VERMONT TECH

COMMUNITY ANAEROBIC DIGESTER

Powered by students and driving practical education

Final Report for the U.S. Department of Energy

This project was formerly known as the Central Vermont Recovered Biomass Facility.

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APPENDICES

VERMONT ACRONYMS

ANR	–	Vermont Agency of Natural Resources
AQCD	–	Air Quality and Climate Division
CEDF	–	Clean Energy Development Fund
CVRBF	–	Central Vermont Recovered Biomass Facility
CVSWMD	–	Central Vermont Solid Waste Management District
PSB	–	Public Service Board
RESET	–	Renewable Energy Standard and Energy Transformation
SPEED	–	Sustainably Priced Energy for Economic Development
VAAFM	–	Vermont Agency of Agriculture, Food and Markets
WLEB	–	Working Lands Enterprise Board

VERMONT TECH

www.vtc.edu/meet-vtc/anaerobic-digester

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EXECUTIVE SUMMARY

The ***Vermont Tech Community Anaerobic Digester*** (VTCAD) was conceived and funded by a partnership of educational, agricultural, waste management and environmental groups to create a living laboratory demonstrating the value of recycling nutrients, renewable energy and agricultural co-products from organic wastes. VTCAD was constructed on the Randolph Center, Vermont campus of Vermont Tech, a public college offering engineering technology, agricultural, renewable energy education and workforce training. With funding from the U.S. Department of Energy (DOE), the Vermont State Colleges and others, construction was completed in early 2014 and the facility has been operational since April 2014. At full power, VTCAD uses 16,000 gallons of manure and organic residuals to produce 8,880 kilowatt hours (kWh) of electricity per day, 'waste' heat that will be used to heat four campus buildings, bedding material for the college dairy herds and recycled nutrients used as crop fertilizer. VTCAD uses a mixture of manure from co-managed farms and organic residuals collected from the community. Feedstock materials include brewery residuals, the glycerol by-product of biodiesel production from waste cooking oil, grease trap waste, and waste paper and, soon, locally collected pre- and post-consumer food residuals.

Groundbreaking at Vermont Technical College for VTCAD, with Vermont Governor Peter Shumlin (sixth from left), representatives from Senator Leahy's office, and various state and state college officials present.

At full power, VTCAD uses 16,000 gallons of manure and organic residuals to produce 8,880 kWh of electricity per day, 'waste' heat that will be used to heat four campus buildings, bedding material for the college dairy herds and recycled nutrients used as crop fertilizer.

Permitting of construction and operational phases of the project was complex, time consuming and required legal assistance. **VTCAD is the first anaerobic digester in Vermont to go through the permitting process to accept food waste.** Permitting of AD is new and still evolving, but has resulted in improved communication between the many state permitting agencies involved. Several new pieces of legislation changed and improved the permitting process during the development and implementation of VTCAD.

Laying the foundations for the VTCAD in August 2013.

Bio-Methatech, a design-build firm from Quèbec, designed and constructed VTCAD using a licensed German design. Unfortunately, Bio-Methatech was dissolved near the end of construction and while construction continued at a much slowed pace, lack of support negatively impacted completion of the project, start-up and operations.

This report describes the construction, initial start-up, and first year of operation of VTCAD, through June 2015. Information regarding additional years of operation will be provided on the college website." VTCAD reached full operation, powering the generating engine without stop, in late March and early April of 2014. Operations have been reduced while mechanical and operational issues were resolved, but the facility operated at just over half-maximal power during its first year of operation. Successful diets have been created that combine manure and a variety of off-college organic residuals. Vermont Tech faculty has worked with waste generators to increase the digestability and value of some waste streams. The addition of ferric chloride has been used to control levels of hydrogen sulfide in biogas and reduce corrosion of piping and the generating engine. Operational data are presented in more detail in this report and will be publically available on the college website.

Collaboration with project partners, local farmers and businesses, feedstock generators and haulers, and public officials and regulators has been critical in both the feasibility and implementation phases of this project. Over the next several years we will pull together a community of organizations (e.g., haulers, waste generators, composters, regulators, and so on) that collects their organic residuals in a manner that allows them to be harvested and recycled, and a community of farms that benefits from the nutrients produced.

The college has developed an anaerobic digester apprentice-training program that combines hands-on experience at VTCAD with classroom education, and will offer a 3-credit Bioenergy course to Renewable Energy and Agriculture students in fall 2015. Over one hundred tours of VTCAD have been given so far during construction and following completion, and we expect this wonderful public participation to continue. Students in many of the college's engineering technology and agricultural programs have used the design, permitting, construction, and operations of VTCAD in laboratory coursework and homework assignments.

With the addition of VTCAD, the number of AD projects in Vermont has grown to 19, and groups are planning to build similar sophisticated AD facilities, fueled in part by food residuals, in Massachusetts, Brattleboro Vermont and along the shores of Lake Champlain. There is an interest in using AD to help manage the wave of organics that will be diverted from landfills by 2020 because of Vermont's new ***Universal Recycling Law***. Expansion of AD facilities like VTCAD will also help Vermont meet its ambitious goal of 90% renewable energy by 2050. The operational, economic, permitting and research data collected and made public via VTCAD and Vermont Tech will boost these statewide efforts and help support agriculture in our rural state.

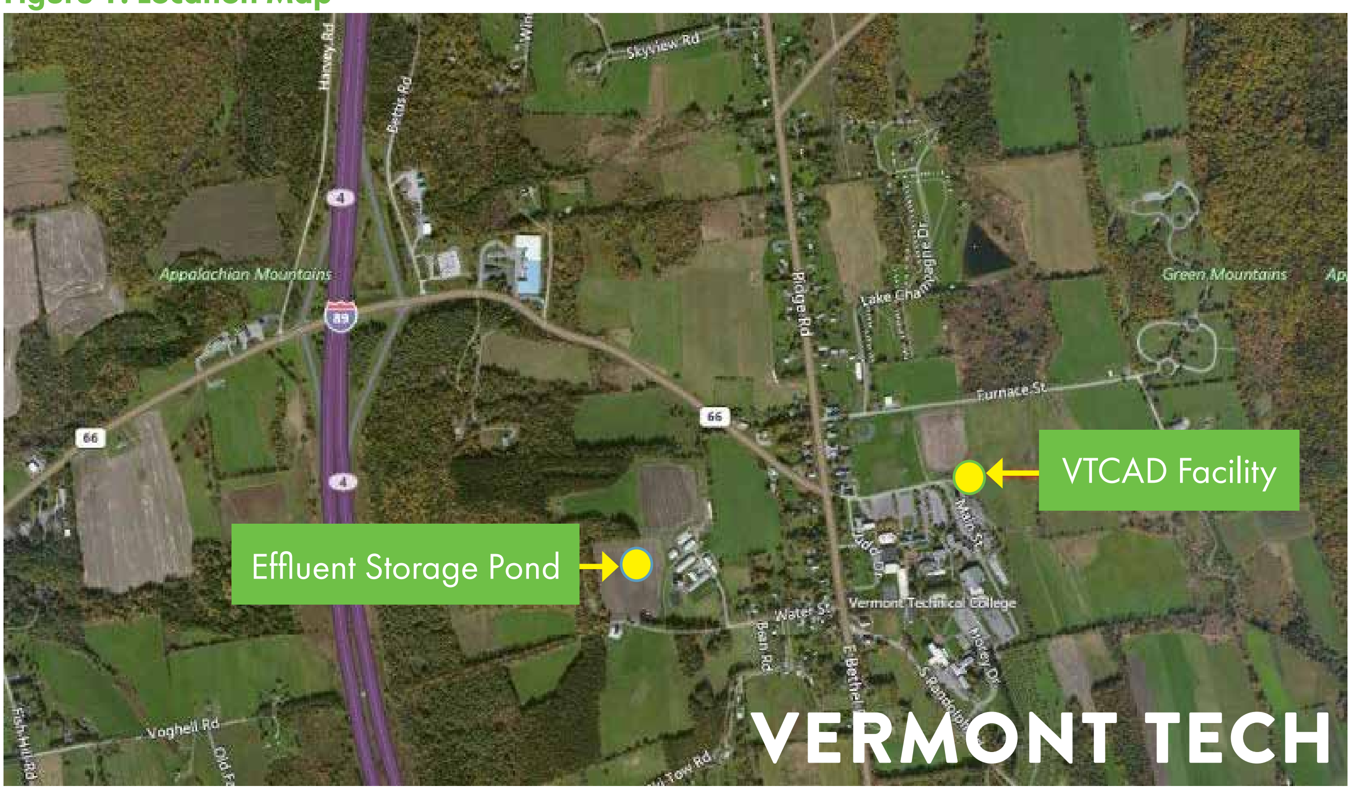
Concrete wall for the liquid effluent tank were built in the last week August 2013.

INTRODUCTION

The Vermont Tech Community Anaerobic Digester (VTCAD) was envisioned as a living laboratory, with the added benefit of adding to Vermont's renewable energy infrastructure and as a means of advancing organics management. The project was conceived of by an innovative partnership between an environmental consortium, a solid waste management district and a technical college who were supported by United States Senator Patrick Leahy and an organization with expertise in grants administration and project execution. The partnership sought to expand the role and scope of anaerobic digestion (AD) in Vermont by creating a working demonstration project that converted a mixture of manure and clean food waste to renewable electricity for the grid, heat for the college, and recycled nutrients for agriculture.

Vermont Tech is one of the five Vermont State Colleges and is the state's only institution of higher education focused on technical education. Applied learning is more than a buzzword at Vermont Tech, real-world involvement is part of every class. In addition to holding advanced degrees, most of the faculty have business or industrial experience and all degrees involve hands-on opportunities to apply the practical knowledge learned in classes and laboratories. Vermont Tech offers certificates and degrees that have relevance in today's economy, as demonstrated by continued high job placement rate for graduates (e.g., the job placement rate was 96 percent for the graduating class of 2014). VTCAD allows Vermont Tech to provide another living laboratory, a unique combination of theoretical education and practical skills.

Figure 1: Location Map



Vermont Tech's Community Anaerobic Digester Facility (VTCAD) is located at our Randolph campus, as shown above. The Randolph campus is located off Route 66 in Randolph Center, VT, east of Interstate I-89 Exit 4.

The college, formerly known as the Vermont School of Agriculture, has its main campus in Randolph Center, and much of the 550 acres are dedicated to a dairy and diversified farm operation operated by dairy farm management and diversified agriculture students. The college offers numerous degrees in engineering technology, including a degree in renewable energy, and has installed other renewable energy projects across the campus: wood and biodiesel are used to heat two building, solar thermal provides hot water at the dairy barn, and two grid-tied solar photovoltaic arrays will soon be expanded by construction of a 500 kilowatt (kW) solar installation. VTCAD is an important addition to the campus's agricultural and renewable energy infrastructure and is a focus of educational programs. Members of Vermont Tech's faculty have been part of the VTCAD Team from the feasibility stage through construction and operation, and classes have visited the project and utilized aspects of its technology for laboratory experiments, homework assignments, and team projects.

Vermont Tech has developed and implemented an anaerobic digester operator-training course, combining daily work at VTCAD with classroom time, which can be taken as a three to four month-long apprenticeship. The program provides our state and region with a corps of trained anaerobic digester operators who understand theory, practice, regulations, compliance and economics, and the integration of mixed substrate AD with farming. Much of this material is also embedded in a new 3-credit Bioenergy course offered to students in the college's renewable energy and agriculture programs. Curriculum for the training course, along with VTCAD technical information and data can be found at www.vtc.edu/meet-vtc/anaerobic-digester.

Concrete is poured for the three feedstock tanks.

Anaerobic digestion tank is wrapped with Pex tubing to insulate in September 2013.

Anaerobic digestion tank and hydrolysis tank under construction.

If replicated across the state, similar AD projects would be make an important contribution to helping Vermont reach its ambitious goals of 90% renewable energy by 2050, diverting organic waste from landfills, preventing the flow of excess nutrients to Lake Champlain, and supporting agriculture and increasing local food production. **The 'plate to farm' aspect of VTCAD complements Vermont's very successful 'farm to plate' movement.**

All data generated at VTCAD—inputs, biochemistry, energy and co-product outputs, and economic —will be made publically available via a website and is routinely shared with regulators. This has already had an impact as new regulatory processes have been created or altered, and other Vermont institutions have requested VTCAD data to assist in the development of new AD projects.

A not insignificant benefit of VTCAD is that revenue from the electricity produced and transfer of captured waste heat to the college's central heating plant will help to hold down the college's operating costs and tuition. In a time of financial challenges for institutions of higher learning in general and the Vermont State Colleges in particular, the ability to manage operating costs while providing relevant educational experiences is critical to the continued existence of our technical programs.

As of June 2015, VTCAD has been operational for less than one year and we are still working through commissioning issues. However, we have produced full power (~8,000-9,000 kWh per day) and have used a number of co-substrates including garden wastes, spoiled dairy feed and silage, brewery waste and yeast sludge from Vermont's finest craft brewers, restaurant grease trap waste and the glycerol by-product from biodiesel production from waste oil. Our application for solid waste certification has been positively reviewed and while the process has been delayed while the concerns of a neighbor are examined, final approval was received in December 2015. With the permit, food waste can be added to our feedstock mixture. Per an existing agreement, the amount of food waste cannot exceed 49% and we will ramp up slowly to allow the microbes to adapt.

Brewery waste from The Alchemist (Waterbury) is delivered by Grow Compost (Moretown) to the prep pit.

ACCOMPLISHMENTS:

Summary

As of June 2015 we have accomplished the vast majority of our original project goals. To date, we have:

- Constructed the AD plant, now operational;
- Received a 20-year contract for electricity through Vermont's SPEED program with locked-in rates ($0.1359/kWh to 0.1503/kWh);
- Reached full power, 100% operation at roughly 8,880 kWh/day, though we are not yet operating at full power routinely;
- Implemented a protocol for controlling hydrogen sulfide levels in the biogas;
- Created a transportation system to haul manure from sending farms and effluent to fields or a holding pond;
- Developed a successful feedstock mixture of manure and food processing residuals;
- Replaced dairy herd bedding with VTCAD's separated solids co-product;
- Developed a comprehensive community nutrient management plan;
- Developed curricula for workforce training and for college credit. Our third pair of anaerobic digester operator apprentices started our workforce training program in May 2015. The first course for college credit will be offered in fall 2015, as part of the college's Renewable Energy degree program;
- Collected feedstock, power, operational and nutrient management data and are developing an Microsoft Access database that will allow us to query and share data;
- Formed a partnership with a central Vermont composter to collect and deliver a clean supply of food waste to the project;
- Received a small grant from Vermont's Clean Energy Development Fund to study the effects of food waste on AD power output, co-product characteristics and microbiology;
- Given at least 100 tours of the project and a number of presentations at meetings of Renewable Energy Vermont and the Vermont Environmental Consortium; and
- Submitted the application for our final permit, a Solid Waste Certification that would allow us to accept more than the 1% food residuals we can accept now as feedstock.

Two significant items are still on our to-do list.

- We have not yet added food waste to our feedstock, but will be doing so before the end of this year. Our solid waste permit has been positively reviewed and was issued in December 2015.
- We have not completed the heat transfer loop that will move waste heat from VTCAD to the campus heating plant for transfer to four campus buildings. Financing has been secured and plans are being reviewed.

Feasibility Phase: Overview

The complete project feasibility report, produced for the U.S. DOE, is referenced here and may be downloaded at ***www.richmond-hall.weebly.com/d-reports--presentations.html***. Please note that VTCAD was referred to as CVBRF during its feasibility phase.

The Central Vermont Recovered Biomass Facility (CVRBF) feasibility study was a joint project of the ***Central Vermont Solid Waste Management District*** (CVSWMD), ***Vermont Environmental Consortium***, the ***Vermont Sustainable Jobs Fund***, and ***Vermont Technical College***. CVSWMD had developed an innovative food waste collection program to supply compost producers and wanted to expand their collection routes. They believed that an anaerobic digestion system, similar to those used in Europe, could accept food waste, produce renewable energy and recycle nutrients. Vermont Tech has a long history of agricultural and technical educational and a working dairy farm and provided an ideal location for the proposed anaerobic digestion (AD) facility. Funding for the feasibility study was provided by the ***Kresge Foundation***, the ***Seventh Generation Fund***, the ***Vermont Agency of Agriculture, Food and Markets***, the ***Clean Energy Development Fund***, and the ***U.S. Department of Energy*** and was facilitated by the patient and enthusiastic support of U.S. Senator Patrick Leahy.

The feasibility study had three goals:

- AD facility feasibility & design;
- Food waste processing feasibility study; and
- Education and outreach.

The AD feasibility study conducted by Vermont Tech concluded that implementation of a sophisticated mixed feedstock AD facility at the college was technically and economically feasible, and could be powered by a mixture of dairy manure and local organic residuals, largely food waste. The recommended design was a two-phase, continuous, stirred tank facility with a biogas-fired electric generator that could produce nearly 2 million kWh and displace 11,000 gallons of heating oil annually, while also recycling nutrients and bedding for agriculture.

During the feasibility phase, $4.17 million of funding for the implementation phase (permitting and construction of the AD facility) was secured from two sources: $1,451,500 million from the U.S. Department of Energy and at least $2,718,409 in cost share from Vermont Tech, which was funded through a bond from the Vermont State College System. Funding for the feasibility phase itself was $492,000 from the U.S. Department of Energy and at least $114,000 in cost share from Vermont Tech.

FOOD WASTE AVAILABILITY AND COLLECTION

Studies conducted by consultants hired by CVSWMD found that sufficient clean food waste for the anaerobic digester project could be collected in Central Vermont, though the collection area would have to expand beyond CVSWMD's 2007 organics collection routes. The study did suggest that increasing capture rates and collection areas would be challenging. When the feasibility report was submitted in 2010-11 there was no legislation that mandated or encouraged organics recycling in Vermont, and the economics of recycling were tenuous.

Stone Environmental Inc., a local environmental consulting firm, mapped Vermont's "food waste shed" and found that approximately six facilities like ours could be built around the state, and that Burlington could host a facility twice the size of ours.

In 2010 Randolph generated 936 tons of food waste annually, or 2.5 tons per day. This volume may have increased slightly due to establishment of several food processors since then, but it demonstrates that even Vermont's mid-sized towns don't produce enough food waste to supply an anaerobic digester dependent on food waste alone. We concluded that a community AD model is most appropriate for Vermont, because the relatively small volumes of food waste available in each town or collection region (food waste shed) could be combined with manure from several farm operations. The combined volume organic waste would be sufficient to allow construction of a mixed-feedstock AD facility that would truly serve the community. VTCAD can accept no more than 49% food waste equivalent to 7,762 gallons of food waste per day. However, based on feedstock and power production data collected during 2014 to 2015 we believe that 13 tons of food waste (just over 3,000 gallons) could substitute for our current high-energy feedstock, glycerol, and allow us to operate at 100% of capacity.

The feasibility study found that a number of factors limited the facile collection of organic waste in Vermont:

1) the low density of food waste generators in rural Vermont and the long distance of collection routes;
2) low participation of generators in clean stream food waste collection systems;
3) economic viability of clean stream food waste (i.e., food waste that is collected independently of any non-biodegradable materials;
4) the small number of organics haulers; and
5) the reluctance of solid waste haulers to create clean stream organics collection which may not be profitable.

CVSMWD hired two consultants to look at the logistics and economics of creating an expanded food waste collection system in central Vermont. In summary they concluded that CVSWMD would have to greatly expand food waste collection (400% or to 40% of generators), increase the price of collection to generators and hire new personnel in order to supply the VTCAD project (Highfields Center for Composting (2010); Sleeping Lion Associates (2010)). The remaining project partners issued an RFP for a food waste collection system to supply the project with feedstock but did not receive any responses to that RFP. We note that this work was done prior to the passage of Vermont's Universal Recycling Law in 2012; the law bans the landfilling of organics by 2020.

A CENTRAL FOOD WASTE COLLECTION FACILITY?

CVSWMD had planned to issue RFPs for a feasibility study of a central food waste processing facility. However, while inquiries were made and RFP's were written, the studies were not conducted. In the aftermath of the 2007 – 2008 national financial crisis, CVSWMD's membership and leadership changed, the organization's plans to expand organics collection were put on hold, and CVSWMD withdrew from the AD project. In retrospect, a central collection facility could increase handling of food waste and thus costs, could increase the distance over which material is transported and thus increase greenhouse gas emissions, and might reduce energy level and introduce pathogens by impeding fresh delivery.

A SHIFTING REGULATORY LANDSCAPE FOR AD IN VERMONT

In 2010, the regulatory hurdles to more widespread development of AD in Vermont included:

- Lack of incentives for the production and use of renewably produced heat;
- Lack of clarity about the types of permits required to accept food waste as AD feedstock;
- Ambiguity about the necessity of pasteurizing food waste prior to anaerobic digestion;
- No specific regulations governing land application of digester effluent as a soil amendment;
- Ambiguity concerning a farm's ability to sell separated solids if food waste feedstock included beef as the prions that cause bovine spongiform encephalopathy ('mad cow disease') are not inactivated by pasteurization; and
- Lack of incentives for capture and mitigation of methane (or other greenhouse gases) and for recycling of waste nutrients back into the agricultural production cycle.

Between VTCAD's feasibility (2007 – 2010) and implementation phases (2012 – 2015) attitudes and regulations concerning organic residuals, renewable energy and nutrient recycling have shifted dramatically (for details, see page 14 of the Permitting section under Implementation Phase). The general public is more aware of the benefits of organic recycling and renewable energy, new regulations have gone into effect forcing the beneficial use of organic residuals, and while there is still some fear of implications of re-using food wastes, the idea is now more acceptable than it once was to many people. We believe the development of VTCAD has contributed to the evolution of AD regulations in Vermont.

APPROPRIATE AD TECHNOLOGY?

The feasibility study considered a number of AD technologies and designs including plug-flow (the most common type of on-farm, manure-only AD technology), sequencing batch, single-phase complete mix and two-phase complete mix technologies. The study, and designs submitted by the four firms responding to our RFP, determined that a two-phase, complete mix AD was the most flexible technology, while also being efficient and able to accommodate mixtures of a wide variety of feedstock materials. VTCAD is an example of this type of AD technology which has been widely used in Europe for over 35 years. Liquid feedstock storage tanks for storage and gradual feeding of food processing residuals, a grinder/pulper and a large Pasteurizer for pre-and post-consumer food waste, and a preparation pit for mixing a slowly changing but biochemically consistent diet were added because anaerobic digestion of organic residuals was the primary goal of VTCAD, and because it was not clear whether or not Pasteurization of food residuals would be required by Vermont regulators. Mesophilic operating temperature (30-35°C) was chosen because it is more stable than thermophilic operating temperatures (50-52°C). Production of electricity and capture of 'waste' heat (i.e., combined heat and power) was the most efficient use of biogas, given the economic conditions in Vermont. Capture and use of waste heat sets VTCAD apart from other Vermont AD projects, and demonstrates how use of waste heat – particularly from renewable energy installations – can contribute to the economic viability of AD and to shrinking Vermont's greenhouse gas footprint.

OUTREACH

Vermont Tech completed a significant amount of public outreach during all phases of the project. The college had a naming contest for the digester; "Big Bertha" was the winning entry, although that is often shortened to "Big B." Big B has a webpage: www.vtc.edu/meet-vtc/anaerobic-digester and updates and events are 'tweeted' on the college's twitter page. Feasibility, construction, and operational activities were designed to reach several key constituencies as well as the general public. A list of events, news articles, and publications can be found on page 42. Outreach to the public included:

- Taking two community leaders to visit Europe to observe and understand the digester industry via funds donated by faculty;
- A Vermont Tech-sponsored bus trip to Montreal, Canada for local community members to show them digesters in operation during VTCAD's feasibility phase;
- Press articles, commentaries, notices, and releases about VTCAD and the project's progress;
- Personal communications;
- Project information provided as part of survey questionnaires;
- Presentations at conferences;
- Presentations to stakeholder groups such as boards, regulators, trade and environmental organizations, and planning commissions;
- Breakfasts & meetings with local farmers to discuss the application of digester effluent on their fields;
- Numerous tours for state regulators including Agency of Natural Resources and Agency of Agriculture, Food and Markets during VTCAD's construction phase;
- Numerous tours for state and regional organizations including the Vermont Organics Recycling Summit (VORS), Vermont Farm to Plate, Women Can Do, and VT Law School, and Water Quality Conferences organized by Vermont Environmental Consortium;
- Open House for the public during construction, initially the 2nd Thursday of every month then approximately every other month;

- BigB Newsletters; and
- A dedicated VTCAD website: **www.vtc.edu/meet-vtc/anaerobic-digester**

The VTCAD project team and the college also consistently communicated with a variety of stakeholder groups whose good will and assistance helped with project completion and operation.

- Boards and administrators of solid waste management districts
- Regional commission planners and administrators
- Administrators and personnel at the Vermont Agency of Agriculture, Food and Markets and the Vermont Agency of Natural Resources;
- Area farmers
- Municipal administrators
- Renewable energy organizations and professionals
- Educators
- Environmental industry entrepreneurs
- Administrators of organizations active in rural development, community sustainability, farm viability, resource conservation, etc.
- Composting industry professionals

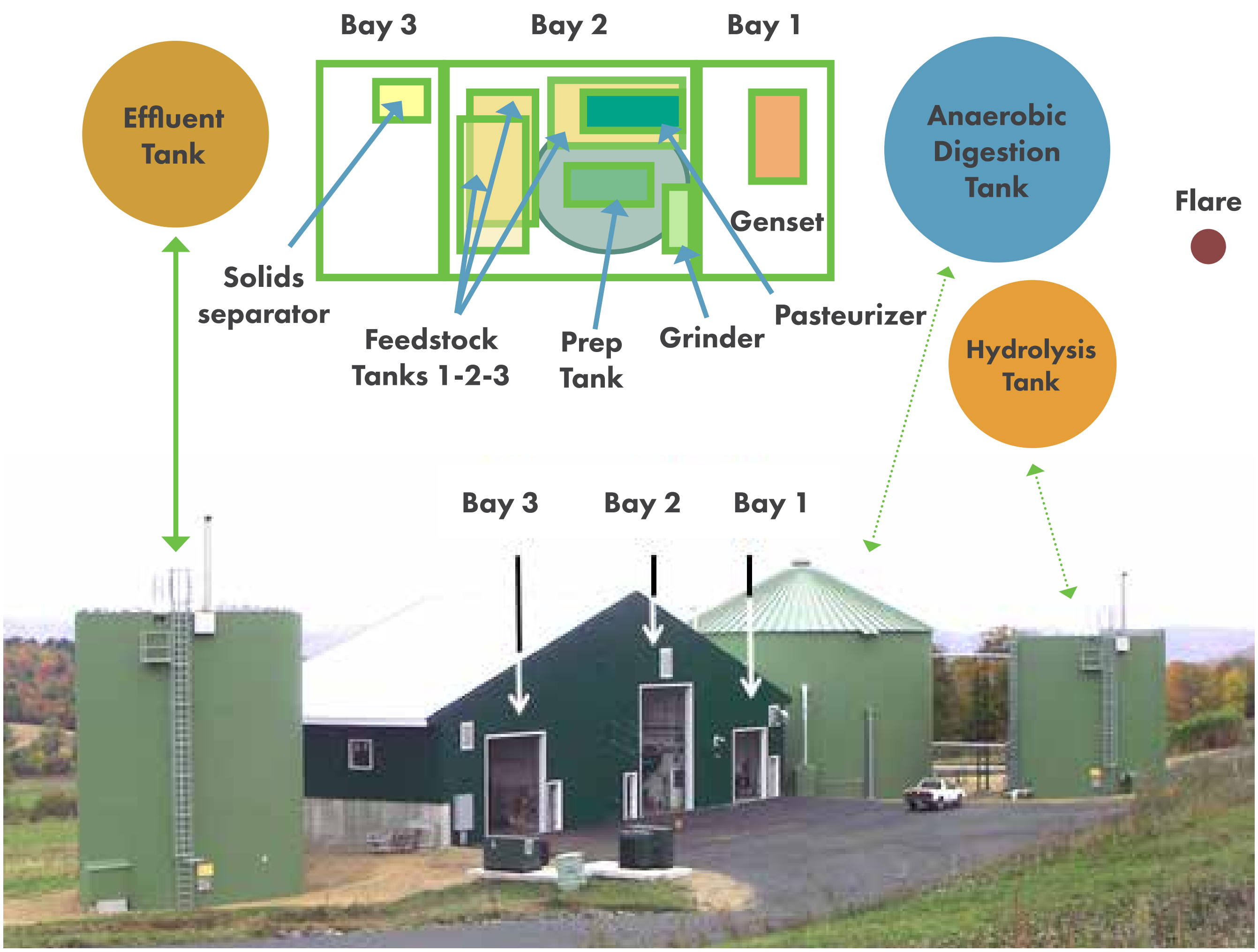
Implementation phase

DESIGN

Bio-Methatech of Québec designed and constructed the VTCAD facility through a design-build contract, using a complete mix technology and design developed by ***Lipp of Germany***. Over 700 Lipp systems have been installed in Europe, and the oldest working facility is now over 30 years old. Lipp systems use Verinox, a duplex steel material: stainless on the inside and galvanized on the outside. Tanks are constructed by spinning bands of this steel into a continuous cylinder. The development of Verinox and the Lipp Dual-Seam System have been recognized by award of the prestigious Rudolph Diesel medal in 1982, the Dr. Rudolf Eberle Award in 2005, and the Steel Innovation Award for Germany in 2006.

Bio-Methatech, a component company of the Canadian firm Dominion & Grimm, subcontracted to local firms for site work design, stormwater, control systems, heat system design, and for much of the construction. The benefit of the design-build approach is that changes can be made quickly as site and project constraints are identified. The disadvantage is that because design and construction changes are made 'on the spot' or very quickly, the full implications of some changes are not apparent until later when another aspect of the project is impacted. In this project, the disadvantage of the design-build process often caused multiple construction changes to the same project component as the project advanced. A description of VTCAD technical design is provided on the VTCAD website and provided in Appendix A.

Figure 2: VTCAD Schematic



During construction of VTCAD, Bio-Methatech underwent significant management changes and ultimately dissolved, emerging, in part, as Biogaz Lipp, a new component of Dominion & Grimm. This process caused significant delays and negatively impacted construction and operations. Vermont Tech has obtained service contracts through the manufacturers for some individual components such as the flare and generating engine (genset). We have limited access to the original Bio-Methatech project personnel through Dominion & Grimm, and discussions continue regarding warranties and the long-term support we had been promised. Limited support regarding biochemistry and feedstock issues, hydrogen sulfide levels, and testing and adjustment of some mechanical systems is still impacting operations. While Vermont has expertise in manure digestion, experience with the operation of complex plants with a wide variety of feedstock materials is limited here and in our region. We will be looking for operational advice and expertise from the handful of co-digestion facilities in the U.S. and in the European AD community.

VTCAD also includes a 3-million gallon effluent storage pond, capable of holding 180 days of effluent produced at full operation. This storage is needed over the winter months when effluent cannot be field applied. The effluent pond is located at the Vermont Tech Farm, adjacent to the Randolph campus. Small manure receptor pits were built at the supplying farms to allow for daily pumping and delivery of manure to VTCAD.

PERMITTING

Regulatory changes from conception through implementation and operation

Since VTCAD project partners began their work in 2007, the regulatory landscape of Vermont has shifted, particularly for renewable energy, organic wastes, and farm operations. Those changes are summarized here.

▶ RENEWABLE ENERGY

Vermont's Comprehensive Energy Plan calls for the shift to 90% renewable energy by 2050. VTCAD has a 20-year contract for electricity via *Vermont's Sustainably Priced Energy Enterprise Development program (SPEED)*. In 2010, SPEED was offering a price of $0.16 per kilowatt-hour for electricity produced by on-farm anaerobic digestion. That price was later lowered to $0.14 per kilowatt-hour after existing Cow Power farm digesters were grandfathered into the program. While AD projects are allowed to keep and sell renewable energy credits (RECs), the market for Vermont RECs is limited due to concerns about 'double dipping;' the sale of renewable energy and associated RECs to different customers.

The SPEED program defines on-farm AD as facilities using at least 51% on-farm feedstock. On-farm AD is paid $0.01368/kWh. Biomass AD facilities may use more than 49% off-farm feedstock, and are now compensated at a rate of up to $0.21/kWh. This is a challenge to the future success of on-farm AD. While we are committed to supporting farming in Vermont, our facility required the significant fiscal investment that the higher rate is intended to support.

In their 2015 session, the Vermont legislature voted to replace Vermont's renewable energy feed-in tariff (the SPEED program) with a renewable energy portfolio standard—*H.40 (Act 56)*—Renewable Energy Standard and Energy Transformation (RESET)—with more aggressive goals (*Herrick, 2015*). RESET is similar to renewable energy policy in the other New England states and will allow Vermont's renewable energy producers to expand regional sales of renewable energy credits (RECs).

▶ NEW COOPERATION AND CLARITY CONCERNING REGULATION OF ORGANIC RESIDUALS

In recent years, the water quality problems in Lake Champlain have resulted in increased and improved communication and coordination between *Vermont's Agency of Natural Resources* (ANR) and *Agency of Agriculture, Food and Markets (VAAFM)*. It appears that this communication will facilitate more effective regulation of organic residuals and nutrients, including regulation of anaerobic digestion and other forms of organic recycling. In Vermont, facilities producing electricity must receive a

Certificate of Public Good (Act 248) from Vermont's Public Service Board (PSB). In July of 2012, the legislature passed Act 88, clearly delineating the PSB's regulatory authority: the PSB will continue to regulate electric generation, but regulation of feedstock, nutrient recycling and agricultural issues is the purview of the Agency of Natural Resources and Agency of Agriculture, Food and Markets.

