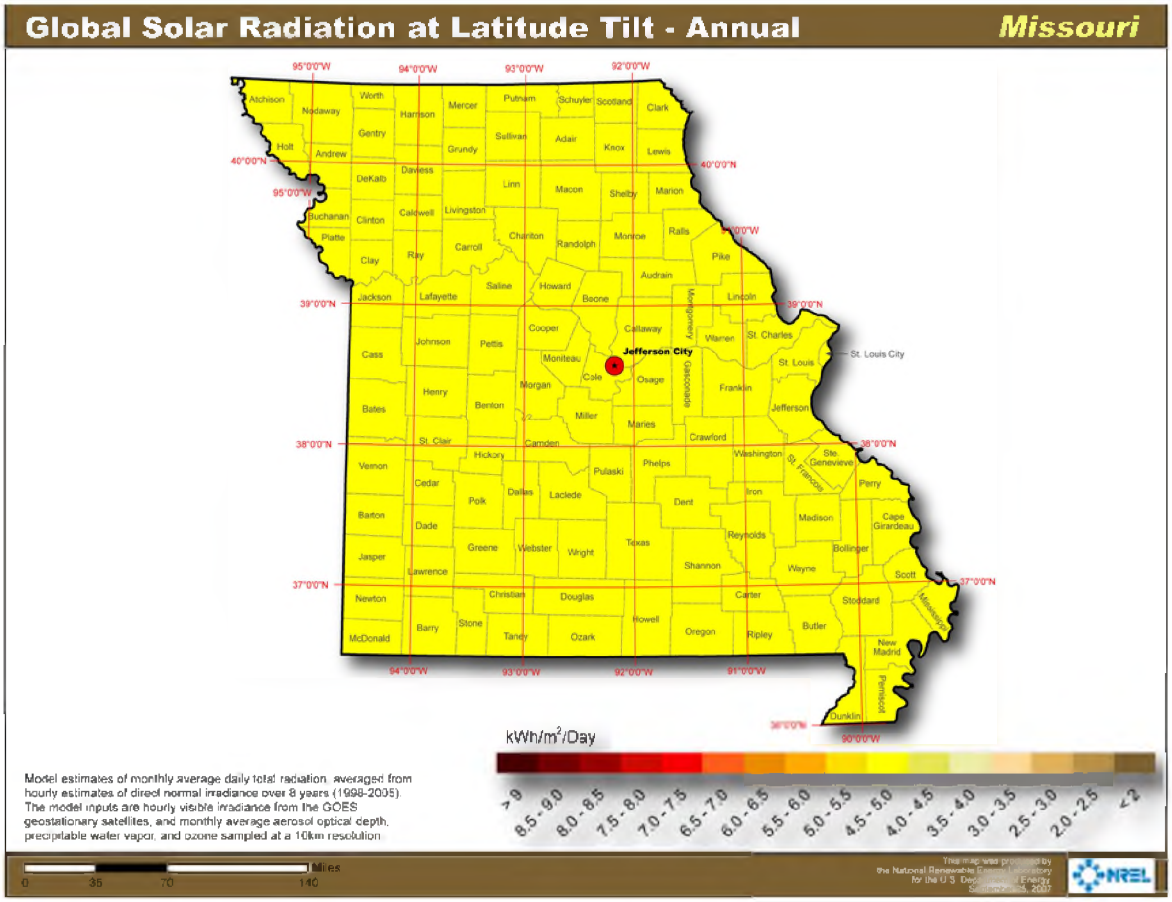


Figure 8. Missouri PV Resource[3]

*Wind Energy (Figure 9)*

A small wind turbine is a device that produces electricity from wind. Moving air causes the turbine to rotate, which generates clean, emissions-free energy. Small wind turbines are a potential alternative energy source which can be used in connection with an electricity transmission and distribution system, or in stand-alone applications that are not connected to the utility grid. A grid-connected wind turbine is the most practical wind system type for use at Federal facilities, and at MoDOT facilities, where lack of power is not an option. These small wind systems reduce the site's consumption of utility-supplied electricity, however, when the turbine cannot deliver the amount of energy needed, the utility makes up the difference. When the wind system produces more electricity than the facility requires, the excess is sold to the utility.

In order for a small wind system to be practical, the average annual wind speed in an area must be 10 miles per hour. Not all areas of Missouri have an average wind speed of 10 miles per hour. (See Missouri Wind Speed map on page 8.) Area maps are fairly accurate; however the actual wind speed at

[3] U.S. National Renewable Energy Laboratory, Dynamic Maps, GIS Data, & Analysis Tools, MapSearch Available at Internet: <http://nreldev.nrel.gov/gis/images/eere_pv/eere_pv_missouri.jpg>

the installation site should be determined. This information can be obtained with a recording anemometer. It is suggested that wind speeds be captured over a year, at the height of the top of the wind turbine tower. Wind speeds are always higher at distances furthest from the ground.

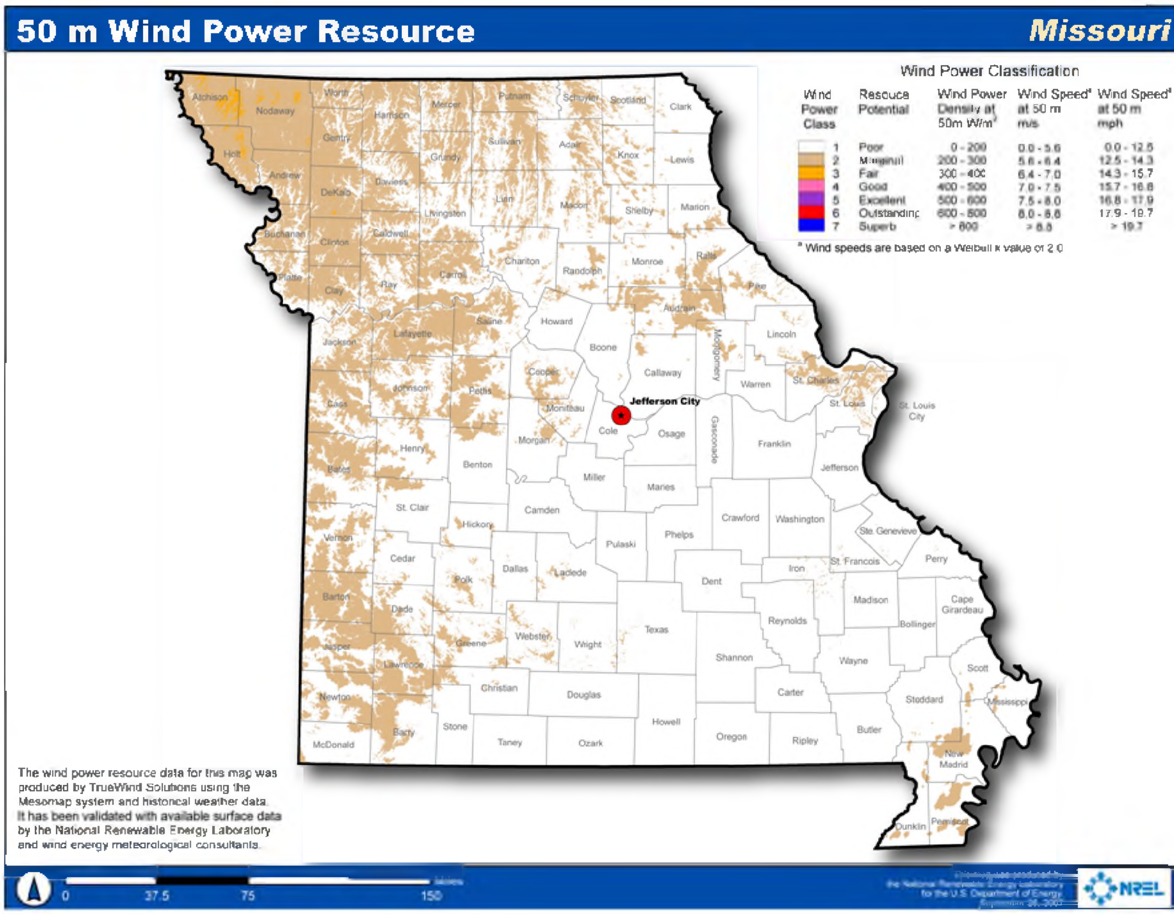


Figure 9. Missouri Wind Map[4]

Wind energy resources of Missouri were investigated. Northwest Missouri has the highest wind energy potential in the state and the project encourages wind turbine installations at MoDOT facilities to be located in this region. The project also investigated the feasibility of modular wind turbine system that can be integrated into the existing MoDOT buildings. Wind resources at a local level can vary significantly and a wind energy study would be required before deciding to install wind turbines at a specific location.

[4] U.S. National Renewable Energy Laboratory, Dynamic Maps, GIS Data, & Analysis Tools, MapSearch Available at Internet: < http://nreldev.nrel.gov/gis/images/eere_wind/eere_wind_missouri.jpg>

Some facilities use hybrid wind-solar photovoltaic panels for energy generation because wind speeds are strongest in the fall, winter, and spring, and at night, while solar energy is strongest in the summer and during the day. A hybrid system allows a facility to generate some energy from the system for most of the year.

*Geothermal Energy (Figure 10)*

Geothermal energy is the heat within the earth. This renewable source of energy could be used to heat or cool rest areas, offices, garages, rest areas, and other facilities, as well as to provide hot water at these facilities. These technologies are usually installed while constructing/renovating a facility. Although systems have higher capital costs than conventional HVAC systems, low operating costs lead to a reduction in utility bills with relatively short payback periods.

Geothermal energy uses heat from inside of the earth to generate clean, reliable, and local power. Geothermal power plants are often of modular design making them flexible and easy to expand as power demand increases. Geothermal reservoirs are formed when water is heated as it comes into contact with rocks heated by magma from the center of the earth. Currently power is generated when steam, heat, or hot water from these reservoirs provide force to spin turbines to produce energy.

Missouri does not have geothermal reservoirs with hot enough water close enough to the crust to generate geothermal power with current technology. Missouri does use geothermal heat pumps which do not produce energy directly, but greatly reduce the amount of energy required for heating and cooling. By placing a plumbing system under the ground, the thermal starting point for generating hot air in the summer and cool air in the winter is greatly decreased. This can reduce energy for heating and cooling by 30 to 60 percent.

The facilities located at the Missouri Department of Natural Resources' Division of Geology and Land Survey campus in Rolla, Missouri are the most energy efficient state-owned buildings. The installation of a ground source heat pump system, along with lighting and window replacements have reduced the Division of Geology and Land Survey's energy intensity for electricity by over 40%, and eliminated the use of natural gas.

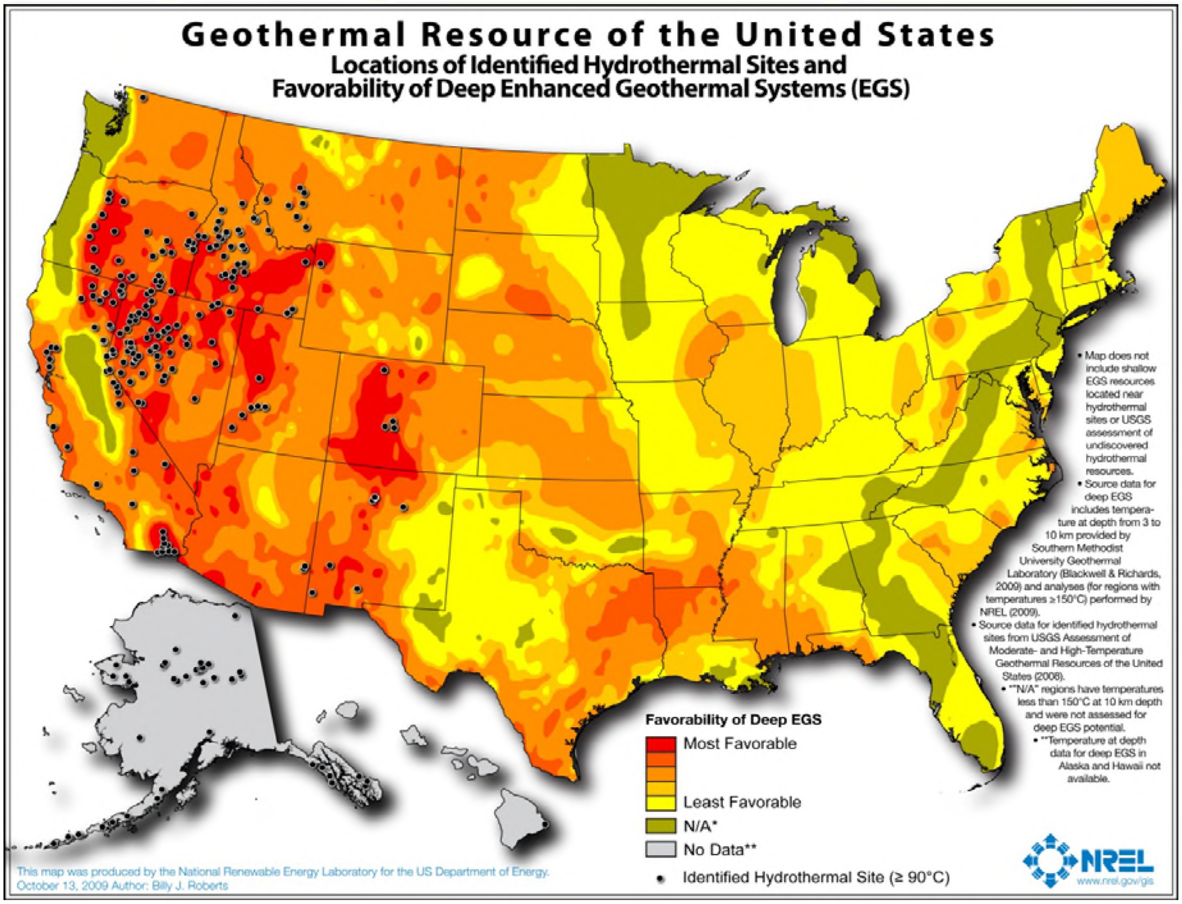


Figure 10. Geothermal Resources of the United States[5]

The Missouri Division of Geology and Land Survey has been funded by the Department of Energy to identify geothermal sources in Missouri to support a national database of geothermal information. Improvements in drilling technology may make geothermal power feasible in Missouri in the not too distant future. Much of the world, including Missouri has hot dry rock 3-6 miles below the earth's crust. These reservoirs have no water, but lots of heat. Experiments have been formed to pipe water into the deep hot rocks to create geothermal power. As deep well drilling technology improves geothermal energy and capturing the full potential of the earth's inner heat will be realized.

