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March 2, 2015

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LA PUBLIC SERVICE
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VIA HAND DELIVERY

Ms. Terri Lemoine Bordelon
Louisiana Public Service Commission
Records Division
Galvez Building
602 North Fifth Street, 12th Floor
Baton Rouge, LA 70802

Re: Cleco Power LLC - LPSC Docket No. R-28271, Subdocket B
In re: Re-study of the feasibility of a Renewable
Portfolio Standard for the State of Louisiana

Dear Ms. Bordelon:

Enclosed for filing in the above-referenced docket are five (5) copies of Cleco Power LLC's 2015 Renewable Energy Pilot Program Report being filed pursuant to Louisiana Public Service Commission Corrected General Order issued December 9, 2010, as amended and continued by General Order issued September 20, 2013 in the above-referenced docket.

Please date stamp one (1) copy of the filing, and return it us at the time of filing.

If you have any questions, please do not hesitate to contact me at 225-376-0241.

Sincerely,

Paul F. Guarisco

PFG:jj
Enclosures

cc: Ms. Melanie Verzwyvelt
Official Service List

Before the Louisiana Public Commission In re: Re-study of the feasibility of a renewable portfolio standard for the State of Louisiana : DOCKET NO. R-28271, SUBDOCKET B

CLECO POWER LLC's REPORT PURSUANT TO SECTION 7 OF THE LPSC'S RENEWABLE ENERGY PILOT PROGRAM IMPLEMENTATION PLAN, ADOPTED IN THE CORRECTED GENERAL ORDER IN DOCKET NO. R-28271, SUBDOCKET B, ISSUED DECEMBER 9, 2010, AS AMENDED AND CONTINUED BY GENERAL ORDER R-28271 SUBDOCKET B, ISSUED SEPTEMBER 20, 2013

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This report is provided by Cleco Power LLC ("Cleco Power") pursuant to Section 7 of the LPSC's Renewable Energy Pilot Program Implementation Plan (the "Implementation Plan"), adopted by the LPSC in its Corrected General Order in Docket No. R-28271, Subdocket B, as amended and continued by General Order R-28271 Subdocket B, issued September 20, 2013. In an effort to encompass academic research and analysis, Cleco Power teamed up the University of Louisiana Lafayette and the following professors who have provided data for sections of the report relating to biomass gasification, solar thermal power plant, torrefaction, and the digestion of waste material and their potential applications in generating electrical energy:

- Mark Zappi, Ph.D., P.E., Dean of Engineering
- Terrence Chambers, Ph. D., P.E., Associate Dean of Engineering
- John Guillory, Ph. D., P.E., Associate Professor
- Prashanth R. Buchireddy, M. S., Research Scientist
- Jonathan R. Raush, M.S., P.E., Research Scientist

Executive Summary

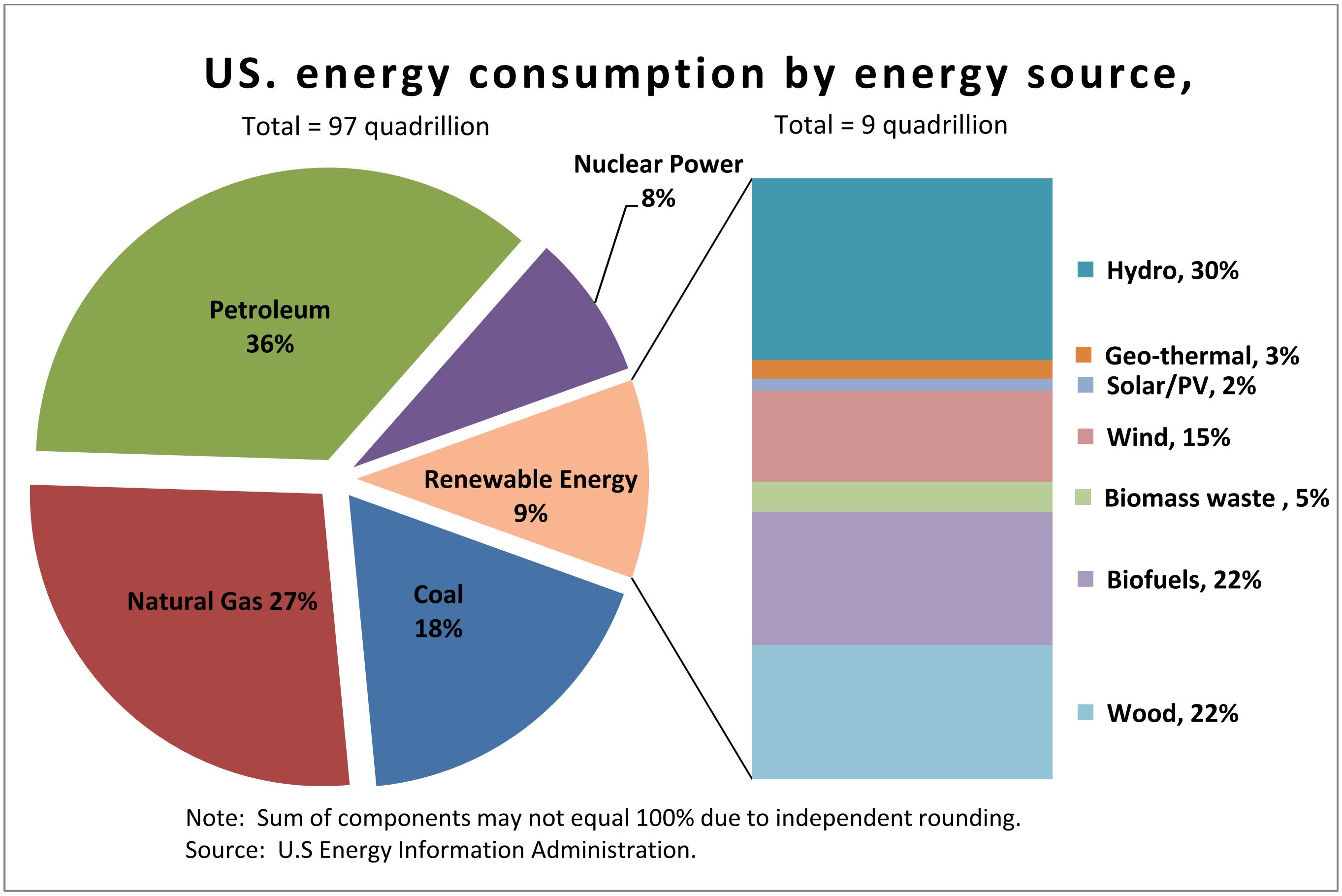
This report details and summarizes Cleco Power's pilot projects researching and analyzing a broad spectrum of renewable energy technologies. Specifically, Cleco Power has conducted pilot projects on: (1) biomass co-firing at its Madison 3 generating plant; (2) biomass gasification; (3) photovoltaic solar generation; (4) solar thermal power generation; (5) wind power; (6) geothermal energy; (7) wastewater digestion; and (8) biomass torrefaction. This report provides overviews of each technology along with a discussion of operational considerations and a technology assessment. This report concludes with a discussion of certain generation costs.

The Availability of Renewables for Energy Consumption

An increase in the demand for energy worldwide has prompted concerns regarding the possible depletion of fossil fuel sources. Hence, attention has been focused on developing alternative energy sources worldwide, including United States. United States has been actively promoting the utilization of alternative energy sources by introducing several policies and legislations such as, “The Energy Independence and Security Act of 2007”, “Energy Policy Act of 2005”, etc.

The most common alternative energy sources available to date include solar energy, wind energy, geothermal energy, hydropower energy, and biomass. In 2013, total energy consumed in the United States was 97 quadrillion BTU, which was generated from coal, natural gas, nuclear, petroleum, and renewables. More than 9% of the total energy consumed was generated from renewable sources (wind, solar, biomass, hydropower, geothermal). Biomass energy by itself accounted for about 50% of the renewable energy produced, as shown in **Figure 1**. Therefore, biomass is considered as a promising alternative energy source that has a potential to replace fossil energy sources to an extent, for sustainable energy production.

Figure 1: The Role of Renewable Energy in the Nation’s Energy Supply, 2013



Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S Energy Information Administration.

Biomass Resources

Forest Biomass

Forest biomass[1] is the most likely biomass fuel for immediate use, because of the physical attributes of the material, its abundant availability, its cost relative to other potential renewable solid fuels, its potential environmental benefits, and the associated opportunities to complement the region's existing forest products industry.

Forest biomass possesses favorable physiochemical characteristics based on a consistent energy content (typically ranging from 8,400 ~ 8,700 Btu/pound) and relatively low ash content (typically less than 2%). The moisture content of "green" forest biomass is 45% ~ 50% (wet basis), although seasoned material can be below 40%.[2]

According to data compiled from the U.S. Forest Service, over 5.4 million tons of harvest slash and rough/cull timber material is generated within 100 road miles of Cleco Power's Madison Unit 3 facility each year; this figure does not include pre-commercial thinning or underbrush.[3]

Based on research from the U. S. Department of Agriculture and the U.S. Department of Energy, and validated by land grant universities in the southern U.S., the rule-of-thumb maximum ecologically sustainable removal rate of harvest slash is 65% of the material generated from timber harvesting and left in the woods. Engaging fuel supply contractors that understand forest biomass sustainability processes and will abide by Best Management Practices and other guidelines as deemed appropriate for central Louisiana conditions by the Louisiana Department of Agriculture and Forestry, the U.S. Forest Service, and/or other qualified entities is critical to maintaining a sustainable supply of forest biomass.

Woody residues from forest products manufacturing facilities are typically sawdust and off-cuts. While these products could be used as fuel at biomass generation facilities, it is not expected that such materials will be targeted as feedstocks since most such materials are already being used as industrial fuel for on-site cogeneration at existing forest products manufacturing facilities and for other purposes. According to the U.S. Forest Service, of the 322 million cubic feet of primary mill residue produced in Louisiana in 2005, "less than 1 percent of

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[1] Examples of forest biomass include harvest slash, rough/cull timber not used as a raw material for value-added processing by the existing forest products industry, pre-commercial thinning, right-of-way clearings, underbrush and other fire hazard reduction material, and whole tree chips from silvicultural improvement or other beneficial land management activities. Additionally, forest biomass can include damaged trees from fire, pestilence, disease, or other causes.

[2] Various management techniques such as delayed harvesting or bundling might be used to reduce further the moisture content of forest biomass materials; mechanical drying is well proven technically, but is generally considered cost-prohibitive.

[3] Unless otherwise noted, all references to quantities of woody biomass will be based on an assumed average moisture content of 50% wet basis; thus, 1 million green tons equates to 0.5 million tons on a dry matter basis.

the residues were not used for a product".[4] However, it can be expected that some woody processing residues may be delivered to biomass generation facilities from time to time without having disruptive effects on existing markets for such materials.

Dedicated woody crops are trees grown specifically for use as fuel. Currently, Cleco Power is unaware of any known commercial tracts of dedicated woody energy crops in the central Louisiana region, although several stands have been under consideration. The primary benefit of dedicated woody energy crops will be the increased assurance of future fuel supplies but the economics of such crops have not yet been determined.

Other Biomass Resources

Agricultural crop residues such as corn stover or rice stubble can be used as supplemental fuel[5] but most crop residues have a relatively high ash and alkali content, which is problematic for many boilers. In addition, supplies are seasonal, and there is currently no significant infrastructure for the harvesting and storage of crop residues in the region. Based on the foregoing, the suitability and availability of crop residues as fuel for biomass generation facilities is currently considered low, relative to forest biomass.
Agricultural processing residues such as rice hulls or sugarcane bagasse could also be used as fuel, although the same physiochemical and availability concerns discussed with crop residues apply to agricultural processing residues.

Dedicated agricultural energy crops, primarily perennial grasses such as switchgrass or miscanthus constitute a possible fuel option for the future. Compared to dedicated woody crops, the primary benefits of grass crops are much higher agronomic yields and the opportunity to use high-productivity mechanized harvesting equipment.[6] However, these fuels have relatively high ash and alkali content, and the economics of such fuels have not yet been determined under Louisiana conditions.

Biofuel generation operating costs are also scale-sensitive; large-scale facilities typically have higher system efficiencies than smaller systems.

While the cost of forest biomass fuels such as harvest slash, underbrush, or cull material is expected to include a nominal "stumpage" cost (e.g., 50¢ to $1.00 per ton), it is far less than typical round wood stumpage prices.

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[4] "Louisiana's Timber Industry—An Assessment of Timber Product Output and Use, 2005"; SRS-130; US Forest Service; March 2008. http://www.srs.fs.usda.gov/pubs/rb/rb_srs130.pdf

[5] "Biomass Energy Resources in Louisiana"; LSU Ag Center; November 2006.

[6] Agronomic yield is generally considered a critical economic factor by bioenergy specialists. Perennial grasses produced in central Louisiana are estimated to attain average yields of 12~18 tons per acre per year (dry matter basis), compared to 2~4 tons/acre/year dmb for dedicated woody crops.

In fact, if for no other reason, higher stumpage costs for pulp timber or saw timber may almost certainly preclude medium-to-large diameter round wood from being purchased and used as biomass fuel for power generation.

Other variable operating expenses include electricity and maintenance (primarily associated with the wood yard equipment). Fixed operating costs primarily include labor, along with other operating expenses typically associated with a power plant operation (e.g., insurance, preventative maintenance, and site upkeep).

The biomass fuel supply chain is considered to encompass the greatest uncertainty for biopower generation. Key issues that must be addressed include the following considerations:

1. Long-term reliability of the fuel supply, taking into consideration the continued viability of the region's forest products industry, potential competition for the resources, and potential disruptions in the supply chain such as hurricanes or other natural disasters.[7]
2. Cost of the fuel and factors affecting fuel cost/price fluctuations, the most critical being the price of diesel fuel for the harvesting, pre-processing and transport equipment. Almost all biomass supply contracts—whether for traditional pulpwood, round wood, or for biomass fuel—include fuel price adjustment clauses reflecting diesel fuel and other inflation/escalation factors.
3. Logistical issues, including the ability to maintain an on-site fuel inventory sufficient to minimize weather-related fuel supply disruptions.
4. Average fuel moisture content. This is a critical factor for power generation, because it impacts the usable energy content of the fuel. Therefore, fuel prices cannot reasonably be based on a delivered cost per ton without adjusting for moisture content. In other words, for power generation the biomass fuel should be purchased on an energy basis, not on a weight basis.
5. The energy content of woody biomass. Btu per pound dry matter basis is relatively consistent, ranging from about 8,300 to 8,700 Btu per pound; most of this variation reflects the tree species make-up or the bark fraction of the delivered fuel.
6. The availability of harvest slash and other forest biomass fuels. This may be greatly affected by the economic vigor of the existing forest products industry, in addition to seasonal variations, primarily reflecting reduced access to forestlands during wet winters. Other supply disruptions could result from inclement weather and/or natural disasters.

The cost of in-woods harvesting and processing, (i.e., gathering, chipping and loading the forest biomass), will depend on the following three factors:

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[7] Without timber production and removals by the existing forest products industry there would be no need for pre-commercial thinnings and no harvest slash generated.

1. The extent of harvesting/collecting/gathering efforts required which, in turn, will be affected by the type of timber harvesting methods used at the particular site.
2. The extent of in-woods chipping required (a function of the type of chipper, particle size requirements, and equipment productivity).
3. Whether the material has to be forwarded from the harvesting/processing site to an alternate load-out location.

Chipped forest biomass is typically transported in either end-dump trailers (i.e., "chip vans" that are unloaded by truck lift dumps) or live bottom trailers that are self-unloading (e.g., walking floors, conveyor bottom, or other styles). Transportation costs commonly consist of a base (fixed) price per load, plus a variable per-mile charge (typically incorporating a fuel price index for minimizing diesel price risks by the hauler). Short distance hauls can be 100% fixed cost, whereas long distance hauls can be 100% variable cost.

Increases in diesel fuel prices affect operating costs at every point in the supply chain. A typical strategy for reducing the potential volatility of delivered biomass cost increases is to index the costs to one or more mutually acceptable indices. The most common index method, and one that is widely used in transportation contracts (including the transportation of timber or pulp chips to forest products manufacturing companies), is to index transportation costs to diesel fuel prices maintained by the US Department of Energy. These prices are published weekly for eight regions across the U.S.[8]

Another price/cost management strategy commonly used within the forest products industry is to index timber or pulp costs to a third-party cost monitoring company; there are several companies that provide such services.[9]

Jobs Impact from Woody Biomass

In 2011, **Sundrop Fuels** announced their intention to develop a biofuels refinery in Central Louisiana. In February 2013, the company completed acquisition of land and is preparing to begin construction. Sundrop Fuels is expecting to create 150 direct jobs in addition to 1,150 indirect jobs in the region. The plant will salvage wood waste from forests in Central Louisiana and adjacent regions and use that biomass as a feedstock in addition to hydrogen from natural gas, and develop up to 50 million gallons of fuel annually. This ultra-efficient process positions Sundrop Fuels to compete directly with petroleum products by delivering to the market an ultra-clean renewable advanced biofuel for an estimated unsubsidized cost of less than $2 per gallon.

Cool Planet Energy Systems announced on July 30, 2014, that they will construct and operate a biorefinery in Alexandria, Louisiana to produce drop-in gasoline and a soil enhancing biochar

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[8] http://www.eia.doe.gov/oog/info/wohdp/diesel.asp

[9] For example, http://www.risiinfo.com/pages/product/pulp-paper/market-prices.jsp or http://www.forest2market.com/f2m/us/f2m2/pulpandpaper/south

from renewable biomass. Site preparation and infrastructure improvements have started. The plant is anticipated to employ 24 people.

Section 1 Biomass co-firing at Madison 3

The LPSC studied the development of a renewable portfolio standard for Louisiana, in Docket No. R-28271, Subdocket B. Pursuant to this study, Cleco Power conducted a series of tests in the last quarter of 2011 through the second quarter of 2012 to assess the feasibility of co-firing its Madison Power Station Unit 3 with biomass and petroleum coke. Cleco Power filed on August 3, 2012, its *Report to the Louisiana Public Service Commission: Co-Firing at the Madison 3 Power Plant*, which summarized the results of its assessment.

Further details on Biomass Gasification and Biomass Torrefaction are presented in Sections 2 and 7, respectfully, of this report.

Section 2 Biomass Gasification

Biomass can be converted to different forms of energy via several routes which can be mainly classified into two groups: a) Thermochemical conversion and b) Biological conversion. Thermochemical conversion can be further sub-classified into combustion, gasification, pyrolysis, liquefaction, etc. Conversion of biomass to energy by biological routes involves various techniques including fermentation, digestion, extraction, etc.

Biomass gasification is the most promising thermochemical route for converting biomass to energy. Gasification process involves partial oxidation of carbonaceous fuels at high temperatures to produce an energy carrier. Gasification of biomass produces fuel gases (producer gas or synthetic gas), which can be used in the generation of electricity, production of transportation fuels and chemicals, hydrogen fuel production etc.

In principal gasifiers have been classified into updraft, downdraft, fluidized bed, entrained flow, and pyrolitic, based on the fuel flow and its support and simultaneously the way air/oxygen flows to the fuels. An overview of the state of gasification technology and survey of gasification which includes gasifier projects and manufacturers around the world is provided in “A Survey of Biomass Gasification”[[1]]. Several advantages and disadvantages exist with the type of gasifier and its operation such as allowable moisture content of the feed, fuel gas purity, fuel gas heating value, size of gasifier, level of impurities. Cleco in conjunction with University of Louisiana at Lafayette have chosen a bubbling fluidized bed (BFB) gasification system owing to its advantages; a) high throughput per unit cross section, b) relatively lower tar and particulate contaminants, c) high heat transfer rates, d) ability to tolerate broad range of biomass types and particulate sizes, and e) ability to tolerate high moisture feedstock.

The BFB gasification system was designed to accommodate the following requirements as well:

- Suitability for waste wood feedstock
- 3 tpd (250 lbm/hr) feed rate
- Compact configuration compatible with future semi-portability
- Operate using both air or oxygen as oxidizing medium
- Ability to supplement steam as an oxidizing medium with air/oxygen
- Product gas usable for either power generation or future gas-to-liquid (GTL) synthesis

Technology

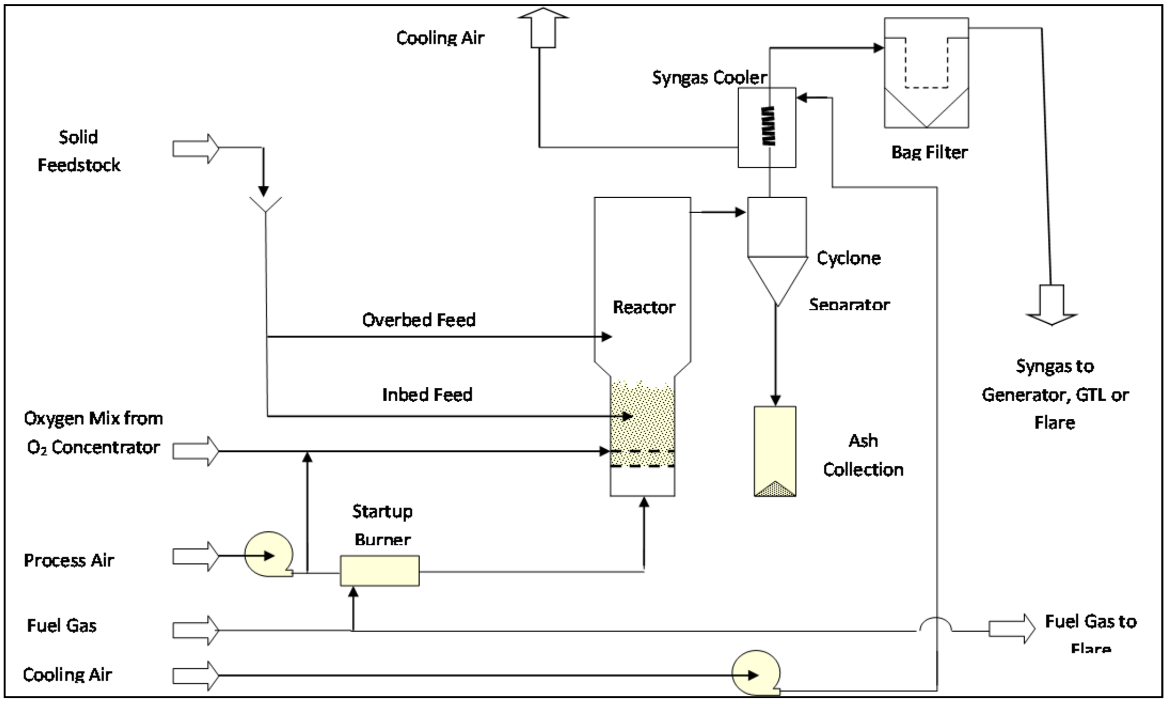
Gasification System

The schematic of the system is shown in **Figure 2**. Major components include

- A fluidized bed reactor with 1’-2” ID bed section and 1’-8” expanded freeboard section
- Provisions for running in either air or oxygen-enriched oxidant modes
- Provisions for either in-bed or freeboard solid feedstock introduction
- Separator cyclone and bag filter for particulate control
- Product gas cooler

The product gas is routed either to an engine-generator system which delivers power to a Cleco transformer or to an elevated flare for disposal of gas during startup and upsets. Dimensions and other technical details of the major components will be provided upon request.

Figure 2: Cleco Power Biomass Gasification System Process Flow



Gasification System Installation, Testing, and Operation

The installation of the 3 ton/day gasification system was completed during the last quarter of 2012 and initial shakedown testing was performed on the system. Since, the gasification system consists of several components that include gasification reactor, cyclone, heat exchanger, pneumatic bag house filter, burner system, flare, generator, piping, material handling system, generator, blowers, motors, and process instrumentation, each component was independently tested prior to testing and operating the gasification system. Post shakedown testing, the biomass gasifier was successfully operated to produce syngas (CO, H_2, CO_2, and CH_4) using biomass such as pine, pine banding board, and oriental stranded board during 2013 and 2014. The syngas thus produced blended with natural gas and was used to generate electricity using a low BTU engine/generator set. The energy produced was supplied to the Cleco electrical grid. A pictorial description of the gasification system is presented in **Figure 3 through Figure 6.**

Figure 3: 3 ton/day BFB Gasification System (Front View)

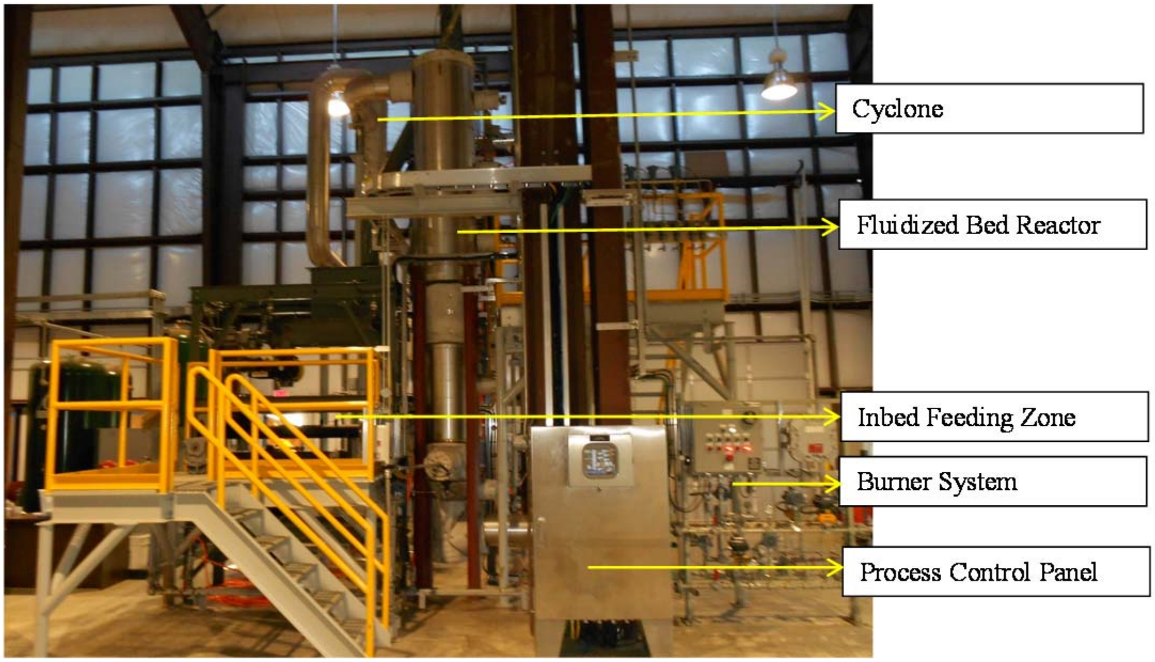


Figure 4: 3 ton/day BFB Gasification System (Side View)

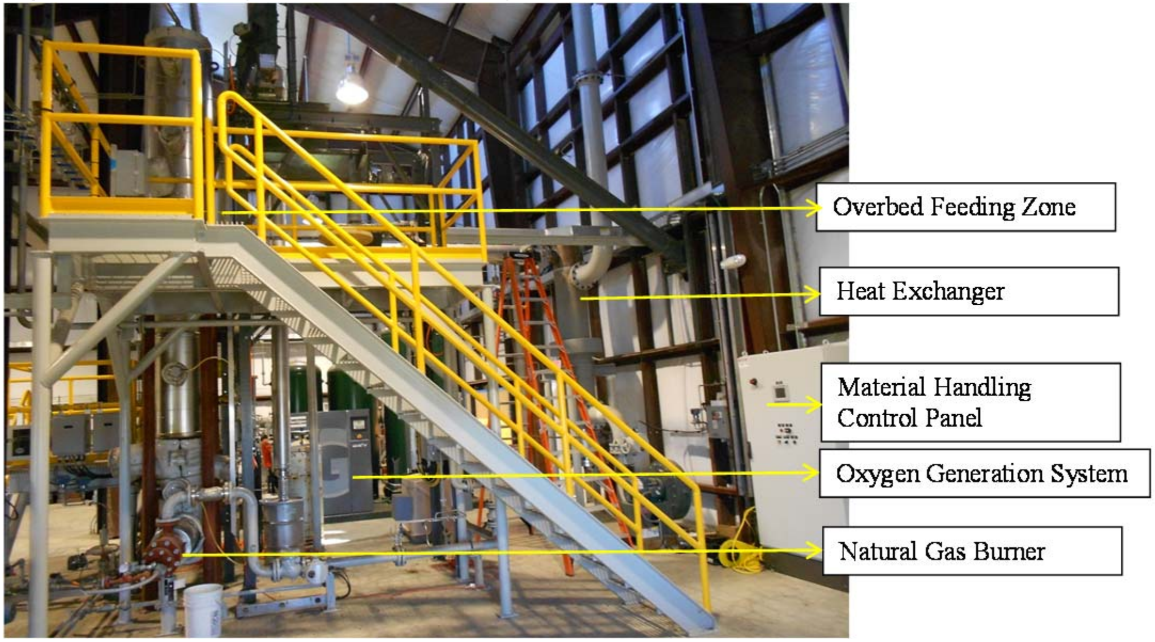


Figure 5: 3 ton/day BFB Gasification System Components

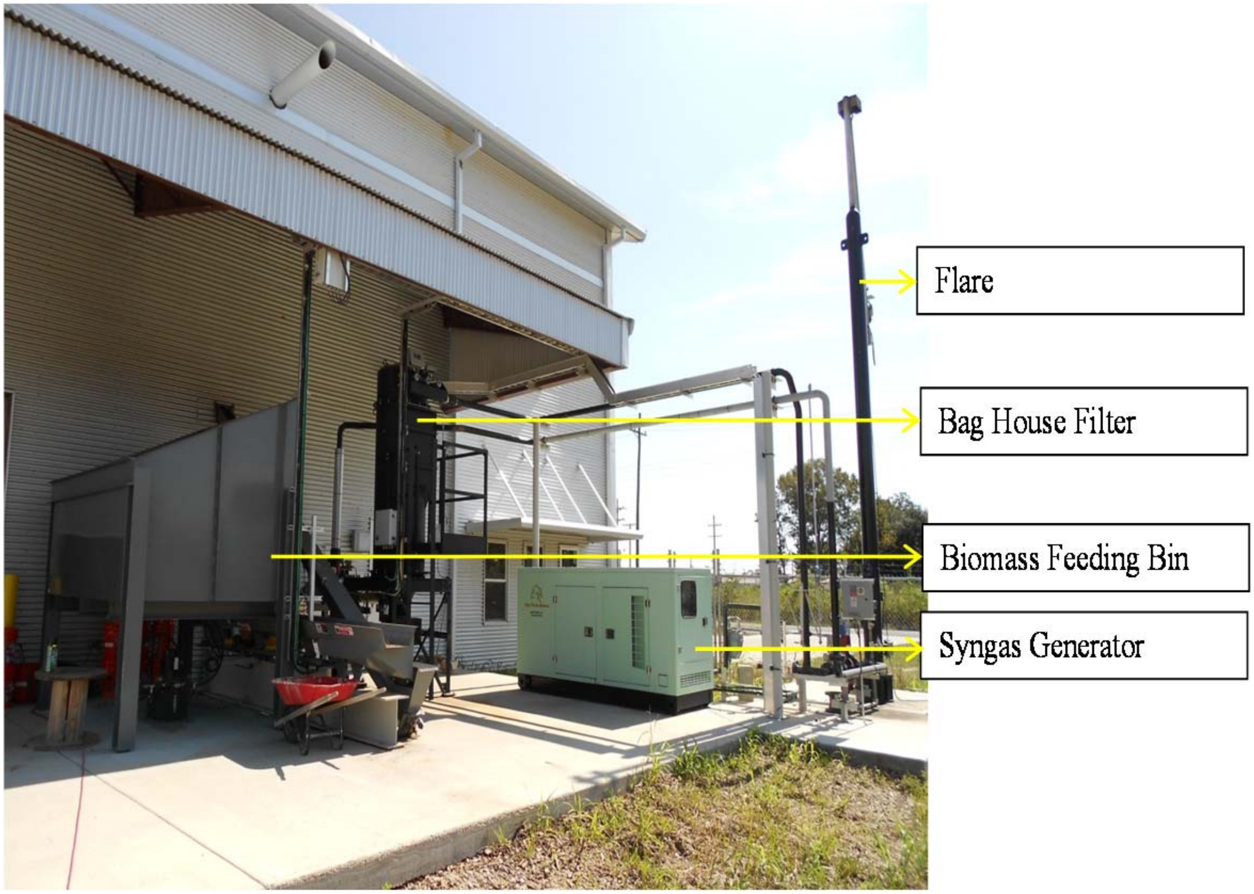
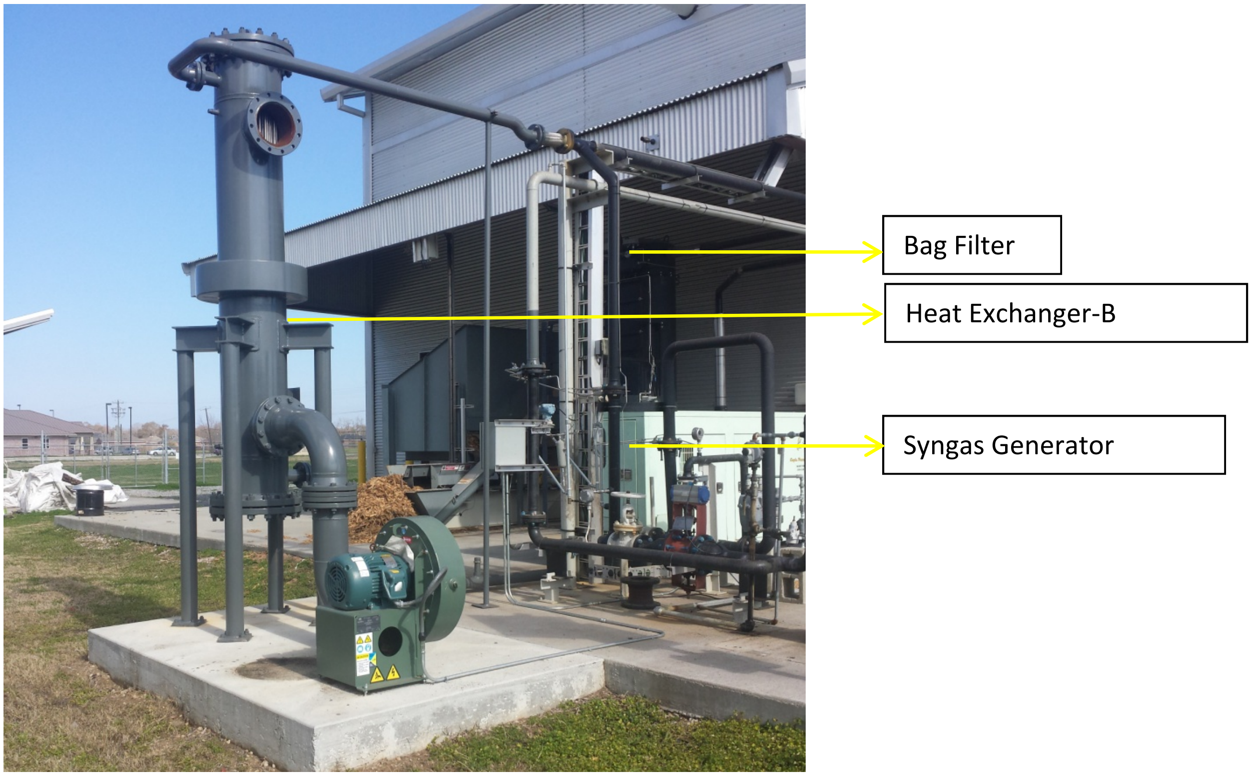


Figure 6: Installation of Heat Exchanger-B between Bag filter and Syngas Generator



Operation of the gasification system continued in 2014 using pine and oriental stranded board as biomass feedstock. The second heat exchanger (Heat Exchanger-B) was installed between the bag filter and generator set which involved construction of support (concrete slab), fabrication and installation of piping, valves, heat exchanger, blower, and associated instrumentation and electrical work. Also, orifice plates were installed to accommodate measurement of flow rates of syngas along all possible routes: 1) Syngas to generator, 2) Syngas routed from bag filter to flare, 3) Syngas bypass line to flare. Post installation of heat exchanger B, plans were to maintain the temperatures of the syngas exiting the existing heat exchanger above the tar condensation temperatures (500 – 600 deg. F) to avoid tar condensation issues as mentioned in the previous annual report. This would allow syngas to pass through the heat exchanger and bag house filter without any tar condensation, while removing the fine particulates from the syngas stream. The temperature of the hot syngas could further be reduced to desired temperatures, ideally 100 deg. F before being routed to the generator according to the specifications provided by the vendor.

As mentioned above, the heat exchanger blower was controlled to maintain the temperature of syngas exiting the first heat exchanger to 500 deg. F. Also, existing Nomex filter bags were replaced with PTFE bags to withstand higher temperatures. Maximum operating temperatures were limited to 375 deg. F. using Nomex bags; however, PTFE bags could withstand temperatures of up to 600 deg. F. Heat exchanger-B that was installed performed according to specifications reducing the temperatures of the gases exiting the bag filter to the desired 100 deg. F. Post installation of the PTFE bags and operation of the gasifier for several runs, it was noticed that two bags had holes the size of a dime or larger, highlighted in red as shown in **Figure 7**. It was concluded that the holes were due to hot entrained particulates that were present in the syngas stream. To counter this issue with hot entrained particulates, an impact screen was installed inside the bag house. This allowed for removal of relatively large hot particulates before the gases hit the PTFE bags and resolved the issue with hot particulates.

The Gasifier was operated without any further issues with tars and particulates, however, this system would allow for the production of clean low temperature syngas only for short time periods. The heat exchanger tubes will have to be cleaned regularly to keep the tubes from plugging and to maintain the pressure drop. Also, the energy contained in tars is not being utilized in the existing set up and all the condensed tars and water will have to be disposed in an approved fashion which is expensive. If all the tars were to be reformed, the potential to improve the quality of syngas is as high as 20% as reported in literature. Issues with tars and associated problems are discussed further in the following section.

Figure 7: Damage to PTFE bags due to hot entrained particulates

Tars and Associated Problems

Tars are a complex mixture of polynuclear aromatic hydrocarbons (PAH's) having molecular weights of greater than 78. They range from single ring compounds such as phenol, to six-ring compounds such as coronene. However, tar formation and composition varies widely and depends on a number of factors including gasifier type, feedstock nature and gasifier operating conditions. The type of gasifier has a significant impact on the tar composition and formation. According to Milne et. Al[2]., a very crude generalization would place updraft tar concentrations at 100 g/m^3, fluid beds at 10 g/m^3, and downdraft at 1 g/m^3. Also, gasifier conditions including reactor temperature, residence time, thoroughness of circulation (fluidized beds), degree of channeling (fixed beds), gasifying medium (air, oxygen, steam) and geometry of the bed have a strong effect on tar formation and composition.

Syngas produced from biomass gasification can be used in a number of applications such as generation of electricity, fuel cells, chemical production, and transportation fuels. However, the presence of tars in fuel gas can lead to several undesired problems and issues. Tar build up can cause blockages, plugging, corrosion, and catalyst deactivation, resulting in serious operational and maintenance problems. For example, tars can condense along the exit pipes and particulate filters, and eventually, tar buildup can lead to blockages and clogged filters. Also, tars can plug and clog the fuel lines and injectors when fuel gas is used in internal combustion engines. During compression, tars can condense in transfer lines and compression equipment leading to clogging and corrosion problems. During gas to liquid conversions, tars pose a threat by deactivating the catalysts[3]. Condensation of tars depends on the dew point of the tars which in turn depends on the composition of tars. Typically, tars condense at 600 deg. F and increase with a reduction in temperature. Higher molecular weight aromatics start to condense at high temperatures followed by lower aromatics with a decrease in temperature.

The problems associated with tars depend on the end use application. Tar tolerance limits for heating applications might be high, but for the production of transportation fuels, negligible amounts of tars in syngas are recommended. Several researchers have recommended tolerance limits for different end use applications, which are provided in **Table 1.** Also, the overall efficiency of the gasification process in terms of energy could be improved by converting tars to fuel gases and the carcinogenic nature of tars pose an environmental and health impact may be reduced[4,5].