REGULATION OF AD USING FOOD WASTE AS FEEDSTOCK

During the development of VTCAD, Vermont's ANR released a set of ***solid waste regulations*** that included some specific guidelines for anaerobic digesters accepting non-farm organic residuals that the agency classifies as solid waste . We are encouraged by recent regulatory changes and we anticipate more changes as the Universal Recycling Law is implemented. However, we note that ANR distinguishes between composting and anaerobic digestion, and that the agency appears to be more comfortable with composting. While composting and anaerobic digestion use the same organic residuals as feedstock, the agency maintains a web site devoted to composting. This may be a matter of experience rather than intent; Vermont has an active composting advocacy group—***Composting Association of Vermont***—but no similar group promoting AD. Further, composters do not have to report the fate of nutrients produced through composting, while anaerobic digesters are required to do so via nutrient management planning.

REGULATION OF AD EFFLUENT AS A FIELD AMENDMENT

Vermont ANR's Wastewater Division no longer requires farmers to comply with the 1999 rules for 'land application of dairy waste' when using AD effluent as a field amendment. Instead, they consider AD effluent to be manure, regulated by conventional comprehensive nutrient management planning. The Wastewater Division of the Agency of Natural Resources (ANR) now works with the Vermont Agency of Agriculture, Food and Markets (VAAFM) to ensure that organizations operating with mandated nutrient management plans (i.e., all on-farm AD facilities) have the capacity to accept nutrients before approving that facility as a destination for organic residuals on indirect discharge permits issued to generators the organic residuals (e.g., breweries, cheese producers, dairy processors).

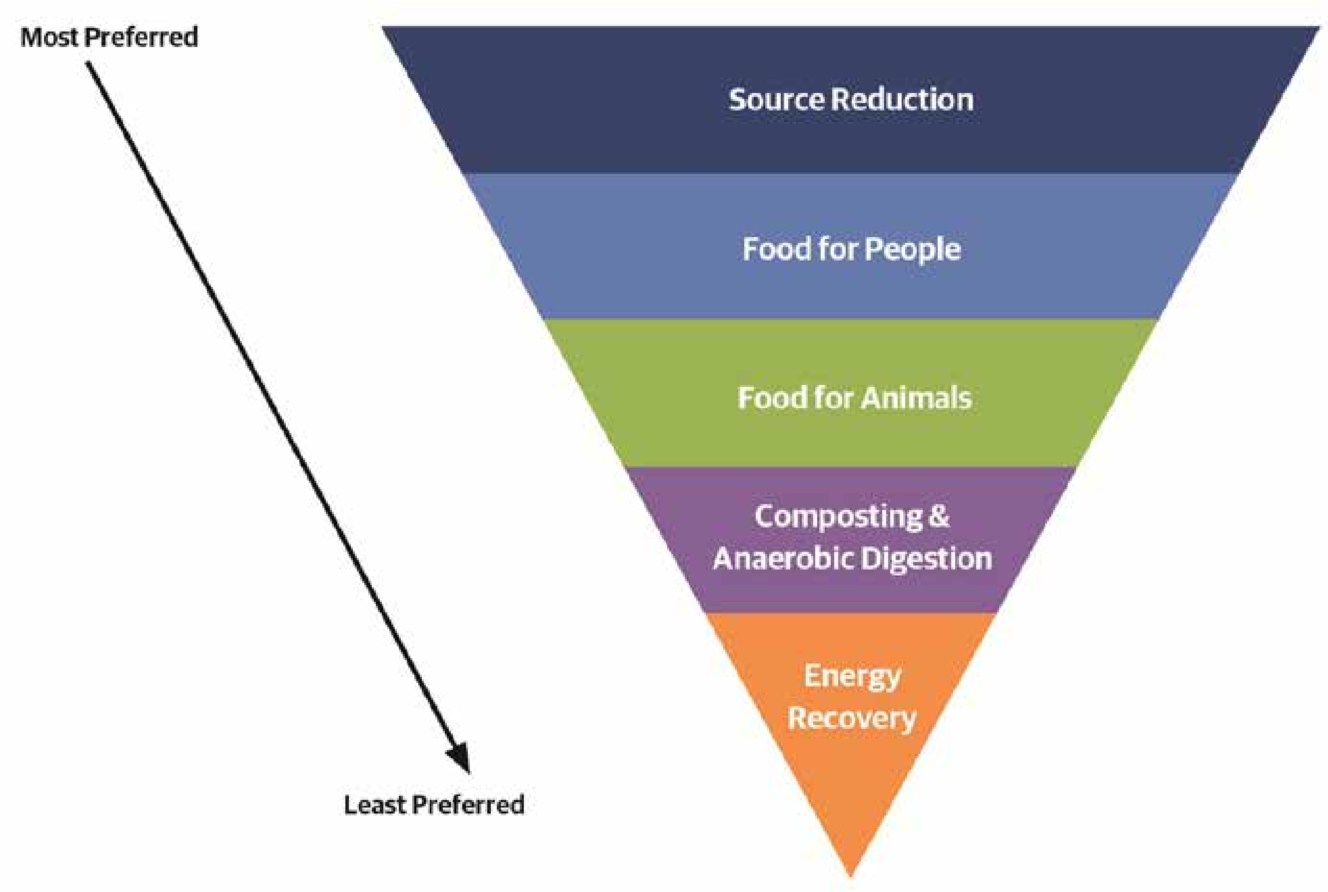
REMAINING REGULATORY AMBIGUITY

Some regulatory ambiguities remain. VAAFM advocates for pasteurization of food waste prior to use as AD feedstock, and they discourage sale of AD-separated solids as dairy bedding to other farms if AD feedstock contains any beef. VAAFM has expressed concern that the beef could contain the prion that causes bovine spongiform encephalopathy (aka 'mad cow disease'). The prion cannot be inactivated by pasteurization, and dairy cows occasionally ingest bedding and might thus contract the disease. However, neither recommendation exists in writing, and composting also does not make the prion inactive. Since AD regulation is still in its nascent stages, AD developers may be taking a risk if they do not install expensive pasteurization equipment and rely on income from the sales of separated solids to other dairies. We note that ANR is actively re-writing composting regulations as well.

VERMONT'S UNIVERSAL RECYCLING LAW

In July of 2012, the Vermont Legislature passed Act 148, now known as the Universal Recycling Law, that bans landfilling of recyclables (metal, glass, some plastics and paper/cardboard) by July 1, 2015; leaf and yard debris and clean wood by July 1, 2016; and food scraps by July 1, 2020. It also requires solid waste haulers and facilities to collect these same materials. VTCAD was planned and designed prior to passage of this law, though with the same intent. However, in part because of VTCAD, anaerobic digestion is increasingly seen as a productive and beneficial means of organics management that can help Vermont comply with the new law.

Figure 3: Act 148 Diversion Hierarchy



Permits required for construction and operation of VTCAD

Although farm-based anaerobic digestion has been expanding in Vermont over the last decade, anaerobic digesters that operate in non-farm settings, or with non-farm based feedstock, are relatively new and regulations are being developed now for these projects. This meant that planning and implementation of VTCAD occurred in a volatile and uncertain regulatory atmosphere, resulting in an added challenge for feedstock and effluent management and delivery, construction choices, and operational parameters. At this point, regulation of AD is complex and still evolving: aspects of anaerobic digestion (and VTCAD) are regulated and administrated through the Public Service Board, numerous divisions within the Agency of Natural Resources, the Agency of Agriculture Food, and Markets, and the Natural Resource Conservation Service. The permits required for construction and operation of VTCAD, their purpose, and the agencies involved are listed here.

▶ CERTIFICATION OF PUBLIC GOOD (CPG) FROM THE VERMONT PUBLIC SERVICE BOARD (PSB)

The Vermont PSB is a quasi-judicial board that supervises the rates, quality of service, and overall financial management of Vermont's public utilities including cable television, electric, gas, and telecommunications. VTCAD received a CPG in April 2013 after a lengthy permit process. At the time, the Public Service Board had jurisdiction over all facility aspects including feedstock, transportation, and effluent distribution. In 2013, soon after VTCAD was permitted, Vermont passed Act 88, which limited the jurisdiction of the PSB over anaerobic digesters to the biogas and electrical generating components, including buildings, equipment and interconnection to the grid. This limitation was also applied retroactively to projects like VTCAD that had already been permitted.

▶ NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) THROUGH U.S. DEPARTMENT OF ENERGY

NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions. Using the NEPA process, agencies evaluate the environmental and related social and economic effects of their proposed actions and provide opportunities for public review and comment on those evaluations. The agency carrying out the federal action is responsible for complying with the requirements of NEPA, in this instance the Department of Energy. There are three types of review under NEPA: categorical exclusions (CX), environmental assessments (EA), and environmental impact statements (EIS). CX refers to a category of actions which do not individually or cumulatively have a significant effect on the human environment and do not require an EA or EIS. VTCAD qualified as a CX under Category B5.20 Biomass power plants and was approved in October 2013.

▶ CONSTRUCTION GENERAL PERMIT 3-9020 FROM THE AGENCY OF NATURAL RESOURCES, STORMWATER SECTION

This permit authorizes the permittee to discharge stormwater runoff from construction activities, provided the project is in compliance with the requirements of the permit. The permitting requirements for projects authorized under this general permit depend upon the risk of having a discharge of stormwater from the construction site and implementation of an Erosion Prevention and Sediment Control Plan. Two risk categories are authorized by the general permit: Low Risk and

Moderate Risk. VTCAD was permitted as a Low Risk site, and both the AD Facility site and the Effluent Storage Pond were permitted, with a total of 7 acres approved for ground disturbance.

AIR POLLUTION CONTROL PERMIT FROM THE VERMONT AGENCY OF NATURAL RESOURCES, AIR QUALITY & CLIMATE DIVISION (AQCD)

AQCD implements state and federal Clean Air Acts and monitors air quality and air pollution sources, proposes regulations to improve existing air quality, ensures compliance with the regulations, and issues permits to control pollution from sources of air contaminants across the state. It was determined by the AQCD that no separate permit was needed for VTCAD, and the facility was included in the college's Air Pollution Control Permit.

PUBLIC SAFETY PERMIT THROUGH THE VERMONT DEPARTMENT OF PUBLIC SAFETY, DIVISION OF FIRE SAFETY

This program provides the review of construction documents, permitting, inspections, safety education and training, and response to emergencies. Permits or Certificates of Compliance were required for the construction and operation of the VTCAD electrical system, fire and alarm system, plumbing, and building structure.

MEDIUM FARM OPERATION CERTIFICATION THROUGH THE VERMONT AGENCY OF AGRICULTURE, FOOD AND MARKETS

The Medium Farm Operation (MFO) program provides a cost-effective alternative to a potentially burdensome federal permitting program by allowing medium sized farms to seek coverage under a single Vermont state General Permit. The program's requirements exceed those of the Federal Clean Water Act and reduce the amount of phosphorus and other nutrients that would find their way into Vermont waterways. This permit is designed to require that MFOs in the state of Vermont generating animal waste do not have a direct discharge of waste into the waters of the state and requires that manure, compost, and other wastes be land applied according to a nutrient management plan. Vermont Tech's Farm did not qualify as a MFO per the typical determination of animal numbers (200 - 699 mature cows or 300 – 999 young stock) however the college agreed to be regulated through this mechanism because it would also operate an anaerobic digester.

SOLID WASTE CERTIFICATION THROUGH THE VERMONT AGENCY OF NATURAL RECOURSES WASTE MANAGEMENT DIVISION

The Solid Waste Program oversees laws, rules, policies, and planning related to solid waste management in the state. It regulates solid waste management facilities and activities and certifies the state's landfills, transfer stations, haulers, composting, and recycling facilities. A new certification was created within this program to accommodate anaerobic digesters. **VTCAD is the first anaerobic digester to be regulated through this permit process.** As of the writing of this report the VTCAD Solid Waste Certification application has been accepted as administratively complete. The process was delayed for several months while we addressed concerns of a neighbor regarding odors from the digester. While there were nuisance odors during winter 2014/2015 we believe we have corrected the issues and are now operating in accordance with the facility design (see *Problems Encountered in the Project Activities* section on page 27). The Draft Permit was received in December 2015.

Incidental permits and agreements

COMPREHENSIVE NUTRIENT MANAGEMENT PLANS (CNMPS)

CNMPs are conservation plans for the management of land-application of nutrients, typically utilized only by farm operations. These plans document practices and strategies adopted to address natural resource concerns related to soil erosion, livestock manure and disposal of organic by-products. Standards are set through *USDA Natural Resource Conservation Services* (NRCS), approval and annual reporting is through the Vermont Agency of Agriculture Food and Markets. The VTCAD CNMP manages the storage and land-application of VTCAD effluent.

FARM STORAGE FACILITIES

Design and construction of the 3 million-gallon effluent storage pond and the farm manure reception pit had to meet NRCS design standards. NRCS approved the plan design, monitored construction of the effluent storage pond, and provided certification of its installation.

WASTEWATER DISCHARGE PERMITS

As anaerobic digestion facilities are relatively new to Vermont, regulation of AD and feedstock procurement are still being developed. The Drinking Water and Groundwater Protection Division is responsible for regulating wastewater discharged to the sub-surface (underground), including the Indirect Discharge Program that reviews and approves wastewater systems designed to dispose of 6,500 gallons per day or greater of wastewater. Food processing residuals are currently permitted as wastewater. VTCAD is not required to get indirect discharge permits, but generators of liquid food processing residuals such as brewery waste are required to get indirect discharge permits in order to dispose of the waste. As part of the generators Indirect Discharge Permit, VTCAD agrees to accept the waste material, specifying details of volume and accepted biochemistry parameters. Currently grease trap waste and glycerol are not regulated through any permit process, although quantities moved are captured through the waste transportation reports.

POWER INTERCONNECTION AGREEMENT

This agreement with its regional power company allows Vermont Tech to operate an electrical generation facility interconnected with and operated in parallel with Green Mountain Power Corporation's electrical system.

SPEED CONTRACT

Vermont's Sustainably Priced Energy Development (SPEED) Program was enacted by the Vermont Legislature in June 2005 in 30 V.S.A. § 8005 and § 8001. The goal of the SPEED program was to promote the development of in-state energy sources that use renewable fuels (SPEED resources) to ensure that, to the greatest extent possible, the economic benefits of these new energy sources flow to the Vermont economy in general and to the rate paying citizens of the state in particular. The VTCAD agreement guarantees increasing rates from $0.1359 – $0.1503/kWh over a 20 year period. While this initially was a substantial benefit for the project, increased rates and changing SPEED policies now puts VTCAD at a disadvantage as different facility (biomass AD) designations are now guaranteed higher rates ($0.21/kWh).

CONSTRUCTION

Construction activities began on July 2, 2013 and substantial completion was achieved by July 1, 2014, such that the AD system was operating successfully although several components had still to be commissioned. Initial schedules had called for construction to be substantially complete by October 2013, feeding to commence in November 2013, and operation to start in December 2014. Construction delays (detailed further in the 'Problems Encountered' section below) delayed feeding until January/February 2014, production of methane and electricity until March 2013, and successful connection to the electrical grid until April 2, 2014. Construction work continued intermittently through July 2014.

Problems that affected construction and delayed completion included:

- A condition in the PSB CPG that required all permits be obtained prior to commencing construction, even for aspects of the project not planned or required until later in the project, such as the 3–million gallon effluent storage pond;
- Delays in shipping equipment from Europe, including finding American vessels for shipping, as required by the U.S.DOE. Very few shipping vessels operate under the US flag, and VTCAD shipments were twice off-loaded in favor of military shipments;
- Challenges in management of subcontractor work schedules as changes to the AD system were made continually during the design-build process;
- High groundwater and bedrock encountered during site work and construction;
- The polar vortex of December 2013 to April 2014 caused significant and repeated freezing of pipes, pumps, trucks, and personnel during the transport of 430,000 gallons of liquid manure to the digester for the initial filling and start-up of the system. In Vermont, typical cold weather was exacerbated as weeks of sub-zero days were punctuated by nights of -20 to -30° F degree temperatures.
- The shutdown of the federal government from October 1 through October 16, 2013 delayed construction of the 3-million gallon effluent storage pond. During the shutdown, approximately 800,000 federal employees were indefinitely furloughed, including employees of the Natural Resource Conservation Services who had designed the effluent pond and were overseeing its construction.

OPERATIONS

Filling, start-up and restart

Dr. Joan Richmond-Hall explains AD controls to Christy Sterner, U.S. DOE Technology Manager.

Filling and start-up were overseen by Bio-Methatech's project manager with the assistance of Vermont Tech faculty and students and facilities staff. Timing could not have been worse, as February and March of 2014 saw the peak of an incredible polar vortex of consistently artic temperatures. VTCAD was filled with 'conditioned' pit manure: dairy manure that had been stored in a manure pit and had become anoxic (low oxygen content). Roughly 120 truckloads, at just under 4,000 gallons each, were required to fill the system. Trucks, pumps, and piping froze repeatedly, complicating filling and start-up. The Hydrolysis and AD tanks were heated to operational temperatures (30—35°C) using heat piped to VTCAD from the campus's central heating plant located about 100 feet uphill from the digester. (Once a heat distribution loop is completed, this connection will be used to transfer waste heat from VTCAD's generator to the heating plant, displacing fuel oil.)

A full-time AD operator was hired in the late spring of 2014 and worked with Bio-Methatech's project manager to direct operations during the summer of 2014. He was assisted by our first pair of AD apprentices, a student and a recent graduate, and by staff and students from the college farm. One of those apprentices continued to work at VTCAD as a certificate student and she has also taken an active role in research and data collection.

The quality of biogas was sufficient to run the generator by late March. In April, enough electricity was produced and sent to the grid two weeks ahead of the deadline specified in VTCAD's SPEED contract. Unfortunately, on the same day that milestone was reached, failure of a failsafe switch resulted in a series of events that breached the integrity of the biogas collection bladder. Repair required us to stop operations and empty the AD tank and part of the hydrolysis tank. This process occurred during April and May of 2014. Refilling occurred in June, and electric production resumed in July of 2014. Refilling was time consuming, expensive, and complicated. It diverted 300,000 gallons of manure that had been slated for field application and this decreased crop yields.

Sawdust and wood chips in the manure pits clogged manure pumps, trucks and digester plumbing. The clogging was dramatic and persistent; through the summer, fall and winter of 2014 operators had to remove clogs from pumps and piping on a daily basis, often many times per day. Some plumbing, valves and pumps had to be rethought and replaced. Vacuum trucks had to be brought in to resolve some clogs and we took advantage of the biogas bladder repair to purge built up wood debris at the bottom of tanks. Thankfully, by the spring of 2015 most of that material had moved through the system and clogs are now much less frequent.

Routine operations

By the early summer of 2015 VTCAD operations had become fairly routine. Feedstock deliveries, transportation of effluent to fields or the effluent pond, and trucking of solids to the farms is largely done by late morning. Feedstock mixtures are prepared and fed into tanks during the same period of time. Routine maintenance, ordering, administrative work and communications, and research is done in the afternoon by the operator and assistant. AD apprentices finish their hands-on work three mornings per week and work some weekends. They attend class and study at times scheduled around their work schedules.

At full capacity, VTCAD requires an input (feedstock) volume of 16,000 gallons per day. During our first year of operation input volumes averaged 12,000 gallons per day and we are now working towards full capacity. In our first year of operation, feedstock has consisted mainly of dairy manure, heifer manure, spoiled silage, low-quality grass, waste from the college's market garden, liquid effluent from the digester, and off-farm organics: yeast slurry and sludge from Vermont breweries, glycerol waste from generation of biodiesel from used cooking oil, and grease dilute trap waste. Off-farm organics didn't reach 10% of total feedstock volume until 2015. Between January and March of 2015, off-farm organics were gradually increased to just below 50% but were decreased to 41% by June of 2015. The monthly average volume of off-farm organics has not exceeded 48.7%. 2015 feedstock data are presented in Appendix D and 2014 – 2015 feedstock data are presented in Appendix E.

VTCAD has been operational for just about one year. To date, we have not used food waste as a feedstock for two reasons. First, we have not formally received our full solid waste certification, though Vermont ANR has reviewed and accepted our application, inspected our facility and has identified no 'red flag' concerns. Second, we are participating in a Clean Energy Development Fund (CEDF) grant with our feedstock and grant partner, Grow Compost. The grant involves comparison of AD operation with and without food waste as feedstock and we are completing the first phase. We anticipate adding food waste to VTCAD feedstock by the end of the 2015 calendar year.

On-farm feedstock materials

A variety of on-farm feedstock materials were added during the summer of 2014. Heifer manure was added in June after the heifers were sent to pasture and winter manure was cleaned out of the barn. Spoiled silage or haylage was first added in July. Fresh grass whose quality didn't merit feeding to cows, was mowed out of fields and fed from July to November. Refuse from the campus market garden was added in July and August. Hay bedding and goat manure from ***Ayers Brook Goat Dairy*** was added in July, but was deemed too difficult to feed because of its heavy, compacted nature. In October, leaves collected from campus were used as feedstock. Cross-cut shredded waste paper has been fed in small quantities since the summer of 2014. Grass, garden refuse and leaves will be available in summer, while heifer manure will be available except in summer.

Off-farm feedstock

The first off-farm feedstock, yeast slurry and sludge from the ***Alchemist Brewery*** (producers of the renowned 'Heady Topper') were fed to VTCAD in March of 2014. In June and July glycerol from a local biodiesel producer and grease trap waste from local restaurants were added. We now receive brewery waste from both the Alchemist, hauled by ***Grow Compost of Vermont*** (Moretown), and from ***Long Trail Brewery***, hauled by Recycled Organics (Randolph). Our original source of glycerol went out of business, but we now receive a steady supply from a producer just across the state line in New Hampshire. Brewery waste is added directly to the feedstock preparation pit, as is the diluted grease trap waste. We have avoided feeding concentrated grease trap waste because the flocculants used to dewater it can be toxic to aquatic organisms. The glycerol is a very concentrated and high-energy feedstock, so we store it in 9000-gallon stainless steel tanks at VTCAD and add small volumes to each day's feedstock. During cold winter weather glycerol can be too viscous to transfer by pump. We have found that a 50:50 mixture of glycerol and 'crumb water', the dewatering fraction from waste oil collection, is more pumpable and still has very high energy potential. A higher proportion of glycerol can be used in warmer weather.

Feedstock economics

To date, VTCAD has not charged tipping fees for any deliveries of organic waste feedstock for a number of reasons. First, the Universal Recycling Law has resulted in a very volatile market for organic wastes. We did not want to count on an income stream that might disappear as organic wastes become a sought after commodity. Second, VTCAD needed to acquire sufficient feedstock for full operations quickly. Lack of a tipping fee has made us an attractive destination for organics. Third, we did not want to establish a fee that would exclude other smaller AD facilities from the organics marketplace as Vermont's composting and anaerobic digestion sector must expand rapidly if we are to successfully divert all organics from landfills by 2020. However, economics may force us to charge a tipping fee over the next several years. We need to compile and review a year's worth of stable operational data, expenses and revenue before making this decision.

Power production

At full operation VTCAD's 370-kW generating engine produces 8,880 kW of electricity per day. The energy content of feedstock was increased slowly from the summer of 2014 through the winter. The cold winter weather exposed some insufficient insulation and caused some difficulty with pumps and piping. During the last week of March 2015, the generating engine first ran for 24 hours without stop, producing an average of 7,855 kWh per day. Within a month we had to decrease the energy content of feedstock to slow biogas production while we identified and repaired a piping problem that was leading to odor issues. That issue was resolved, but other technical and mechanical issues have kept us from returning to full operations. During the first six months of 2015, consumption of electricity at VTCAD has averaged 660.5 kWh per day, with a standard deviation of 219.6 kWh per day. Electric production has averaged 4,683.4 kWh per day with a standard deviation of 2,502.5 kWh per day, just above half of maximal power output. We had anticipated a slow and gradual startup and hope to be operating at full power routinely by the end of this calendar year (2015).

The heat in genset exhaust is captured for reuse.

Operational data

VTCAD's operators and apprentices manually collect and record operational data on a daily basis. Loss of support from Bio-Methatech has slowed automatic data logging and transfer to databases. Reliable data sets exist from September of 2014 onwards and we have focused on the compiling, summarizing and analyzing operational data from 2015. Biogas volume (cubic meters per day) is measured by a flow meter in the piping leading from the gas collection balloon to the generating engine. Note that this meter does not measure gas that is sent to the flare when the generating engine does not start or is being serviced. Biogas quality is measured using digital sensors for methane (%) and hydrogen sulfide (parts per million). VTCAD's electric consumption (kWh/day) is measured using a meter installed by the electric utility. Electric production (kWh/day) is recorded by in the generating engine sensors. The pH values of slurry in the hydrolysis and the anaerobic digestion (AD) tanks is measured manually using a pH probe installed at VTCAD. The Ripley ratio, a ratio of partial alkalinity to intermediate alkalinity, is measured by manual titration of slurry from the hydrolysis and AD tanks with 0.25 molar sulfuric acid

(Ripley et al., 1985). The Ripley ratio estimates the ratio of volatile fatty acids to bicarbonate alkalinity, and is a critical indicator of the 'health' or balance of the AD process. Operational data is discussed in more detail in the Data section of this report, and in the appendices. More detailed testing is conducted, either by college personnel or by commercial laboratories, as deemed necessary.

Feedstock energy content, recipes and energy prediction

European estimates of the energy content of feedstock materials are used to calculate biogas output of feedstock mixtures. Appendix F presents a version of these values published by the Sustainable Energy Authority of Ireland. Biogas volume (cubic meters per fresh metric tonne) and electricity output (kW per fresh metric tonne) are listed for each feedstock material that is also described in terms of its total solid and organic dry solids content. The energy content of our feedstock materials are shown to the right.

FEEDSTOCK MATERIAL	BIOGAS YIELD (M3/FRESH TONNE)
Dairy manure	20.5
Heifer manure	60.0
Fresh grass	72.9
Corn silage	138.6
Haylage	116.9
Garden refuse	72.0
Paper	178.0
Brewery waste	80.0
Glycerol	712.5
Grease trap waste	98.8

We adjusted some of these values. For example, we knew that the undiluted glycerol was 60% glycerol in mainly water, and then we diluted that with crumb water. So we down-graded the energy content of the 50:50 mixture to 214 m3/fresh tonne. Appendix G shows predicted biogas volumes for 2014 – 2015, along with recorded biogas values. To date, prediction of biogas yield via these feedstock energy content values has overestimated biogas production by an average of 53%. Feedstock energy and biochemical testing are discussed in more detail in the Data section of this report.

COLLABORATIONS:

Feedstock partners

We have developed a number of feedstock partnerships during our first year of operation. As discussed above, Grow Compost of Moretown, Vermont is our food waste partner, and is developing collection route for pre- and post-consumer food waste in Randolph. Grow Compost has brought us a partnership with the Alchemist of Waterbury, Vermont. The Alchemist sends us brewery waste from their nationally recognized "Heady Topper" IPA. We have an agreement (MOU) with Grow Compost, but need to learn more about the optimal feedstock mix for VTCAD before making firm long-term agreements with other producers or haulers of organic residuals. We are also working with Recycled Organics of Randolph Vermont, run by Robert Dimmick. Rob has brought us a partnership with ***Long Trail Brewing Co.*** of Windsor Vermont; they too send us brewery waste. Recycled Organics is seeking to source other high strength feedstock in, and outside of, Vermont. We've worked with Bill Rees of ***Green Power Solutions*** in Connecticut to secure a mixture of glycerol and 'crumb water', the energy rich byproducts of biodiesel processing and of waste food grease collection respectively, from a large biodiesel producer in a neighboring state. We have also been in conversation with Vermont Creamery of Websterville Vermont, about their combined stream of whey and buttermilk.

Partners for community nutrient management planning

Once Vermont Tech had secured funding for VTCAD, we began to talk with our neighboring farmers about potential collaborations as the addition of off-farm feedstock to VTCAD may produce more recycled nutrients than needed on the acreage managed by the college. We found that seven neighboring farms would be willing to accept nutrients from VTCAD for use as field amendment providing that Vermont Tech took responsibility for nutrient management planning (NMP) and land application of nutrients for the first year. Vermont's Agency of Agriculture agreed to this community nutrient management approach. Until this year, small farms did not have to file NMPs, though all farms with AD facilities are required to use NMPs. During our first year of operation we have not produced more nutrients than our co-managed farms can handle, but we believe that farm partners will be needed as our feedstock evolves and our nutrient output increases.

Research partners

In 2014, we partnered with Grow Compost on a Clean Energy Development Fund (CEDF) grant to look at the effect of food waste on power production, nutrient recycling and hauling. We are actively exploring joint research opportunities with another college in Central Vermont.

AgSTAR

We are a partner in the Environmental Protection Agency's ***AgSTAR*** program that "promotes the use of biogas recovery systems to reduce methane emissions from livestock waste. In addition to producing biogas, anaerobic digestion systems can also help achieve other social, environmental, agricultural and economic benefits."

PROJECT ACTIVITIES

ORIGINAL HYPOTHESIS

The VTCAD project began with a simple hypothesis: anaerobic digestion could be used to create renewable electricity and heat from a mixture of manure and food waste, while recycling nutrients from that food waste. AD facilities using food waste could provide a useful destination for food waste diverted from landfills and wastewater treatment plants, and could help Vermont meet agricultural and renewable energy goals. Further, the addition of food waste to on-farm AD facilities could improve their economic viability.

APPROACHES USED

VTCAD project partners used funding from the U.S. Department of Energy and the Vermont Agency of Agriculture, Food and Markets (VAAFM) to conduct a detailed ***feasibility study*** of the required technology, feedstock, energy production, and funding. Vermont Tech used an RFQ and RFP process to identify vendors with the capacity to design and build a sophisticated complete mix, mixed substrate AD facility, and to determine the cost of implementation. After implementation funding was secured from the U.S. DOE and the Vermont State Colleges, a Canadian firm was selected to construct the facility in a design-build process. The college used legal assistance to obtain permits necessary for construction, including the Certificate of Public Good. Construction utilized a design-build contract with project management through a faculty and staff Task Force. The college used a partnership approach to source feedstock and develop a comprehensive nutrient management plan. The Randolph Center community was kept informed by a series of information meetings and forums and by articles in the local paper.

PROBLEMS ENCOUNTERED

Significant problems and delays were encountered, mainly in the construction and operational phases of the project. The most significant issues are listed here.

CONSTRUCTION DELAYS

- Construction was delayed by lengthy permitting processes, and new regulations were created during the permitting and construction phases directly relating to our project.
- Construction glitches delayed the start of operations from November 2013 to January/February of 2014 during which there was a national extreme cold weather event (identified by meteorologists as a “polar vortex”).

COLD WEATHER AND START-UP ISSUES

- Delays in construction led to difficulties with manure management and storage as manure stored for start-up had to be field-spread at the very last regulatory permissible date to allow for new storage over winter 2013-2014.

- Delays and cold weather, and the rush to meet the SPEED deadline, required initial start-up and operation under less than ideal circumstances and construction upgrades continuing during the first year of operation.

MECHANICAL/CONTROL FAILURE AND RESTART

- A mechanical/control system failure occurred just after electricity was first generated in April. This failure caused a rupture in the digester's gas balloon that required operators to drain approximately 300,000 gallons of partially digested material to allow for repair. This large volume had to be trucked to the effluent pond.
- Use of partially digested material saved from the draining in April and the remaining manure from farm pits was used to re-fill and start the AD in the first week of May, along with fresh manure. Although this material heated up quicker than the original start-up, its lower energy level (because it was already partially digested) meant that it took much longer to get to the 45% methane required to run the genset.
- Initial budgets for VTCAD did not incorporate the cost of transferring manure from the farm pits to the digester, an estimated $250,000 cost item.
- Refilling required using manure that the farm had saved for field amendment and impacted cropping and yields.

FEEDSTOCK CHALLENGES

- Because our farms use bedding from sawdust and wood chips, and because we had to use the most dense and chip-laden manure for refill, our initial feedstock caused severe and persistent clogging of pipes and pumps, requiring extraordinary management by operators.
- Some feedstock presented biochemical challenges that required the college to work with generators to implement changes that improved the suitability of the material as feedstock. For example, farmers needed to restrict their use of copper sulfate for hoof management as copper sulfate inhibits anaerobic digestion. College faculty worked with biodiesel producers to change their production chemistry to lower sulfur levels and produce near neutral pH in the high-energy glycerol by-product.
- Although some white papers exist regarding AD recipes for energy production and biochemical health, most of them are theoretical or from small scale research projects. We are developing optimum recipes "on the fly," depending on the mix of inputs we receive.

ISSUES CAUSED BY THE DISSOLUTION OF DESIGN-BUILD FIRM BEFORE PROJECT COMPLETION

- The dissolution of our design-build company, Bio-Methatech, during construction caused delays and negatively impacted construction, start-up and operations. While we are able to have limited service through Biogaz Lipp and Dominion & Grimm, the process of getting service and operational guidance is slow and sporadic. Operations are handicapped by a lack of a complete set of as-built drawings and specifications, and lack of an operations manual. Data automatically recorded is not easily accessible, but must be manually logged and transferred to databases.