*Biomass Energy (Figure 11)*

Biomass is any plant or animal matter. Biomass fuel sources include wood, animal waste, biodiesel, and trash (paper from trees). Several Federal military installations have trash-to-heat operations in place, and wood pellet furnaces are being considered in projects in collaboration with the US Forest Service. Disposal of animal waste from large livestock operations generate a continuous biomass source and could be considered as a future fuel source for Missouri.

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[5] U.S. National Renewable Energy Laboratory, Dynamic Maps, GIS Data, & Analysis Tools, MapSearch Available at Internet: < http://www.nrel.gov/gis/images/geothermal_resource2009-final.jpg>

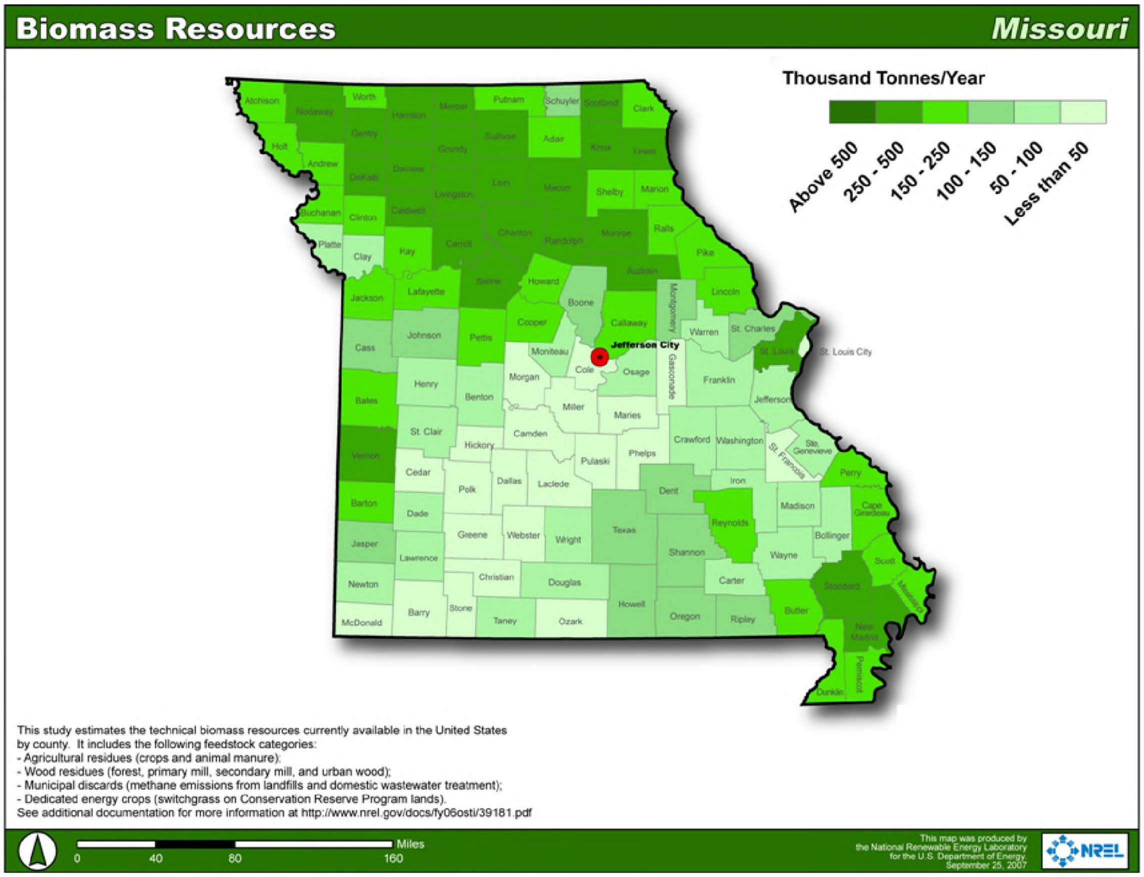



Figure 11. Missouri Biomass Resource[6]

*Hydrogen and Fuel Cells*

Fuel cells are gaining importance because of their efficiency, high reliability, low emissions, low noise, low vibrations, fuel flexibility, and combined heat and power capability. The project investigated the feasibility of using fuel cells to provide auxiliary (combined heat and power generation) and backup power at MoDOT facilities, as well as the use of fuel cells at remote MoDOT locations that need constant and reliable power. The project also examined infrastructure availability and benefits of using fuel cell powered forklifts, utility vehicles, and use of portable fuel cell products by MoDOT personnel. Analysis indicates that hydrogen and fuel cells are not likely a near-term solution.

*Alternative Fuel Vehicles*

Missouri statutes, Sections 414.400 - 414.417, set standards for economically and environmentally responsible state fleet management. The statutes seek to increase the average fuel efficiency of the state fleet and increase the use of cleaner alternative transportation fuels in state vehicles. Section

[6] U.S. National Renewable Energy Laboratory, Dynamic Maps, GIS Data, & Analysis Tools, MapSearch Available at Internet: < http://nreldev.nrel.gov/gis/images/eere_biomass/eere_biomass_missouri.jpg>

414.406 require that the annual state fleet report include the state's use of alternative fuels.

Per the Missouri State Fleet Efficiency and Alternative Fuel Program Annual Report for fiscal year 2009, MoDOT owned 233 E85 fleet vehicles, and 9 hybrid vehicles, which was the largest number of alternative fuel vehicles among the reporting state agencies. In order to expand the use of alternative fuel vehicles, it is critical that the alternative fuel infrastructure in Missouri can support these vehicles across the state.

Table 3 shows the number of alternative fuel infrastructure (fueling stations) in Missouri as indicated by U.S. DOE's Energy Efficiency & Renewable Energy alternative fuels & advanced vehicles data center.

Table 3. Alternative Fueling Stations in Missouri

| Type of alternative fuel | # of stations |
|---|---|
| Compressed Natural Gas | 9 |
| E85 | 97 |
| Propane | 76 |
| Electric Vehicle Charging | 1 |
| BioDiesel | 4 |
| Hydrogen | 1 |
| Total | 188 |

The electric vehicle charging infrastructure will be expanding in the Kansas City area, as Kansas City Power & Light installs 20 rapid charging stations in and around the "Green Impact Zone" under two separate Department of Energy grants. Missouri S&T in Rolla has also installed a rapid charging station on campus at the Renewable Energy Transit Depot off of University Avenue. This transit depot also includes the hydrogen fueling station identified in the above table.

MoDOT recently expanded the use of hybrid electric vehicles in the state of Missouri by assisting local public transit agencies in Poplar Bluff and Warrensburg in purchasing a hybrid electric shuttle bus for their current transit services. As plug-in electric and hybrid electric vehicles become more affordable and available, MoDOT should consider integrating these vehicles into their fleet and transit operations, especially in those areas where rapid charging will be available.

### 3.2 Applications

Potential applications include, but are not limited to, traffic control and safety devices (e.g., traffic signals, roadway and intersection lighting), intelligent transportation system equipment (e.g., dynamic message signs and CCTV cameras), and MoDOT facilities (e.g., fleet vehicles, power generation, and heating and cooling systems). Additional potential applications include data storage, specialty vehicles, and communications systems.

An initial listing of potential MoDOT alternative energy applications was generated for further investigation. These applications include:

- Rest areas: small-scale, energy efficient waste processing systems and solar PV arrays,
- Night construction work: hydrogen fuel cell lighting,
- Northwestern MoDOT Facilities: use of architectural wind turbines,
- MoDOT light truck/car vehicle fleet: electric vehicles and other alternative fuel vehicles,
- Compost in median, right of way,
- LEED construction of new and retrofit facilities, and
- Building energy management.

Paragon Business Solutions, Inc. (Paragon) assisted with identifying alternative energy opportunities for MoDOT facilities by analyzing MoDOT energy usage data, comparing MoDOT's building energy usage per square foot to the national average, evaluating options and potential solutions for energy efficiencies that reduce consumption per square foot, and recommending alternative energy projects that could be used by MoDOT to increase its use of alternative energy sources, decreasing its energy usage and costs per square foot and reducing its overall carbon footprint. In making recommendations, Paragon evaluated the successes of other public agencies reducing energy usage as a result of Executive Orders 13423 and 13514. Alternative energy project opportunities utilizing clean and sustainable energy derived from solar, wind, geothermal, nuclear, hydrogen, and natural gas were explored.

Executive Order 13514 (EO 13514) was issued October 5, 2010 by President Obama. The goal of EO 13514 is to "establish an integrated strategy towards sustainability in the Federal Government and to make reduction of greenhouse gas emissions a priority for Federal agencies". EO 13514 sets numerous Federal requirements directly and indirectly related to energy efficiency and greenhouse gas management. Compliance with EO 13514 is not just a Federal agency issue; it is expected to impact those working with Federal agencies, by changing the way Federal agencies do business with their internal and external partners, and by providing strong motivation for all organizations to adopt sustainability measures.

## 4.0 Recommendations for Alternative Energy Projects

The initial listing of potential MoDOT alternative energy applications was narrowed based on previous experience with current/past projects funded by MoDOT, and others. Four main source/applications combinations were the focus of the economic analysis:

1. Baffled Bio-Reactors for Wastewater Treatment,
2. LED Roadway Lighting,
3. Miscellaneous Energy Savings Projects, and
4. Solar/Wind Installation for Miscellaneous Facilities.

### 4.1 Baffled Bio-Reactors for Wastewater Treatment

The Baffled Bioreactor (BBR) technology, based on US Patent #6,787,035 is an advanced wastewater treatment system. It employs a group of uniquely arranged baffles that separate the unit into several functional zones: an anoxic chamber for denitrification; an aeration zone for organic matter oxidation and nitrification; an internal settler for concentrating and returning biomass; and a final clarifier for removing solids from treated effluent (see Figure 12 for flow pattern, shown with arrows). The key component in the BBR, the internal settler, settles and returns biomass back to the aeration zone automatically without a return pump. Therefore, the unit requires only one influent pump, one air blower, and 3 timer-controlled valves (to control sludge discharge) to be functional. The implication of this simple system is a significant amount of energy and maintenance needs, normally used in other treatment processes for sludge return or backwashing, is virtually eliminated. After treatment, the effluent of the BBR unit can be discharged to a nearby creek or stored in a pond to possibly be reused for non-potable, non-contact applications such as watering, irrigation, toilet flushing, etc.

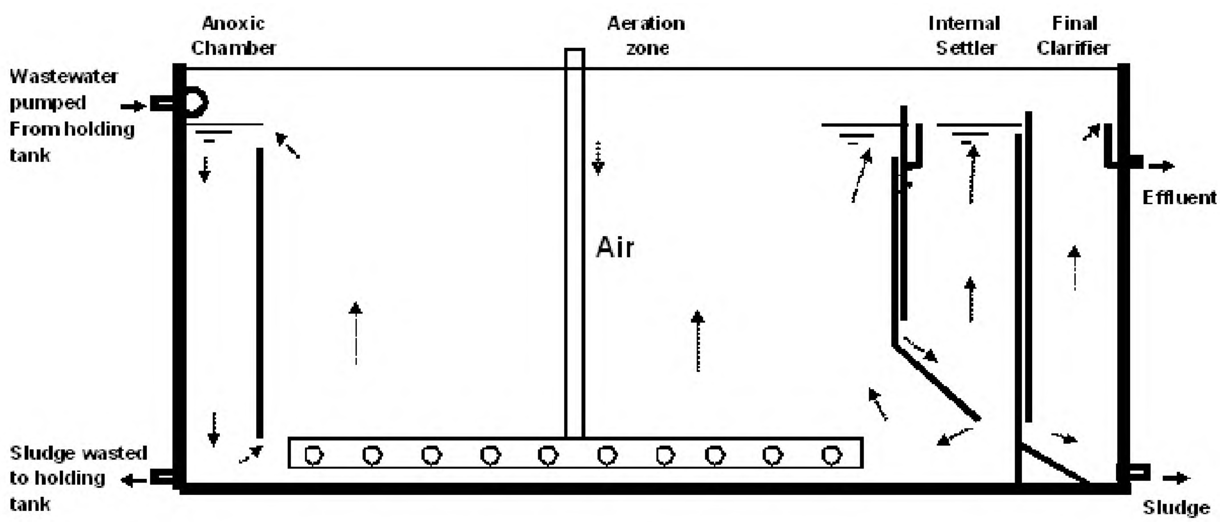



Figure 12. Innovative BBR working principle

This innovative BBR technology has many advantages over conventional activated sludge processes and other technologies normally used for wastewater treatment: (i) it has a very small footprint (less than 50% of the size of conventional activated sludge processes, and 5% of the size of regular on-site treatment systems such as recirculating sand filters); (ii) it uses off-the-shelf, low-tech parts, and thus is easy to maintain and repair; (iii) the moving parts are limited to one influent pump, one air blower, and three timer-controlled solenoid valves (for sludge wasting) located in the easily accessible utility chamber, and one retrievable mixer located within the tank; (iv) it can achieve an advanced level of treatment, and the effluent can be directly used for non-contact applications; (v) it is plug & play and requires almost no operational knowledge for success; (vi) the total power requirement for a unit serving 100 people is estimated to be 3 kW, which means that it consumes very little energy to operate compared to other comparable technologies; and (vii) it has a unique maintenance-mode function, i.e., when there is no influent pumping to the unit, the unit will automatically switch to a stand-by mode, using only 10% of the energy to sustain the activity of the biomass. This further reduces the energy use for wastewater treatment.

**4.2 LED Roadway Lighting**

Over the last two decades light-emitting diodes (LEDs) have replaced incandescent bulbs in traffic signals use because of their energy saving and much longer service life (Urbanik, 2008). Energy savings can be as high as 93% and service life can reach 10 years or more, however, initial costs are higher than traditional incandescent bulbs. Two investigators (Drs. Long and Qin) from this project were part of a concurrent project with MoDOT (TRyy1001) to develop useful life replacement strategies for LED traffic signals based on a comprehensive, life-cycle approach. Their findings are available as part of the final report for TRyy1001.