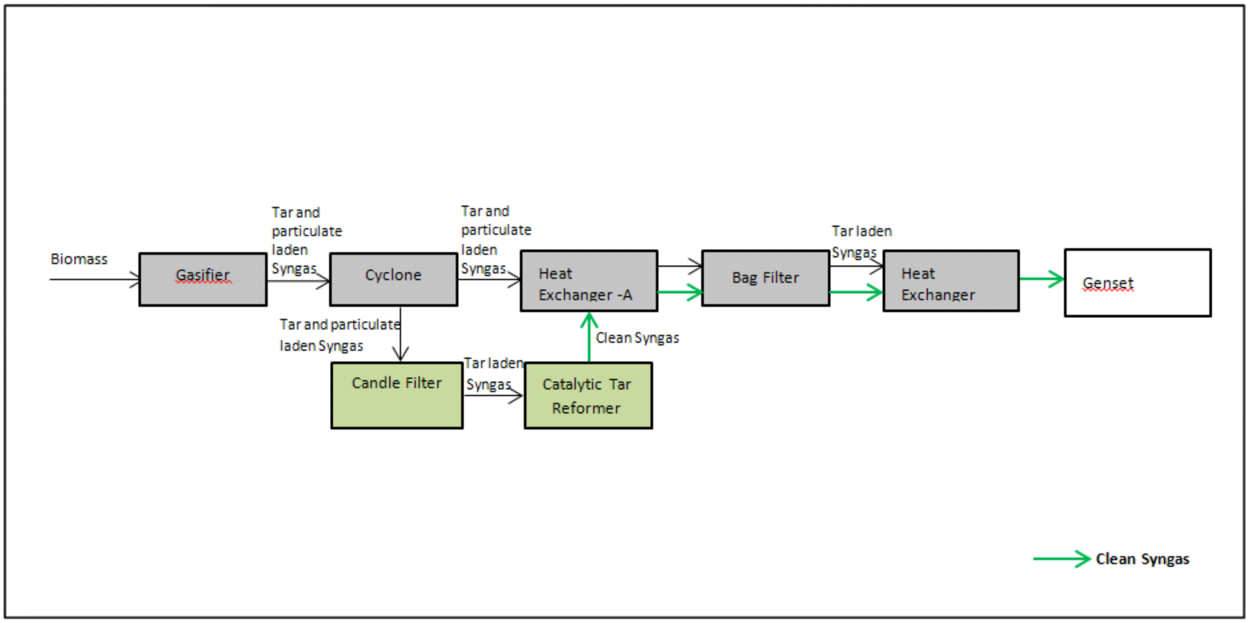
Table 1: Tar tolerance limits for different end use applications

Application	Tar Tolerance Limits
IC Engine	< 10 mg/Nm^3 10-50 mg/Nm^3
Gas Turbine	8 mg/Nm^3 0.5-50 mg/Nm^3
Methanol Synthesis	<0.1 mg/Nm^3

Tar Reforming/Removal Module:

In an attempt to find a permanent solution and tackle the issue of syngas tars, the following modifications/improvements have been proposed and funds have been approved to proceed with the tar reforming unit. Installation of a high temperature ceramic candle filter post- cyclone followed by catalytic tar reformer as shown in the **Figure 8** has a potential to solve most of the issues associated with tars. Installation of the tar cleanup module (ceramic filter and tar reformer) would improve the gasification process efficiency two fold: 1) Produce clean syngas free of tars and particulates and 2) improve the quality of syngas by converting tars to carbon monoxide and hydrogen. Installation of the tar reforming module will enable operation of the generator set to produce power on a continuous basis. Also, this will give our team an opportunity to test novel catalysts on pilot scale. The updated system could also serve as a test bed for external parties interested in testing their catalysts. Hence, funding was requested and approved to resolve the above mentioned issues with tars and successful implementation of the project by generating electricity on a continuous basis. Currently efforts are underway to design a fixed bed catalytic tar reforming system.

Figure 8: Schematic of proposed tar cleanup module



Modifications to the Gasification System

Heat Exchanger Installation

As mentioned in the previous report, condensation of tars was a major issue and potential modifications to the gasification system have been initiated. This issue has been resolved by installing air cooled shell and tube heat exchanger-B between the bag house filter and genset. This heat exchanger was designed and fabricated by Louisville Heat Exchangers, KY and has been installed as shown in **Figure 6**. This allows for syngas to be cooled to 100 deg. F before feeding to the generator set. Also, tars and water condenses along the heat exchanger tubes at these low temperatures, which are periodically being discarded till a permanent system to tackle tar and particulates is installed.

Steam Generator Installation

During 2014 most of the gasifier operation was performed using oriental stranded board (OSB) chips supplied by NorthStar Resources. Syngas generated using OSB gasification yielded very low percentage hydrogen content (< 6%). This was attributed to low moisture content of the feedstock, which was less than 13% during the preliminary analysis. Hence, it was decided to inject steam to the gasifier to improve hydrogen content of syngas. Addition of steam would allow production of improved hydrogen content via methane steam reforming, water gas, and water gas shift reactions. A steam generation system was procured and installed with an ability to inject steam at several locations along the longitudinal axis of the gasifier. Experiments are being conducted to evaluate the effect of steam injection at several locations on the gasifier. Till date, very limited data was generated with steam injection. Future plans would include a systematic evaluation of the effect of steam addition to the gasification process on syngas composition.

Performance of the Gasification System

The gasification system was successfully operated using different biomass feed stocks including pine, waste banding board, and waste oriental stranded board at different operating conditions. Performance data from a test run with waste OSB as feed stock are presented in **Table 2 through Table 4 and in Figures 9 and 10.**

Proximate and ultimate analysis of banding board chips was performed using an elemental analyzer at our laboratory, the results of which are presented in **Table 2**. Gasifier was operated using waste OSB chips sized to approximately 0.5 X 1 inch as feedstock. The operating conditions of the gasifier are shown in **Table 3**. To improve the heat and mass transfer properties, high silica sand was used as a fluidizing medium. As shown in the Table, 120 lb/hr of biomass was fed to the gasifier which was operating at 1,600 deg. F. The equivalence ratio was maintained at 0.23-0.25 by controlling the amount of fluidization air (oxidizing medium) supplied to the reactor. The syngas flow rate produced under the conditions presented in the Table was 75-85 scfm. The temperature profiles along the longitudinal axis of the gasifier are presented in **Figure 9**. As shown in the graph the gasification fluidization zone temperature (TE1000B) was maintained around 1,600 deg. F and the free board temperature (TE1000E) was maintained around 1,300 deg. F. The temperature of the syngas entering the heat exchanger was observed to be approximately 1,100 deg. F as shown in **Figure 10**. The temperature of syngas exiting the heat exchanger was maintained above 450 deg. F to avoid issues with tars as mentioned earlier. The gasifier was operating at 1.5 – 2.0 psig pressure, while the pressure drop across the cyclone was observed to be averaged around 2-4 inches of water.

During the process of gasification, carbon, hydrogen, and oxygen in biomass reacts with oxygen via a series of both exothermic and endothermic reactions such as oxidation, partial oxidation, boudard, water gas shift, water gas, dry reforming, methane reforming, etc. occurring both concurrently and consecutively to produce synthesis or producer gas. Overall, gasification process is exothermic and the heat generated is sufficient enough to sustain the gasification process, hence no external energy is required to run the process.

The rate of syngas produced under the previously mentioned operating conditions ranged between 75 - 80 scfm. Also, the composition of syngas produced during this run is presented in **Table 4** and has a calculated heating value of 133 Btu's/scf. Also, syngas was sampled according to the modified EPA method 5 sampling train to determine the quality of syngas. The sample collected was analyzed on Gas Chromatograph (GC) Mass Spectrometer and GC Flame Ionization Detector. Tar concentrations of over 20 g/m^3 were measured, which is relatively high for a fluidized bed gasifier and could be attributed to the operation of the gasifier at lower equivalence ratios.

Table 2: Proximate and Ultimate Analysis for Oriental Stranded Board

Proximate Analysis		Ultimate Analysis	
% Moisture Content	10 - 13	% Carbon$_{daf}$	48.2
% Ash	2.1	% Hydrogen$_{daf}$	6.7
% Volatile Matter	-	% Oxygen$_{daf}$	41.2
% Fixed Carbon	-	% Sulfur$_{daf}$	0.15
Higher HeatingValue,$_{daf}$ (Btu/lb)	8786	% Nitrogen$_{daf}$	0.12
Biomass Particle Size, (inch x inch)	0.5 x 1		

Table 3: Gasifier Operating Conditions

Feedstock	OSB
Biomasss Feed Rate, lb/hr	120349.1*
Equivalence Ratio	0.23-0.25
Operating Bed Temperature, F	1,600
Operating Freeboard Temperature, F	1,350
Operating Pressure, psig	1.5-2.0
Bed Material	High Silica Sand
Oxidizing Medium	Air
Product Gas Flowrate, scfm	75-80

Table 4: Product Syngas Composition

Syngas Composition	
Hydrogen, % Vol.	5.7
Carbon monoxide, % Vol.	15.9
Carbon dioxide, % Vol.	15.9
Methane, % Vol.	6.2
Nitrogen, % Vol.	56.3
Syngas HHV, Btu/scf	133.2
Tar Content, g/m^3	>20

Figure 8: Gasifier Temperature Profile for run with OSB

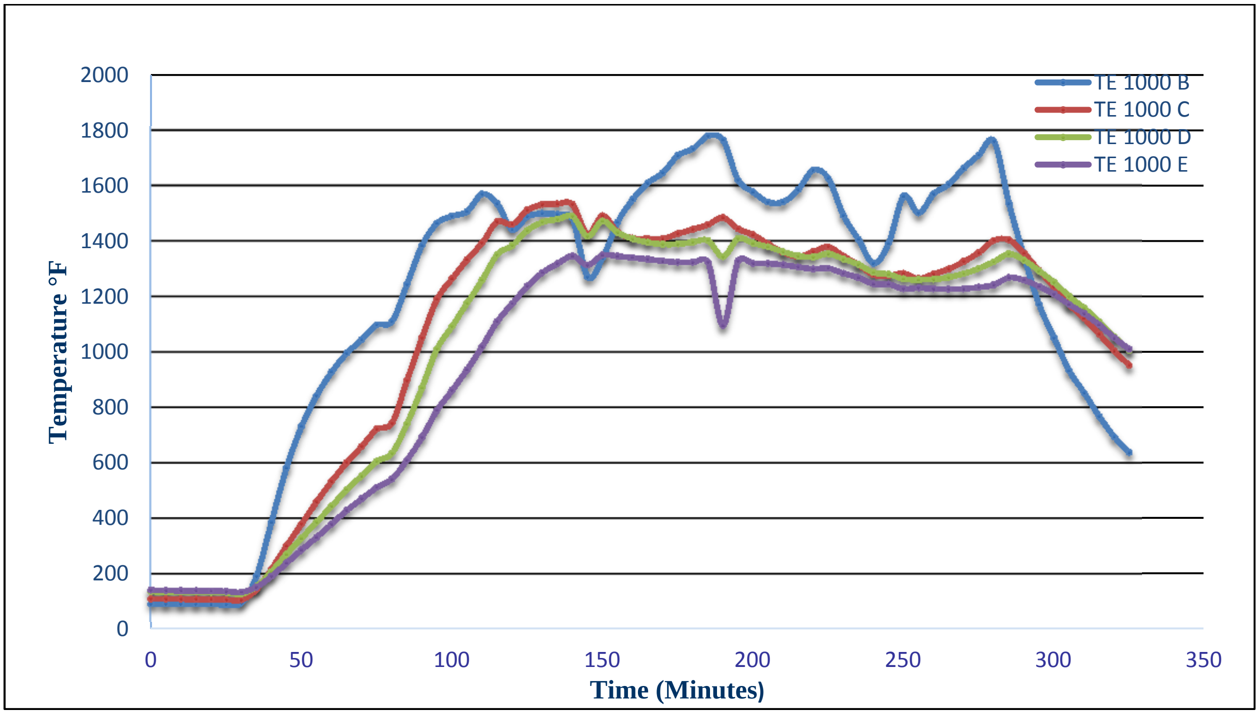
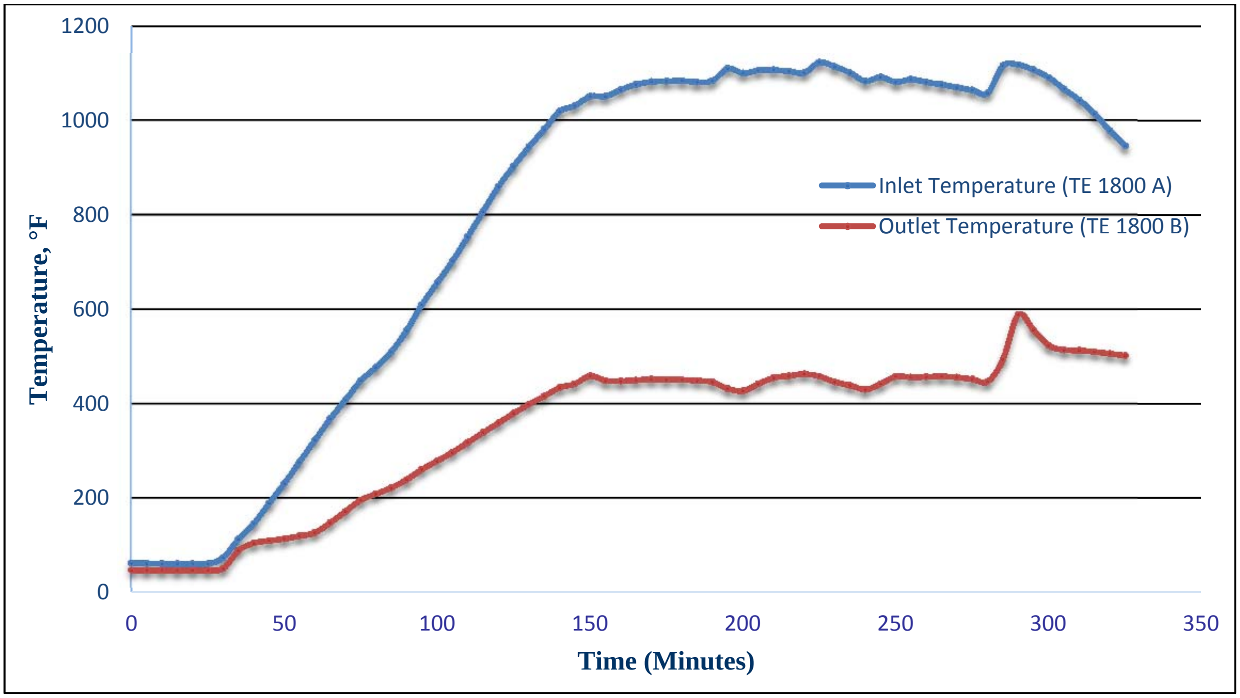


Figure 9: Heat Exchanger Temperature Profile



Future Work

In an effort to improve the gasifier performance, optimize the biomass gasification system, and generate power, the following activities are proposed and will be implemented in future;

1) Optimization of the gasification system to produce high quality syngas by varying system operation parameters.
2) Continue evaluation of different bio-based feed stocks including woody fuels, energy crops, and waste materials on the syngas production both in terms of quality and quantity
3) Test, operate, and optimize the gasification system using oxygen as an oxidizing medium to produce higher quality syngas compared with air gasification.
4) Evaluate the quality of syngas both in terms of quality and quality using the tar and particulate sampling set up.
5) Design, fabricate, and install a catalytic tar reforming module in an effort to produce clean and improved syngas quality.
6) Generate power using syngas produced during gasification using a 25kW induction type gaseous fuelled generator.
7) Automate gasifier operation using Wonderware HMI such that the gasification system is operational using a “START”, “STOP”, buttons.

8) Operate gasification system and generate power over long time periods in the order of several days on a continuous basis.
9) Perform an overall economic analysis of the gasification system using the results obtained from pilot scale unit.

Impacts

Impact of Cleco Alternative Energy Facility on Funding from External Sources

Ever since the collaborative partnership between UL Lafayette and Cleco Power LLC., to work on alternative energy projects commenced, and the inception of the Cleco Alternative Energy Center took shape, UL Lafayette has procured several external grants and established research collaborations both with the Universities and private organizations. Following is a list of grants and collaborative partnerships that have been evolved as a result of UL Lafayette working with Cleco Power LLC. In addition, efforts are underway to procure funds to establish gas to liquids research.

UL Lafayette in collaboration with ***Missssissippi State University*** has been actively working towards procuring grants to address the issue of cleaning up syngas produced via biomass gasification. As a result of the collaborative efforts, two projects were awarded through the SunGrant Initiative, Southeast Regional Center till date.

Louisiana Board of Regents through its Industrial Ties Research Subprogram has awarded a project focused on commercialization of biomass torrefaction technology using a pilot scale indirectly heated rotary torrefaction system. This project is a collaborative effort between UL Lafayette, Cleco Power LLC., and LA Biofuel Resources, LLC., based in Evergreen, LA.

NFR BioEnergy LLC., is an innovative technology sales and engineering company that is seriously pursuing to establish a commercial biomass torrefaction production facility in Louisiana and have evinced interest in bagasse as feedstock. Abundant availability of bagasse in Louisiana has prompted NFR BioEnergy LLC., to establish their production facilities in Louisiana. Since, UL Lafayette has been leading several research and developmental projects in this field, NFR BioEnergy LLC., expressed interest in collaborating with UL Lafayette to perform a series of torrefaction tests and assist with their pilot scale (2 tons/hour system) bagasse torrefaction system. NFR BioEnergy LLC., recently announced plans to invest $312 million to install biorefineries in the state of LA and acknowledged Cleco Alternative Energy Center's and UL Lafayette's collaborative efforts, the details of which could be found at;
http://www.opportunitylouisiana.com/index.cfm/newsroom/detail/600

Following are the details of the grants awarded to-date:

1) "The Development and Evaluation of a Cost Effective Catalyst for the Treatment of Syngas Tars Produced from a Woody Biomass", SunGrant Program (U.S. D.O.T-RITA), Project Duration: 2 years, Total Award Amount: $180,969, UL Lafayette Award: $65,005

2) "Biomass Gasification: Development and Evaluation of a Cost Effective Bimetallic Clay Catalyst for Woody Biomass Syngas Tar Destruction", Sungrant Program (USDA.-NIFA.), Project Duration: 2 years, Total Award Amount: $150,000, UL Lafayette Award: $52,000

3) "Pilot Scale Investigation of Biomass Torrefaction Technology Using an Indirectly Heated Reactor", Louisiana Board of Regents, Industrial Ties Research Subprogram, Project Duration: 3 years, Total Award Amount including private sector match: $396,269, Collaborators: Cleco Power LLC., and LA Biofuel Resources, LLC., based in Evergreen, LA

4) "Influence of Torrefaction on Fuel Properties of Bagasse", NFR Bioenergy LLC., Project Duration: 1 year, Total Award Amount: $49,872. Potential to fund for an additional year at the same funding level.

Impact of Cleco Alternative Energy Facility on Establishing Industrial Collaborations

The collaborative partnership with Cleco Power LLC., and UL Lafayette have resulted in establishing ties with several private industrial entities including;

1) Sundrop Fuels – UL Lafayette has supplied Sundrop Fuel's a biofuel company established in central Louisiana with torrefied biomass produced using pilot scale torrefaction unit which was tested in Sundrop Fuel's process. Torrefied biomass has a very good potential to be used as feedstock in the Sundrop Fuel's GTL process during the second phase of their project.

2) R3Sciences – R3Sciences a Lafayette, LA based company, is partnering with UL Lafayette to set up and test their pilot scale GTL technology system at the Cleco Alternative Energy Facility. Plans are to integrate the syngas produced from biomass gasification with R3Science's GTL technology. In addition, UL Lafayette has supported and is working actively with R3Sciences in procuring external grants.

3) The Earth Partners LP., is a business entity involved with developing scalable business models addressing bioenergy production. They have been supporting the growth of bioenergy markets and development of markets for ecosystem services. UL Lafayette has been supportive of their efforts by agreeing to evaluate switch grass as a potential feedstock for bioenergy production both using gasification and torrefaction technologies.

Impact of Cleco Alternative Energy Facility on Workforce Development

UL Lafayette has been playing a significant role in the development of an alternative energy program at the South Louisiana Community College, Crowley campus. The new program took shape and classes commenced during Fall 2013. Students attending this program had an opportunity to visit the Cleco Alternative Energy Center and got firsthand, in-depth knowledge of the renewable energy projects that are being carried out at the facility. The same students will get further hands on experience scheduled during the first quarter of 2015 by participating in sessions that will involve operation of the gasification and torrefaction systems.

In addition, this center provides both graduate and undergraduate students from UL Lafayette gain unique experience working on industrial grade pilot scale systems. Till date this center provided an opportunity to 8 undergraduate students and 5 graduate students gain invaluable research experience on both laboratory and pilot scale systems. One of the students Mr. Joseph R. Vutukuri successfully completed M.S. degree with a focus on catalyst development for cleanup of syngas produced during biomass gasification. During this reporting period, 2 M.S. level and 2 Ph.D. level graduate students have been hired to work on several projects in the area of thermochemical biomass conversion.

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2. Milne T.A, A.N., Evans R.J., *Biomass Gasifier "Tars": Their Nature, Formation, and Conversion*, in *NREL/TP-570-25357*. 1998, National Renewable Energy Laboratory: Golden, Colorado.
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5. Sutton D., K.B., Ross J.R.H. , *Review of literature on catalysts for biomass gasification.* Fuel Processing Technology, 2001. **73**: p. 155-173.

Section 3 Photovoltaic and Solar Thermal

Solar Thermal Power Plant

Project Overview

Cleco Power and UL Lafayette have recently completed the installation of a pilot solar thermal power plant, which is the first of its kind in Louisiana. All components in the system are commercially available and have been proven to be successful in other states, however to date there has not been sufficient data for the Louisiana area to perform an evaluation of the technology.

The pilot plant has been installed at the UL Lafayette Energy Research Complex, which includes the Cleco Alternative Energy Center and the UL Lafayette Solar Technologies Applied Research and Testing (START) Lab. The pilot plant will provide Louisiana-specific performance and price information regarding the use of solar thermal technology in Louisiana. **Figure 13** below shows the solar power plant on the right and the Cleco Alternative Energy Center on the left while **Figure 14** is an aerial photograph of the facility while operating.

Figure 13: Artist Rendition of the Cleco Alternative Energy Center and UL Lafayette START Lab

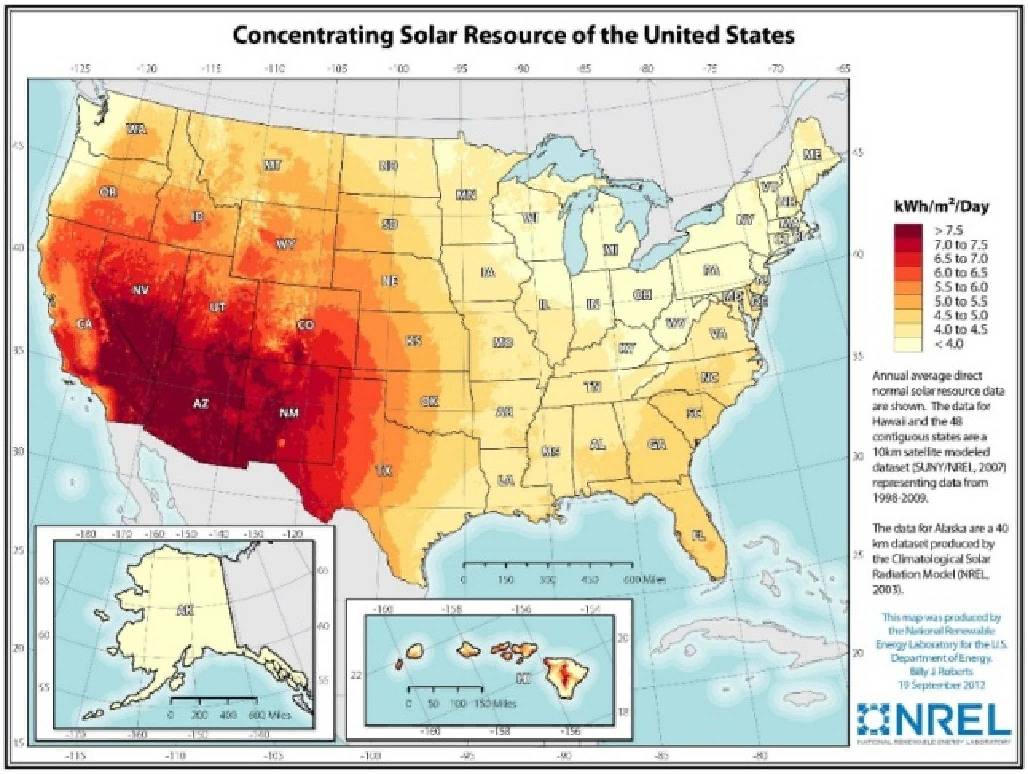
Figure 14: Aerial Photograph of Solar Thermal Power Plant While in Operation

The 20 kW pilot project objectives are to test a solar thermal power system under actual conditions in Louisiana, to gain experience in maintaining and operating such a system, to determine the scalability of the technology, and to determine the overall feasibility of the installation.

Solar Resource

Louisiana resides in an area of the United States where the solar resource is substantially less than that of the current commercial scale concentrating solar power (CSP) installations of the southwest U.S. **Figure 15** shows a map of the U.S. Solar Resource developed by the National Renewable Energy Laboratory (NREL). Economical utilization of the solar resource in remote areas of this region would significantly increase the footprint of viable areas for commercial development. Louisiana has an average solar resource between 4 and 5 kWh/m^2/day. NREL Typical Meteorological Year (TMY3) data resulted in a median peak direct normal irradiance (DNI) for the 6 months beginning in April of 688 W/m^2 for the Lafayette area, with a 15 percent error band. While these levels are substantially lower than those of the southwest U.S., the insolation still represents a significant level of energy. Indeed, based on the existing installed power capacity of Louisiana, one square mile of installed CSP projects would generate about one percent of the current total capacity, based on a solar-to-electric efficiency of 20 percent.

Figure 15: Concentrating Solar Resource of the U.S. Source: National Renewable Energy Laboratory Solar Data Center.



Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

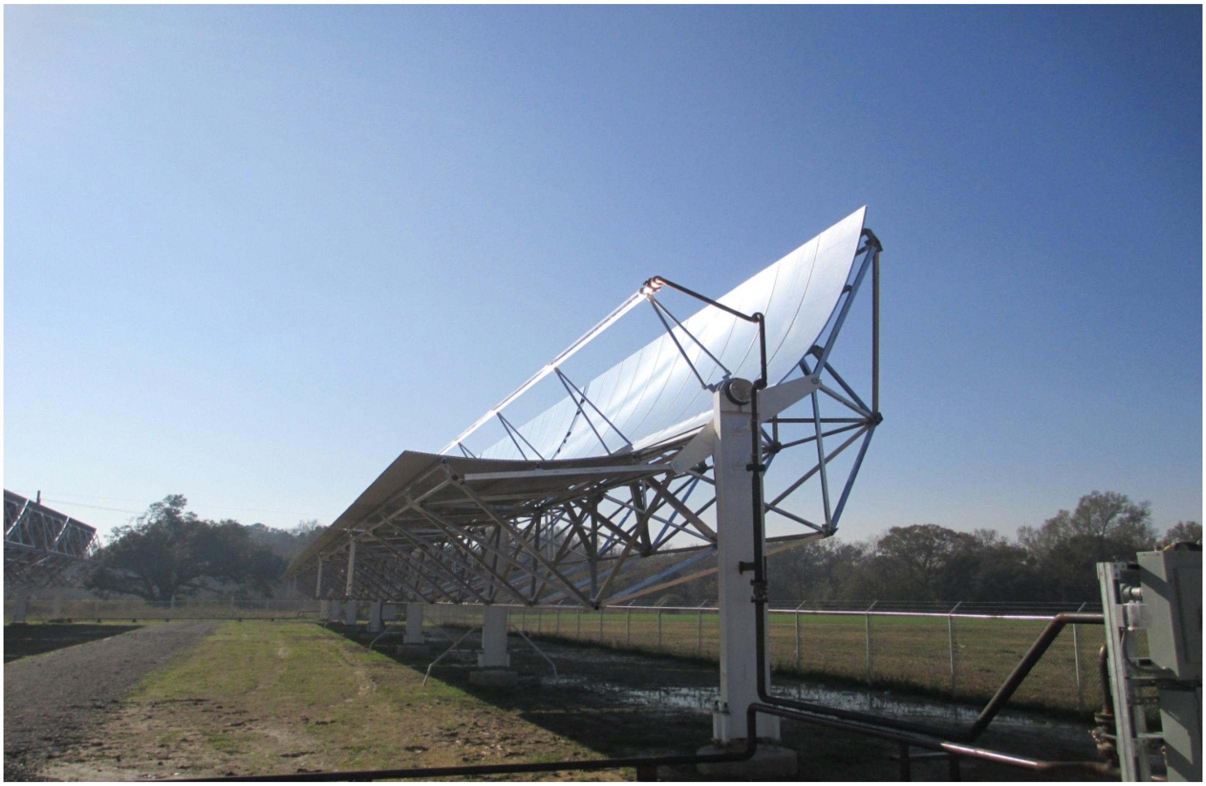
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Billy J. Roberts 19 September 2012

Power Plant Overview

The pilot solar thermal power generation power plant uses reflective solar troughs to create heat that is used to generate 20 kW of electrical power. The system consists of four main components: (i) the solar collector field, (ii) the power block, (iii) the cooling system, and (iv) the control system. Each major component of the plant is described below.

The solar collector field consists of 12 reflective parabolic troughs, which sit on approximately 1 acre of land, as shown in **Figure 16**.

Figure 16: Solar Collector Field



Each trough is roughly 39.4 feet long by 24 feet wide, and has an effective reflective area of 942.9 ft^2 (87.6 m^2). The troughs can track the sun through one degree of freedom, and can be automatically stowed in a safe position during high winds and inclement weather.

A Heat Transfer Fluid ("HTF"), in this case water, flows through a 2.75" steel pipe at the focus of the parabolic trough, and is heated to a temperature of approximately 250 ºF under slight pressure to ensure that it remains in liquid form. A hot water pump causes the water to flow down the trough assembly to the right, cross over and then through the left trough assembly. The hot water then enters the power block, as described below.

The solar collector technology selected was the large aperture trough (LAT) parabolic trough solar collectors produced by Gossamer Space Frames (GSF). The GSF LAT, with an aperture of 7.3 meters, was the largest aperture trough available in commercial production at the time of construction. This installation represents the second demonstration facility for the LAT. The collectors utilize an all-aluminum space frame which provides high rigidity for improved accuracy while also minimizing weight. The collectors also satisfied the local building codes for wind load rating. The reflectors consisted of thin film polymer technology provided by 3M with silver as the reflective layer.

Schott PTR70 heat collection element (HCE) tubes with 70 millimeter outside diameter were employed which, when combined with the large aperture, results in an industry leading concentration ratio (the ratio of the area of collected radiation to the area of concentrated radiation) of 104. Due to the design of the power block, water could be used as the HTF for the collector field. NREL laboratory testing of the GSF collectors demonstrated a slope error of less than 1.5 milliradian with over 99% intercept factor. The combination of a high concentration ratio and high accuracy reflector results in a higher energy flux on the receiver, while minimizing losses due to the length of the trough, thereby increasing solar conversion efficiency.

Power Block and Cooling System

The power block for the system is the Green Machine, manufactured by ElectraTherm, which operates on the thermodynamic cycle called the organic Rankine cycle (ORC). It works in a manner similar to a steam turbine generator system, except that the working fluid for the power block is an organic refrigerant, R245fa, which has a much lower boiling point than water. The refrigerant working fluid picks up thermal energy as it passes through a liquid-to-liquid heat exchanger, where hot water from the solar collector field is on one side of the heat exchanger, and the refrigerant is on the other side. The hot refrigerant is allowed to expand and create steam in a steam generator, and then the refrigerant steam is converted to mechanical energy by expanding it through a twin-screw expansion system. After the working fluid is expanded through the expander, it is condensed by passing through another heat exchanger. This time the hot refrigerant is on one side of the heat exchanger, while cold water from a cooling tower is on the other side. The refrigerant is condensed as it passes through the heat exchanger and it is pumped back to the evaporative heat exchanger, and the cycle starts again. The twin-screw expander turns an AC generator that produces three-phase electrical power at 480 V and 60 Hz, which is synchronized to the grid. **Figure 17** below shows the power block to the right and the cooling tower on the left.

Figure 17: Power Block and Cooling Tower

Control System

A Direct Digital Control ("DDC") system interfaces with flow meters, temperature sensors, the tracking and focusing motors on the troughs, the circulating pumps, the turbine-generator system, and the fans on the cooling system in the power block to insure the operation described above. When there is adequate sunlight, the operator signals the DDC to focus the troughs and start the circulation pump in the solar collector field. When the temperature in the solar field reaches a predetermined temperature, the power block working fluid loop is activated and power is produced. At night, the solar collection loop is shut down and the troughs are stowed. During rain or high winds, the operator signals the DDC to shut down the operation of the plant and stows the troughs in the safe position. Additional key design parameters and metrics are listed in **Table 7**.

Table 7: Plant characteristics

Plant Location	Crowley, LA
Yearly Direct Normal Solar	1590 kWh/m^2
Plant Size (nominal)	50 kWe
ORC Gross Output	50 kWe
Solar Field Heat Transfer Fluid	Water
Inlet Temperature	93 ^{o}C
Outlet Temperature	121 ^{o}C
ORC Working Fluid	R245fa
ORC Design Point Efficiency	8%
Solar Field Size	1051 m^2
Land Area	4050 m^2 (1 acre)
Solar to Electric Design Point Efficiency	6%

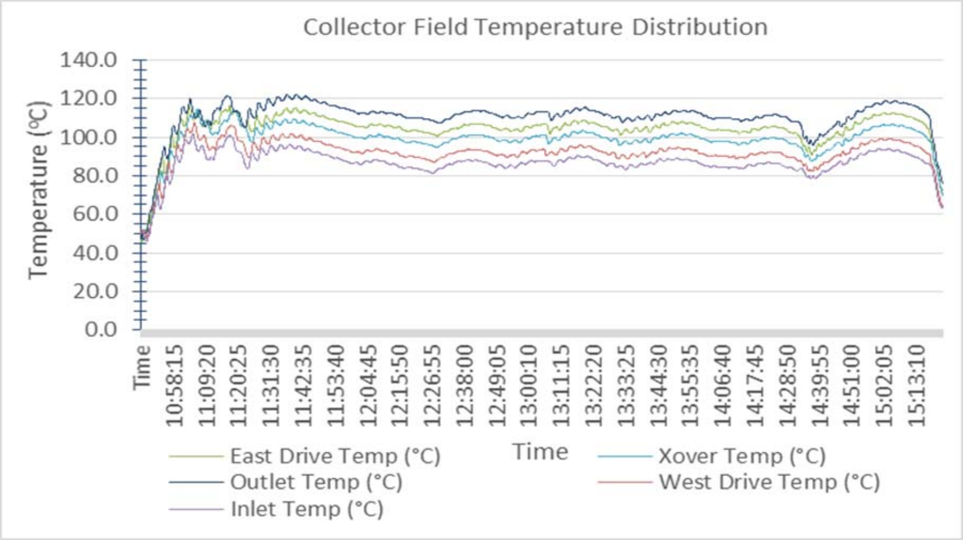
The solar thermal power plant was commissioned in December of 2012. Operation and testing began in early 2013. The system was operated approximately 40 different days throughout the year of 2013 for various testing and calibration operations. The initial operational testing and 'tuning' resulted in a limited electricity production time of about 150 hours and 1700 total kW hours. The system was operated for approximately 65 different days throughout the year of 2014 resulting in electricity production time of about 215 hours and 5800 total kW hours. Most of these days occurred in the first half of the year as the second half of the year comprised component testing of new technologies and maintenance operations. Operational activities continued the study and optimization of operational performance characteristics and data collection. The system was operated for another approximately 30 different days without producing power in order to facilitate testing and monitoring of new technologies and components in conjunction with the industrial collaborators listed below. Maintenance activities consumed approximately 20 days of activity. It is anticipated that electricity production will increase as automation and remote generation capabilities are enhanced during planned 2015 improvements, including requiring less or no supervision for operation during non-business hours and days. The project continues to demonstrate that solar thermal technologies can be used for electrical power production in Louisiana.

Performance Data

Due to interference by the atmosphere and local weather patterns, much of the solar spectrum becomes diffuse or is absorbed as it passes through the atmosphere. Concentrating solar technologies utilize the direct beam portion of the global solar spectrum to reach the ground. Therefore, in an effort to quantify the solar collector and power plant efficiency, a local real-time measurement of the direct normal irradiance (DNI) was required. A tracking pyrheliometer was installed in mid-July of 2013 to provide a measurement of the local DNI, or the fraction of solar radiation that may be concentrated and converted into thermal energy. With the DNI measurement, efficiency calculations of the solar collector assemblies (SCAs) could be conducted. The pyrheliometer is the CHP1 from Kipp&Zonen and is First Class radiometer with a World Radiometric Reference (WRR) calibration certificate. A Kipp&Zonen CMP10 Secondary Standard pyranometer was then installed in November of 2014 to measure the global horizontal irradiance, a measure of the total (diffuse + direct) radiation reaching the surface. Until now, the only data available for local solar resource measurement and prediction was modelled from the NREL database which extrapolated data from stations in Lake Charles, Louisiana and in Mississippi. The installation of the instruments at the UL Lafayette START Lab helps to fill a large gap in direct solar resource measurement in Louisiana.

Figure 18 gives the temperature distribution through the collector field vs. time for a typical day in the spring season of 2013. Several peaks can be identified where one SCA was defocused in order to prevent temperatures in excess of the high temperature limit of the ORC. The apparent noise (rapid fluctuation) in the temperature measurements was possibly due to two phenomena, although both can be attributed to the lack of a thermal buffer.

Figure 18: Collector Field Temperature Distribution



The temperature distribution was found to be regular across the collector field as would be expected. Wind effects were found to be negligible.

Figure 19 presents the solar collector field energy output (flux) vs. time relative to the approximated DNI for the same day in 2013 (prior to installation of the pyrheliometer). An error band of five percent is displayed as a conservative estimate of the actual DNI and is given for visualization in **Figure 19**. **Figure 20** depicts solar collector field energy flux relative to measured DNI values for a day later in the fall of 2013. The fluctuation in temperature measurements also had the effect of creating noise in the calculated energy flux, which is a function of the temperature rise through the system. It can be seen that the design output of 650 kWth was reached and maintained on the first day with design solar irradiation. In contrast, the design output was not reached for the second day presented. Here, several degrading conditions are present that have not been quantified in the graphic, including the build-up of particles from collector usage resulting in reduced specularity (addressed later). The thermal efficiency of the collector field could then be evaluated by the given formula:

$$\boldsymbol{\eta_{th}} = \frac{\dot{\boldsymbol{Q}} * \mathbf{cos}(\boldsymbol{\theta})}{(\boldsymbol{Aperture\ Area}) * (\boldsymbol{DNI})}$$

Here η_{th} represents the thermal efficiency and $\dot{Q}$ is the thermal energy flux from the flow field, and $\cos(\theta)$represents the cosine effect due to the solar incidence angle, θ. The cosine effect was not included for the first day without measured DNI data in order to be conservative. The efficiency of the solar field, based on the approximated DNI values, ranged between 70 and 80 percent (**Figure 21**), while the efficiency of the second day, based on measured DNI values, ranged between 65 and 75 percent (**Figure 22**). When considering the degrading factors mentioned earlier that have not been accounted for in the measurement, the efficiency values represent an industry standard, even after accounting for the low thermal losses which would be expected due to the low temperature operating regime. Additionally, the cross-over piping between the two SCAs remain uninsulated, which is estimated to account for a one to two ^{o}C (2-4 ^{o}F) temperature drop based on measured data, which would further increase overall thermal efficiency when insulated.