- Multiple pumps of differing sizes did not allow for interchanging pumps during pump failures.
- The use of butterfly valves instead of ball valves in AD piping, in combination with the thicker than expected manure feedstock, caused significant blockages throughout the system piping. Inaccessible clean-out valves were replaced by accessible versions allowing for simpler management.
- System mechanical and control problems have resulted in so many operational fluctuations througout operations that obtaining baseline data, developing recipes, and developing predictive models for energy and biogas production has been nearly impossible. CEDF funded research has also been impeded and delayed.

ODOR ISSUES

- Various mechanical and system control component failures have resulted in significant odors, mostly in October-December 2014. Nuisance odors affected students in dorms near the AD, students, faculty and staff on the Randolph campus, and neighbors. Odor complaints from neighbors have resulted in possible investigations from the PSB and delays in the finalization of our Solid Waste Certification permit.
- When feeding rates were lowered for intervals to minimize odor, biogas and power production were impacted and the health of the bacterial process suffered.
- The main source of odors was a water trap produced in a gas transfer pipe by frost-heaving of a pipe support. This was repaired in early 2015. An inconsistently operating flare contributed to less significant odor problems and was repaired in the spring of 2015.
- As the college is located in a rural agricultural area, odors from farming operations by others has mistakenly been perceived as coming from VTCAD.

PERMITTING CHALLENGES

- Somewhat ambiguous permitting and reporting requirements have required a great deal of communication with responsible agencies.

FISCAL CHALLENGES

- Operational challenges and construction delays have increased the expected costs of the project while limiting the expected revenue, during a time of considerable financial difficulty for the college. This has caused many within the college community to question the need for, and viability of, VTCAD.

ASSESSMENT OF PROJECT IMPACT—SHARING WHAT WE'VE LEARNED

During construction and our first year of operation we have given many (100+) tours of the VTCAD facility to professionals, government officials, educational groups and individuals. We believe that our work to date with legislators and state agencies has, and will continue to, increase their understanding of the AD's potential and will help them create regulations that encourage expansion of AD in service to Vermont's renewable energy, agricultural and environmental goals. During summer 2015 we held a series of meetings with state agencies, waste haulers and other stakeholders in order to share what we've learned and help generators, haulers and regulators understand the needs of anaerobic digesters.

Since the completion of our feasibility study, the number of farm AD projects in Vermont has grown to nineteen. We recently learned that a Vermont energy developer plans to build a group of on-farm cooperative or community AD plants on the eastern shores of Lake Champlain powered by manure from surrounding farms and locally sourced food waste. These facilities will profit from the larger supplies of food waste in Chittenden County, and will contribute to the management of nutrients that might otherwise contribute to pollution in Lake Champlain. In Brattleboro, an anaerobic digester developer is planning to develop a food waste-only AD facility at the Windham Solid Waste Management District landfill. In neighboring Massachusetts, a group of farmers and AD developers has come together to build on-farm AD powered by food waste collected in metropolitan Boston. The *AGreen Energy LLC* has constructed two of its five planned AD facilities.

There is now a specific form and application process for anaerobic digesters to be certified as solid waste facilities in Vermont. Specific legislation restricted the jurisdiction of Vermont's Public Service Board over plants that use methane obtained from agricultural activities. Regulatory agencies not typically in constant communication with each other, including ANR's Solid Waste and Wastewater divisions and VAAFM, have had to meet and agree on jurisdiction, reporting, testing requirements, and sharing of data.

Organics management and renewable energy are growing industries in Vermont and nationally, and AD technology is part of both sectors. A significant number of emerging businesses will evolve around the need for organics recycling, management of 'waste' nutrients and renewable electricity and heat.

VTCAD has helped us understand the need for trained anaerobic digester operators with broad understanding of a wide variety of topics from plumbing and electrical basics, to microbiology, biochemistry and nutrient management. To meet this need, Vermont Tech has developed an apprenticeship training program for anaerobic digester operators. A pair of AD apprentices works at VTCAD for 25 hours a week and attend class weekly for terms that could last 3 - 4-months. The curriculum is based on an AD course developed by the University of Wisconsin Extension, and has been expanded and adapted to anaerobic digestion in Vermont and neighboring rural states. Topics include:

- Introduction to anaerobic digestion (AD);
- Factors affecting AD;
- Types of AD;

Meet "Big Bertha"—Vermont Tech's operational community anaerobic digester project.

- AD startup and operation;
- AD feedstock;
- AD & farm operations;
- Energy generation;
- Nutrients recycling and nutrient management planning;
- Regulation of AD;
- Economics of AD;
- Cooperative / community AD; and
- Latest developments in AD.

The AD apprentice training curriculum includes case studies and uses operational protocols, data and outputs from VTCAD. The curriculum and enrichment materials are freely and publically available at ***http://richmond-hall.weebly.com/ad-apprentice.html***.

This fall (2015) Vermont Tech's Renewable Energy bachelor's of science program is offering a ***3-credit Bioenergy course***. The course is focused on anaerobic digestion and also discusses wood biomass and biodiesel energy technologies. The course includes a weekly hands-on lab.

Vermont Tech students have been involved in all aspects of the VTCAD project. Students from the following programs have toured VTCAD throughout construction and initial operations:

Agribusiness Management Technology	Architectural & Building Engineering Technology
Dairy Farm Management	Civil & Environmental Engineering Technology
Diversified Agriculture	Electrical Engineering Technology
Landscape Design and Sustainable Horticulture	Electromechanical Engineering Technology
Business Technology & Management	Mechanical Engineering Technology
Computer Engineering Technology	Renewable Energy
Computer Information Technology	Fire Science
Computer Software Engineering	Automotive Technology
Construction Management	Diesel Power Technology

VTCAD technical information has been used to create homework and lab assignments for students enrolled across the college. Examples include: assessing VTCAD pipe capacity and pump sizing between the off-farm feedstock intake and storage tank; pipe flow rate losses through the AD system; economics of renewable energy; chemistry of anaerobic digestion; topographic survey of the AD site; analysis of wetland and geotechnical soil data from the VTCAD site; stormwater design for the VTCAD parking lot; and landscape design for the VTCAD site. In the 2014-15 academic year a group of computer software students designed a 'dashboard' display systems that will allow users to monitor VTCAD operation, power and co-product production from the web.

BIOGAS METHANE CONTENT	VOLUME OF GAS REQUIRED TO PRODUCE 8,880 KWH (M3)
50%	4,674
60%	3,895
70%	3,338

DATA

Data from VTCAD are presented graphically in a number of appendices of this report. Feedstock data are presented in Appendices C, D, and E and operational data are presented in Appendix B. In Appendices B and C, daily data are presented in monthly summaries from January to June of 2015. Note that all graphs shown use common scales to allow easy comparison from month to month. Appendix D presents monthly summaries of feedstock data from March of 2014 to June of 2015.

Summaries of data, and trends and epiphanies that have emerged from early analysis are discussed in this section of the report.

Biogas volume and quality

The volume of biogas required for full operation depends on the quality of biogas as the energy content of biogas is dependent on the amount of methane in the biogas. Power output can be calculated using this simple equation for an engine with an efficiency of 38.8 percent.

kWh = (m3 methane)(10 kWh/m3)(0.388)

So, the amount of gas required drops as the methane content of that gas increases as shown here.

From January to June of 2015, methane content varied from 46.5 – 61.9% with an average of 56.2%. Biogas volumes varied from 541 – 2,930, with an average of 1426.2 cubic meters per day (Appendix G). We have found that our calculations of power production from biogas volume and methane content fall short of observed power production. In the examples shown below, VTCAD's generating engine ran 24 hours without stop and therefore should have produced 8,880 kWh of electricity.

DATE	BIOGAS VOLUME (M3)	METHANE (%)	CALCULATED OUTPUT (KWH)	ACTUAL OUTPUT (KWH)	BIOGAS REQUIRED (M3)
25 March 2015	2,322	56.9	5,126	9,028	4,089
1 April 2015	2,779	58.6	6,318	8,442	3,713
2 April 2015	2,930	57.0	6,480	8,404	3,800

This suggests that VTCAD's generating engine's gas flow meter is only measuring 68% of gas burned, or that our methane meter is not working properly, or that this is the world's most miraculous generating engine.

Hydrogen sulfide (aka hydrosulfuric acid or H_2S) is a minor component of biogas, but is highly corrosive and can damage gas collection equipment and generating engines. Anaerobic digestion of diary manure alone can produce 2,000 – 4,000 parts per million (ppm) of hydrogen sulfide. Addition of high-protein feedstock materials like dairy and food wastes can increase these levels. We found that our source of glycerol, the waste product of biodiesel production, contained large amounts of sulfur as a result of the chemical process used to produce the biodiesel. We were able to suggest process changes that dramatically lowered the glycerol's sulfur levels and improved the value of this feedstock material. VTCAD uses a feedstock additive, ferric chloride ($FeCl_3$) to precipitate sulfide in our feedstock mixture and decrease the levels of hydrogen sulfide produced in biogas. While ferric chloride is costly (roughly $3/gallon or up to $150/day) and hazardous (highly corrosive) we believe that its use will extend the lifetime of our generating engine, particularly when operating at less than full capacity. When generators are cycled off, they cool and water and hydrogen sulfide condense onto the working surfaces of the engine. From January to June of 2015, hydrogen sulfide levels have ranged from 10 to 539 ppm, and averaged 236.1 ppm (Appendix H). We note that VTCAD's gas monitor has been replaced and repaired several times, so instruments varied and the biogas quality data likely reflects those changes.

pH of slurry in hydrolysis and anaerobic digestion tanks

In a two-phase AD process, the pH values of the hydrolysis and AD tanks should be 4.5 to 6 and 6.8 to 7.2 respectively. The pH range of the AD tank is critical for production of methane gas, while the pH of the hydrolysis tank is less critical and lower, reflecting the production of the volatile fatty acid precursors to methane. Measurement must be performed quickly, as exposure to the atmosphere changes the pH of slurry. From January to June of 2015, the pH of the hydrolysis tank ranged from 4.80 to 6.28 with an average of 5.40, and pH in the AD tank ranged from 6.99 to 7.91, averaging 7.42 (Appendix H). As biogas production increased during March and April, hydrolysis tank pH dropped, reflecting greater production of volatile fatty acids.

Ripley ratio

The Ripley ratio is a critical measure of the state of the AD process that can be monitored with rudimentary equipment and minimal chemistry training. When laboratory space is available, we monitor the Ripley ratio weekly. Published research suggests that Ripley ratios between 0.1 and 0.4 are indicative of a healthy AD process, and that values of 0.8 and above indicate process failure (Ripley et al., 1985; Drosg, 2013). The Ripley ratio is a more sensitive indicator than pH. Ratios in the hydrolysis tank should be higher, reflecting the production, but not consumption, of volatile fatty acids. At VTCAD, the Ripley ratio in the AD tank climbed slowly from 0.15 (January 2015) to 0.63 (April 2015). In late April the vertical mixing pump was removed from the AD tank to replace a more critical pump that needed repair. We believe that loss of vertical mixing was responsible for the subsequent rise of the Ripley ratio to 0.86 before the vertical mixing pump was replaced (Appendix E). We have lowered the energy content of feedstock in order to lower the AD tank's Ripley ratio; it remains at 0.78 (early July 2015). Ripley ratios in the hydrolyzer could be measured until the pH levels in this tank dropped in February; this drop is normal in the hydrolysis process.

Feedstock energy content

As described in the Operations section of this report, prediction of biogas yield via these feedstock energy content values has overestimated biogas production by an average of 53% (Appendix G). An example showing predicted vs. actual biogas yields is shown here for March of 2015. Daily feedstock volumes are converted to fresh (wet) feedstock masses using the density of water (264 gallons/metric tonne) and the water content of feedstock (generally 70% for organic solids and nearly 100% for liquids). The fresh mass of each feedstock material (metric tonnes/day) was multiplied by that material's energy value (m3 of biogas/fresh metric tonne) to predict the biogas yield of each feedstock material in m3 of biogas/day. This predicted value is compared to the average daily biogas yield for March of 2015. Actual biogas yields are, on average, 59.6% of predicted yields. This apparent underperformance (or over-prediction) may be, in part, a result of bad data. As discussed earlier in this report, it appears that VTCAD's gas flow meter or gas quality meters readings are low, and we believe the gas meter is the more likely source of error. Electric production figures suggest that we may be measuring roughly 68% of gas produced and combusted. So, use of feedstock energy values to predict biogas volumes may be more accurate than they appear.

MARCH 2015	VOLUME (GALLONS/ DAY)	FRESH MASS (TONNES/ DAY)	BIOGAS VALUE (M3/TONNE)	PREDICTED BIOGAS (M3/DAY)	AVERAGE ACTUAL BIOGAS (M3/DAY)	ACTUAL AS % PREDICTED
On-Farm						
Dairy manure	5,548	21	21	431		
Heifer manure	738	2	60	117		
Silage/Haylage	101	0	128	34		
Effluent	532	2	10	20		
Off-Farm						
Brewery	1,638	6	80	510		
Glycerol	903	3	214	731		
Grease trap	4,516	17	99	1,694		
Total	**14,021**	**52**	**612**	**3,537**	**2,107**	**59.6**

Using 264 gallons/metric tonne & rough density

= fresh mass (biogas value)

We will investigate the accuracy of our biogas flow meter and will be applying several other methods of predicting the energy yield of feedstock mixtures. As Vermont diverts organic wastes to composting and anaerobic digestion we believe that it is critical that operators understand how to create safe and effective feedstock mixtures. Economic viability depends on full operation and predictable biogas yields. Excess biogas yields can result in release of biogas, and emission of potent greenhouse gases and odor.

Testing of feedstock material for AD inhibitors & routine operational indicators

We have done some initial biochemical screening on feedstock materials and compiled results are shown in Appendix H. There, tables of compiled test data include optimal concentrations of biochemical parameters, and concentrations that are moderately and strongly inhibitory to the anaerobic digestion process. On-farm feedstock materials have moderately or strongly inhibitory levels of potassium, calcium, copper, iron and magnesium. Glycerol has moderately inhibitory levels of potassium and sodium; the sodium comes from base required for the biodiesel production process. One source of grease trap waste has strongly inhibitory levels of copper and iron. One of the most common inhibitors in dairy manure is copper because copper sulfate footbaths are often used to kill or inhibit pathogens that cause foot problems in cattle. The college farm and the co-managed Osha farm no longer use copper sulfate footbaths and have switched to oxidizing footbaths that inactivate with time, or copper sulfate that is sprayed onto the feet of cattle needing treatment. Despite these efforts, our feedstock materials still contain copper at concentrations that inhibit anaerobic digestion. Our feedstock also contains relatively high levels of iron. Some iron is necessary for efficient AD, but higher levels are inhibitory. We are adding much of this iron when we add ferric chloride to control levels of hydrogen sulfide in biogas. The bacteria responsible for anaerobic digestion are capable of adapting to, and function in, concentrations of inhibitors if the concentration of those compound increases slowly, remains below critical levels, if few inhibitors are present, and if other conditions are favorable. Our routine biochemical testing does not screen for the presence of more complex organic molecules that inhibit the anaerobic digestion process. Examples include antibiotics and other antimicrobial compounds, detergents, cleaning compounds, and solvents. These compounds are not likely found in food waste itself, but may be introduced during the cleaning and collection process. Grease trap waste would be our most likely source of such compounds.

While phosphorous is not an inhibitor of anaerobic digestion, high phosphorous levels may limit use of AD effluent as a field amendment in fields with high phosphorous indices. We note that glycerol does contain significant levels of phosphorous, added in the biodiesel conversion process. Successful AD feedstock recipes combine feedstock materials to create sufficient energy and to avoid inhibitory levels elements like metals. Testing of feedstock mixtures created in VTCAD's preparation pit shows the total solids content to be roughly 8% total solids with a volatile solids content of 80-90% that indicates that energy content is high.

Biochemical balance and diet optimization

Biochemical testing is ongoing and our next focus will be total carbon and nitrogen content, to allow us to calculate carbon-to-nitrogen (C:N) ratios of our feedstock mixtures, and in-house testing of volatile solids content as a measure of energy content. Optimal C:N ratios for anaerobic digestion are 20:1 to 30:1. Our use of glycerol and grease trap waste may have put us in a slight nitrogen deficit. The addition of food waste should increase the solids content and reduce the C:N ratio. We are focusing on volatile solids, rather than biological oxygen demand or chemical oxygen demand, because the test is simple and can be done with minimal equipment. Initial volatile solids determinations show that the destruction of volatile solids as organic material is converted to methane through the anaerobic digestion process: prep pit (prior to AD) to hydrolysis tank to AD tank and then out as digested liquid effluent and separated solids. The volatile solids content of the separated solids increases because the solids include the cellular remains of the bacteria that drive the process. Bacteria have converted some energy and nutrients from the feedstock into biological structures that are collected in the solids. Recalcitrant organic matter—material like woody lignin that is poorly degraded by anaerobic digestion—is also found in the separated solids.

SAMPLE	%TS	%VS	VS AS % TS	%VS REMAINING	%VS DESTROYED
Prep pit	7.46 – 10.99	81.51 – 83.31	6.1 – 9.2	100	0
Hydrolysis tank	6.82 - 8.10	80.87 – 81.98	5.5 – 6.6	72 – 91	9.3 – 28
AD tank	4.80 – 5.18	72.14 – 73.86	3.5 – 3.8	38 – 63	37 – 62
Liquid effluent	3.35 – 3.80	64.20 – 66.40	2.1 – 2.5	23 – 41	59 – 77
Separated solids	34.58 – 38.27	89.04 - 89.32	30.8 – 34.2	373 - 507	NA

We have sent samples to a number of forage testing labs that serve the agricultural community. However, the turn around time for these labs is long, generally four to six weeks, and they are not always experienced with the types of samples and testing we need. We will now send samples to a local lab, ***Endyne***, serving the wastewater, environmental and food production communities. Endyne is more expensive, but has much shorter turnaround and more relevant experience. Real-time knowledge of operational parameters is essential for efficient anaerobic digestion of complex, mixed and high-energy feedstock materials. To that end, we are conducting routine testing in-house using rudimentary equipment that could be set up at any digester. We are measuring the pH, titration of alkalinities and determination of Ripley ratio, and total solids and volatile solids of feedstock materials. We would like to invest in a device that would allow rapid micro-scale testing of chemical oxygen demand, another metric indicating energy content and efficiency of AD.

Microbiological testing and herd health

In-house screening for pathogens is scheduled to begin this summer of 2015. Testing will use differential growth on a variety of culture media and will focus on changes in overall pathogen level and change in species with addition of a variety of off-farm feedstock materials. The effects of pasteurization of food waste prior to feeding will also be studied. We expect that anaerobic digestion will decrease pathogen levels and shift pathogens species. We will confirm our results by sending select samples for analysis at a local lab.

Anecdotal evidence from our dairy farms suggests that herd health has not been negatively impacted by bedding on separated solids. Because separated solids are 'free,' deeper bedding with this material has increased cow comfort. Sub-clinical and mildly clinical cases of environmental mastitis continue to occur but do not seem more frequent. It appears that the dominant organism responsible may have shifted from *Klebsiella* to *Lactococcus*, and the farm is using a different antibiotic that is working well. We believe that an operational incident that dramatically decreased hydraulic retention time for a period of a few days combined with a period of very hot weather in July of 2014 to create three cases of very serious clinical mastitis, one fatal. However, clinical mastitis is often seen during spells of hot weather, and the switch to separated solids bedding had just occurred. A detailed analysis of herd health data and VTCAD operational data is warranted.

Adding food waste

Food waste will replace some, but not all, of our off-farm organics. Food waste volumes will increase as collection routes are expanded. Obtaining sufficient off-farm feedstock to produce sufficient power has been less difficult than anticipated. Instead, technical challenges have dominated our first year of operations (See the Construction Problems Encountered and Operations sections).

VTCAD's food waste collection partner, Grow Compost, has six years of experience collecting a clean stream of high-quality food waste from a variety of generators in Central Vermont. In 2014, Grow Compost won the Small Business Administration award for micro-enterprise of the year. Grow Compost is now using their expertise to create collection routes centered on Vermont Tech and Randolph. Their collection process uses education and clear and frequent communication to help generators understand what constitutes clean food waste, free of non-compostable contaminants. Food waste is collected in totes and sawdust is used to cover each large addition to the tote. Totes are collected frequently using box trucks or trucks designed to haul and transport food waste slurry. By the end of 2015, Grow Compost will bring collected food waste directly to VTCAD in totes, or pulped during the collection process by an innovative truck they have designed and built with Clean Energy Development Fund and/or Working Lands Enterprise Board grant funding. If VTCAD is down for maintenance, Grow will compost collected food waste. Their partnership with VTCAD also allows Grow Compost to accept and haul liquid organics that cannot be composted to the AD facility. For example, liquid beer waste is a valuable AD feedstock that cannot be composted. Grow's ability to accept a wider variety of organic wastes allows them to serve a wider variety of clients.

VTCAD ECONOMICS

Implementation phase: permitting, construction and start-up

As mentioned previously, the $4.17 million of funding for the permitting, construction, and start-up of VTCAD was secured from two sources: $1,451,500 million from the U.S. Department of Energy and at least $2,718,409 in cost share from Vermont Tech, which was funded through a bond from the Vermont State College System. While final numbers are still being compiled, the actual cost is closer to $4.5 million. The reasons for the increased cost include:

- Legal costs were close to triple the $50,000 estimate. This was in large part due to the extended and involved permitting process through the Public Service Board for the CPG. Additional costs were accrued during the dissolution of Bio-Methatech.
- The budget for transfer of manure to VTCAD for the initial filling or subsequent start-up daily operations was not included. Many of the farm-based ADs are located immediately adjacent to barns and therefore costs involve piping and pumps from the barn. However, moving manure from the sending farms to VTCAD requires trucking. This decision was made consciously in early stages of the project, as the alternative was to locate VTCAD at the college Farm. This would have required the piping of captured heat across private, state, and town properties to the campus buildings, a significant undertaking deemed inefficient and expensive. Costs to transport manure was estimated in summer 2013 to be approximately $250,000/year. Some of these costs would be balanced by savings within the Farm budget, and it was anticipated that efficiencies would be identified as we got through our first couple years of operation. This is still under development, although using trucks to deliver manure and then off-load or spread effluent on the return trip is one of the identified cost savings.
- Costs for the construction of reception pits at the sending farms were not included in the initial budget estimate. Once the farm manure pits were emptied for the initial filling, daily manure feedstock could not be pumped from the manure pits as the daily volume was too low to pump from the large pits (2000-4000 gallons in a 500,000-gallon pit).
- Individual items cost slightly more than estimated, for example: the initial phase of heat capture and piping, glycol for the heat system piping; and ferric chloride deliveries.
- There were only two small change-orders to the Bio-Methatech contract, less than 0.1% of the contract amount.

We note that a 5% or 10% project contingency budget item, typical for large construction projects, was not included as in the early stages of the project budget creation as it made the overall project costs seem too daunting. However, cost overruns are to be expected and should be planned for. We also note that although some of the Vermont Tech faculty time was directly charged to the project, a significant amount of hours were volunteered by various faculty members from feasibility phase through on-going operations.

Because of the construction delays and the longer than expected time to get to full operation, the costs of construction and start-up has blurred with on-going operations.

Operating costs

Operating costs are available for Fiscal Year 2015 (July 1, 2014-June 30, 2015), although due to the mechanical and feedstock challenges and the biogas balloon repair period, reliable data has not yet been obtained for routine operations. We received $128,000 in revenue for FY 2015, against costs of $252,000, resulting in a loss of $124,000 for the year. The VSC bond and finance repayment costs are not included.

**Costs do not include repayment of the bond and finance costs*

CATEGORY	FY 2016 BUDGET
Salaries & Wages	$107,950
Supplies	$10,000
Insurances	$5,000
Utilities	$29,300
Repairs/Maintenance Agreements	$30,000
Prof. Services (trucking)	$60,000
Misc.	$4,500
Total Costs	**$246,750**
Revenue	**$275,000**
Total*	**$28,250**

Heat Capture Economics

Phase 1 of the heat capture portion of the project has been completed. Anticipated savings for VTCAD heat capture is shown below, from a Heating Interconnection study completed by LN Consulting, Inc. in February 2013.

SYSTEM	PHASE	PROBABLE COST	FUEL SAVINGS	SIMPLE PAYBACK
Hot Water to Maintenance	1	$75,000	$9,700	7.7 years
Hot Water to Auto Center Bldg	—	$125,000	$6,950	18.0 years
Hot Water to Nutting Dorm	2	$260,000	$42,130	6.2 years
Hot Water To Green Hall	3	$80,000	$23,069	3.5 years
Hot Water to SHAPE pool	4	$150,000	$31,075	4.8 years

Due to the long payback of using captured waste heat from VTCAD for the previously named Auto Center Building, this option was not included in funding and planning. We note that Phase 1 costs were closer to $125,000, we anticipate updating costs and savings as we move forward with funding and implementation.

LEVERAGING OUR SUCCESS: NEXT STEPS

Now that daily operations can nearly be described as "routine," much of the "real work" can begin. Ongoing plans and goals are discussed below.

OPERATIONS

Once we have understood the impact and effect of each of the food processing materials that we are now feeding, we will slowly add pre-and post-consumer food residuals to the VTCAD diet. This should happen by the end of 2015. Food waste will be characterized physically, chemically and microbiologically and the efficiency of grinding/pulping and pasteurization will be evaluated. Operational data will demonstrate the effects on energy output and process stability.

We will determine the costs, benefits and timing of construction of the heat transfer loop that will allow waste heat from VTCAD to be used to heat four campus buildings. This phase of the project will likely occur after operation of VTCAD is clearly able to cover the costs of the bond used to build the project.

The VTCAD team will create and post a complete set of operational Standard Operating Procedures (SOP) for training and to aid others operators using a variety of feedstock materials. SOPs will include diet formulation and directions for simple operational lab testing. We had hoped to receive an operations and maintenance manual from Bio-Methatech, but need to create documentation in lieu of those materials.

DATA COLLECTION AND RESEARCH

We will continue to test and characterize feedstock materials in order to optimize digester health and energy output. This will include microbiological study of feedstock mixtures before and after digestion and before and after pasteurization. Outside laboratories will be used and some in-house testing will be developed. We will review herd health data and bulk tank milk testing data during the farm's transition from wood bedding to separated solids and for the first year of solids bedding. We will characterize liquid effluent and quantify the effects of effluent fertilization on cropping procedures, costs and yields. This information will help us understand how to maximize use of recycled nutrients without runoff and negative impacts on water quality. If funding can be obtained, we would like to conduct water quality studies of streams and ponds on fields being fertilized with effluent. And we will complete a nascent Microsoft Access database for feedstock, operational and nutrient management data.

We will work with Grow Compost to map the collection route for VTCAD feedstock. This information will help us understand the economics of food residual collection and the greenhouse gas footprint of collection.

We also plan a thorough economic analysis of VTCAD operation and the effects on farm and college operations and economics. This analysis will include capital costs, maintenance costs, operational costs and personnel costs as well as electric revenue and offset costs provided by co-products. The effect of using tipping fees will be studied.

OUTREACH AND EDUCATION

Tours of VTCAD have been very popular and we plan to add a visitors' guest book to learn more about their interests and questions. We will also create an educational brochure that introduces the AD process, the idea of recovering energy and nutrients from organic wastes and that answers frequently asked questions. The brochure will be printed and posted electronically. We also plan to create a video version of our popular AD tour.

Updated feedstock and operational data presented in this report will be posted to our websites on a monthly basis. We'll add links to news from our facility and about regional and national progress in AD.

Finally, we will continue to work with legislators and state regulators to simplify the permitting process for constructing and operating AD facilities that accept off-farm organic residuals. We believe that our data and experience can provide valuable information to decision makers. For example, we believe that permitting incentives could expand implementation of AD and help Vermont meet ambitious renewable energy and waste management goals.

LOOKING FORWARD

As we finish our first year of operations, Vermont Tech is looking forward to optimizing our operational procedures, improving our in-house laboratory equipment, and expanding VTCAD knowledge and research to a broader audience. Vermont Tech would like to work with identified partners and others to form a Vermont AD consortium whose overall goal is to optimize anaerobic digester operations in Vermont (and the region) through education, data collection and applied research to optimize AD performance, biogas and energy production, nutrient use and regulatory compliance. We will use our operational, feedstock, biochemical data and performance data as a basis for this work. Ideally this consortium would encourage conversation with (small) organic waste haulers to determine what diverted organics would be best suited for AD.

GOALS:

- Provide **training and education for AD operators** by expanding our AD apprenticeship operator program via low residency and on-line delivery to existing AD owners and operators.
  - Convene one-day **annual AD operator conferences** to share experiences, present findings and regulatory updates.
- Create a **library (database) of feedstock materials** (particularly off-farm materials) that lists test results, known use of feedstock, caveats and cautions, complementary feedstock materials, and additional emerging data.
- Provide simple **spreadsheet tools** that we've developed to facilitate AD operation and regulatory reporting
  - Tracking feedstock inputs
  - Tracking effluent use and nutrient value for nutrient management planning

    - Predicting biogas output dietary balance for AD feedstock mixtures

- **Profile willing AD facilities** in Vermont and the region with a focus on their feedstock materials and operational efficiency.
    - Work with several facilities each year.
    - Using student interns, collect feedstock and operational data and perform routine operational testing.
    - Collect information about genset size, make, maintenance, run-time and efficiency, and whether measures are taken to control or scrub hydrogen sulfide.
    - Add new profiles to our database, making this information publically available.
    - Recommend changes to optimize power production, operation and compliance.
- Provide lab services for **critical operational testing** and train operators to perform simple tests at home.
    - Focus on operational tests most likely to predict digester failure and success.
- **Work with regulators** at VAAFM and ANR to answer their questions about AD.
- In concert with Envirotox, a Vermont based firm, use **bench-scale anaerobic digesters** to:
    - Determine biogas yield of local and available feedstock materials;
    - Measure the inhibitory potential of local and available feedstock materials and dairy farm treatments for hoof health and cleaning of milking parlors;
    - The ability of mixtures of feedstock materials to complement one another and create synergistic biogas yields;
    - Investigate novel feedstock materials like aquatic algae and plants, invasive species, soiled paper and cardboard. Focus on biogas potential, inhibitors and inactivation of seeds of invasive species.
    - Determine the effect of AD conditions and effluent storage on levels of common bacterial pathogens (*E.coli* and *Salmonella*).

Within this wide set of goals, priorities would be determined by the interests of members of the consortium and by funding and capacity.

We hope the information shared in this report is helpful to other organizations considering mixed substrate AD expansion in other parts of Vermont, New England, and rural America.