Based on study results, we feel that solar-powered LED traffic signals are a reliable, efficient, and environmentally friendly means of traffic management; however energy consumption reductions are minimal and highly dependent on the initial investment used in converting to solar-powered systems. Three main scenarios result from an analysis of current energy consumption patterns for existing LED traffic signals in Missouri.

(1) If the initial investment of solar powered LED is just 10% higher than the grid powered LED and maintenance is 100% higher, the payback period can be as high as 20 years.

(2) If the initial investment of solar powered LED is just 10% higher than the grid powered LED and maintenance keeps the same, the payback period is about 4 years.

(3) if the initial investment of solar powered LED is 50% higher than the grid powered LED and maintenance is the same, the payback period can be 19 years.

A case study on Missouri LED traffic signals is provided in Appendix B. The Appendix B case study evaluates solar-powered LED traffic indicators and demonstrates payback periods, operations and maintenance cost comparisons. A cost-benefit analysis, including payback periods, for solar-powered LED Dynamic Message Signs, and CCTVs reveals limited energy savings. Although there might be limited environmental benefits, or increased goodwill generated with the citizens of Missouri as a result of additional uses of renewable energy sources, the energy consumption levels and associated energy levels will not be altered through the conversion of DMS and CCTV to solar-powered systems.

Our findings suggest that further evaluation of LED roadway luminaires over high pressure sodium (HPS) luminaires for intersection and highway applications may provide opportunities for additional energy and environmental efficiencies. Conventional street lamps last 3-5 years and require high manpower and maintenance costs for lamp replacement. Energy efficient street lights have a higher initial cost than traditional lighting applications, but use less energy and last longer, thus resulting in significant energy and maintenance savings. Many cities and DOTs are currently converting to LED streetlights. Solar-powered LED street lamps provide a value-added mechanism for recouping installation costs at a reduced pay-back period. To date, LED street lamps do not possess the lumen output of traditional lighting and some studies suggest that the output is distracting for some drivers. A careful cost-benefit, as well as cost-utility, analysis should be conducted prior to wide-scale adoption of LED street lamps for use by MoDOT. An investigator (Dr. Long) from this project (along with Dr. Qin) will lead a team recently selected to perform this analysis. Findings from this study will be available as part of the final report for TRyy1101 in September 2011.

### 4.3 Miscellaneous Energy Savings Projects

Energy efficiency is the primary focus of most of the energy reduction work occurring at Federal Facilities. The first step in reducing energy consumption and identifying inefficiencies is to conduct an evaluation of the current buildings, systems, and practices and to quantify energy usage. Commonly, the three main areas where buildings use the most energy are heating, ventilation and air-conditioning systems, lighting systems, and the loss of energy through the building shell. The type of equipment used in the building also contributes to energy use.

Reductions in energy consumption can be achieved by reducing the number of facilities and the overall square footage of facilities within an organization. Activities occurring in underutilized buildings are consolidated into the most efficient buildings and surplus buildings are demolished or maintained in a "mothballed" status thus reducing energy requirements. Energy intensity, a key metric at Federal Facilities, is energy use divided by the square footage of facilities.

#### *4.3.1 Heating Ventilation and Air-Conditioning (HVAC)*

Preventive/Predictive/Reliability maintenance of HVAC systems can have a significant impact on a facility's energy efficiency. Efficiency measures can be achieved by establishing a process for ensuring routine HVAC maintenance, evaluation, and repair activities are carried out and data is provided to top management regularly.

Effective routine maintenance activities that will greatly improve a system's efficiency include:

- replacing and/or cleaning air filters regularly,
- cleaning all heat exchanger surfaces, condensers, evaporators, and water and refrigerator coils, and
- regularly reviewing systems for leaks in piping, coils, fittings, and air ducts, and repairing leaks when needed.

It should also be noted that refrigerants have extremely high global warming potential, from 140-11,700 times that of carbon dioxide. Repairing leaks as soon as possible will minimize greenhouse gas emissions. In addition, the systems insulation should be maintained to ensure it is performing as required.

Replacing older boilers, chillers, and air conditioning units with new, more energy efficient equipment can have an immediate impact on the energy efficiency of a building. When a new unit is selected, an organization should ensure it is sized correctly for the occupancy needs and building load characteristics of the facility, and include performance requirements and commissioning requirements in the contract for this equipment. The organization should also ensure the contractor is able to identify efficiencies and prove them after installation.

*4.3.2 Lighting*

According to the United States Green Building Council, lighting accounts for 40% of electricity use in offices and other commercial buildings. This energy is often wasted resulting in higher energy costs and increased greenhouse gas emissions for the organization. Some changes in lighting use can be impacted with behavioral awareness. The practice of turning off lights in places where they are not in use can become part of the culture of an organization and result in energy savings. Many organizations have installed light sensors to ensure lights are only on when there are people occupying an area. Maximizing the use of natural light and desk lighting are other methods used by Federal Facilities to control energy use from lighting.

There have been dramatic improvements in energy efficiency of commercial lighting in the last few years. Typical office fluorescent lighting fixtures, which include 2 magnetic ballasts and 4 fluorescent lamps, are being replaced with electronic ballasts and smaller diameter tubes. This reduces the watts of power from approximately 170 watts to 115 watts which, if implemented office-wide, can result in considerable savings. In addition, some Federal facilities are adding special reflectors to optimize the light distribution, which results in a 50% reduction of the number of lamps needed in each ballast. The change in the type of lamps used and the addition of reflectors to optimize distribution can lead to energy savings of almost 70% if implemented together. There are additional benefits to this improved practice. The more efficient fluorescent tubes produce a more natural light and reduce glare resulting in less eye strain for persons working in these facilities, which in turn results in higher productivity and a better work environment.

The latest technology in lighting is Light Emitting Diodes (LED) lamps. LED was originally for single bulb use (such as Christmas tree lights); however manufactures are now clustering several of these bulbs into a one bulb type use. The benefits of LED lights include a much longer life, contain no mercury, and produce less heat than fluorescent bulbs. The drawback has been the cost of LED lights. There is currently research underway which is very promising in reducing this cost. LEDs are currently used primarily in parking areas and for signage at Federal facilities.

*4.3.3 Windows*

Windows can have a significant impact on a facility's energy use by reducing the heating and cooling load required by the HVAC system and providing natural light to offset lighting use. Window replacement can be expensive; however the energy savings can be substantial. Window designs have changed dramatically due to the renewed focus on energy efficiency. The high-performance, energy-efficient window and glazing systems now available on the market can dramatically cut energy consumption due to lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. These high-performance window systems feature double or triple glazing specialized transparent coatings, insulating gas sandwiched between panes, and improved frames. All of these features reduce heat transfer, and cut the energy lost through windows. The Missouri Department of Natural Resources' Division of Geology and Land Survey office recently made significant efforts to improve energy efficiency at their campus in Rolla, Missouri. Joe Gillman, State Geologist and Geology and Land Survey Director, believes a major factor in making their facility the most energy efficient state-owned building was the replacement of windows to Low-E windows, which suppress radiant heat while allowing visible light to pass through, increasing energy efficiency.

#### *4.3.4 Energy Management System*

To manage energy effectively, it is necessary to understand not just how much energy is used, but where and when it is used. Federal facilities, especially those with vendor-funded energy programs, are starting to install completely automated energy management systems. These systems are active systems which control the variable speed motors, fans, occupancy sensors, automatic dimming devices and other controls that ensure efficient energy use. These systems also prompt maintenance and filter changes and diagnose malfunctions.

#### *4.3.5 Re-Commissioning and Continuous-Commissioning*

Commissioning ensures that a facility performs according to its design and the needs of its occupants. The commissioning process is an important aspect to Federal energy management for both new and existing facilities. However, commissioning is rarely performed to the level needed for success. And as a result, systems degrade quickly as well as the overall efficiency and cost-effectiveness of the facility.

Many Federal buildings were either never commissioned, or were commissioned long ago and the occupancy and building use have changed since that time. Re-commissioning involves testing and adjusting building systems to meet original design intent and/or optimize systems to satisfy current operational needs. The Department of Defense is currently researching the cost-benefit analysis of Continuous Commissioning. Continuous commissioning schedules commissioning activities on a regular basis as part of the maintenance plan. Continuous commissioning is costly, but allows for the maximum energy efficiency because it identifies inefficiencies as they occur.

### 4.4 Solar/Wind Installation for Miscellaneous Facilities

Use of alternative energy sources such as wind and solar energy can reduce energy cost while providing clean and renewable power. Recognizing the benefits of solar and wind energy systems, MoDOT is installing solar and wind energy systems at various facilities. Completed projects include solar and wind energy projects at the St. Clair maintenance facility, Conway Welcome Center, and MoDOT District Office in Joplin. The St. Clair maintenance facility has 48 solar warm air collectors for space heating and two solar hot water systems for truck washing equipment and domestic hot water. This project is assumed to lower the heating and hot water cost at the facility significantly. The Conway Welcome Center has two 1.2 kW wind turbines, one in each travel direction powering the lights over the information counters. The solar panel installation at the MoDOT District Office in Joplin consists of a 16.5 kW solar panel system. The roof-mount, grid-tied system installed in February, 2010 is capable of selling power back to the utility company and potentially generate revenue for MoDOT.

MoDOT facilities including offices, maintenance buildings, storage, etc can have reliable power and stand-alone capability if wind and solar energy systems are integrated with an energy storage system (batteries). Maintenance facilities with low energy consumption (less than 1,000 kWh per month) provide an excellent candidate for installation of standalone solar panel system with battery storage. Facilities with medium energy consumption (1,000 kWh -5,000 kWh per month) should explore combined solar and wind energy systems for reducing its energy cost. To power facilities with more than 5,000 kWh per month demand, MoDOT should investigate buying solar or wind energy from centralized production facilities. Since wind velocity is highly dependent on the location, it is advisable to do a preliminary wind study or obtain wind speed data at the proposed location before installing a wind turbine to explore its feasibility.

## 5.0 Cost-Effectiveness and Financial Feasibility Analysis

Energy availability has become a limiting factor of sustainable development (Kruger, 2006). Traditional energy use is unsustainable (Twidell and Weir, 2006). Strategies for implementing alternative energy are drawing wide attention. Huge investments have been and will be continuously made to promote energy efficiency and the use of renewable energy; therefore, a thorough economic analysis would be needed to justify the investments.

Even if a project is technically feasible, there is no guarantee that it is cost-effective. A cost-effectiveness analysis (CEA) provides the reference for strategy selections by considering both effects and costs of each strategy (Brigham and Ehrharht, 2007). CEA is a method designed to rate or rank projects or strategies on the basis of their costs and effectiveness. CEA is especially useful for cases where incurred effects can be measured, but not in monetary units. For example, emission reduction is such an effect (United States Environmental Protection Agency, 2007). Many researchers have used CEA as a tool of economic evaluation for public projects, including healthcare strategies, policies, and programs (Shiell, 1998; Griekspoor et al., 1999; Jusot and Colin, 2001; Hoel, 2006; Anonychuk et al., 2008; Severens, 2008), and for water management, treatment, and conservation (Platt and Delforge, 2001; Jin and Englande, 2008; Aulong et al., 2009), as well as pavement projects (Singh et al., 2007).

CEA is an appropriate approach to evaluate energy strategies because many effects of these strategies cannot be measured in monetary units, but can be expressed by effectiveness. State agencies are usually the early adopters of alternative energy. The cost-effectiveness of energy efficiency has been studied from various aspects (Grobler and Heijer, 2001; Gaterell and McEvoy, 2005; Markandya, et al., 2009; Kneifel, 2010). Research on CEA applications to alternative energy has addressed the cost-effectiveness of energy policies (Naill et al., 1992; Iliopoulos and Rozakis, 2010) and studied specific cases, for example, the cost-effectiveness of alternative fuels for school buses (Cohen, 2005). However, relatively few studies have performed a complete and systematic CEA for applying major types of alternative energy.

A CEA framework is developed to systematically assess alternative energy strategies as following. The CEA framework to be developed in this part specifies costs and effects associated with five representative sources of alternative energy: solar, wind, geothermal, biomass and alternative energy vehicles. A case study (located at Rolla, Missouri) is included in this paper to illustrate the entire process in which a decision-maker defines a problem, collects information, and performs the analysis. The CEA framework provides MoDOT with a systematic guideline to evaluate the economic facet of the project. It also serves as a guideline to data collection for further investigation.

### 5.1 The CEA Framework

CEA measures the incurred effectiveness per unit cost (the E/C ratio), or the required cost per level of effectiveness (the C/E ratio). If a decision-maker would like to use the maximum effectiveness per unit cost as the criterion for strategy selection, the E/C ratio is calculated. If the least cost per level of effectiveness is the selection criterion, then the C/E ratio is used.

In CEA, costs and effectiveness are always measured incrementally. Let $A_1$ denote the strategy to be studied, and $A_0$ be the base representing the original strategy in use before applying $A_1$. Then, the E/C ratio for the $i^{th}$ effect that is associated with the substitution of $A_0$ with $A_1$ is calculated as

$$E^i / C = (E^i_{A1} - E^i_{A0})/(C_{A1} - C_{A0}) \quad \text{For any i}^{\text{th}} \text{ effect} \quad (1)$$

Similarly, the C/E ratio is

$$C / E^i = (C_{A1} - C_{A0}) \quad /(E^i_{A1} - E^i_{A0}) \quad \text{For any i}^{\text{th}} \text{ effect} \quad (2)$$

To provide the information in Equation (1) or (2) for decision makers, an assessment of any incurred effectiveness, and an estimate of associated costs, are required. Therefore, two hierarchical structures constitute the CEA framework: an effect structure and a cost structure. The effect structure identifies the primary effects of five representative alternative energy types and classifies the effects as categories (and subcategories if needed), while the cost structure lists cost components and establishes their relationship based on a study of representative facilities that can be operated by alternative energy.