Figure 19: Collector Field Energy Flux, Spring 2013

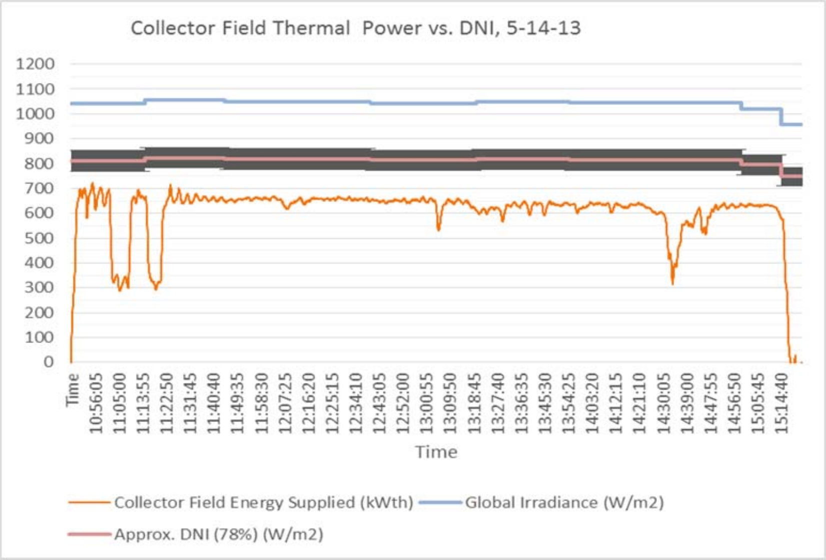


Figure 20: Collector Field Energy Flux, Fall 2013

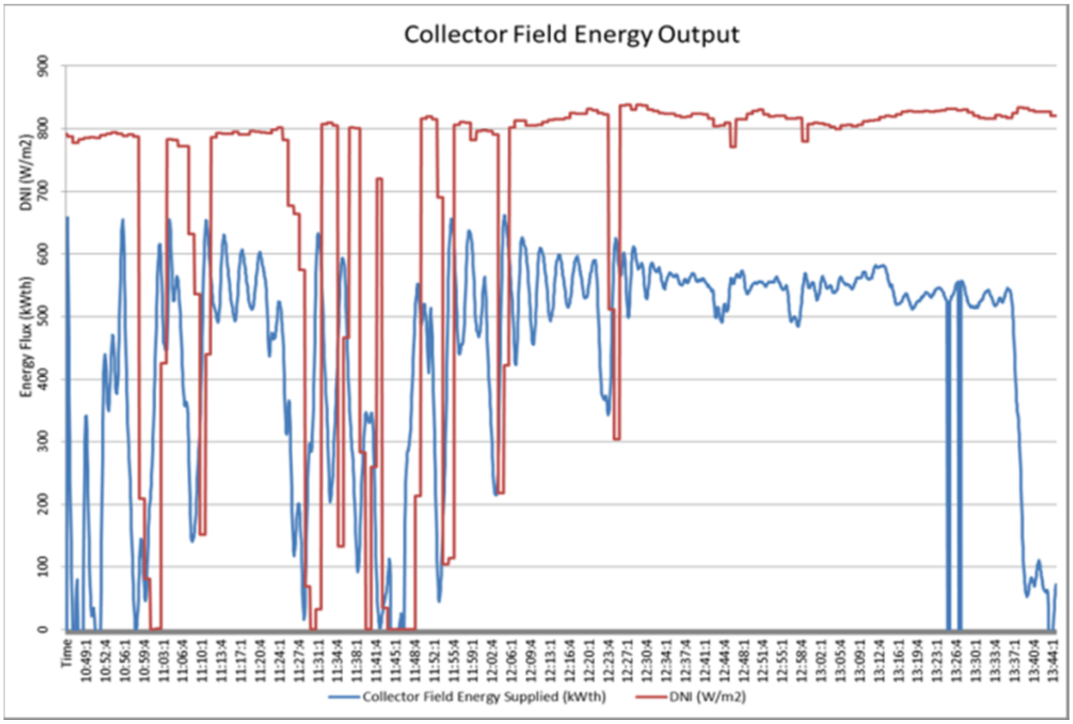


Figure 21: Collector Field Efficiency, Spring 2013

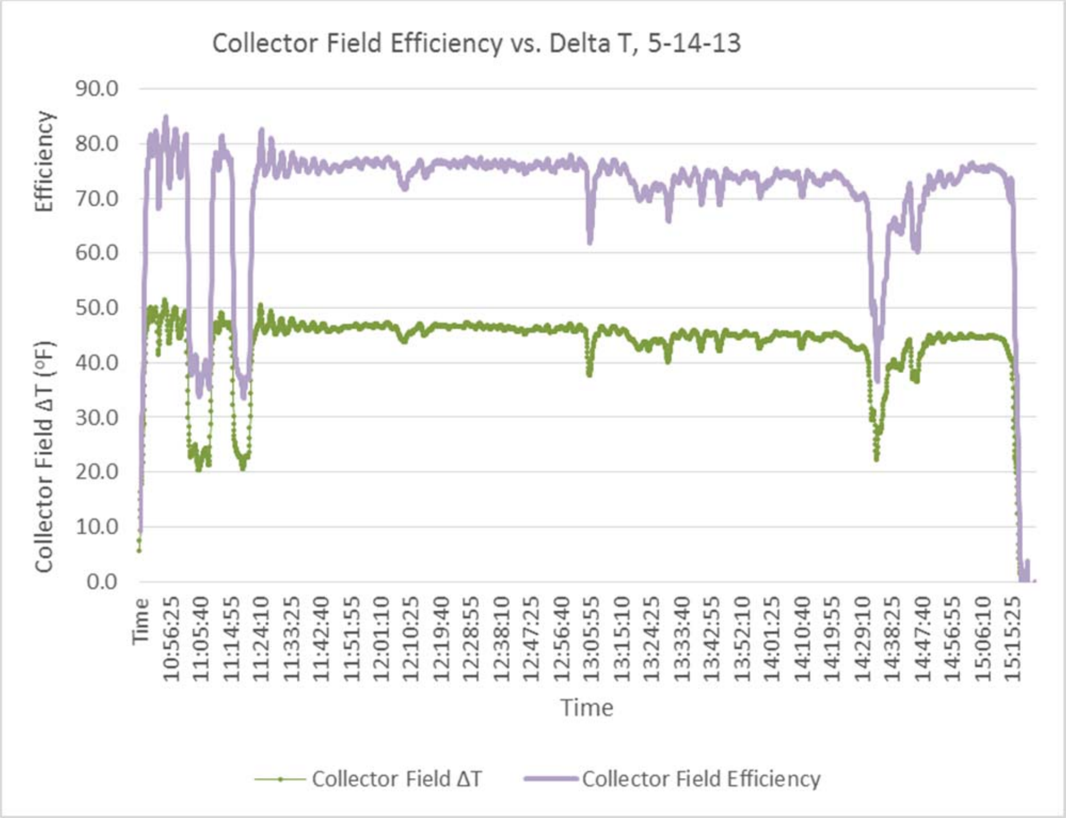
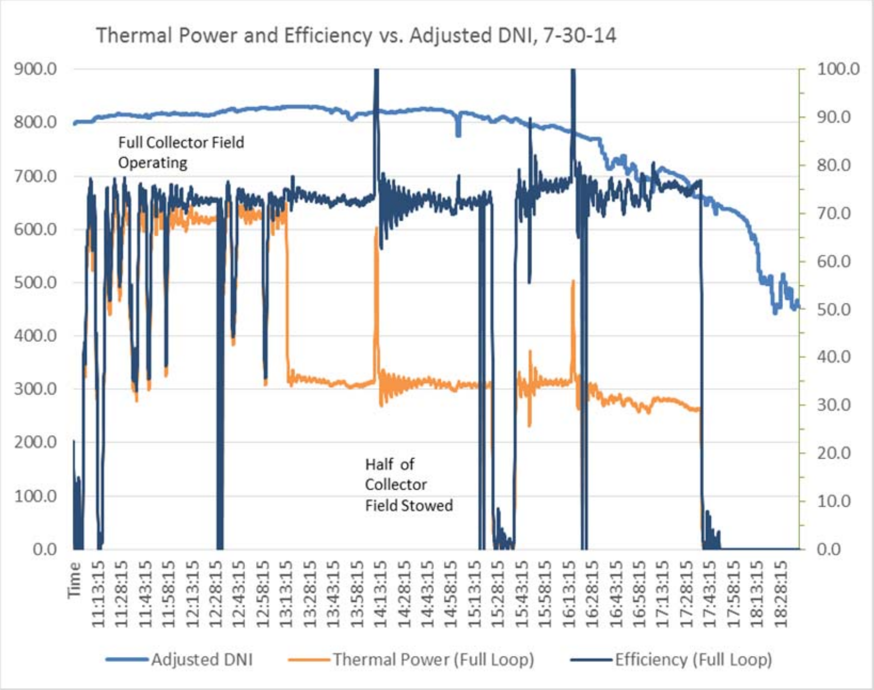


Figure 22: Collector Field Efficiency, August, 2013



Performance data has been included from 2014 which shows that the system has not degraded over the course of an additional year of operation. **Figure 23** depicts the solar field thermal flux and efficiency for a typical summer day, where efficiencies range between 70 and 75 percent, and note that a portion of the piping remains uninsulated. **Figure 24** depicts a typical winter day, where the cosine effect and additional seasonal effects, known as incident angle modifiers (IAMs) have a deleterious effect on thermal efficiency. Here, the thermal efficiency ranged between 55 and 75 percent. **Figure 25** depicts the performance during a spring day in 2014.

Figure 23: Collector Field Efficiency, Summer 2014

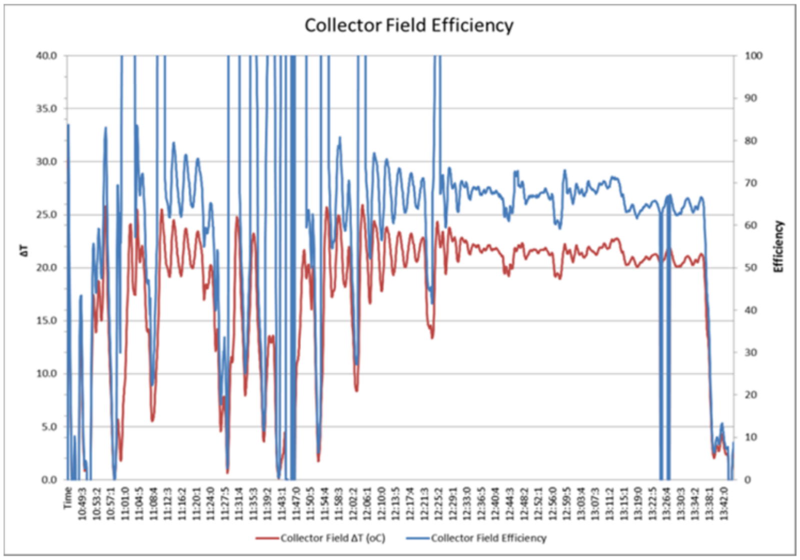


Figure 24: Collector Field Thermal Output and Efficiency, Winter 2014

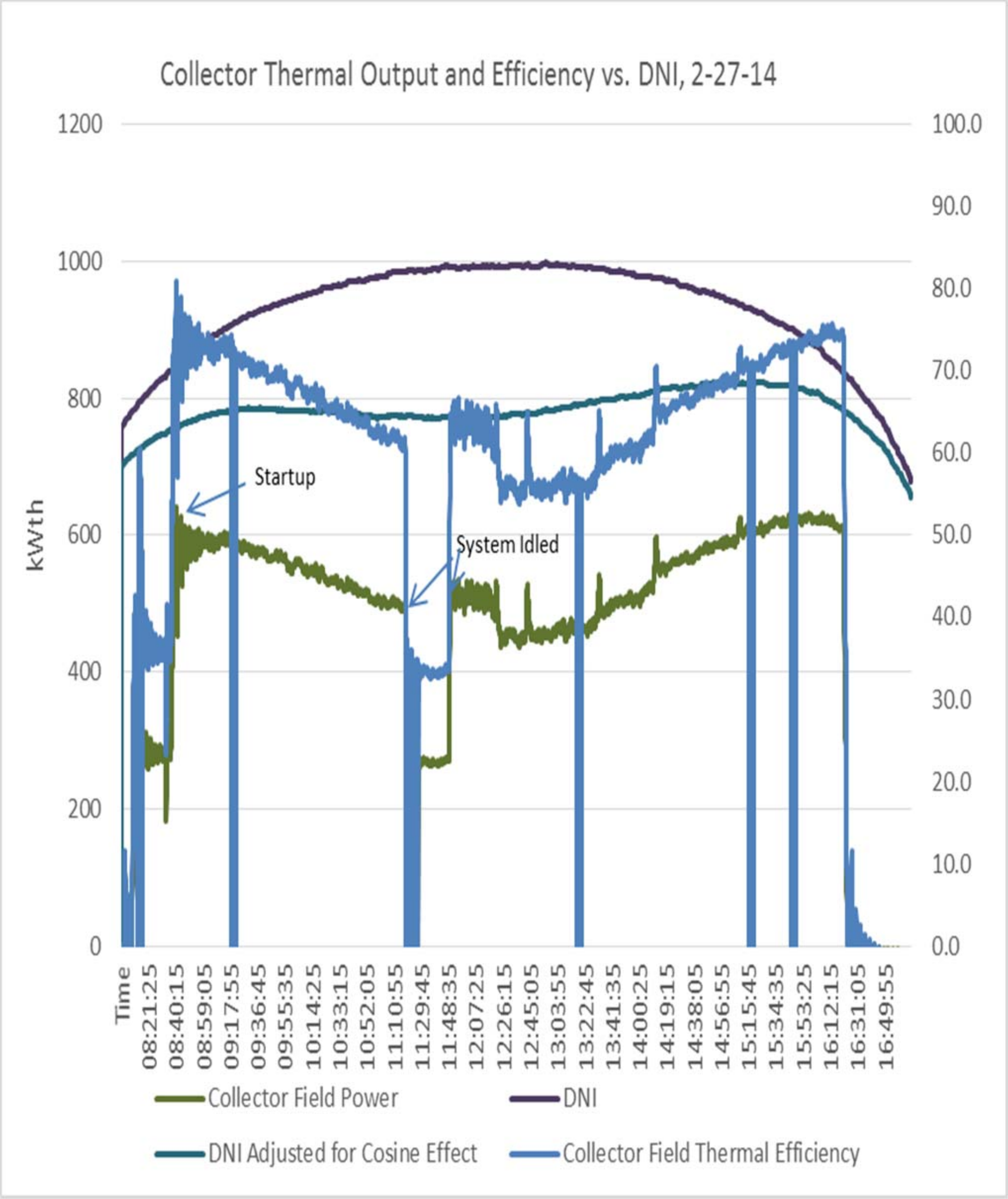


Figure 25: Collector Field Thermal Output and Efficiency, Spring 2014

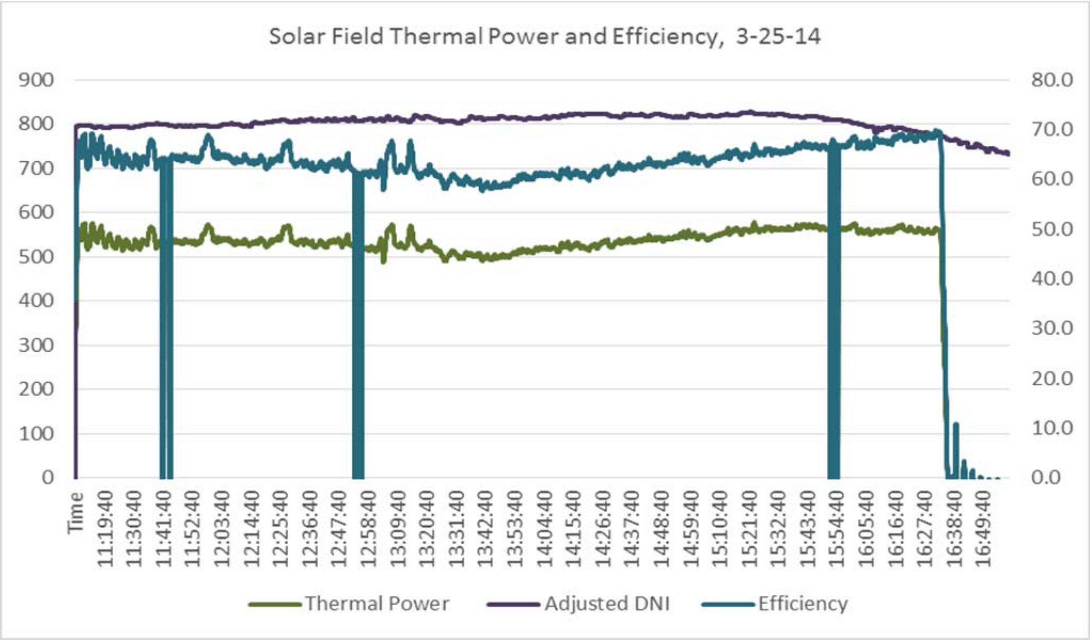


Figure 26 presents data depicting the ORC performance for the same day presented for the solar field in Figures 19 and 21. The ORC power production is primarily a function of the temperature difference between the heat source and the cooling source. Depicted also is the power production in kWe relative to the ΔT mentioned above. **Figure 27** depicts the performance of the evaporative cooler. The low humidity and moderate temperatures result in effective cooling relative to the ambient temperature. Finally, the thermal efficiency of the ORC was determined by simply calculating the ratio of electric power produced to thermal power supplied. **Figure 28** presents the thermal efficiency of the ORC, which was between 7 and 8 percent, within the design conditions. Also shown is the theoretical Carnot efficiency for the cycle and 75 percent of the Carnot efficiency, which is commonly considered the engineering limit.

Figure 26: ORC Performance Data

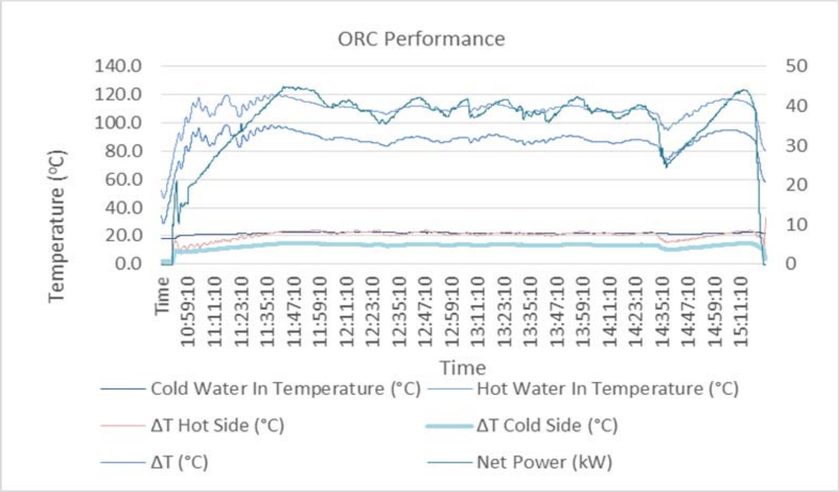


Figure 27: ORC Cooling Data

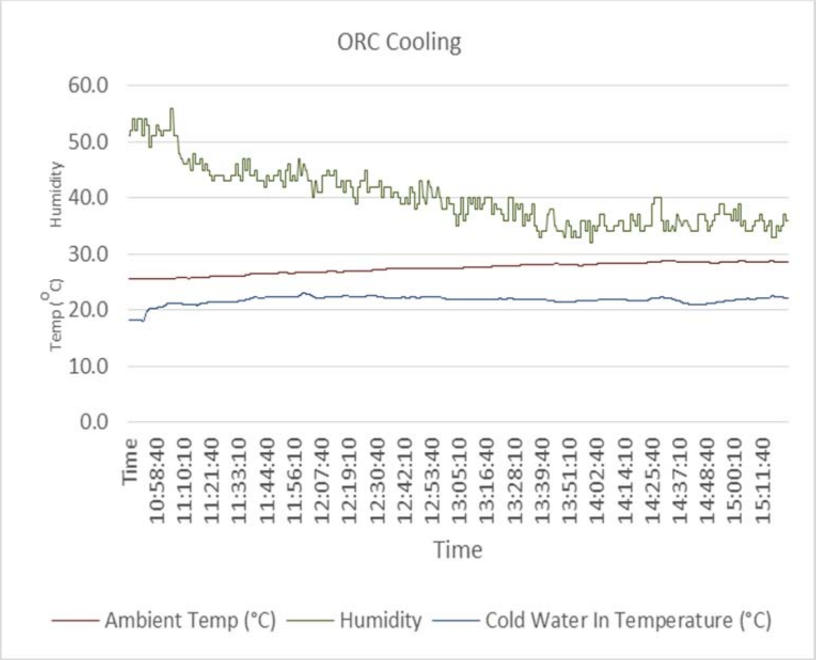
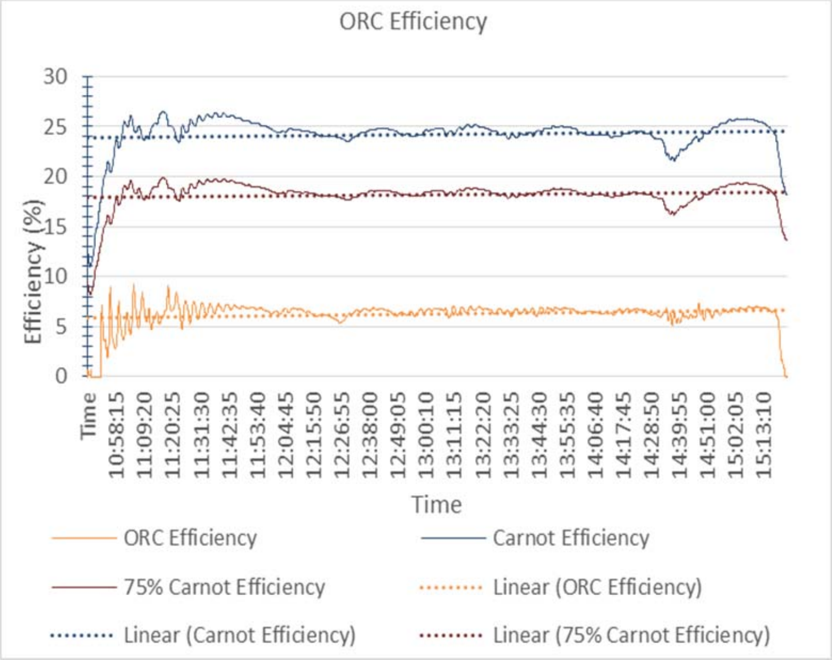


Figure 28: ORC Efficiency



a. To the extent the utility has developed cost estimates, what are the estimated capital costs of the different resource types and technology types within a given type of renewable resource?

For solar thermal energy, capital costs are currently too high due largely to the lack of the economy of scale. As more solar thermal plants are built, the unit cost of each system component will come down significantly. Methods will continue to be investigated to bring down the initial capital investment in solar thermal technologies.

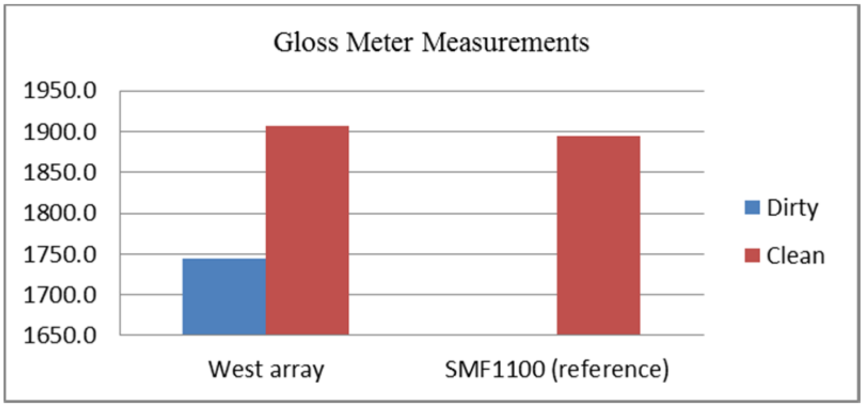
Several investigations were begun in conjunction with industrial partners that have the potential to dramatically bring down the costs of solar technology components. These include the reduction in cost of the thin film currently being used for the reflective surface of the mirrors, the type of materials used for the production of the trough frame, upgrading the tracker system to decrease the tracking error to less than 0.01 degrees of the actual sun location, and the inclusion of photovoltaic surfaces in a hybrid configuration in order to increase overall efficiency. All of these projects fall in line with the DOE SunShot goals for installed costs of the technology types required for a utility scale power plant.

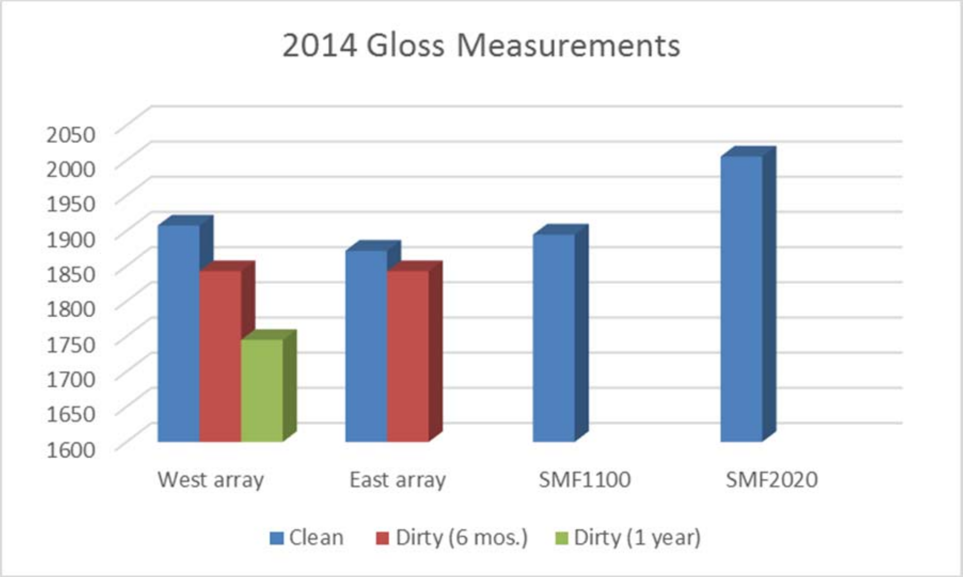
b. What are the estimated operating costs of the different renewable resource types that the utility has considered (non-fuel)?

For solar thermal power plants utilizing an Organic Rankine Cycle power block, such as this one, the operating costs are expected to be significantly lower than the operation of a standard steam power plant, due to the fact that ORC power blocks are much simpler in design and are much simpler to operate. The pilot solar thermal power plant can easily be operated remotely, for example, and a centralized monitoring facility could potentially operate several ORC plants. The operating cost of the solar field is also expected to be very low, limited primarily to occasional washing of the mirrors. This project will record and report on the actual cost of operating this pilot plant.

Mirror washing was completed following approximately one year of deployment. In the second year of operation (2014) a full wash was completed twice. The complete washing of the system (1050 m^2) required approximately 16 man hours during the first washing and was reduced to about 8 man hours in subsequent washes, although it is considered that this can be reduced further with more specialized tools. The total water volume of the washing was less than 30 gallons. Measurements taken of the specular reflectance showed that following washing, the mirrors returned to original performance specifications for reflectivity (> 95%) after having been reduced to less than 80%. **Figure 29** shows the Gloss Meter readings for the West SCA, which can be correlated to specularity. The degradation rate of the mirrors from particle accumulation is being monitored currently. Based on the data collected, it appears that a quarterly cleaning would be more than sufficient to ensure near optimal operation.

Figure 29: Gloss Meter Measurements of SCA





In 2013, minor mirror repairs were required as a result of a combination of small manufacturing deficiencies and the high humidity creating “tunnels” where moisture accumulated under the surface of the outermost mirror layer. However, because of the polymer thin film construction of the mirror, the repairs were simple and non-costly. Very few additional repairs were required in 2014. 3M has corrected the manufacturing processes which allowed the condition. In addition, a newer model of thin film, SMF2020 has been developed by 3M which was installed in several locations of the solar field in the summer of 2014 and is being monitored by the START Lab. The film has a tougher outer surface, is more resistant to scratches, and has resisted soiling better than its predecessor thus far. Another operational cost experienced was the need for replacement of an HCE tube due to vandalism in 2013. The total cost of replacement of the tube, which represents 1/36 of the total number of tubes, was about $3000.

Maintenance activities in 2014 also included the need for adding freeze protection to the plant due to an unusually cold winter. The total cost of the added protection was about $3000, but should not need to be replaced in the subsequent winters.

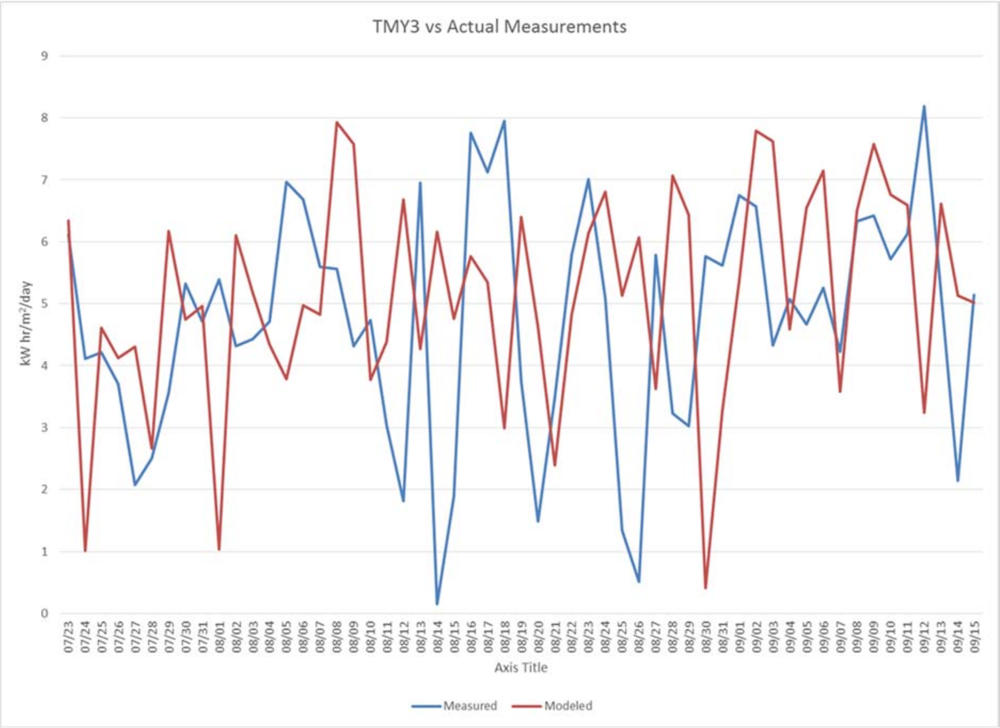
c. What uncertainties should be evaluated that would impact the costs to build and operate new renewable resources?

One of the main uncertainties with regard to solar thermal power technologies is the number of days per year when power can actually be produced. Since solar thermal power plants require direct irradiation from the sun, as opposed to diffuse sources of solar energy, the technology is only applicable on sunny days. One of the main purposes of this pilot project will be to document the number of days per year that power can be produced in Louisiana, and to identify the number of hours per day, on those days when power is produced. This information is directly related to the final calculation of the cost of electricity per kWh, and will have an effect on decisions for future deployment of this technology in Louisiana. In addition, valuable information will be gathered on the uncertainty of the durability of the equipment in the harsh humid climate.

A tracking pyrheliometer was installed in mid-July of 2013 to provide a measurement of the local Direct Normal Irradiance (DNI), or the fraction of solar radiation that may be converted into thermal energy. Based on the experience to date operating the power plant, the plant could be operated when DNI values exceed 400 W/m^2 of direct beam irradiation. Based on data collected in 2014 assessing the local solar resource, the plant could be operated on approximately 275 days throughout a given year. In addition, the system could operate for approximately 1720 hours in a given year, with an average irradiance of 679 W/m^2. For reference, the Typical Meteorological Year (TMY3) dataset predicted a total of 303 days of the year with at least one hour of 400 W/m^2 irradiation on average and a total of 2017 hours at an average of 655 W/m^2.

With the DNI measurement, efficiency calculations of the SCAs could be conducted. DNI measurements from the first full month of installation resulted in an average daily peak of 771 W/m^2. This compares to the TMY3 dataset which predicted an average daily peak of 652 W/m^2 for the same time period, or an 18 percent increase from the predicted value. This highlights the need for a high fidelity model of the local annual DNI determined from local measurements. **Figure 30** shows the measured solar insolation in kWh/m^2/day versus predicted data.

Figure 30: Measured Solar Insolation vs. Actual



DNI values are being recorded in order to compile a data set which will inform a high fidelity model for the local conditions. In addition to the DNI, the cosine effect due to the solar incidence angle must be considered. The cosine effect is a function of the local latitude and acts to reduce the available DNI for collection and significantly alters the available resource from season to season. Examples of the total and adjusted DNI for typical summer and winter days are given in **Figures 31 through 34** and an early spring day in **Figure 35**.

Figure 31: DNI and Adjusted DNI in Winter, 2013

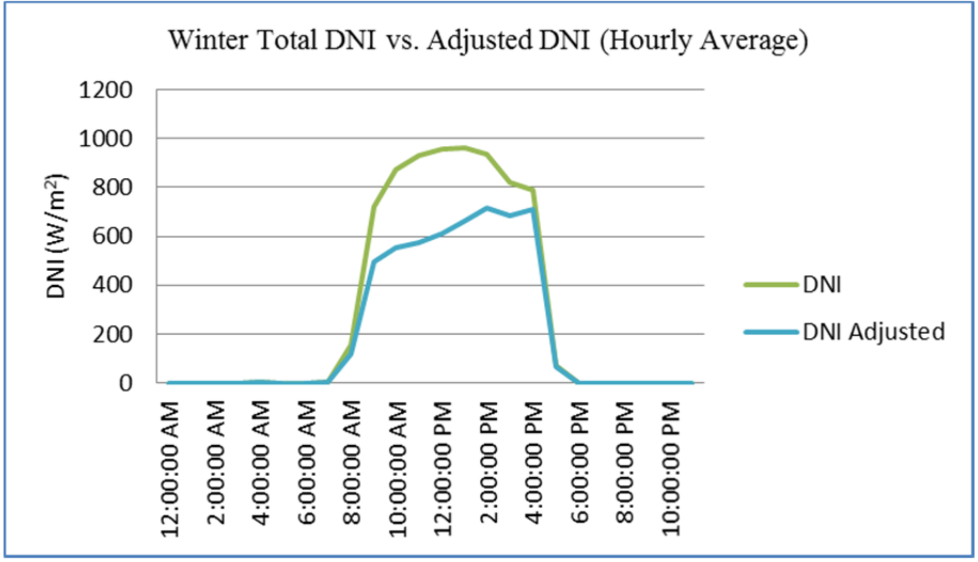


Figure 32: DNI and Adjusted DNI in Winter, 2014

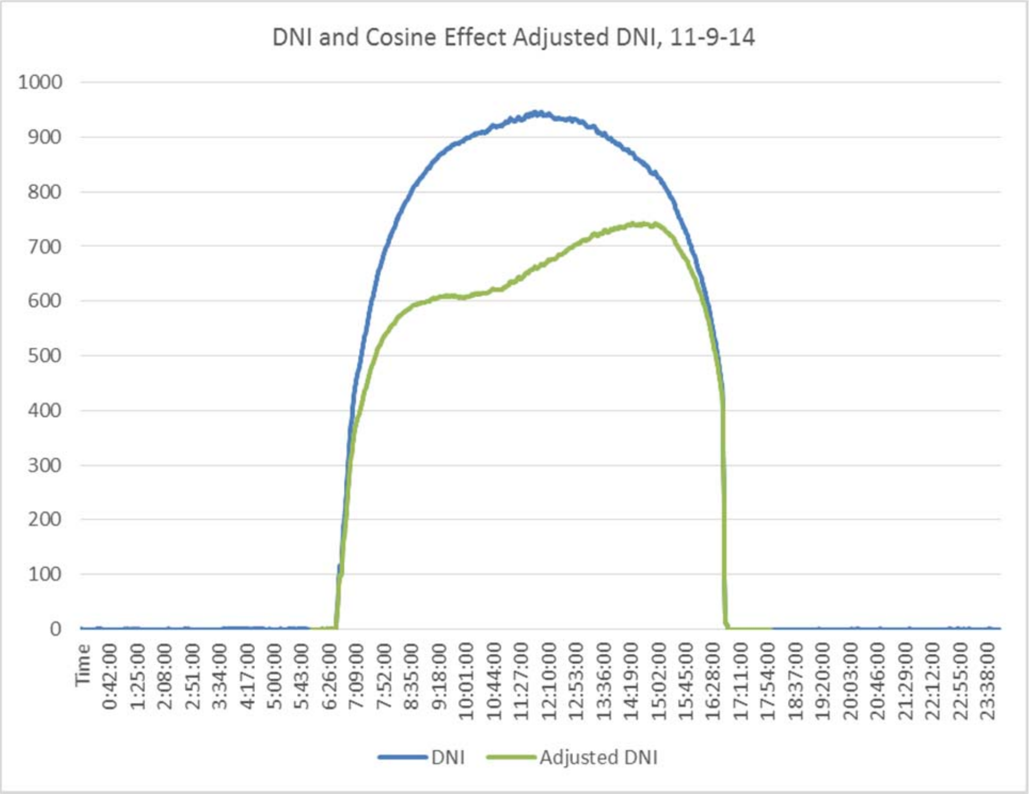


Figure 33: DNI and Adjusted DNI in Summer, 2013

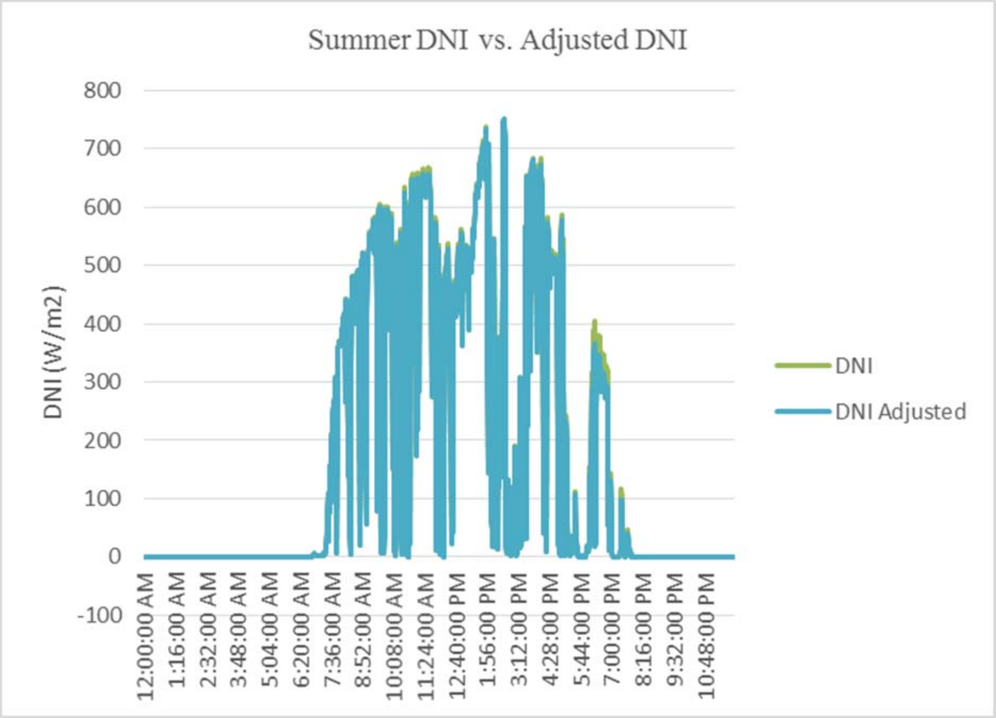


Figure 34: DNI and Adjusted DNI in Summer, 2014

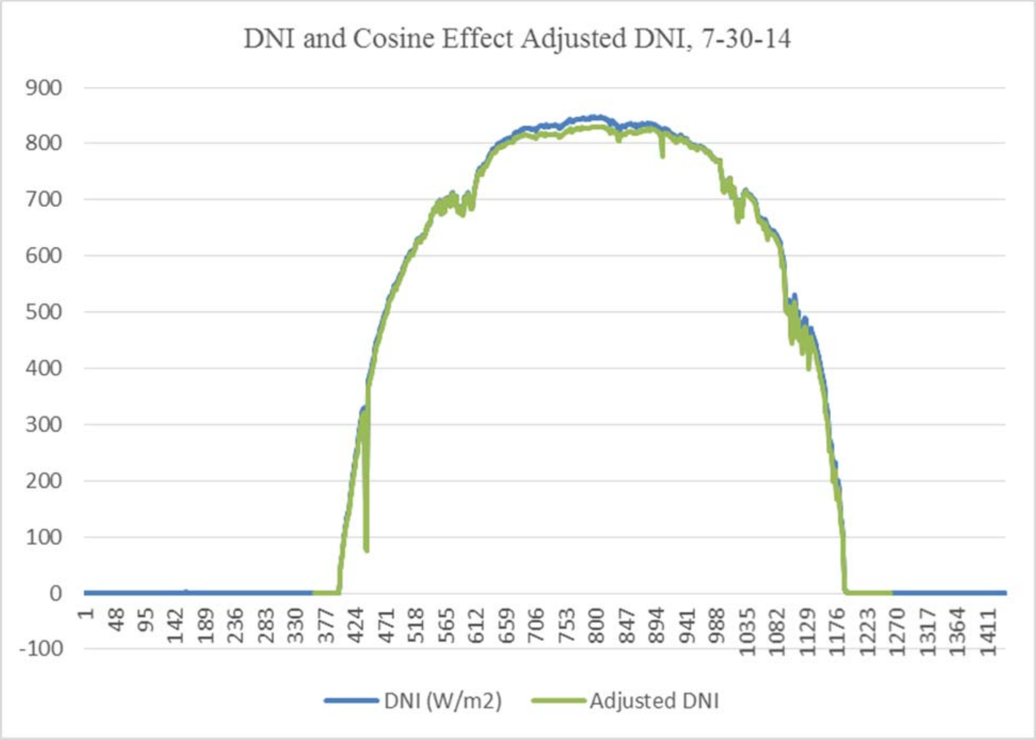
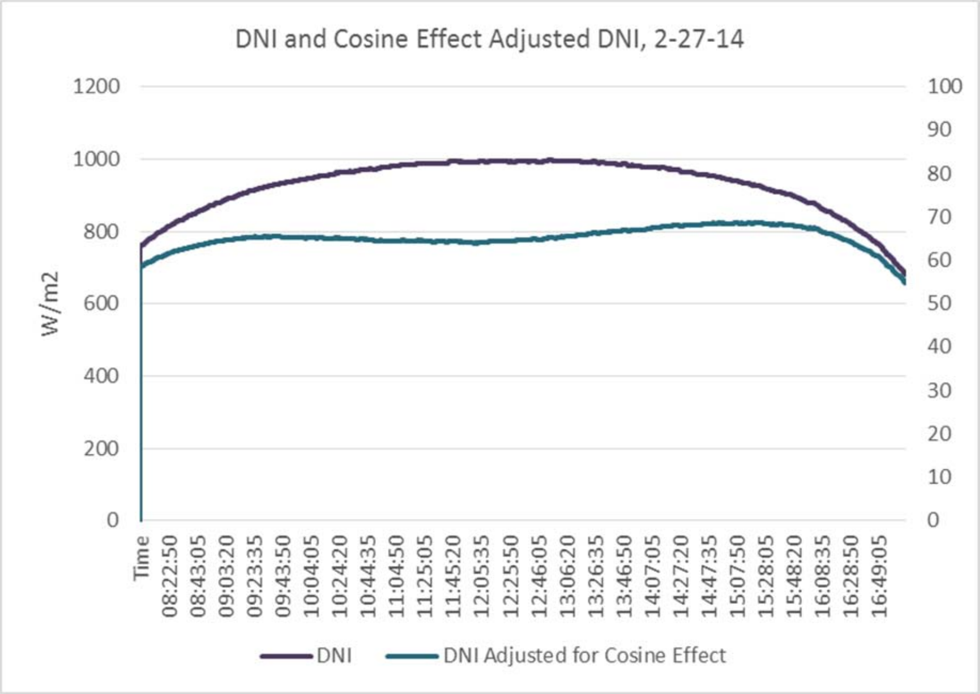


Figure 35: DNI and Adjusted DNI in Spring, 2014



Interestingly, the cosine effect is greatest during the daytime hours in the winter months, although the winter months also offer strong DNI. The cosine effect is least during the summer months, although the summer months offer a lower DNI. The above data shows that the production potential will be limited in winter and summer with the most potential in the fall and spring, as shown in the modelled monthly output in **Figure 36**. Modelling work continues in an effort to better predict the short term as well as long term performance of the system. In addition to the cosine effect, the IAMs, discussed previously, must be quantified to accurately model performance. **Figure 37** shows the thermal performance of the system and **Figure 38** compares that data to the modelled performance. There are still parameters that have a high enough degree of uncertainty to skew the model and that require further refinement, such as tracking error, depicted in **Figure 38**, and the effect of a certain level of soiling on optical efficiency.