PRODUCTS DEVELOPED

Vermont Tech maintains an informational website about VTCAD that includes curriculum for the college's anaerobic digester apprenticeship training program

www.vtc.edu/meet-vtc/anaerobic-digester

A description of Vermont Tech's Bioenergy Course

www.vtc.edu/course/mec-3040/bioenergy

REFERENCES & SOURCES

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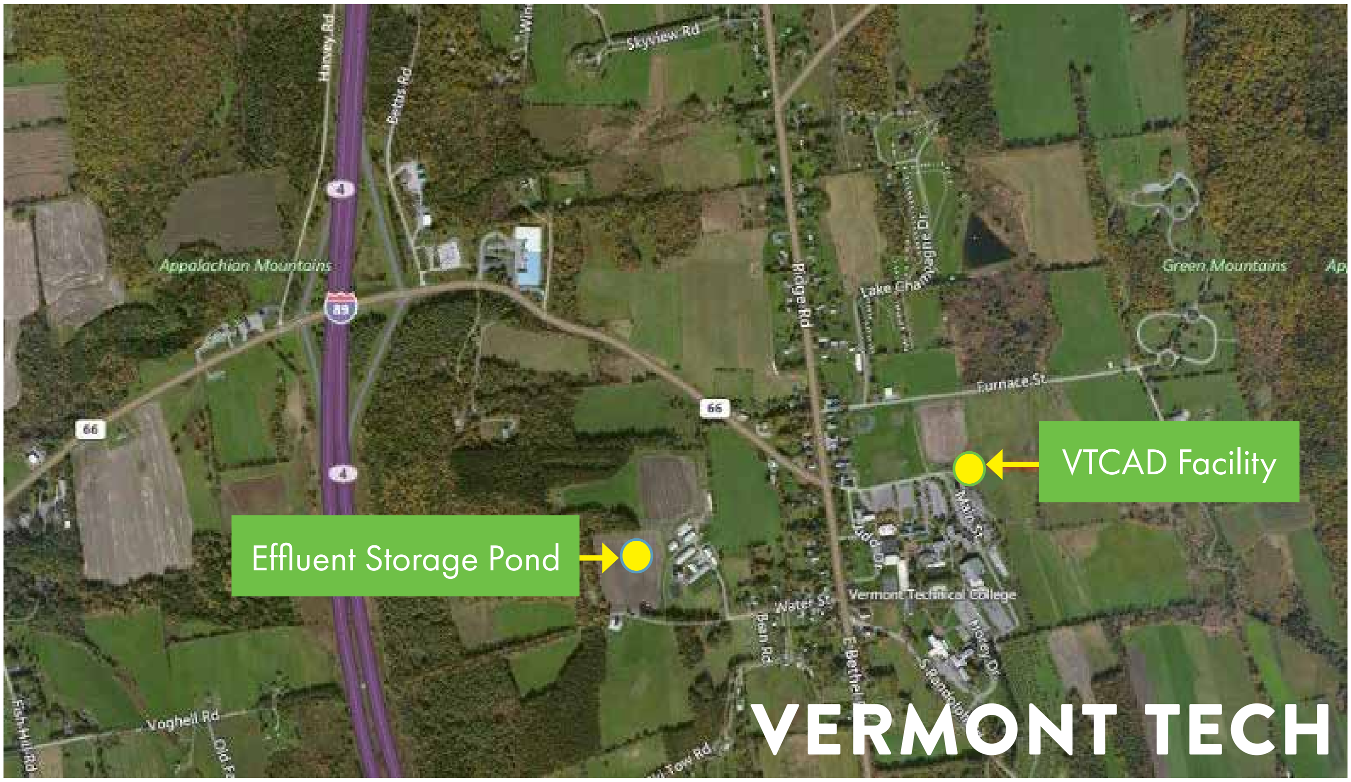
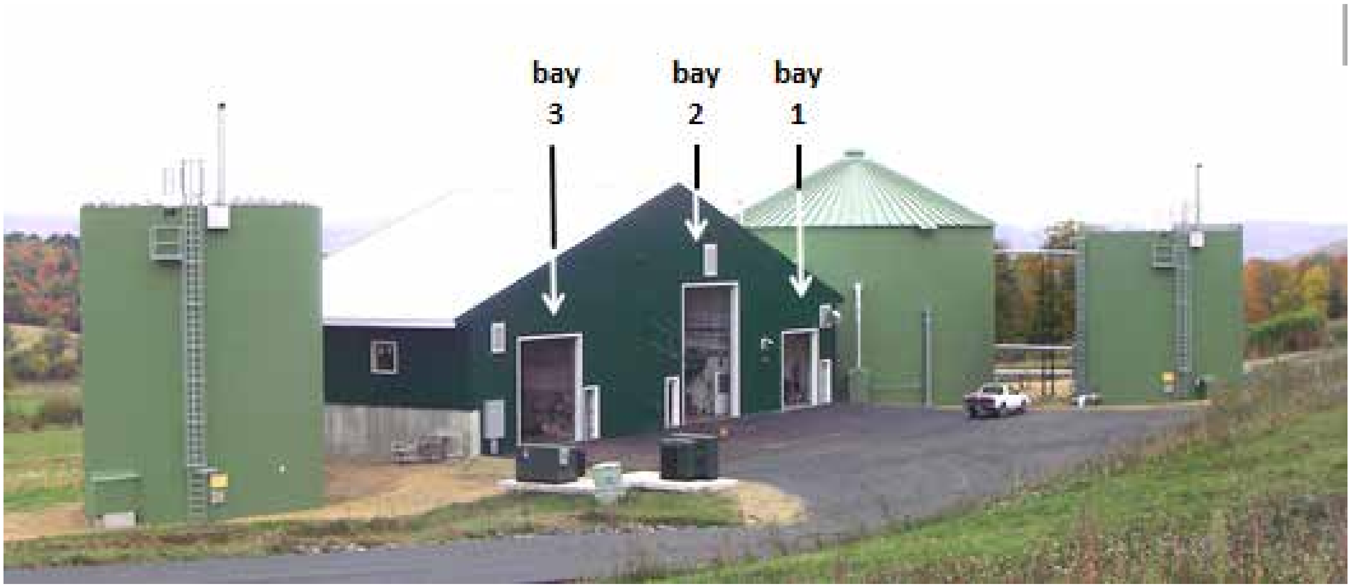
APPENDIX A: VTCAD MAP AND SYSTEM DESCRIPTION

Vermont Tech's Community Anaerobic Digester Facility (VTCAD) is located at our Randolph campus, as shown below. The Randolph campus is located off Route 66 in Randolph Center, VT, east of Interstate I-89 Exit 4.



VTCAD utilizes a two-stage complete-mix technology that separates the aerobic and anaerobic steps of digestion in two tanks, and continuously mixes and stirs feedstock to increase efficiency of microbial digestion.

The anaerobic digestion facility consists of one 40' x 100' building, three exterior tanks and an external flare. The wood truss/wood frame building sits on a concrete slab and is covered by sheet metal siding and a standing-seam metal roof. The building is divided into three bays each with a large overhead door, a standard door, and additional ventilation. Bay 1 is located at the southern end, Bay 2 in the center, and Bay 3 at the northern end of the building. Bay 1 houses the electrical generating engine, the electrical control room and the heat exchange system.



Bay 2 is the feedstock receiving, storage, preparation and wash-up area. This bay contains:

(a) a 16,000-gallon preparation tank, centrally located and installed below grade, to receive manure, dry organic materials, and substrates directly from off-loading trucks or mixed from the other tanks and/or the pasteurizer;

(b) a 9,000-gallon tank to receive fats, oils, and grease (FOG);

(c) two additional 9,000-gallon tanks to receive other liquid feedstock;

(d) a 1,250-gallon pasteurizer;

(e) macerator/chopper equipment for food residual processing;

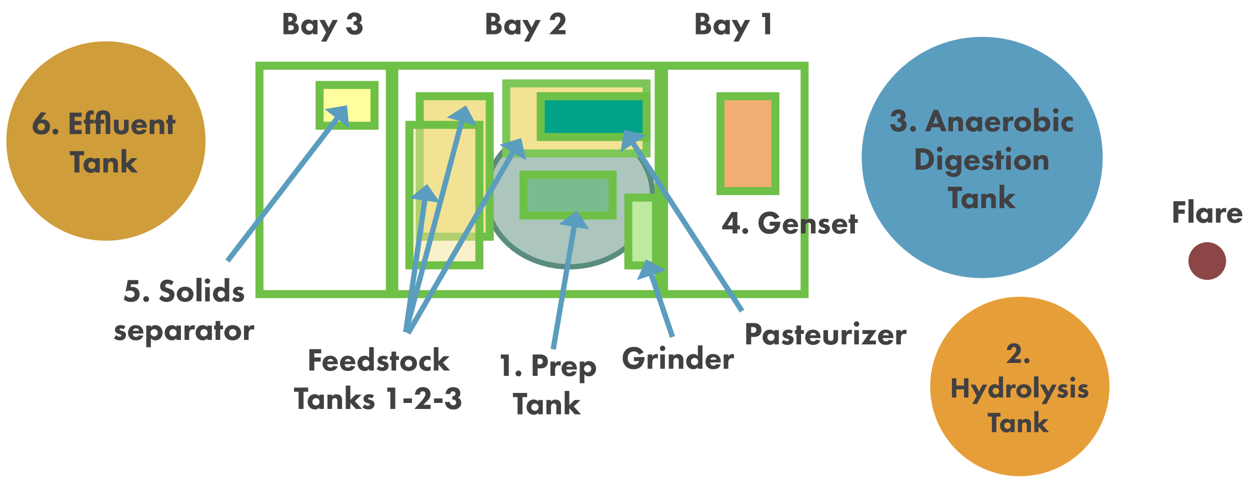
(f) various pumps; and

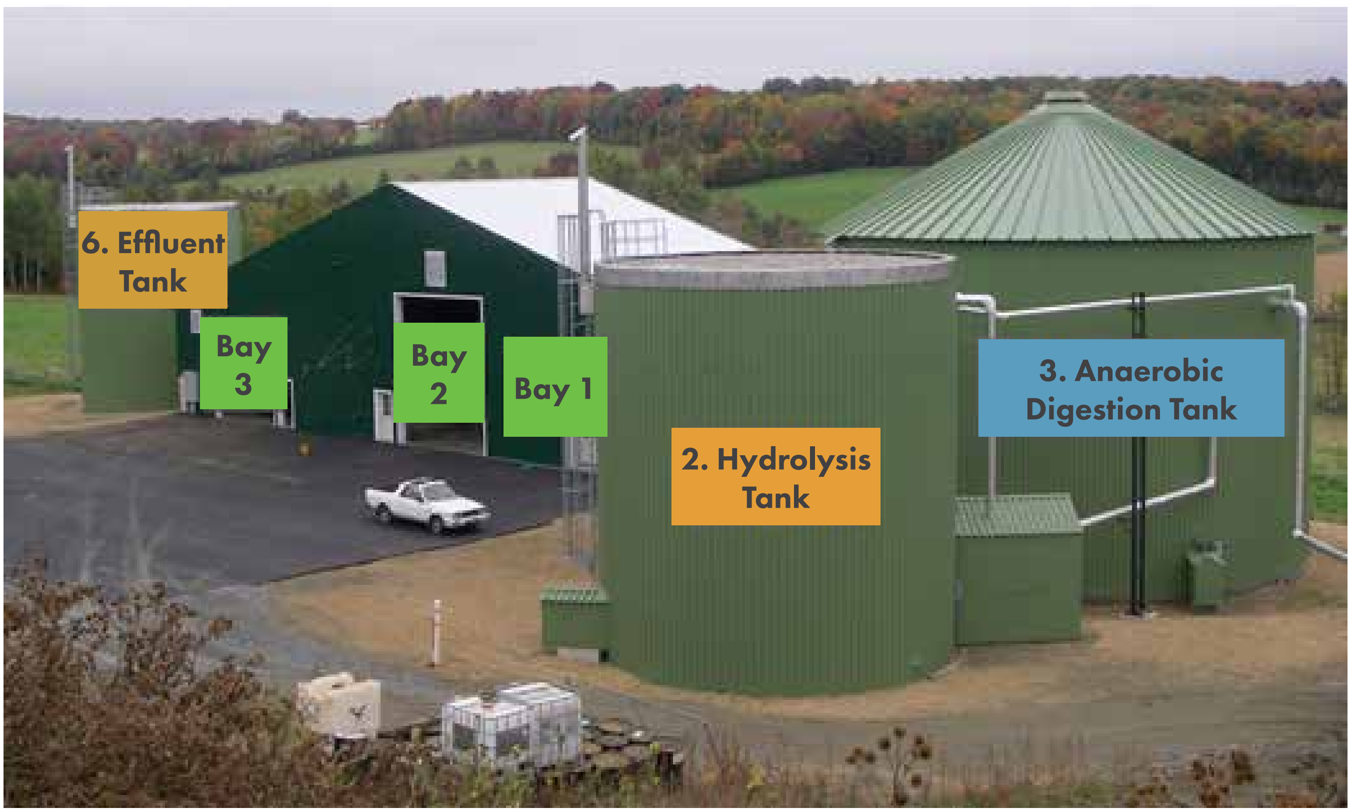
(g) a computer system with touchscreen control and monitor used to observe and operate the entire anaerobic digestion facility. A hose allows for washing of equipment and totes used to deliver food residuals.

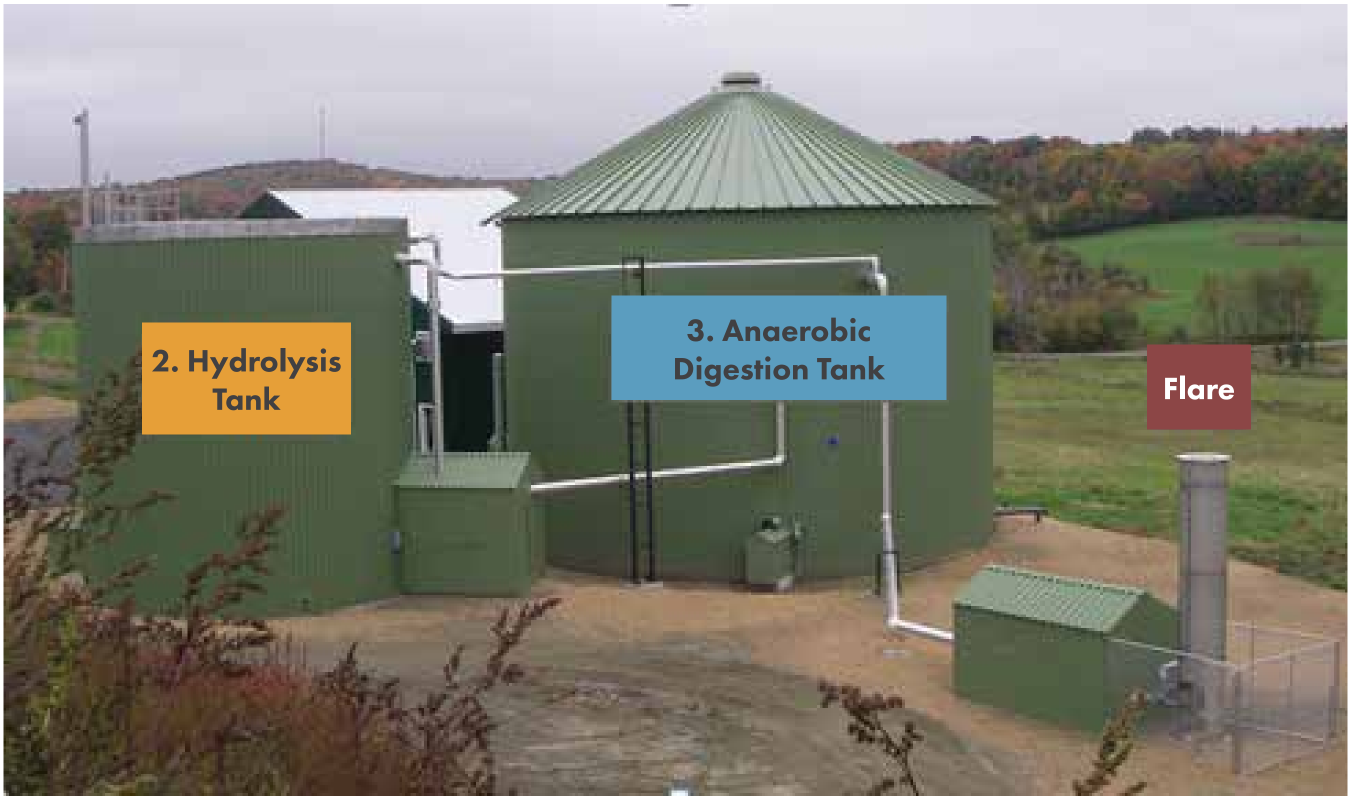
Bay 3, in the northern end of the building, houses a screw auger press and conveyer used to separate solids from liquid digestate. The design of Bay 3 allows a loader (bobcat) to scoop up solid feedstock, such as silage or hay, for delivery to the preparation tank in Bay 2 or to load separated solids into trucks or trailers.

All three bays are accessed by large overhead doors controlled from within the individual bay and each bay has a 'people' door. All doors are locked when AD operators are not present. Only authorized VTCAD personnel and Vermont Tech public safety officials have keys to the facility. The AD facility area is monitored by security camera.

Figure 1: VTCAD Schematic







The major VTCAD components are:

1. Up to 15,840 gallons of organic material, the daily meal for the digester, are macerated and mixed in the **RECEPTION (PREPARATION) TANK** within the AD building. The mixture is balanced for pH and consistency, heated to about body temperature, and can be pasteurized if necessary. Ferric chloride from an adjoining tote and pump system is added to precipitate sulfur and prevent the formation of corrosive hydrogen sulfide gas. Meal preparation takes 1 - 4 hours.

2. The meal is pumped to the 135,000-gallon **HYDROLYSIS TANK** that holds 106,000 gallons of feedstock and here the first microbial process takes place. In the presence of oxygen, microbes break down food particles and large (macro) molecules into small organic acids via the aerobic process of fermentation. Because the tank is sealed, the microbes use up all the oxygen in the feedstock. After 3 – 6 days the hydrolyzed feedstock is pumped to the anaerobic digestion tank.

3. The 410,000-gallon **ANAEROBIC DIGESTION TANK** holds 317,000 gallons of hydrolyzed feedstock and is topped by a gas bladder that can hold 93,000 gallons of biogas: a mixture of methane, carbon dioxide, hydrogen gas and water vapor. The second microbial process, anaerobic digestion, happens here in the absence of oxygen. Methane forming microbes (that cannot function in the presence of oxygen gas in the hydrolyzer) break the organic acids down into methane, carbon dioxide and hydrogen gas in a process that takes roughly 20 days. Efficient digestion requires complete mixing. An impeller moves feedstock around the tank in a very slow vortex. A chopper pump can move material from the bottom of the tank to the top or

Figure 2: Lipp Anaerobic Digester Tank

Feedstock is mixed both vertically and horizontally to increase efficiency

Undigested material can be purged during operations.

vice versa to achieve complete mixing. Any solid material falls and can be removed through a valve in the conical bottom of the tank.

4. Biogas travels from the bladder in the anaerobic tank to the **GENERATING ENGINE (GENSET)** where it is combusted to create electricity and heat. The electricity is sold to ***Green Mountain Power***, and the 'waste' heat is captured, transferred to the campus heating plant, and will be used to heat campus buildings. At full capacity, the digester should produce 2.8 million kilowatt hours of electricity per year. Excess biogas is burned via a flare located to the south of the hydrolyzer and anaerobic digestion tanks.

5. Once digested, the slurry is pumped from the anaerobic tank to a small holding tank in Bay 2, then through to Bay 3. A screw press, or auger, **SOLIDS SEPARATOR** in Bay 3 squeezes effluent into liquid and solid fractions. The solids have 65% moisture content and can be used for bedding for cows, creating compost, or spreading directly on fields for fertilizer.

6. The liquid effluent is pumped to the 115,000-gallon **LIQUID EFFLUENT STORAGE TANK** that holds about one week's worth of material. From there the liquid fertilizer is either spread on fields or moved to a waste storage pond at the campus farm. The pond is designed to safely store 180-days of liquid effluent, assuming full operation levels.

Additional components

FLARE

For safety reasons, and to realize the full environmental benefit of the anaerobic digestion process, biogas must be collected and burned. If VTCAD produces more biogas than the genset can combust, or if the genset is shutdown for maintenance, an exterior **FLARE** will combust the biogas. The stainless steel flare is an enclosed, stand-alone structure approximately 15 feet in height mounted on a concrete base. The flare houses a burner within a cylindrical enclosure lined with refractory material. The flare is equipped with a properly sized screen to minimize visual impacts and prevent blowout of the flame. The flare is equipped and operated via an automatic ignition system to ensure immediate and continuous combustion of any biogas routed to it. This system ensures that the flare ignites whenever gas pressure exceeds a set point and when the genset does not start.

WASTE STORAGE POND

During the winter season liquid effluent cannot be spread on fields and instead is brought to the newly constructed 3 million gallon waste storage pond, located at the Vermont Tech Farm (see map on page 43). The lined pond is capable of holding 180-days of effluent and was designed by Natural Resource Conservation Service, and certified by that agency as designed and built in accordance with NRCS-VT Standard Conservation Practice 313.

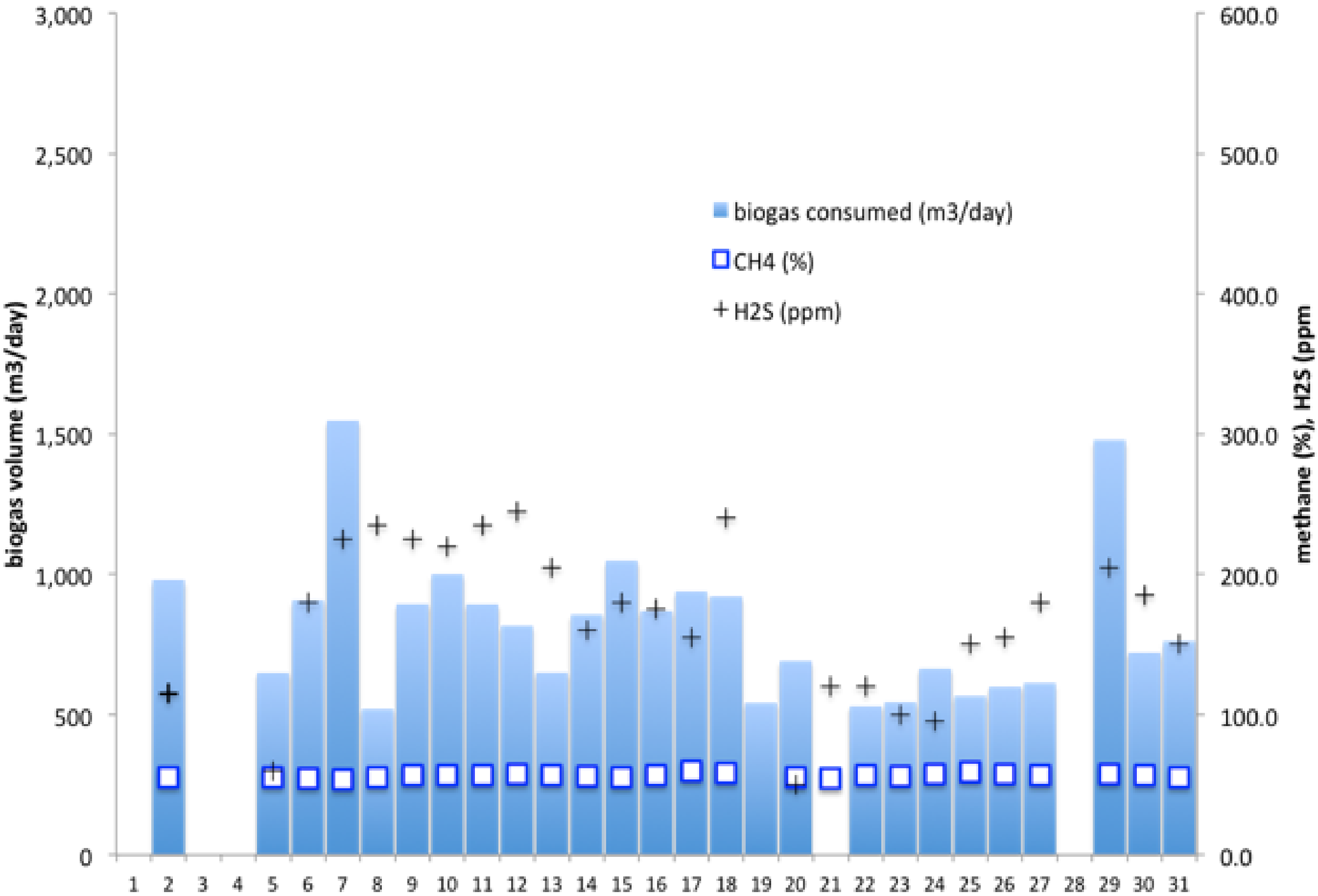
VTCAD Equipment List

DATE	SOURCE	EQUIPMENT	MANUFACTURER	MODEL NO.	SERIAL NO.	COST	INTENDED PURPOSE
June 2014	BioMethatech	Biogas Analyser	Chemec GmbH	BC30	A007-0114-001	$42,000	Measures biogas components
Dec 2013	BioMethatech	Generating Engine	2G Energietechnik GmbH	CHP 2G-KWK-370BGG	SK0912C-BMLB-370188	$407,050	Convert biogas to electricity and heat
Feb 2014	BioMethatech	Flare	Abutec	Abutec 100		$84,400	Burn excess biogas
Feb 2014	BioMethatech	Solid Separator	FAN Separator Gesellschaft m.b.H.	PSS 3.2 - 520	1310383	$60,400	Separate liquid/solid digestate
Feb 2014	BioMethatech	Receiving Tanks (3)	Dominion & Grimm	9,000 gallon, stainless		$2,000	Store feedstock prior to use
Feb 2014	BioMethatech	Pasteurization		Heat exchanger		$124,444	Pasteurize food scraps
Feb 2014	BioMethatech	Thermal Liquid Tank	Dominion & Grimm	1,250 gallon, stainless		$5,000	Pasteurize food scraps