*Hierarchical Structure of Effects*

Table 4 shows the hierarchical structure that summarizes major effects of using solar, wind, geothermal, biomass, and hydrogen fuel cell energy. These effects are identified through an extensive review of literature. We find that effects of alternative energy uses are mainly focused on three aspects:

environmental impacts, social impacts, and economic impacts. Some of the effects are positive (i.e., favorable) from the viewpoint of users, and they are indicated as "P"; the others are negative (unfavorable) and are indicated by "N". The implementation of an alternative energy strategy could produce an effect in two distinct directions, and so we use a "+" sign to indicate the effectiveness is supported or confirmed and a "-" sign to indicate the opposite. For example, the hierarchical structure of effects shows the use of wind power reduces green house gas (GHG) emissions and air pollutions, yet increases land use, kills more birds and bats, and produces more noises.

*Hierarchical Structure of Costs*

Figure 13 is the general cost structure developed in a bottom-up approach (Sullivan et al., 2008). It defines major cost components and their relationship. From a view of project life cycle, the overall cost is first broken down as initial capital investments, operating and maintenance (O&M) costs, and final recycling and disposal costs. The capital investments are further classified as the investments in physical assets, personnel, and others (e.g., available financing and incentives, such as federal and state taxes or property taxes, have impact on costs). Frequency is a critical factor for classifying components of O&M costs. Costs for an unplanned activity are likely to be higher than for a planned recurring activity. Therefore, we differentiate emergency/unplanned activities from regular/planned activities.

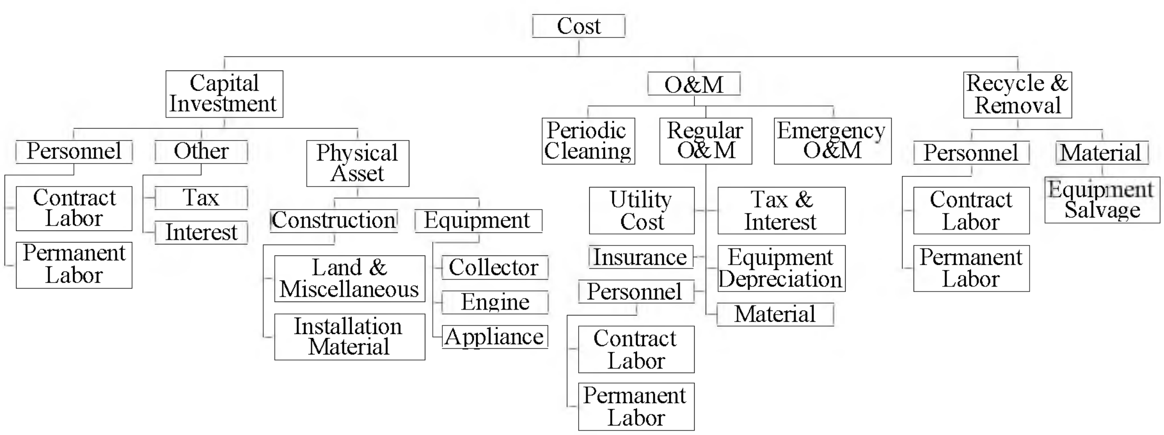



Figure 13. General Cost Structure (Level 1)

Table 4. The Hierarchical Structure of Effects

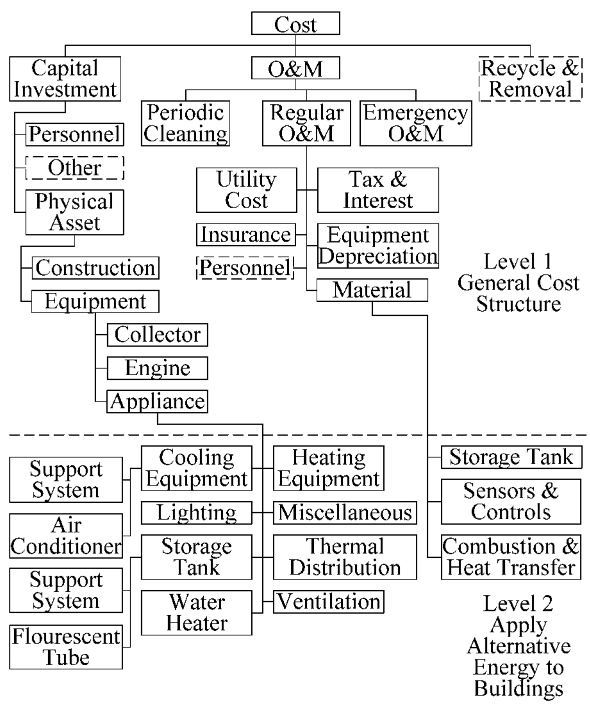
| | | | Solar | Wind | Geothermal | Biomass | Hydrogen |
|---|---|---|---|---|---|---|---|
| Environmental impacts | P | Reduced water pollutions | – | | +,– | | |
| | | Reduced GHGs emissions | + | | + | + | + |
| | | Nitrous oxide emission | | + | | | |
| | | Sulfur dioxide emission | | | + | | + |
| | | Carbon dioxide emission | + | | | + | + |
| | | Reduced air pollutions | | + | + | + | + |
| | | Reduced precipitation | | | | + | |
| | | Land | | | | | |
| | | Reduced land use | – | – | + | | |
| | | Reduced land subsidence | | | + | | |
| | | Reduced ecosystem disturbance | – | – | – | – | |
| | | Increase good by-products | | | + | + | |
| | N | Land | | | | | |
| | | Induced seismicity | | | + | | |
| | | Induced landslides | | | + | | |
| | | Increased bird and bat kills | | + | | | |
| | | Increased noise | | + | – | | |
| | | Increased bad by-products | + | | + | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Social impacts | P | Technology | | | | | |
| | | Increased energy safety | + | | + | | +,– |
| | | Increased sustainability | | | + | + | + |
| | | Increased independency | + | + | | + | + |
| | | Public | | | | | |
| | | Increased public health | – | – | | | |
| | | Increased national security | + | | | + | – |
| | | Increased job opportunity | + | + | | + | |
| | | Increased farm income | | | | + | |
| | N | Increase Visual Intrusion | + | | | | |
| Economic impacts | P | Costs/Savings | | | | | |
| | | Increased tax credit & interest | + | + | – | + | |
| | | Reduced energy costs | +,– | + | – | – | |
| | | Increased market capacity [e] | + | + | + | + | |
| | | Increased compatibility with existing infrastructure | | + | + | +,– | |
| | | Efficiency | | | | | |
| | | Increased energy efficiency | + | + | + | +,– | + |
| | | Reduced installation lead time | – | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Increase initial investment | | | + | | | |

Notes: 1. Some of the effects are positive (i.e., favorable) from the viewpoint of users, and they are indicated as "P"; the others are negative (unfavorable) and are indicated by "N".
2. "+" sign indicates the effectiveness is supported or confirmed and "-" sign indicates the opposite.

Figure 14 shows that when the application of alternative energy strategies is determined, the general cost structure must be modified and further expanded to the next level (level 2) to obtain a more adaptive plan of cost estimate. For example, in the application of alternative energy to buildings, we need to specify the "appliance" under the "physical assets" by detailing related cost components such as ventilation and thermal distribution, heat pumps, cooling equipments and water heaters. Similarly, if alternative energy is applied to an intelligent traffic system (ITS) or a traffic control device (TCD), cost ingredients, such as a close-circuit television (CCTV) cameras and energy storage tank, should be specified.




Notes: Dashed boxes represent cost components that will not be considered for this object.

Figure 14. A Hierarchical Cost Structure for Buildings (Level 2)

To obtain an accurate estimate of the equipment investment, the cost structure still needs to be further detailed for specific alternative energy strategies (level 3), because some costs differ by energy types. That is, costs associated with the use of an alternative energy may depend on the climate, energy demand, and local energy market. For example, a detailed cost structure of installing a solar water heater system in a building can be developed based on the two-level cost structure. The three-level cost structure would further specify the cost components that must be precisely estimated for a solar energy system, such as the costs of the collector, receiver, and engine of water heater. After the installation of a solar water heater in a building, day-to-day operation and maintenance activities, like glazing and sealing the collector, and wiring connection, incur more costs, which would be exhibited in level 3. Figure 15 shows these costs are all affected by the amount of hot water in demand, the geographic location, and the availability of solar resources.

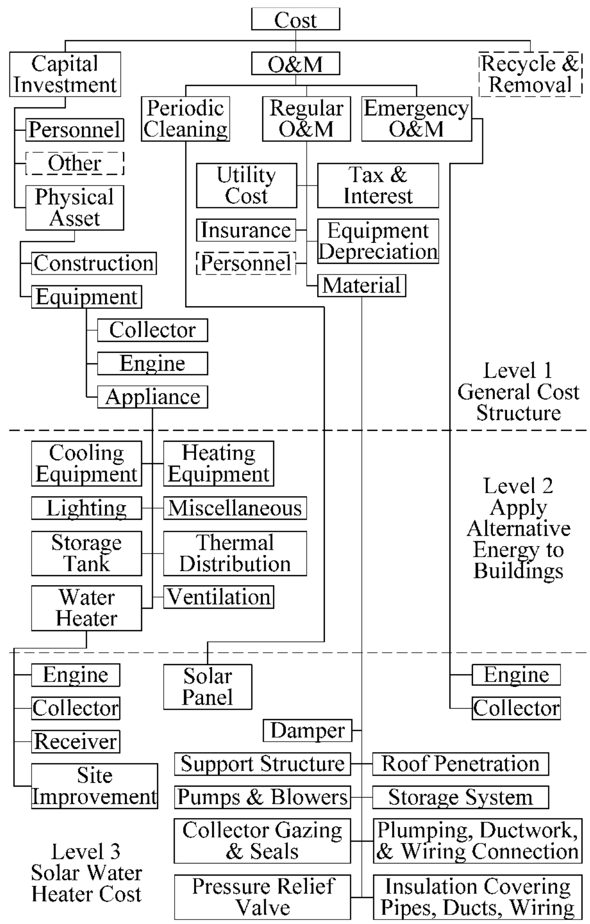



Figure 15. Hierarchical Cost Structure for Installing a Water Heater in a Building (Level 3)

The CEA framework developed in this paper is highly adaptive, allowing the decision-maker or engineering manager to generate assessment reports for a variety of alternative energy research and practice, for example, the selection of an alternative energy strategy among competitive proposals for projects; or the identification of the best application of an alternative energy type.

### 5.2 Case Studies

A study of a renewable energy demonstration project is presented in this paper to illustrate ways in which the developed framework facilitates the entire CEA process.

*4.2.1 Missouri Highway Patrol Headquarters Case*

A demonstration project located at the Troop I Highway Patrol Headquarters in Rolla, Missouri is designed to show the application of renewable energy systems has potential to reduce the State's energy bills. The project is also intended to facilitate the development of outreach activities for pre-college students, university students, and the general public. The project involves a hybrid wind/photovoltaic (PV) system, which is composed of a wind turbine, a weather station, and a PV system. The detail application process is presented in Appendix C.

#### *4.2.2 Rockport Welcome Center Case*

Rest areas as part of the Interstate Highway System provide safety and convenience to travelers. Their service includes providing parking spaces, eatery, local landscapes and comfort facilities. The Rockport Rest Area is located on southbound I-29, in Atchison County, Missouri. To reduce the energy cost and make this rest area more attractive, MoDOT plans to redevelop the Rockport Rest Area into a modern welcome center which will utilize some alternative energy.

In this study, utility use of the Rockport Rest Area is analyzed. The energy use of Rockport Welcome Center (after reconstruction) is estimated. Several alternative energy implementation strategies are applied virtually. Cost associated with these strategies is analyzed as well. This study also compares different models of energy device in the market and a final recommendation is provided. The results show a hybrid system with wind energy as the main power and solar energy as the backup is feasible in this case. A ground source heat pump system for heating/cooling is also recommended. For detailed case study report, please see Appendix D.

### 5.3 Implementation

CEA is especially useful for assessing sustainability strategies from an economic viewpoint. This is because many effects of the strategies can be measured, but not in monetary units. The CEA method is simple; however, performing CEA is complex, particularly for alternative energy strategies. When performing CEA for alternative energy strategies, managers have to make many assumptions to control the variables.

The CEA framework provides major effects, and associated costs, of alternative energy uses. On the basis of the framework development, case studies show how the framework facilitates the entire CEA process, including defining a problem, collecting information, assessing effectiveness, estimating costs, deriving C/E or E/C ratios, and performing the analysis. This framework is not only an information source but also a decision-making tool that will aid engineering managers in implementing cost-effective projects in the field of energy and sustainability. Therefore, it allows users to perform a thorough assessment of sustainability strategies in a systematic approach and make recommendations. The framework builds a foundation for advanced economic and financial studies related to sustainability strategies related to financial feasibility assessment, financial sensitivity analysis, energy risk management, and energy portfolio strategies.

To further illustrate the application of CEA framework, a CEA calculation model for the LED traffic signals is exhibited in Table 5. In this case, the grid-powered LED and the solar-powered LED are chosen as challengers, and the traditional traffic lights are identified as defenders (base case). The first step is collecting relevant data for the LED case. In this case, a 10-year study period and a 3.92% discounting rate are assumed. The second part is to estimate the annual energy consumption for base case and challengers. The difference of energy consumption between the LEDs and conventional traffic lights is the annual energy savings in the following step. The next step is to project the net annual cash flows based on discounted annual cost and annual savings. The simple payback period and net present value (NPV) are the key outputs in cost analysis. Combining the cost results with the effect data, the E/C ratio is generated.