Figure 36: Modelled Monthly Energy Delivered by the Solar Field

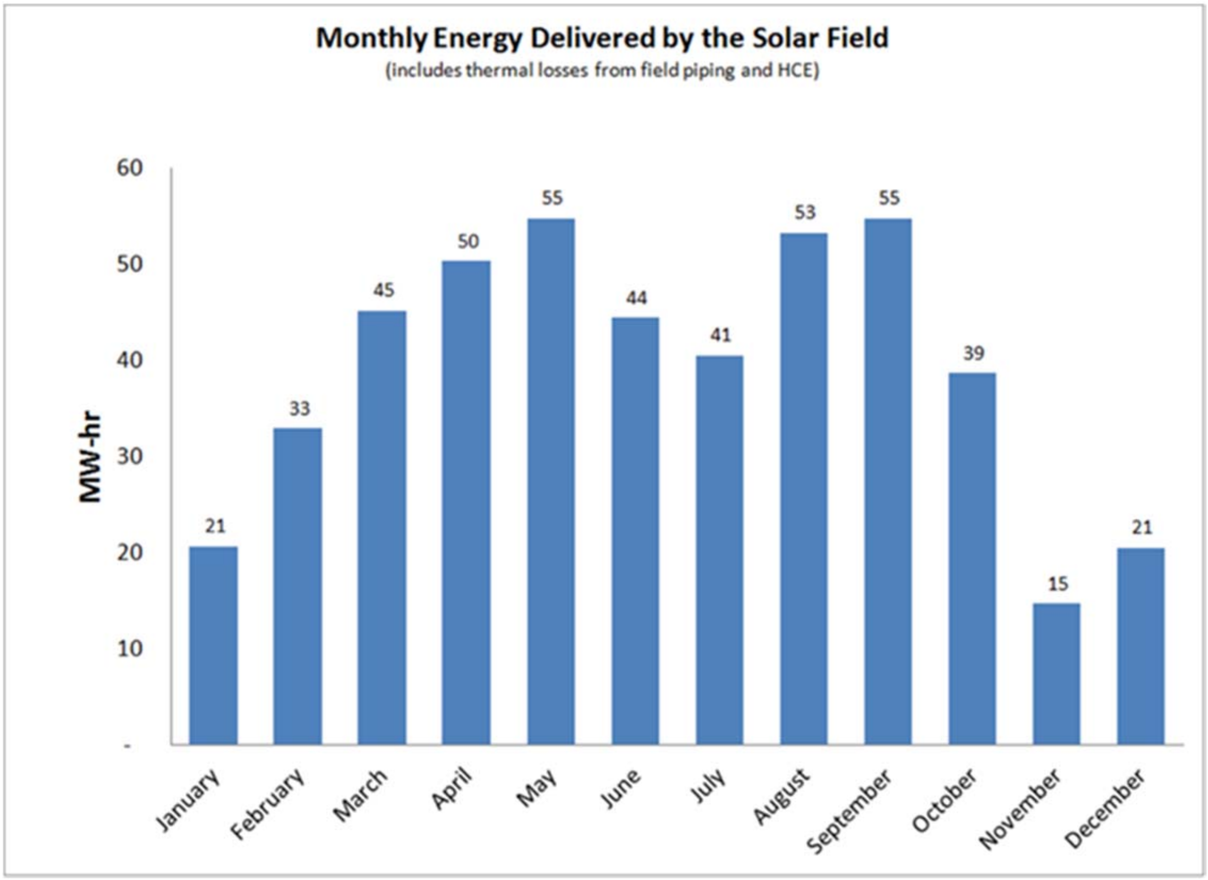


Figure 37: Thermal Flux and Efficiency, Spring 2014

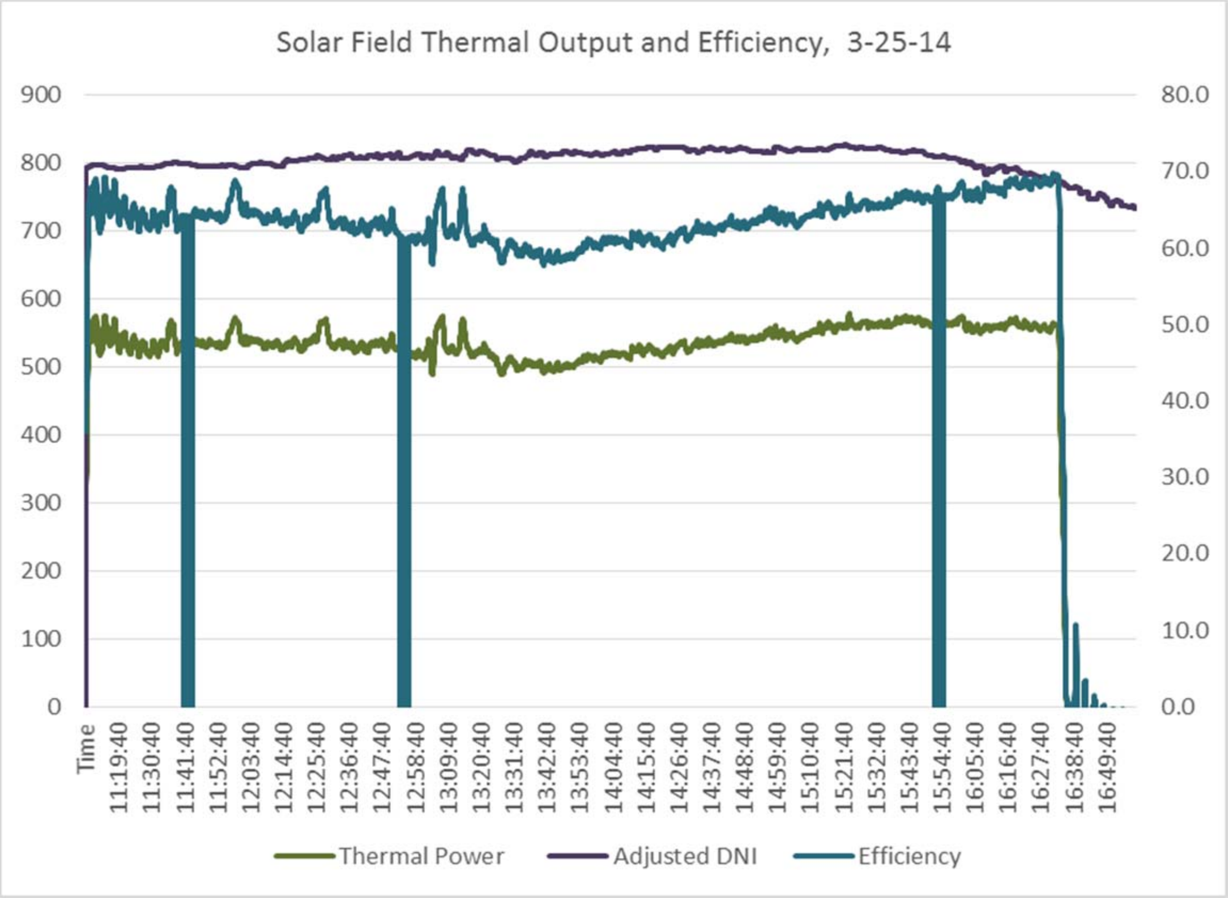


Figure 38: Comparison of Test Data to the Modelled Data

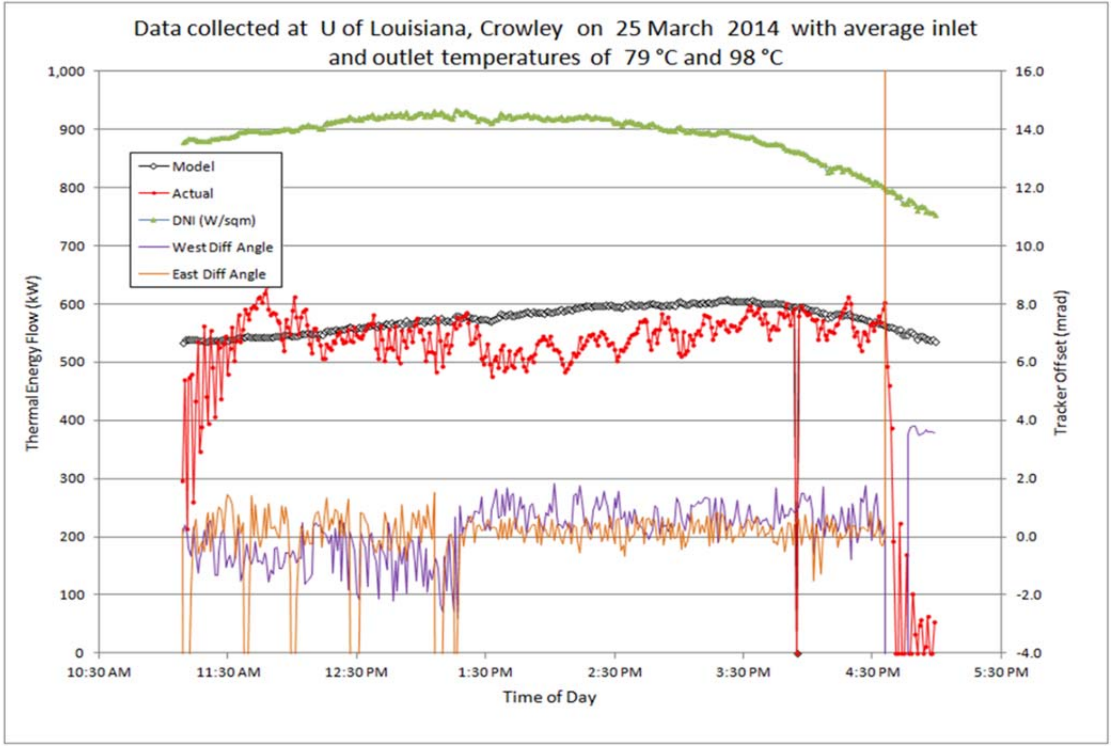
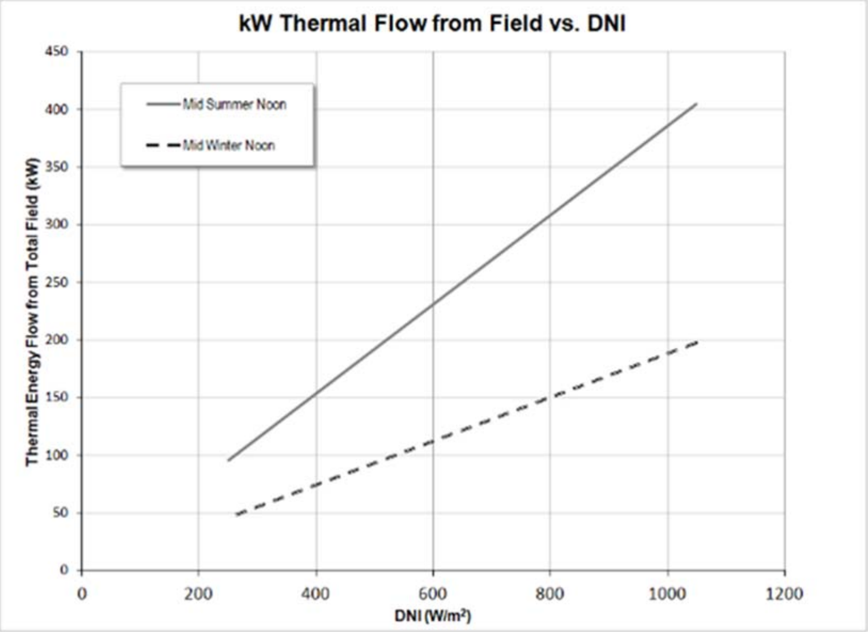


Figure 39 shows the modelled output of the solar field per loop based on DNI, and the NREL TMY3 dataset. For the design output of 650 kWth (325 kWth per SCA), a summer DNI of about 800 DNI would be expected to be required to maintain a constant output.

Figure 39. Collector field output vs. DNI. Source: 3M



Figures 40 and 41 show the measured DNI for the second day presented with the collector performance data, averaged by the minute and hourly, respectively, which highlights the variable conditions seen in the collector field data.The below variability highlights the potential impact thermal energy storage can have in stabilizing the power output, both in short term and long term power production.

Figure 40: Measured DNI for Day Two, Averaged by Minute

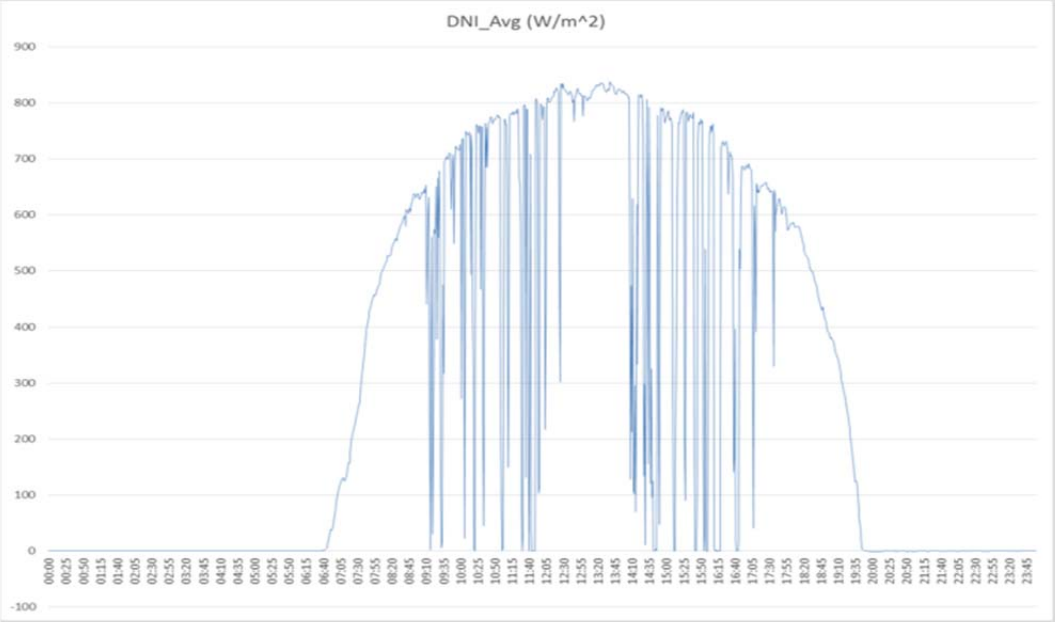
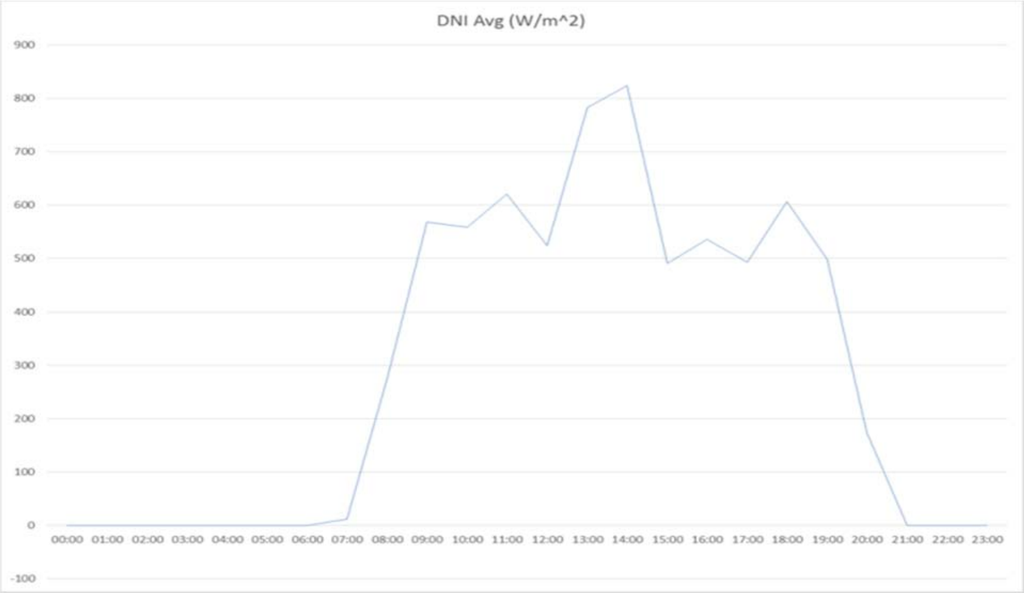


Figure 41. Measured DNI for Day Two, Averaged Hourly



d. To the extent available and known, where are the best locations to site the different types of renewable resources?

For solar thermal power, the following siting issues greatly affect the feasibility of the use of this technology. First, the site should be located close to the need for thermal energy. Solar thermal energy technologies are approximately 75% efficient in terms of creating thermal energy from available solar irradiation, but they are significantly lower in terms of producing electricity from the thermal energy, due to the lower efficiencies of the power block used. Therefore, if the solar collector field can be located next to a facility that is using a fossil fuel to create thermal energy, either to produce electricity or for some industrial process, and if the solar thermal energy is used to partially offset the use of fossil fuels to produce thermal energy, then there is a greater likelihood that the economics for the use of solar thermal technology will be feasible.

Second, care should be given to the stability of land on which the solar collector field will be located. On this project, it turned out that the foundations for the solar collector fields required more dirt work than originally expected.

Third, solar thermal facilities should obviously be located not only where the daily direct normal irradiation ("DNI") levels are high in general, but also where the climate is such that there will be a large number of days per year when the level of cloudiness is low enough that the DNI for that day will be sufficient to run the system.

Fourth, solar thermal facilities are tall structures with a very large surface area, which means that high winds can present a problem with tipping. As a result, solar collector fields located in high wind areas may require larger and more expensive foundations.

e. Within a given renewable resource type, what specific technology types might be the most appropriate for Louisiana?

This is an area of on-going investigation. Questions that are being asked include: What is the optimal trough size to use? What is the best receiver to use? What is the best power block to use? Is it better to use a water-cooled or an air-cooled condenser, and what are the conditions that govern the choice? How much more efficient would hybrid solar-fossil fuel power plants be?

Significant strides were made in 2014 to answer these questions as operational data is now being used to inform analytical models. In addition, the existing facility is being leveraged for use in testing components with which direct measurement of side-by-side operation can be conducted.

Preliminarily, a parabolic trough type of CSP plant co-located with an existing fossil fuel power plant seems an attractive option for low cost and reliable power production while also offsetting large amounts of greenhouse gases.

Fuel Issues

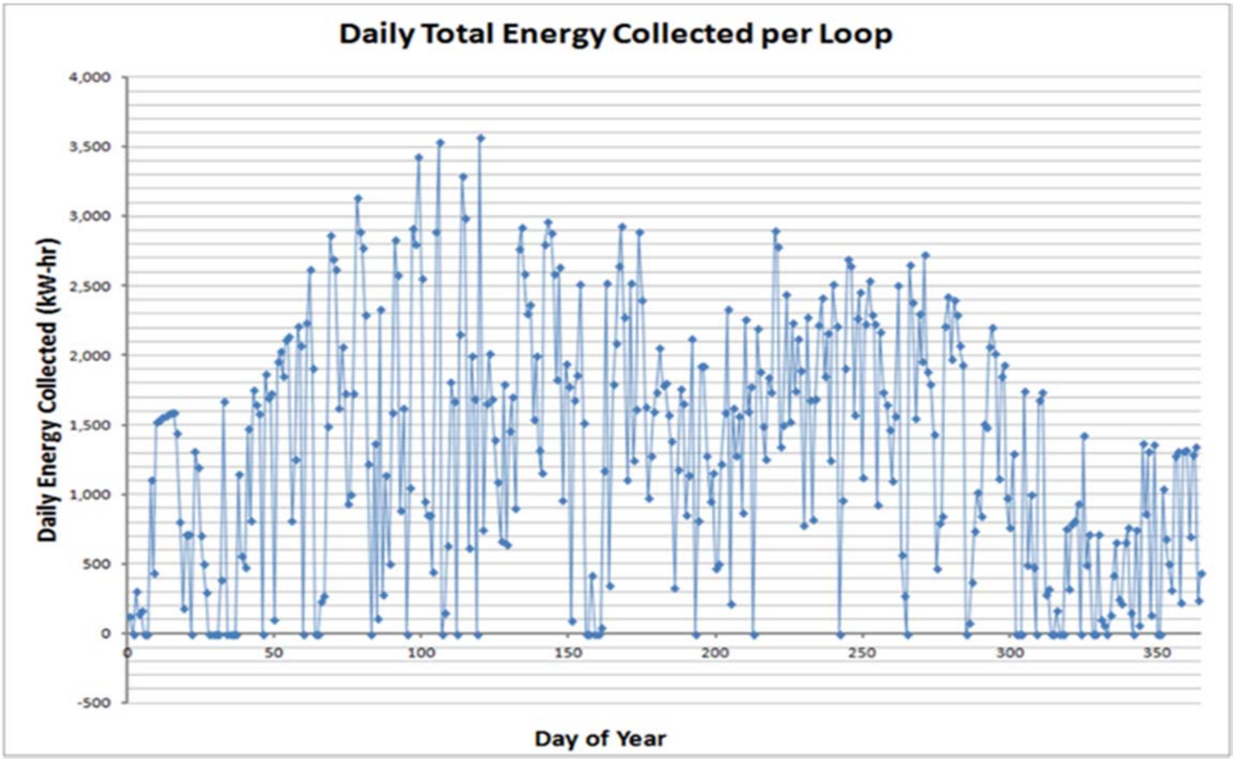
a. For renewable resources that have been evaluated by the utility, what are the fuel issues that should be addressed?

Since the fuel for solar thermal power plants is the sun, the main issue with the fuel is the availability of a sufficient DNI to obtain the solar thermal energy needed to operate the plant. Fuel availability is a function of the climate, as described above, and is a subject of further investigation under this project.

b. What uncertainties should be evaluated that impact the fuel costs and fuel availability associated with the renewable resources?

The uncertainty in DNI availability dictates an uncertain short-term production output. Significant variability was expected due to seasonal weather conditions. **Figure 42** uses the TMY3 dataset to model daily output over the course of one year. It should be noted the significant number of days forecasted with zero energy produced due to local weather conditions. However, on a yearly basis, it is expected that the number of available hours for production will be more constant and predictable. The TMY3 data predicted 303 days in a year with at least one hour averaging 400 W/m^2 of DNI. In 2014, there were 273 days measured with at least this minimum amount of solar irradiance. As this project continues, the yearly solar resource assessment will build a 'library' for which prediction of availability can be conducted with more confidence.

Figure 42. Modelled Energy Collected per Day per Loop. Source: 3M



c. Please discuss how the use of this renewable fuel might impact other industries, and consider how those impacts might be evaluated in order to decide whether this renewable fuel should be used in Louisiana renewable energy policy.

Use of solar thermal technologies provides the ability to partially offset the use of a traditional fossil fuel to produce thermal energy. To the extent that fossil fuel use is reduced, a corresponding reduction can be expected in pollution and greenhouse gasses.

d. Based on the utility's best estimate for technologies they have evaluated, what are the costs of the renewable fuels and how are the costs impacted by the risks discussed above?

The nominal cost of the fuel, which is energy from the sun, is zero. The cost to produce electricity is largely a function of the up-front capital costs, as will be discussed below.

Economic Evaluation

a. Provide a levelized cost analysis comparing new renewable energy types, and even more specifically compare the cost of different technology types. This analysis should include the conversion of any existing solid fuel capacity resources to operate using biomass co-firing.

Until we have completed studying the availability of the necessary level of DNI from the sun in Louisiana, we will not have a good idea of the levelized cost of electricity when using solar thermal technology. However, preliminary calculations based on previously recorded climate data suggest that using existing solar thermal technology to supply supplemental thermal energy to an existing fossil fuel power plant may allow the levelized cost of electricity to dip below ten cents per kW-hr, and it may go as low as 7.5 cents per kW-hr. Additional cost savings will be possible with improved technology and with the savings brought about by the economies of scale. Verifying these initial calculations and refining these predictions is a major goal of this pilot project.

Job Impacts

a. Based on available information, discuss both job creation and job loss impacts of the renewable resources considered in the pilot.

The technology used in solar thermal power plants is uncomplicated, and a great deal of local knowledge and skills have already been created as a result of this project. Louisiana engineers are now perfectly capable of designing a future solar thermal power plant. Louisiana manufacturers are quite capable of manufacturing any of the components of a solar thermal power plant and some have shown significant interest, and Louisiana installers have shown that they are perfectly capable of installing a solar thermal power plant. As this project progresses, we will also develop local skill in the on-going operation of a solar thermal power plant, which will help to improve Louisiana's competitive position in developing a larger plant.

Impact of Cleco Alternative Energy Facility on Workforce Development

UL Lafayette has been playing a significant role in the development of an alternative energy program at the South Louisiana Community College, Crowley campus. The new program took shape and classes commenced during Fall 2013. Students attending this program will have taken numerous opportunities to visit the Cleco Alternative Energy Center and gain firsthand, in-depth knowledge of the renewable energy projects that are being carried out at the facility. In addition, students from the four year Industrial Technology program at UL Lafayette have visited the facility yearly for an introduction into the types of jobs being carried out.

Industrial Collaborations

As a result of collaborative work with Cleco Power, UL Lafayette has established ties with several private industrial entities including:

- Gossamer Space Frames – UL Lafayette is working in close collaboration with Gossamer to develop thermal energy storage solutions that will improve and optimize the performance of the solar collector field. GSF has been a collaborator on multiple grant applications in this area. Additional improvements and modifications to the existing solar collector frames will be tested and demonstrated at the site.

- 3M – UL Lafayette continued testing of the 3M SMF1100 thin film polymer technology for the solar collector reflective surfaces. The newest 3M film, SMF 2020, was installed in several panels during the summer of 2014, for operational testing.

- D&D Manufacturing – Based out of Florida, D&D Manufacturing has developed a novel parabolic trough design which is constructed of high strength plastics. The resulting framework is extremely versatile and also ultra-low cost to manufacture compared to existing technologies. UL Lafayette is working with D&D to further refine the trough design to bring the technology closer to market and also in the modeling and testing of a solar desalination design which can operate within the framework of the trough. UL Lafayette is currently partnering with D&D on two SBIR grant applications to the DOE.

- Sentel Corp. – Based out of Virginia, Sentel Corp. is a large contractor providing logistical and technical support to enterprises which included the U.S. Department of Defense, D.O.E., among others. UL Lafayette is currently partnering with Sentel on a grant application to the NSF.

- Konica Minolta – Partnering with Gossamer Space Frames, Konica Minolta has developed a low cost high performing thin film reflector which will be tested at the START Lab in 2015.

- GreenField Solar – GreenField Solar is partnering with UL Lafayette to set up and test their pilot Concentrating Solar Photovoltaic (CSPV) technology in a hybrid configuration with the existing solar thermal collector for the potential of large improvements in overall efficiency (**Figures 43 and 44**). GFS is currently their second generation system to the UL Lafayette

START Lab for deployment and testing and plans to partner with UL Lafayette on a SBIR grant application to the DOE.

Figure 43: Installation of GreenField Solar CSPV System

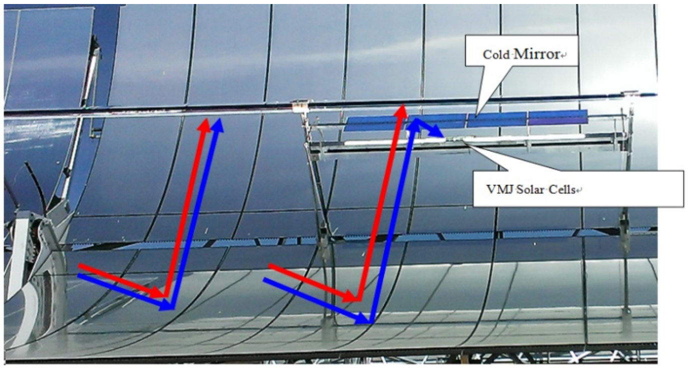
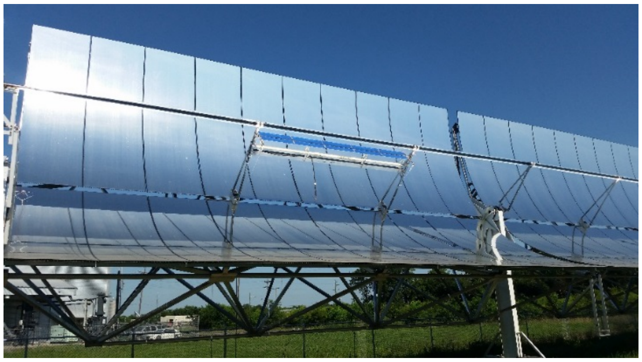


Figure 44: Operation of the CSPV System at the UL Lafayette START Lab



Publications and Presentations

The findings of the work being conducted at the Cleco Alternative Energy Center have been presented at several meetings and conferences. In addition, manuscripts have been and are being prepared for submission to peer reviewed journals. Following is the list of presentations:

Raush, J., Chambers, T., 2014, "Initial field testing of concentrating solar photovoltaic (CSPV) thermal hybrid solar energy generator utilizing large aperture parabolic trough and spectrum selective mirrors," Accepted, *International Journal of Renewable and Sustainable Energy {IJRSE)*, Received October, 2014.

Ritter, K.A. III, Chambers, T., 2014, "Educational Gaming and Use for Explaining Alternative Energy Technologies," *International Journal for Innovation in Education and Research, Vol. 2-03, 2014, pp. 30 – 42.*

Raush, J., Chambers, T., Russo, B. 2013, "Demonstration of Pilot Scale Large Aperture Parabolic Trough Organic Rankine Cycle Solar Thermal Power Plant in Louisiana," Journal of Power and Energy Engineering, Vol. 1, No. 7, pp. 29 – 39. Published December, 2013. Available at: http://dx,doi.org/10.4236/jpee.2013.17006.

Chambers, T. L., Raush, J., Russo, B, "Installation and Operation of Parabolic Trough Organic Rankine Cycle Solar Thermal Power Plant in South Louisiana," *Energy Procedia*, *49*(Proceedings of the SolarPACES 2013 International Conference), 2014, pp. 1107-1116. doi:10.1016/j.egypro.2014.03.120

Chambers, T. L., Raush, J. R., Massiha, G. H., 2013, "Pilot Solar Thermal Power Plant Station in Southwest Louisiana," *International Journal of Applied Power Engineering (IJAPE)*, Vol. 2, No. 1, April 2013, pp. 31 – 40. ISSN: 2252-8792.

Leger, J., Raush, J.R., Chambers, T.L., 2012, "Parametric Study of Solar Thermal Power Plant Configuration Considering Effects of Solar Multiple, Thermal Storage, Plant Size, and Plant Location Utilizing System Advisor Model (SAM)," SAM Virtual User Conference, Hosted by the National Renewable Energy Laboratory, June 20, 2012. Available online at: https://sam.nrel.gov/content/sam-virtual-conference-june-20-2012.

Additional Selected Conference and Industry Presentations

Raush, J., Chambers, T., Russo, B., 2013, "Installation and Operation of Parabolic Trough Organic Rankine Cycle Solar Thermal Power Plant in South Louisiana," VerTech 2013, La Rochelle, France, May 2013.

Chambers, T., Raush, J., Russo, B., Crouch, B., "Potential for Solar Thermal Power in Louisiana, VerTech 2012, Lafayette, Louisiana., November, 2012.

Raush, J. R., 2012, “UL Solar Energy Project,” Department of Natural Resources “Save Energy Now” Project, Crowley, Louisiana, October, 2012.

Chambers, T. L., Raush, J.R., 2011, “Solar Thermal Power Plant,” Lafayette Economic Development Authority, Acadian Alternative Energy Committee Lecture Series, Lafayette, Louisiana, October, 2011.

Summary of Results and Future Work

The University of Louisiana at Lafayette, in conjunction with Cleco Power LLC, has installed and commissioned a pilot scale solar thermal power plant in Louisiana for the first time. Following commission in December, 2012, testing and operation of the facility commenced. Initial short-term performance data has been presented which demonstrates that the collector field and ORC power block are operating at or near the design point on an efficiency and power output basis. In the case of the collector field, initial performance has in some cases exceeded expected values. The power plant has been operated in all seasons of the year and the data is being aggregated for analysis on an annual basis. Operation and maintenance experience over two years has been compiled to create a ‘manual’ which is being continually updated and will inform a component of the LCOE calculations.

Continued improvements to the performance will be expected when additional work is completed including adding insulation to exposed piping at the cross-over between SCAs (15 linear meters) and automated operation is completed. Regarding the ORC, the initial performance at or near design point is highlighted by the fact that the input flow rate of the ORC requires a minimum of 379 l/min while the current HTF flow rate is at a maximum at this value. Future work will include adding variable frequency drives to the HTF pump to modulate and optimize the HTF flow rate for improved ORC heat removal. Losses in the system must be quantified for optimization, including continuing to quantify and correlate the level of degradation in specularity due to soiling of the mirrors versus time. Pumping losses for the HTF and the evaporative cooler totaled about 3.5 kWe.

Considerable fluctuations in the thermal output of the collector field were due to a lack of thermal buffer. Future work calls for the installation of a thermal storage/buffer system which will act to remove the high levels of variability due to cloudy conditions and collector field-ORC balancing acting to further optimize the system. Concepts for advanced energy storage with the potential to greatly reduce the LCOE of the power plant are also being investigated and external funds are being pursued for continuation of the research.

Additional work will also include the continued collection and study of measured DNI data, which will serve to improve efficiency calculations, create a database for local conditions which will replace TMY3 data in analytical models, and inform local DNI/GNI ratios. Additional work remains to quantify incident angle modifiers (IAM) which augment the performance of single-axis concentrators on a seasonal basis in addition to the cosine effect. This data together with quantification of IAMs will paint a complete picture of the local solar resource which will continue to enhance analytical tools developed for power plant feasibility and optimization. An accurate assessment of the local solar resource together with the operation and maintenance experience and familiarity with the technology enhancements will allow for accurate economic forecasts concerning this technology.

Of significant interest is the implementation of an integrated combined cycle (ICC) concept whereby the solar collector field provides thermal energy to a traditional steam Rankine cycle power block, thereby offsetting the needed use of coal or natural gas, and integrating the ORC as a bottoming cycle, increasing overall efficiency. This would allow the LAT collectors to operate at a higher temperature and lower flow rate, providing higher quality thermal energy to the power block. The power block could then operate at a higher efficiency and potentially much lower cost with the reduction in solid fuel or natural gas consumption. This concept would have the advantage of being able to be retrofitted to existing fossil fuel burning power plants at a much lower cost than building a stand-alone commercial scale solar thermal power plant.

Cleco Photovoltaic and Solar Thermal

Photovoltaic ("PV") devices use semiconducting materials to convert sunlight directly into electricity. Solar radiation, which is nearly constant outside the Earth's atmosphere, varies with changing atmospheric conditions (clouds and dust) and the changing position of the Earth relative to the sun.

The sun produces an enormous amount of energy; however, only a very small percentage of this energy strikes the Earth. A nearly constant 1.36 kilowatts per square meter (the solar constant) of solar radiant energy strikes the Earth's outer atmosphere. Approximately 70% of this solar radiation makes it through Earth's atmosphere on a clear day. In the southwestern United States, the solar irradiance at ground level regularly exceeds 1,000 watts per square meter ("w/m2"). In some mountain areas, readings over 1,200 w/m2 are often recorded. Average values are lower for most other areas, but maximum instantaneous values as high as 1,500 w/m2 can be received on days when puffy clouds are present to focus the sunshine; however, these high levels seldom last more than a few minutes. The atmosphere is a powerful absorber and reduces the solar radiation reaching the Earth at certain wavelengths. The part of the spectrum used by silicon PV modules is from 0.3 to 0.6 micrometers, approximately the same wavelengths to which the human eye is sensitive. These wavelengths encompass the highest energy region of the solar spectrum.

Discussing solar data requires some knowledge of terms, because on any given day the solar radiation varies continuously from sunup to sundown and depends on cloud cover, sun position, and content and turbidity of the atmosphere. The maximum irradiance is available at solar noon, which is defined as the midpoint, in time, between sunrise and sunset. Irradiance is the amount of solar energy striking a given area and is a measure of the intensity of the sunshine. Insolation (now commonly referred as irradiation) differs from irradiance because of the inclusion of time. Insolation is the amount of solar energy received on a given area over time measured in kilowatt-hours per square meter (kwh/m2) - this value is equivalent to "peak sun hours." Peak sun hours is defined as the equivalent number of hours per day, with solar irradiance equaling 1,000 w/m2, that gives the same energy received from sunrise to sundown. In other words, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the sun shone for six hours with an irradiance of 1,000 w/m2. Therefore, peak sun hours correspond directly to average daily insolation given in kwh/m2. Many tables of solar data are often presented as an average daily value of peak sun hours (kwh/m2) for each month. Insolation varies seasonally because of the changing relation of the Earth to the sun. This change, both daily and annually, is the reason some systems use tracking arrays to keep the array pointed at the sun. For any location on Earth, the sun's elevation will change about 47° from winter solstice to summer solstice. Another way to picture the sun's movement is to understand the sun moves from 23.5° north of the equator on the summer solstice to 23.5° south of the equator on the winter solstice. On the equinoxes, March 21 and September 21, the sun circumnavigates the equator. For any location, the sun angle at solar noon will change 47° from winter to summer.

The power output of a PV array is maximized by keeping the array pointed at the sun. Single-axis tracking of the array may increase the energy production in some locations by up to 50 percent for some months and by as much as 35 percent over the course of a year. The most benefit comes in the early morning and late afternoon when the tracking array will be pointing more nearly at the sun than a fixed array. Generally, tracking is more beneficial at sites between 30° latitude north and 30° latitude south. For higher latitudes, the benefit is less because the sun drops low on the horizon during winter months.

For tracking (structures that follow the sun across the sky by various mechanisms, thereby increasing the energy captured from the sun) or fixed arrays, the annual energy production is at its maximum when the array is tilted at the latitude angle; i.e., at 40° latitude north, the array should be tilted 40° up from horizontal. If a wintertime load is the most critical, the array tilt angle should be set at the latitude angle plus 15° degrees. To maximize summertime production, fix the array tilt angle at latitude minus 15° degrees.[10]

Cleco Power currently has photovoltaic solar projects in Rapides Parish as shown in

Figure 1, and in Iberia Parish. The Iberia Parish installation involves evaluation of a solar thermal water heating system (discussed further below). Cleco Power also completed an installation in Sabine Parish, shown in **Figure 2**, at the end of 2011, which represents Cleco Power's largest solar installation, consisting of more than 1,200 panels with a DC rating of 293 kW and an AC rating of 249.87 kW. The project did not create any new jobs, nor does Cleco Power expect the project to require the future establishment of new jobs.

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[10] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

Figure 1: Cleco Power Photovoltaic Solar Projects in Rapides Parish

Figure 2: Solar Panels Mounted on Commercial Building in Sabine Parish

The three solar panel technologies being tested by Cleco are (i) monocrystalline, (ii) polycrystalline, and (iii) amorphous. The expected advantages and disadvantages of each type of panel are:

Monocrystalline

- Made from a large crystal of silicon

- Most expensive of the three types of solar panels
- Most efficient of the three types of solar panels
- Does not charge when part of the panel is covered by a shadow
- Degradation of approximately 0.5 percent each year
- Eighteen percent efficient

Polycrystalline

- Most common of the three types of solar panels
- Made of multiple small silicon crystals
- Does not charge when part of the panel is covered by a shadow
- Degradation of approximately 0.5 percent each year
- Fifteen percent efficient

Amorphous (thin film)

- Covered by a thin film made from molten silicon spread over stainless steel
- Lowest cost per watt of the three types of panels
- Continues to charge while part of the panel is covered by a shadow
- Degradation of approximately 1 percent each year
- Ten percent efficient

In addition to the three types of solar panels, a subset of the polycrystalline panels is mounted on a fixed tilt structure, while another subset of the panels is mounted on a tracking structure, which allows the panels to follow the track of the sun. Output collected from the two mounting structures will provide critical data in determining if the additional cost of a tracking structure is justified.

Table 1 below shows the monthly capacity factors for each type of solar panel technology along with their monthly and annual capacity factors for 2014.

Table 1: 2014 Cleco Power Photovoltaic Solar Capacity Factors by Technology

Month	Polycryatalline	Monocrystalline *	Amorphous	Polycrystalline (Tracking)
1	13.29%	14.72%	11.15%	14.13%
2	9.61%	10.87%	7.89%	9.70%
3	14.63%	15.88%	12.70%	15.35%
4	17.91%	18.73%	16.18%	19.94%
5	18.39%	19.58%	16.99%	21.21%
6	17.78%	18.16%	16.82%	20.70%
7	18.53%	19.81%	17.85%	21.91%
8	16.57%	19.14%	16.13%	18.57%
9	15.68%	16.56%	15.14%	16.99%
10	16.74%	17.65%	15.54%	17.50%
11	13.44%	14.75%	12.29%	14.24%
12	8.92%	8.40%	7.47%	8.91%
Annual	15.16%	16.22%	13.88%	16.64%
		*Includes WalMart and PVGO		

Cleco Power is also evaluating a solar thermal water heating system in Iberia Parish. The system is a closed loop, simple drain back, solar thermal water heating system, composed of two solar thermal panels and one solar water heater tank. In 2014, data shows that the system had the potential to save 5,862 kWh, with a maximum of 628 kWh in May and a minimum of 308 kWh in December.