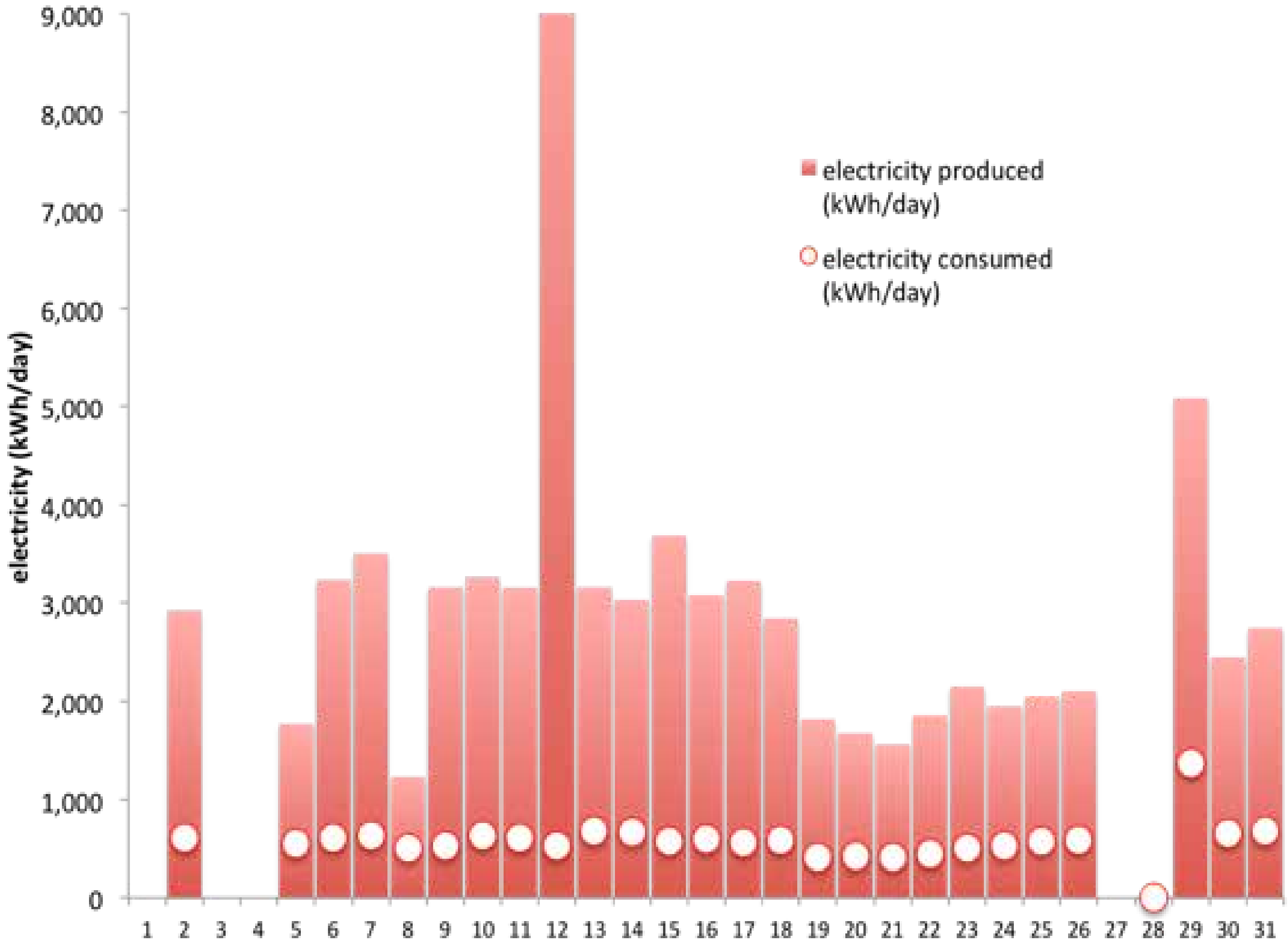
APPENDIX B: DAILY OPERATIONAL DATA FOR 2015

January 2015

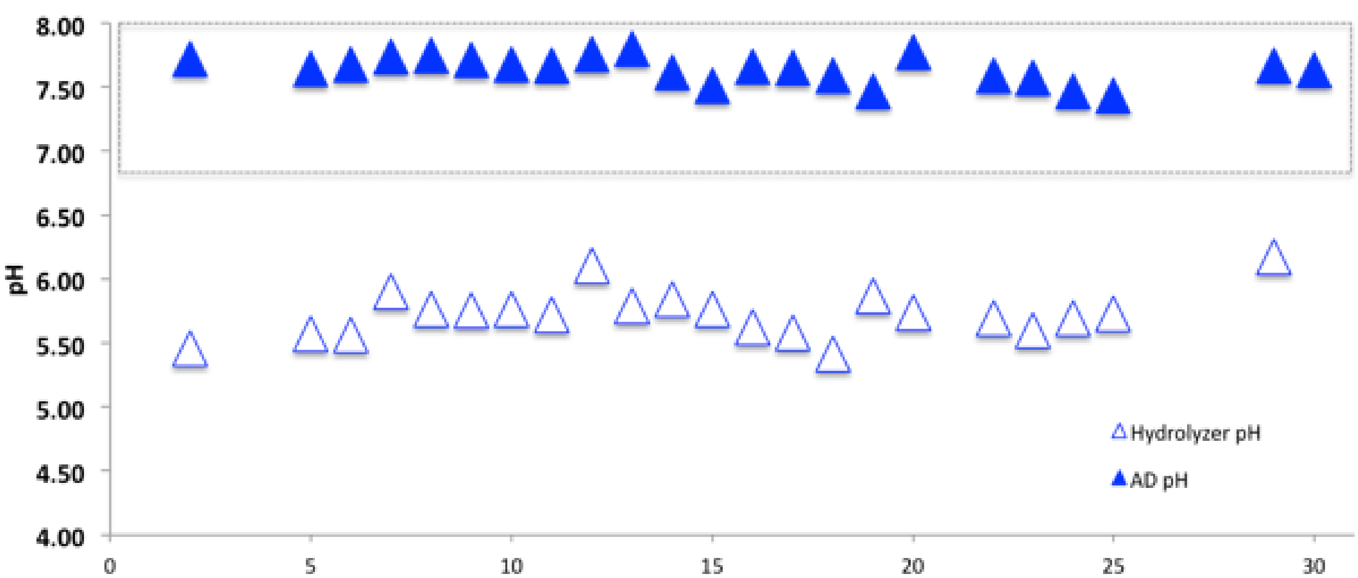
BIOGAS VOLUME & QUALITY



ELECTRIC OUTPUT & CONSUMPTION



TANK pH



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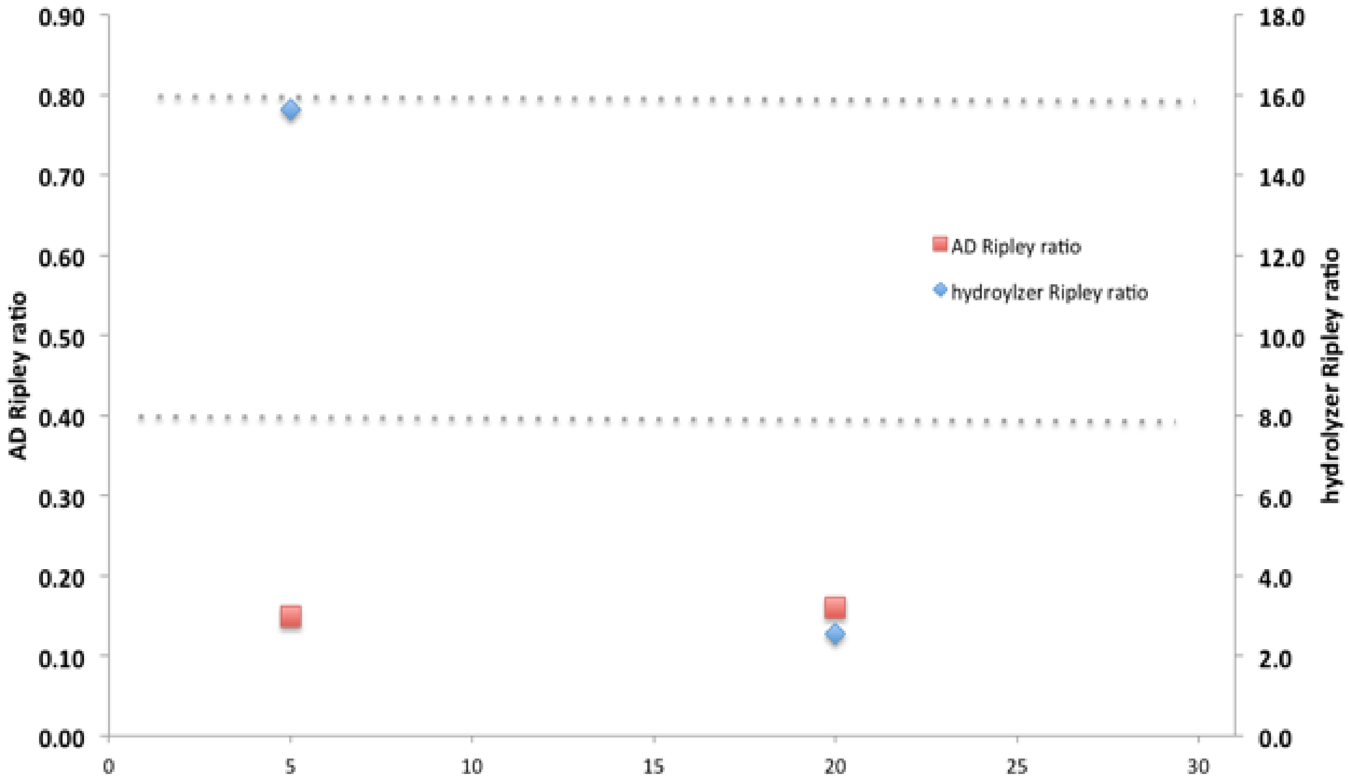
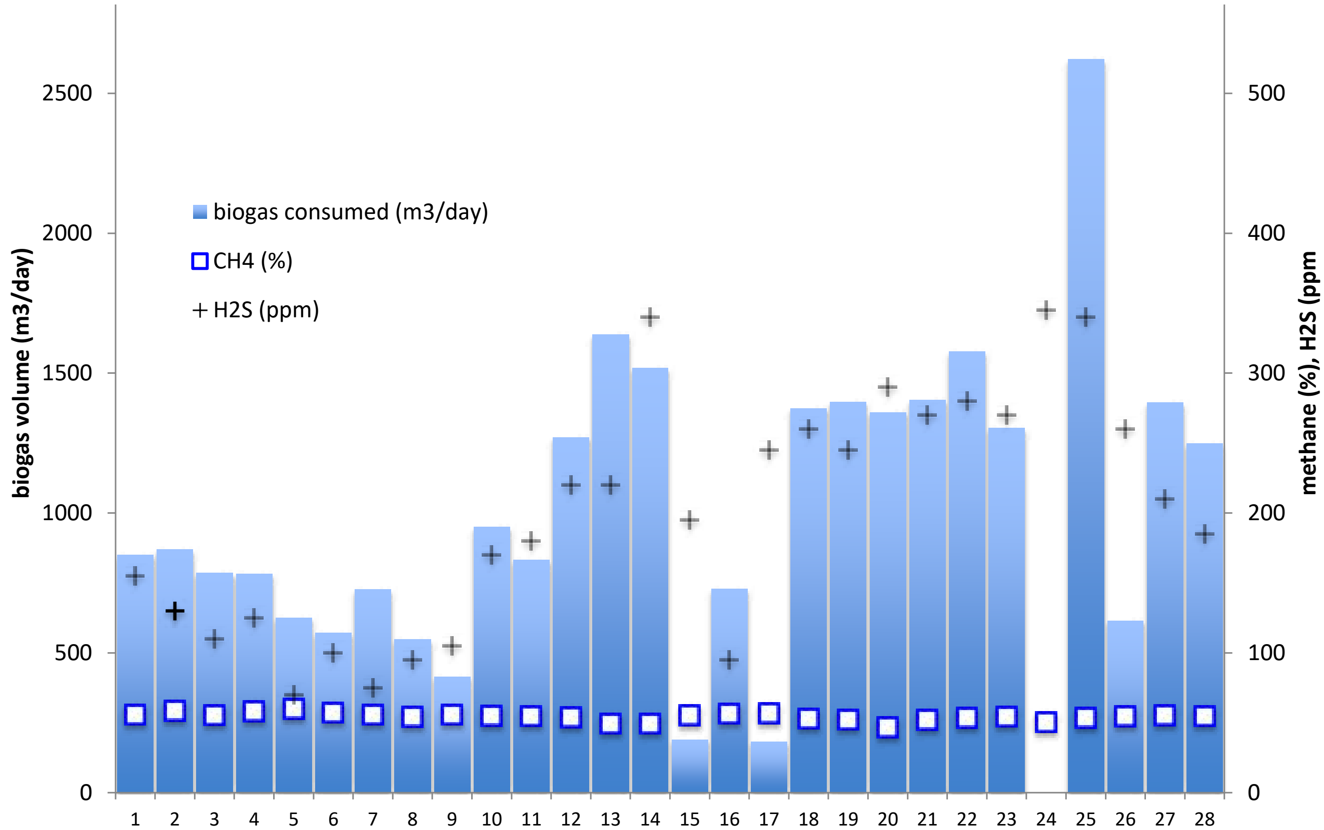
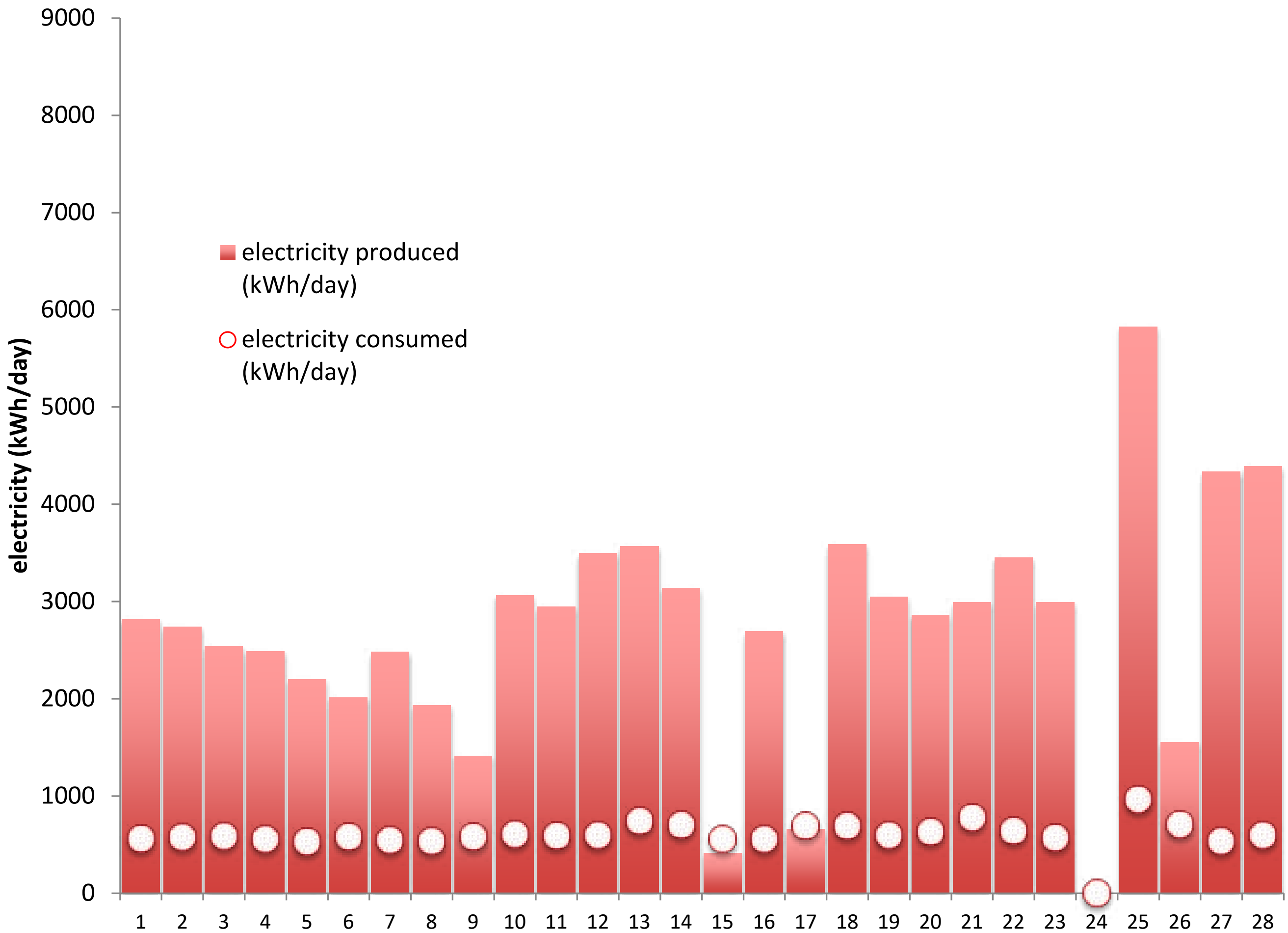


February 2015

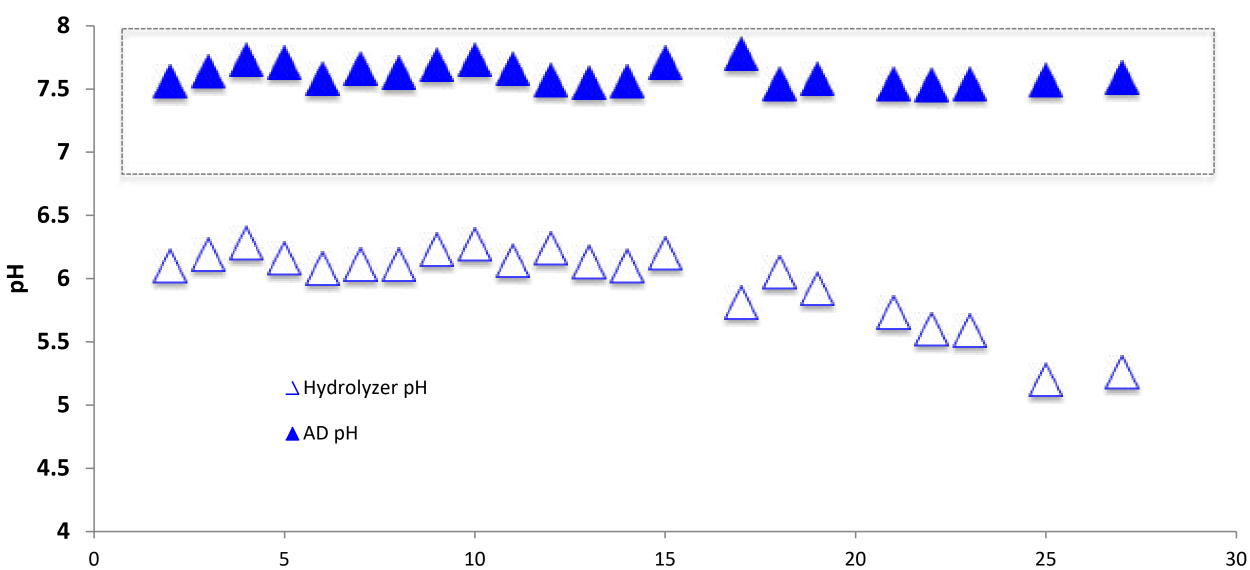
BIOGAS VOLUME & QUALITY



ELECTRIC OUTPUT & CONSUMPTION



TANK pH



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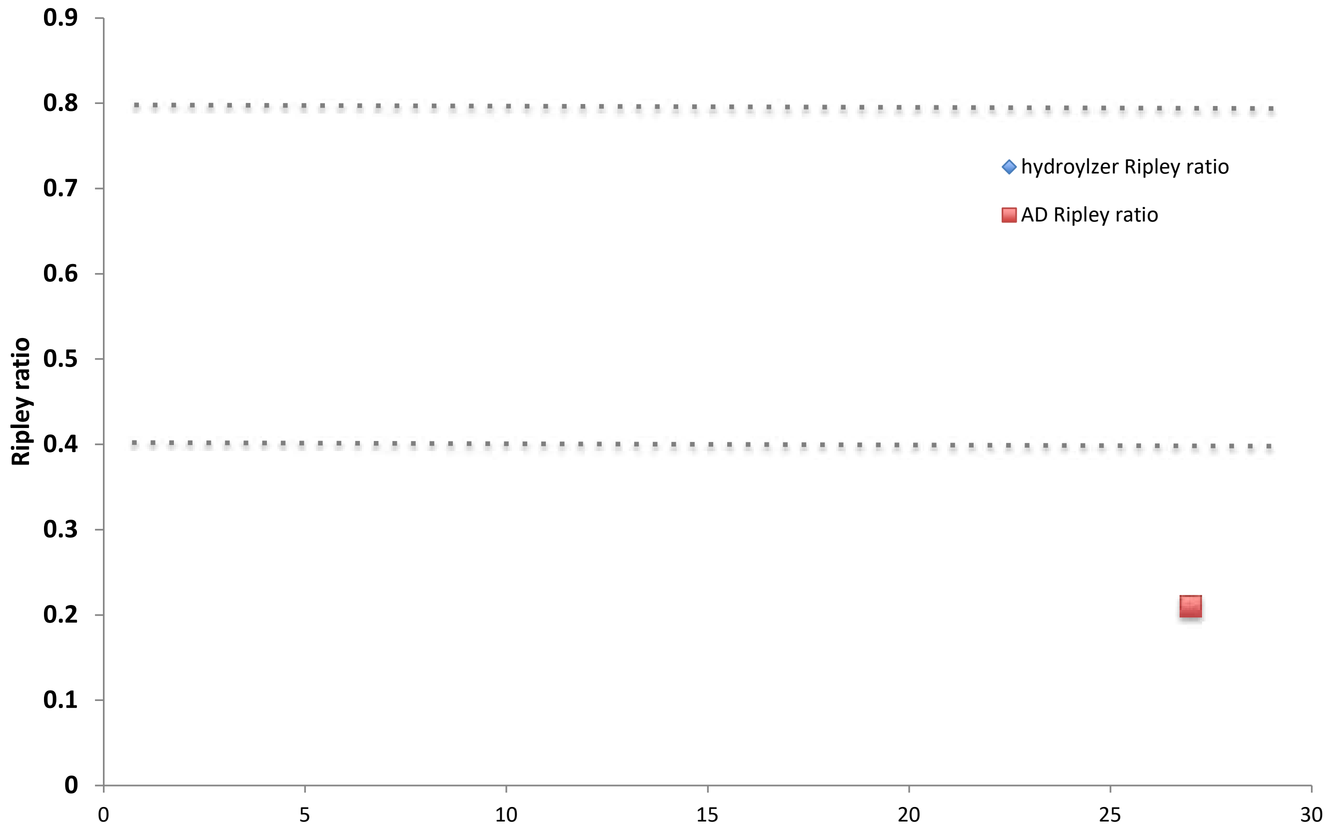
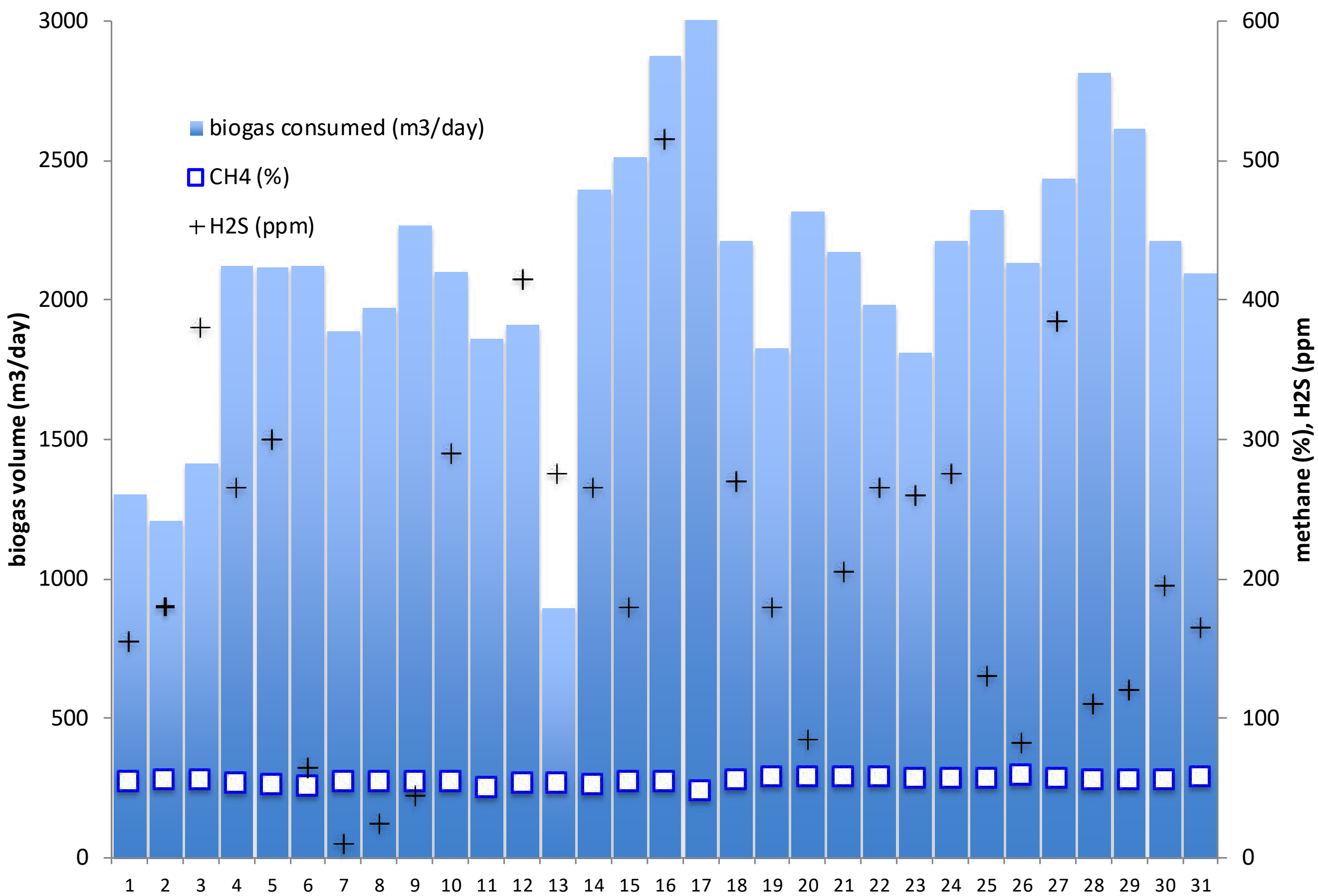
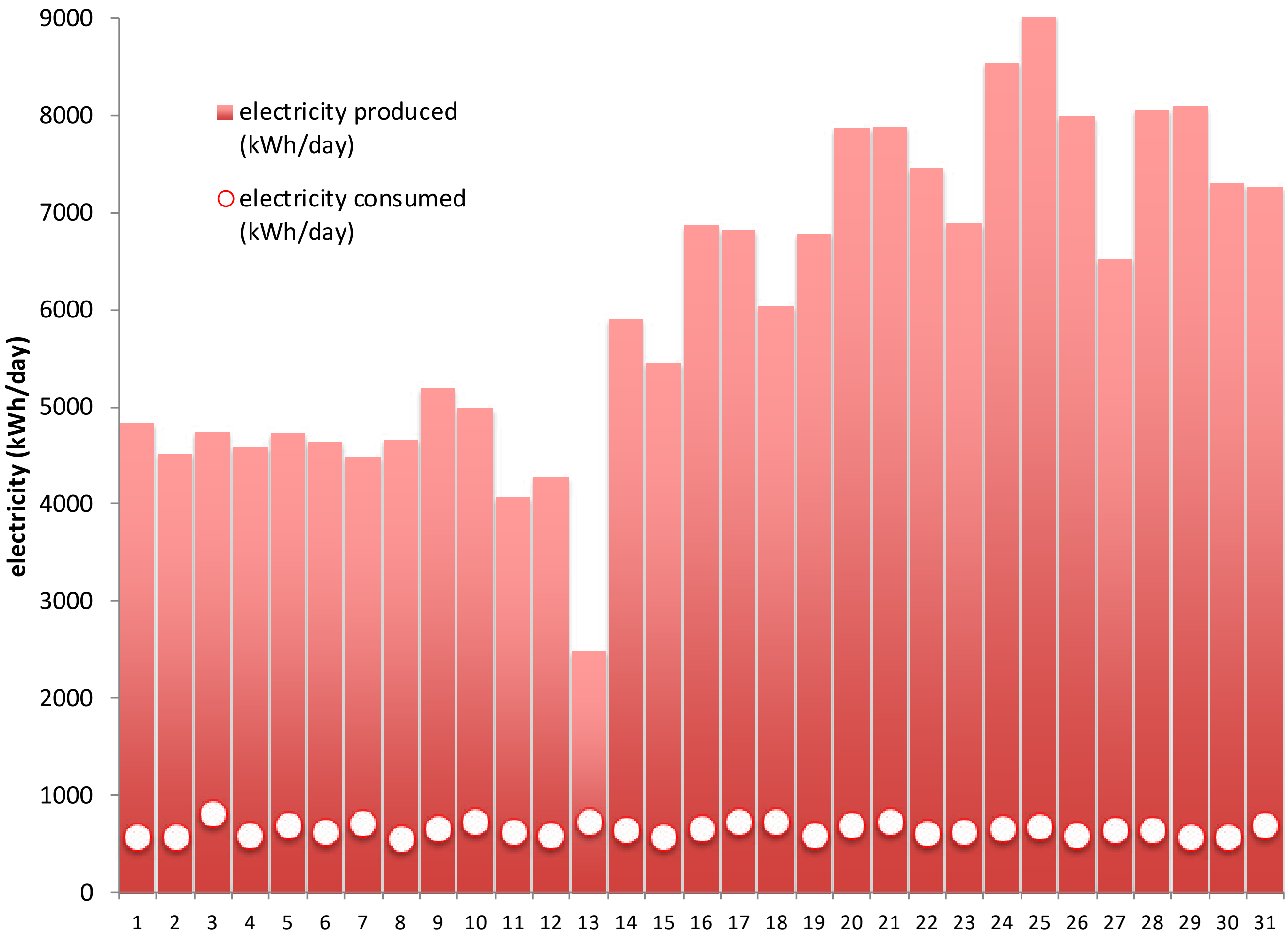


March 2015

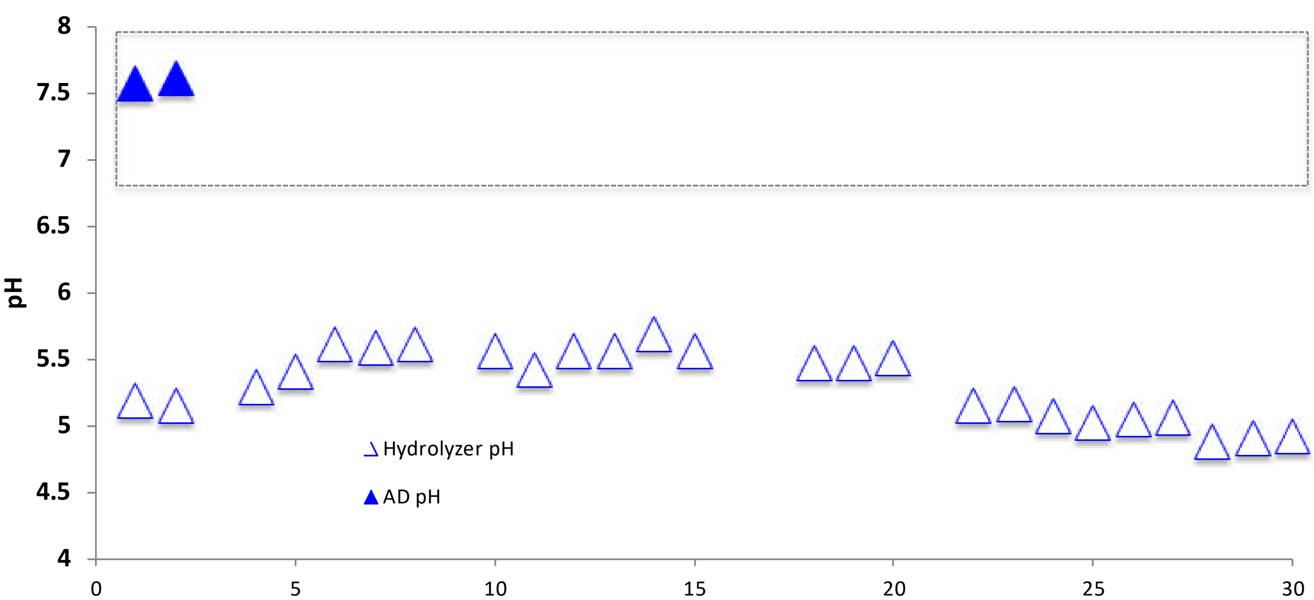
BIOGAS VOLUME & QUALITY



ELECTRIC OUTPUT & CONSUMPTION

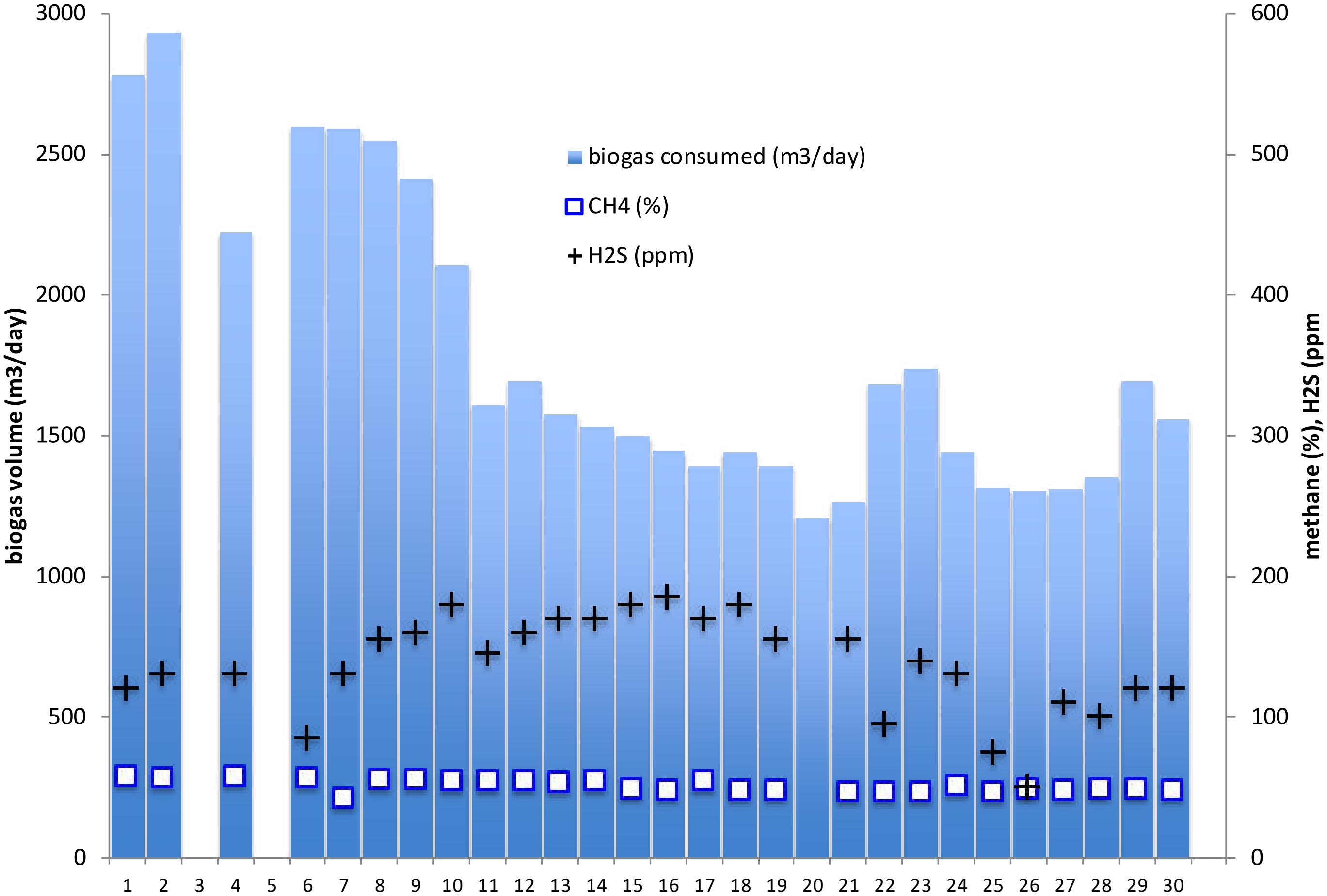


TANK pH



April 2015

BIOGAS VOLUME & QUALITY



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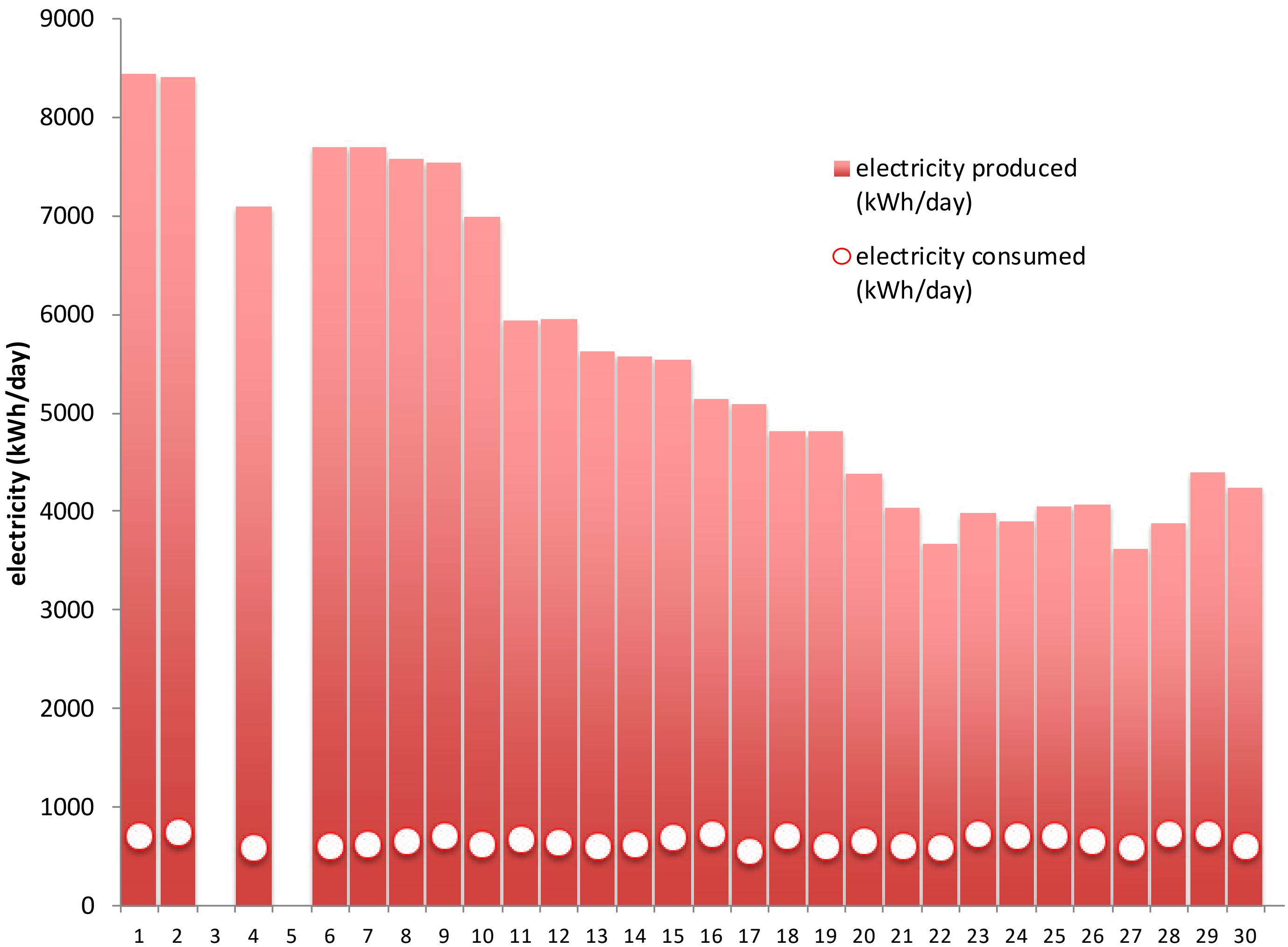
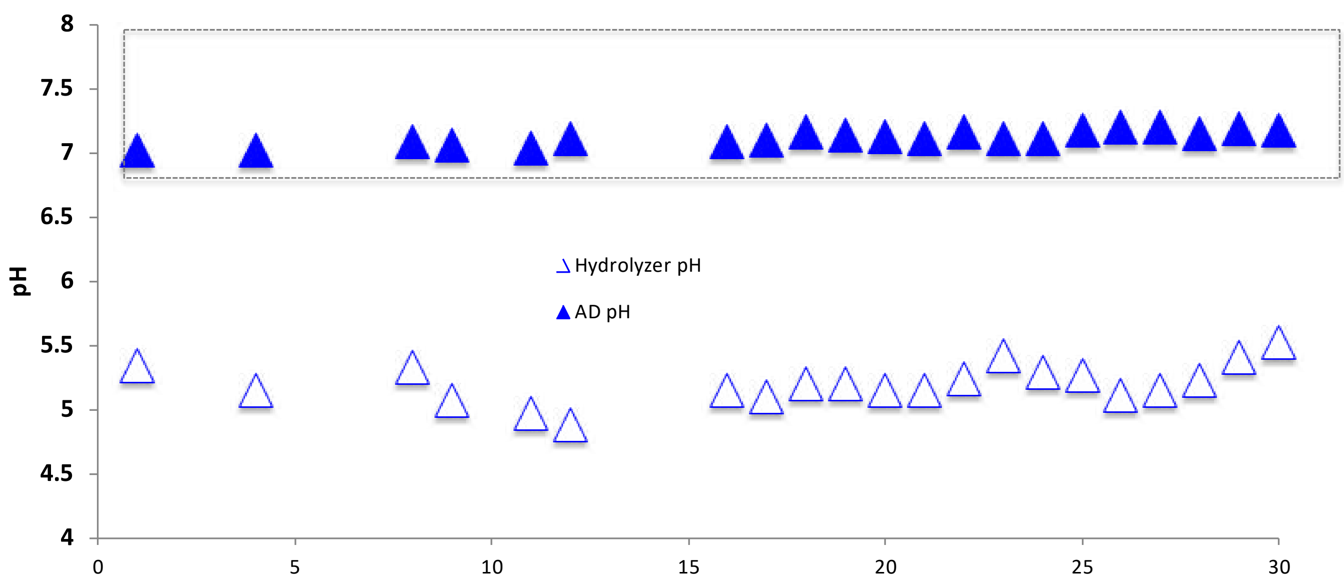