Table 5 CEA Calculation Model for LED Case

**Step 1. Cost Estimation**

*Part 1. Input Data*

| | | | |
|---|---|---|---|
| Electricity cost ($/yr) | 0.10 | Time horizon (yr) | 10 |
| Hours/yr | 8,640 | Discounting Rate | 3.92% |
| Unit Wattage of con. light (kW) | 0.150 | $CO_2$ production (lbs/kWh) | 0.000685 |
| Total No. of LED lights | 155,200 | | |

*Part 2. Annual Energy Consumption Estimation*

Conventional Traffic Lights

| Color | Red | Yellow | Green |
|---|---|---|---|
| Cycle time | 50% | 6% | 44% |
| Working time/year | 4,320 | 518 | 3,802 |
| No. of lights | 58,200 | 38,800 | 58,200 |
| Annual Consumption | 37,713,600 | 3,017,088 | 33,187,968 |
| Total Annual Consumption (kWh) | 73,918,656 | | |
| Annual Electricity Cost ($) | 7,391,866 | | |

Grid-powered LED Traffic signals

| Color | Red | Yellow | Green |
|---|---|---|---|
| Cycle time | 50% | 6% | 44% |
| Working Time/year | 4,320 | 518 | 3,802 |
| No.of Lights | 58,200 | 38,800 | 58,200 |
| Unit Wattage of LED (kW) | 0.0105 | 0.0135 | 0.0105 |
| Unit price ($, including labor fee) | 100 | 145 | 145 |
| Annual Consumption (kWh) | 2,639,952 | 271,538 | 2,323,158 |
| Total Annual Consumption(kWh) | 5,234,648 | | |
| Annual Electricity Cost($) | 523,465 | | |

*Part 3. Projected Net Cash flows*

| LED Type | Grid-powered LED | Solar-powered LED |
|---|---|---|
| Total Initial Cost ($) | 19,885,000 | 29,827,500 |
| Annual Cost ($) | 2,441,886 | 3,662,830 |
| Annual O&M Savings ($) | 853,600 | 426,800 |
| Annual Energy Savings ($) | 6,868,401 | 7,391,866 |
| Total Annual Savings ($) | 7,722,001 | 7,818,666 |
| Net Annual Cash Flow ($) | 5,280,114 | 4,155,836 |

*Part 4. Key Output*

| | | |
|---|---|---|
| Simple Payback Period (yr) | 2.58 | 3.81 |
| NPV ($) | 23,112,524 | 4,014,694 |

**Step 2. Effect Data**

| | | |
|---|---|---|
| Annual $CO_2$ Reduction (lbs) | 47,049 | 50,634 |

**Step 3. E/C Ratio**

| | | |
|---|---|---|
| $CO_2$ Emission Reduction (lbs/$) | 0.02 | 0.01 |

Note: blue cell: input data, yellow cell: final calculated result.

A spreadsheet for calculating both simple payback period and discounted payback period of different alternatives was developed and is in Table 6. This table can be used for determining the payback period and verifying economic feasibility of the project.

Table 6. Calculation model for 15 year simple payback period and discounted payback period

**Inputs**

Project cost of capital= 10%
fill in the cells with net cash flows

**Outputs**
simple payback period= 2.33
discounted payback period= 2.95

**Cash Flow Table**

| | | For simple payback period | | For discounted payback period | | |
|---|---|---|---|---|---|---|
| Year | Net Cash Flow | Cumulative cash flow | Percentage of year required for payback | Discounted cash flows | Cumulative discounted cash flow | Percentage of year required for payback |
| 0 | $ (1,000,000) | $ (1,000,000) | | $ (1,000,000) | $(1,000,000) | |
| 1 | $ 500,000 | $ (500,000) | 1.00 | $ 454,545 | $ (545,455) | 1.00 |
| 2 | $ 400,000 | $ (100,000) | 1.00 | $ 330,579 | $ (214,876) | 1.00 |
| 3 | $ 300,000 | $ 200,000 | 0.33 | $ 225,394 | $ 10,518 | 0.95 |
| 4 | $ 100,000 | $ 300,000 | 0.00 | $ 68,301 | $ 78,820 | 0.00 |
| 5 | $ 100,000 | $ 400,000 | 0.00 | $ 62,092 | $ 140,912 | 0.00 |
| 6 | $ 50,000 | $ 450,000 | 0.00 | $ 28,224 | $ 169,136 | 0.00 |
| 7 | $ 50,000 | $ 500,000 | 0.00 | $ 25,658 | $ 194,793 | 0.00 |
| 8 | $ 100,000 | $ 600,000 | 0.00 | $ 46,651 | $ 241,444 | 0.00 |
| 9 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 10 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 11 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 12 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 13 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 14 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |
| 15 | $ - | $ 600,000 | 0.00 | $ - | $ 241,444 | 0.00 |

The simple payback period and estimated lifecycle for each alternative energy option are compared in Tables 7 and 8, respectively. The payback period data is collected from different cases. It is important to note that payback period is sensitive to tax credits, government incentives and energy availability, as well as the development of alternative energy technology.

Table 7 Payback Period: Comparing for Each Alternative Energy Option

<table>
<tr><th>Options</th><th>General Payback Period (years)</th><th>Payback Period for Missouri (years)*</th></tr>
<tr><td>Rooftop PV Systems</td><td>5</td><td rowspan="3">>15</td></tr>
<tr><td>    Multicrystal-Line-Silicon PV Modules</td><td>4</td></tr>
<tr><td>    Thin-Film Modules</td><td>3</td></tr>
<tr><td>Small Wind Systems</td><td>6~30</td><td rowspan="4">> 30</td></tr>
<tr><td>    California</td><td>7~35</td></tr>
<tr><td>    Minnesota</td><td>9~45</td></tr>
<tr><td>    South Dakota</td><td>23~40</td></tr>
<tr><td>Geothermal Heat Pump (GHG)</td><td>2-10</td><td>5</td></tr>
<tr><td>Biomass</td><td>< 20</td><td rowspan="3">5-10</td></tr>
<tr><td>    Darby Public schools (Montana)</td><td>7</td></tr>
<tr><td>    Middlebury College</td><td>11</td></tr>
<tr><td>Hydrogen & Fuel Cell<br>(at initial cost $950/kWh)</td><td>5</td><td>5</td></tr>
<tr><td>Lighting (incandescent lamps to CFL)</td><td>< 1</td><td>0.5</td></tr>
</table>

*The payback periods for solar and wind systems were calculated based on the actual energy production from the solar panel and wind turbine installation at the Missouri Troop I Headquarters Rolla, Missouri. It was assumed that no incentives or rebates were applied for systems and the energy rate is 8 cents/kWh. The payback period will decrease significantly if incentives or rebates are applied.

Table 8 Expected Lifecycle for Each Alternative Energy Option

| | Estimated Life Cycle (years) |
|---|---|
| Photovoltaic systems | |
| Modules | 30 |
| Inverters | 15 |
| Structure | 30-60 |
| Small wind systems | 20 |
| Geothermal | |
| Geothermal heat pump | 20-25 |
| Biomass (by case) | N/A |
| Hydrogen (at initial cost $950/kWh) | 7500-20000 hours |

## 6.0 Implementation Strategies and Financing Mechanisms

Using the set of lessons learned/best practices established in Task 1, strategies for implementing the sources/applications identified in Task 2 and shown to be financially feasible in Task 3 have been developed. The strategy also includes investigation of alternatives that are currently not technically or economically feasible. These strategies are aimed at providing an understanding of the environmental, legal, and financial processes with respect to undertaking investment in alternative energy sources. The strategy provides a framework/roadmap for alternative energy in Missouri, and not only addresses the technical and economic feasibility of potential sources/applications, but will also address risk mitigation, financing mechanisms, and near-term actions with potential economic development benefits.

In addition to economic analysis provided in Task 3, unique financing mechanisms suitable for investment in alterative energy are available. For example, Public-Private Partnerships (PPP) are contractual agreements, formed between a public agency and private sector entity, which expand on the traditional public sector role in the delivery of transportation projects. The USDOT FHWA identifies and defines the more common PPP structures (http://www.fhwa.dot.gov/ppp/). There are many different PPP options, and the exact combination of services and responsibilities differs from one application to another. PPP also help with effective project management and risk mitigation, which are as important to successful implementation of alternative energy as technology and economic feasibility. Allocation of risks is not entirely straight forward; thus, MoDOT must allocate risks to those best able to absorb the risks. For example, as the responsibility of the private sector increases, so does the amount of risk that needs to be managed by the private sector. However, the public sector may have the ability to pool risks from multiple projects that a single private firm would not have the ability to do. By doing so, not only are the risks likely to be better mitigated, but the associated costs and project delays may be decreased as well.

Similarly, MoDOT may want to consider an “Energy Savings Performance Contract” (ESPC) as one funding option for energy savings within MoDOT facilities. The State of Missouri has enabled legislation to allow state agencies to engage in ESPC contracts (Missouri Revised Statutes Section 8-231: Guaranteed Energy Cost Savings Contracts). MoDOT would work with an Energy Savings Company (ESCO) to identify and implement energy saving building retrofits that would be funded with the resulting energy savings. Many government agencies find the ESPC model attractive because it is a "turnkey" arrangement and usually doesn’t require up-front capital funds. The ESCO is responsible for arranging for financing, determining cost effective retrofits, retrofitting the building, and verifying the energy savings; demanding minimal effort from building owners. The ESCO and client consider a long list of efficiency measures that could be implemented. Each one is evaluated for its payback: efficient light bulbs, for example, have a short payback, whereas the client could take much longer to recoup the investment on an alternative energy project. In the final ESPC, the client customizes the exact combination of building retrofits that meet their needs. The energy savings from the improved buildings cover the debt service and measurement and verification fees for the ESPC, during the length of the contract. During the contract the ESCO guarantees the savings. Once the contract is over, the building owner has exclusive rights to the energy savings. Follow-up meetings will be necessary to move the program forward.

## Project Team

**Dr. Scott E. Grasman** is an Associate Professor of Engineering Management and Systems Engineering as well as Associate Chair for Graduate Studies at Missouri University of Science and Technology. He received his B.S.E, M.S.E, and Ph.D. in Industrial and Operations Engineering from the University of Michigan. His primary expertise relates to the application of quantitative models the design and development of supply chain and logistics process. He has been involved in a variety of research and consulting projects, and also has a strong interest in supply chain design for alternative energy.

**Dr. Suzanna Long** is an Assistant Professor with the Department of Engineering Management and Systems Engineering at Missouri University of Science and Technology. She holds a Ph.D. and an M.S. in Engineering Management, a B.S. in Physics and a B.A. in history from the University of Missouri-Rolla and an M.A. in History from the University of Missouri-St. Louis. She worked as a scientific and electronic records management specialist for the federal government and continues to consult in that arena. Her research interests include strategic management of sustainable supply chain partnerships, transportation-logistics, supply chain management, and organizational analysis.

**Dr. Ruwen Qin** is an Assistant Professor of Engineering Management and Systems Engineering at Missouri University of Science and Technology (formerly University of Missouri - Rolla). She received her Ph.D. in Industrial Engineering and Operations Research from the Pennsylvania State University, her M.E. and B.E. degrees in Spacecraft Design both from Beijing University of Aeronautics and Astronautics, China. Her research interests include Financial Engineering, Engineering Economy, Operations Research, and their applications on manufacturing and service operations, renewable energy, transportation, workforce engineering, and revenue management. She has been co-PI on a project funded by MoDOT, leading the statistical analysis for the development of maintenance/replacement schedules for LED traffic signals.

**Ms. Rolufs** is the Director of the Institute for Environmental Excellence (IEE) where she is responsible for leading Missouri S&T programs to advance campus sustainability while fostering strategic alliances to support energy and environmental research, education, and outreach. She is also engaged in seeking out opportunities that will engage Missouri S&T faculty and students in cutting-edge environmental sustainability and renewable energy research and demonstration projects.

**Mr. Mark Imel PE**, is Director of Energy Services, Sustainable Design Solutions. Through HDR's Sustainable Solutions Program he is helping clients sort and prioritize projects based on long-term sustainability. Using this approach, organizations are positioning themselves to provide projects and programs that provide economic, social, and environmental value, backed by business cases that are green, transparent, and accountable. A description of this program is provided with this submission.

**Dr. Alice Beechner Reeves** is co-founder of Paragon Business Solutions. Established in 1997, Paragon Business Solutions, Inc provides expert management services, system design, consulting and training to both public and private sector clients. Paragon's focus is primarily in four areas: Environmental Management Systems (EMS) and Services, Quality Management Systems and Services, Occupational Health and Safety Management Systems and Services, and Construction Management Services.

**Yaqin Lin** is currently a M.S. student within the Department of Engineering Management and Systems Engineering at Missouri University of Science and Technology. She received her B.A. in Accounting from Southwest Jiaotong University, China. Her research interests include Cost-Effectiveness Analysis, Financial Engineering, and their applications in alternative energy strategies.

**Mathew Thomas** is a Ph.D. candidate of Engineering Management and Systems Engineering at the Missouri University of Science and Technology. He received his Bachelor of Technology in Mechanical Engineering from the Rajiv Gandhi Institute of Technology Kottayam, India, an M.S. in Engineering Management and Systems Engineering, and an M.S. in Mechanical Engineering from Missouri University of Science and Technology. His M.S. research entailed hydrogen systems applications. His recent research interests include hydrogen design, construction and management. He is also an active member of the Missouri S&T Eco CAR Team.

**Rajit Mishra** is currently a B.S. student in Industrial Engineering at Purdue University. He performed research at Missouri University of Science and Technology as part of an undergraduate research program. His research interests include energy supply chains.

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# APPENDIX A

## Survey

**Use of Alternative Energy in Transportation Survey**

This survey is intended to solicit information on the alternative energy use in transportation section by different agencies/organizations in the country. Information provided in the survey will not be shared with other agencies and the respondents will remain anonymous.

This survey has 21 questions and will take 5-10 minutes to complete.

1 Which agency/organization do you belong to?

- Federal
- State
- City
- University
- National Lab
- Research agencies
- Consultant
- Other, please specify

2 Name of the agency/organization (optional):

3 Which of the following describes your job function?

- Administration
- Engineering
- Research and Development
- Academia
- Fleet manager
- Building and Construction
- Finance/Accounting
- Information Technology/MIS
- Other, please specify

4 **How long have you worked at this position?**

5 **Have your agency/organization installed/planning to install alternative energy projects in transportation sector?**

YES NO

6 **Type of facilities where alternative energy will be used**

- Office buildings
- Traffic management/logistics
- Traffic signals
- Maintenance facilities
- Fleet vehicles
- Welcome centers/rest areas
- Other, please specify

7 **Location of your alternative energy projects**

City :

State:

Facility (optional):

8 **What type of alternative energy sources were used in the project?**

- Solar
- Wind
- Geothermal
- Fuel Cells
- Alternative fuels in vehicles
- Waste water treatment
- Other, please specify

9 **Maximum rated output of the solar panels used in the project**

**10** Maximum rated output of the wind turbines used in the project

**11** Maximum rated output of the fuel cells used in the project

**12** Capacity of the geothermal system used in the project

**13** Alternative fuel used in the project

**14** Capacity of the waste treatment plant used in the project

**15** Have your agency/organization installed/planning to deployed projects that increases energy efficiency in office buildings, traffic management, etc?

