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Executive Summary

As a leader in the development of new and innovative ways of solving problems, Washington University is committed to addressing many of the energy and environmental problems of the world. One way to address energy and environmental issues surrounding carbon emissions and fossil fuel use is through the installation of renewable energy systems. Yet, these systems have not be widely embraced or deployed in the state of Missouri. This study was undertaken by Washington University in St. Louis to assess the technical and economic feasibility of installing various renewable systems at specific locations on campus.

Potential projects were first identified using a variety of sources, including vendor-sponsored studied, student-led initiatives (through coursework or in various graduate-level analyses), and by reviewing existing installations on University property. Next, a long list of potential technologies were identified and analyzed for technical and economic feasibility.

The analysis of potential technologies led to the identification of five specific possible renewable energy projects, which are listed on Table ES-1.

Table ES-1. Summary of Measures for Further Evaluation

Measure No.	Description
1	Solar Hot Water Heaters for Athletic Complex Pool
2	Outdoor Parking Lot Lighting Conversion to PV Power
3	Cooking Oil Conversion to Biodiesel
4	Cofiring of Advanced Coal Pilot Boiler with Biomass
5	Food Waste Digester for Biogas Generation

Each of the measures on Table ES-1 was studied in detail. Both installation costs and potential energy savings were estimated, and this information was used to develop net present value (NPV). The NPV analysis included the "savings" from avoided carbon dioxide emissions, which were assumed to be $ 20 per ton of carbon. Unfortunately, only the third measure, whereby cooking oil is converted to biodiesel, had a positive NPV.

There are several technical obstacles to using more renewable systems, given the centralized heating and cooling systems in use on campus. However, a principal cause of the poor return on renewable energy systems is from the very low unit cost of electricity the University pays. The study team concludes that in the near term energy efficiency measures are a better way to reduce carbon emissions on campus.

1 Introduction & Project Goals

1.1 Background

Renewable energy offers many possible benefits to Missouri's economy and environment. Renewable energy systems are well-established, relatively easy to deploy, minimize carbon emissions, and lead to new jobs. Yet developing the state's portfolio of renewable energy projects is a challenging task. Current energy supplies for transportation, residential, commercial, and industrial uses come from mature industries. The infrastructure used to deliver that energy, including petroleum and diesel fuels, electricity, and natural gas, has been in place for decades. The utilities, private companies, and governmental agencies that participate and oversee this market are also well-established, and many of them are very large, bringing economies of scale to products that, especially in the case of petroleum, is a worldwide commodity. Thus, there are significant market obstacles in place that must be overcome in order to expand the use of renewable energy systems.

In fact, renewable energy systems will require a change in the current paradigm used for providing energy. By their nature, many renewable energy systems are small and must be deployed in a small-scale fashion. Further, renewable energy systems deployed at commercial establishments or in residential homes change the historic relationship between energy consumers and producers, by making the owners of these systems both consumers and producers. The ramifications of these changes are leading to many changes in a variety of areas, from regulations to billing practices to outage restoration. Speeding up the implementation of renewable energy systems requires a variety of parties address these issues.

Washington University in St. Louis is a premier research institution in the United States. Within the University, there is an impressive array of talent in all academic fields, including engineering and business. In fact, cutting-edge research is currently underway at the University to lower the costs associated with renewable energy systems . Thus, as a leader in the development of new and innovative ways of solving problems, Washington University is committed to addressing many of the energy and environmental problems of the world.

One small way to address these on the local level is through the adoption and implementation of renewable energy systems wherever possible.

This study was conducted to assess the economic potential of a variety of renewable energy projects on the campus of Washington University. Two principal goals of the project included the development of a list of feasible projects, along with order-of-magnitude estimates of implementation costs, and the training of young engineers and scientists in the procedure needed to better evaluate renewable energy systems. If renewable energy is to become a viable and cost-competitive alternative to conventional, fossil-fuel based energy industries, its success will be based on successful installations over time. Washington University, in conducting this study, is assessing both the economic feasibility and educational value of these systems. In the process, our team identified some unique characteristics to the energy situation at the University, and we conclude with some observations concerning the most likely next steps.

1.2 Washington University & its Energy Use

Implementing renewable energy systems at Washington University presents some challenges. The campus is situated in the center of the St. Louis metropolitan area. The campus is landlocked and has an extensive array of buried infrastructure, including steam tunnels, electrical lines, an underground parking garage, and sewer and stormwater collection piping. Since 1990, the portion of the campus under roof has expanded by nearly 90 % to over six million square feet (Webber et. al., 2010). Given existing buildings along with requirements for parking and walking paths, the campus has lost a significant amount of open land which could be used for green space, but has gained a large amount of roof space for the installation of solar panels. The campus purchases electricity from the local electrical supplier at a high voltage (4160 V) and steps it down in University-owned transformers, which lowers the effective rate to approximately $ 0.045/kWh (based on January, 2011 rate schedules). Thus, achieving a reasonable payback on any energy alternative to grid electricity is a challenge.

Nevertheless, the outlook for renewable energy systems in Missouri is bright. A recent study listed Missouri as the fourth best state in the nation for solar power, based on a low cost-per-watt for installed solar power, high demand, and above average opportunities for jobs in the industry (Chung, 2011). In

addition, the Renewable Energy Portfolio standard in Missouri adopted by voters in 2008 is one of only 16 in the nation with a specific goal for solar power.

These challenges the University confronts in adopting renewable systems have not prevented students and faculty from evaluating the implementation of a variety of renewable energy systems on campus. Currently, two renewable energy "demonstration" sites are installed and operating. A third site at University-owned property in west St. Louis County generates more electricity than what is consumed by the building (however this was only possible after much "learning on the job"). In addition, there have been a handful of formal evaluations and numerous more informal evaluations of solar and wind on campus.

The existence of a number of interesting studies along with the unique characteristics of the University's energy system led to the development of this study, where we more closely consider potential applications. Many of the past endeavors were very broad, with proposals to replace the entire amount of electricity or natural gas consumed on campus with a renewable system. Our goals were more modest, and sought to identify and promote smaller-sized applications in specific locations where these renewable resources fit particular needs. We have completed this task using a process that involved three graduate students, including two from engineering and one from the Business School. First, existing information and studies were collected and analyzed to determine potential renewable energy installations on campus. Those studies are summarized in Chapter 2. It became apparent during this assessment that many of these studies were too vague or poorly defined to serve as blueprints for implementing specific renewable energy projects, yet the information gathered in them was quite useful in determining the most promising technologies to consider.

Once the technologies were established, we consider their deployment in a number of locations throughout campus. This discussion was held informally between the research team and members of the University's Facilities Department, which knows the campus utility system best and is responsible for all capital projects. These informal discussions were meant to serve as a means of identifying the most promising places to implement renewable energy on campus. The outcome from those discussions is given in Chapter 3. Once the potential locations to consider these projects was identified, an economic

evaluation was developed to provide the University decision makers with an appropriate assessment of both costs and savings along with other, less quantitative benefits. The results of that economic evaluation were used to compute the net present value for specific projects This information will be provided to the Facilities Department in assisting their actions to move forward with project implementation.

2 Summary of Prior Evaluations & Activities

With the recent growth in concern over greenhouse gas emissions, the University has been quite active in a variety of areas covering more sustainable living. This commitment is most obvious in the establishment of the Vice-Provost-level post of Director of Sustainability, which is the single person responsible for directing all of the campus-level activities associated with sustainability. (A new Sustainability Director was announced on August 22, 2011.) In addition to the presence of this individual, there have been a number of other activities conducted throughout campus under various groups, department and organizations that fit within sustainability. Much of the key technical research efforts on energy efficiency and renewable energy have been conducted by students and faculty in the College of Arts and Science, the School of Architecture, and in the School of Applied Science and Engineering.

The information generated throughout the University was researched and reviewed. Activities can be divided up into existing installations, student-led assessments, and vendor-based studies. These activities are very different and lead to different conclusions about the feasibility and justification for more renewable energy systems on campus, so each set is discussed in more detail below. A copy of the Washington University Strategic Plan for Environmentally Sustainable Operations can be found at the following web link:

http://www.wustl.edu/initiatives/sustain/strategicplan2-final.html

2.1 Vendor-Based Studies

A handful of vendors have approached Washington University to consider installing renewable energy systems. These installations have a variety of formats depending on the technology chosen, along with economic considerations. As a non-profit institution, Washington University does not qualify for many of the tax benefits and other incentives available from governmental bodies when installing renewable energy systems such as wind or solar. Vendor-sponsored studies often propose to avoid this issue so that ownership of the equipment remains with the vendor, and the energy generated by the renewable goes to the University “over the fence”.