TANK pH



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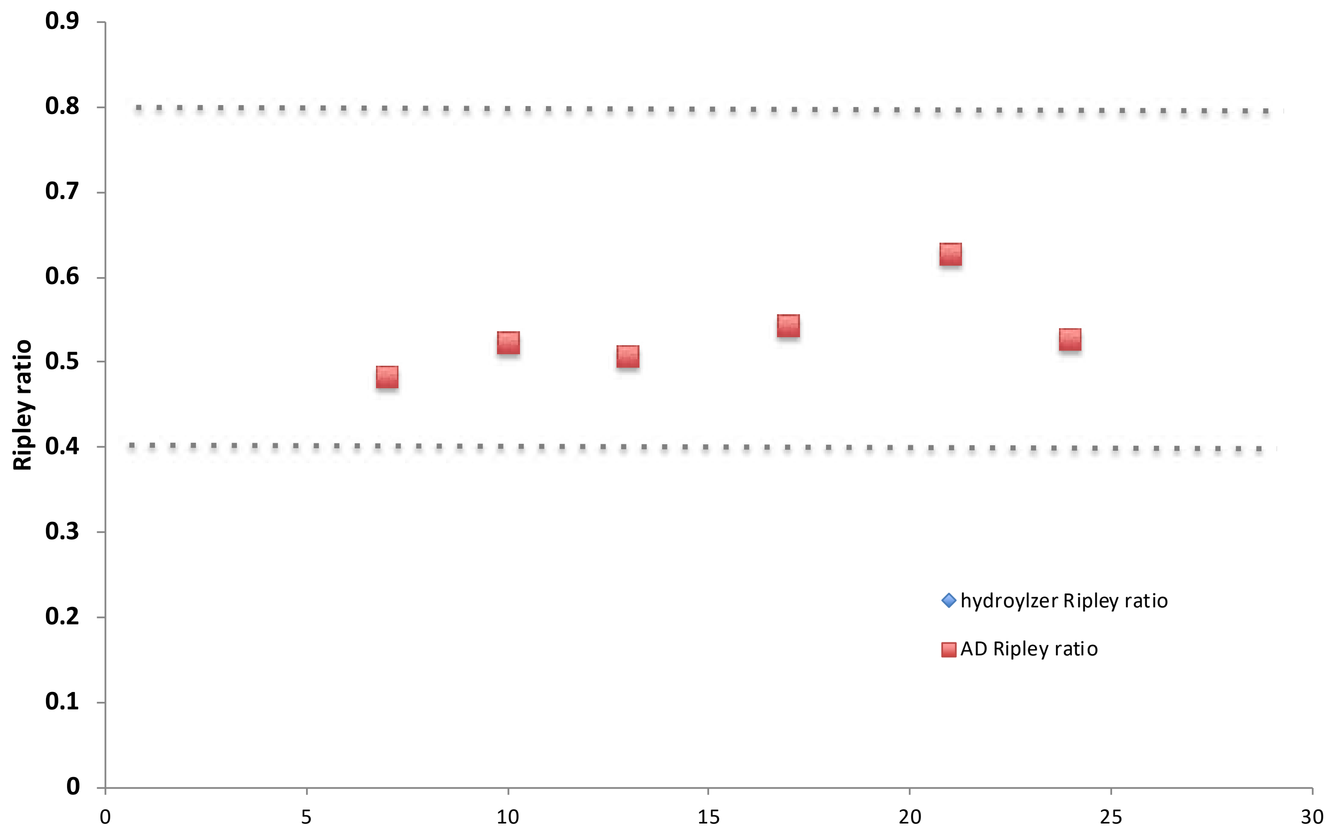
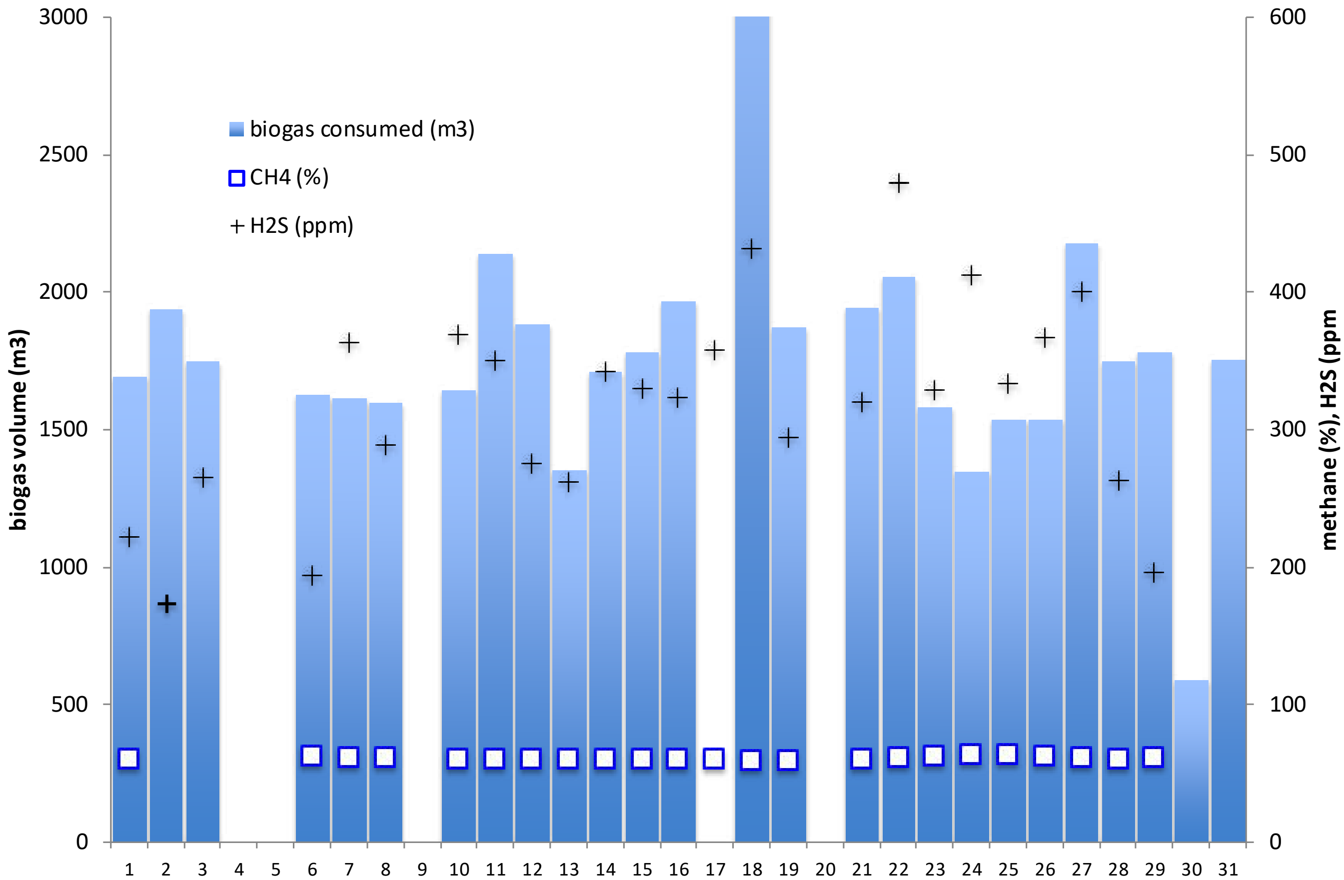
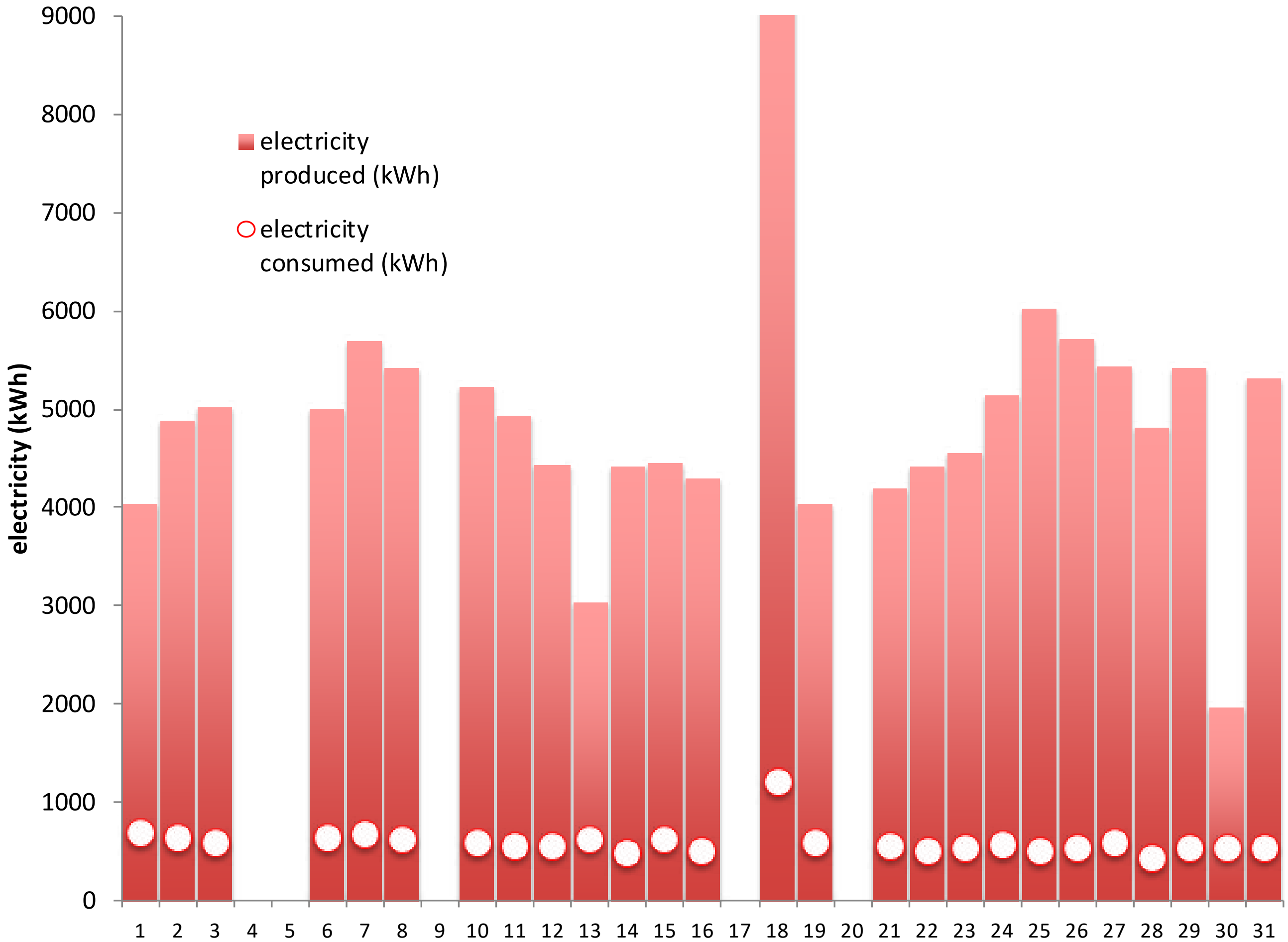


May 2015

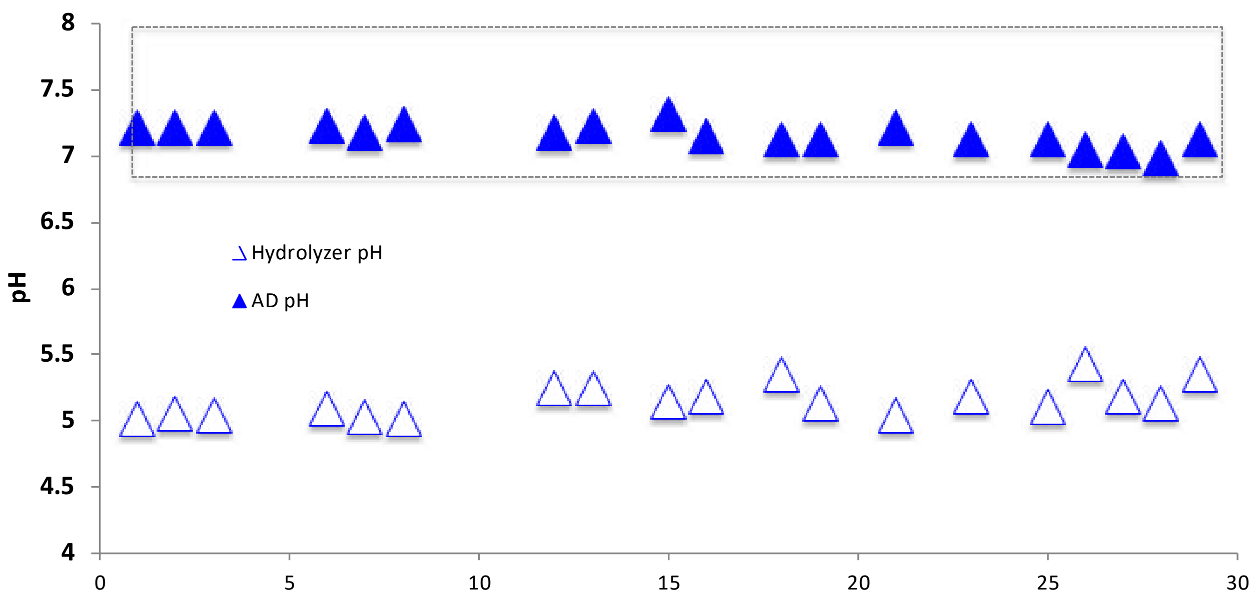
BIOGAS VOLUME & QUALITY



ELECTRIC OUTPUT & CONSUMPTION



TANK pH



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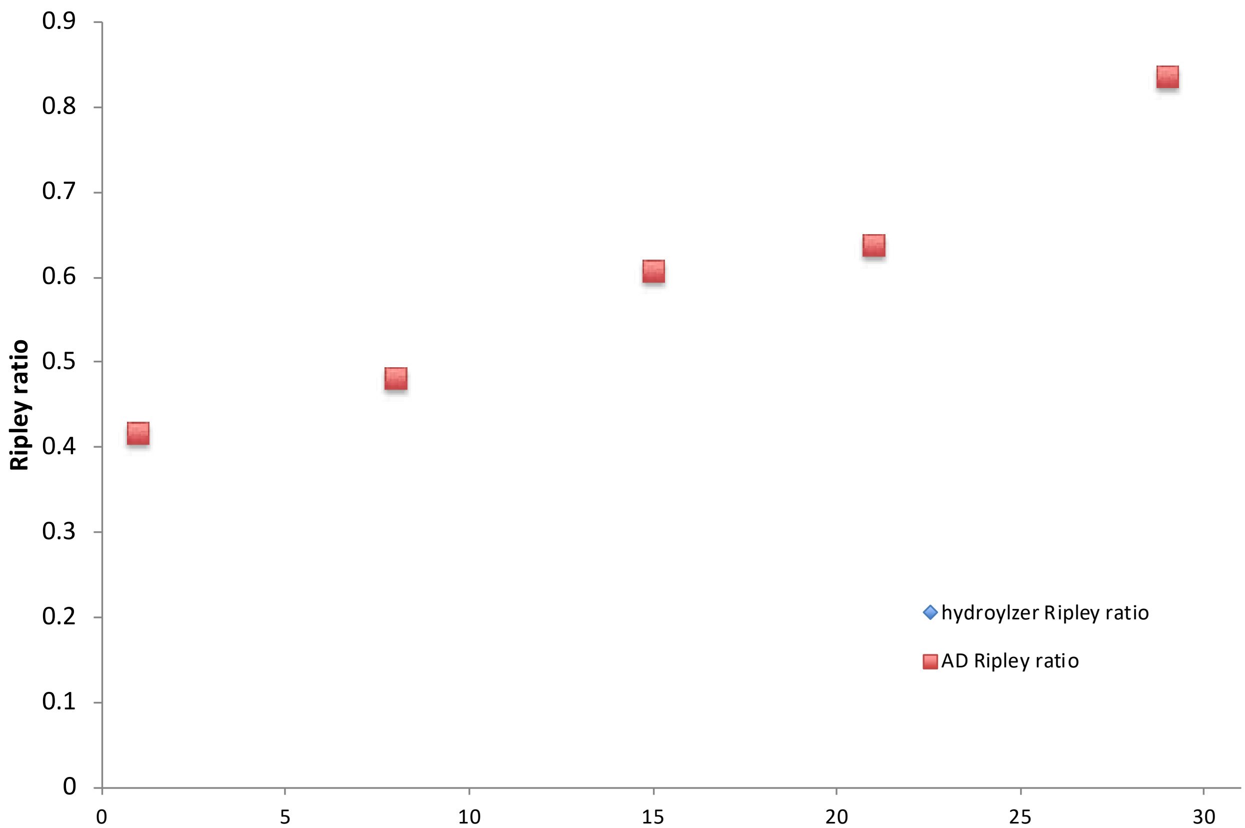
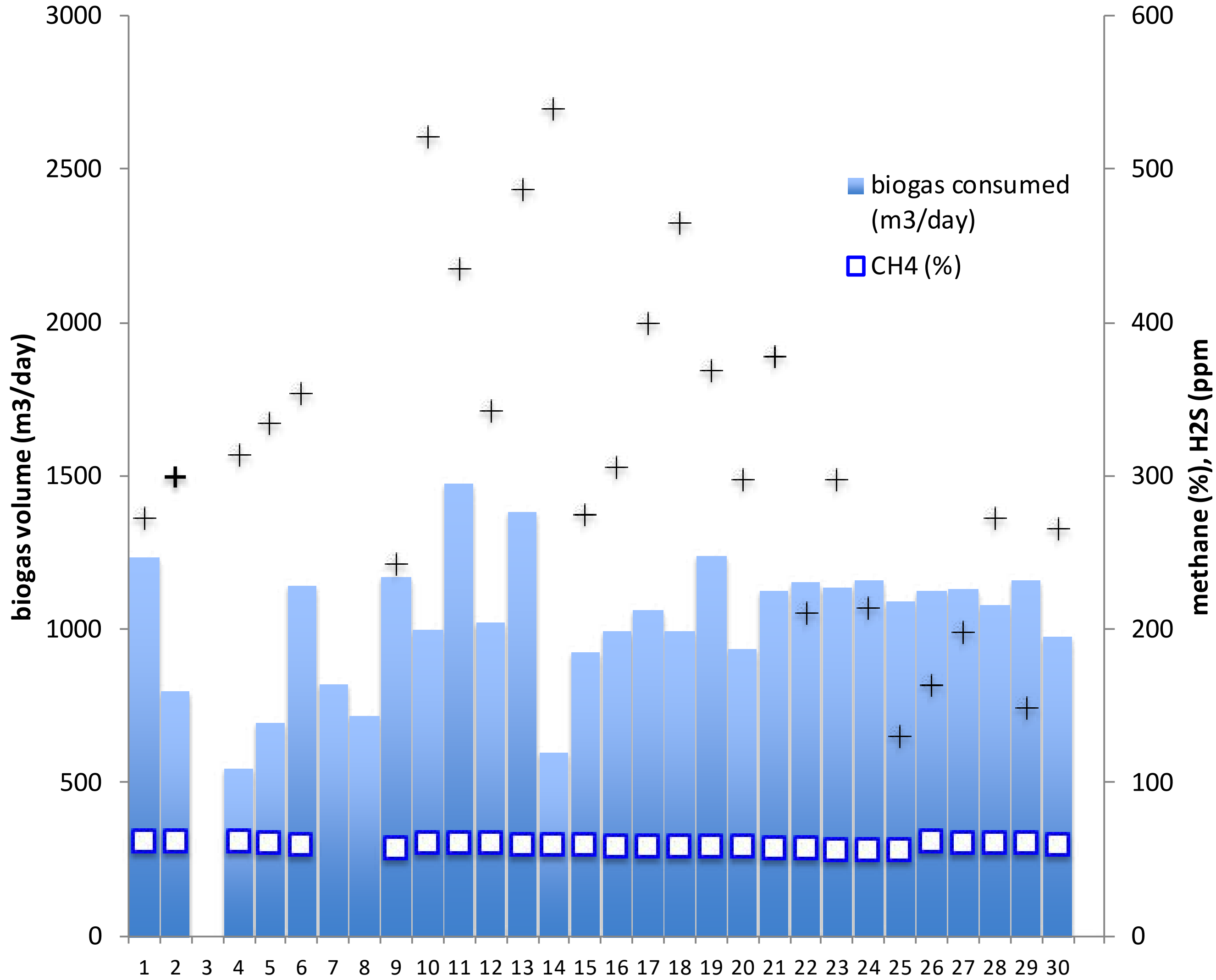


June 2015

BIOGAS VOLUME & QUALITY



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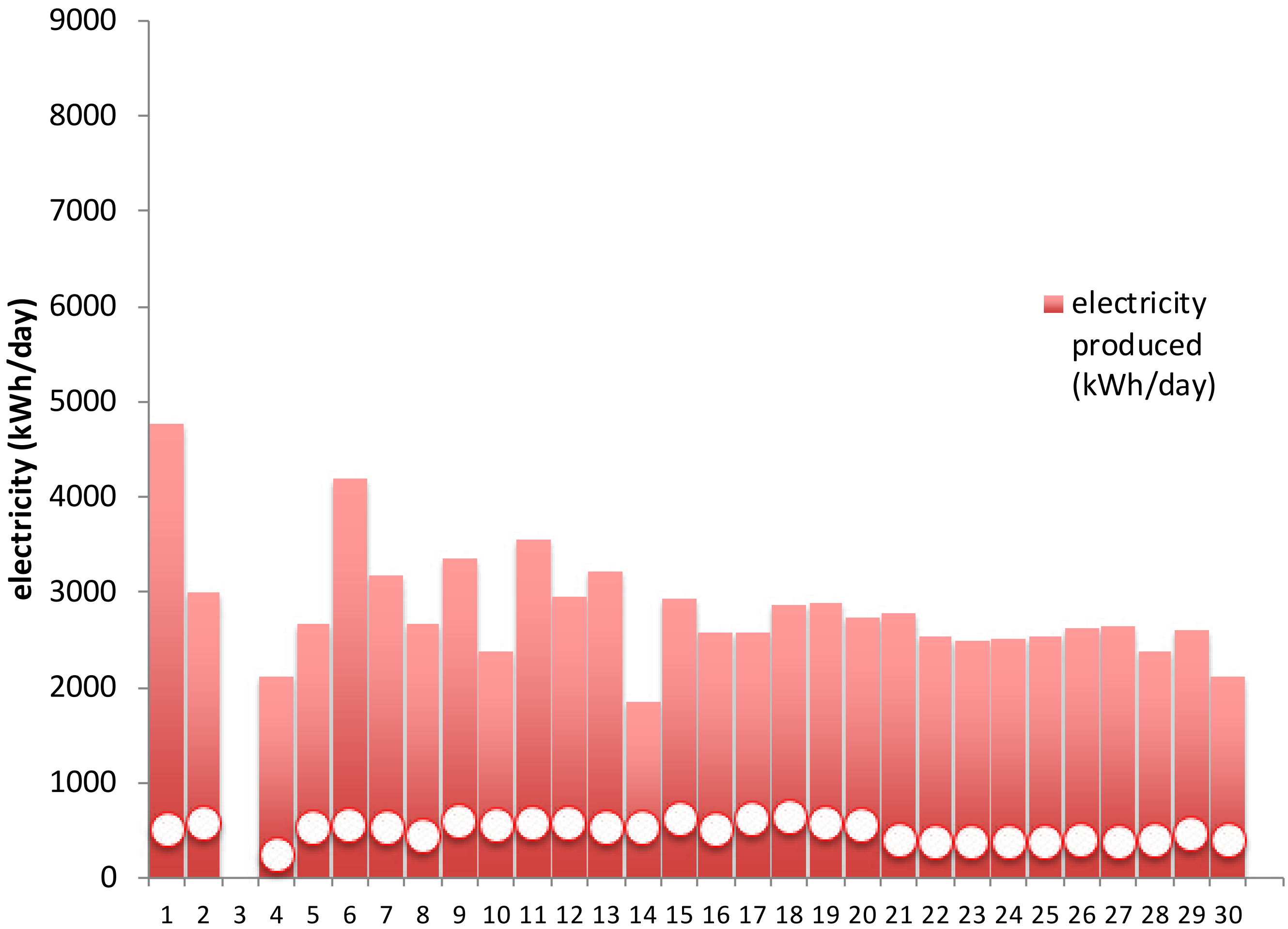
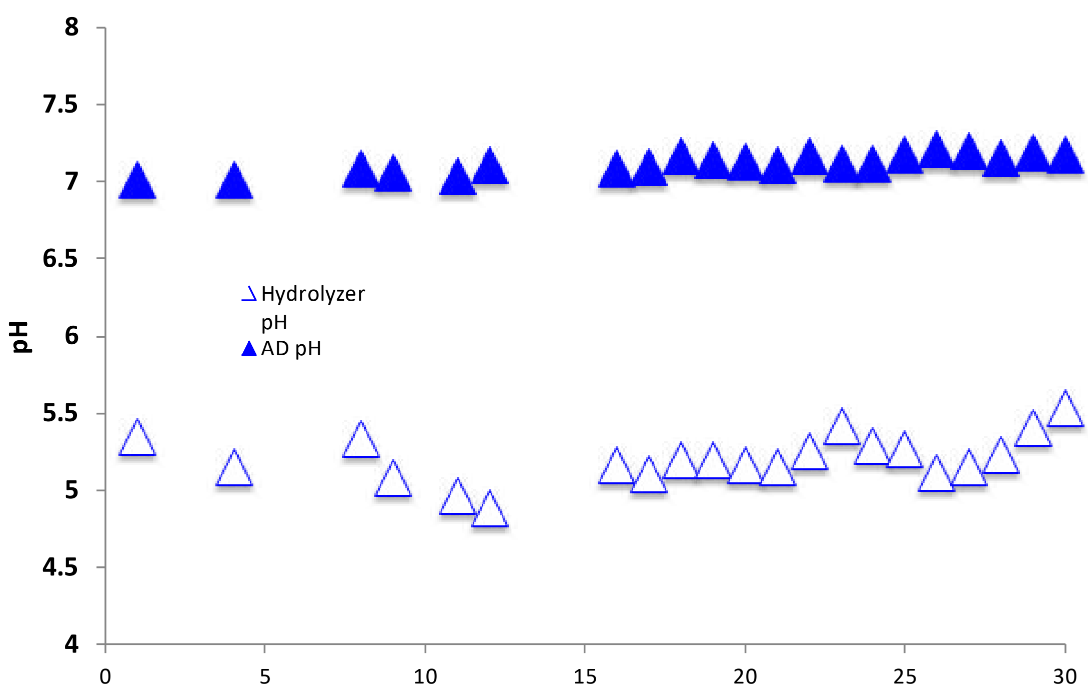


TANK pH



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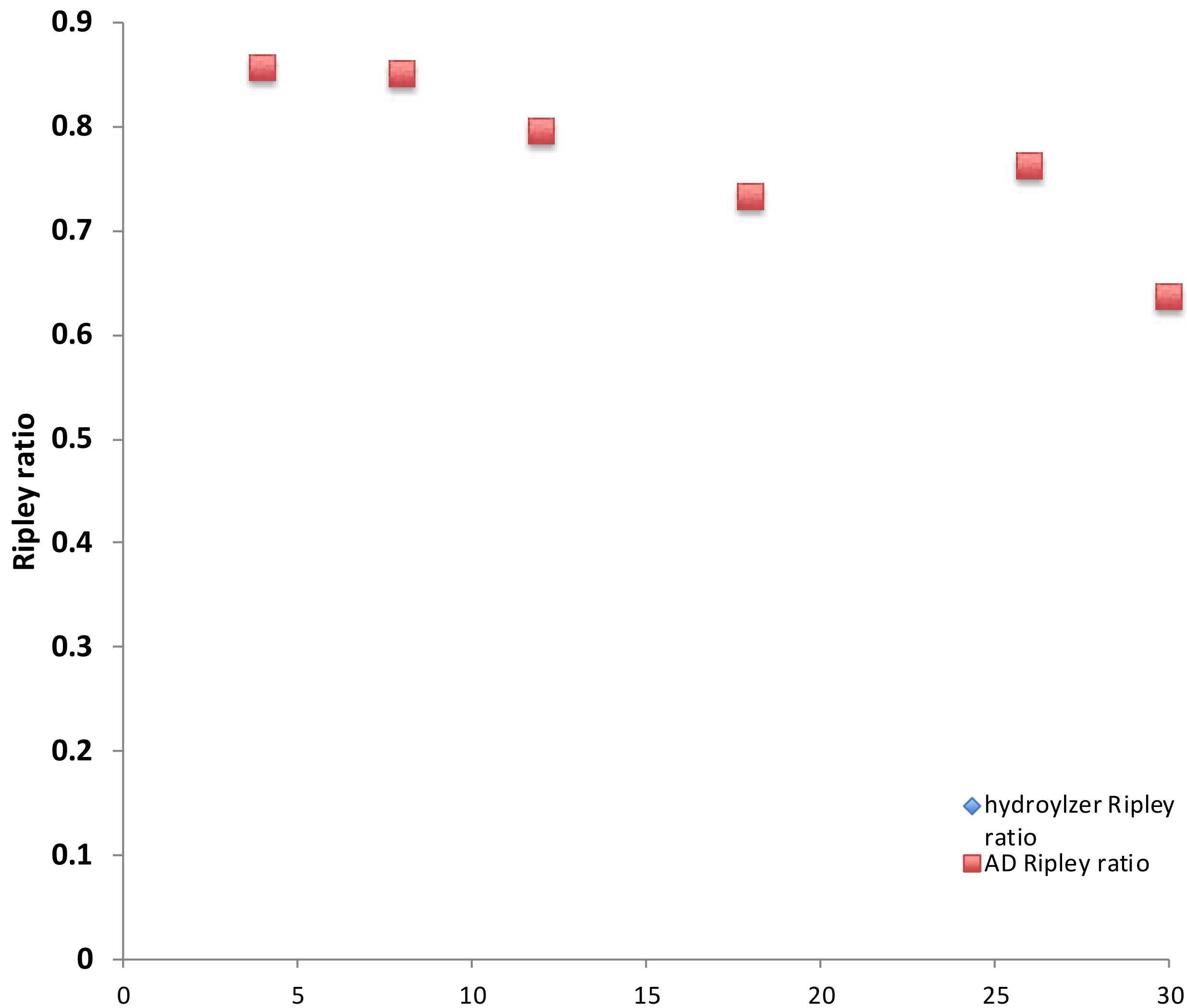
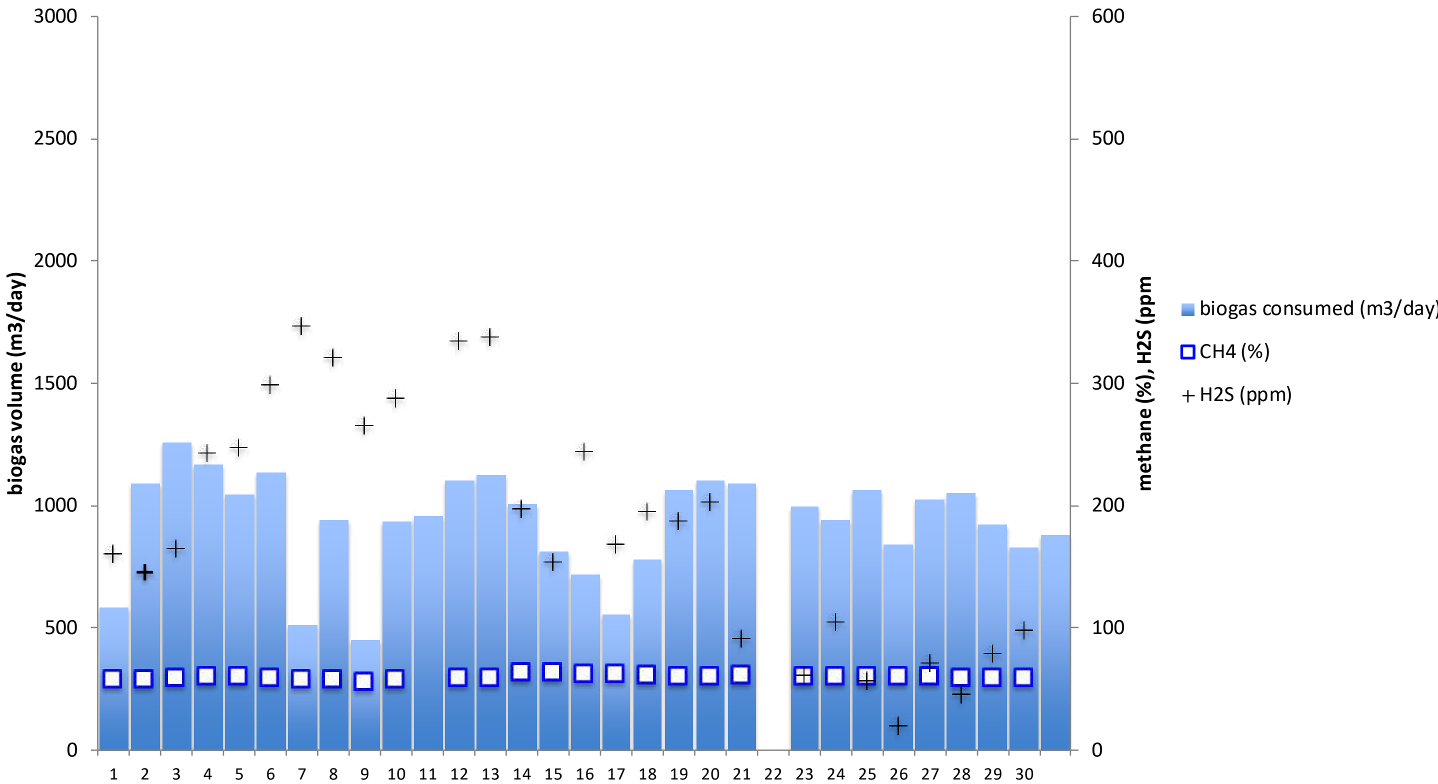