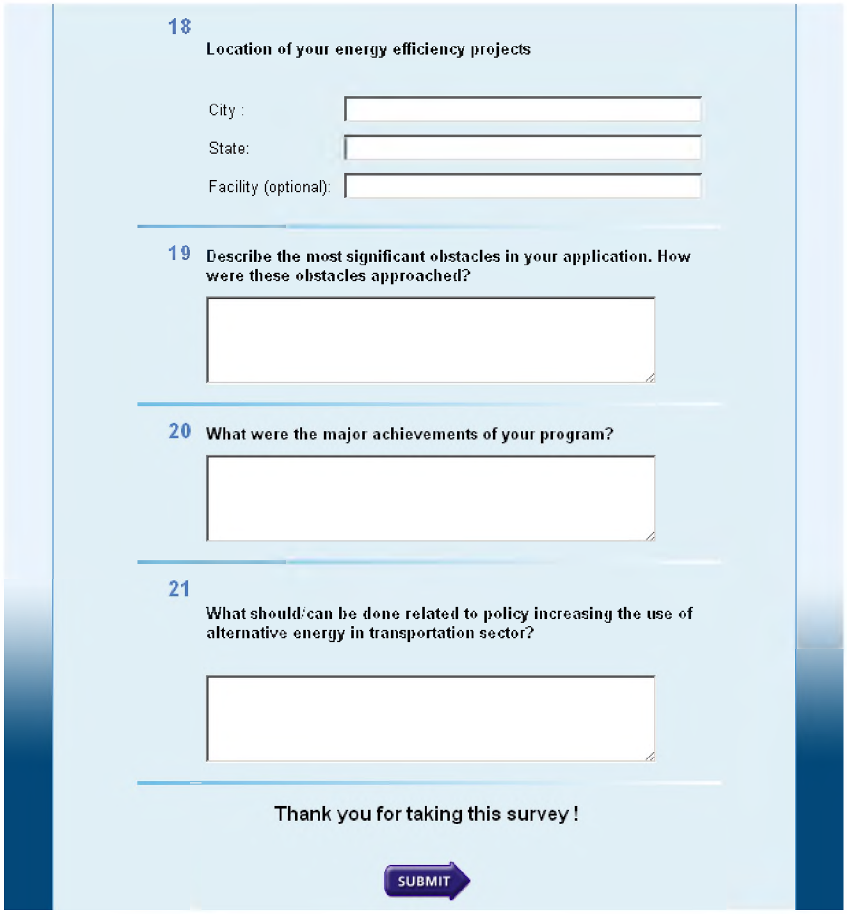
YES NO

**16** Where will these be used?

- Office buildings
- Traffic management/logistics
- Traffic signals
- Maintenance facilities
- Fleet vehicles
- Welcome centers/rest areas
- Other, please specify

**17** What types of systems are used?

- High efficiency lighting
- High efficiency HVAC
- LED lighting
- Green roof
- Rain water collection
- Intelligent systems
- Other, please specify



18 Location of your energy efficiency projects

City :

State:

Facility (optional):

19 Describe the most significant obstacles in your application. How were these obstacles approached?

20 What were the major achievements of your program?

21 What should/can be done related to policy increasing the use of alternative energy in transportation sector?

Thank you for taking this survey !

SUBMIT

**Survey Results - Raw Data**

**1.** Which agency/organization do you belong to?

| | | |
|---|---|---|
| Federal | 1 | 3% |
| State | 25 | 69% |
| City | 0 | 0% |
| University | 3 | 8% |
| National Lab | 0 | 0% |
| Research agencies | 0 | 0% |
| Consultant | 7 | 19% |
| Other, please specify | 0 | 0% |

**2.** Name of the agency/organization (optional):

View 31 Responses

**3.** Which of the following describes your job function?

| | | |
|---|---|---|
| Administration | 9 | 25% |
| Engineering | 8 | 22% |
| Research and Development | 6 | 17% |
| Academia | 2 | 6% |
| Fleet manager | 2 | 6% |
| Building and Construction | 3 | 8% |
| Finance/Accounting | 0 | 0% |
| Information Technology/MIS | 1 | 3% |
| Other, please specify View Responses | 5 | 14% |
| Total | 36 | 100% |

**4.** How long have you worked at this position?

| | | |
|---|---|---|
| Less than 1 year | 1 | 3% |
| 1-2 years | 11 | 31% |
| 3-5 years | 3 | 9% |
| 5-7 years | 2 | 6% |
| 7-10 years | 0 | 0% |
| more than 10 years | 18 | 51% |
| Total | 35 | 100% |

**5.** Have your agency/organization installed/planning to install alternative energy projects in transportation sector?

| | | |
|---|---|---|
| Yes | 26 | 72% |
| No | 10 | 28% |
| Total | 36 | 100% |

**6.** Type of facilities where alternative energy will be used

Actions

| | | |
|---|---|---|
| Office buildings | 14 | 52% |
| Traffic management/logistics | 8 | 30% |
| Traffic signals | 9 | 33% |
| Maintenance facilities | 12 | 44% |
| Fleet vehicles | 15 | 56% |
| Welcome centers/rest areas | 12 | 44% |
| Other, please specify View Responses | 6 | 22% |

**7.** Location of your alternative energy projects

Actions

View 23 Responses

**8.** What type of alternative energy sources were used in the project?

Actions

| | | |
|---|---|---|
| Solar | 18 | 64% |
| Wind | 11 | 39% |
| Geothermal | 6 | 21% |
| Fuel Cells | 4 | 14% |
| Alternative fuels in vehicles | 13 | 46% |
| Waste water treatment | 2 | 7% |
| Other, please specify View Responses | 4 | 14% |

**9.** Maximum rated output of the solar panels used in the project

Actions

| | | |
|---|---|---|
| < 1 kW | 1 | 5% |
| 1-5 kW | 2 | 9% |
| 5-10 kW | 4 | 18% |
| > 10 kW | 3 | 14% |
| N/A | 12 | 55% |
| Total | 22 | 100% |

**10.** Maximum rated output of the wind turbines used in the project

Actions

| | | |
|---|---|---|
| < 1 kW | 1 | 5% |
| 1-5 kW | 3 | 15% |
| 5-10 kW | 0 | 0% |
| > 10 kW | 3 | 15% |
| N/A | 13 | 65% |
| Total | 20 | 100% |

**11.** Maximum rated output of the fuel cells used in the project

| | | |
|---|---|---|
| < 1 kW | 0 | 0% |
| 1-5 kW | 0 | 0% |
| 5-10 kW | 0 | 0% |
| > 10 kW | 0 | 0% |
| N/A | 15 | 100% |
| Total | 15 | 100% |

**12.** Capacity of the geothermal system used in the project

| | | |
|---|---|---|
| 1-10 tons | 0 | 0% |
| 10-25 tons | 2 | 13% |
| 25-50 tons | 0 | 0% |
| >50 tons | 0 | 0% |
| N/A | 13 | 87% |
| Total | 15 | 100% |

**13.** Alternative fuel used in the project

| | | |
|---|---|---|
| Biodiesel | 2 | 10% |
| Ethanol | 3 | 15% |
| CNG | 4 | 20% |
| Other | 4 | 20% |
| N/A | 7 | 35% |
| Total | 20 | 100% |

**14.** Capacity of the waste treatment plant used in the project

| | | |
|---|---|---|
| <1000 gal/day | 0 | 0% |
| 1000-5000 gal/day | 0 | 0% |
| 5000-10,000 gal/day | 0 | 0% |
| >10,000 gal/day | 0 | 0% |
| N/A | 14 | 100% |
| Total | 14 | 100% |

**15.** Have your agency/organization installed/planning to deployed projects that increases energy efficiency in office buildings, traffic management, etc?

| | | |
|---|---|---|
| Yes | 31 | 89% |
| No | 4 | 11% |
| Total | 35 | 100% |

**16.** Where will these be used? Actions

| | | | |
|---|---|---|---|
| Office buildings | | 24 | 80% |
| Traffic management/logistics | | 8 | 27% |
| Traffic signals | | 11 | 37% |
| Maintenance facilities | | 15 | 50% |
| Fleet vehicles | | 8 | 27% |
| Welcome centers/rest areas | | 13 | 43% |
| Other, please specify View Responses | | 1 | 3% |

**17.** What types of systems are used? Actions

| | | | |
|---|---|---|---|
| High efficiency lighting | | 20 | 67% |
| High efficiency HVAC | | 12 | 40% |
| LED lighting | | 20 | 67% |
| Green roof | | 4 | 13% |
| Rain water collection | | 6 | 20% |
| Intelligent systems | | 12 | 40% |
| Other, please specify View Responses | | 7 | 23% |

**18.** Location of your energy efficiency projects Actions

View 21 Responses

**19.** Describe the most significant obstacles in your application. How were these obstacles approached? Actions

View 23 Responses

**20.** What were the major achievements of your program? Actions

View 24 Responses

**21.** What should/can be done related to policy increasing the use of alternative energy in transportation sector? Actions

View 23 Responses

Thank you for taking this survey !

# APPENDIX B

## Case Study: Missouri Solar-powered LED vs. Grid-powered LED

### Objective

The primary objective of this report is to provide an economic estimation to demonstrate the potential value of replacing grid-powered LED lights with solar-powered LED traffic signals for MoDOT. Cost and effectiveness of applying general LED traffic signals are analyzed in this report. A summary concludes the report to help MoDOT make decisions.

### Background

Since the late 1990s, LED traffic signals systems are drawing wide attention from many cities in the US and in the world (Anonymous, 2000a). Several big replacement cases include Boston, MA (Palmer, 1999; Suozzo, 1999), Framingham, MA (Suozzo, 1999), Newton, MA (Suozzo, 1999), Denver, CO (Winer, 1998; Briggs, 2000), Lee County, FL (Crawford, 1999), Portland, Oregon (Anon., 2001), Stockholm, Sweden (Jonsson, 1999), and Victoria, Australia (Das, 1999). A 2004 report from the California Energy Commission listed 78 cities that installed LED traffic signals (Anon., 2004). Two major advantages of using LED traffic signals include remarkable energy savings and noticeable maintenance savings. One major disadvantage is high initial cost. Our analysis shows that both grid-powered and solar-powered LED traffic signals have equal or better functionality compared to traditional incandescent traffic lights (See the following effectiveness analysis), and simple payback period of solar-powered LED is longer than that of grid-powered LED.

### Effectiveness Analysis

We divided effectiveness of installing LED traffic signals in three categories: functionality, environmental effects and economical effects. Advantages and disadvantages of LED traffic signals compared to traditional incandescent traffic lights are summarized as follows:

Functionality

- LED bulbs have a much longer life than incandescent light bulbs, referred number include 100,000 hours vs. 5000 hours (Anon., 1999), 6 years vs. 2 years (Anon., 2001)
- LED eliminates catastrophic failure of traffic signals, thanks to multiple LEDs in one unit.
- LED does not change color when dimming, which is a problem with traditional traffic lights.
- For the most part, the visibility of LED traffic signals is better than incandescent lights.
- In dawn and dusk, when the sunlight shines directly into the traffic signals, there will be uncomfortable glare reflecting from the reflection material behind incandescent traffic lights. LED traffic signals do not require such material and thus eliminate this problem (Anon., 2003).
- LED traffic signals have more directional light beams than traditional ones. This will cause some visibility problems if the traffic signals are hanging freely in some intersections. This problem could be solved by using a stable fixture to secure the traffic signal (Anon., 2003).
- LED traffic signals are sometimes too bright to view in the dark. This issue could be solved by regulating the power input to the traffic signals using some light sensors.

- The LED traffic signals do not generate as much heat as incandescent ones, thus they avoid burning the lens cover. However, in heavy snow days, the heats from LED traffic light are usually not enough to melt snow and ice that accumulate on the light bulb (Anon., 2003).
- LED uses low enough power to operate using battery back-up during power outage.

Environmental Effects

- LED saves a lot of energy consumption and thus reduces greenhouse gas emissions. Denver reported reducing 5,300 metric tons of $CO_2$, 23.3 metric tons of $SO_2$ and 20.8 metric tons of $NO_x$ emissions each year after installing 20,500 LED traffic signals (Winer, 1998).

Economic Effects

- LED traffic signals have a much higher initial cost compared to incandescent light, typically $100 vs. $3 per unit (Anon., 2000).
- After years of operation, LED traffic signals save millions of dollars in relamping, emergency repairing, maintenance and energy cost. Denver replaced 20,500 traffic lights and reported annual savings of $430,000 (Winer, 1998). Stockholm replaced 27,000 traffic lights and reported annual savings of $479,000 (Jonsson, 1999).

Table 1. Effectiveness of replacing traditional traffic lights with LED traffic signals

| Categories | A/D | Description | Reference |
|---|---|---|---|
| Functionality | A | Long life time | Suozzo, 1998 |
| | A | Elimination of catastrophic failure | Anon., 2003 |
| | A | Brighter | Suozzo, 1998 |
| | A | Elimination of reflection of sunlight | Anon., 2003 |
| | A | Avoid burning lens cover | Anon., 2003 |
| | A | Do not change color when dimming | Anon., 2000 |
| | A | Use battery backup during power outage | Anon., 2004 |
| | D | Directional visibility causes | Anon., 2003 |
| | D | Not enough heat to melt covering snow and ice | Anon., 2003 |
| | D | Too bright in night if not regulated | Anon., 2000 |
| Environmental Effects | A | Lower energy consumption | Wu et al., 2008 |
| | A | Lower GHG emission | Anon., 2003 |
| Economic Effects | A | Lower emergency fix cost | Anon., 2003 |
| | A | Lower relamping cost | Anon., 2001 |
| | A | Lower maintenance cost | Wu et al., 2008 |
| | D | higher initial cost | Anon., 2000 |

Note: A = Advantage, D = Disadvantage. Most effects are reported from more than one literatures. Referenced literature was selected at the authors' convenience.