Figure 3 provides a view of a typical solar thermal water heating system. When there is sufficient heat to be drawn from the collectors, a controller automatically activates pumps. Heated fluid is then circulated from the collector through a heat exchanger where its heat is transferred to water in the storage tank. The fluid is then pumped back to the collector to be reheated. This circulation loop will continue as long as there is heat to be drawn from the collector. During times when there is little or no sun, or when outside temperatures are below 50 degrees Fahrenheit, the fluid is withdrawn from the collectors and a backup heating system is activated to provide adequate hot water.[11]

Figure 3: System Schematic for a Standard Solar Thermal Water Heating System

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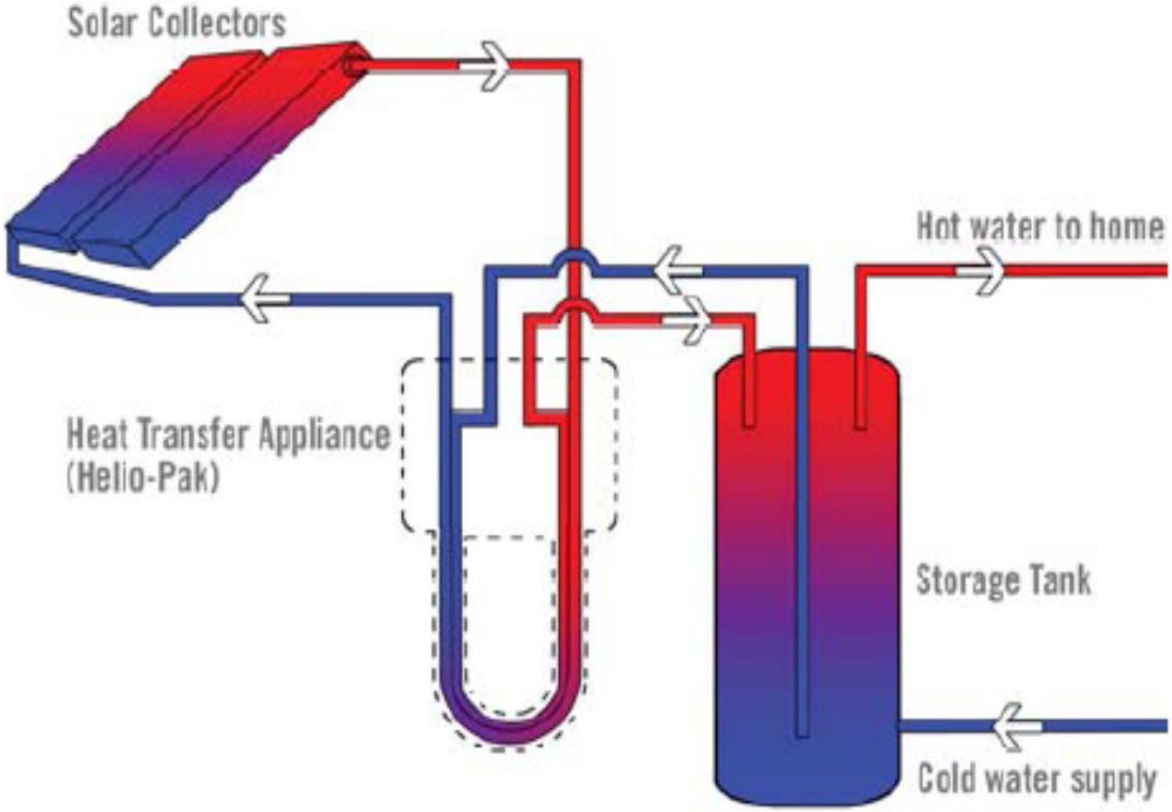
[11] http://www.heliodyne.com


Solar Collectors
Hot water to home
Heat Transfer Appliance
(Helio-Pak)
Storage Tank
Cold water supply

Section 4 Wind Power

Kinetic energy present in wind motion can be converted to mechanical energy for driving pumps, mills, and electric power wind turbines, with some turbines capable of producing 5 MW of capacity. There are two primary types of wind turbines used today - horizontal-axis wind turbines and vertical-axis wind turbines. Vertical-axis wind turbines make up only a small percentage of the wind turbines in use today.

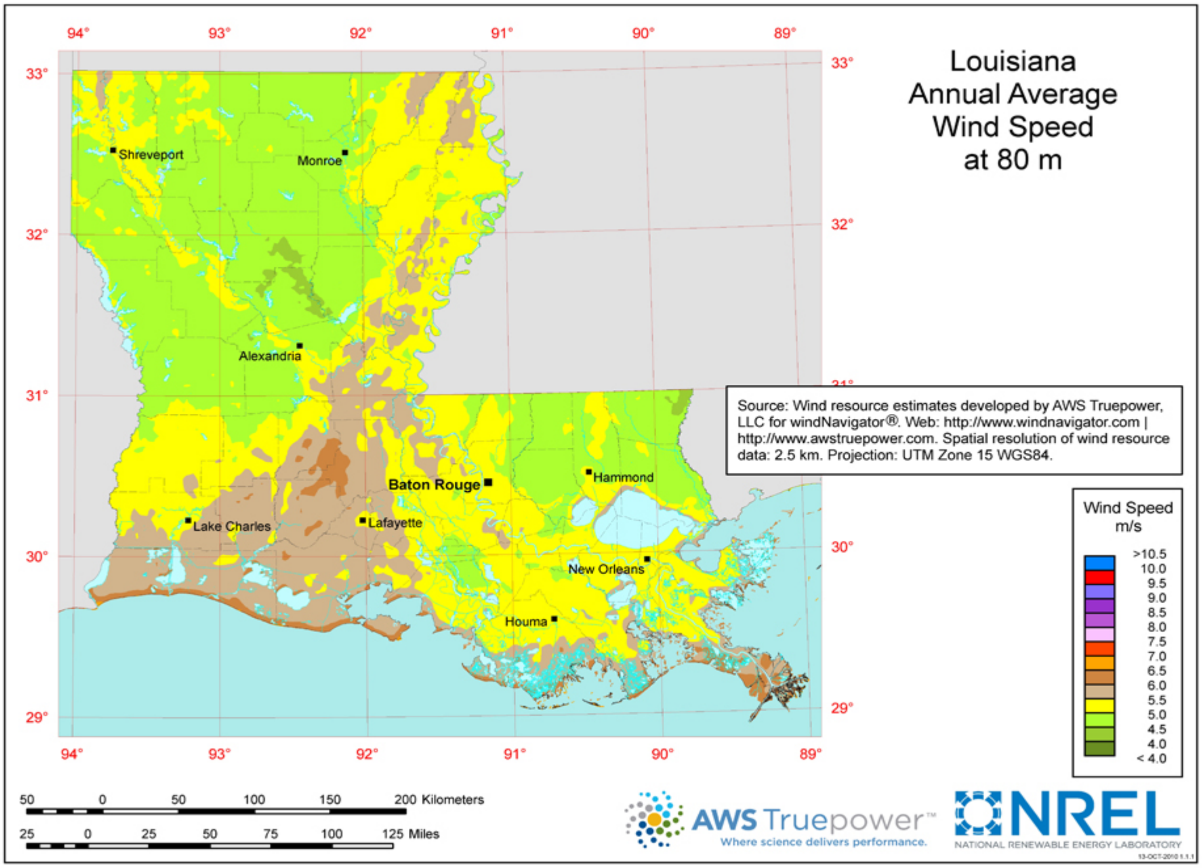
Cleco Power, in conjunction with the Greater New Orleans Expressway Commission, is evaluating a wind turbine at the foot of the Lake Pontchartrain Causeway bridge in Mandeville, Louisiana **(Figure).** This Wind Turbine is connected to the grid and supplies power to the surrounding area. The Nameplate Capacity of the Wind Turbine is 2.4MW.

Figure 1: Wind Turbine at the Foot of the Causeway Bridge in Mandeville, LA

Winds are typically a result of uneven heating of the atmosphere by the sun, irregularities of the Earth's surface, and the rotation of the Earth. Consequently, winds are strongly influenced and modified by local terrain, bodies of water, weather patterns, vegetative cover, and other factors. Climate patterns present in Louisiana does not support sufficient sustained winds installed to be considered a wind power generation state.

Figure below, from The National Renewable Energy Laboratory, depicts the average wind speed in meters/second for Louisiana.

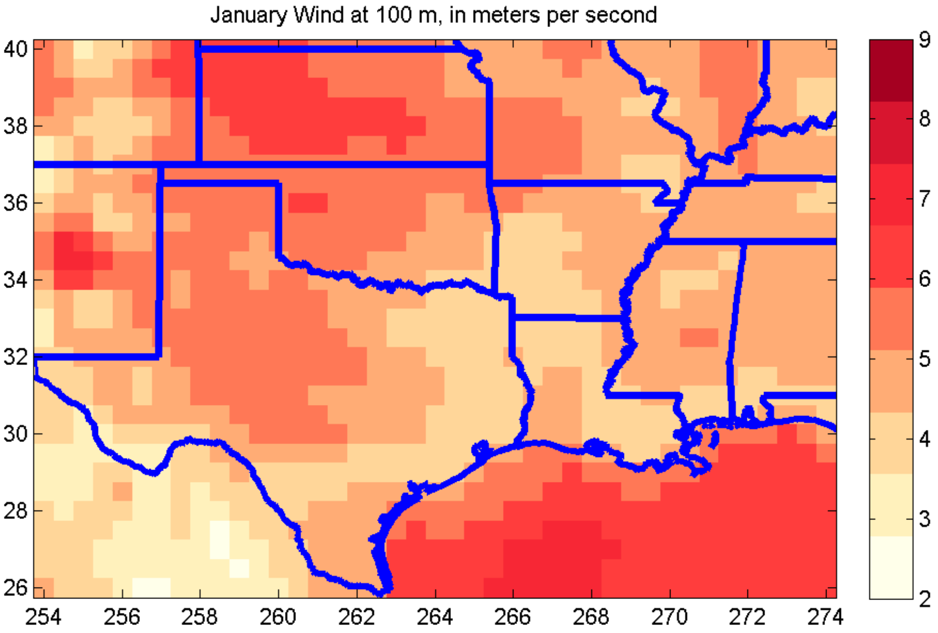
Figure 2: Average Annual Wind Speed in Louisiana

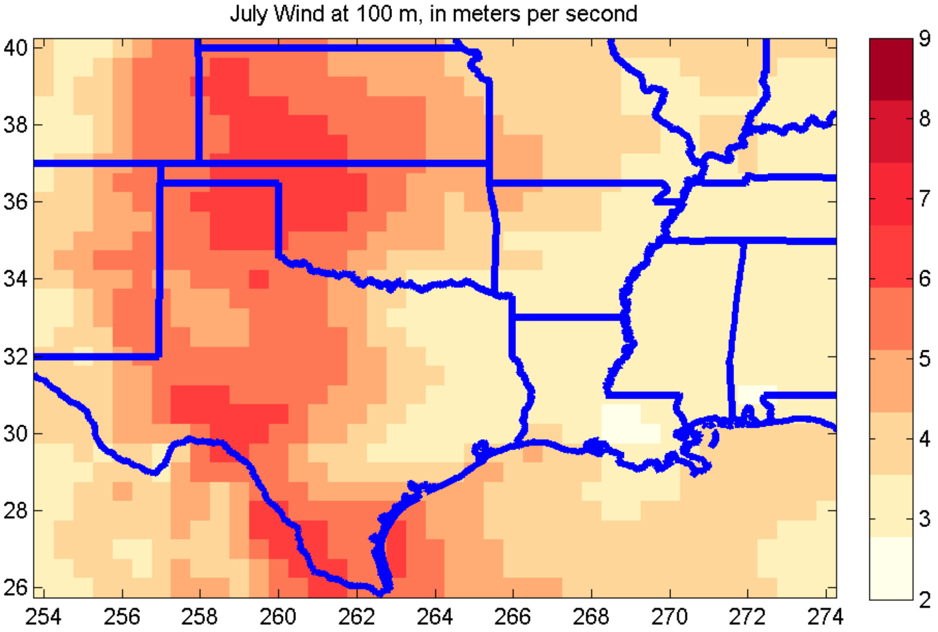


Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 15 WGS84.

Although Louisiana has significant amount of coastline to support the installation of offshore wind turbines, the average wind speed along Louisiana's coastline is neither sufficient nor consistent enough to make generation of electricity by wind power economical. Data from NOAA's Climate Forecast System Reanalysis**, shown in Figure 3,** illustrate further the absence of sufficient wind speeds in Louisiana as compared to surrounding states.

Figure 3: Average Annual January and July Wind Speeds in Louisiana





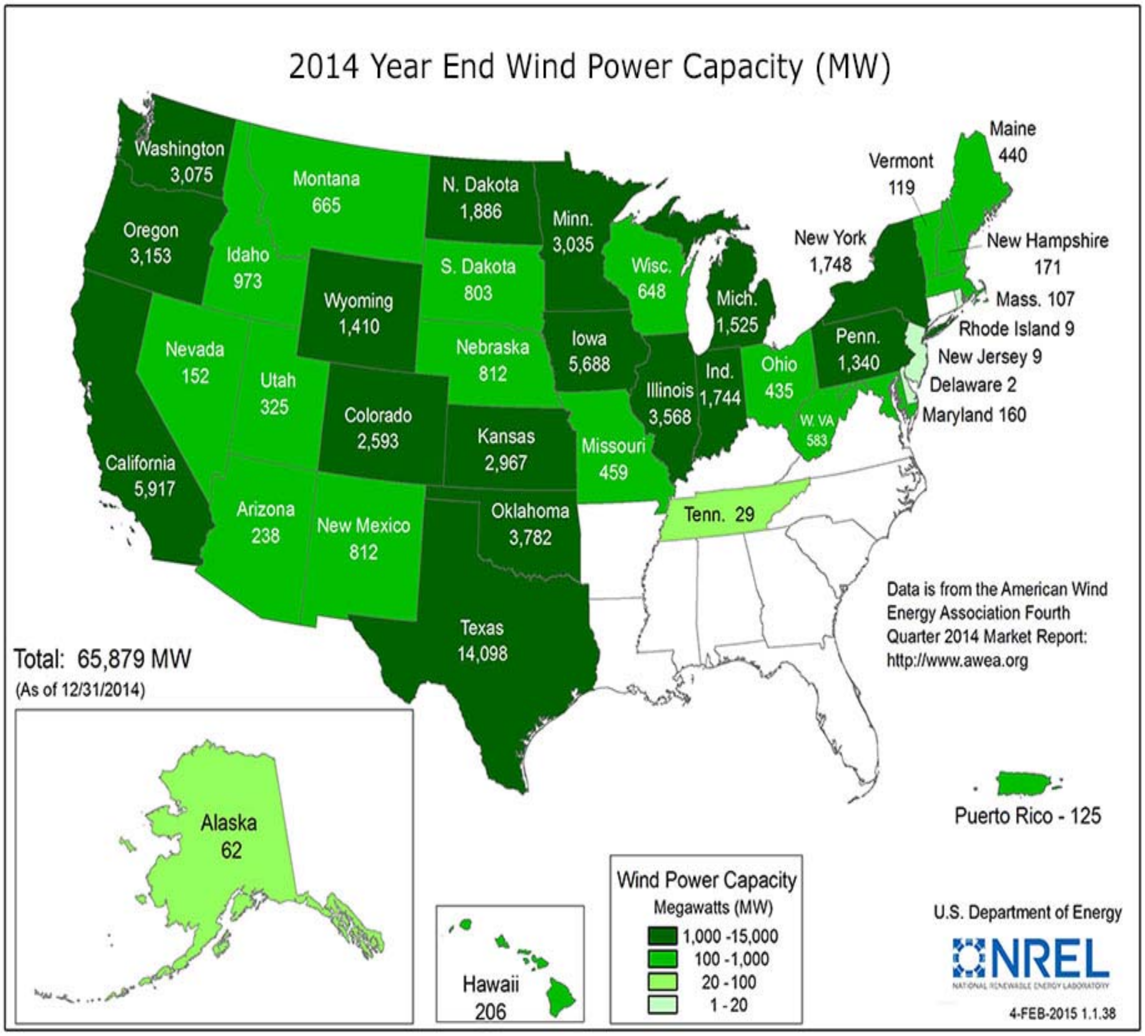
The operating statistics collected by Cleco Power for its research wind turbine in Mandeville support the above wind speed data. **Table** 1 shows the monthly capacity factors for the wind turbine along with the annual capacity factor for the year 2014.

Table 1 Mandeville Wind Turbine Monthly Capacity Factor

Month	Capacity Factor
1	1.79%
2	3.94%
3	1.81%
4	4.81%
5	5.03%
6	4.41%
7	2.28%
8	0.09%
9	0.85%
10	3.14%
11	0.07%
12	0.79%
Annual	2.40%

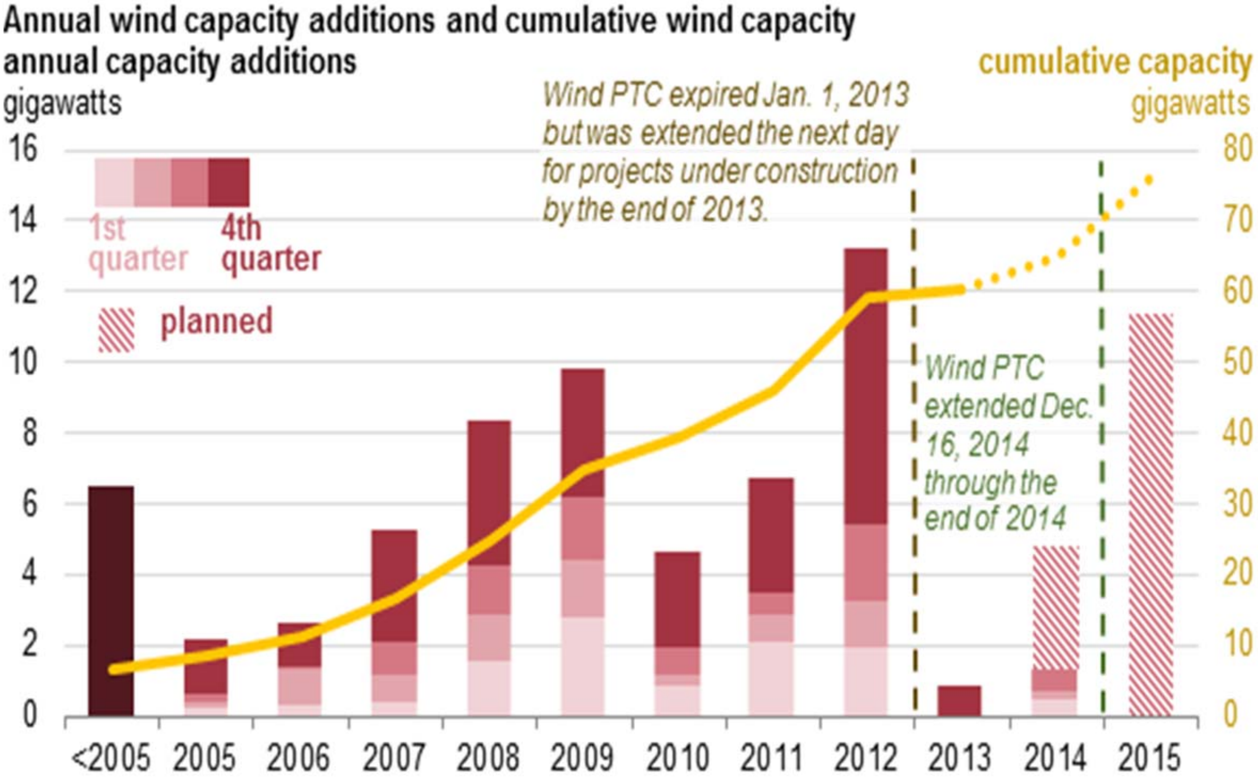
Notwithstanding power generation from wind in Louisiana, over the past decade worldwide installed maximum capacity from wind power increased from 2.5 GW in 2000 to just over 60.0 GW in 2013. **Figure 4** below shows the installed wind power capacity at year end 2014 in MW.

Figure 4: Installed Wind Power Capacity as Reported by NREL as of November 2014



The EIA anticipates installed wind cumulative capacity to be over 70GW if construction of planned wind farms is completed. See **Figure 5**.

Figure 5:



Source: U.S. Energy Information Administration, Forms EIA860A and EIA860M

On December 16, 2014, the U.S. Senate approved a bill (already passed by the U.S. House of Representatives on December 3) that retroactively extends the federal production tax credit (PTC) for wind plants, which had previously expired at the end of 2013. However, because of timing, this extension is unlikely to spur significant additional wind development activity beyond what installers had already planned. The PTC allows eligible wind generators to take an inflation-adjusted tax credit per unit of generation (2.3 cents per kilowatthour in 2014) for the first ten years of operation.

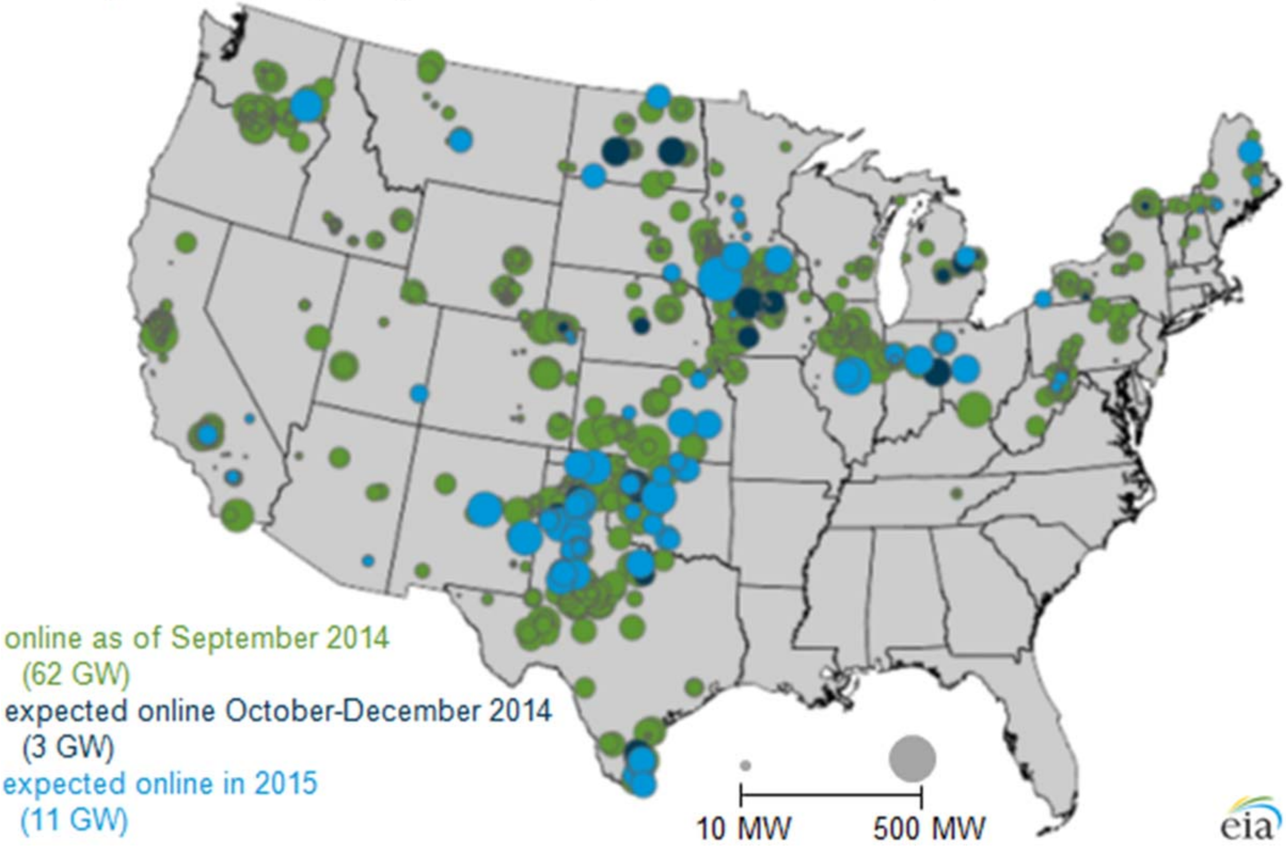
Previously, the PTC had been allowed to lapse or nearly lapse on several occasions. Before 2013, the tax credit legislation specified that projects must be in service by the end of the year. The 2013 and 2014 extensions required that projects must have been under construction by the end of the year.

The change in eligibility requirements and the timing of the 2013 extension (the deadline wasn't extended past 2012 until the beginning of 2013) contributed to wind capacity additions falling from an all-time high of 13 gigawatts (GW) in 2012 to less than 1 GW in 2013.

Capacity additions in the first three quarters of 2014 totaled less than 2 GW, but project developers have reported to EIA an additional 3 GW of expected capacity additions for the fourth quarter. They have also reported to EIA an additional 11 GW of wind projects with expected completion dates in 2015, primarily in states such as Texas, Oklahoma, Illinois, Iowa, and Minnesota, as illustrated in **Figure 6**.

Figure 6

Existing wind capacity and planned wind plant installations through 2015



Source: U.S. Energy Information Administration, Forms EIA860A and EIA860M
Note: Data include facilities with a net summer capacity of 1 MW and above only. Data are reported as of November 25, 2014, covering through September of 2014. Data are based the reported online dates of currently operational or planned wind generation facilities.

Section 5 Geothermal Energy

Geothermal energy is energy obtained by tapping the heat of the Earth itself, usually from miles deep into the Earth's crust. It is expensive to build a power station using this resource, but operating costs are low resulting in low energy costs for suitable sites. Geothermal electricity is created by pumping a fluid (oil or water) into the Earth, allowing it to evaporate and using the hot gases vented from the Earth's crust to run turbines used to drive electric generators.

The geothermal energy from the core of the Earth is closer to the surface in some areas than in others. When hot underground steam or water can be tapped and brought to the surface, it may be used to generate electricity. Such geothermal power sources exist in certain geologically unstable parts of the world such as Iceland, New Zealand, and the U.S., for example. The two most prominent areas for geothermal energy in the United States are in the Yellowstone basin and in northern California. Some relatively small resources exist within Louisiana, including Hot Wells near Alexandria.

Although geothermal sites are capable of providing heat for many decades, eventually specific locations cool down. Some interpret this as meaning a specific geothermal location can undergo depletion, and question whether geothermal energy is truly a renewable resource.

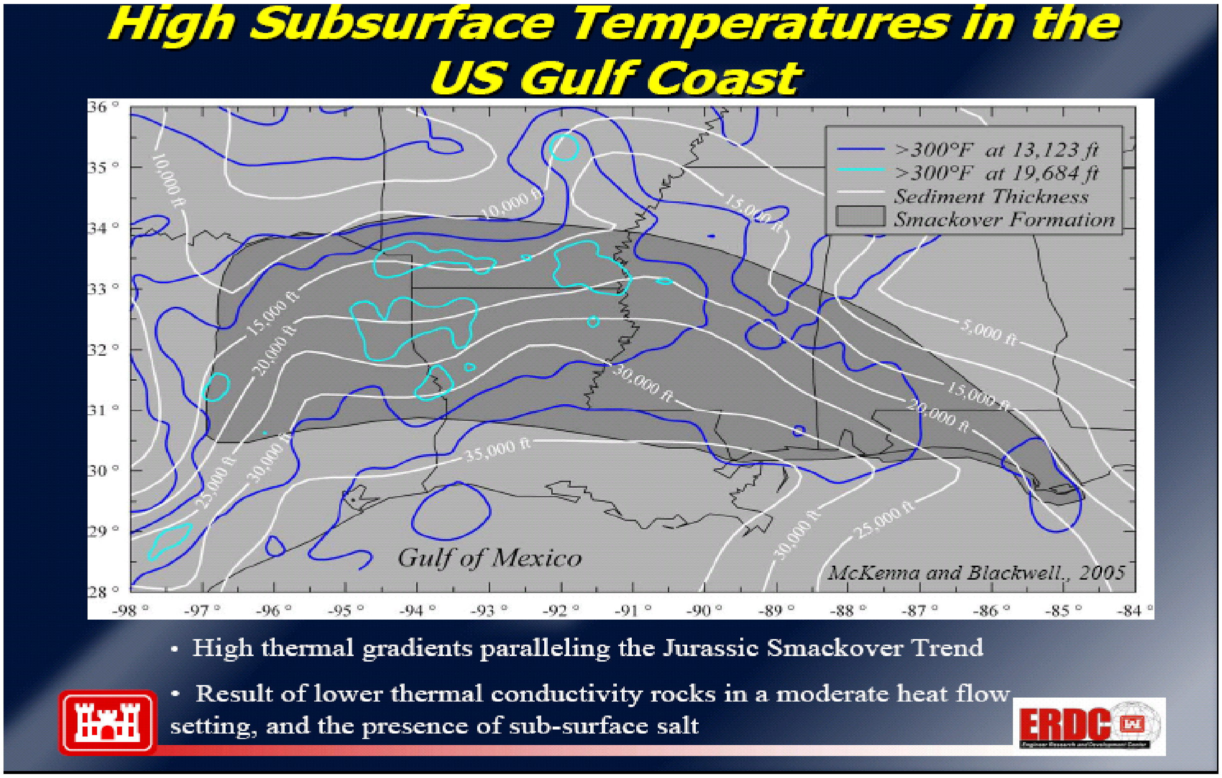
In areas where geothermal temperatures are insufficient to generate steam to produce electricity, a binary geothermal power plant can be utilized. The binary plant utilizes a high vapor pressure liquid instead of water to turn the turbine. The heat is removed from the geothermal liquid by a heat exchanger, which heats the high vapor pressure liquid. The high vapor pressure liquid turns to vapor and turns the turbine. The vapor is then cooled, which returns it to a liquid and the process begins again. The advantage of the system is that the geothermal fluid does not have to be as hot; it is a closed loop system and considered environmentally friendly.

The U. S. Army Corps of Engineers has initiated studies to determine if an effective geothermal energy program can be developed utilizing a binary geothermal power plant from existing Gulf Coast hydrocarbon production facilities. The premise of the study concentrated on utilizing the wastewater from wells that have hydrocarbon production depths of between 9,000 feet to 19,800 feet. The wastewater from these wells ranges from 250 to 400 degrees Fahrenheit, which is expected to be hot enough to produce energy using the closed loop binary energy system.

The critical factor for successful geothermal electrical power generation is sufficient high in situ permeability to provide fluid flow rates equal to or greater than 1,000 gpm. This is attained primarily by utilizing a system that has a central collection facility for hydrocarbon separation and water disposal. Piggybacking on existing infrastructure eliminates the need for expensive drilling and hydrological fracturing operations that plague engineered geothermal systems. Currently, there are hundreds of existing oil and natural gas wells in Louisiana producing oil, natural gas, and hot brine. In a typical oil and natural gas production process, the oil and natural gas are separated from the hot brine. The brine is then piped to a disposal well, where it is injected back into the ground with no capture of the waste thermal energy present in the brine. In a geothermal energy production mode, the brine would be piped to a heat exchanger, where the transfer of the thermal energy causes a liquid media also present in the heat exchanger to become a high-pressure vapor. The brine would be re-injected into the ground and the vapor then turns a screw expander and generator to produce electricity. The vapors then go to an economizer where some of the heat is used to preheat the liquid media. After the vapor leaves the economizer it travels to a fin fan air cooler where the remaining heat is released to the atmosphere, and the vapor returns into a liquid before the process begins again.

Figure 1 and Figure 2 show that Louisiana has numerous high temperature hydrocarbon wells that are in the thermal range needed to produce energy. It is estimated that there is approximately 73 MW of energy at 210 degrees Fahrenheit and approximately 398 MW of energy at 400 degrees Fahrenheit.[12]

Figure 1: Subsurface Temperatures in the US Gulf Coast



High Subsurface Temperatures in the US Gulf Coast

- High thermal gradients paralleling the Jurassic Smackover Trend
- Result of lower thermal conductivity rocks in a moderate heat flow setting, and the presence of sub-surface salt

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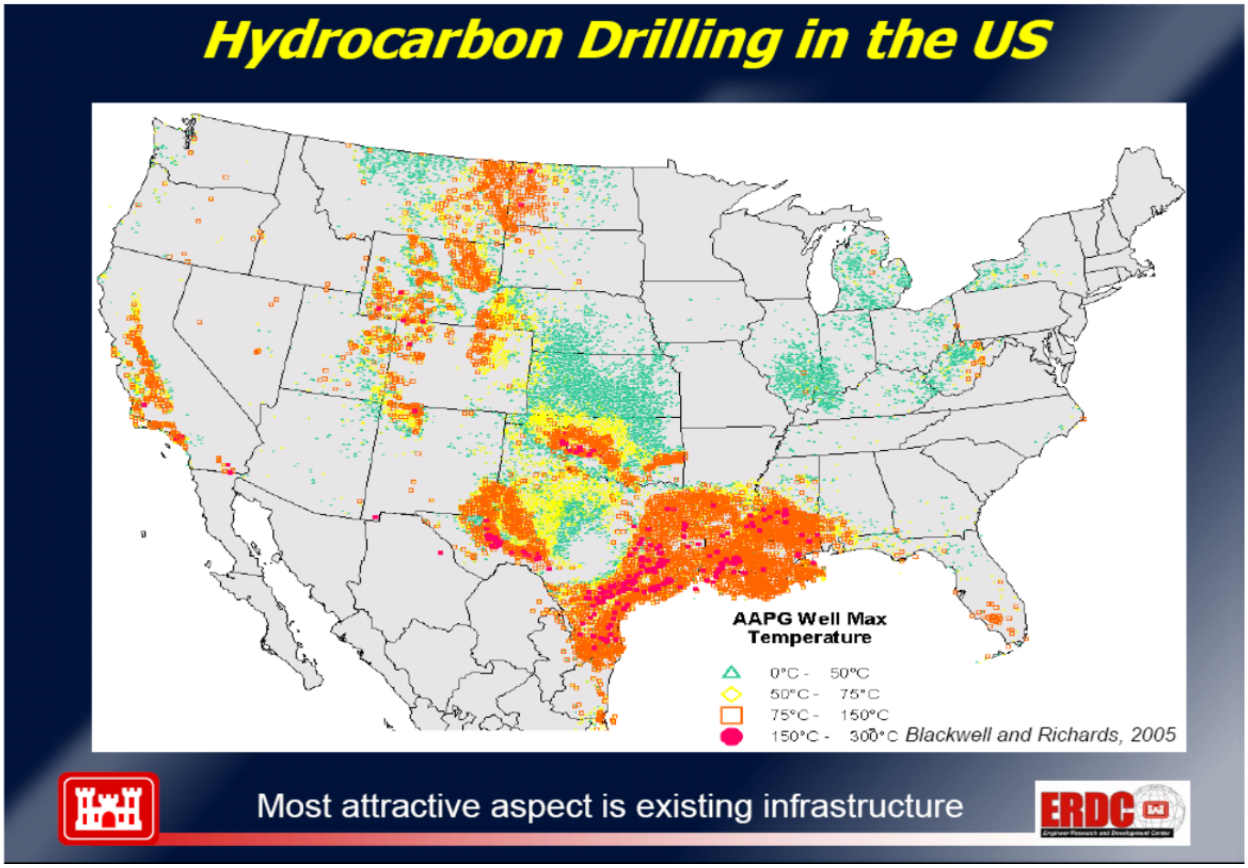
[12] "Geothermal Electric Power Supply Possible from Gulf Coast, Midcontinent Oil Field Waters", Oil & Gas Journal, September 5, 2005 at p. 39.

Figure 2: Hydrocarbon Drilling in the US



Hydrocarbon Drilling in the US

Blackwell and Richards, 2005

Most attractive aspect is existing infrastructure

After approximately two years of evaluations with oil and gas productions companies, governmental groups, universities, consultants and equipment manufacturers, Cleco Power entered into a partnership with a large independent oil and gas company and Access Energy to install a geothermal energy project in South Louisiana. The test site was selected that produces approximately 5,000 barrels of geofluid at approximately 260^{0}F per day, in addition to being very close to Cleco Power's existing infrastructure.

Cleco and its partners successfully installed an operating system that had consistently produced between 50 and 70 kW of geothermal energy per hour. However, due to fluctuations in brine flow and problems associated with the generator, heat exchanger, and the cooling system extended periods of down time were experienced. We are still addressing brine flow and cooling tower issues; however, when generating, the unit produces an average of 60 kW of energy per hour. Additionally, due to lower oil and gas prices the volumes associated with production have varied reducing the generating potential. We are looking forward to generating a full year's worth of data so we will be able to formulate a true outlook for geothermal energy in Louisiana.

Due to the nature of the cooling systems that are required as part of an Organic Rankine Cycle process, it appears that the geothermal output will be greater in the cooler parts of the year and less in the warmer parts of the year. This is due to the increase in dry cooling fans operating in the warmer part of the year pushing larger amounts of air over the cooling surfaces, since the ambient temperature is warmer and has less of a ΔT. This increases the auxiliary load and reduces the net output of the project. Cleco Power has evaluated various technologies to see if they can be integrated into the project in order to decrease the auxiliary load, and will continue to monitor viable technologies. In addition, Access Energy is working on modifying the generator system to work with lower temperature wells, which will enable the production of geothermal energy from a wider variety of sources. **Figure 3 and Figure 4** show the layout of Cleco Power's geothermal energy project.

Figure 3: Cleco Power Geothermal Project (View 1)

Figure 4: Cleco Power Geothermal Project (View 2)

Section 6 Wastewater Digestion

Cleco Power has funded the University of Louisiana at Lafayette (UL) to evaluate and provide conceptualized design summaries on digestion technology to determine if the technology is capable of producing power at a reasonable cost and level of process stability within Louisiana. Using both bench and pilot scale testing efforts, UL has been evaluating the operational potential of digestion for a variety of waste streams found in Louisiana. Additionally, the opportunity to produce value-added, co-products during digestion is also being evaluated as a means of offsetting capital costs (problematic for smaller installations). Finally, the potential to house the technology within different Louisiana companies in terms of labor, capital, and O&M costs is under evaluation. A key aspect of this effort was the design and construction of a novel pilot scale system capable of providing data to allow process feasibility to be evaluated – which was completed in 2013. To summarize in terms of functionality, the pilot system is fully transportable to remote field sites thus allowing for an on-site evaluation of the potential of digestion technology within actual commercial settings using a variety of actual “fresh” industrial waste streams. The system is currently customized to run in a batch mode of operation and additional functionalities are being added for the system to cater fed-batch and continuous modes of operation.

Technology Overview

Many Louisiana industries produce tremendous amounts of waste and wastewaters containing organic materials (solids and soluble substrates) that require treatment prior to disposal (often as environmental discharges). Example facilities include food processors, confined animal raising operations, slaughter houses, breweries, and food preparation operations. Most generally operate at a small margin of profitability in which waste management places a significant financial burden on the “bottom line” aspects of business operations. As environmental regulations are increasing in terms of number and acceptable minimum treatment requirements, these changes are only worsening their situation. Any conversion of waste materials into value-added, marketable commodities and/or reduced cost operations can add a significant stability factor to the future plans of these companies to not only stay in business, but actually potentially expand due to the envisioned level of increased profitability that this project may deliver for them.

Digestion is a technology in which microorganisms are used to anaerobically degrade organic waste constituents with methane and carbon dioxide (biogas) as ultimate products. The process can also be directed to hydrogen and volatile organic acids (VOAs) production. The hydrogen can then be used as fuel while the VOAs can be used as commodity chemicals or as precursors to transportation fuel production through esterification followed by hydrogenation. The VOAs can also be used as feedstock for microbial lipids production, thus work has been initiated to determine if it is feasible to produce both hydrogen/biogas mixture along with a lipid-rich bacterial culture.

For biogas production, the produced methane can be fed into a genset for on-site production of electrical power and/or used to replace/displace natural gas as a fuel burned on-site (for example, energy source for cookers within a food processor). In the case of power production, the generated power can be used to offset internal usage and/or be input into the grid. The overall result is the reduction of targeted pollution to an acceptable level while at the same time producing power from a renewable source. An additional side product that is emerging within selected markets is the use of the resulting digestion liquids and solids as amendments to consumer plant growers; albeit emerging, this is still a growing niche market.

The overall digestion process relies on anaerobes to stepwise breakdown the complex proteins, lipids, and carbohydrates that tend to make up the bulk of the wastes planned for use in digesters. The resulting key product is a gas, known as biogas. Most biogas produced from industrial digestion systems have a gas composition made up of almost exclusively methane (CH_4) and carbon dioxide (CO_2). The general composition range of these gas constituents is 60 – 80% methane (v/v) with the balance being mainly carbon dioxide. For biogas having 70% methane, this would result in an energetic value of 700 BTUs per cubic feet of gas (natural gas is ~1,000 BTUs per cubic feet of gas).

The actual process of digestion involves a reactor system, which provides conditions conducive to the support of the anaerobic microbial consortia, to degrade the waste from a typically complex chemical form into biogas. The reactor is called "digester". The design of digesters can vary dramatically, but in general, they are made up of rigid tanks with some form of mixing provided for operation on a periodic basis (most are not continuously mixed). The two key operational parameters in the digester are influent residence time and in-reactor solids concentration. System chemistry parameters of primary interest during operation of a digester include pH, oxidation/reduction potential or ORP, and effluent COD (chemical oxygen demand). In most applications of digesters, materials handling is the main operational challenge if the solids concentration is greater than 20%.

The use of digesters to produce biogas from waste is not a new technology. However, the applicability of the technology to any given waste streams can be difficult to predict given the limited data on many industrial wastes. Application history is also exclusively oriented toward municipal biosolids and confined animal raising operations (mainly dairy and swine production). In most cases, conversion numbers generally range in the 3 – 6 cubic feet per pound of chemical oxygen demand or COD degraded (COD is a standardized chemical oxidation analytical method used to estimate the pollution strength of a wastewater). Historically, full-scale digestion application efforts have produced very mixed results with financial and technical problems often noted (many of these efforts fielded in the Midwest US) – often due to poor design and/or difficult site operations. Applicability of digestion toward other wastes tends to be very much a case-by-case basis at this stage of development. However, where successes have been noted with the industrial application of digestion, these tend to be food-processing based (which bodes well for application within Louisiana).

Project Scope

This pilot study is targeting the evaluation of the potential for producing biogas from a variety of Louisiana-based waste streams. Several pilot evaluations using the pilot digester system fed different strength wastewaters from Gulf Crown Shrimp Processor (Delcambre, LA) have been conducted in late 2013 and early 2014 at the UL campus. In this case, it was found logistically easier to move water than the unit in terms of testing and operations. However, also in 2014, the pilot system was transported to the East Wastewater Treatment Facility in Lafayette, LA for a series of evaluations and operational fine-tunings using municipal wastewater from the LUS System. In this case, the on-site location was advantageous with respect to handling and disposal of different types of wastewater, which could present hazards/odors at the UL campus.