July 2015

BIOGAS VOLUME & QUALITY



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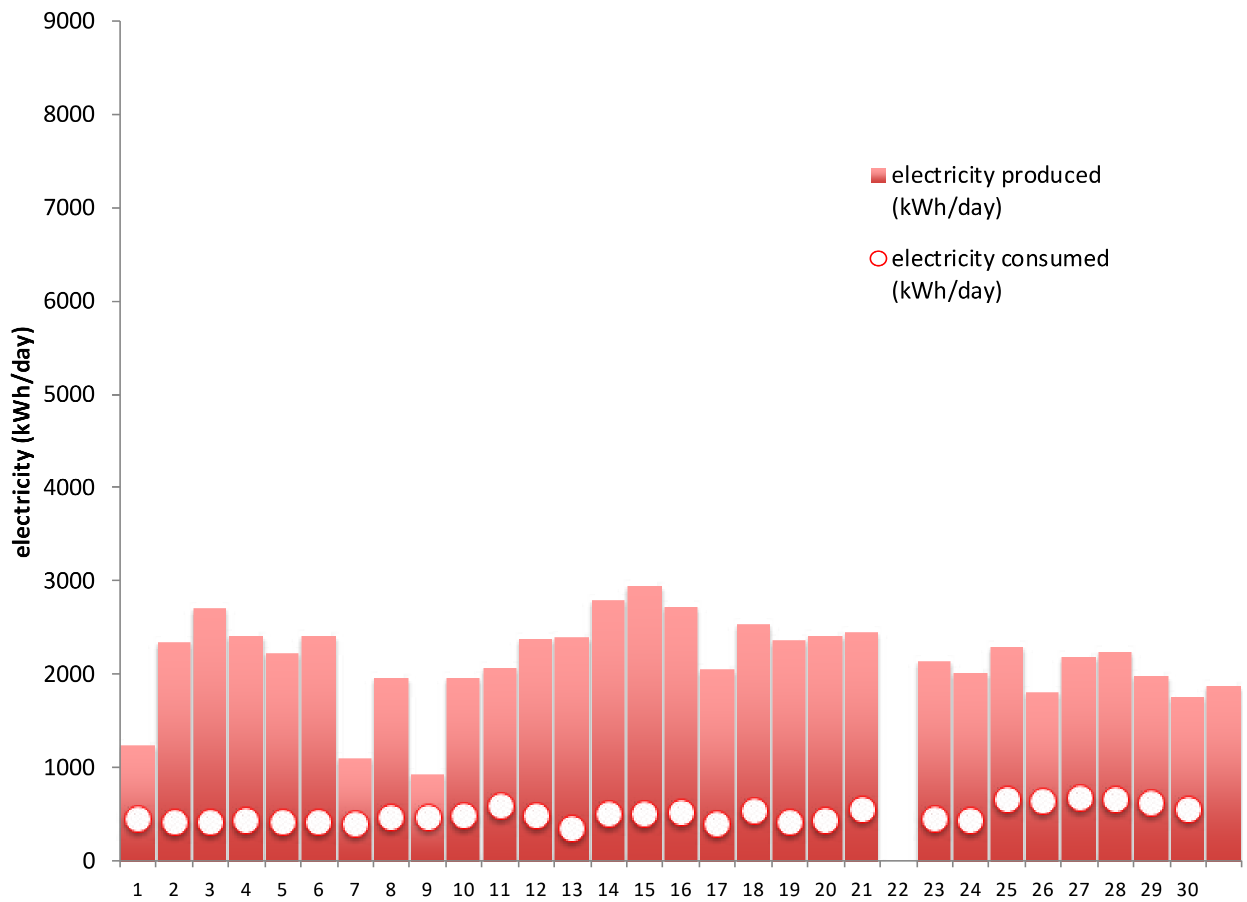

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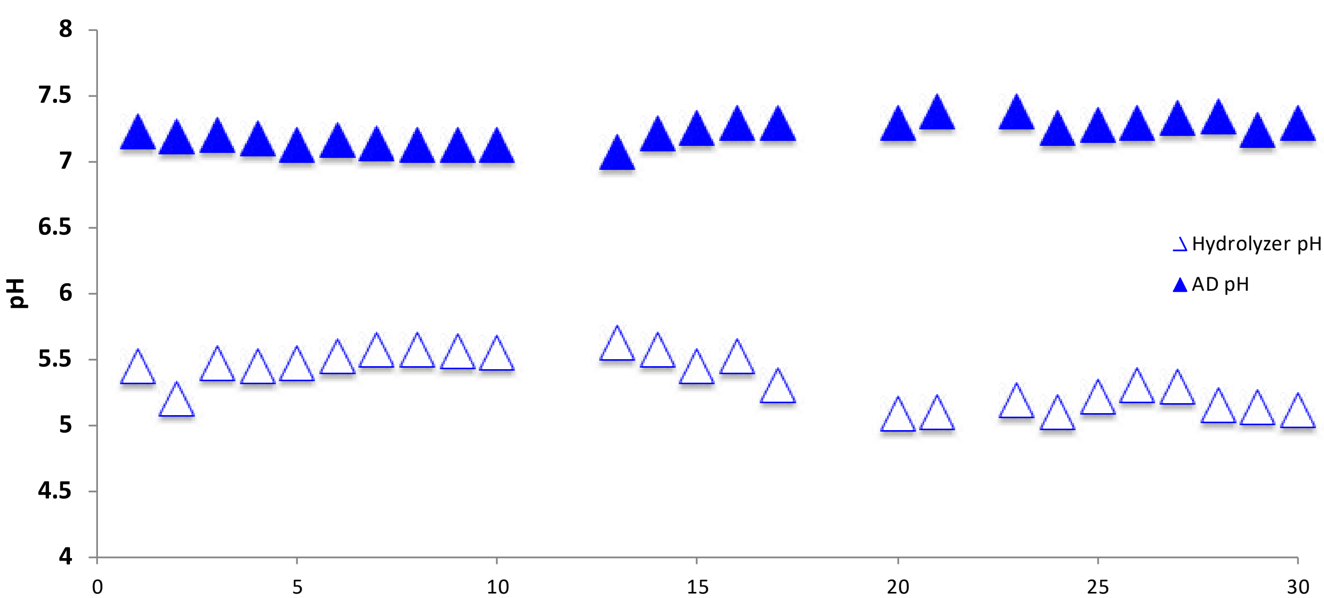

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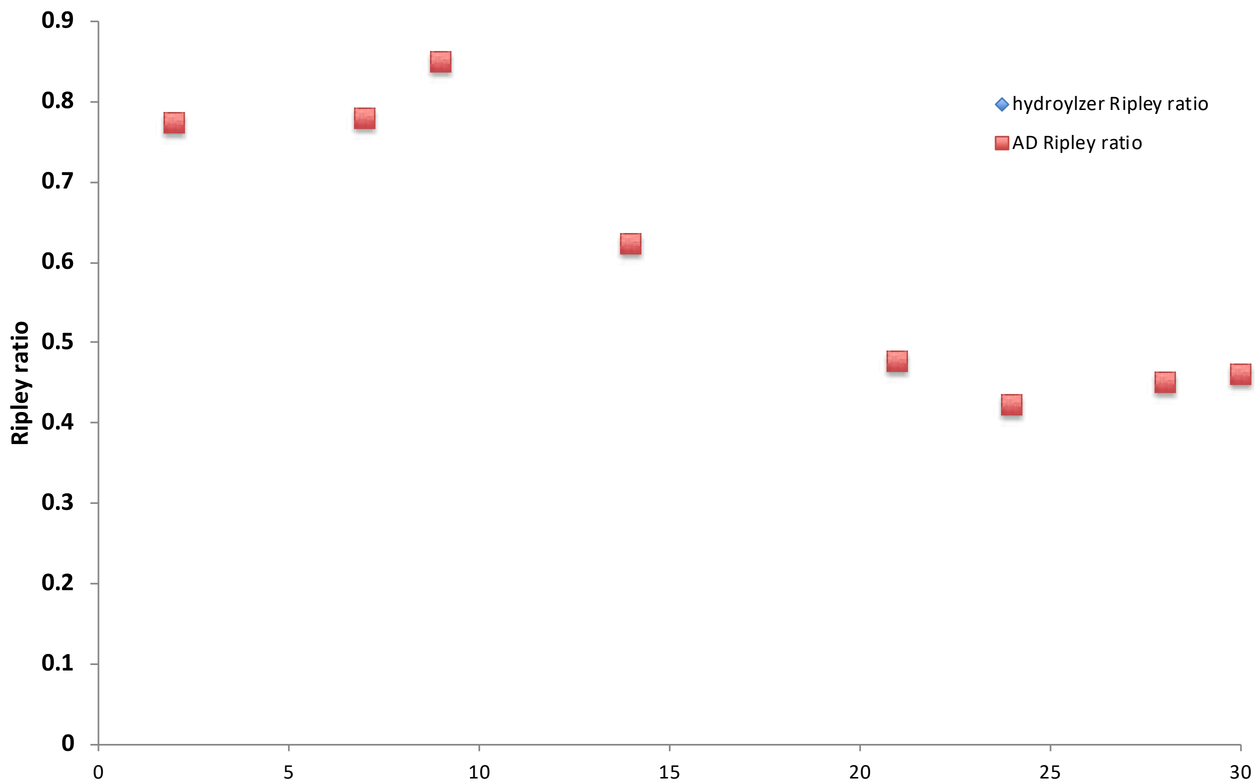

August 2015

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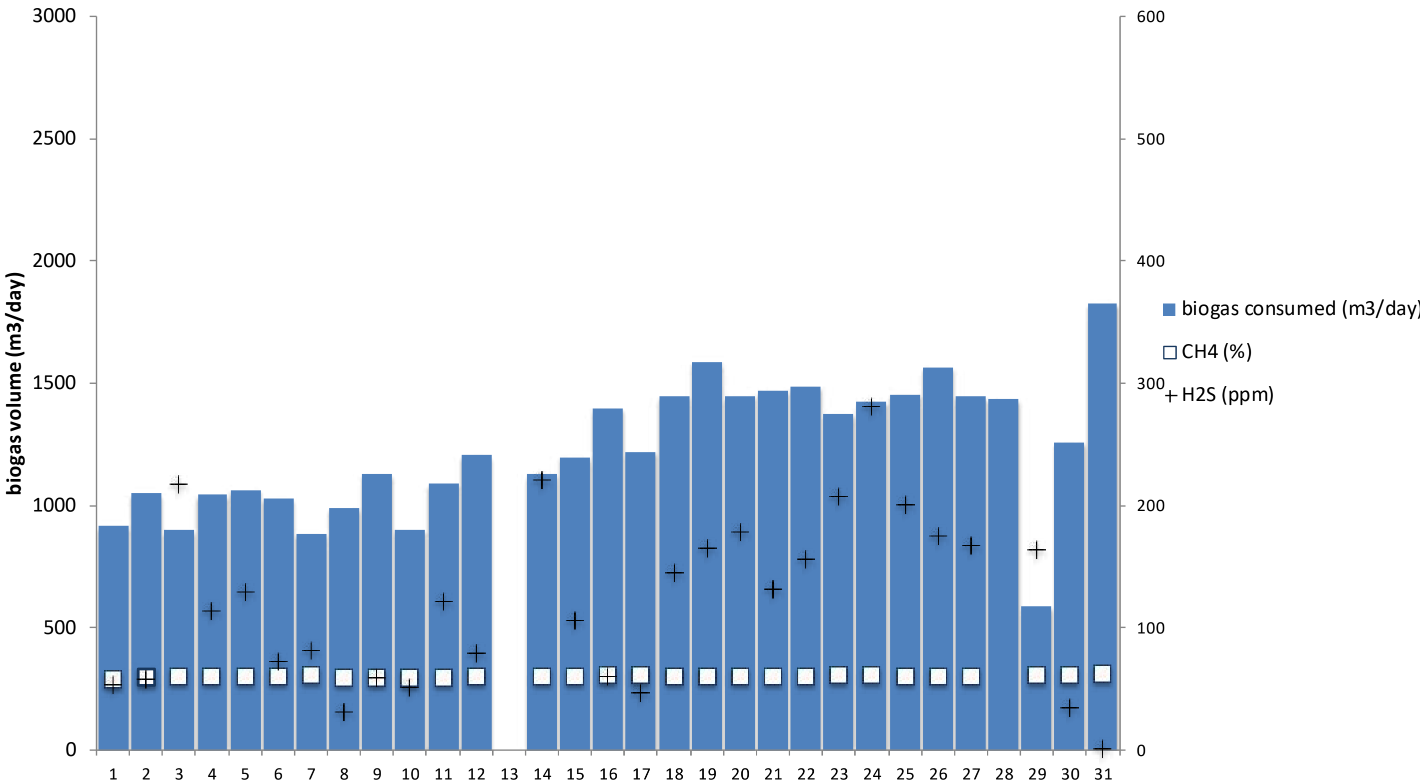

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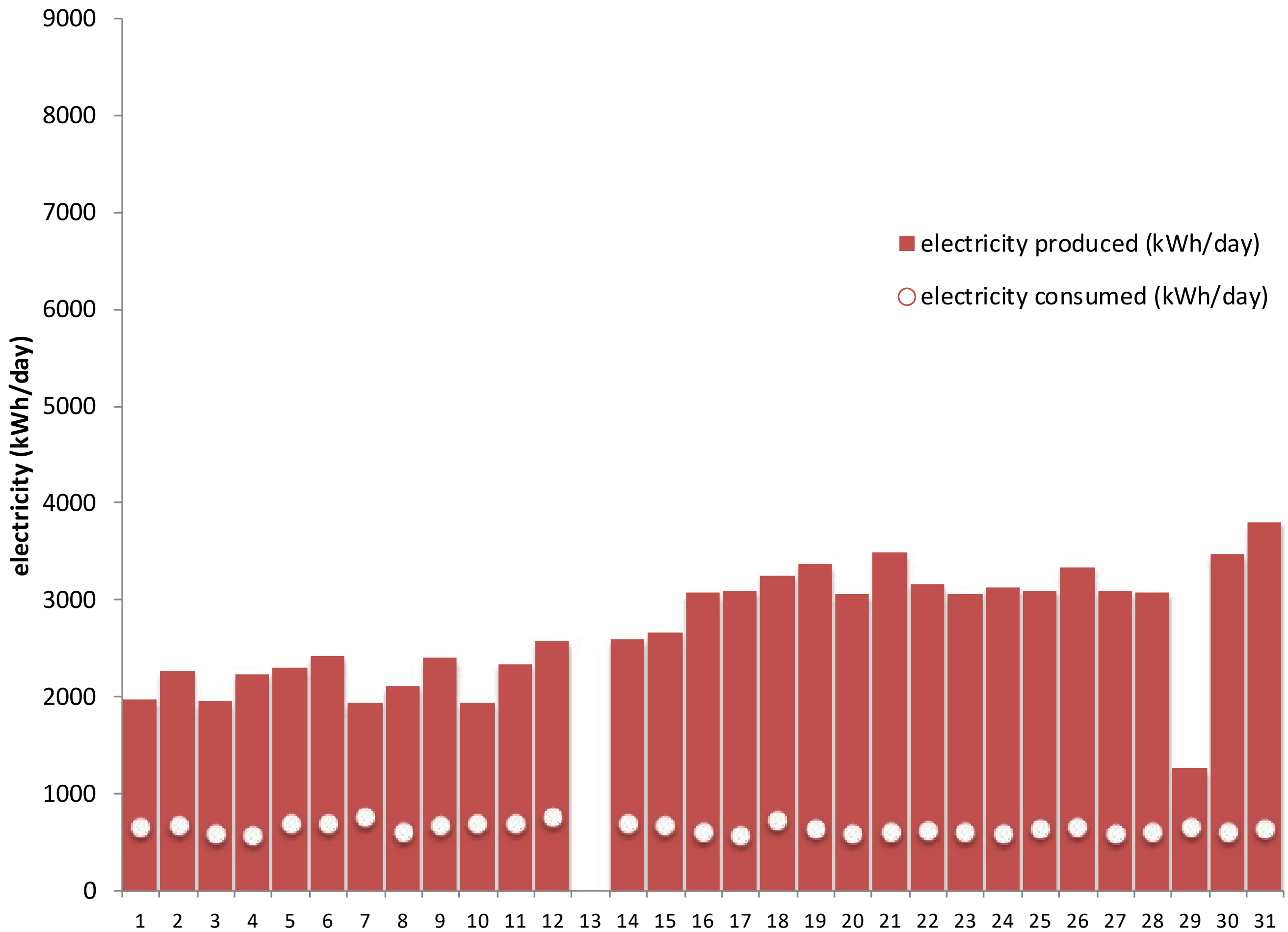
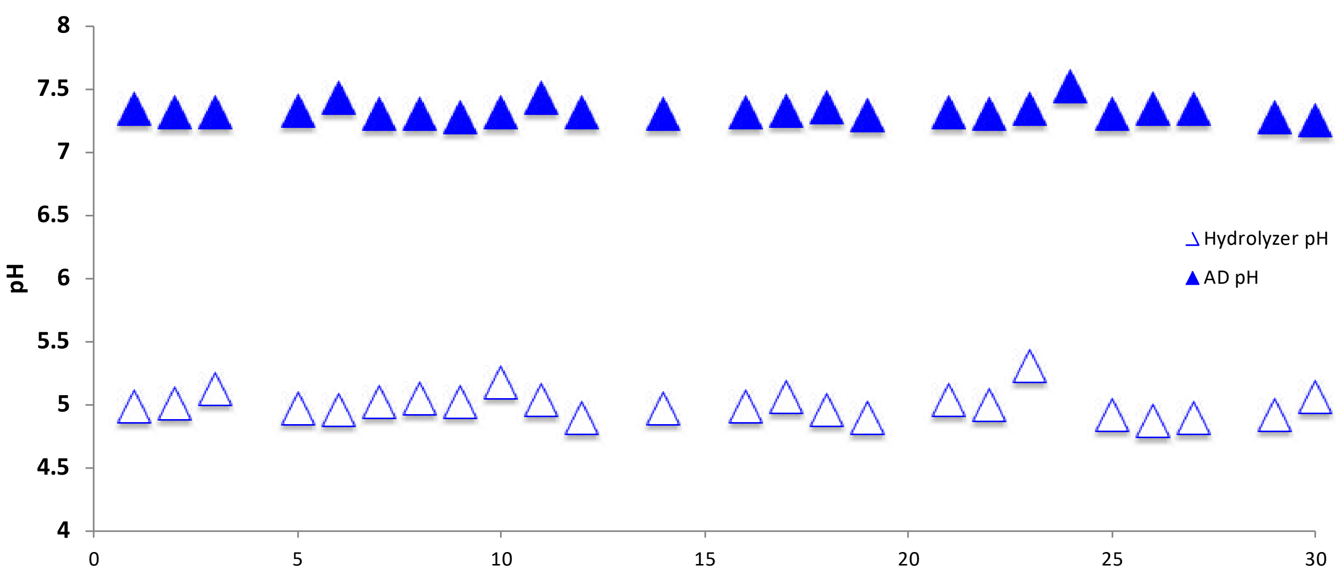


TANK pH



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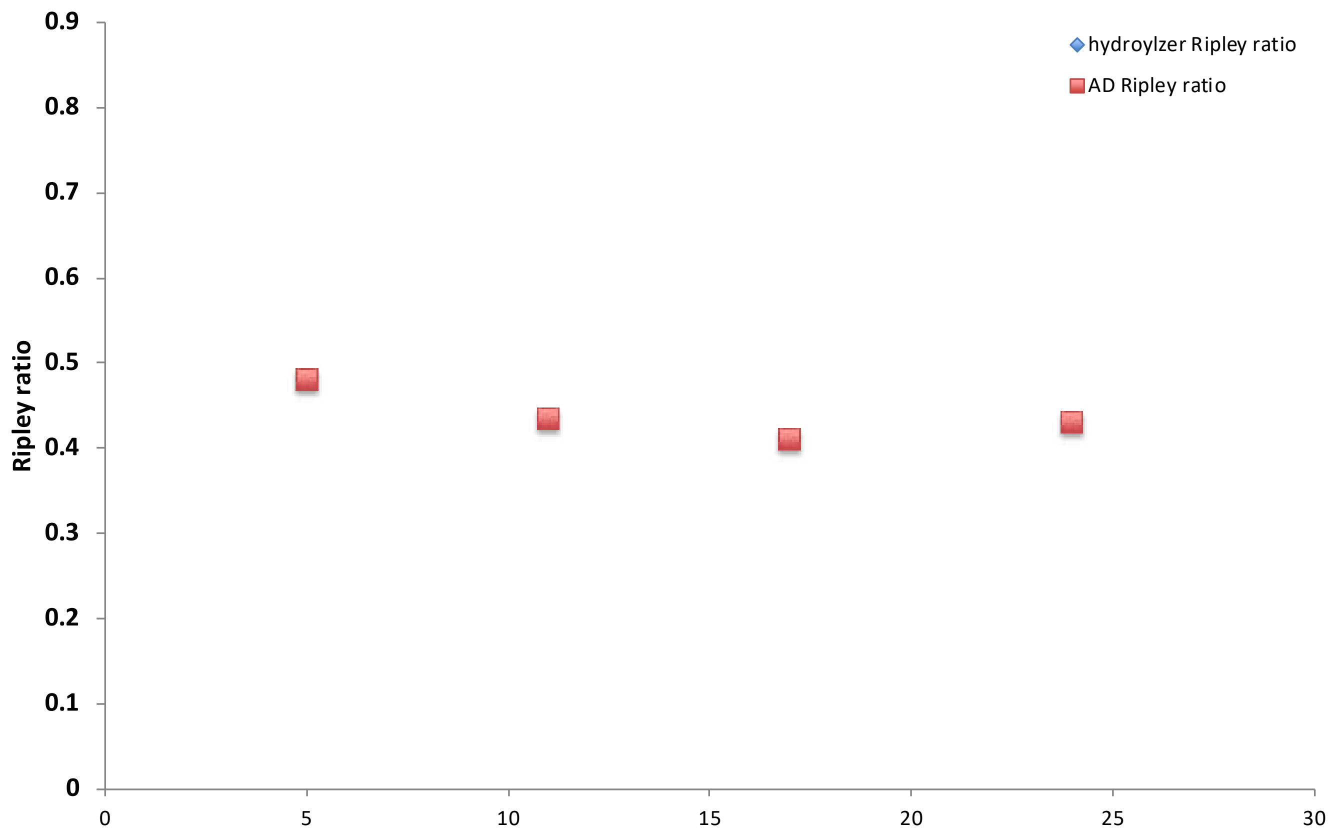

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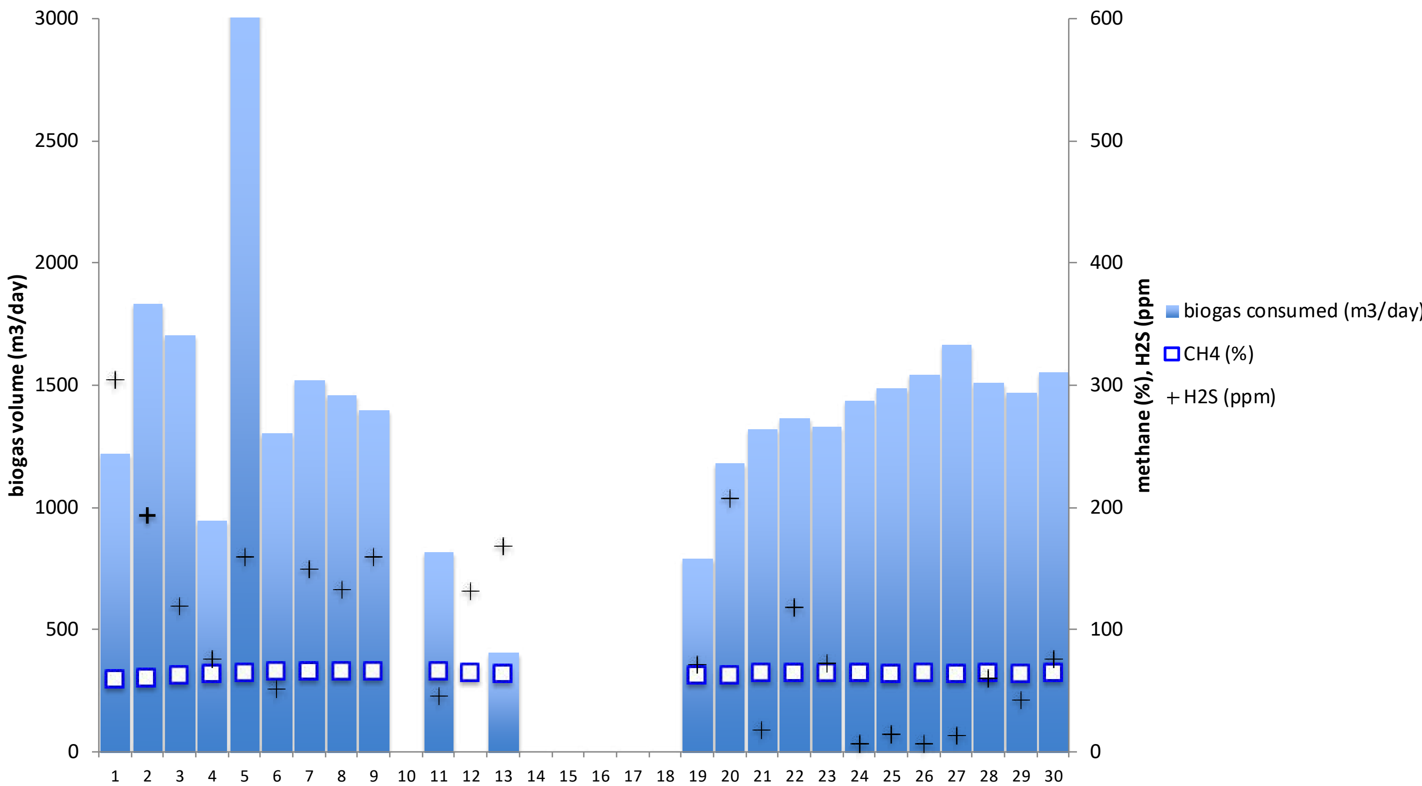
BIOGAS VOLUME & QUALITY



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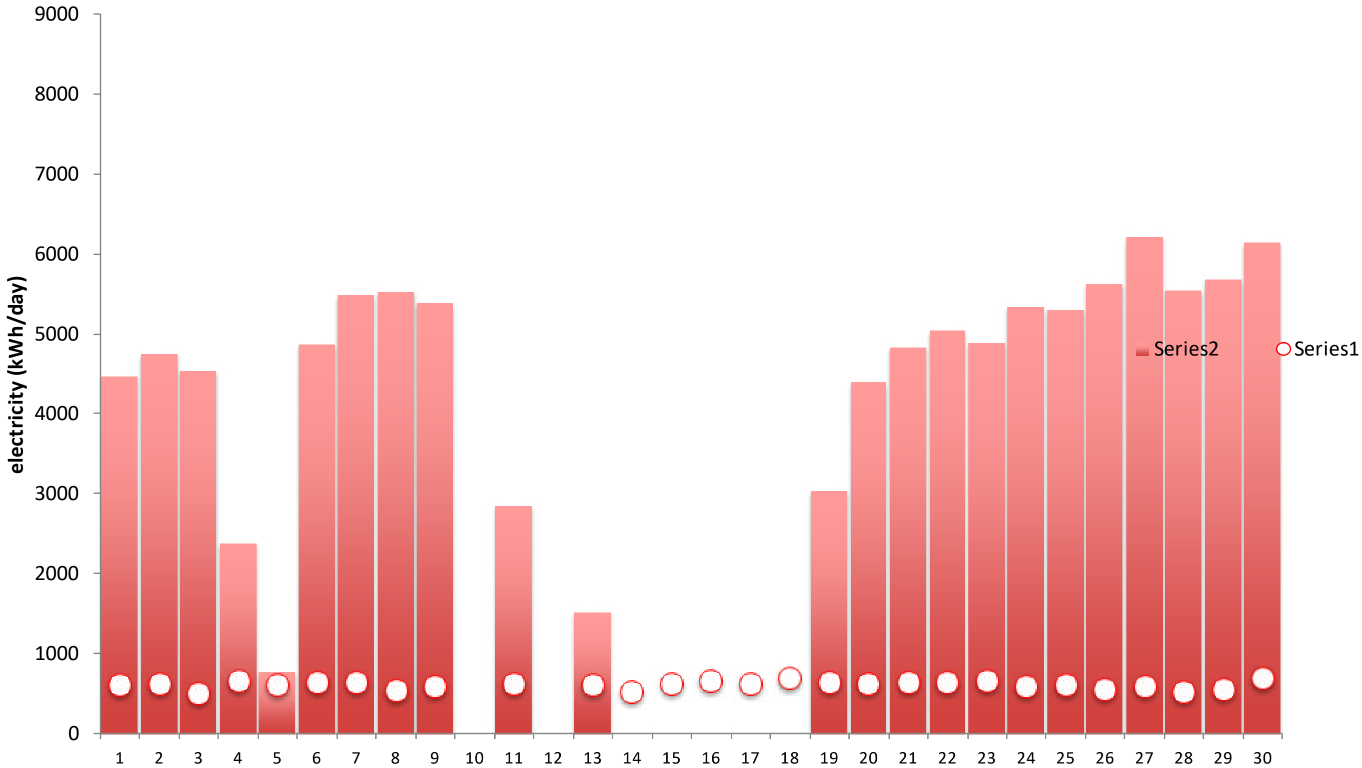

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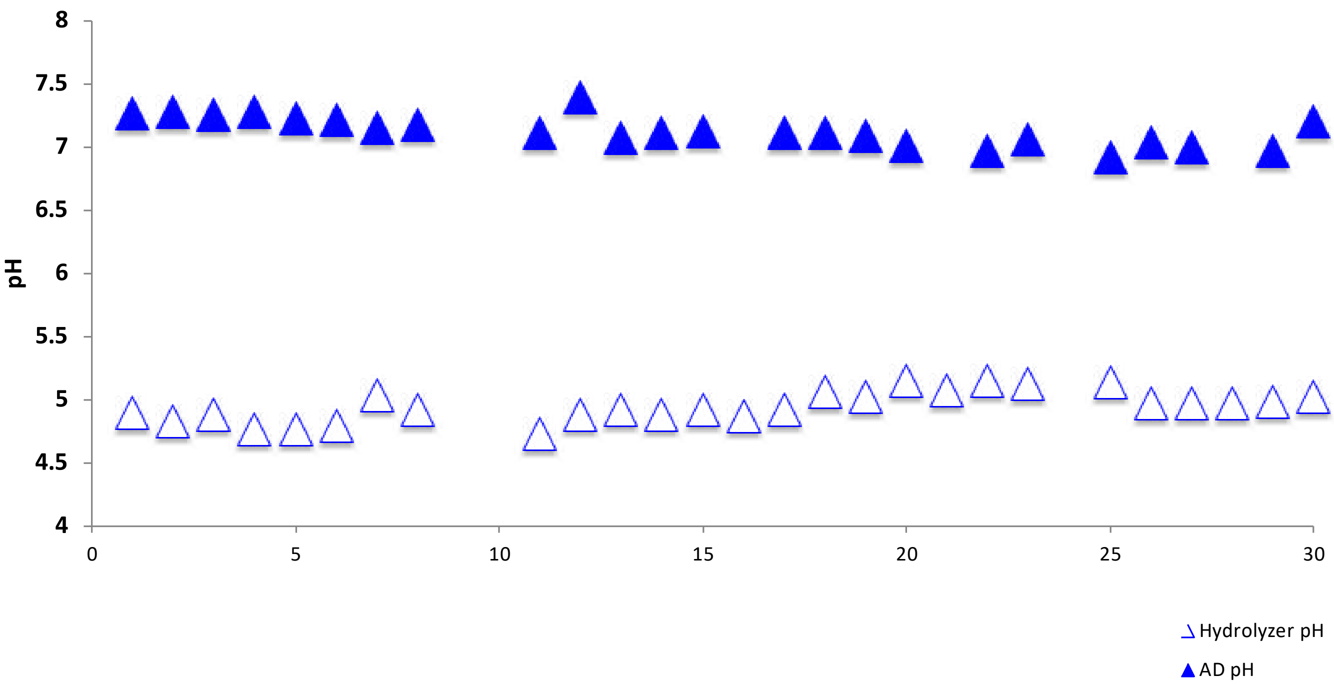