**Economic Evaluation**

The low power requirement of LED traffic signals makes it possible to use solar power to light up. It is as simple as attaching an approximately 25W solar panel and an about 40AH battery to power a single

LED traffic signal. The best thing is that it cuts the electricity bill to zero. It has several other advantages listed below:

- No trenching, wiring or electrical work required,
- Can be easily set up by retrofitting conventional LED traffic light, and
- Much easier to set up for temporary use.

There are 2,425 signalized intersections, and approximately 155,000 signal indications in Missouri. Combining the findings and relevant data provided by MoDOT, we found that the simple payback period of LED traffic signals in Missouri is about 4 years. A 10-year study period and 3.92% discounted rate is assumed in this study. Based on these assumptions, the net present value and the total reduced $CO_2$ emissions are summarized in Table 2. According to Wu's research (Wu, 2008), the initial cost (including materials and installation) of solar-powered LED lights is about 1.5 times that of grid-powered LED lights. Also, solar-powered LED lights save less maintenance cost (about 0.5 times that of grid-powered LED lights). Based on these assumptions, the comparison between grid-powered and solar-powered LED is listed as following:

Table 2 Summary of Results

| | Grid-powered LED | Solar-powered LED |
|---|---|---|
| Total Initial Cost ($) | 19,885,000 | 29,827,500 |
| Annual O&M Savings ($) | 853,600 | 426,800 |
| Annual Energy Savings ($) | 6,868,401 | 7,391,866 |
| Total Annual Savings ($) | 7,722,001 | 7,818,666 |
| Simple Payback Period (year) | 2.58 | 3.81 |
| NPV ($) | 42,997,524 | 33,842,194 |
| Annual $CO_2$ Reduction (lbs) | 47,049 | 50,634 |

Notes: The base case to calculate annual energy savings and annual O&M savings is the traditional traffic bulb.

The calculation shows that solar-powered LED traffic signals have a longer payback period, mainly because of its lower maintenance saving. This reduces its popularity. Not surprisingly, the initial cost of these "green" traffic lights is a little bit higher than grid-powered LED traffic signals. However, solar-powered LED reduces more CO2 emissions than grid-powered LED. With the increasing energy price, the zero electricity bill will surely earn more points for solar-powered LED traffic signals.

**Summary**

This effectiveness analysis shows that both grid-powered and solar-powered LED traffic signals have many advantages over traditional ones. Although LED traffic signals installing requires a high initial investment, the payback period is about 2 to 4 years. However, since the solar-powered LED traffic signals are still new to the marketplace, no recorded data show a reliable operation and maintenance cost. Although many manufacturers claim that the operation and maintenance cost is near zero, these claims are also hard to confirm. Meanwhile, there is not an appropriate depreciation method for LED signals. This report established estimations for payback periods. We recommend any organization to take serious consideration of replacing signals with solar-powered LED ones.

Solar-powered dynamic message systems also draw some attention. New York State Police uses 10 units in order to reduce the energy cost. Types of solar-powered LED dynamic message signs in the market range from 1 line of text to multiple lines of text. Some of them are even capable of displaying monochrome images/animations. The power of each ranges from 100 W to 500 W; weight ranges from 300 lbs to 3000 lbs; price ranges from $5,000 to $50,000. The use of solar power and battery systems eliminate the requirement of hardwire electricity work, increases the portability and also, cuts the electricity bill to zero.

Just like solar-powered battery LED traffic lights, solar-powered battery roadway lights consist of 3 major components: LED lights, solar panels, and a battery. The difference is that the power for LED traffic light is smaller. A single signal light is only about 10W, whereas roadway lighting requires greater power. Given the brightness demand, the lighting range, the dispersion of the lights, etc, a roadway light needs LED power ranging from 30W to 600W. Similarly, depending on the power of the LED light, the charging time of the battery and the frequency and time span of the cloudy/rainy days, associated batteries range from 75AH to 600AH. A detailed study of the solar-powered scenarios for LED lighting will be provided by project TRyy1101.

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# APPENDIX C

## Case Study: Demonstration Project in Rolla, Missouri

### Background

The demonstration project located at the Troop I Highway Patrol Headquarters in Rolla, Missouri, is designed to show that the application of renewable energy systems has potential to reduce the State's energy bills. The project is also intended to facilitate the development of outreach activities for pre-college students, university students, and the general public. The project involves a hybrid wind/photovoltaic (PV) system, which is composed of a wind turbine, a weather station, and a PV system. The amount of energy produced by this system over a 17-month period is shown in Table 3. The wind turbine sits on a 120 ft lattice tower and can produce 10 kW at a wind speed of 29.3mph. The expected annual output of this wind turbine is 14,300 kWh. The live data of this project show that the average wind speed at a 10-foot height is 6.7mph. The PV system can produce 2.16 kW if all panels work together. The average peak sun hours (i.e., the average number of hours during which the sun is at its maximum potential of 1,000 $W/m^2$ each day) is 3.04.

Table 1. Energy Production over 17 Months

| Preliminary (Unreviewed) Data | | | | | |
|---|---|---|---|---|---|
| 17 months | PV Energy (kWh) | Wind Energy (kWh) | Speed (mph) | Insolation ($W/m^2$) | Avg.Peak Sun Hours/Day |
| Total | 3874.0 | 8460.0 | - | 2157.5 | - |
| Avg. | 227.9 | 497.6 | 6.7 | 126.9 | 3.0 |

Source: Energy Research and Development Center, Available from Internet: <http://energy.mst.edu>

### Data Collection

We do not have complete data of the project over the system's expected useful life; therefore, data for assessing this project is collected from multiple sources, including the recorded data for this project, similar projects, and manufacturer publications. The purpose of this project is to demonstrate environmental and economic impacts of renewable energy. From the effect structure in Table 1, we know that using wind power and solar power can reduce GHG emissions and air pollutions, yet increase noise. Moreover, the hybrid system promotes energy efficiency and cost savings, and can benefit from tax credits. Ideally, the system would be evaluated by measuring these reductions; however, as a small-scale project with a demonstration purpose, it records only the GHG emissions data and energy production data. Since the installation on June 12, 2008, the green house gases have been reduced by 15,690 lbs, equivalent to the total emission of an average passenger car over 573 days. The total energy production is 12,334 kWh, equivalent to an average monthly production of 725.5 kWh.

Table 2 shows the equipment information of this project, including equipment types, quantities, their suppliers, and their costs. It indicates that the initial investment of the equipment was $60,700. Assuming all equipment qualifies as renewable energy equipment, the tax credit could reach $18,210 about 30% of the initial investment. Thus, the actual investment is estimated to be $42,490. Construction costs of the wind system were estimated on the basis of a similar case (Middlebury College Case) in 2005, which were as follows: $8,000 for a tilt-up tower with gin pole and all hardware, $3,000 for site improvement (concrete, concrete forms, rebar for foundations, and wire run to service panel), $800 for excavation and back-fill, and $3,000 for a data collection system (data logger, sensor, hardware). Therefore, the total installation cost was $14,800. The personnel cost (supervising electrician and labor and industry inspection) was estimated to be $2,932. We use the inflation rate calculated using a Bureau of Labor Statistics tool to derive adjusted costs in 2008 dollars for our case study: the adjusted construction cost is $16,316, and the adjusted personnel cost is $3,232. Thus, the initial investment is estimated to be $62,038.

Table 2. System Equipment

| Equipment | Quantity | Suppliers | Cost ($) |
|---|---|---|---|
| Bergey Excel S Wind Turbine (10 KW) | 1 | BergeyWindpower | 36,700 |
| Gridtek 10 Wind Turbine Inverter | 1 | BergeyWindpower | |
| Sharp ND216U2 Solar Panel (2 KW) | 10 | Carmanah Technology | 13,700 |
| Fronius IG 2000 Solar Panel Inverter | 1 | Fat Spaniel | |
| Wind Anemometers | 3 | Fat Spaniel | 10,300 |
| Pyranometer | 1 | Fat Spaniel | |
| Temperature Probe | 1 | Fat Spaniel | |
| Barometer | 1 | MetOne | |

Source: Energy Research and Development Center, Available from Internet: < http://energy.mst.edu>

The annual O&M cost for a small wind turbine can be estimated in two methods: $0.01-$0.05 per kWh (DeMeo, 2004), or about 1% of the installation cost (Sagrillo, 2002). Since the wind turbine is waiting for repair, the future energy production cannot be forecasted accurately based on the energy production during the past 17 months. Thus, the first method, which is based on the energy production, is not appropriate for this project, and thus the second method is used: the annual O&M cost is estimated to be $620 (i.e., 1% of the installation cost). The O&M cost for PV systems is less than $0.01/kWh (Public Renewable Partnership). Based on the energy production during the past 17 months, it is approximately $27 per year. The total annual O&M cost is $647.

Not much actual solar panel recycling has been done (Zweibel, 2004). With limited experience on the removal and recycling of wind turbines, we are unable to estimate the disposal and recycling costs for this project. The system is expected to last 30 years (Fthenakis, 2000). The historical inflation rate from January 2000 to April 2010 shows no trend of significant increase or decrease (Bureau of Labor Statistics). Based on the historical data, the average inflation rate was calculated as 2.57±1.2% per year. We thereby assume a constant inflation rate, 2.57%, for this project throughout its life. A 30-year real interest rate on treasury notes and bonds is used as the discounting rate, which is 2.7% (Circular No. A-94 Revised, Whitehouse).

**Results**

Table 3 summarizes the effectiveness, associated costs, and E/C ratios for this project. Since the system has already selected solar-wind hybrid alternative energy, the results of analysis are more a performance evaluation rather than an effort to select from among various alternatives.

Table 3. CEA of the Hybrid Alternative Energy System

<table>
<tr><th>Effects</th><th>Costs($)</th><th>E/C (the hybrid system)</th><th>E/C (the coal system)</th></tr>
<tr><td>Annual Energy Production 8,706.4 kWh</td><td rowspan="2">Annual Worth 3,639</td><td>Energy Production Cost 2.36 kWh/$</td><td>Energy Production Cost* 9.01 kWh/$</td></tr>
<tr><td>Annual Reduction in GHG Emissions 8,858.2 lbs</td><td>GHG Emissions Reduction 2.40 lbs/$</td><td>-</td></tr>
</table>

Note: *. More than 4/5 of the energy in Missouri is produced from Coal (http://tonto.eia.doe.gov).

The E/C ratio of energy production by the hybrid system is 2.36 kWh/$, which means the cost for producing energy is $0.42 per kWh. The coal generated energy cost is $0.11 per kWh (Lazard Report, 2008). The energy production cost of the hybrid system is about 400% higher than the average energy production cost in Missouri, indicating that the hybrid system is less economical than a typical coal system. It is noteworthy that the wind turbine monitoring equipment is not functioning properly and will be improved soon. This might be one reason that the CEA results are significantly off from our expectations. Also, due to incomplete information, this analysis is based on a set of assumptions, such as a 30-year life expectancy, a fixed inflation rate, adjusted costs, and ignorable recycling or removal costs. Some of the assumptions might be changed with the rapid development of this industry.

The demonstration project is a small-scale system. Some effects would be significant, yet not recorded. A recorded effect is reduced GHG emissions, and the E/C ratio is 2.40 lbs per dollar. Producing 1 kWh energy using this hybrid alternative energy system reduces 1.02 lbs GHG emissions. The hybrid system costs more to produce energy than a coal system due to the malfunction of the wind turbine, but positive environmental effects have been added advantages to the implementation of the hybrid system. Repair will definitely lower the energy production cost.

# APPENDIX D

## Case Study: Rockport Welcome Center

**Background**

Rest areas as part of the Interstate Highway System provide safety and convenience to travelers. Their service includes providing parking spaces, vending machines, local landscapes and comfort facilities. There are 19 rest areas in Missouri. It is estimated that 20 million travelers visit Missouri rest areas every year (Schreiber, 2010), which make them prime locations to convey the idea of applying green technologies.

The Rockport Rest Area (40.41N, 95.516W, Elevation is 942 feet)) is located on southbound I-29 in Atchison County, Missouri. It provides 30 car parking spaces, 9 trucks and recreational vehicle (RV) parking spaces. Its amenities for the traveling public consists of restrooms, drinking fountains, picnic tables and shelters, vending machines, information dispersal, pet accommodations, telephones, trash collectors and Americans with Disabilities Act (ADA) accessible. Where sanitary facilities are provided, an adequate water supply, sewage disposal system, and power supply will be required. To reduce the energy costs and make this rest area more attractive, MoDOT plans to redevelop the Rockport Rest Area into a modern welcome center which is expected to be open in early 2011.

**Objectives and Approach**

The objective of this analysis is to evaluate the financial and environmental feasibility of a proposed alternative energy system into the Rockport Welcome Center. The major methodology includes: an analysis of monthly electricity data for both Conway Welcome Center and Rockport Welcome Center; a scan of alternative energy technologies and of alternative energy sources in Rockport; NPV and payback period are applied to provide a basis for economic comparison of each alternative strategy.

This study was done with the assumption that the new construction scheduled at the Rockport Welcome Center is similar to the Conway Welcome Center. The basic design, building type, square footage, equipments, and other energy efficiency efforts are the same. The Conway Welcome Center provides 85 car parking spaces, 75 trucks and recreational vehicle (RV) parking spaces. It features considerable green technology, like automatic sinks and toilets in the restrooms to conserve water, small wind turbines to power lights over the information counters, a ground source heat pump system for heating and air conditioning and a modern wastewater treatment plant. In this study, we intend to bring up several possible strategies and forecast potential financial performance of each strategy.

**Data Collection and Assumptions**

We analyzed the electricity usage of Rockport Welcome Center provided by MoDOT from September 2006 to June 2010 (shown in Figure 1). According to the data, the Rockport Rest Area has a relative stable electricity usage before reconstruction (starting from June 2008). It consumes more energy in winter than in summer. The average monthly electricity consumption of the Rockport Welcome Center is approximately 6,500 kWh. This amount is comparable to the electricity consumed at the Conway

Welcome Center (7,300 kWh) before the construction of new restroom facilities and tourist information center. It was observed that the electricity consumption at the Conway Welcome Center increased since its re-opening in May 2009. The increase could be due to the additional new restroom facilities and tourist information center. Once Rockport builds new restroom facilities and a tourist information center, it is assumed that the average monthly power consumption at this site will increase (to approximately 16,000 kWh) analogous to the increase at the Conway Welcome Center.