These arrangements have the benefit of accessing credits and tax benefits that are crucial to making renewable systems affordable, but they can present thorny issues about equipment access, liability, and maintenance. In the past, Washington University has been reluctant to enter into the agreements needed to make these arrangements possible. Nevertheless, this reluctance has not kept certain vendors from proposing these projects, two of which were identified. Those two studies are presented below.

2.1.1 Solar Thermal Electric by Kohkola

Kokhala Energy, Inc. proposed a renewable energy power purchase agreement with Washington University for Brauer Hall in July, 2009. Kokhala's proposal called for the company to design, build, own and operate a solar electric thermal system on Brauer Hall. Output from the system was designed to provide electricity and hot water to the building for 25 years at below market prices. Kokhala intended to own the equipment for the duration of the contract, while Washington University had the option of buying the equipment at fair market price after six years of operation.

Initially, Washington University was to pay Kokhala $ 0.04 per kWh generated and $ 1.00 per therm equivalent generated, and these rates were to be adjusted annually based on inflation.
The preliminary system included a 25 kW solar array for electricity and a solar thermal plant with a capacity of 100 kWt (341,300 btu/hour). The system is more complex than many solar systems; the heat transfer fluid passes through a solar collector and fluid heater to a heat exchanger. That heat exchanger passes the solar heat to a separate loop, where it is pumped along with waste heat from chillers or other refrigeration systems through an expander to generate AC electricity. The hot water exiting the expander flows to a hot water storage tank for use as space heating or domestic hot water consumption. The system included 200 square meters of photovoltaic arrays and a CPC thermal collector with evacuated tubes operating on a supercritical organic Rankin heat engine cycle.

While a provocative and enticing proposal, the project was not initiated due its technical complexity, which concerned Washington University facility staff. Further, Washington University was reluctant to allow third-party ownership of equipment on University property.

2.1.2 Solar Thermal Hot Water System by Engineered Solar Solutions

Engineered Solar Solutions of St. Louis proposed installing a solar hot water system at the Danforth House on Washington University's South 40 (the area where dorms are located). The system was designed to give a 60 degree temperature rise to 854,000 gallons of water annually. The proposed system was a closed loop heating system, with the heat transfer fluid passing through a heat exchanger to transfer the solar energy to the domestic hot water. The collectors used ESS evacuated tube collectors, with a glycol based solution circulated to a storage tank designed to raise the temperature of the incoming domestic hot water.

The system included a differential controller, expansion tank, air scoop, pressure gauge, pressure relief valve and other safety mechanisms. Given the preliminary nature of the proposal, a price estimate of $ 150 to 200 K was quoted. At current natural gas prices of $0.80 per therm, this would save the University under $ 4,000 per year. Given the poor economics of the installation, it was not pursued.

2.1.3 Summary of Vendor Studies

Vendor-based studies are an intriguing possibility for Washington University that have not yet been adequately explored. Both proposals, by Engineered Solar Solutions and by Kokhala Energy, were of a preliminary nature and lacked specificity has to how best to incorporate the devices into the campus energy systems. However, both vendors are well-respected ones that have been successful in implementing systems of a similar size in other areas.

There is promise in pursuing more of these "over-the-fence" proposals, which enable a private organization to obtain federal and state government tax credits and rebates to help the overall project costs. However, the chief obstacle from the University's viewpoint is equipment ownership. The University would rather not allow a third-party owner of energy generating equipment on its property, and particularly in more difficult places to access like roofs and penthouse mechanical rooms. Yet, in order for these types of schemes to work the third-party must have access at all times. Further, damages incurred from interactions between a privately owned renewable energy system and University property has not been addressed to the University's satisfaction. It is clear, however, that problems with implementing these arrangements are

more legal than technical. Further efforts to resolve the legal issues would be time well spent.

2.2 Student-Led Studies

Given the University's prominence as a research institution, there have been a variety of student-led initiatives considering potential renewable energy installations on campus. The research team reviewed these studies, which are discussed individually below.

2.2.1 Campus-Wide Solar Energy Panel Study

Dacanay and Menon (2009) conducted an evaluation of installing photovoltaic panels on various buildings on the Danforth campus. (The entire study may be accessed on line at www.aerosols.wustl.edu/education/energy/SolarPanel/index.html.) The authors presented their findings with the caveat that they recognized that installing PV systems on campus is not economical, and estimated the unit cost of solar electricity to be 20 to 25 cents/kWh. In spite of the economic hurdles recognized upfront, the intent of the study was to determine the approximate capacity of roof space on the Danforth campus available for installing PV panels.

Using 2008 electricity consumption data, the students determined that annual consumption of electricity on the Danforth Campus is 120 million kWh. In order to generate this amount of electricity using solar PV arrays, the campus would need 90,000 1-kW solar arrays (consisting of six 170 W solar panels each). If the solar panels were to lie flat, this number of solar panels would be equivalent to 169 acres. Given that the entire Danforth campus is about 127 acres, using solar PV to supply all electricity needs is clearly unworkable.

The students next estimated the total potential roof area available for installation of solar panels. They first estimated the output of solar arrays if all 1,000,000 square feet of rooftop on the Danforth campus was covered in solar panels, and determined that this represents about 12.7 percent of the electricity used on campus in 2008. However, these assumptions are unrealistic because many roofs on campus are not flat, and laying the solar panels flat would reduce their output due to the incidence of sunlight throughout the year. Given this limitation, the

students instead assessed 13 of the more than 180 buildings on campus more closely for solar power feasibility.

Thirteen different buildings were chosen based on size and use. The potential footprint for solar systems was evaluated using two methods: first, University records on building square footage were obtained and listed; second, Autocad records of each building were obtained and evaluated to determine building footprint. This information was then used to estimate the amount of south facing area on each roof. This estimate, in turn, was used to estimate the amount of area realistically available to install solar panels. Based on their analysis of the 13 buildings and projecting those results to the entire campus, the students estimated that using all of the suitable space on campus would enable the University to produce approximately two (2) percent of their electricity from solar PV.

The students took the analysis one step further by developing a detailed analysis of a few optimal locations and the associated costs. In their analysis, they focused on three structures, including the Athletic Complex, the library, with flat roofs and one parking garage. Their analysis showed that these systems would collectively produce about one (1) percent of the campus' electric needs (1.2 million kWh per year) at a cost of $ 4.82 million. However, this cost was solely for the panels and did not include a number of important considerations, including construction, panel mounts, and other electrical devices (e.g. inverters and monitoring systems), nor does it factor in the structural stability of placing the panels on the buildings' roofs. Thus, the actual costs would be considerably higher. In fact, total costs for solar arrays already installed at Washington University buildings suggest costs of $ 7 to $ 9 per kWh, or higher. This will be discussed in more detail below.

2.2.2 Danforth University Center Carbon Evaluation

A different student team from a class titled "Sustainable Air Quality" in Spring 2010 completed a carbon evaluation of the Danforth University Center (DUC). The DUC, which was completed in 2007, is the University's student union. With over 111,000 square feet, it includes a variety of dining areas, cafes, kitchens, offices and meeting rooms. The building is open 24 hours per day and though it includes a number of energy efficient technologies is a significant energy user.

Unfortunately, most energy sources (i.e. natural gas, electricity, etc.) are not metered at the building level throughout the campus, so one important component of the study was to estimate electricity consumption and other energy uses within the facility. The students made good use of previous energy modeling done on the building during design and construction as it was built in an effort to obtain LEED certification. Using that model, they estimated that total energy use within the building was about 20,000 MMBtu per year.

While the focus of the project was on establishing the carbon emissions related to the building, the project team assessed the potential for renewable energy use within the building. Their focus was strictly limited to electricity use because that was the largest energy stream consumed and accounted for nearly 60 percent of the building's carbon emissions. The team considered solar photovoltaic and wind generated electricity as possible sources.

Their findings are instructive. In order to replace the facility's electricity with solar photovoltaic, the team determined that the total panel installation area would need to exceed 57,000 square feet. Based on a twenty year lifespan for the panels, the team calculated that the total cost for this electricity would be $ 0.21/kWh. Wind power fared slightly better as the lifetime cost for the wind turbines would cost about $ 0.116/kWh. The students concluded that even with a carbon tax, the option of paying the tax and continuing to use the existing grid electricity at a cost of $ 0.045/kWh is the most economical approach. This conclusion exemplifies the challenge faced in implementing renewable energy systems in eastern Missouri in general and at Washington University in particular.