The intent of the project is to use an engineered digestion system that is similar to a full-scale reactor system. Several candidate waste streams have and are being considered. Bench-scale tests have and are being performed at UL to first assess if the waste is digestible and second to determine the optimal operating conditions to be used in the pilot reactor. Not all candidate waste streams tested at the bench level will be also tested at the pilot level. Only those that show reasonable promise will be tested in the pilot system due to time and cost limitations. In 2014, different shrimp processing wastewaters and municipal wastewaters were pilot tested with several water samples tested in the laboratory and many more planned for testing in 2015.

As stated above, prior to performing the on-site pilot studies, a series of bench-scale experiments are performed to determine the following:

1 - Determine if a candidate waste stream has appreciable amount of digestible organics present as identified by the steady production of gas within 500-ml microcosms.

2 - Assess methods to optimize biogas production via the dosing of nutrients and other similar amendments including bacterial seeds and vitamins (bench testing allows efficient testing for a wide range of concentration and reagent amending strategies).

3 - For waste streams showing minimal biogas production, yet having CODs above 1,000 mg/l, evaluate pretreatment methods using powerful chemical oxidizers to partially degrade the complex, recalcitrant organic chemicals into intermediate by-products that should be easier to anaerobically degrade into biogas. As done with the St. Landry landfill leachates in 2012 and 2013.

4 - Maximize the methane to carbon dioxide ratio using differing reactor operations and selected microbial seeds.

5 - Perform continuous flow experiments to determine the long-term stability of the overall bench-scale digester system using the real waste streams.

Once a candidate waste stream is evaluated using the bench-scale protocol detailed above, the project team then evaluates if the waste stream is a good option for pilot testing. With the pilot project phase, the pilot digester system is operated for an extended period. The objectives of the pilot studies are to evaluate the process under "real" industrial conditions, evaluate the design and operation of a standard digester design, and verify cost and technical performance estimates derived from the bench studies.

Summary of Bench Tests

Candidate waste streams are tested first for the ability of a "standard" seed of anaerobic consortia to simply produce biogas within a reasonable incubation period (10 days or less). The bulk of these tests are done within 500-ml glass microcosms equipped with sensitive test pressure gauges (0-15 psi). The test gauge is used to monitor the amount of biogas being produced by tracking any pressure increases within the microcosm headspace. **Figure 1** presents a photograph of the microcosms with **Figure 2** presenting a schematic of the microcosm. These microcosms, designed by UL researchers several years ago for digestion process feasibility evaluations, provide flexibility for sampling and ease of operation during testing allowing for many test conditions to be evaluated at the same time.

Each test condition was tested using either duplicate or triplicate runs to ensure reproducibility of results. The units were charged with a candidate waste stream, a microbial seed (collected from an operating anaerobic digester from the East Wastewater Treatment Plant), and various test amendments (vary by targeted condition under consideration). All incubations using the microcosms were done within a temperature controlled incubator (usually $35^{o}C$). Note that the microcosms were operated in full batch mode. Test analytes commonly measured during testing includes liquid phase COD and pH (both run using standard methods) and gas phase CO_2 and CH_4 (both run using gas chromatography or GC).

During bench testing, the first testing stage-gate decision needed was any reasonable production of gas which provided evidence of some digestion potential for the candidate wastewater. Once biogas production is observed, the next phase of testing is to evaluate a series of operational conditions as a means of optimizing the process in terms of maximizing biogas methane composition (greater than 60% methane is considered good); maximizing the volume of biogas produced (greater than 4 cubic feet per pound of COD is good); and the reduction of the COD in the effluent (liquid) to levels less than 50 mg/l.

As part of by-product development, hydrogen and VOAs production studies were also initiated this year (i.e., 2014). Tests were initially conducted using glucose as COD source to determine if the microbial consortia present in the digester sludge (used as seed in all the tests) can be directed to hydrogen and VOAs production. Methane generation in digester systems are dictated by two reactions:

$$\mathbf{CH_3COO^- + H^+ \rightarrow CH_4 + CO_2} \qquad (1)$$

$$\mathbf{4H_2 + CO_2 \rightarrow CH_4 + 2H_2O} \qquad (2)$$

Reaction (1) represents the degradation of acetic acid (VOA) into biogas while Reaction (2) shows the consumption of hydrogen (produced from preceding reaction steps) and carbon dioxide to produce methane and water. The microorganisms responsible for these reactions are called methanogen – or methane producing microorganisms.

Looking at the two reactions above, the digestion process can be directed to hydrogen and VOAs (other VOAs i.e. butyric and propionic acid are produced in previous digestion steps) production by inhibiting the methanogens in the digester, thereby preventing Reactions (1) and (2) to proceed. Inhibition of methanogens is commonly done using chemical inhibitors (e.g. acetylene), heat shock pre-treatment of inucula, and keeping low system pH (5.8 - 6.5). For the tests conducted in this project, low system pH ($pH < 6$) was the only inhibition used to direct the digestion process to hydrogen and VOAs production. For example, in 2014, after establishing optimal "normal" digestion conditions, the VOA path to lipids and hydrogen production process modifications were applied to the shrimp processing wastewater to determine its potential for hydrogen and/or VOAs production.

Analytical Procedures Developed For Bench Testing of Wastewaters and By-Product Development

Gas Chromatography (GC)

Figure 3 shows the gas chromatograph dedicated for the analysis of gases (carbon dioxide, methane and hydrogen). This instrument is also being used to determine oxygen levels (anaerobic condition) in the digesters prior to commencing experimental runs.

The GC is an Agilent 6890N gas chromatograph equipped with single filament thermal conductivity detector (TCD). Analysis is accomplished using an 80/100 mesh, 6 ft. × 2mm ID Porapak-Q and 80/100 mesh, 10 ft. × 1/8 in. Molesieve 5A columns in series. The injector and detector were running at 150°C and 180°C, respectively. The GC oven program is as follows: 70°C for 2 minutes, ramped to 130°C at 10°C/minute and held at 130°C for 2 minutes.

Liquid Chromatography (LC)

Figure 4 shows the HP 1100 liquid chromatograph that the project uses for the analysis of VOAs (lactic, acetic, butyric and propionic acids). Samples were filtered through 0.45 micron nylon syringe filter prior to analysis. This instrument is equipped with a Rezex ROA-Organic acid having dimensions of 300 × 7.8 mm and a guard cartridge system. Detection of VOAs is accomplished using diode array detector set at 210 nm. Sample analysis is done at 40°C for 30 minutes with 0.005N H_2SO_4 as mobile phase at a flowrate of 0.60 mL/minute.

Ion Chromatography (IC)

In 2014, an analytical procedure was also developed using ion chromatography to characterize the wastewaters with respect to different minerals/nutrients that are necessary for microbial growth. Microbial nutrient requirement is vital to ensure growth and to drive biochemical and metabolic reactions. These nutrients are divided in two groups: macro and micro. Macro nutrients include C, N, P and S while micronutrients include a range of trace elements such as Na, Ca, K, Mg, and Fe.

The procedure involves two-Dionex DX600 equipped with electrochemical detector (**Figure 5**). One unit is dedicated for anion analysis while the other unit is for cation analysis. Anion analysis involves a 2-mm ASRS suppressor and a KOH eluent generator. The ECD is set at 35°C with a 2 × 250 mm AS 16 (+2 × 50 mm AG16) at a constant eluent flow of 0.30 mL/min. The gradient elution is as follows: 23 mM KOH for 6 min, ramp to 50 mM at 9 min, and go back down to 23 mM at 12 min followed by a 4 min stabilization period.

The cation analysis uses a 2-mm CSRS suppressor, a MSA eluent generator and a column oven. The oven is set at 30°C, suppressor at 50 mA, and eluent flow rate at 0.40 mL/min with a 2 × 250 mm CS 18 column (+2 × 50 mm AG18 guard column). The eluent concentration is at 30 mM for the duration (30 min) of the analysis.

The IC procedure was used to characterize the three food processing wastewater streams considered this year: shrimp, catfish and vegetable processing wastewaters. The results are presented in **Table 1**. This initial characterization of wastewater is of utmost importance if one wants to predict the potential digestibility of any given feedstock without any amendments. Furthermore, this will provide the required information as to which nutrient or nutrients are required to be added for successful anaerobic digestion of the wastewater (or any feedstock).

Studies indicated that the mass ratios of COD to N (COD:N) and COD to P (COD:P) are critical for the anaerobic digestion process. Typically, a COD:N of ~40 is recommended although it could be as high as 150 while COD:P can vary from 80 to 200. In addition to these ratios, the sulfur (S) concentration in the digester is equally important and have been reported to be between 0.001 – 1 mg/l. Knowing these typical requirements, one can predict that the shrimp processing wastewater is a suitable candidate for anaerobic digestion (**see Table 1**). This is indeed the case, as was previously determined experimentally. As for the case of catfish processing wastewater, it can be deduced from **Table 1** that there could be some amendments needed for this feedstock. This includes addition of other source of COD to increase the COD:P ratio to acceptable level and more importantly, addition of S source. The vegetable processing wastewater, on the other hand, needs addition of S source, as well as N and P to decrease the COD:N and COD:P ratios to acceptable levels. Simultaneous with wastewater characterization, experimental determination of their digestibility was conducted and the results are presented in the next section.

Table 1. Characterization of food processing wastewater streams.

Nutrients	Shrimp	Catfish	Vegetable
pH	7.55	7.30	6.80
Temperature (°C)	22	21.7	12.8
C (as COD), mg/l	1120 ± 14	4776 ± 148	9389 ± 489
NO^{2-} (N-source), mg/l	12.64	17.00	22.67
NH_4^+ (N-source), mg/l	6.10	29.32	20.57
SO_4^{2-} (S-source), mg/l	1.10	non-detected	non-detected
PO_4^{3-} (P-source),mg/l	36.65	411.62	116.08
Na^+, mg/l	88.95	332.56	186.16
K^+, mg/l	31.71	163.65	341.83
Mg^{2+}, mg/l	23.61	16.05	32.76
Ca^{2+}, mg/l	non-detected	6.64	104.11
Cl^-, mg/l	88.30	151.95	137.37
F^-, mg/l	3.94	7.53	non-detected
COD:N mass ratio	105.23	155.37	353.26
COD:P mass ratio	93.71	35.58	248.03

Candidate Waste Streams Tested To Date Using Bench-Scale Systems

From late-2013 to the end of 2014, three candidate commercial waste streams have been tested. These wastewaters are all from food processing operations: (1) a large commercial shrimp processing operation (Gulf Crown Shrimp Processor) located in Delcambre, LA, (2) a catfish processing plant (Guidry's Catfish) in Breaux Bridge, LA, and (3) a vegetable processing operation (Guidry's Fresh Cut, Inc. – no ties to the catfish processor) in Arnaudville, LA. The source of the organic pollution is residuals from the cleaning and food processing operations performed by these commercial vendors. The envisioned application of digestion technology is to use the methane produced to offset power use within the processing plant while also treating their waste stream (**Figure 6**).

Shrimp Processing Wastewater

The COD of this wastewater stream has been found to generally range from approximately 500 mg/l to 3,000 mg/l. The range of COD concentrations is quite broad and thus we have been evaluating different waters that were collected at different operational times.

This water has been found to be extremely digestible with little to no acclimation needed for the anaerobic microbial seed to produce appreciable conversion into biogas with a high level of methane (>60% v/v). **Figure 7** presents a time-dependent curve of methane and carbon dioxide production over incubation time. From these data, it can be seen that rapid conversion of the shrimp wastewater into biogas is occurring within 5 days. By Day 15, the digestion is almost done and the biogas produced contained >72% v/v. From these positive results, once the pilot system was completed in 2013, it was decided to initiate a series of pilot tests using this wastewater (**see Section 7a**).

Previous studies indicated that at lower pH (below neutral), production of methane is inhibited and the produced biogas contains high proportion of hydrogen. Thus, another set of experiments were conducted to determine the effect of initial pH on the digestion process particularly on the methane yield. The results are presented in **Tables 2 – 4 and Figure 7**. Significant COD reduction was observed in all the tests conducted. The volatile suspended solid (VSS) is often used as an indication of microbe concentrations in wastewater. Based on the results presented in **Table 3**, a fraction of initial VSS of the shrimp wastewater represents non-microbial materials, which were then degraded during the process. Thus, the final VSS values were lower than the initial values. If one looks at the final VSS, the values for lower initial pH (6.45) are significantly lower than those for pH 7.4 (at the same seed concentration). This indicated that some microbes were likely inhibited (or most probably died) due to the lower initial pH. These microbes are probably the ones responsible for methane production (methanogens). This is also evident in **Figure 7** where methane production was lower for tests with lower initial pH. Although no significant hydrogen production was observed in any tests, these results are good indication that the process can be directed into production of bio-hydrogen or possibly other biomolecules (i.e. organic acids). The seed concentration (for the seeded tests), on the other hand, merely affected the time by which maximum biogas production was reached (**Figure 7, b and c**).

Table 2. COD reduction after digestion

Anaerobic Sludge Seed (% v/v)	Initial COD (mg/L)	Final COD (mg/L)
0% (pH: 7.4)	1493.67 ± 44.00	1278.50 ± 43.13
0% (pH: 6.45)		1408.00 ± 86.47
2% (pH: 7.4)	1589.42 ± 51.16	773.33 ± 44.66
2% (pH: 6.45)		770.33 ± 88.10
5% (pH: 7.4)	1733.05 ± 51.16	1418.00 ± 95.14
5% (pH: 6.45)		1427.67 ± 90.91

Table 3. VSS changes after digestion

Anaerobic Sludge Seed (% v/v)	Initial VSS (mg/L)	Final VSS (mg/L)
0% (pH: 7.4)	1073 ± 89	400 ± 170
0% (pH: 6.45)		360 ± 28
2% (pH: 7.4)	1181	420 ± 11
2% (pH: 6.45)		300 ± 69
5% (pH: 7.4)	1343	733 ± 21
5% (pH: 6.45)		580 ± 72

Table 4. pH changes after digestion

Anaerobic Sludge Seed (% v/v)	Initial pH	Final pH
0%	7.4	6.98
	6.45	6.93
2%	7.4	7.14
	6.45	7.14
5%	7.4	7.06
	6.45	7.03

To determine a rough estimate of the performance of the pilot system, the results of the bench tests were also used for process modeling. This was done to estimate the performance of the system at the most favorable condition for methane production: unadjusted pH, 5% (v/v) seed. Two kinetic models were tested given below:

For Substrate:

Monod: $\frac{dS}{dt} = -\frac{\mu_m}{Y}\frac{SB}{K_S + S}$

Haldane: $\frac{dS}{dt} = -\frac{\mu_m}{Y}\frac{SB}{K_S + S + S\left(S/K_I\right)^n};\ n = 1, 2$

For Biomass:

$$\frac{dB}{dt} = -Y\frac{dS}{dt}$$

For Methane:

$$\frac{dP}{dt} = -\alpha \frac{dS}{dt}$$

where:
S = substrate concentration
B = biomass concentration
P = methane concentration
μ_m = maximum specific growth rate
Y = yield coefficient
K_S = half-saturation coefficient
K_I = inhibition constant
t = time
α = methane transformation coefficient

The data were fitted using non-linear regression of the ordinary differential equations presented above. The results (presented **in Table 5 and Figure 8**) suggested that the process can be best represented by the Haldane model (with n = 1). Using this model, the methane yield can be calculated using α (0.16 mL methane/mg COD). For example, the bench test which had total COD = 433.26 mg would yield 69 mL of methane. The experimental (actual) yield was 71.58 mL. Assuming that the pilot system will perform similarly, the methane yield would be 2.56 ft^3 methane/lb COD.

These results all indicated a very positive potential to use digestion within the Louisiana shrimp processing industry. They were very complementary to the results generated over the past couple of years, but now were used to better model the projected performance of a large system installed within a processing facility. Pilot runs were performed over the 2013 – 2014 period. More bench scale testing may be done as an attempt to upset the system with wider COD concentration swings – however, the decision to perform this additional work will be decided in 2015 based on further modeling and cost analysis.

Table 5. Kinetic parameters for Monod and Haldane models

Parameter	Monod	Haldane (n = 1)	Haldane (n = 2)
μ_m (1/day)	7.658×10^{-5}	3.528×10^{-8}	2.745×10^{-4}
Y (mg Biomass/mg COD)	0.37	4.819×10^{-8}	-0.75
α (mL Methane/mg COD)	75.90	0.16	36.88
K_S (mg COD)	0.05	276.38	3.022×10^{-15}
K_I (mg COD)	-	247.92	3.567

Catfish Processing Wastewater

The evaluation of catfish processing wastewater was initiated this year (2014). The wastewater was obtained from Guidry's Catfish right after their grease trap and before entering their waste treatment facility. As previously discussed, this wastewater was characterized with respect to nutrients required for microbial growth and metabolisms. Based on the characterization results, it was anticipated that the anaerobic digestion of this wastewater stream will not be as good as the shrimp processing wastewater. This was mainly due to undetected level of sulfur in the water and a very high concentration of phosphorus. The wastewater obtained, which has about 5,000 mg/l of COD, was evaluated for digestion potential using the 500-ml microcosms (shown in **Figure 1**). The results, presented in **Figure 9,** indicated that this wastewater is digestible. The yield of methane per unit volume of catfish processing wastewater is a little higher than that of the shrimp processing wastewater (see **Figure 7c**). Note however that the catfish processing wastewater has a COD that is almost 4 times higher than the shrimp processing wastewater. Thus, ideally, a significantly higher yield of methane was expected from catfish processing wastewater – which was not the case.

As previously inferred, amendments must be done on this wastewater stream to increase biogas yield as well as methane concentration. **Figure 9** shows that at the initial digestion period (< 15 days), the biogas produced was mostly carbon dioxide and hydrogen was detected in the system. At the conclusion of the tests, the biogas produced contains only about 50% (v/v) methane. This indicates that the methanogens responsible for Reaction (2) above (consumption of carbon dioxide and hydrogen to produce methane and water), were somehow inhibited. Again, this could be due to the undetected level of sulfur or high level of phosphorus in the wastewater. It is also possible that some organics in the water are highly recalcitrant to anaerobic biodegradation. Despite these results, it is believed that the catfish processing wastewater has high potential for use for producing high quality biogas using digestion technology. This will be verified in the next phase of this portion of the project by applying different conditions, amendments and pre-treatments to this wastewater (during 2015).

Vegetable Processing Wastewater

In the same manner as the catfish processing wastewater, the potential of vegetable processing wastewater as feedstock for biogas production through anaerobic digestion was evaluated. The wastewater was obtained from Guidry's Fresh Cut, Inc. on their combined waste stream that enters the municipal sewer system. The wastewater has about 9,000 mg/l of COD making it a really good candidate for biogas production. The initial characterization of this waste stream indicated that it requires amendments to facilitate enhanced microbial activity, particularly the addition of nitrogen, phosphorus and sulfur for proper microbial growth and metabolism. And as anticipated, the yield of methane was almost negligible as shown in Figure 10 due to the lack of nutrients.

Vegetable processing wastewaters are considered to be one of the waste streams that have very high potential to generate energy due to their high organic composition and biodegradability. Further testing, which will include nutrient amendments and possibly pre-treatments, is required for this waste stream. This will be the subject of the next phase of the evaluation to be performed in 2015.

By – Product Development: Hydrogen and VOAs

The microbial consortium used within most anaerobic digester systems often has unicarbonic anaerobes that are capable of converting organic materials directly into hydrogen. With some current industrial operations, the potential to produce hydrogen offers a unique opportunity in that the hydrogen could be used as a supplemental fuel source or potentially serve as a co-product (could be sold to refineries to support their hydrotreaters or GTL facilities needing more hydrogen content in their syngas). Hence, a series of laboratory assessments of potentially producing a high quality hydrogen gas was initiated in 2014. Also, an additional process path that was considered viable was the production of volatile organic acids (acetic acid for example) that are produced as a mid-point conversion step in the digestion process. It is theorized that stopping the digestion process at the production point of VOAs then using aerobic fermentation may be an economically and technically viable method to produce on-site bacterial oil (lipids) that will yield a potentially high market value as a co-product. A summary of results for these two laboratory efforts are presented in this section.

The production of hydrogen and VOAs was initially conducted using glucose as COD source present in a synthetic wastewater. The composition of this synthetic wastewater is presented in **Table 6.** This was to establish suitable operating condition for the process sought. Experiments were conducted at 35°C with agitation rate of 90 rpm for 8 days using a 10-l digester (**see Figure 11**) using digester sludge from East Wastewater Treatment facility as microbial seed (2% v/v seed loading). Gases produced were continuously removed as formed and was monitored using a DFM-102 digital gas flow totalizer. Gas and liquid samples were taken periodically for analyses.

As previously mentioned, the main inhibition factor considered at these initial stages of the project was low process pH (< 6). Although the initial pH of the system was near neutral, results indicated that pH adjustment to below 6 prior to digestion was not necessary. In a typical digestion process, the methane – forming step is very slow as compared to the acid – forming steps. This commonly leads to accumulation of VOAs that consequently decreases the pH of the system. Thus, in digestion processes where methane is the target metabolites, addition of alkalinity (e.g. sodium carbonate, caustic soda, soda ash, sodium bicarbonate, ammonium bicarbonate) is required to keep the system pH near neutral. Since it is the natural tendency of the anaerobic digestion process, low system pH was chosen to inhibit the methanogens in the system. It should be noted that the system pH was only monitored but not controlled in these experiments.

After 24 hours, the pH of the system dropped to below 4 and triggered the production of hydrogen as shown in **Figure 12a**. In the initial digestion period (t < 24 hrs), methane and carbon dioxide are the main constituents of the gas produced. After 24 hours, hydrogen comprised around 60% (v/v) of the gas produced from the system. The same is true for VOAs, where accumulation became faster after 24 hours as shown in **Figure 12b**. Interestingly, lactic acid was the major organic acid accumulated in the system, indicating the presence of lactic acid bacteria in the digester sludge. Lactic acid can be used in the production of polylactic acid, a biopolymer with a huge potential market (over 1M metric tons annually). Acetic and butyric acids also accumulated in the system resulting to a system pH of around 2 at 96 hours. Due to this very low system pH, the system shut down even if nutrients are still present in the system. As shown in **Figure 12b**, the system still has about 3.5 g/l of glucose. Extremely high concentration of unionized VOAs (or very low pH) is known to be inhibitory to microorganisms. This could be the primary reason of the shutdown of the system. These results indicated the potential of producing hydrogen and VOAs at low system pH. However, the system pH must be maintained between 2 and 6 to ensure system operation. This could be accomplished by addition of alkalinity or by continuous removal of VOAs as they are formed such as those of two-phase partitioning bioreactors.

Table 6: Composition of synthetic wastewater used for hydrogen and VOAs production through anaerobic digestion.

Component	Concentration (mg/l of water)
Glucose	10000
NH_4Cl	1018.0
KH_2PO_4	34.6
$Na_2S_2O_3 \bullet 5H_2O$	206.2
$CaCl_2$	29.1
$MgCl_2 \bullet 6H_2O$	12.2
$FeCl_2 \bullet 4H_2O$	5.6
$NiCl_2$	0.71
$CoCl_2 \bullet 6H_2O$	0.98
$ZnCl_2$	3.4

The digestion conditions were then applied to shrimp processing wastewater to evaluate its potential for hydrogen and VOAs production. For these experiments, however, the initial pH of the system was adjusted to pH 6. The results (**Figure 13**) showed that hydrogen was mainly produced during the initial period (t < 5 days) of the process (**Figure 13a**). This initial period was when the pH of the system was decreasing (and below pH 4) due to accumulation of VOAs (**Figure 13a and b**). After this period the microbial consortia in the system was able to recover by consumption of the VOAs, which resulted to increased system pH and methane production with negligible hydrogen generation. At the conclusion of the experiments, there was negligible accumulation of VOAs in the system and methane was the major constituent of the gas produced.

The results of these experiments could be due to contributions from several factors: 1) the COD of the shrimp processing wastewater is not high enough for the process sought (~1100 mg/l versus ~10,000 mg/l for the experiments using glucose); 2) the pH of the system must be below pH 4; and 3) the low system pH is not sufficient to inhibit methanogens when using a more complex substrate. These are the factors that will be considered for the next evaluation steps in 2015, i.e. increase the COD of the system (possibly by adding other wastewater such as the vegetable processing wastewater discussed in the previous section), keep the system pH between 2 and 4, and use other method of methanogen inhibition such as heat and/or acid treatment of seed microbial consortia.

Pilot System Design and Construction

The pilot system design was completed in June 2012. Construction of the system began in July 2012 and was completed in December 2012 after some redesign and subsequent redoing of some process system features. Figure 14 presents a schematic of the overall process flow diagram for the pilot system. By February 2013, the first generation of the completed pilot system was ready for testing and a series of a wet system shake-out runs using clean water was done to evaluate system operation in terms of wastewater handling and to check for leaks. No problems were encountered as the system performed as designed. However, it was observed that improvements to the heating aspect of the system were needed along with a more rigorous design for the process analysis strategy for the system. These improvements were made by August 2013 and a series of pilot studies were initiated in October 2013.

Figures 15 – 21 present some views of the completed pilot system. These photographs include views of the system in operation – including operation in sub-25°F conditions. Each photograph is described below:

Figure 15 – Preparation of the pilot system

Figure 16 – Digester insulation

Figure 17 – Heater for digester core temperature

Figure 18 – a) Biogas analyzer, b) Flow totalizer

Figure 19 – Digester with controls cabinet

Figure 20 – Shrimp wastewater collection for Delcambre, LA

Figure 21 – Digester operation during cold conditions

Pilot Testing Results (2013)

As detailed above, a series of pilot runs were initiated in the last quarter of 2013 and into 2014 using the shrimp wastewater as the influent. The tests were performed at UL campus because it was viewed as logistically easier to move the water using a large tank than to move the unit to the site. This allowed for significant adjustment of the reactor layout and optimization of the system operation within close access to the resources available on campus. One key addition was made in October in that a gas mass flowmeter and totalizer was installed to better quantify biogas production.

The results of the first pilot system run using shrimp processing wastewater are presented in **Figure 22**. The run had a COD load of 1.052 kg. Based on the process modeling conducted for the batch test, this COD load should yield about 168 Liters of methane. The actual experimental yield was 171 liters of methane. Thus, the yield coefficient of 2.56 ft^3 methane/lb COD can also be used for the pilot system running at the same conditions as the bench tests. Although the biogas production rate was inconsistent (probably due to extremely cold weather) for the pilot run system, the biogas concentration was consistent at around 80% (v/v) methane.

Pilot Testing Results (2014)

Another pilot run using shrimp wastewater was conducted in January 2014 to verify the results obtained in 2013. A COD loading of 1.250 kg was loaded in the pilot digester, which resulted to an experimental methane yield of 191 liters (a yield coefficient of 2.45 ft^3 methane/lb of COD) (see Figure 23). This was consistent with previous results obtained using the same wastewater stream both on the bench and pilot testing. On this verification run, however, one important characteristic of the anaerobic digestion of shrimp wastewater has become apparent: that the total COD of this wastewater stream is a contribution from different (and complex) organic compounds such as proteins, lipids and carbohydrates.

The digestion of a single COD source (i.e. carbohydrates) should result to a single Gaussian-like plot of methane production rate versus time. That is, neglecting other factors, the methane production rate increases in the initial stages of the digestion process. Then, following a peak in the production rate, it decreases with time as methanogens run out of substrate for methane production. This was not the case for the shrimp wastewater. As shown in Figure 23, there are three Gaussian-like peaks on the methane production rate versus time plot. This result was not observed in the previous run. Each peak is believed to represent a class of compounds. Digestion of carbohydrates is usually faster than proteins and lipids tend to be the most recalcitrant among the three compounds. Based on this information, it can be inferred that the first peak represents the carbohydrates, second peak for proteins and the third peak shows degradation of fats present in the wastewater stream. These three classes of compounds have been found to be present in abundance in shrimp processing wastewater. Analytical determination and quantification of specific compounds within the three classes of compounds is yet to be conducted.

In the 3rd quarter of 2014, the pilot digester was transported to East Wastewater Treatment Facility in Lafayette, LA (**Figure 24**). The main aim was to compare the performance of the pilot digester system with the facility's digester. The transport proved to be a challenge since the location was not ready mainly with respect to the power requirements of the pilot digester. At this point, this tends to be the main issue that needs to be addressed at different targeted locations prior to transporting the pilot digester to these sites. Another option is to keep the digester at its current location and transport the targeted wastewaters instead. The decision on the logistics of the pilot system will be decided during the implementation of fed-batch mode of operation, which will be initiated this year (2015).

The pilot digester was evaluated using the municipal wastewater stream that feeds the anaerobic digester of the East Wastewater Treatment Facility. In contrast to the previous run with shrimp processing wastewater, the production rate versus time plot for the municipal wastewater runs has only one peak (**Figure 25a**). This indicated the possibility that there is only one general compound class present in the wastewater. This is a possibility since the stream was right after the oxidation ditch of the facility. Thus, this waste stream is more homogeneous as compared to the shrimp processing wastewater. The results showed that at 5% (v/v) sludge seed loading, the system has to acclimatize for about 25 days suggesting a more recalcitrant organics in the waste stream. This is also due the nature of the waste stream being a residual of a previous biodegradation process (oxidation ditch). For this waste stream, the biogas produced (at the peak production rate) has ~50% (v/v) methane with a yield coefficient of 3.18 ft^3/lb of COD loaded.

The results of the initial runs on municipal wastewater will be used to initiate a fed-batch operation mode of the pilot digester. This would give a better performance comparison with the facility's digester, which is running on a fed-batch mode. The pilot digester is currently not suited to run in fed-batch and retrofitting of the unit has been initiated for it to be capable of doing so.

Economic Assessment: Shrimp Processing Wastewater

Using the experimental results from the anaerobic digestion of shrimp processing wastewater, the economics of the envisioned process in **Figure 6** was estimated using Aspen Plus simulation software. It should be noted that only electrical power was considered as product in this initial assessment. The hot gas coming out of the process could provide heat that can be used in-house and will be considered in the economic calculation once the digestion process has been optimized using the pilot digester. In the simulations, it was assumed that the feed streams are free and that the cost of electrical energy (as product stream) is $0.075 per kWh. No tax credits were included in the calculations and it was also assumed that the plant is running throughout the year.

The simulations were aimed to determine the minimum plant capacity that will result to a payback period of 10 years. This is to determine if small seafood (shrimp) processors can adapt the digestion technology individually or would it be best to have a centralized digester for power generation. The simulation was run varying the plants daily capacity and results indicated that a capacity of 2MGD is needed for the required payback period **(see Table 7**). The plant has an output of about 60 ft^3/hour of methane that produces 0.74 MW of electrical power. Based on this initial estimate, it seems advisable to have a centralized digester for seafood processors. This, however, is based solely on the information that has been obtained so far and this estimate will be updated as more data are acquired through this project.

Table 7: Summary of estimated economics of the envisioned process in Figure 6.

Total Project Capital Cost	$9.2M
Total Operating Cost	$2.83M/year
Total Utilities Cost	$354,949/year
Total Product Sales	$5.88M/year
Desired Rate of Return	20%/year
Payback Period	10 years

This economic analysis represents minimal optimization of the system. However, it does provide solid in-sight into the potential of digestion to provide benefit to Louisiana industries. Note that the savings of not having to aerobically treat the wastewaters using conventional treatment processes are not included as an economic benefit (which it is). Hence, in 2015, UL will be further refining this cost estimate.

Technology Assessment: Renewable Resource Type - Digestion Technology

a. What is the utility's view to the status of the different renewable resources that have been investigated by the utility?

The digestion study has indicated a high potential for using digestion as a means of producing on-site electrical power at many industrial facilities within Louisiana. The technology is mature from a system design; yet, the heterogeneity of potential influents, particularly many unique to Louisiana, challenges the state of the knowledge for the technology. The designed evaluative study should provide a strong data base to determine the potential for the proposed technology to perform within the state.

b. To the extent the utility has developed cost estimates, what are the estimated capital costs of the different resource types and technology types within the given type of renewable resource?

Only very early data in terms of technology gas production are available. Cost estimates based on recent tests are being evaluated. In general, capital costs for digestion tend to run in the $500 per 100 kW capacity range. Capital investment straight ROIs tend to be in the 5 to 10 year range for digesters. Power displacement in industries over input into the grid tends to provide a much more positive investment viewpoint.

c. What are the estimated operating costs for the different renewable resource types that the utility has considered (non-fuel)?

The estimated labor needs and other associated costs for digesters are estimated to be in the $0.005 per cubic foot of methane produced. First line estimates from observed systems in the field provides a UL-generated estimate that digestion technology in most of the targeted

Louisiana facilities will fall in the 0.5 to 1.0 man-year labor requirement. However, these costs are generalized from UL experience and literature, the results to be generated will allow for much more refinement for the actual case studies performed within Louisiana.

d. What uncertainties should be evaluated that would impact the costs to build and operate the new renewable processes?

Several uncertainties should be evaluated that include flow ranges over daily operation time and seasonal variations in plant operations; changes in chemical matrix within the wastewaters that may occur; available plant labor for system operation with regard to seasonable operations (if any); and potential other uses of the methane produce that may compete for use of the generated resource (firing for direct heating). Optimization of digester operation that could result in reduced wastewater residence time could result in significant reduction in digester tank sizing which in turn would reduce capital (this highlights the importance of bench testing).

e. To the extent available and known, where the best locations to the site the different types of renewable resources?

Digestion performs best with industrial operations that produce wastewaters and/or solids that are high in biodegradable organic content with minimal water flow/usage. Liquid wastes tend to be much easier to manage. Additionally, using digestion to meet discharge standards as opposed to stand-alone aerobic waste treatment will increase the value of the digestion process to the facility because it will replace current waste management costs along with producing on-site power and potential value-added by-products (solids that can be used as fertilizer and liquids sold as liquid fertilizer - both are a developing niche market to home gardeners). Hence, the many Louisiana food processor facilities offer potentially excellent locations to house digesters. The concept of potentially siting a centralized digester system to handle wastes from multiple sources offers even more economic promise (for example, a location with several shrimp processors being in a small geographic area footprint).

f. Within a given renewable resource type, what specific technology types might be the most appropriate for Louisiana?

More data needs to be generated to appropriately answer this question in terms of digestion technology. However, given the vast amount of primary and secondary processing of foods within Louisiana that are known to produce high volumes of wastewaters with high CODs, the technology does hold significant promise for the state.

Fuel Issues

a. For renewable resources that have been evaluated by the utility, what are the fuel issues that should be addressed?

Since digesters will utilize waste materials, there are no fuel issues to be addressed other than availability and stability of the wastes over time (storage and ensuring long-term availability).

Additionally, interest for adoption of the technology within the waste producer's facility needs to be addressed (and will be during the pilot tests).

b. What uncertainties should be evaluated that impact fuel costs and fuel availability associated with renewable recourses?

There are minimal uncertainties that are envisioned other than addressing seasonable and daily time implications of waste production (both flow and concentration).

c. Please discuss how the use of this renewable fuel might impact the other industries and consider how those impacts might be evaluated in order to decide whether this renewable fuel should be used in Louisiana renewable energy policy.

Since digestion will use waste materials (wastewaters and waste solids) generated within Louisiana within a highly decentralized format, there does not appear to be any negative aspects of this technology in terms of adversely impacting industries. In fact, digestion has a great positive aspect in that it is also treating the wastes while producing power and potentially value-added residuals. The biggest down side of the technology is that it does not represent a large power production source. Its application is more of a benefit to a single industry or closely located industries where wastes are pooled and digested to provide produced methane as a localized resource.

d. Based on the utility's best estimate for technologies they have evaluated, what are the costs of the renewable fuels and how are the costs impacted by the risks discussed above?

In the case of digestion, fuel costs are extremely low, and in fact, likely with no cost if used within a facility where the wastes are produced (the most likely scenario). Capital and labor costs will be the largest economic consideration with digestion, not fuel cost.

Economic Evaluation

a. Provide a levelized cost analysis comparing new renewable energy types, and even more specially compare the cost of different technology types. This analysis should include the conversion of any existing solid fuel capacity resources to operate using biomass co-firing.

This project (digestion) is in its early phase of application. Economic analysis will evolve as the actual waste streams are evaluated within the pilot studies. However, in general, biogas conversion technology currently is commonly assumed to require power production costs generally in the 100% higher cost range than coal-based power (around the $0.04 - $0.06 range). As optimization works proceeds and evaluation of various candidate waste streams are performed, these costs are believed to end up on the lower side of the reported range.

Jobs Impacts

a. Based on available information, discuss both job creation and job loss impacts of the renewable resources considered in the pilot.

Based on the information known at this time, it is expected that each installation of digestion technology will result in a half to one man-year of labor requirements (will depend on the facility hosting the technology). However, one interesting aspect of digestion over many of the other potential renewable technology options is that digestion may provide a reduction in the overall operating cost of many critical rural-based industries (such as seafood processing, meat processing, vegetable processing, and food preparation) that may result in the saving of jobs within areas of the state that desperately need these commercial entities to remain open.

Presentations and Publication

i. E Revellame, M Zappi, W Holmes, R Hernandez, Effect of Medium Formulation on the Products of Anaerobic Digestion, *to be submitted to Bioresource Technology*. [Draft Available]
ii. E Revellame*, DL Fortela, W Holmes, R Hernandez, M Zappi, Fuels and Chemicals from Wastes through Anaerobic Digestion, *Presented at the 2014 AIChE Annual Meeting*. Atlanta, GA. November 16 – 21, 2014. **[Poster]**
iii. A Bienvenu*, W Holmes, E Revellame, A Mondala, R Hernandez, M Zappi, A Rapid Analytical Method for Quantification of Volatile Organic Acids in Fermentation Broth, Presented at the 2014 AIChE Annual Meeting. Atlanta, GA. November 16 – 21, 2014. [Poster]

Figure 1: Photograph of Bench-Scale Microcosms.

Figure 2: Schematic Diagram of the 500-ml Microcosms (septum allows for syringe gas collection).

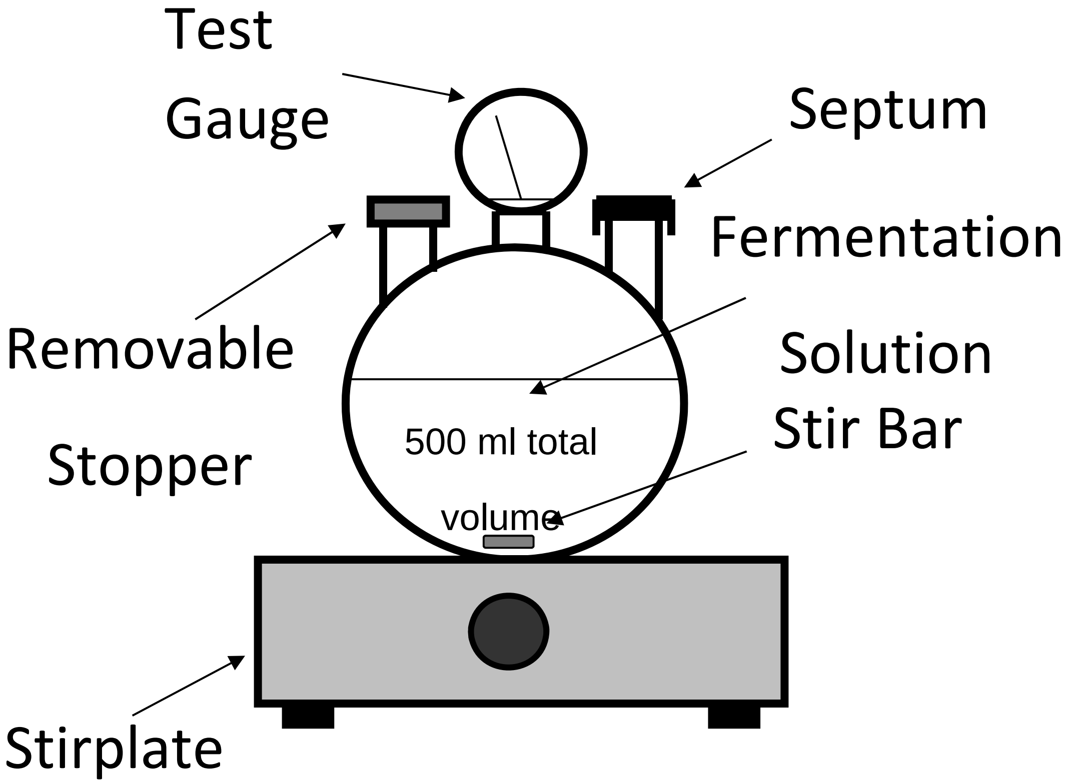


Figure 3a: Gas chromatograph equipped with thermal conductivity detector for analysis of gases from anaerobic digestion of wastewater.

Figure 3b: Sample chromatogram.

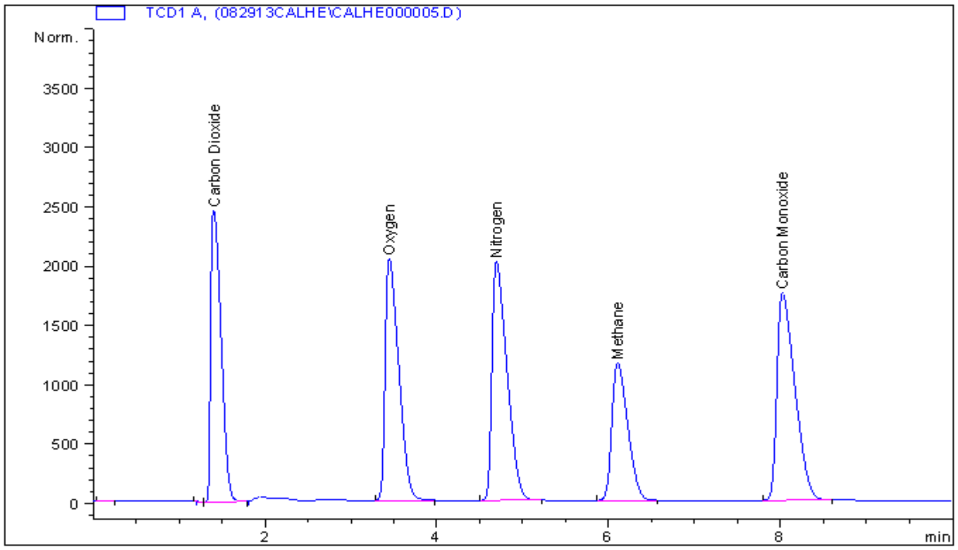


Figure 4a: Liquid chromatograph equipped with diode array detector for analysis of VOAs from anaerobic digestion of wastewater.