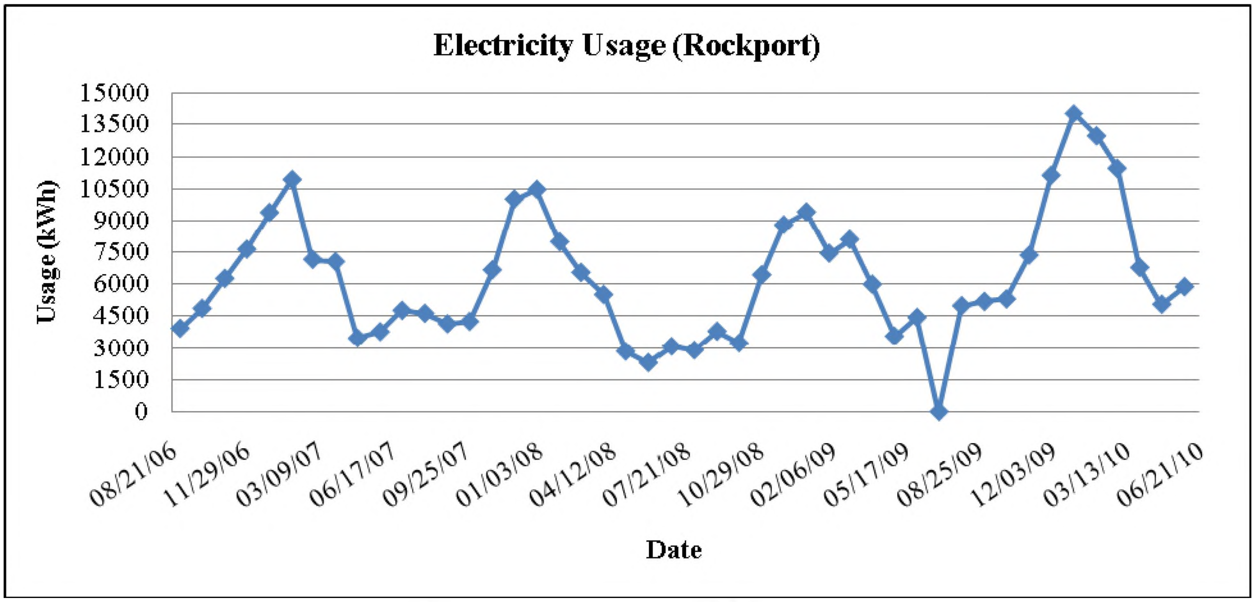


Figure 1.Rockport Electricity Usage

To cover the estimated electricity usage, a 20 kW class power generator is appropriate. We analyzed the alternative energy source in Missouri before we decided what energy to use. The wind power density (at 50 Meters) in Rockport is about 100-300 W/m2 (from NREL). The solar insolation map (incidence of solar radiation) shows that Rockport is located in zone 4 with an average 4.5 hours insolation per day. Large scale solar panel needs a big area to install, while a wind turbine only takes up a limited area to stand. We considered a hybrid system which uses wind turbines as major power sources and solar panels as backups.

The wind turbines selected in this study are from 4 major small wind turbine manufacturers. Selected models include Bergey Excel S 10 kW, WTIC Jacobs 20 kW, Evolve EG-12 20 kW and Aeolos H 30 kW. The kilowatts number at the end of each model is the theoretical optimal power capacity of each wind turbine. The actual wind turbine power generation is dependent on the wind speed, and the wind speed increases with the height of tower (DOE Energy Efficiency and Renewable Energy, 2010). The payback period is calculated based on the following assumptions.

- The estimated average annual power productions are calculated by multiplying wind speed dependent power by 8,640 hours/year.
- The annual energy savings are calculated assuming electricity price is 10 cents/kWh.

- The installation fee is $19,821, which is on the basis of a similar case (Middlebury College Case) in 2005. We use the inflation rate calculated using a Bureau of Labor Statistics tool to derive adjusted costs in 2010 dollars for our case study. In reality, the installation fee might change due to shipping distance, sitting and permitting requirements, regional tax and other factors.
- The initial cost is calculated from a retail price offered by the vendors and assuming that 30% Federal tax credit is applicable.
- The annual O&M cost is 0.01 dollar/kWh times the annual power production (DeMeo, 2004).
- The total initial cost of a solar panel system is 50% panel/material, 35% inverter and 15% labor.

In much of the United States, wind is strong in winter, but weak in summer. A solar panel can be used as a backup in summer seasons to ensure constant renewable energy production. The solar energy system considered in this study is Sharp ND-224UC1 panels, which was used in a demonstration project in Rolla, MO and proved to be working at a high efficiency. This solar system requires a 4,032 square feet area and its power output is 2.24 kW at the peak. The Rockport Welcome Center has a roof area of 5,200 square feet and it should be big enough to install this system.

**Results**
Wind turbine power output is strongly dependent on the wind speed. Thus the energy saving and payback period are also dependent on wind speed. Figure 2 exhibits payback period of each wind turbine model under different wind speeds. From the figure we can see that WTIC Jacobs 20 kW shows a best payback period result. This analysis is estimated based on available data from various sources, including manufacturers' reports, research publications and case studies. Due to uncertainties regarding this data and many unpredictable factors in real situations, these results should not be considered absolute.

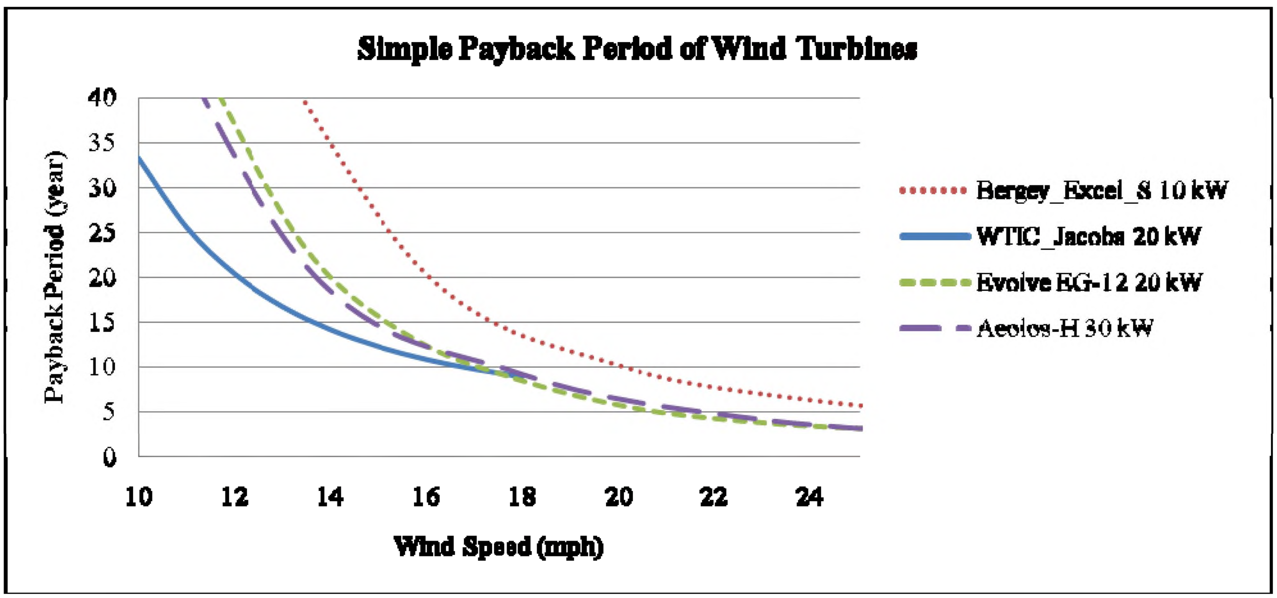


Figure 2. Simple Payback Period of Wind Turbines at Different Wind Speeds

At a normal wind turbine height, 120 feet, Rockport's wind speed is assumed to be 15.5 mph (Southwest Windpower, 2010; WTIC, 2010). In Table 1 we listed initial cost, annual energy savings and payback period for all wind turbines models at a wind speed of 15.5 mph.

Table 1 Summary of Results for Wind Energy System

| Model | Initial Cost ($) | Energy Saving ($/yr) | Payback (yr) | Disc. Payback (yr) | NPV ($) |
|---|---|---|---|---|---|
| Bergey Excel S 10 kW | 40,256 | 1,555 | 29 | >30 | -15,816 |
| Evolve EG-12 20 kW | 56,711 | 4,406 | 14 | 22 | 12,536 |
| WTIC Jacobs 20 kW | 64,280 | 6,067 | 12 | 17 | 31,056 |
| Aeolos-H 30 kW | 65,874 | 5,400 | 14 | 20 | 18,988 |

Note: Discounted payback period of Bergey Excel S 10 kW is longer that the study period of 30 years.
Data Source: Bergey (http://www.bergey.com/), Evolve and Aeolos (http://www.mywindpowersystem.com/), WTIC (http://www.windturbine.net/).

Considering these four models are mutually exclusive alternatives, an incremental capital associated with a model and its incremental benefits are compared to help make decisions. Bergey Excel S 10 kW was chosen as base since it has the least capital investment. Table 2 shows that investing additional capital of $16,455 in Evolve EG-12 20 kW can obtain $28,352 in benefits. So Evolve EG-12 20 kW is preferred, and it becomes the new base. Table 3 shows that an additional capital investment in WTIC Jacobs 20 kW is justified. Using WTIC Jacobs as a new base, Table 4 shows that WTIC Jacobs 20 kW is preferred to Aeolos-H 30 kW because the additional capital investment in Aeolos-H 30 kW is not justified.

Table 2 Comparison between Every Two Models: First Round

| | Bergey Excel S 10 kW | Evolve EG-12 20 kW | Incremental |
|---|---|---|---|
| Initial Cost ($) | 40,256 | 56,711 | 16,455 |
| Annual Savings less O&M ($) | 1,400 | 3,966 | 2,566 |
| | | NPV | 28,352 |

Table 3 Comparison between Every Two Models: Second Round

| | Evolve EG-12 20 kW | WTIC Jacobs 20 kW | Incremental |
|---|---|---|---|
| Initial Cost ($) | 56,711 | 64,280 | 7,569 |
| Annual Savings less O&M ($) | 3,966 | 5,460 | 1,494 |
| | | NPV | 18,520 |

Table 4 Comparison between Every Two Models: Third Round

| | WTIC Jacobs 20 kW | Aeolos-H 30 kW | Incremental |
|---|---|---|---|
| Initial Cost ($) | 64,280 | 65,874 | 1,594 |
| Annual Savings less O&M ($) | 5,460 | 4,860 | (600) |
| | | NPV | (12,068) |

As mentioned previously, a solar energy system (Sharp ND-224UC1) is considered to be used as a backup in the summer seasons. Table 5 shows the results of adding a set of identified solar energy system to the selected wind energy system. According to the results, the hybrid system (simple payback period is 13 years) will take longer to recover its initial investment than the system only using wind energy (simple payback is 12 years). Although the hybrid system has a longer payback period, it provides more constant energy year-round.

Table 5 Summary of Results for the Hybrid System

| Model | Initial Cost ($) | Energy Saving ($/yr) | Payback (yr) | Disc. Payback (yr) | NPV ($) |
|---|---|---|---|---|---|
| WTIC Jacobs 20 kW | 64,280 | 6,067 | | | |
| Sharp ND-224UC1 | 12,620 | 363 | | | |
| Total | 76,900 | 6429 | 13 | 19 | 26,031 |

Note: The installation fee for solar panel is not exhibited equipment cost in this table does not include the installation cost of this system. The installation cost is considered when calculating corresponding financial indicators.

## Conclusion

From previous Rockport Rest Area electricity bill and present Conway Welcome Center electricity bills, we estimate that after reconstruction, the Rockport Welcome Center will consume about 16,000 kWh each month. A 20 kW class power generator can fulfill the need. Based on the alternative power source of Rockport region, we consider a hybrid alternative energy system which uses wind power as the main source and solar power as a backup for summer seasons when wind power is not strong enough. A comparison of 4 different wind turbine models shows that WTIC Jacobs 20 kW is the winner, which leads to a shorter payback period and a higher NPV. We also analyzed the whole hybrid system using a Sharp ND-224UC1 solar panel as the backup. Results show that adding solar panels prolong the payback period. But it is still feasible considering that it ensures a more constant renewable power supply year-round.

Another recommendation from the research team, which is not analyzed in details, is to use geothermal heat pumps for space heating and cooling. According to statistical data (Energy Star), heating and cooling consumed 46% of total energy of a commercial building. Heating in the winter even takes 29% of total energy consumption, causing the utility bills of Rockport and Conway to be much higher in winter than in summer. Geothermal heat pumps, known as ground source heat pumps, utilize the constant underground temperature throughout the year, transferring heat from underground up to the facility in the winter, and from the facility back down into underground in the summer (DOE: Geothermal). They have higher energy efficiency (up to 400%) compared to the most efficient electric heater on the market (94%), thus providing savings on heating bills up to 70% (Geothermal Genius). A geothermal heat pump costs about $2,500 per ton of capacity. Considering the building size of the Rockport Welcome Center, it would use a 6-ton unit ($15,000). The initial cost including air conditioning is about twice the price of a system, so about $30,000 for the Rockport Welcome Center. This cost does not include drilling cost, which is from $10,000 to $30,000, depending on the drilling depth, terrain and other local factors (Consumer Energy Center). The maintenance cost of a geothermal heat pump is much lower compared to traditional heating devices because it has no outdoor compressors and is not susceptible to vandalism (Energy Savers). We estimate Rockport Welcome Center uses 190,000 kWh/year, in which 90,000 is for heating and cooling. Assuming that the geothermal heat pump saves 45,000 kWh (50% of heating and cooling energy) annually, the simple payback period will be 8 years, much lower than the life of a geothermal heat pump system (>15 years) (Geothermal Genius). The underground pipe even has a warranty of 50 years. The geothermal heat pump is a quiet, clean and safe system, which has a much lower operating cost, saves energy and reduces greenhouse gas emissions (Energy Savers). It can reduce energy bills, improve comfort and help protect the environment.

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