2.2.3 Solar Thermal Heating at Millbrook Pool

During Spring, 2011 an undergraduate engineering student conducted an assessment of using solar thermal heaters to heat the swimming pool in the Athletic Complex (Holt, 2011). The University's Facilities Department provided data on the water consumption at the indoor, Olympic-sized pool. The pool is not heated continuously; instead, water dumped during the cleaning process is replaced with water which must be heated using an indirect heating system. That system is fed through a steam loop serving the Athletic Complex and other buildings. The

process consumes approximately 4,000 gallons per cleaning, which are done biweekly. Assuming a loss of 4,000 gallons every two weeks and that the water is heated to 80 °F, the student estimated total heating needs at approximately 67 Mbtu per year.

Using the calculated heating need, the student determined that a solar thermal heating system using seven (7) evacuated tube collectors would meet the heating needs for providing heating to the makeup water. The solar tube collectors cover about 280 square feet and weigh a little more than 1,000 lbs, which are modest requirements for installation. The system could be installed on a lower roof at the complex, which would eliminate the need for roof penetrations and potentially reduce installation costs. A detailed economic evaluation was not completed, but a ballpark estimate of $ 10,000 to $ 15,000 was given. We used this assessment as the basis for a more detailed cost estimate in Chapter 4.

2.2.4 Summary of Student-led Studies

The initial student-led studies focus on replacing a portion of the campus' energy supply using either solar arrays or wind generators. In fact, it is unlikely that our review of these studies is comprehensive because, given the University's decentralized nature, it would be a challenge to identify all of the studies conducted in the past. Based on the research team's subsequent findings, along with discussions between the research team, the Office of Sustainability, the Energy Reduction Committee, and the University Facilities Department, both the solar evaluation and the DUC carbon study come to the similar conclusions: renewable energy systems, like wind generation and solar arrays, are a very hard sell and not economical at Washington University. In fact, their cost estimations are remarkably consistent and show that the installed cost for solar is somewhere above $ 0.20/kWh and for wind somewhere above $ 0.10/kWh.

On the other hand, the third student-led study evaluates solar water heating. This technology shows more promise because it replaces a more expensive energy source (i.e, natural gas rather than electricity). Unfortunately, the campus' domestic hot water needs are rather small, and the huge infrastructure in place for the campus low-pressure steam plants can make this an economic challenge, too. Much will depend on the future costs of natural gas which was extremely volatile in the first

decade of the 2000's. With the advent of advanced methods to extract natural gas, such as fracking, much of this volatility has been reduced in the past few years. Thus, in the near term more price volatility is unlikely, which will suppress the potential for solar hot water at the University.

2.3 Washington University Renewable Energy Installations

Both vendor studies and student efforts provide important reference for the feasibility of specific projects on the Washington University campus. However, perhaps the best way to assess potential feasibility is to review the existing installations currently installed on the campus. There are three specific installations at Washington University, including solar panels and a wind turbine on Brauer Hall, a solar array at the Tyson Research Center in southwest St. Louis County, and a solar array on the campus main library. Each of the installations is described in this section.

2.3.1 Solar Array on Olin Library

A student environmental group led the installation of a 1 kW array on the roof of Olin Library, situated in the center of the campus. The system has produced power since its installation in 2005 with a minimal level of maintenance. Installation funding was solicited from a variety of on-campus sources; unfortunately, there is no record of total expenses and much of the labor and material costs were donated. While this installation verified the theoretical possibility of installing solar PV on campus, it is of little help in determining the economic viability of this form of renewable energy. A picture of the array is presented on Figure 2.1. Output from the array on a daily, weekly, yearly and lifetime basis can be reviewed at the following web site:

http://view2.fatspaniel.net/FST/Portal/CromwellEnvironmental/OlinLibrary/EndUserView.html

Figure 2-1: A 1 kW solar array installed on the roof of Olin Library

2.3.2 Renewable Systems at Tyson Research Center

Completed in 2009, the Living Learning Center is Tyson's newest building. Built to address Tyson's growing needs for research and teaching space, the Living Learning Center is also designed to meet the most stringent green building standard of the time, the Living Building Challenge. Among other requirements, Living Buildings must create all their own electricity and harvest all of their own water. Electricity used at the facility is provided by a 23 kW solar array that is equipped with tracking capabilities to follow the sun's path. This improves the array's efficiency to generate sufficient power to meet the facility's yearly electric demand. Electricity is not stored at the site; instead the facility is connected to the grid, and excess energy flows into the grid while grid electricity is used at nighttime and during low production periods (e.g cloudy winter days). Array output can be reviewed at

http://view2.fatspaniel.net/PV2Web/merge?&view=PV/standard/Simple&eid=258485

In its first full year of operation the solar array successfully produced more electricity than what was consumed on site. However, major modifications (i.e. the tracking capabilities) were necessary before the array could achieve this feat. Those modifications greatly increased the costs associated with implementing the renewable energy features. The initial design called for a fixed array, but the modifications drove the installation costs up to a grand total of approximately $ 100,000 for a 23 kW array, or about $ 4,300/kW. The solar array meets all of the building's energy needs due to a very efficient building envelope and the use of a geothermal heat pump; however, the return period on the solar array is greater than the lifetime of the project.
Output from all soalr panels on campus can be reviewed at:

http://solarpanels.wustl.edu/

2.3.3 Renewable Systems on Brauer Hall

Brauer Hall opened in August, 2010 and its 150,000 square feet are home to the Department of Energy, Environmental and Chemical Engineering. In addition, it is home to the School of Engineering Dean's office, over twenty laboratories, numerous offices, a long-distance learning classroom and a vivarium. For educational and demonstration purposes, a solar PV array and wind turbine were installed on the roof of the building.

The solar PV system consists of forty-two (42) Evergreen ES-A-205 solar modules and a Fronius IG Plus inverter. Output from the array flows into the building's electrical system; given its small output in relation to overall building use, it is used entirely within the building.

The system has a rated output of 9.8 kW according to the vendor. From January through July, 2011 the system produced 6,325 kWh. Given that during that time period there were approximately 2,200 hours of daylight, the effective output of the system during daylight hours was closer to 2.8 kW, or about 1/3 of the manufacturer's rated output. This is an important consideration because it demonstrates that in order to develop a solar array capable of meeting a facility's entire needs, array size must take into account those periods, even during daylight hours, when production will be minimal.

In addition, the building has a wind turbine with a rated output of 1 kW. The turbine has 58 kWh in the first seven months of 2011. If a similar analysis is conducted on the turbine, output from that device is only equivalent to 11 W (i.e. 0.011 kW), or about 1 percent of the turbine's rated output. There are two principal reasons for this poor performance of this turbine. First, the location of the turbine is less than ideal in that it is located on a portion of the roof lower than the peak. Second, the turbine needs a minimum of 4 mph wind before it generates any electricity. Thus, while it may spin at lower wind speeds, no electricity is generated.

The building's solar array and wind turbine output can be observed at the following link:

– http://www.eece.wustl.edu/brauer

The solar array was installed during the building's construction so apportioning the costs associated with its installation proved to be a challenge. Certain activities, such as the use of the crane to lift the system onto the building's roof could not be accurately determined because the construction crane used was already on site. However, the best estimate developed was approximately $ 96,000, or about $ 10,000 per kW of manufacturer's rated output. This is fairly high but within the range shown by other WU projects.

Figure 2-2: The 8 kW solar array installed on the roof of Brauer

2.3.4 Biodiesel

In November 2009 the WUSTL dining services (operated by Bon Apetit) partnered with a St. Louis company Kelley Green Biofuel, founded by 2008 WUSTL alumnus Kristopher Kelley to collect and distill used cooking oil from the campus to diesel for the dining services truck.

Cooking oil is collected at three campus locations including, the Village House, Mallinckrodt Student Center and the South 40 House. Collection amounts depend on usage but during the most recent school year (2010-2011) ranged between 75 and gallons per week. The oil is collected at the three locations, trucked to a refinery in Louisville, Kentucky (along with other collected cooking oils), and converted to biodiesel using a transesterfication process. The fuel is returned to the campus and stored in a 300- gallon holding tank at North Campus.

One gallon of waste vegetable oil yields about one gallon of biofuel, which is approximately equal to one gallon of petroleum biodiesel (by energy content). In order to make the process work, Kelley Green adds a small amount of petroleum diesel, depending on the time of year. (Additional petroleum diesel is added in the winter for freeze protection.) The company is able to convert the biodiesel at a cost of about $.057 to $ 1.00 per gallon, but total consumption is only about ½ of the total oil delivered to the company.

One possible renewable project is the expansion of this process to include other used cooking oil sources to power more campus vehicles. That exercise is presented in a subsequent chapter.