Figure 4b: Sample chromatogram.

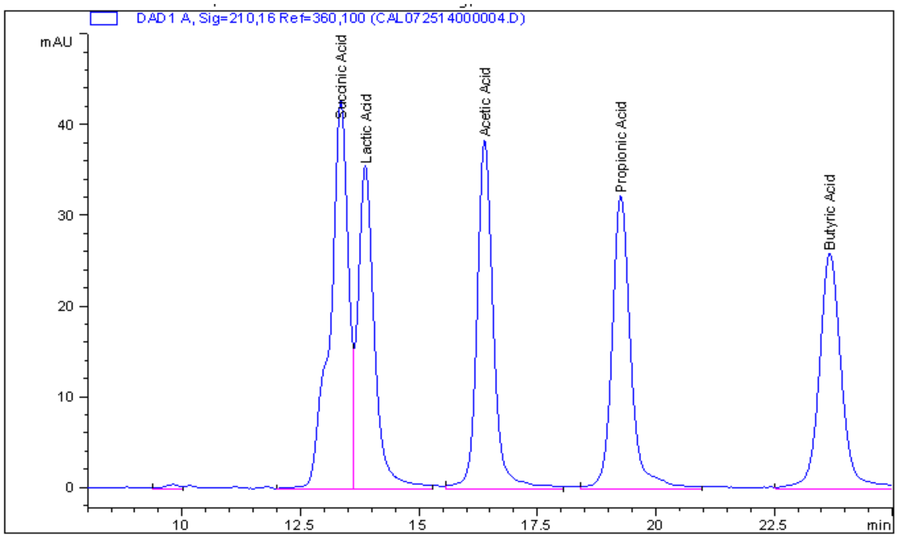


Figure 5: a) Ion chromatographs equipped with electrochemical detector for analysis of minerals and nutrients (anions – left, cations – right) c) Sample chromatogram – cations.

Figure 5b: Sample chromatogram – anions

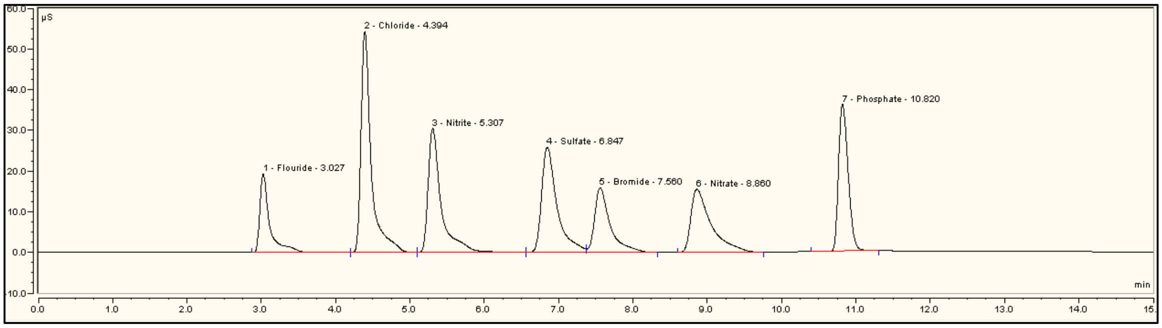


Figure 5c: Sample chromatogram – cations.

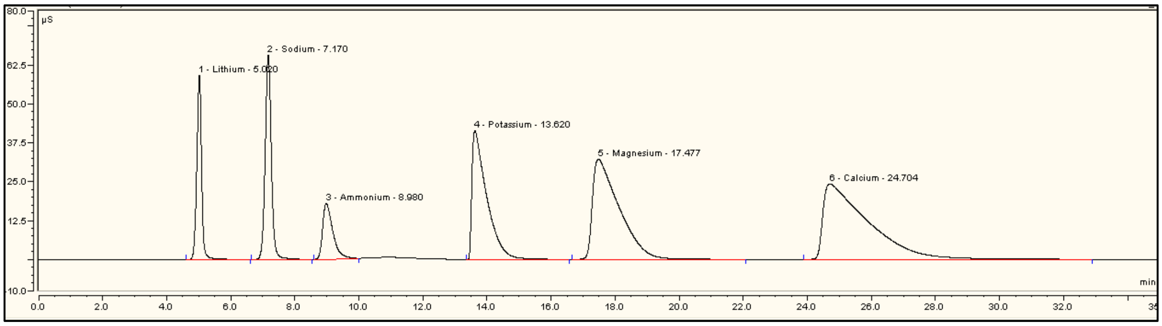


Figure 6: PFD of an envisioned application of the technology.

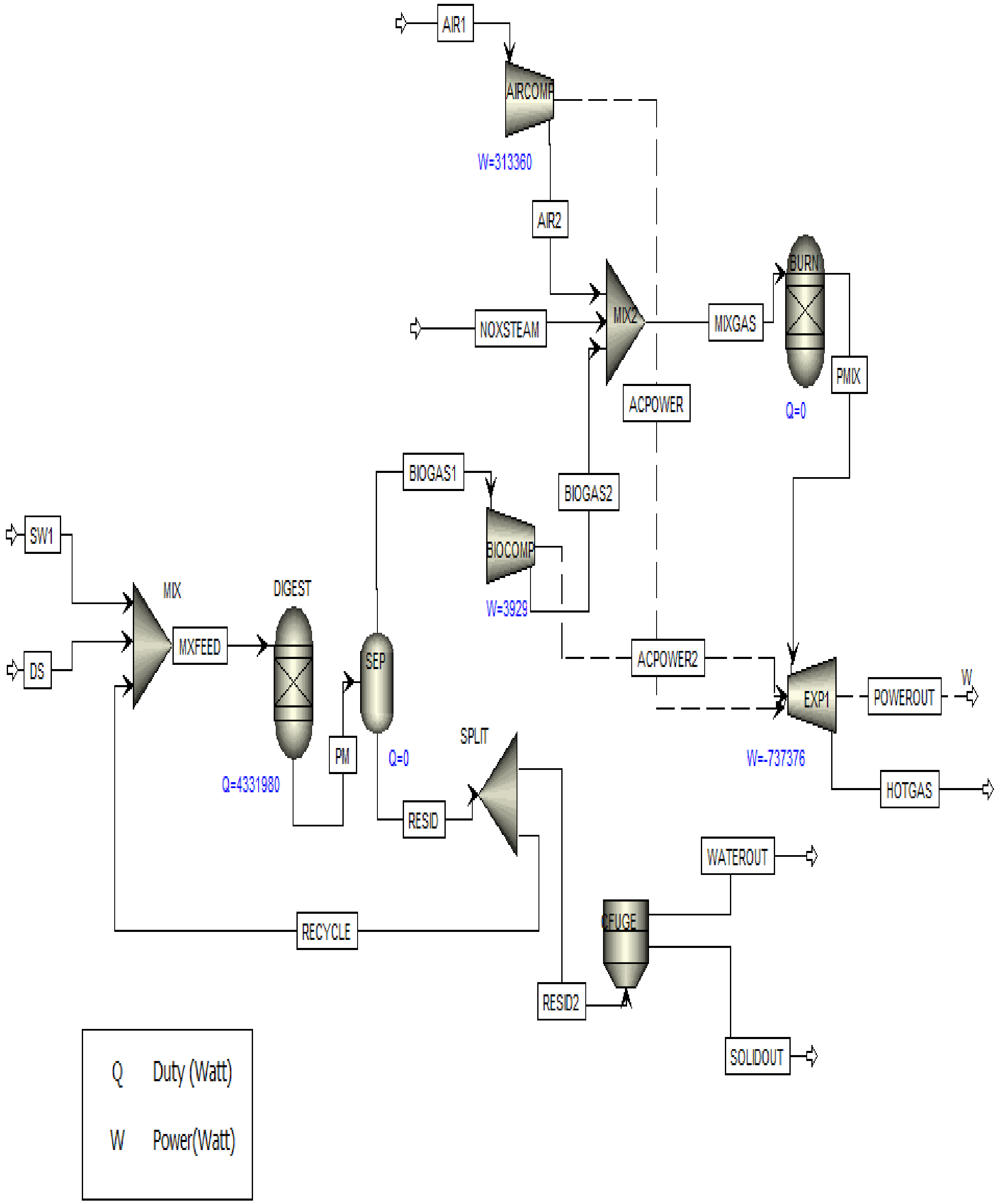


Figure 7a: Microcosm tests using shrimp processing wastewater: no seed addition (native microbes as sole microbe seed). Microbial seed was obtained from anaerobic digester at the East Wastewater Treatment Facility at Lafayette, LA.

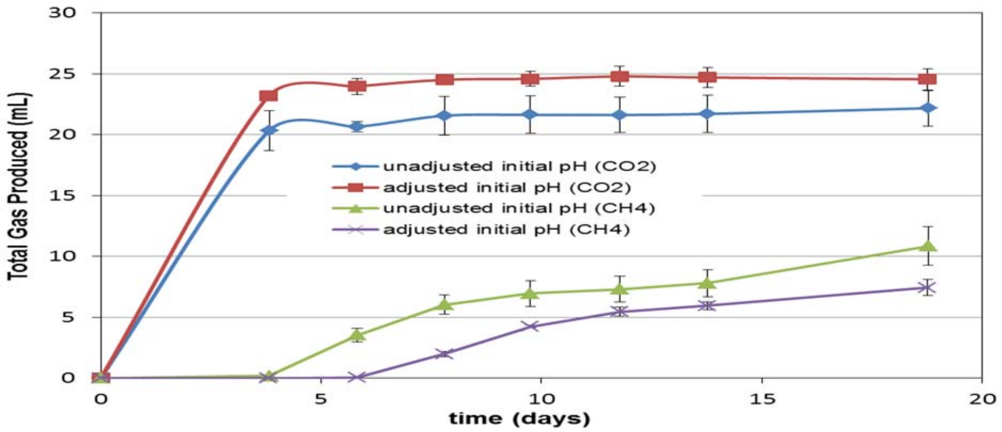


Figure 7b: Microcosm tests using shrimp processing wastewater: 2% (v/v) seed,

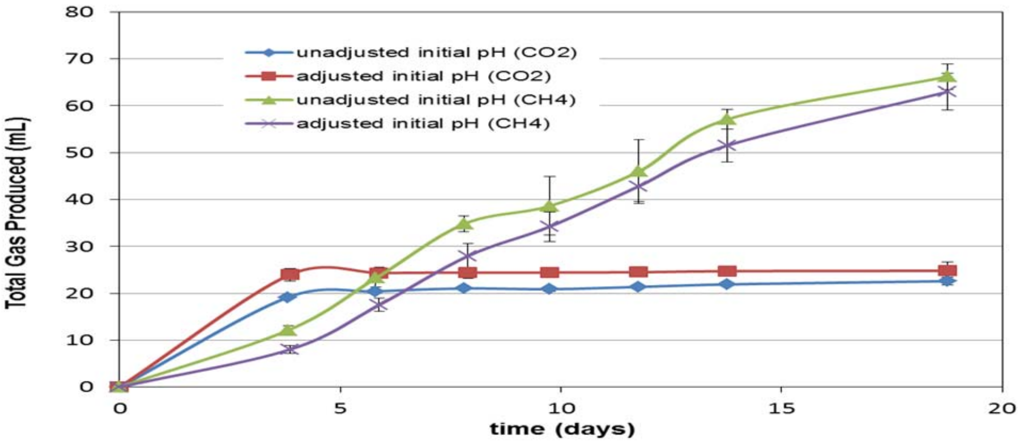


Figure 7a: Microcosm tests using shrimp processing wastewater: 5% (v/v) seed

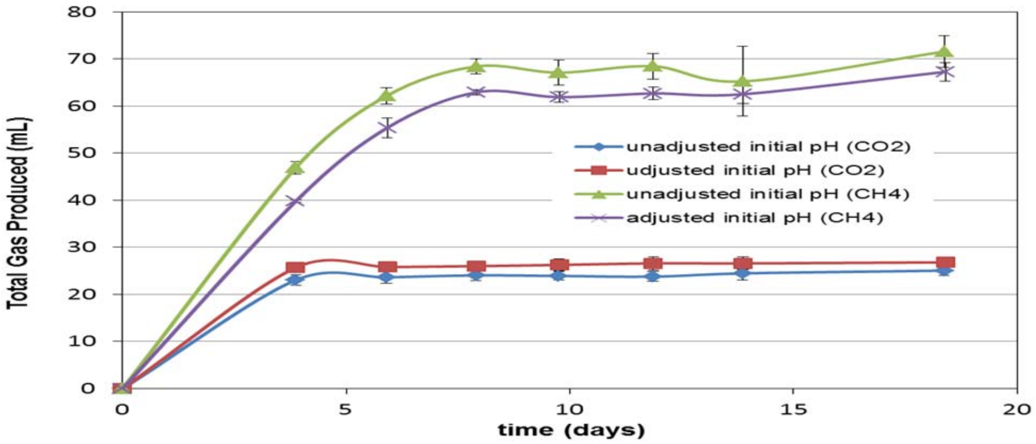
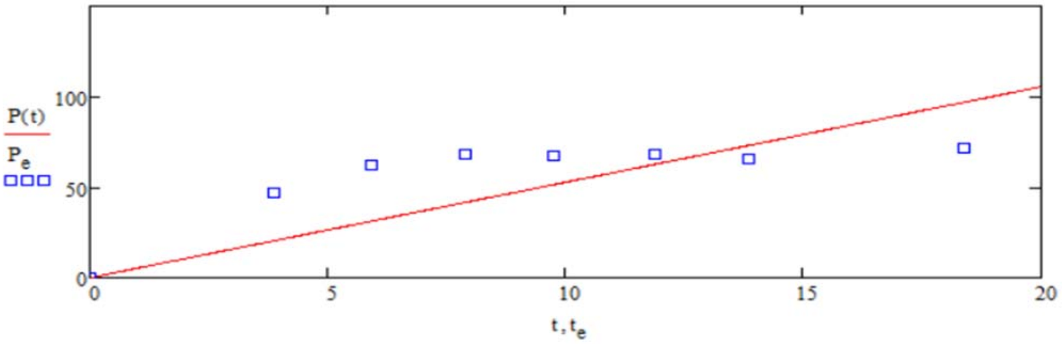
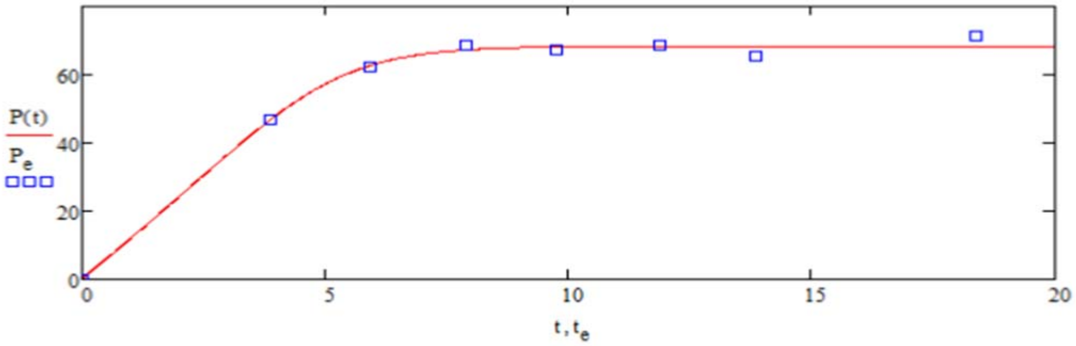


Figure 8: Modeling of bench data using Monod and Haldane models (data fitting).

Monod



Haldane (n = 1)



Haldane (n = 2)

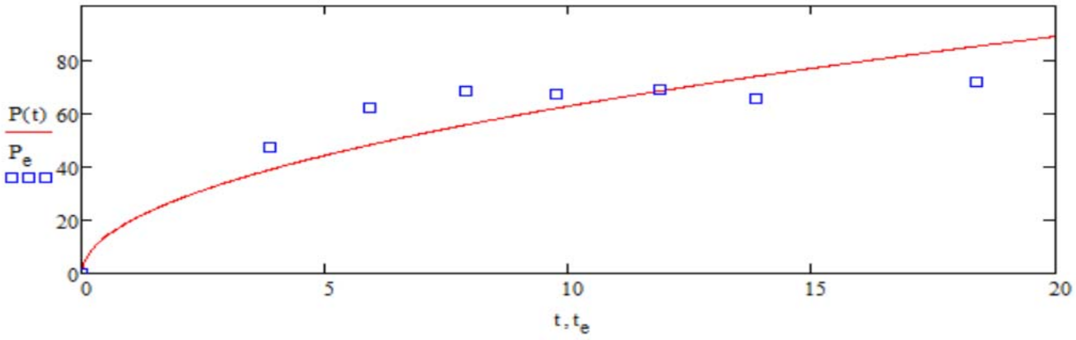


Figure 9: Microcosm tests using catfish processing wastewater: 5% (v/v) digester sludge seed, 35°C, unadjusted initial pH, 4776 mg/l initial COD

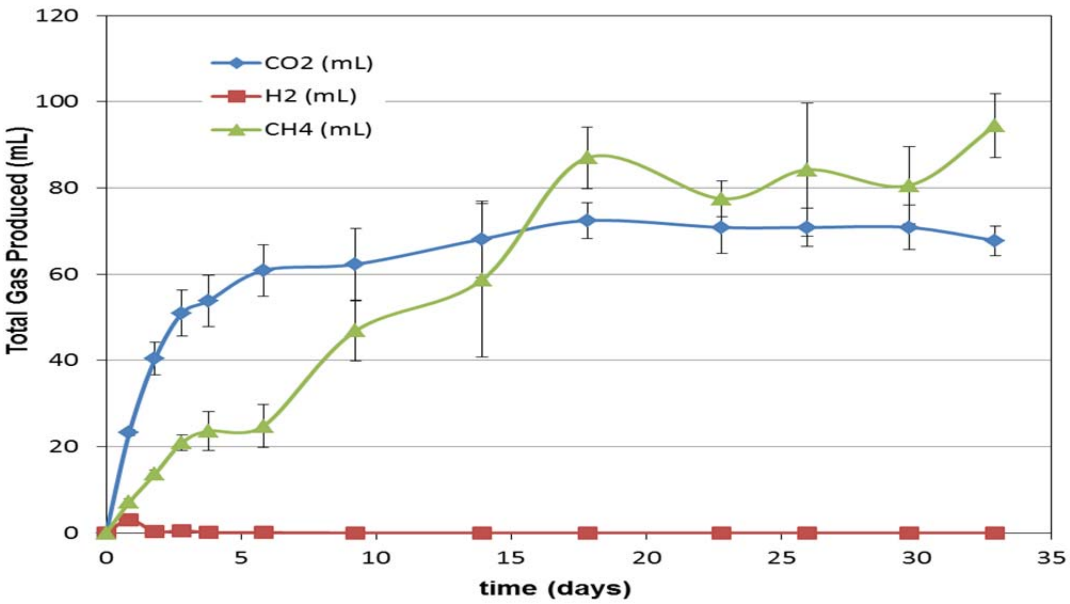


Figure 10: Microcosm tests using vegetable processing wastewater: 5% (v/v) digester sludge seed, 35°C, unadjusted initial pH, 9389 mg/l initial COD.

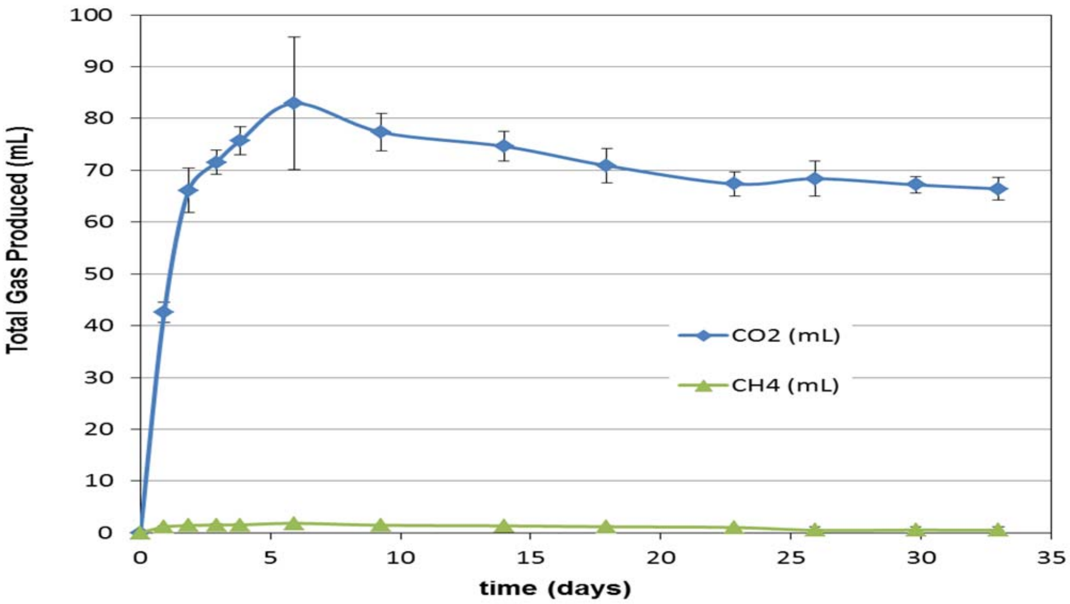


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Figure 11a: Diagram of fermentation system for hydrogen and VOAs production, b) Experimental run at 24 hours.

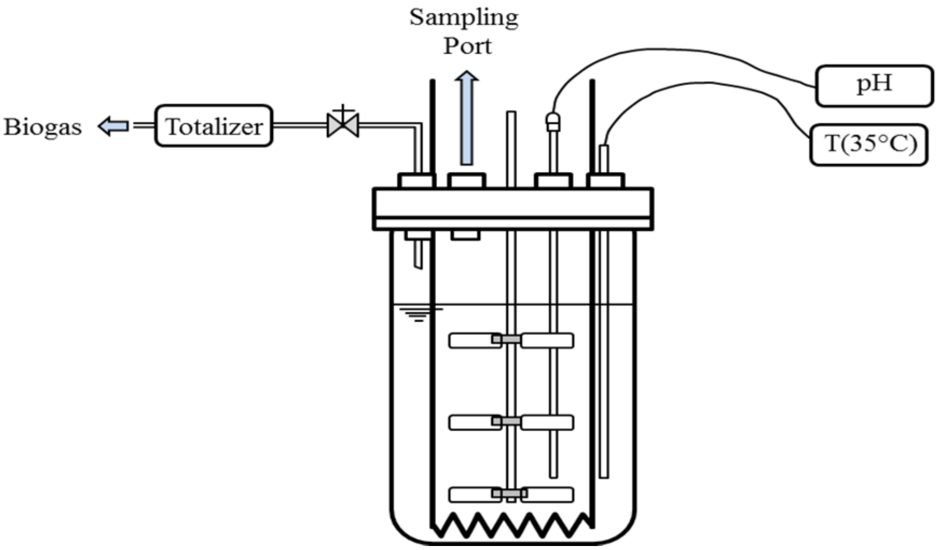


Figure 11b: Experimental run at 24 hours.

Figure 12a: Profile of products during anaerobic digestion of glucose for production of hydrogen and VOAs: 2% (v/v) digester sludge seed, 35°C. Gaseous products.

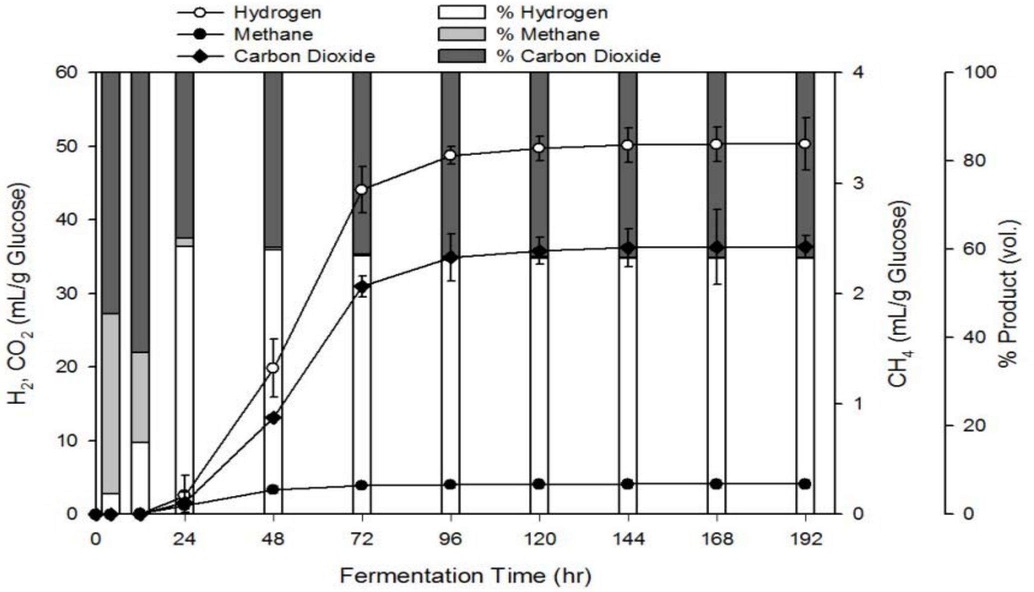


Figure 12b: Profile of products during anaerobic digestion of glucose for production of hydrogen and VOAs: 2% (v/v) digester sludge seed, 35°C. Residual glucose and VOAs.

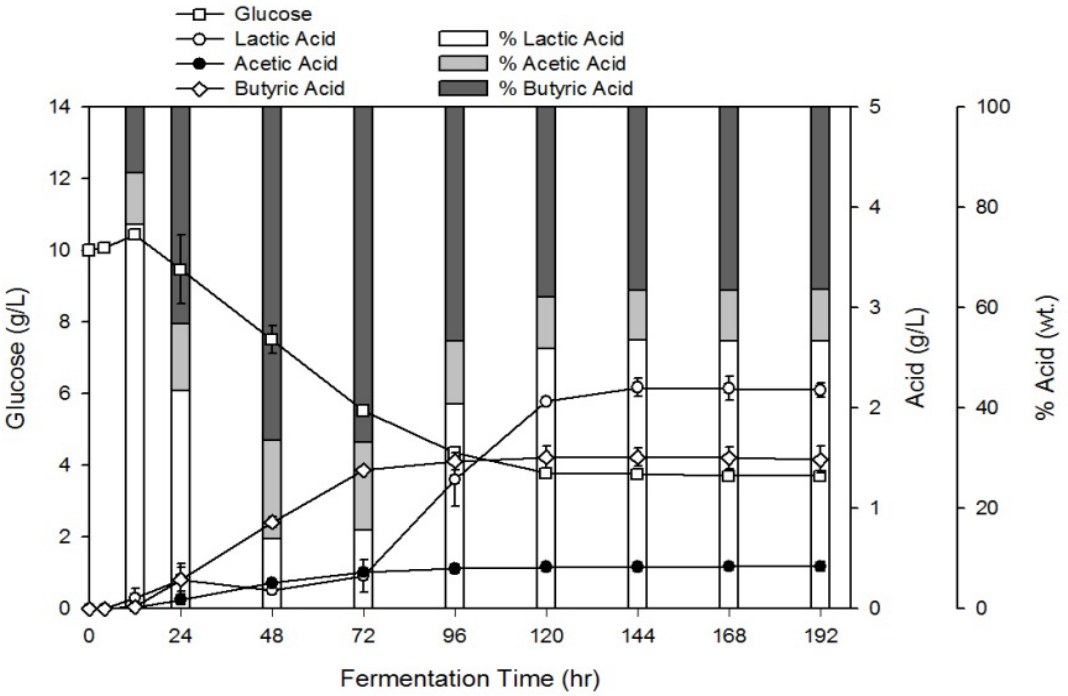


Figure 13a: Profile of products during anaerobic digestion of shrimp processing wastewater for production of hydrogen and VOAs: 2% (v/v) digester sludge seed, 35°C, ~1100 mg/l initial COD - Gaseous products.

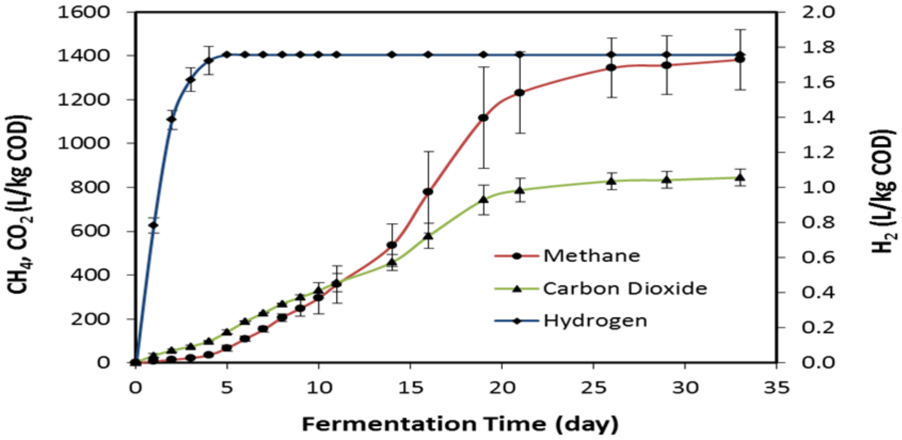


Figure 13b: Soluble metabolites – VOAs.

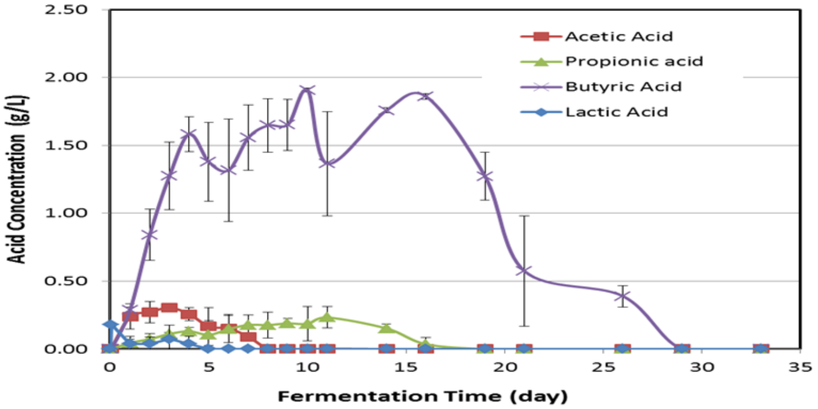


Figure 13c: System pH.

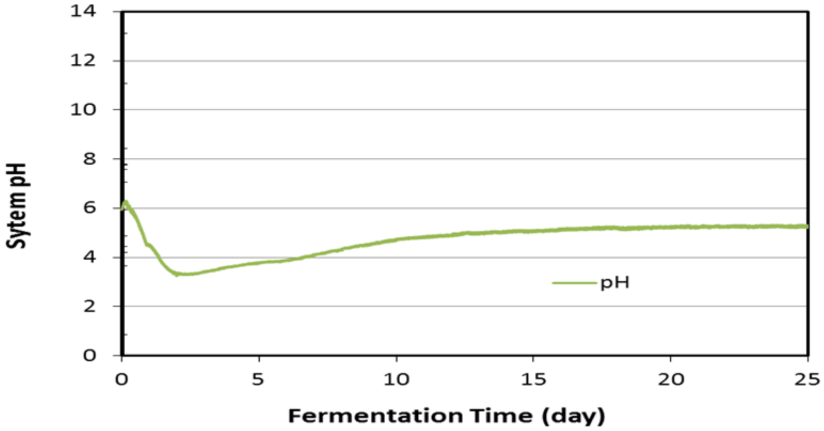
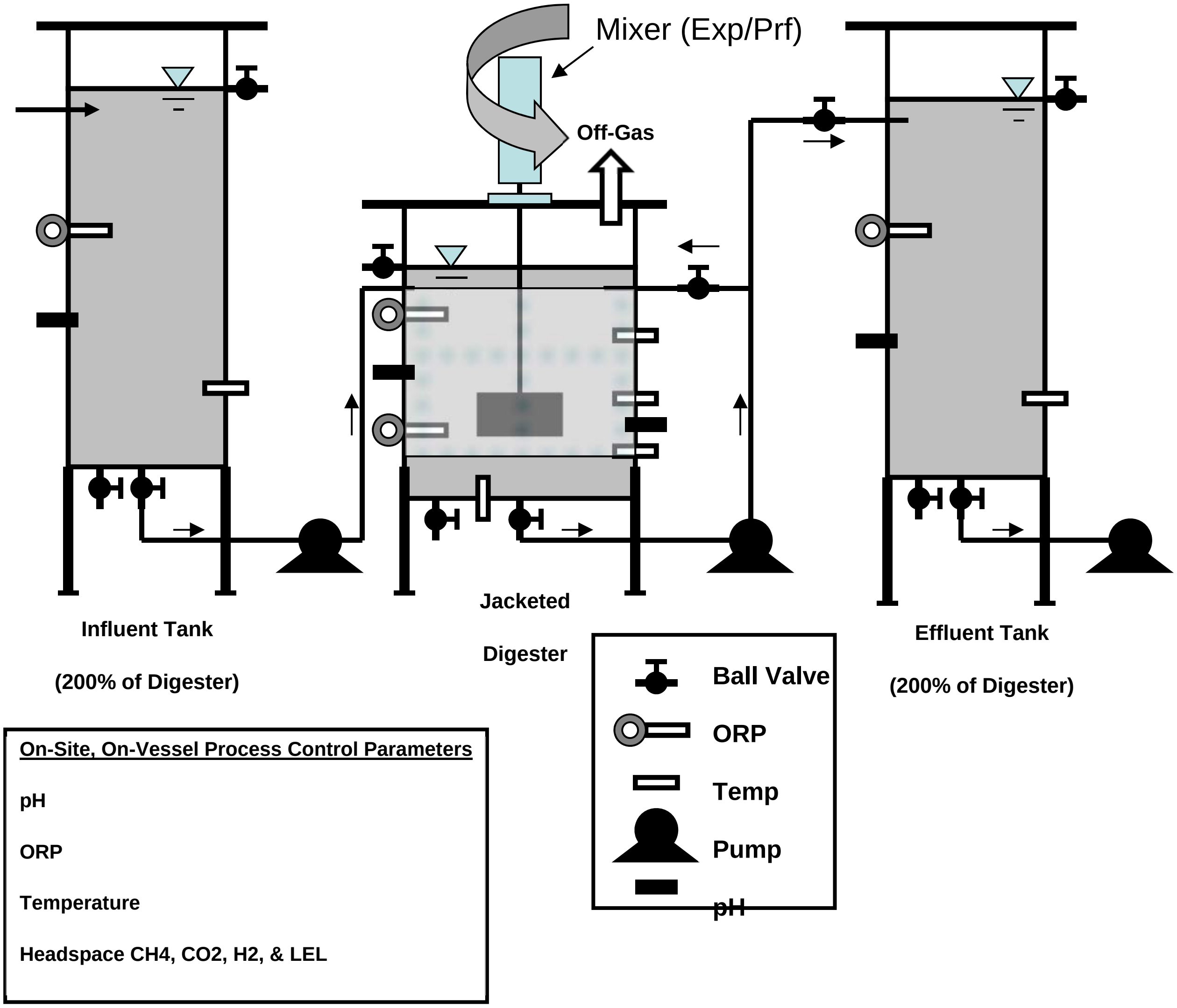


Figure 14: Pilot Digester Process Layout Schematic.



On-Site, On-Vessel Process Control Parameters

pH

ORP

Temperature

Headspace CH_4, CO_2, H_2, & LEL

Figure 15: Preparing the pilot system for charging with shrimp wastewaters.

Figure 16: Insulated (Jacketed) view of the digester.

Figure 17: Heater to maintain digester temperature.

Figure 18: Analytical system for continuous monitoring of biogas quality and quantity.

Figure 19: Controls cabinet shown beside the digester reactor.

Figure 20: Collecting shrimp wastewater from processor in Delcambre, LA.

Figure 21: Operation during cold conditions (system performed flawlessly).

Figure 22a: Biogas production and production rate for the pilot system: (~5% (v/v) seed concentration, 35°C, 665 L shrimp processing wastewater.

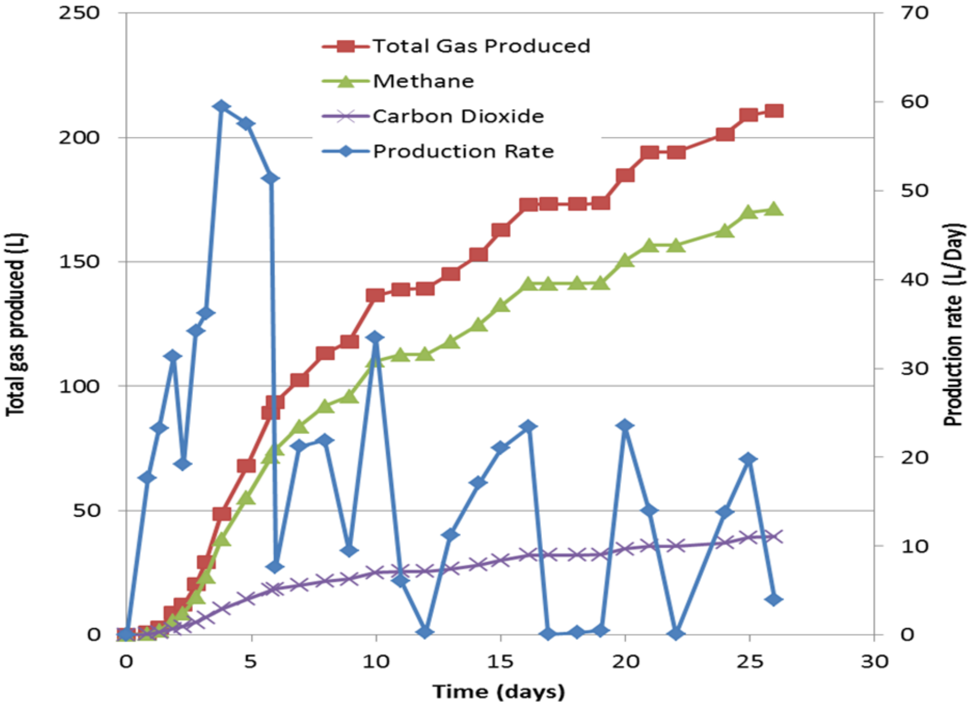


Figure 22b: Biogas composition.

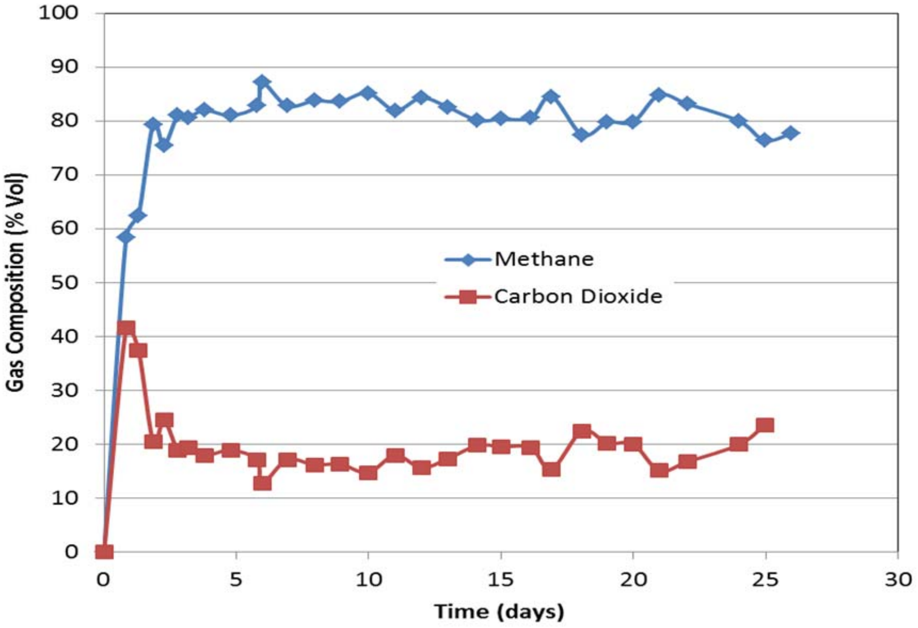


Figure 23: Biogas production and production rate for the pilot system: (~5% (v/v) seed concentration, 35°C, 625 L shrimp processing wastewater.