2.3.5 Summary of Existing Renewable Installations

The existing renewable energy installations are demonstrative of the many challenges in implementing new energy systems. Even in the case of new construction, solar and wind generation compete poorly (at least on an economic basis) with grid electricity. In the case of Washington University's Danforth campus, renewable systems cannot compete with electricity priced below $0.05/kWh.

While solar is technically feasible, the local experience with wind is even less encouraging. The National Renewable Energy Laboratory publishes wind resource maps of the contiguous United States; the St. Louis region's wind resources fall just below the threshold that NREL considers adequate for wind development. Of course, this guidance is for larger turbines, so it may be more appropriate to implement smaller systems on the campus. However, the experience at Brauer shows that technical feasibility may not be the primary stumbling block to implementing wind power. There was concern that the installation of a windmill on Brauer may detract from the architectural style that predominates this campus setting. Any such installation will have to be designed with an aesthetically pleasing style and complement the gothic buildings and campus setting.

The campus experience with solar and wind installations shows that widespread implementation of these systems will face a variety of obstacles. Thus, the project team concluded that other, more uncommon renewable energy sources should be considered. Possibilities like cofiring of boilers with biomass, niche applications of solar PV, solar

hot water heating, and biodiesel may have a better chance at implementation. These ideas are explored in the next chapter.

3 Project Short List Descriptions

3.1 Development and Evaluation of Project Ideas

Based on an intensive literature search, research conducted to date at the University, and the results from several installations already in place on various Washington University buildings, the project developed a list of four primary projects which could find potential application on the campus.

It becomes clear upon assembling the results of the various studies along with existing information on the economics of various renewable installations that renewable energy systems are difficult to justify on conventional economic bases. In fact, the great majority of installations on campus and in the St. Louis metropolitan area have taken full advantage of various rebates and tax incentives, and these are crucial to getting many projects installed (Confidential interview, 2011). This conclusion is further bolstered by the results of a Task Force assembled by the Chancellor to assess the energy use on campus which concluded that while commendable, the high installation costs of both solar and wind generation combined with the low cost for natural gas and electricity in St. Louis did not justify widespread implementation of renewable energy systems. In fact, the Task Force concluded that capital budget and effort should focus on energy efficiency first.

A list of all renewable energy project ideas given any consideration is presented on Table 3-1. Given the history of renewable energy installations on campus, along with the Energy Task Force's focus on energy efficiency, our team concluded that proposing additional solar PV and wind installations was not justified. Instead, we focused on alternative renewable energy systems. A third, common renewable energy idea with much merit in Missouri was quickly rejected because of technical infeasibility. Geothermal heat pumps use the earth as a heat source and heat sink through the use of closed-loop piping drilled into the ground. The campus uses an underground steam and chilled water loop for heating and cooling, and buries all electrical and telecommunication cable. Given the density of these installations and

the limitations of a land-locked, urban campus, we determined that there was insufficient land in which to install the ground piping, and so the idea was not studied further.

Table 3-1. List of renewable project ideas.

Ideas Rejected	Ideas Considered	
Solar PV for electricity	Cofiring boilers with biomass	Green waste digester for methane gas
Wind turbine for electricity	Converting cooking oil to biodiesel for campus vehicles	Water turbines in campus domestic water pipes
Geothermal heat pumps	Solar hot water for domestic hot water uses	Solar PV for outdoor lighting

Six project ideas were considered and are described in the section below.

3.1.1 Solar Hot Water Heaters

While electricity generation by solar photovoltaics was deemed inappropriate, solar thermal (which is the direct heating of hot water for domestic consumption) is more promising. Renewable energy contractors are installing these systems with more success in the St. Louis area. One of the prime reasons solar thermal is being installed while solar PV is not is that solar thermal displaces natural gas, which has in the past ten year been more expensive and volatile than electric costs. These systems are most appropriate where domestic hot water use is high, such as in dormitories or cafeterias. Typical office and classroom buildings have rather small hot water consumption patterns and so are typically not good candidates for these systems. However, a demonstration system was installed on the roof of Brauer. Technical difficulties unrelated to the technology's applicability to the campus are precluding its use currently but it likely to be operational in early 2012. Two specific solar hot water heating applications are examined in the next chapter.

3.1.2 Cofiring Boilers with Biomass

Using biomass in boilers is not new to Missouri. Biomass has been in use at the University of Missouri power plant since 2007 (University of Missouri, 2007). The power plant boilers have been cofiring wood waste up to 10 percent with coal in the existing plant boilers. The university recently made the decision to replace an existing boiler with a 100 percent biomass-fired boiler that will produce 150,000 pounds of steam per hour. This will increase the power plant's steam output by 30,000 pounds per hour once the unit is replaced-enough to build capacity and meet anticipated growth. The new boiler should be in operation in 2012.

Figure 3-1: The University of Missouri investigated the possibility of using corncobs in their boilers before settling on wood

The motive behind a new boiler was initially to expand the overall power plant capacity, but the University's pilot evaluation helped evaluate the feasibility of using biomass. The new boiler will displace coal use at the facility by about 25 percent.

In a related manner, in 2009 Washington University installed a $ 7 million 1-MW pilot scale boiler to evaluate clean coal technologies. The University ended the direct firing of coal on campus in the 1990's, so the new one is used strictly for research (although steam output from the facility will be used on campus). The Advanced Coal and Energy Research Facility (ACERF) is a greenfield pilot-scale (1 MW, thermal) research facility designed for the development and testing of new technologies for large-scale combustion applications, with emphasis on reducing carbon and pollutant emissions, carbon capture, and CO_2 utilization. Areas of active research include: oxy-coal combustion, biomass cofiring, mercury control, burner design, fly ash utilization and

algae production in high CO_2 combustion flue gas. ACERF has a unique test furnace for high-temperature oxy-fuel applications, and is one of the largest oxy-fuel facilities located at a university. It is accessible to industry, faculty and students within the U.S. and abroad. The University has already conducted important research on combustion using oxy-fuel techniques (Holtmeyer et. al., 2011) and impacts associated with cofiring with biomass (Skeen et. al., 2010). The potential for cofiring the boiler with biomass is examined in the next chapter.

3.1.3 Outdoor Lighting on Solar Photovoltaic

As a non-profit, the University is unable to take advantage of solar system tax credits which greatly improve the economic picture for solar installations in eastern Missouri, yet the University enjoys very low unit electricity costs. Thus, electricity generation using solar photovoltaic is uneconomical for Washington University. Nevertheless, there are occasional places where solar powered systems may make economic sense. One such possibility is in outdoor lighting on selected places on campus.

We considered a small-scale but noticeable example of installing solar PV powered lights on selected surface parking lots close to existing student housing. These systems are manufactured by SolarOne of Needham, MA. The company manufactures a variety of styles and systems, but all rely on LED lighting to minimize power draw. The light comes with a 50 to 130 Watt panel (depending on the number of lamps), a lamp or lamps with an output ranging up to 2400 lumens, one or two 12 volt, 118 Ah batteries, a charge controller and an LED driver (one per lamp). It can be used as a direct replacement for any pole mounted light standard currently used on the campus' parking lots. (Pedestrian walkways are lit by more decorative posts for which the company does not make an equivalent). We considered the possibility of replacing the lighting on the top level of four garages, including Millbrook, Wohl, Lien and Snow, which constitutes a total of 54 lighting standards. Evalution of the outdoor lighting project is presented in the next chapter.

3.1.4 Cooking Oil Conversion to Biodiesel for All Campus Vehicles

Washington University has four (4) diesel powered campus vehicles used by a variety of departments for various purposes. We assumed that each vehicle is driven approximately 5,190 miles per vehicle per year, based on 2009 estimates from the University greenhouse gas emissions

inventory, where it was assumed the vehicle mileage was 20 mpg. If a fuel efficiency of 10 miles per gallon is assumed, total fuel consumption is approximately 7,800 liters per year.

Figure 3-2: WU's campus contractor for dining services, Bon Appetit, operates one delivery truck with biodiesel from waste oil

Currently they are producing 150 gallons (567 liters) per week, which powers one Bon Appetite truck. So, during the year there is (theoretically) enough biodiesel produced to power all University diesel trucks, with additional volume left to power other vehicles, such as Campus Circulator buses. Extension of this program is developed in the next chapter, but assessment of this possibility is complicated by a lack of data on the amount of cooking oil consumed and collected. The University uses a third party for the collection and conversion; the third party mixes the University's oil with other sources and so determining volumes proved to be a challenge. Given the use of a subcontractor and the lack of data, developing cost estimates also proved to be a challenge.

3.1.5 Green Waste Digester for Methane Production

One renewable energy idea which is gaining prominence, particularly in the United Kingdom, is the anaerobic digestion of food waste and landscaping. The digestion process yields a medium grade methane gas (with approximately 60 % of the energy content of pipeline-quality natural gas). These green waste digesters are heavily promoted for homeowners (where the gas is not collected for reuse). However, on larger scales it is possible to collect the gas and use it to power a small microturbine.

The grocery chain Sainsbury in England signed a three year contract in 2010 to send food waste from forty of their stores to an anaerobic digestion facility operated by a waste management firm (IGD, 2009). The

firm uses the waste to power an electricity generator. The concept is currently in use by Harvest Power, Inc. of Waltham, MA at their British Columbia facility operated by Fraser Richmond Soil and Fibre, Ltd (Sanderson, 2010). The company is constructing an anaerobic digester for food waste and yard debris to be collected from the companies' current collection routes.

This idea has significant merit within the Washington University campus. With approximately 10,000 students and staff on campus during the work week, the campus generates an enormous quantity of waste during the academic year. The waste generated has the potential to generate significant amounts of methane gas. The methane gas could then be used in the existing boilers currently present on campus to provide steam for comfort heating. Based on assuming that 4.5 lbs of food is discarded by each person per day (EPA, 2003), we estimated that the campus could realistically collect approximately 7,500 lbs of food waste from the campus for approximately 250 days per year. The campus has a much lower population during the summer months, so the collection cannot be year round.

Based on estimates for typical energy content from food waste, we determined that a food waste digester would produce slightly more than 13,000 cubic feet of biogas per day with the potential to displace 86 therms of purchased natural gas daily. Based on $ 0.90 per therm for natural gas, this could save the University approximately $ 19,360 per year.

This idea has merit but it would not come easily. There would be labor charges associated with collecting the waste and putting it into the digester. Two primary obstacles to implementing this renewable energy project is the construction of a biogas digester and the improvement in the collection rates of food waste. Ideally the food waste would need to be placed somewhere on the campus to minimize the transportation needed to get the food waste to the digester, but space on the campus is at a premium and so siting the digester could prove difficult. In addition, the University already has a collection program for food waste which does not collect anywhere near the amounts estimated in this study. Improving the collection process will require that the University embark on a large educational campaign and improve the overall collection

process. A University green waste digester is evaluated in the next chapter.

3.1.6 Water Turbines in Campus Domestic Pipes

A unique renewable energy method is through the installation of small turbines in potable water distribution pipes. The water within potable water pipes is under high pressure, typically more than 45 psi, which is generated by pumps at the treatment plant and within the distribution system. The turbines are in essence pumps that run backward. The turbines generate electricity, which can be used onsite or put back into the grid. The method is not truly a renewable energy technology, but rather an energy recovery device in that a portion of the energy used to pump the potable water is recovered by the turbine.

The turbines recapture a portion of the energy used to pump the water at the treatment plant. These devices are relatively new to the market and have only limited experience. One manufacturer of these devices is Rentricity, Inc. of New York (*www.rentricity.com*). The company manufactures and installs turbines but focuses primarily on municipalities for installation within their distribution systems. There are two technical problems with this measure. First, the commercially-available turbines are sized for larger mains (6-inch diameter or greater) and thus would be less appropriate for the University which, while a larger user, is nevertheless a water customer, and so does not have many large diameter water pipes. Second, any smaller-scaled systems would not recovery sufficient energy to make their installation at the University worthwhile. Given these two problems, this idea was not pursued further.

3.2 Summary of Projects for further evaluation

Six projects were considered for evaluation. After initial, "back-of-the-envelope" analysis five of the six were deemed viable enough to conduct a more thorough evaluation. That more thorough technical and economical evaluation is presented in the following section. The chosen projects are given on Table 3-2.

Table 3-2. Summary of Measures for Further Evaluation	
Measure No.	Description
1	Solar Hot Water Heaters for Athletic Complex Pool
2	Outdoor Parking Lot Lighting Conversion to PV Power
3	Cooking Oil Conversion to Biodiesel
4	Cofiring of Advanced Coal Pilot Boiler with Biomass
5	Food Waste Digester for Biogas Generation

4 Detailed Project Evaluations

The measures listed in Table 3-2 were chosen based on a preliminary assessment of their technical and financial feasibility. Once these projects were identified, detailed cost estimates were developed to better determine the feasibility of each potential project. The economic evaluations were based in part on the development of a spreadsheet tool which could take into account certain noneconomic factors, including potential carbon-reducing value. Carbon emissions do not currently have a cost associated, but the University is committed to a sustainable development path and thus considers the impact of carbon emission reductions in the projects considered. In these circumstances, the University uses a value of slightly less than $ 20 per ton of carbon emitted.

The spreadsheet tool used to assess individual projects was based on one used by the University administration to evaluate capital projects. The spreadsheet determines a project's net present value (NPV) for the life of the project. Lifespans varied from 12 to 20 years, while inflation was assumed to be 3 percent per year. In all cases, these lifespan assumptions are likely conservative, given the reliability of systems currently available on the market. However, this method enabled the research team to provide a more direct comparison to each of the possible renewable energy ideas. In order to be a project worthy of funding, the NPV must be greater than zero.
Detailed evaluations are summarized below.

4.1 Solar hot water heater at Athletic complex

One of the more promising renewable energy ideas on campus is the use of solar to heat domestic hot water needs. The technology is well-established, efficient, and fairly cost-effective in the St. Louis region. Its economical nature is driven primarily by the fact that it displaces natural gas, which has in recent years become more expensive (and with greater price volatility) than electricity from the grid. The price volatility in the mid-2000's is unlikely to return in the near future given the advances in natural gas drilling in the continental U.S. from fracking. However, demand for the energy source will continue to grow given its low carbon footprint compared to other fossil fuels.

As presented earlier, an undergraduate student evaluated the technology to heat water in the pool at the Athletic Complex (Holt, 2011). This evaluation was further refined by the project team and is presented here.

The Athletic Complex has an Olympic-sized pool for lap swimming and diving competitions. The pool is open for a variety of team sports, intramural competitions, and other water-related activities year round. The pool is located indoors, so there is very little water lost through evaporation. However, the pool has a filter which is backwashed on a biweekly basis. The backwash is discharged to the sewer, so makeup water must be heated prior to use. According to WU facility staff, backwashing the filter uses approximately 270,000 gallons per year. Based on the average water temperature, it was calculated that heating needs were 67 million btu per year to heat the makeup water.

Further investigation revealed that the pool is heated using waste heat from the pool's dehumidification system, and steam heat is needed only occasionally when the heat recovery system is inadequate (e.g. major cleanings or extremely cold and dry periods). Thus, the actual heating load is likely less than the 67 MBtu estimated here. In spite of this difference, a preliminary system design was developed and is presented.

The evaluation process included considering a number of solar collector technologies. The chosen method was evacuated tube collectors, where the heat transfer fluid is circulated through a separate tube positioned within a vacuum tube. The design protects the fluid from freezing and preferentially absorbs ultraviolet wavelengths, making them effective collectors on cloudy days (which is one of the problems with solar systems in St. Louis). A diagram of the evacuated tube collector is presented on Figure 4-1.

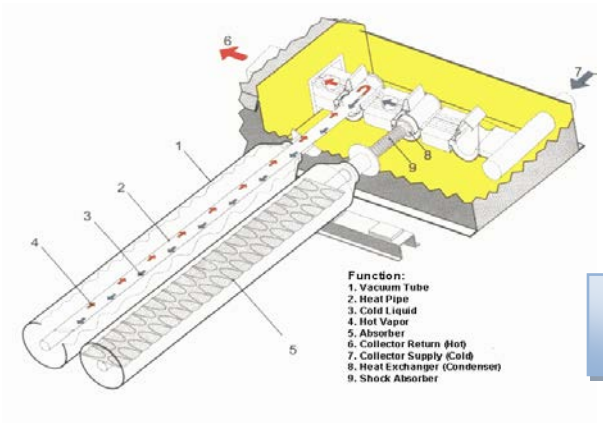

Figure 4-1: Diagram of an Evacuated Tube

The undergraduate student developed a system using seven (7) evacuated tube collectors which, according to his calculations, will meet the computed demand. The heat reclaimed from the dehumidification system contributes a portion of that reheat, but some steam heat is needed to meet total heating demands. Unfortunately, there is no metering of the energy used within this system, so it is challenging to determine the total heat needs. Given the fact that the University's non-profit status precludes its use of any tax credits, the payback on these systems is not as good as it could be. Nevertheless, the technology has merit and could be successfully implemented. The financial analysis is presented below.