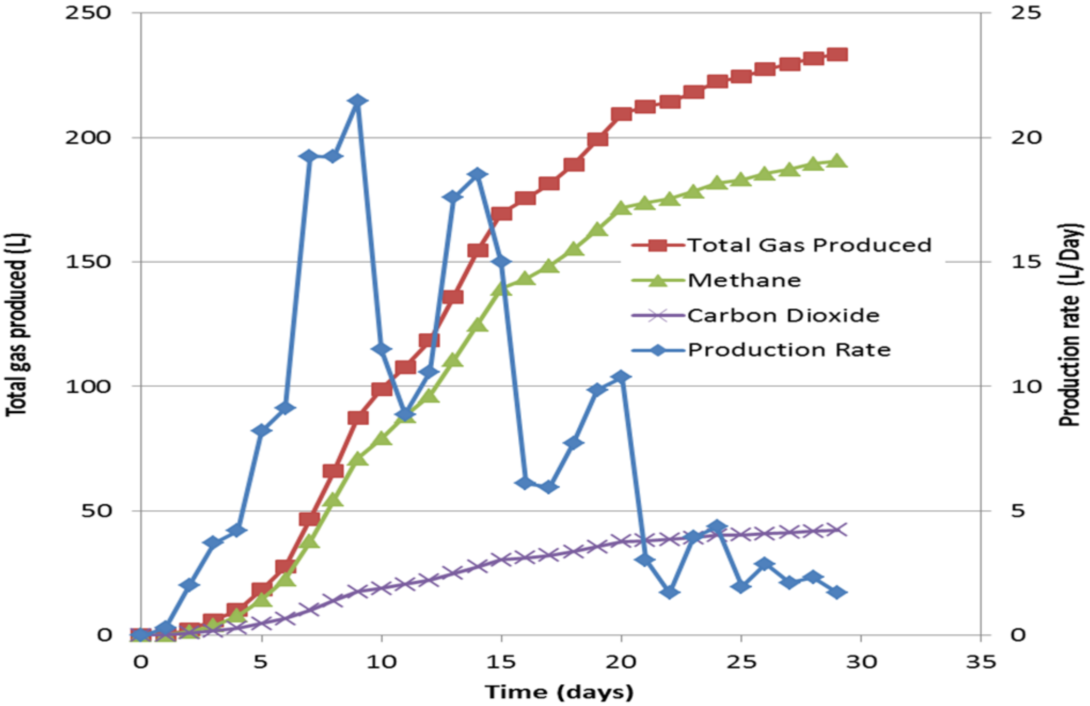


Figure 24: The pilot digester at its present location at the East Wastewater Treatment Facility in Lafayette, LA.

Figure 25a: Biogas production and production rate for the pilot system: (~5% (v/v) seed concentration, 35°C, 220 gal municipal wastewater. Note: Average of two runs.

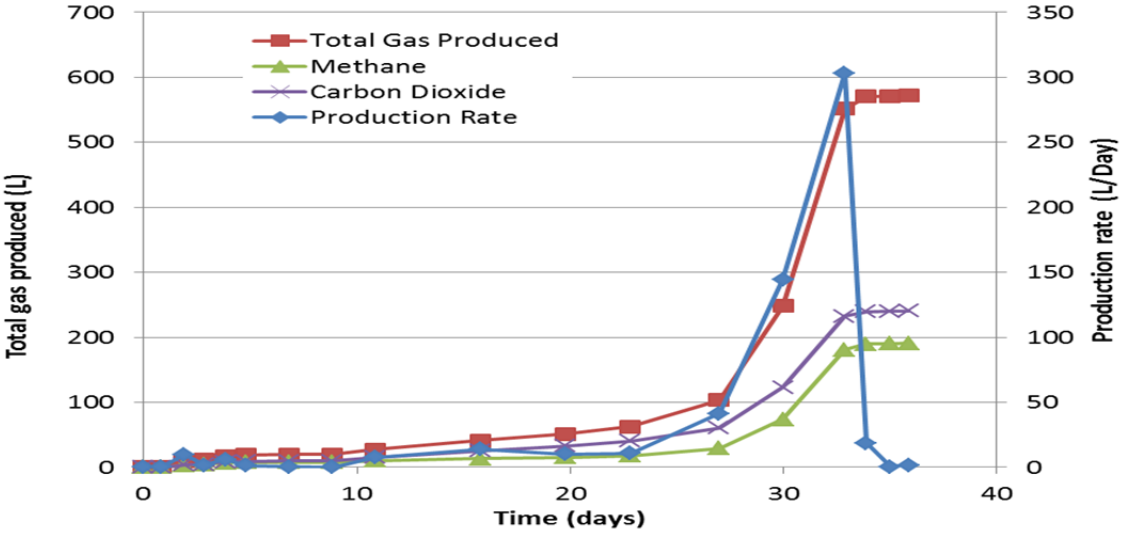
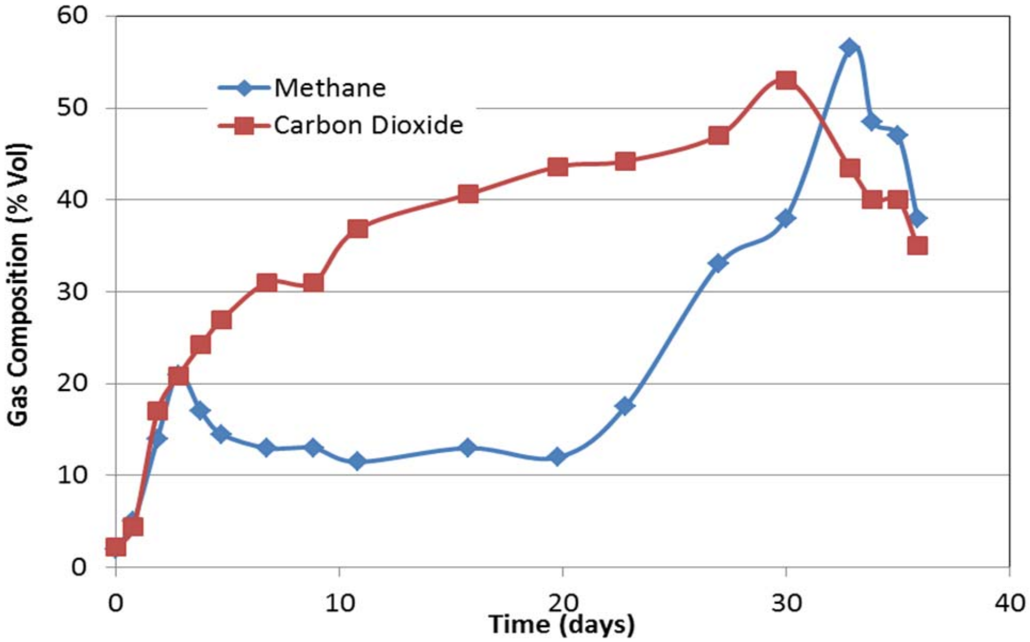


Figure 25b: Biogas composition.



Section 7 Biomass Torrefaction

Biomass Torrefaction Technology

Torrefaction of biomass is a thermal pretreatment process in which biomass is heated to temperatures of 230-300^{o}C, in the absence of an oxidizing agent. Several byproducts are released including water, volatile organic compounds, and gases, during the process. At these temperatures the hemicellulose fraction of biomass, which is the most reactive component of lignocellulosic material is extensively decomposed to produce volatiles and a solid char like product. Cellulose and lignin fractions of biomass also undergo limited volatilization during the process. The condensable volatile compounds released during torrefaction include organics such as sugars, acids, alcohols, ketones, furans, and lipids such as terpenes, waxes, phenols, fatty acids, and tannins. Permanent gases are also released during the process which includes carbon dioxide, carbon monoxide, methane, hydrogen, etc.

Typically, during torrefaction 70% of mass is retained in the solid product which contains 90% of the initial energy. The remaining 30% of biomass is converted to volatiles and gases that contain 10% of the biomass energy. Thus, energy densification can be achieved via torrefaction by a factor of 1.3 on mass basis. Also, during torrefaction the ratio of hydrogen to carbon (H/C) and oxygen to carbon (O/C) tends to decrease, increasing the net calorific value of torrefied biomass. Typically wood has a net calorific value of 7,000-9,000 Btu/lb. An increase in calorific value is observed when wood is torrefied and has values in the range of 9,000-11,000 Btu/lb[4].

Pilot Scale Evaluation of Biomass Torrefaction

Cleco under partnership with UL Lafayette and LA Biofuel Resources, have installed, tested, and demonstrated the production of torrefied biomass using a pilot scale torrefaction reactor. The pilot scale torrefaction unit is a continuous, indirectly heated reactor and has a capacity to produce 15-20 pounds of torrefied material per hour. Till date over 3 tons of torrefied biomass has been produced using the pilot scale reactor at 10-25 lbs an hour production rate. Most of torrefied biomass produced has been provided to Sundrop Fuel's to be tested as feed for their GTL process and approximately, 1.5 tons of torrefied biomass was generated from a wide range of experiments performed till date that focused on optimizing the torrefaction process and improving the overall efficiency of the torrefaction system.

Several modifications were made during this reporting period to the torrefaction system to improve its overall efficiency. The feeding system was modified to increase the capacity of the screw conveyer, which increased the feed capacity by approximately 30%. In addition, the system has been retrofitted with a heat traced gas line to utilize the energy from the volatiles and gases generated during the torrefaction process as shown in **Figure 1.** This heated line allows the volatiles and gases to be routed into the natural gas combustion zone where the volatiles and gases are combusted, utilizing the energy which otherwise was flared.

Figure 1: Torrefaction reactor retrofitted with heat traced gas line to route volatiles and gases into natural gas combustion zone.

Experimental Results and Project Significance

In an effort to optimize the indirectly heated pilot scale torrefaction reactor, several experiments were performed which include, the effect of varying lignocellulosic composition on torrefied product, effect of reactor operating conditions such as temperature and residence time, and effect of feedstock properties including moisture content and particle size on torrefaction process and product. Following paragraphs briefly summarizes a few results from experimental work performed during this reporting period.

Table 1 presents the properties of various lignocellulosic biomass feedstock evaluated in this study. Experimental conditions under which tests were performed on pilot scale reactor for pine, hardwood, and arundo at 600 ^{o}F and the properties of the torrefied product are provided in Table 2. The screw feeder and rotary retort frequencies were set at 60 and 90 Hz, respectively and all the experiments presented in **Table 2** were performed at combustion zone temperatures set at 600 ^{o}F. However, the temperature of the retort (reactor) varied with type and properties of feedstock. In addition, product collection procedure contributes to lower temperatures in the retort. A typical temperature profile within the reactor is presented in **Figure 2** for an experiment performed with pine at 600 ^{o}F. It can be seen that the temperature of the reactor in the center zone varied between 555 and 585 ^{o}F and should be considered as the true operating temperature for the process. Comparison of calorific values for pine, hardwood, and arundo in **Tables 1 and 2** shows an increase in the energy content of the torrefied product for all the feedstocks tested. Also, the ratio of carbon to hydrogen increases in all the cases which attributes to an increase in the energy content of the torrefied product, increasing the energy density of torrefied material. In addition, the moisture content of the torrefied material was less than 4% which confirms the hydrophobic nature of the torrefied material compared with untreated biomass for all the biomass species tested. Feeding and torrefied product production rates were similar for both pine and hardwood under the set operating conditions, but arundo had very low feeding rates due to its low bulk density.

Similar results in terms of increase in the energy density, reduced moisture content, and improved grindability characteristics were obtained for all the experiments performed. Energy densification increased with an increase in temperature and residence time. Experiments performed with high moisture content posed serious operating issues with clogging of reactor lines which lead to reactor. Also, energy consumption was more than twice for tests performed with 35% moisture content. Energy consumption was 12.2 liters per minute at 35% moisture content pine versus 5.8 liters per minute for 14% moisture content pine under similar operating conditions. The quality of the torrefied material produced using 35% moisture content had lower energy content (9,148 btu/lb) in comparison with 14% moisture content feed (10,078 btu/lb).

Figure 3 shows the modified EPA Method 5 sampling train that was set up to sample condensable volatiles from the exhaust gas stream. Condensable organic compounds were collected using the set-up shown in Figure 3 and analyzed using GC mass spectrometer. A wide complex range of compounds were identified that included acids, alcohols, aldehydes, ketones, substituted phenols, and aromatics. A list of compounds identified in relatively higher concentrations is presented in **Table 3**. Also, permanent gases including hydrogen, carbon monoxide, carbon dioxide, and methane were detected in the post condensed gas stream. Although, hydrogen and methane concentrations were lower than 1% by volume, greater than 10% carbon monoxide was detected. Condensed organic and gas composition widely varied with biomass species and reactor operating conditions.

Figure 4 presents the effect of torrefaction temperature on pine in comparison with various solid carbonaceous fuels on H/C and H/O ratios. As shown in the Figure, with an increase in torrefaction temperature from 460 deg. F to 610 deg. F and a residence time of 30 minutes, the elemental composition of torrefied pine approaches that of coal, which suggests the potential of torrefied pine as a coal replacement. The production rate of torrefied pine with this set of experiments post modifications to the feeding system ranged between 21- 24 lbs an hour. This increase is attributed to increased feeding rates and decreased residence times from 60 minutes to 30 minutes. Typical temperature profile along the reactor and combustion zone is presented in **Figure 5** for one of the experiments performed with pine at 12 – 14% moisture content and residence time of 30 minutes. Internal zone temperatures correspond to the temperatures inside the torrefaction reactor while the burner and combustion zone corresponds to the temperatures of the reactors combustion shell.

The results from the tests performed till date demonstrates the feasibility of using a pilot scale indirectly heated rotary reactor technology to produce torrefied biomass. In addition, the results presented in this section illustrate the advantages of torrefied biomass such as energy densification, hydrophobic nature, and improved grindability characteristics in comparison to unprocessed biomass. Also, the increased energy density and improved grindability characteristics make this product comparable to coal and petroleum coke. The results obtained and the reactor operational experiences thus far have provided valuable information that will improve both the process efficiency and economics. Several conclusions were drawn that will improve the overall torrefaction process using the existing indirectly heated rotary reactor design. The existing reactor size could accommodate improved production rates (capacity) using the existing reactor size by modifying 1) screw design to increase feed rate and 2) retort speed. Also, the results suggest drying feedstock to a uniform moisture content of less than 15% before feeding into the torrefaction reactor. This would result in superior performance of the process and increased production capacity and process efficiency leading to decreased processing costs, improving the overall process economics, thus paving way for a competitive torrefaction technology to be realized in short term.

Table 1: Properties of biomass feedstock evaluated

	Pine	Hardwood	Arundo
Moisture Content, %	34.05	12.9	12.2
Ash, %	0.64	1.34	4.59
Calorific Value, Btu/lb dry	8,637	8,275	7,751
Carbon, % dry	51.7	51.9	47.6
Hydrogen, % dry	7.3	7.3	6.7
Oxygen, % dry	40.7	40.3	44.6
Nitrogen, % dry	0.1	0.2	0.6
Sulfur, % dry	0.1	0.1	0.4

Table 2: Operating conditions, torrefied biomass production rates and properties

	Pine	Willow	Arundo
Moisture Content, %	14	15	6.2
Retort Temperature Range, F	555-585	570-585	580-595
Feeding Rate, lbs/hr	21.2	20.6	9.8
Production rate, lbs/hr	8.3	9.9	3.8
Natural Gas Consumption, lpm	5.7	5.3	4.3
Product Moisture Content, %	3.3	1.2	2.9
Product Ash Content, %	2.2	1.34	6.8
Product Calorific Value, Btu/lb dry	10,078	9,817	10,871
Product Elemental C, % dry	63.4	57.6	63.7
Product Elemental H, % dry	6	5.8	5
Product Elemental O, % dry	30.1	36.1	30.3
Product Elemental N, % dry	0.3	0.4	0.7
Product Elemental S, % dry	0.1	0.1	0.3

Table 3: List of organic compounds identified in torrefaction exhaust stream

Ethyl alcohol	Limonene
Acetic acid	bis-2,2-[ethylidenebis(oxy)]propane
1-hydroxy-2-propanone	2,6,6-trimethyl-bicyclo[3.1.1]hept-2-ene
2-methoxyphenol	2,6,6-trimethyl-bicyclo[3.1.1]hept-2-ene
2-methoxy-4-methylphenol	beta-pinene
4-ethyl-2-methoxyphenol	4-hydroxy-3-methoxybenzeneacetic acid
2-methoxy-3-(2-propenyl)phenol	3-allyl-6-methoxyphenol
2-methoxy-4-(1-propenyl)phenol	Fluoranthene
Vanillin	1-phenanthrenecarboxylic acid
2-methoxy-4-(1-propenyl)phenol	Furfural
1-(4-hydroxy-3-methoxyphenyl)ethanone	1-(4-hydroxy-3-methoxyphenyl)2propanone

Figure 2: Torrefaction reactor center zone temperature profile for experiment conducted with pine at 14% moisture content and burner temperature set at 600 °F.

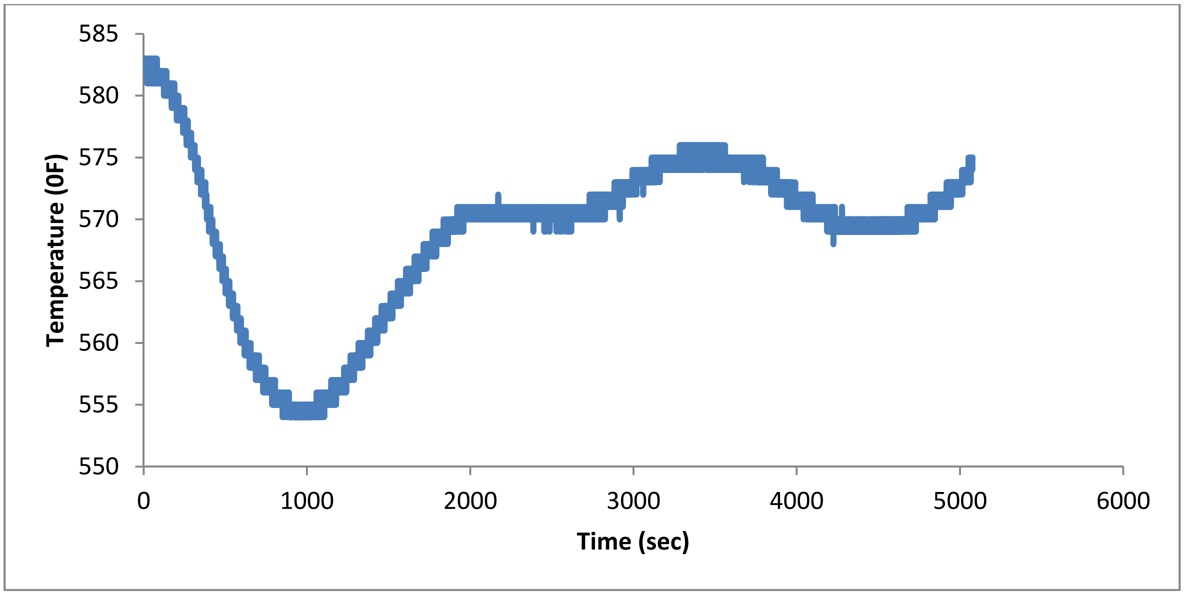


Figure 3: EPA Method 5 sampling system set-up to analyze condensable volatiles and gases

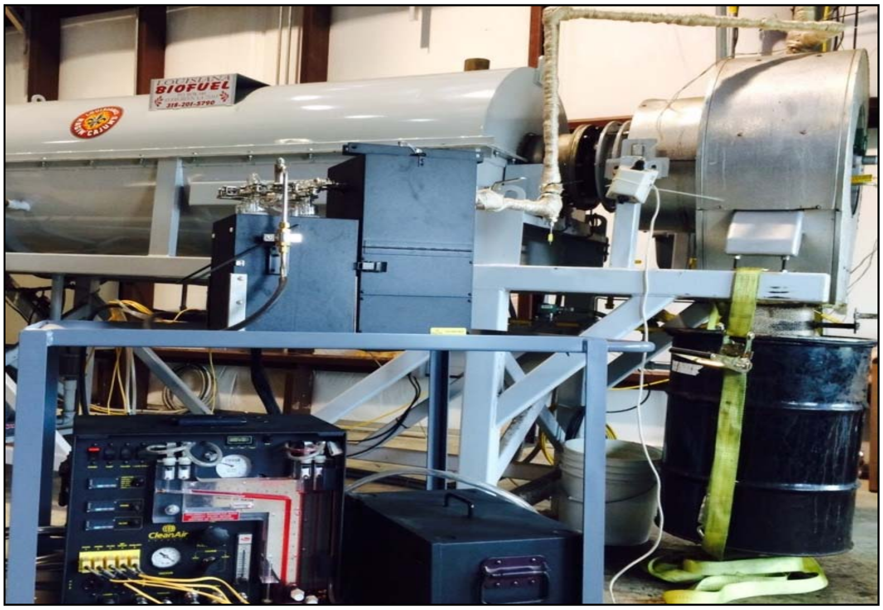


Figure 4: Van Krevelen diagram[5] with an overlay of torrefied pine produced with increasing temperatures (460 deg. F to 610 deg. F)

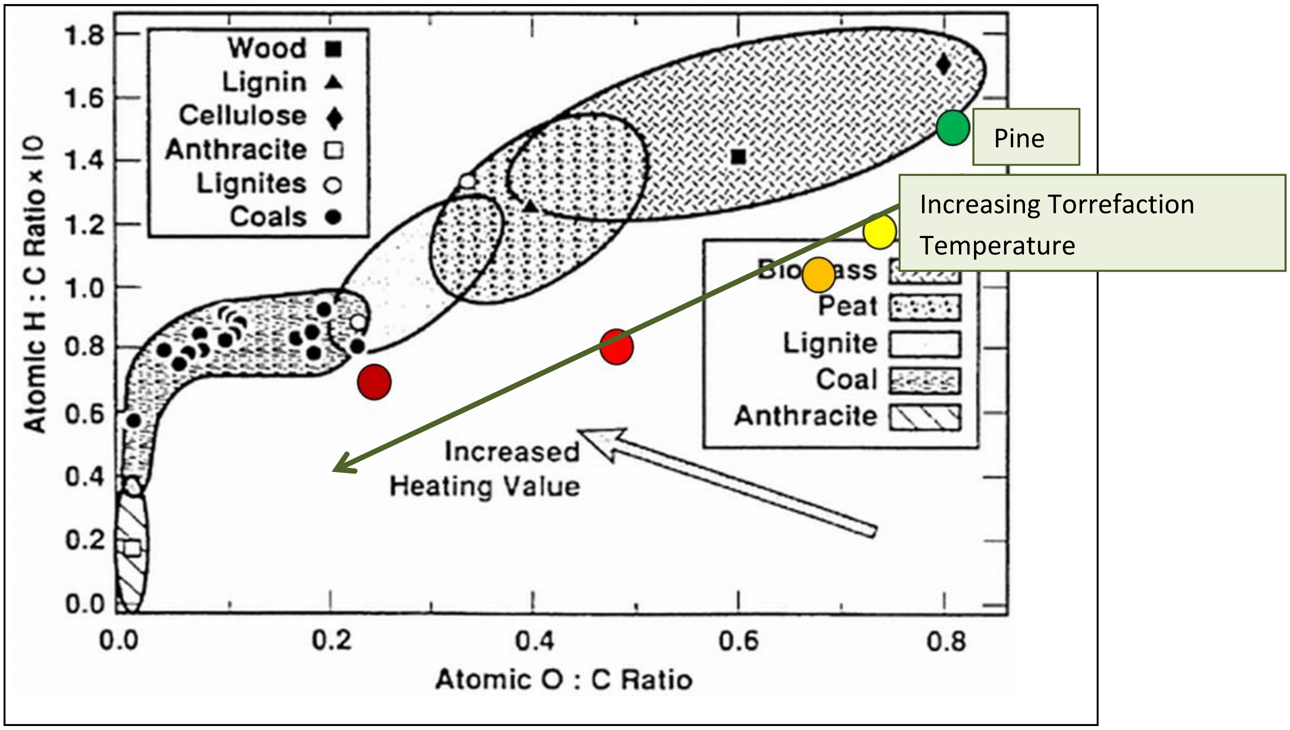
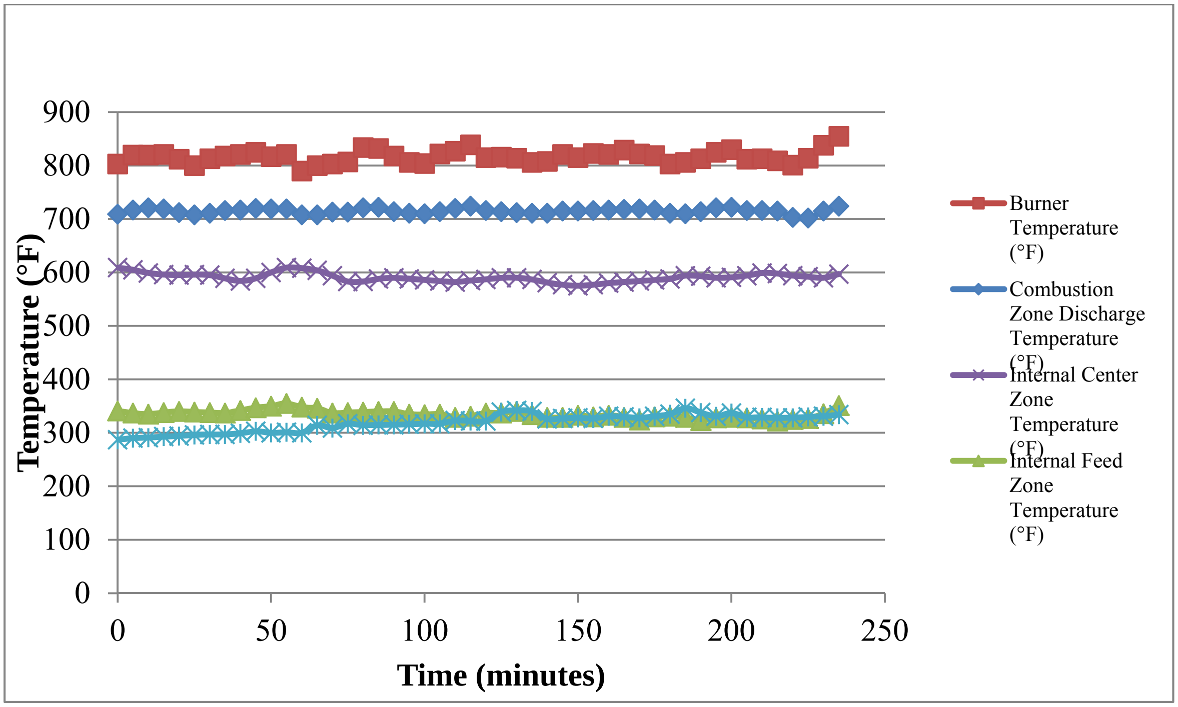


Figure 5: Temperature profile of the torrefaction reactor for an experiment performed with pine at 12 - 14 % moisture content and 30 minute residence time.

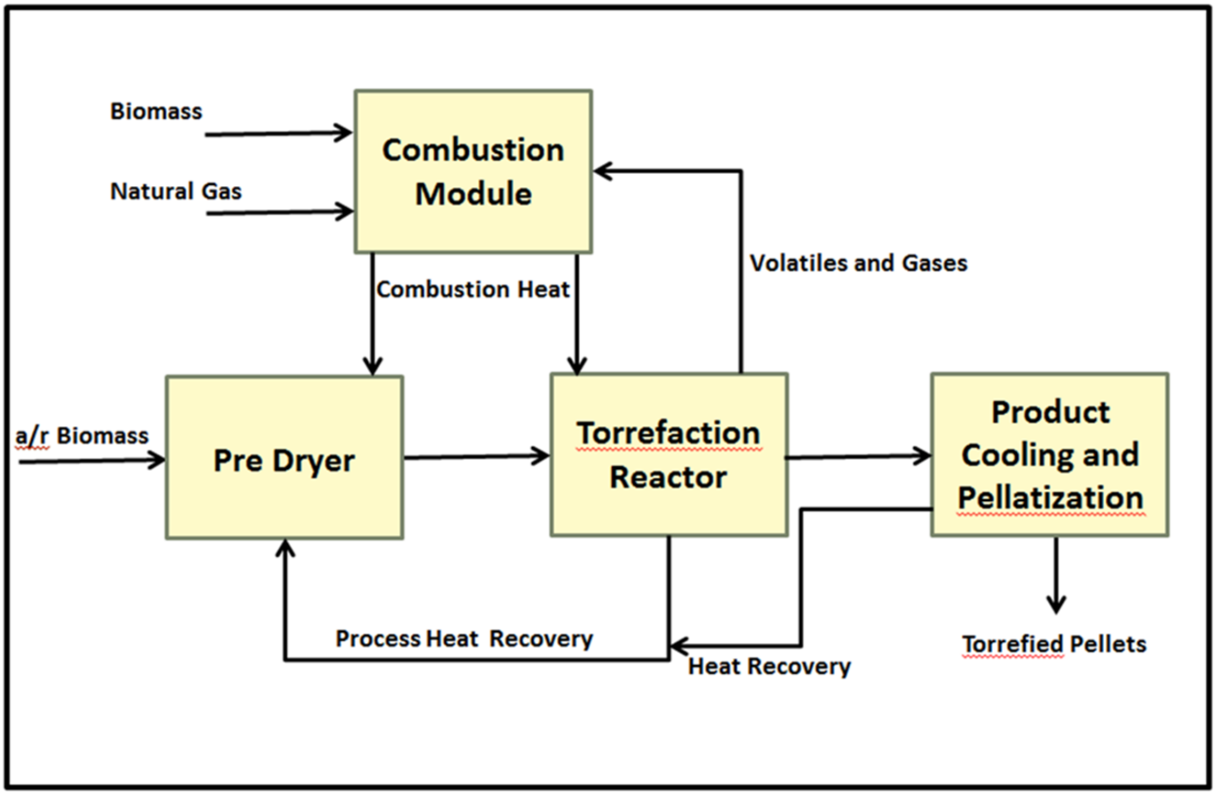


Future Work

Future work will focus on process optimization, design of a full scale torrefaction system, and techno-economic analysis. Efforts are underway to procure additional funds to have an integrated torrefaction system including biomass dryer, product cooling and conveying system, and a pelletizer installed as shown in Figure 6**.** Following objectives will be evaluated during the future course of this project:

1) Continue performing experiments under various operating conditions using a wide range of feedstock.
2) Evaluate the energy content and utilize the energy from the volatiles and off gases to supplement energy either in torrefaction or biomass drying process (Design, fabrication, and installation of a separate combustion module with a multi-fuel burner system that has a potential to use natural gas, volatiles and gases generated during torrefaction, and torrefied biomass).
3) Evaluate process efficiency by integrating the energy generated from the combustion of volatile gas stream produced during torrefaction/drying.
4) Perform techno-economic analysis on the pilot scale unit using the data generated and ultimately design a full scale torrefaction reactor system (1-5 ton/hour Capacity).

Figure 6: Biomass Torrefaction Process Flow



References:

1. Sami, M., Annamalai, K., and Wooldridge, M. , *Co-firing of coal and biomass fuel blends.* Progress in Energy and Combustion Science, 2001. 27: p. 171-214.
2. *Program on Technology Innovation: Utility Scale Use of Biomass: Torrefaction and Pellating Technology Application for Biomass Co-Firing with Coal*, in 2009. 1018661, EPRI: Palo Alto, CA.
3. *Program on Technology Innovation: An Aspen Plus Model of Biomass Torrefacton.* 2009. 102050, EPRI: Palo Alto, CA.
4. Bergman, P.C.A., Boersma, A. R., Zwart, R. W. R., and Kiel, J. H. A., *Torrefaction for biomass co-firing in exixting coal-fired power stations, ECN-C-05-013*. 2005, Energy Research Center of the Netherlands: The Netherlands.
5. Van Loo, S., Koppejan, J., *The handbook of Biomass Combustion & Co-firing*, Earthscan publishing house, 2007, 978-1-84407-249-1, Earthscan Publishing House, London, U.K.

Section 8 Levelized Cost of Energy

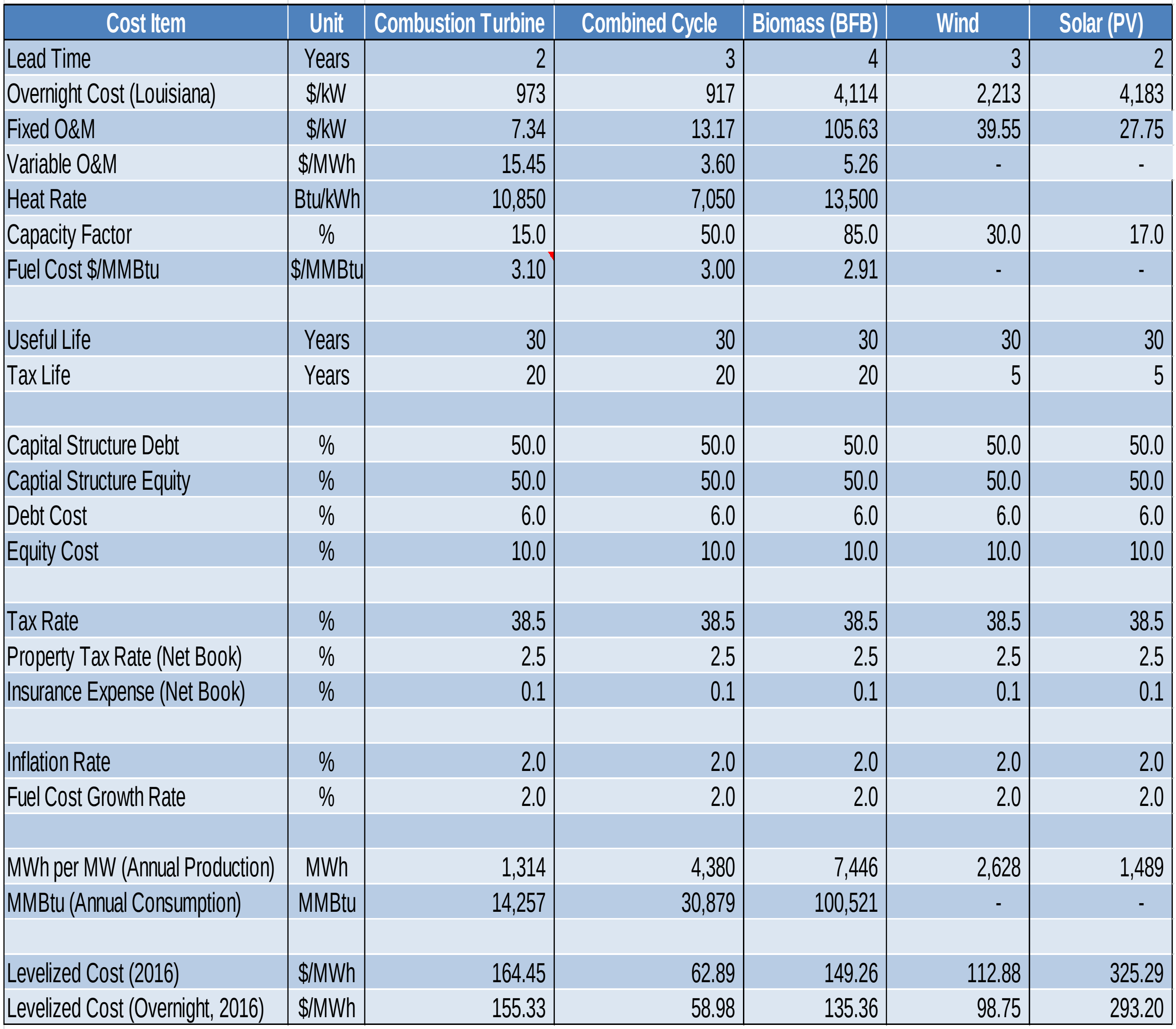
Levelized cost is often cited as a convenient summary measure of the overall competiveness of different generating technologies. Levelized cost represents the present value of the total cost of building and operating a generating asset over an assumed financial life and duty cycle, converted to equal annual payments. Overnight cost is an estimate of the cost at which a plant could be constructed assuming that the entire process from planning through completion could be accomplished in a single day and is included in the levelized cost calculation.

It is important to note that actual plant investment decisions are affected by the specific technological and regional characteristics of a project, which involve numerous considerations other than the levelized cost of competing technologies. The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity is needed, is one such factor. The existing resource mix in a region can directly affect the economic viability of a new investment based on the displacement of existing resources. A wind resource may have a lower levelized cost relative to a biomass facility, but the wind project typically provides energy during off-peak hours and outside of summer and winter seasons, while the typical biomass facility is capable of providing energy during peak hours in Summer and Winter seasons when energy demand is typically at its highest. Another consideration is the amount of capacity attributable to the technology. Intermittent technologies such as wind and solar typically have dependable capacity values that are significantly reduced when compared to dispatchable technologies.

In addition, since load must be balanced on a continuous basis, technologies whose output can be varied to follow demand generally have more value to a system than less flexible technologies or those whose operation is tied to the availability of an intermittent resource. Policy-related factors, such as investment or production tax credits for specified generation sources, can also influence investment decisions.

Error! Reference source not found. provides both the levelized cost and the assumptions used to calculate the associated levelized cost for each technology.

Table 1: Levelized Generation Assumptions and Cost



Cost Item	Unit	Combustion Turbine	Combined Cycle	Biomass (BFB)	Wind	Solar (PV)
Lead Time	Years	2	3	4	3	2
Overnight Cost (Louisiana)	$/kW	973	917	4,114	2,213	4,183
Fixed O&M	$/kW	7.34	13.17	105.63	39.55	27.75
Variable O&M	$/MWh	15.45	3.60	5.26	-	-
Heat Rate	Btu/kWh	10,850	7,050	13,500		
Capacity Factor	%	15.0	50.0	85.0	30.0	17.0
Fuel Cost $/MMBtu	$/MMBtu	3.10	3.00	2.91	-	-
Useful Life	Years	30	30	30	30	30
Tax Life	Years	20	20	20	5	5
Capital Structure Debt	%	50.0	50.0	50.0	50.0	50.0
Captial Structure Equity	%	50.0	50.0	50.0	50.0	50.0
Debt Cost	%	6.0	6.0	6.0	6.0	6.0
Equity Cost	%	10.0	10.0	10.0	10.0	10.0
Tax Rate	%	38.5	38.5	38.5	38.5	38.5
Property Tax Rate (Net Book)	%	2.5	2.5	2.5	2.5	2.5
Insurance Expense (Net Book)	%	0.1	0.1	0.1	0.1	0.1
Inflation Rate	%	2.0	2.0	2.0	2.0	2.0
Fuel Cost Growth Rate	%	2.0	2.0	2.0	2.0	2.0
MWh per MW (Annual Production)	MWh	1,314	4,380	7,446	2,628	1,489
MMBtu (Annual Consumption)	MMBtu	14,257	30,879	100,521	-	-
Levelized Cost (2016)	$/MWh	164.45	62.89	149.26	112.88	325.29
Levelized Cost (Overnight, 2016)	$/MWh	155.33	58.98	135.36	98.75	293.20

Source: http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf

Figures in 2012 dollars.

Section 9 Capital Costs

Table 1 contains the total capital investment since inception of Cleco Power's renewable projects through December 31, 2014 along with the current projection of annual operating and maintenance costs.

Table 1: Renewable projects capital cost (Millions)

Project	Capital Expenditure	Annual O&M
Biomass Gasification	$ 1.6	$ 0.1
Geothermal Project	$ 1.7	$ 0.1
Waste Methane	$ 0.5	$ 0.2
ULL Solar Thermal	$ 1.1	$ 0.2
Torrefaction	$ 0.1	$ 0.1
WalMart Solar Project	$ 1.0	
Energy Center Facility	$ 1.4	
Cleco Renewable Projects	$ 0.6	
• **Solar**		
• **Electric Vehicle**		
• **Wind**		
	$ 8.0	$ 0.7

In its income tax filings, Cleco Power has received, or is scheduled to apply for, available tax credits based on its qualified investments in renewable energy projects. Current renewable project tax credits are 30% of qualified project costs. Cleco Power also has applied for and received two grants to offset a portion of the capital costs associated with its solar projects.

Presentations and Publications

The findings of the work being conducted at the Cleco Alternative Energy Center have been presented at several meetings and conferences since 2012. In addition, manuscripts have been and are being prepared on both pilot scale and bench scale gasifiation and torrefaction research for submission to peer reviewed journals. Following is the list of relevant presentations:

1) Buchireddy, P. R., Guillory, J. L., Zappi, M. E., Russo, B., and Krump, K., "Torrefaction of Biomass as for Use as an Alternative Power Plant Feedstock as Compared to Coal", 34th Industrial Energy Technology Conference, New Orleans, LA., May 2012.
2) Buchireddy, P. R., Guillory, J. L., Zappi, M. E., Russo, B., and Krump, K., "Torrefaction for Production of New Bio-based Feedstock", VerTech Alternative Energy Conference, Crowley, LA., November 2012.
3) Guillory, J. L., Buchireddy, P. R., and Zappi, M. E., "Performance of 3ton/day Biomass Fed Bubbling Fluidized Bed Gasification System", Gasification Technologies Conference, Colorado Springs, CO, October 2013.
4) Buchireddy, P. R., Guillory, J. L., Zappi, M. E., and Vutukuri, J., "Optimization of a 3ton/Day Biomass Fed Bubbling Fluidized Bed Gasification System", American Institute of Chemical Engineers Annual Meeting, San Francisco, CA., November 2013.
5) Buchireddy, P. R., Guillory, J. L., and Zappi, M. E., "Torrefied Biomass: Superior Fuel for Co-Firing in Pulverized Coal Fired Power Generation Facilities", American Institute of Chemical Engineers Annual Meeting, San Francisco, CA., November 2013.
6) Vutukuri, J., Buchireddy, P. R., Guillory, J. L., Zappi, M. E., Bricka, M. R., and Bajpai, R., "Biomass Gasification: Effect of Sulfur Compounds On Catalytic Tar Removal Activity Using Nickel-Clay Catalysts", American Institute of Chemical Engineers Annual Meeting, San Francisco, CA., November 2013.
7) Buchireddy, P. R., Bricka, R. M., Guillory, J. L., and Zappi, M. E., "Biomass Gasification: Catalytic removal of tars using Nickel supported Clays", Manuscript Submitted to Energy and Fuels
8) Guillory, J. L., Buchireddy, P. R., and Zappi, M. E., Russo, B., and Krump, K., "Thermochemical Conversion Options for Waste Wood", Vertech Symposium, Victoriaville, Qubec, Canada, November 2014.
9) Vutukuri, J. R., "Biomass Gasification: Effect of H_2S in catalytic tar removal from the biomass-derived syngas using Nickel-Montmorillonite catalyst", Thesis, University of Louisiana at Lafayette, December 2014. [Copy available upon request]