Table 4-1. Summary of Economic Evaluation of Solar Hot Water Heating at the Athletic Complex

Installation Cost	$ 12,500
Energy Savings per year	225 therms
Annual value of saved energy (1st year)	$ 225.41
Carbon emissions avoided per year	13.3 tons
15 yr Net Present Value (with carbon emissions)	$ -8,697

4.2 Outdoor Parking lot lighting Conversion to PV Power

Located in an urban environment, Washington University places a premium on safety and security. Thus, lighting on campus is a significant safety and aesthetic concern. SolarOne (www.solarone.net) is a Massachusetts-based company that manufacturers solar-powered outdoor lighting. Washington University has strict standards for path lighting throughout the campus, and recently installed a limited number of LED lights specifically made to meet this standard. However, the lighting used on surface parking lots has a less stringent standard and the SolarOne Basic Series Overhead Light could be

used. However, the entire lamp and post would need to be replaced because the model includes the lamp, solar panel, charge controller, battery enclosure and battery, and lighting controls. A typical system is presented on Figure 4-2. The light offers a variety of benefits. Besides offsetting carbon dioxide emissions and eliminating the associated power costs, the system is immune to power outages. Further, there is no need for trenching of power lines and the associated repaving. In addition, there is an important marketing benefit because the solar panels are readily visible and will "advertise" the University's commitment to sustainable development.

The financial assessment of this measure was done in two ways, to better evaluate the measure. As noted above, the University is currently in the midst of emphasizing energy efficiency. One of the initial measures taken by the University has been retrofitting of lighting in many parking garages, where existing metal halide bulbs were replaced by fluorescent bulbs. Further, a small portion of bulbs on campus were replaced with LED lighting, which is considerably more expensive than fluorescent lighting. Thus, from an economic analysis, the PV-powered lighting was compared to both fluorescent lights and LED lights. That analysis is presented in Table 4-2.

Figure 4-2: SolarOne's Basic Series Overhead Light

Table 4-2. Summary of Economic Evaluation of PV Powered Parking Lot Lighting(1)	
Installation Cost (per fixture)	$ 1,500
Energy Savings per year	1,095 kWh
Annual value of saved energy (1st year)	$ 49.28
Carbon emissions avoided per year	0.9 tons
15 yr. Net Present Value (with carbon emissions)	$ -1,356
(1) Values above are on a per lamppost basis	

4.3 Cooking Oil Conversion to Biodiesel

As the price of oil has risen, interest in alternative transportation fuels has risen. There are a variety of potential feedstocks, but one of the more common is used cooking oil. In fact, plant-based biodiesel has become mainstream, with the U.S. Environmental Protection Agency establishing minimum amounts of biodiesel be used in the United States starting in 2011. The vegetable oil can be burned directly in diesel engines or converted to biodiesel by way of a simple esterification process. The biodiesel is mixed with conventional, petroleum-based diesel (up to 20 percent by volume) as a way to expand the use of home-grown sources for energy and reducing dependence on foreign oil supplies.

As explained previously, the University's food service contractor currently collects used cooking oil from several cooking operations. That material is collected by a third party, which collects, stores and processes the material before reselling it to the University. The used oil is stored in large tanks so that sediment and suspended water settles. The supernatant is trucked to a refinery in Louisville, Kentucky, where it is transesterified to convert it into biodiesel. The biodiesel is mixed with additional petroleum diesel with the ratio varying based on the time of year (cold winters demand a higher conventional to biodiesel ratio).

Based on a preliminary assessment conducted by the research team, the amount of oil produced on campus is sufficient to power all of the University vehicles on campus. The University has only four (4) diesel trucks using a total of 20,000 miles per year (based on the University's Sustainability Assessment). The University would need to convert the diesel trucks so that they could run on the used cooking oil. The cost associated with this is typically minor for the engine conversion, but can be problematic when adding a separate tank. In addition, there are labor costs associated with collecting the used oil which are currently borne by the third party subcontractor but would become the responsibility of Washington University staff.

One member of the project team worked on a similar program at the University of Illinois as an undergraduate student. The program was set up and operated as a demonstration through one of the University of Illinois' research centers (WMRC, 2005). An important observation in the report concerns obtaining the waste vegetable oil, which can be secured from individual grease containers at

restaurants or from grease recyclers. The group found that the waste oil from grease recyclers is free of solids and water but costs more, has a higher percentage of fatty acids that are challenging to transesterify, and can only be purchase in bulk (i.e truckloads rather than 55 gallon drums). On the other hand, while restaurant grease has little or no cost, it can be a challenge to collect it, particularly in the cold winter months when it can solidify. Implementing a more extensive program to capture all used cooking oil will necessitate that the University invest in personnel trained to properly handle this material.

The financial analysis is summarized below.

Table 4-3. Summary of Expanding the Used Cooking Oil Program

Installation Cost	$ 25,000
Energy Savings per year	6,300 gallons diesel
Annual value of saved energy (1st year)	$ 27,119
Carbon emissions avoided per year	63.5 tons
15 yr. Net Present Value (with carbon emissions)	$ 132,046

4.4 Cofiring of advanced coal boiler with biomass

Given that in the previous section the feasibility of cofiring with biomass was established, the research team took the next step and assessed the feasibility of conducting long-term cofiring at the research boiler located on the Danforth campus. This assessment involved discussions with the staff members and research personnel involved with the Consortium for Clean Coal Utilization to determine if long-term cofiring of biomass was suited to the site.

The 1 MW boiler has been installed in one of the University's engineering buildings, but it was quickly apparent that its location represents a major challenge. A renewable energy project would entail the long term procurement, storage, and use of biomass at the facility. Unfortunately, the facility is located within the confines of the campus and therefore has limited amounts of space available for storage of any raw materials. This presents a major problem for cofiring of biomass because the biomass has a lower btu content per unit volume than coal, which leads to the need for large storage areas for any biomass.

A second problem is that the boiler as configured uses only pulverized fuel, so any biomass would need to be finely-grained (i.e. similar to sawdust). A final problem concerns the facility itself which has been designed as a pilot-scale system designed as an evaluation tool for different firing and fuel concepts rather than a power generating facility. In fact, the boiler's steam is injected into one of the campus' steam loops but no electricity is generated.

Given these limitations, it was determined that cofiring of biomass in the coal boiler is not feasible at this time. The University has a number of natural gas boilers currently in operation throughout the campus, including a handful converted from coal-fired boilers which are located very close to the pilot facility. However, those boilers are not suited for cofiring and would require specific changes. Given the problems entailed by implementing this renewable energy system, this idea was dropped from further consideration.

4.5 Food Waste Digester for Biogas Generation and Use

Food waste contains significant energy value and thus can be processed to obtain that energy. The most practical way to process the waste is to anaerobically digest it, and collect the biogas released in the process. The biogas can either be used directly for heating or can be combusted in a generator, such as a microturbine, to produce electricity. Given the large number of people living on a typical college campus, the food waste generated can be significant. Rather than disposing of the material in a landfill, it can be collected and digested to produce a renewable energy source.

At least one university in the U.S. currently collects food waste to generate electricity. Purdue University has partnered with city of West Lafayette, Indiana to accomplish the project. The City's wastewater treatment facility underwent an upgrade and installed microturbines to generate electricity from methane produced by the facility's anaerobic digester. The engineering consultant worked with Purdue University staff to collect food waste from the dormitories, grind it to a fine pulp, and add it to the digester. The digestion of the food waste with the wastewater treatment solids improves methane output, thus improving the turbine performance and output (EPA, 2009).

The approach used in Indiana has an important advantage. The turbine is a high-cost item; by taking advantage of the local wastewater treatment facility, the program makes use of existing infrastructure in place at the wastewater treatment facility. In the St. Louis metropolitan area, most wastewater

treatment facilities do not digest their biosolids so Washington University would be more limited; if it could be transported, it would still remain a feasible option. Additionally, the program eliminates an existing waste stream that the Purdue had to pay for removal.

Figure 4-3: Yard waste from food carts are dumped into a receiving tank at West Lafayette's wastewater treatment facility.

The major obstacle in installing a food waste digester is in the collection program. By its nature, food waste is highly dispersed. A collection program must be similar in scope to a recycling program in order to better capture as much waste as possible. In addition, the waste must be transported to the digester site. These costs can be significant and must be considered in the development of any new program. We attempted to consider two possible food digester projects. The first would place the digester on campus, and use the methane produced in the existing boilers located on the South 40 (student housing section of the campus). This project entails installation of a new digester and associated gas cleaning equipment. The second would follow the Purdue model, and transport the food waste off-site to a wastewater treatment facility located about 25 miles from campus. This option would entail construction of a storage tank at the wastewater facility, and contracting with a hauling company to get the food waste to the facility on a weekly basis. A summary of the estimates developed for both options is presented on Table 4-4.

Table 4-4. Summary of Two Food Waste Digester Options

Item	*Option 1 – Digester on Campus*	*Option 2 – Transport to WWTP*
Installation Cost	$ 12,500	$ 3,000
Energy Savings per year	24,092 therms	24,092 therms
Annual value of saved energy (1st year)	$ 24,092	$ 24,092
Carbon emissions avoided per year	162 tons	162 tons
15 yr. Net Present Value (with carbon emissions)	$ -360,133	$ -71,785

An interesting aspect of the "Purdue" option is that the economic benefits will flow principally to the wastewater treatment facility instead of Washington University. The economic analysis considered overall project benefit and a more accurate analysis would have excluded the value of the biogas from the analysis (from the University's perspective). In either case, the NPV is negative and thus a poor use of existing capital funds, yet carbon credits will accrue to the University. Considering their pledge to achieve 1990 levels of carbon output by 2020, this project should be reconsidered once the more easily identified projects (e.g. energy efficiency) have been identified and implemented.

5 Summary & Conclusions

This project focused on developing a detailed analysis of potential renewable energy projects throughout the Danforth campus of Washington University in St. Louis. Basing our initial emphasis on data collected through a variety of vendor-based and student-led initiatives, we identified six different possible projects which had the potential to be cost-effective renewable energy projects for the campus. Yet of all the projects studied, only one had a positive Net Present Value (NPV). Future steps for that project is presented in the next section. The poor economics developed in this analysis shows that renewable energy systems are not an economically viable option for Washington University. Other, more productive uses for limited capital should be pursued. In the area of energy use, Washington University would benefit best from a more focused effort on improving energy efficiency. The implications of this issue are explored in the final section.

While this result is unfortunate, it is also instructive in the helping the University direct future efforts on reducing carbon emissions. The computation of NPV depends largely on the assumptions used. It could be argued that our assumptions were too conservative, and thus led to negative NPVs which might otherwise be different. For instance, we assumed a carbon cost of $ 20 per ton, and a 3 percent inflation rate. If comprehensive carbon legislation is adopted in the United States, these numbers will probably be conservative. However, at the time of this study we believe that there is very little likelihood that any carbon tax will be adopted. The projects identified in this study will be worth another look if limits on carbon are established and those limits proceed to rise with time. Until then, it may be best that Washington University focus its efforts on other opportunities.

5.1 Recommended renewable energy projects

In retrospect, the single successful renewable energy project that the project team was able to identify makes sense. A significant hurdle for the University in the renewable energy field is, ironically, its tax-exempt status. The overwhelming majority of solar and wind installations in the St. Louis area are relying on rebates and tax credits to ensure economic success. The University, given it's status, is unable to take advantage of these benefits. Taking away a primary tool to successful implementation combined with very low energy rates

makes the more conventional renewable energy options out of reach. However, the project team identified a potentially ideal project that is already underway. The University could potentially fuel all of its existing diesel-fueled cars and trucks through a more complete collection and conversion of vegetable oil. While this is already practiced on a small scale, the University should expand the program.

Project economics are greatly helped by the cost of diesel, which at the time of this report hovers around $ 3.50 in eastern Missouri . However, before pursuing this venture Washington University should consider several important points. First, the annual inflation rate assumed on this project (and all renewable projects) was assumed to be 3 percent. This is a fair assumption given current fiscal policies but is more for the long term (i.e. 7 years or more) rather than the short term. In the short term, inflation will likely remain low as the economy struggles to regain its footing. Also, we assumed only mild increases in the cost of the used vegetable oil and wastes. However, once the value of the oil and food waste is more widely recognized, it is likely that the price of these materials may rise. If the rise is significant, the economics of this project could change significantly.

In summary, however, the prior experience of this project makes implementing it a simple task. Washington University should consider expanding the collection of used oil from other buildings besides the Danforth University Center, with particular emphasis on the two dormitory kitchen areas on the South 40 and in the east Village.

5.2 Energy efficiency

One very large opportunity, which has already been identified by the University, is energy efficiency. Given the historically low cost of electricity and the emphasis on adding building space on the Danforth campus, there has been less focus on energy efficiency. Nevertheless, the University has incorporated a number of energy efficiency measures in the past to reduce overall use. As noted in the University's Energy Committee Report (Webber et. al., 2010), square footage on campus has expanded by 87 percent, but the energy costs avoided by incorporating energy savings into new building design has yielded savings of $ 76.9 million since 1992. Much of these gains have been achieved through significant changes in the campus' energy supply networks and through improvements in the building systems installed in newer buildings. For instance, the University converted from a single high-pressure steam system for building heat to a number of smaller, low-pressure steam

systems. The conversion led to saving over $ 600,000 annually in natural gas. In addition, variable frequency drives are installed on all ventilation fans in new buildings on campus. These drives vary the speed of the motor driving the fan, and in the process save energy, yet they were not installed in any buildings built prior to 1995. There is clearly a move towards developing and implementing a more formal energy efficiency program.

Most recently, the University Facilities department has launched a significant meter installation program. Given the complexities of the campus' electrical and natural gas delivery and use systems, the metering project is a significant technical and fiscal challenge. However, it has become obvious that metering is crucial to implementing energy efficiency projects on campus.

In the meantime, there are a number of energy efficiency measures that can be implemented. The installation of heat-recovery chillers to eliminate the need to run the thermal plants during the summer is one excellent example. A variety of more simple measures in lighting, HVAC and hot water heating could also be adopted. Based on the results defined in this study, the technical and fiscal resources of the University are better focused on reducing the campus' current energy footprint. Once that footprint has been minimized, the justification for a more aggressive implementation of renewable energy systems should be launched. At that point it is possible that capital costs for solar may have decreased sufficiently to make these systems more affordable.

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Appendix A. Economic Model Output for Alternatives

Solar Thermal for Pool

Solar Thermal

Energy saved per system	**225**	therms
	1.0	
Cost of therm	**$1.00**	per therm
Installed cost	**$12,500.00**	for system
Carbon emission factor	**0.006723000**	metric tons of carbon per therm
Value of a metric ton	**$17.84**	
Inflation/salary increases	**3.0%**	per year

Hours of operation per day	24	
Hours of operation per year	8,760	
Array lifespan	15	years (65,700 hours)
Carbon emissions per year (metric tons)	13.3	
Therms generated each year	**225**	

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Fixture purchase cost	-$12,500.00						
Labor to replace fixture	0.00						
Value of gas	225.41	232.18	239.14	246.32	253.71	261.32	269.16
Avoided Carbon "expense"	236.83	243.94	251.26	258.79	266.56	274.56	282.79
Total costs		$476	$490	$505	$520	$536	$552

	Year 8	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Fixture purchase cost								
Labor to replace fixture								
Value of gas	277.23	285.55	294.11	302.94	312.03	321.39	331.03	340.96
Avoided Carbon "expense"	291.28	300.01	309.01	318.28	327.83	337.67	347.80	358.23
Total costs	$569	$586	$603	$621	$640	$659	$679	$699

Total cost over 15 years	-$15,117.46
15 year NPV (using 3% discount)	-8,697.13
15 year NPV wo carbon (3% discount)	-10,229.06

PV for Parking Lot Lighting

Energy consumed per lamppost	**250**	W
	1.0	
Cost of electricity	**$0.045**	per kw-hr
Installed cost	**$1,500.00**	per fixture
Carbon emission factor	**0.000839274**	metric tons of carbon per kw-hr
Value of a metric ton	**$17.84**	
Inflation/salary increases	**3.0%**	per year

Hours of operation per day	12	
Hours of operation per year	4,380	
Lampost Lifespan	15	years (65,700 hours)
Light Lifespan	20,000	hours
Carbon emissions per year (metric tons)	0.9	
kWh generated each year	1,095	(Brauer's 9.8 kW array generated 5161 kWh for 6 months)

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Fixture purchase cost	-$1,500.00						
Labor to replace fixture/lamps	-200.00				-200.00		
Value of electricity	49.28	50.75	52.28	53.84	55.46	57.12	58.84
Avoided Carbon "expense"	16.40	16.89	17.39	17.92	18.45	19.01	19.58
Total costs		$67.64	$69.67	$71.76	-$126.09	$76.13	$78.41

	Year 8	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Fixture purchase cost								
Labor to replace fixture/lamp			-200.00					-200.00
Value of electricity	60.60	62.42	64.29	66.22	68.21	70.25	72.36	74.53
Avoided Carbon "expense"	20.16	20.77	21.39	22.03	22.69	23.38	24.08	24.80
Total costs	$80.77	$83.19	-$114.32	$88.26	$90.90	$93.63	$96.44	-$100.67

Total cost over 15 years	-$1,396.81
15 year NPV of cost wo carbon(using 3%	-1,283.91
15 year NPV w carbon (3% discount)	-1,356.12

Convert cooking oil to biodiesel

Energy generation	**6,300**	gallons
	1.0	
Cost of diesel	**$3.50**	per gallon
Installed cost	**$2,000.00**	LS
Carbon emission factor	**22.384000000**	lbs CO2 per gallon diesel fuel
	0.010072800	metric tons CO2 per gallon diesel fuel
Value of a metric ton	**$17.84**	
Inflation/salary increases	**3.0%**	per year

Gallons per week	150	
Labor hours per year	200	
Array lifespan	15	years (65,700 hours)
Carbon emissions per year (metric tons)	63.5	
Diesel energy generated each year	6,300	gallons

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Capital Expenses	-$25,000						
Labor to collect oil	($10,000)	($10,300)	($10,609)	($10,927)	($11,255)	($11,593)	($11,941)
Avoided Diesel costs	$22,050	$22,712	$23,393	$24,095	$24,817	$25,562	$26,329
Avoided Carbon "expense"	$1,132	$1,166	$1,201	$1,237	$1,274	$1,312	$1,352
Total costs		$13,578	$13,985	$14,404	$14,837	$15,282	$15,740

	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Expenses								
Labor to collect oil	($12,299)	($12,668)	($13,048)	($13,439)	($13,842)	($14,258)	($14,685)	($15,126)
Avoided Diesel costs	$27,119	$27,932	$28,770	$29,633	$30,522	$31,438	$32,381	$33,353
Avoided Carbon "expense"	$1,392	$1,434	$1,477	$1,521	$1,567	$1,614	$1,663	$1,712
Total costs	$16,212	$16,699	$17,200	$17,716	$18,247	$18,795	$19,358	$19,939

Total cost over 15 years	$76,007
15 year NPV of cost (using 3% discount)	$132,046
15 year NPV wo carbon (3% discount)	$65,372

Food Digester Option 1 - Digester on Campus

Energy generation per digester	**24,092**	therms
	1.0	
Cost of gas	**$1.00**	per therm
Installed cost	**$3,000.00**	for system
Carbon emission factor	**0.006723000**	metric tons of carbon per therm
Value of a metric ton	**$17.84**	
Inflation/salary increases	**3.0%**	per year

Therms per week	602	
Labor hours per year	1,500	
Array lifespan	15	years (65,700 hours)
Carbon emissions per year (metric tons)	162.0	
Therms generated	24,092	

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Digester capital expense	-$3,000.00						
Labor to operate digester	-75,000.00	-77,250.00	-79,567.50	-81,954.53	-84,413.16	-86,945.56	-89,553.92
Value of biogas	24,092.25	24,815.02	25,559.47	26,326.25	27,116.04	27,929.52	28,767.41
Avoided Carbon "expense"	2,889.58	2,976.27	3,065.56	3,157.53	3,252.25	3,349.82	3,450.31
Total costs		-$49,459	-$50,942	-$52,471	-$54,045	-$55,666	-$57,336

	Year 8	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Digester capital expense								
Labor to operate digester	-92,240.54	-95,007.76	-97,857.99	-100,793.73	-103,817.54	-106,932.07	-110,140.03	-113,444.23
Value of biogas	29,630.43	30,519.34	31,434.92	32,377.97	33,349.31	34,349.79	35,380.28	36,441.69
Avoided Carbon "expense"	3,553.82	3,660.44	3,770.25	3,883.36	3,999.86	4,119.86	4,243.45	4,370.76
Total costs	-$59,056	-$60,828	-$62,653	-$64,532	-$66,468	-$68,462	-$70,516	-$72,632

Total cost over 15 years	-$370,937.38
15 year NPV of cost (using 3% discount)	-360,133.38
15 year NPV wo carbon (3% discount)	-381,629.81

Food Digester Option 2 - Truck Waste to WWTP for Digestion

Energy generation per digester	**24,092**	therms
Derate Factor (per Brauer)	**1.0**	
Cost of electricity	**$1.00**	per therm
Installed cost	**$15,000.00**	for system
Carbon emission factor	**0.006723000**	metric tons of carbon per therm
Value of a metric ton	**$17.84**	
Inflation/salary increases	**3.0%**	per year

Therms per week	602	
Labor hours per year	700	
Array lifespan	15	years (65,700 hours)
Carbon emissions per year (metric tons)	162.0	
Therms generated	24,092	

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Digester capital expense	-$12,500.00						
Labor to operate digester	-35,000.00	-36,050.00	-37,131.50	-38,245.45	-39,392.81	-40,574.59	-41,791.83
Value of biogas	24,092.25	24,815.02	25,559.47	26,326.25	27,116.04	27,929.52	28,767.41
Avoided Carbon "expense"	2,889.58	2,976.27	3,065.56	3,157.53	3,252.25	3,349.82	3,450.31
Total costs		-$8,259	-$8,506	-$8,762	-$9,025	-$9,295	-$9,574

	Year 8	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Digester capital expense								
Labor to operate digester	-43,045.59	-44,336.95	-45,667.06	-47,037.07	-48,448.19	-49,901.63	-51,398.68	-52,940.64
Value of biogas	29,630.43	30,519.34	31,434.92	32,377.97	33,349.31	34,349.79	35,380.28	36,441.69
Avoided Carbon "expense"	3,553.82	3,660.44	3,770.25	3,883.36	3,999.86	4,119.86	4,243.45	4,370.76
Total costs	-$9,861	-$10,157	-$10,462	-$10,776	-$11,099	-$11,432	-$11,775	-$12,128

Total cost over 15 years	-$73,938.89
15 year NPV of cost (using 3% discount)	-71,785.33
15 year NPV wo carbon (3% discount)	-93,281.77

Appendix B. Map of U.S. States with Solar Mandates

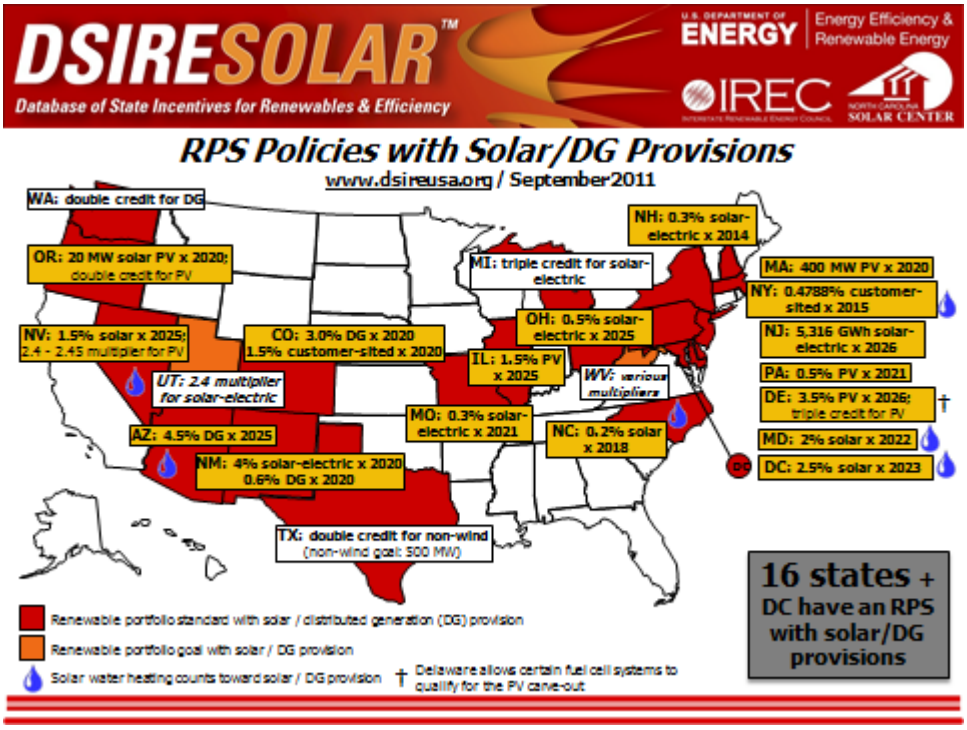

Figure B-1. RPS policies with Solar provisions (DSIRE, 2011)