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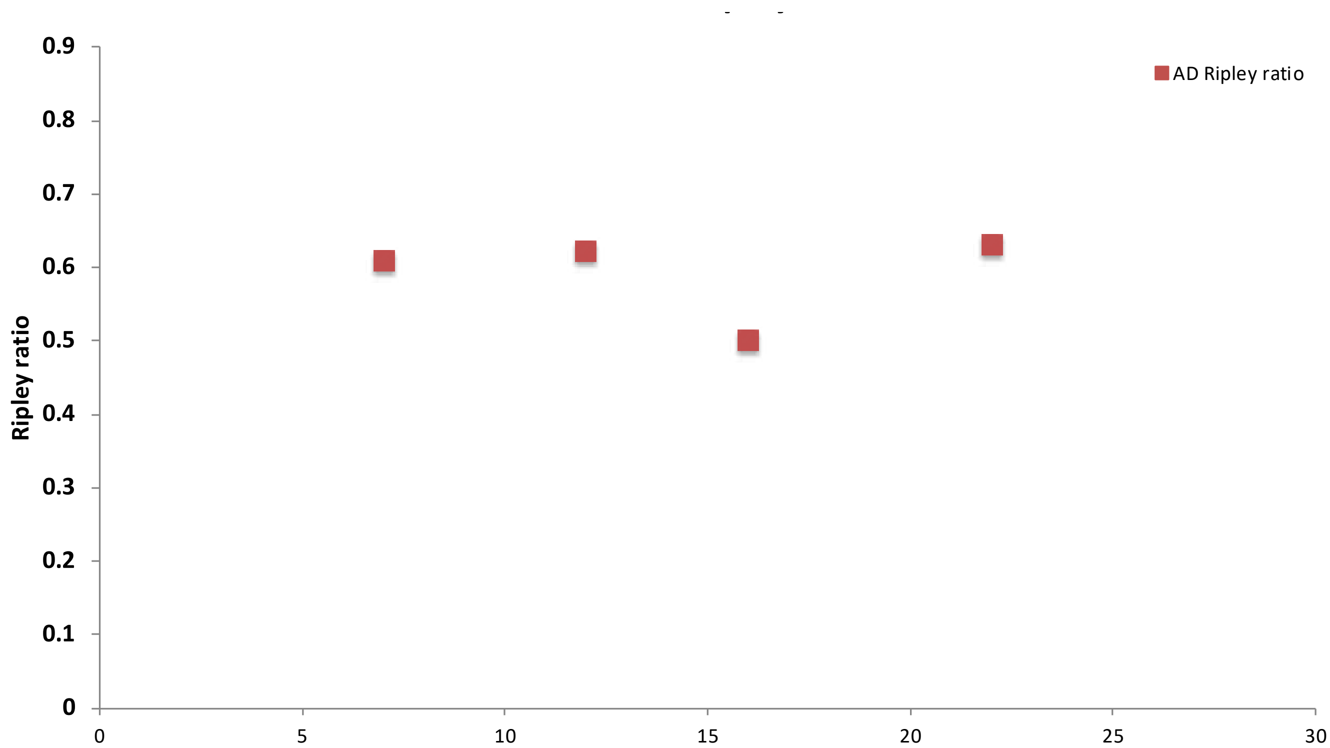
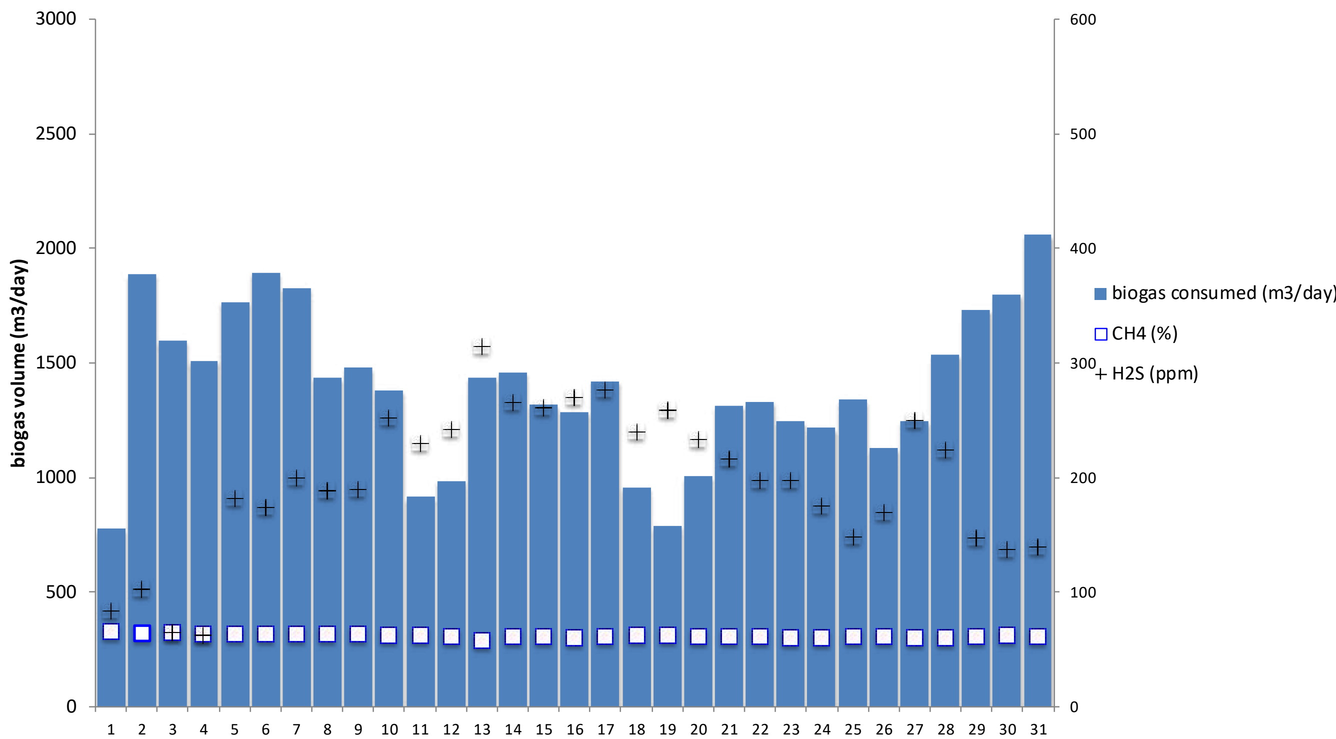


October 2015

BIOGAS VOLUME & QUALITY



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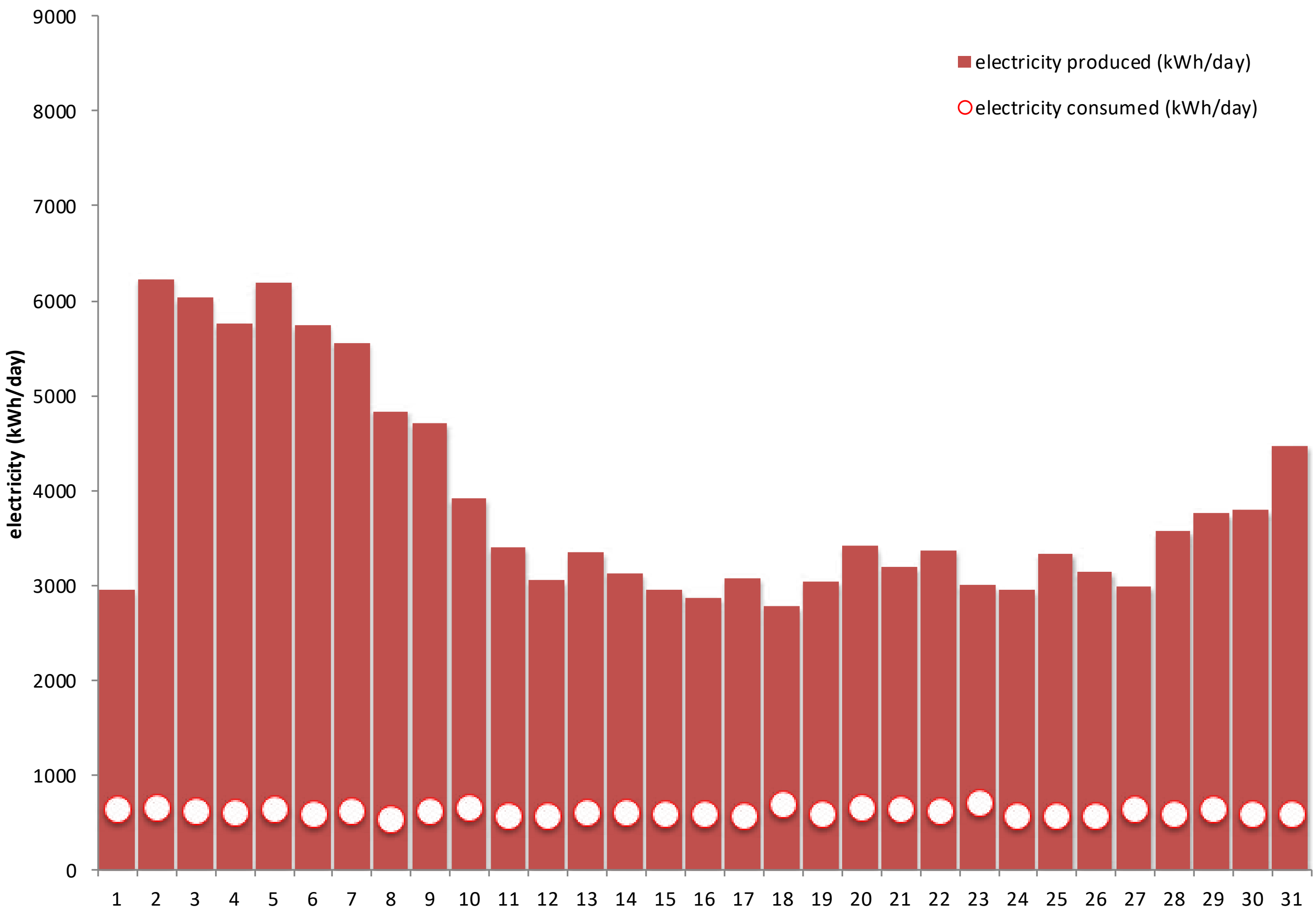
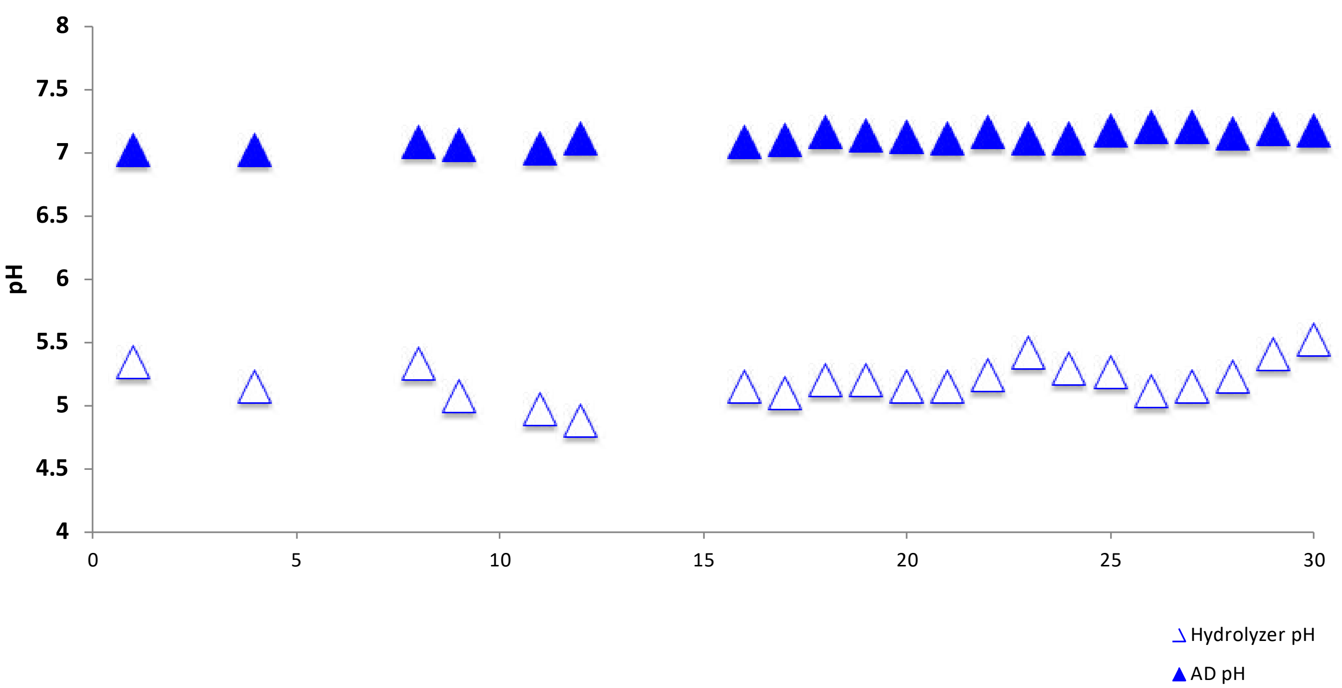


TANK pH



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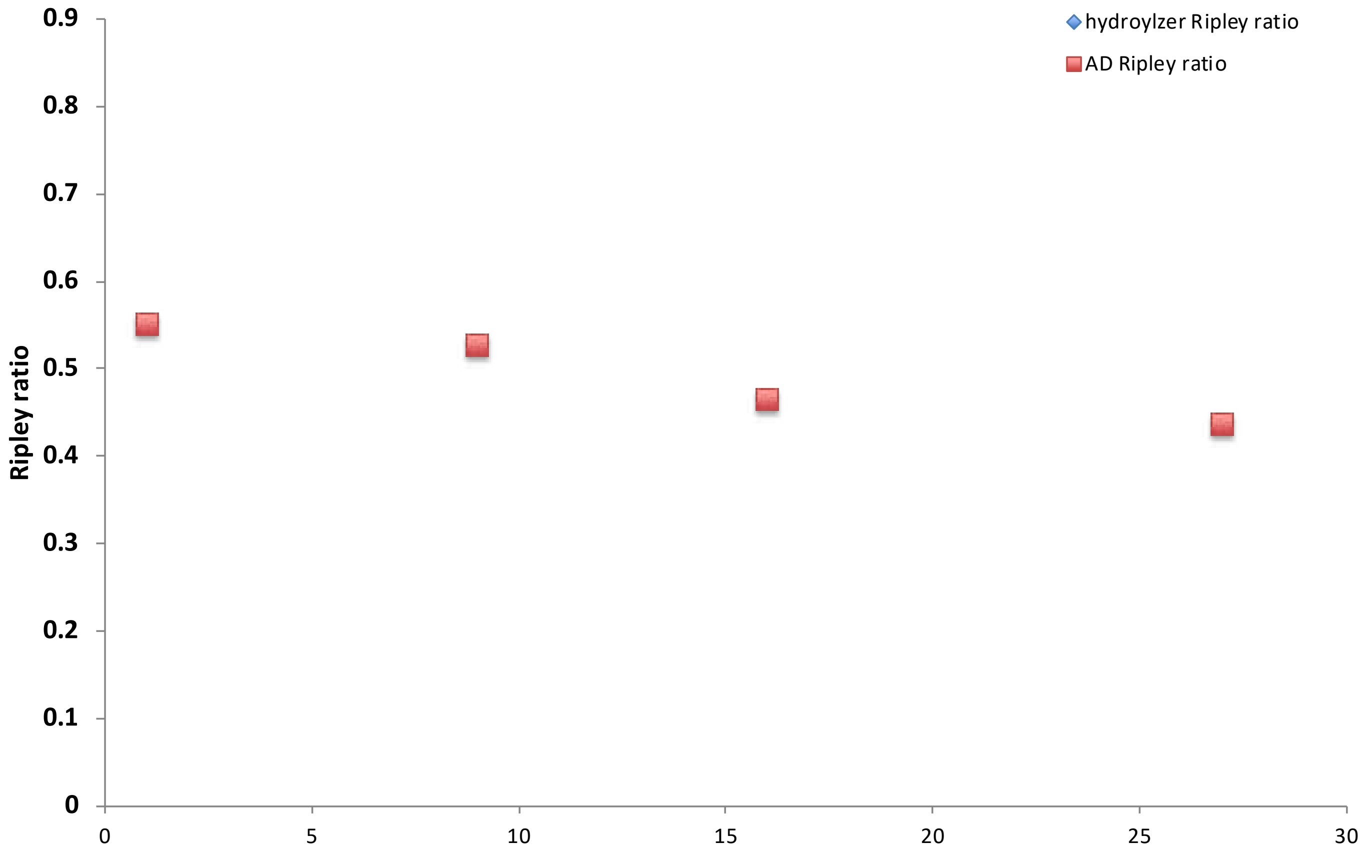
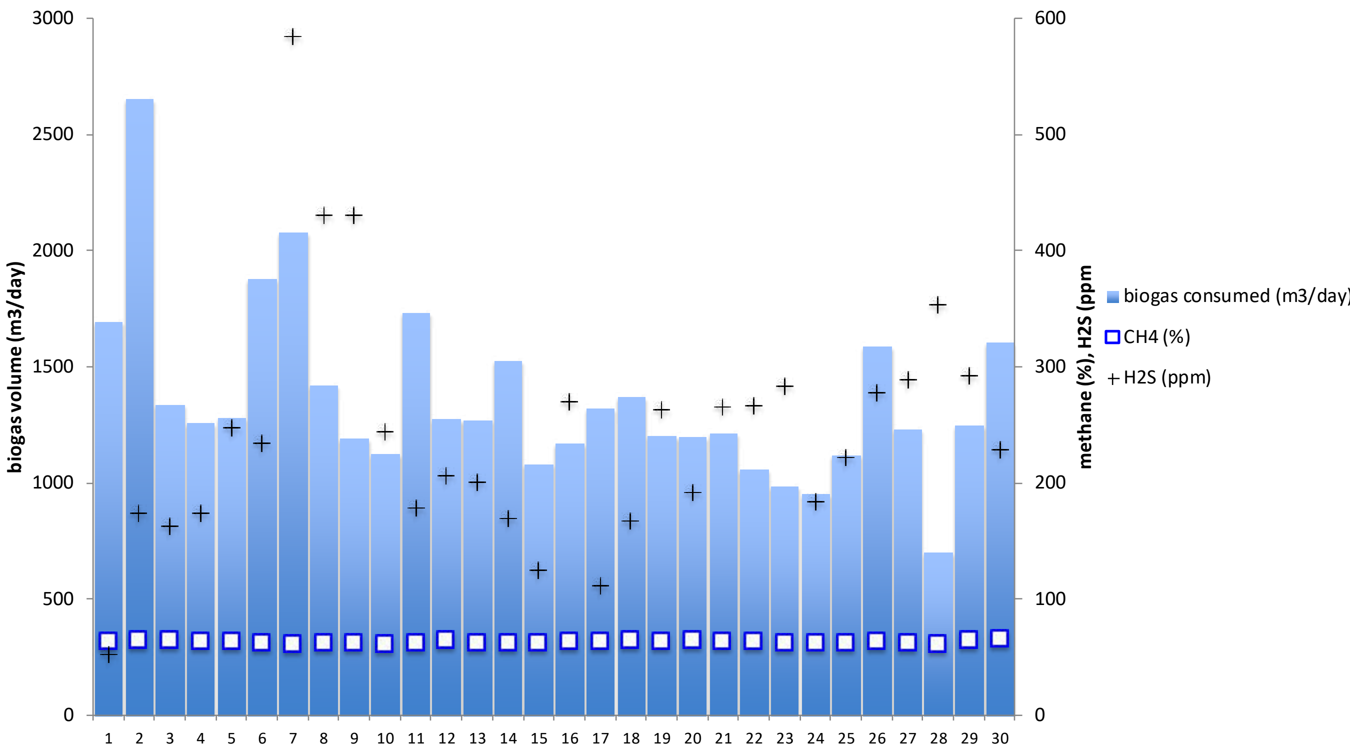


November 2015

BIOGAS VOLUME & QUALITY



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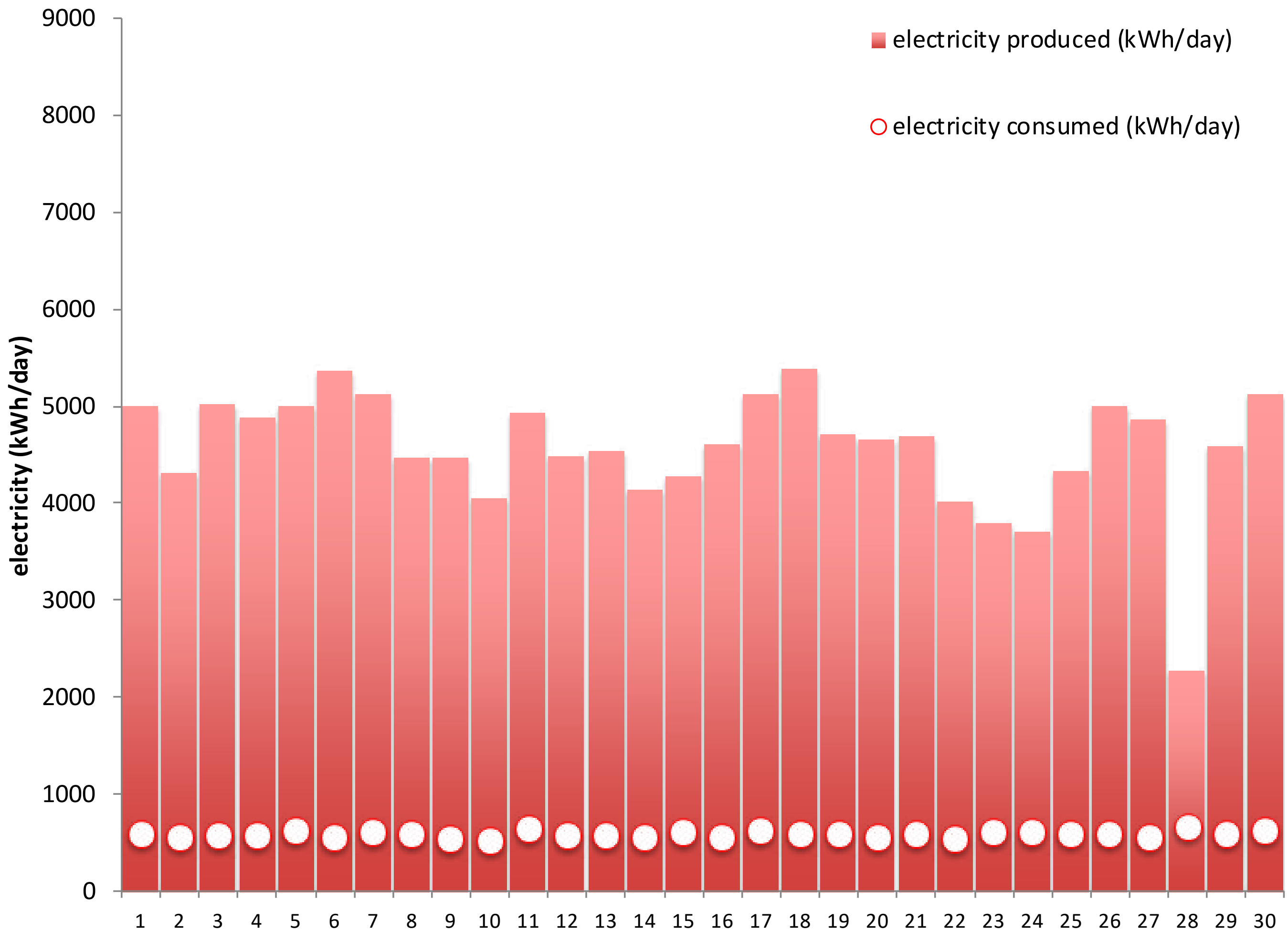

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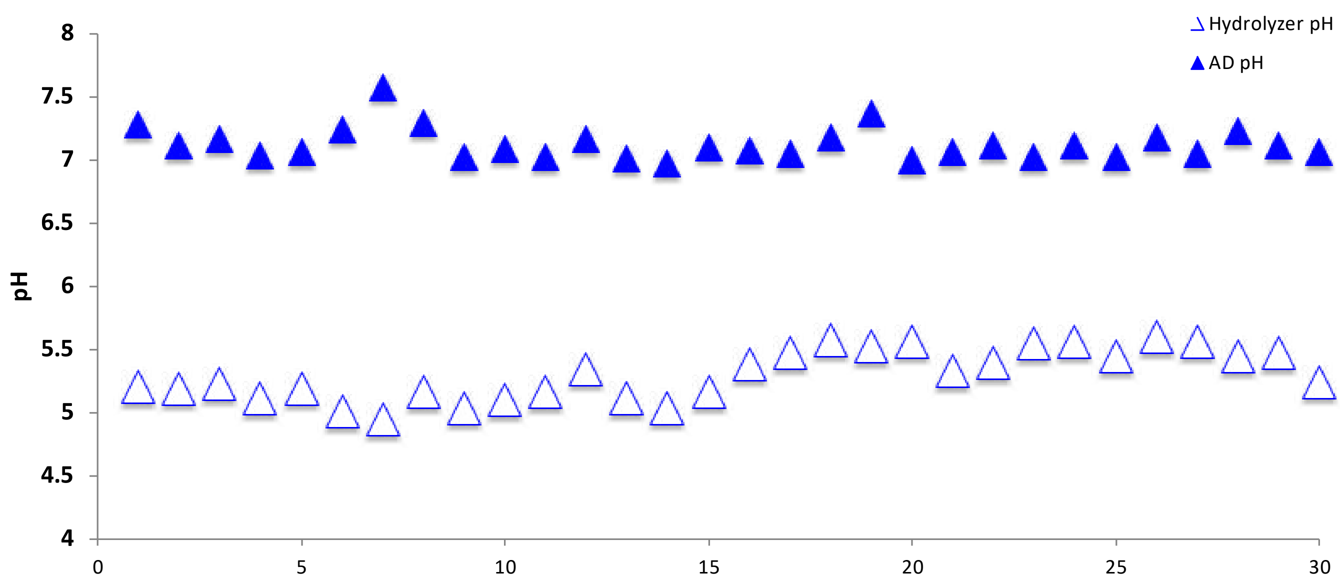

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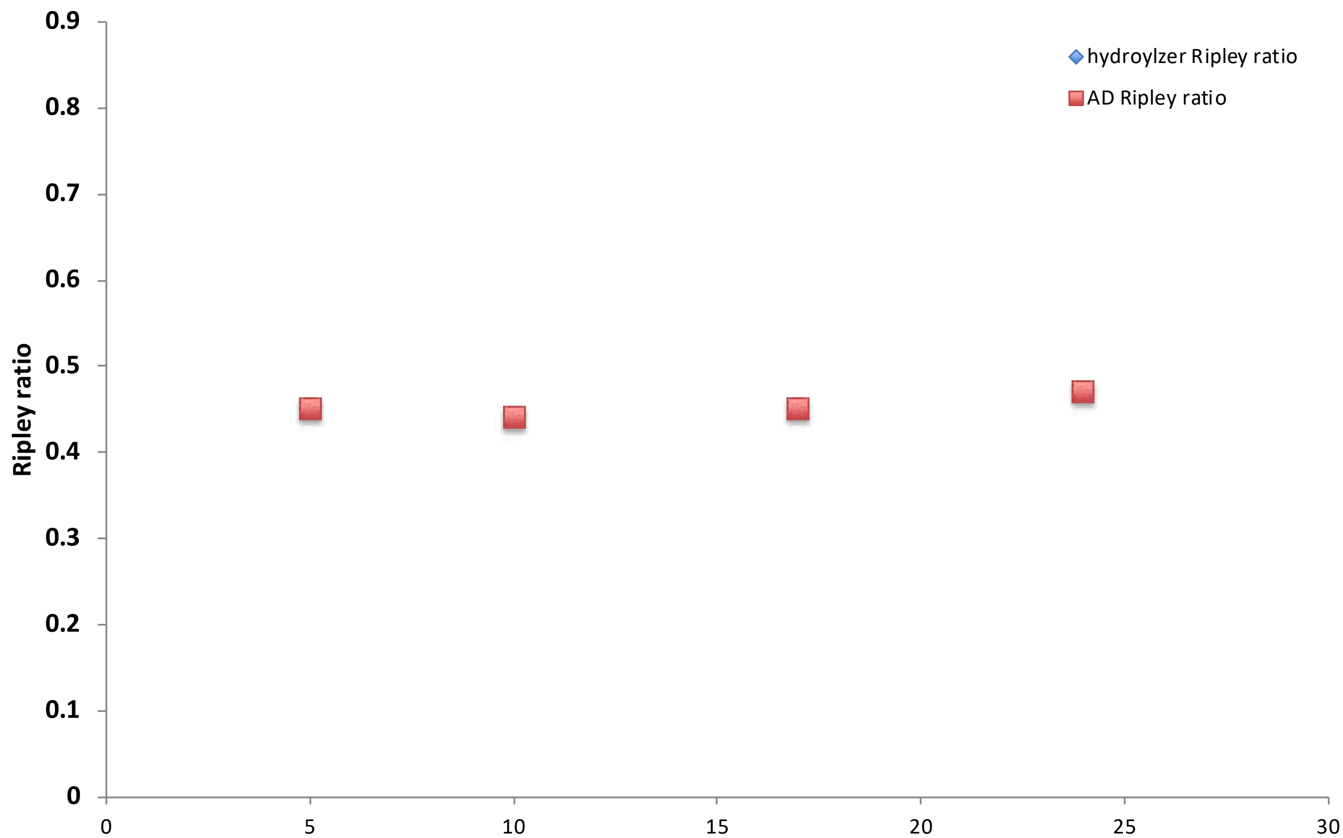
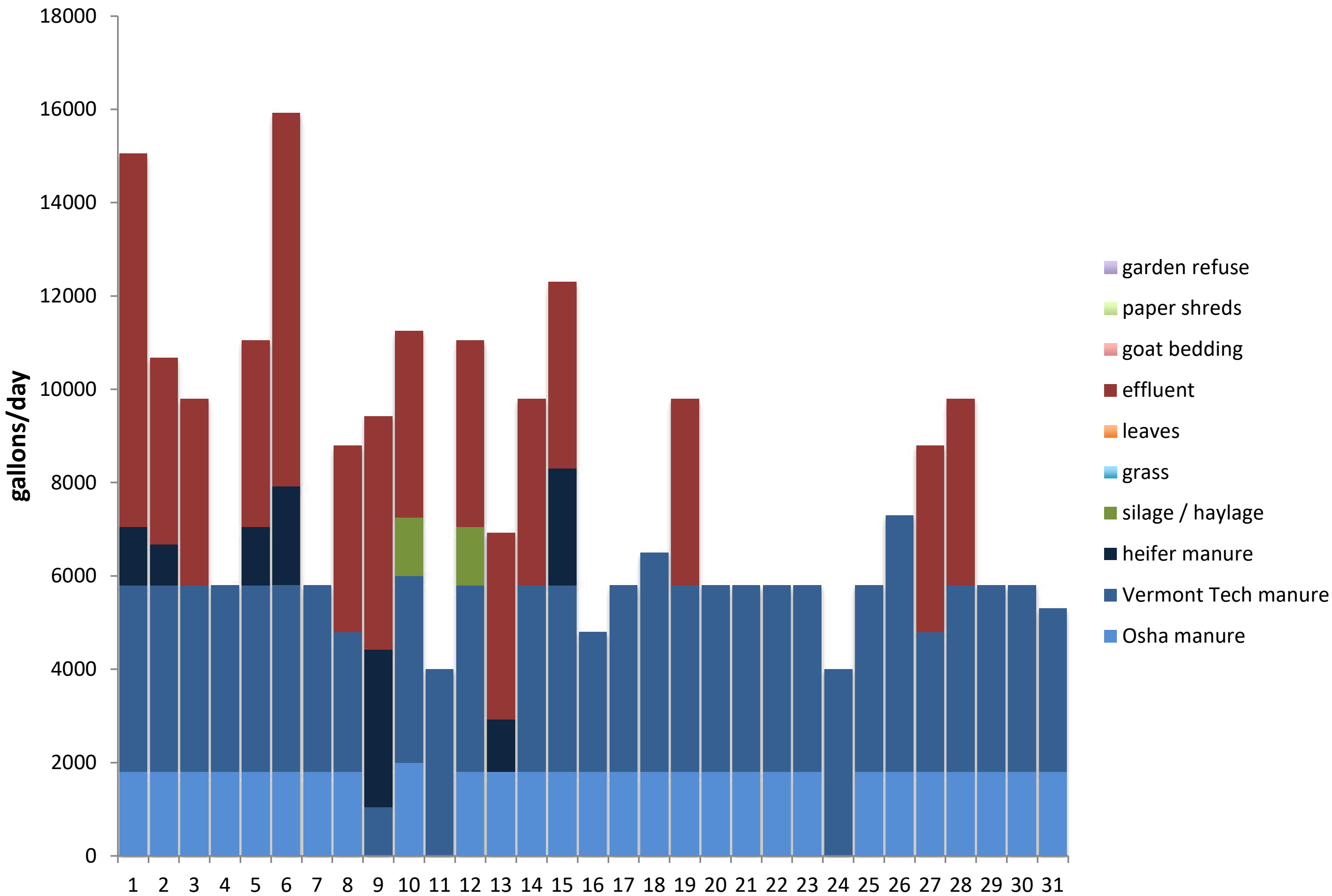


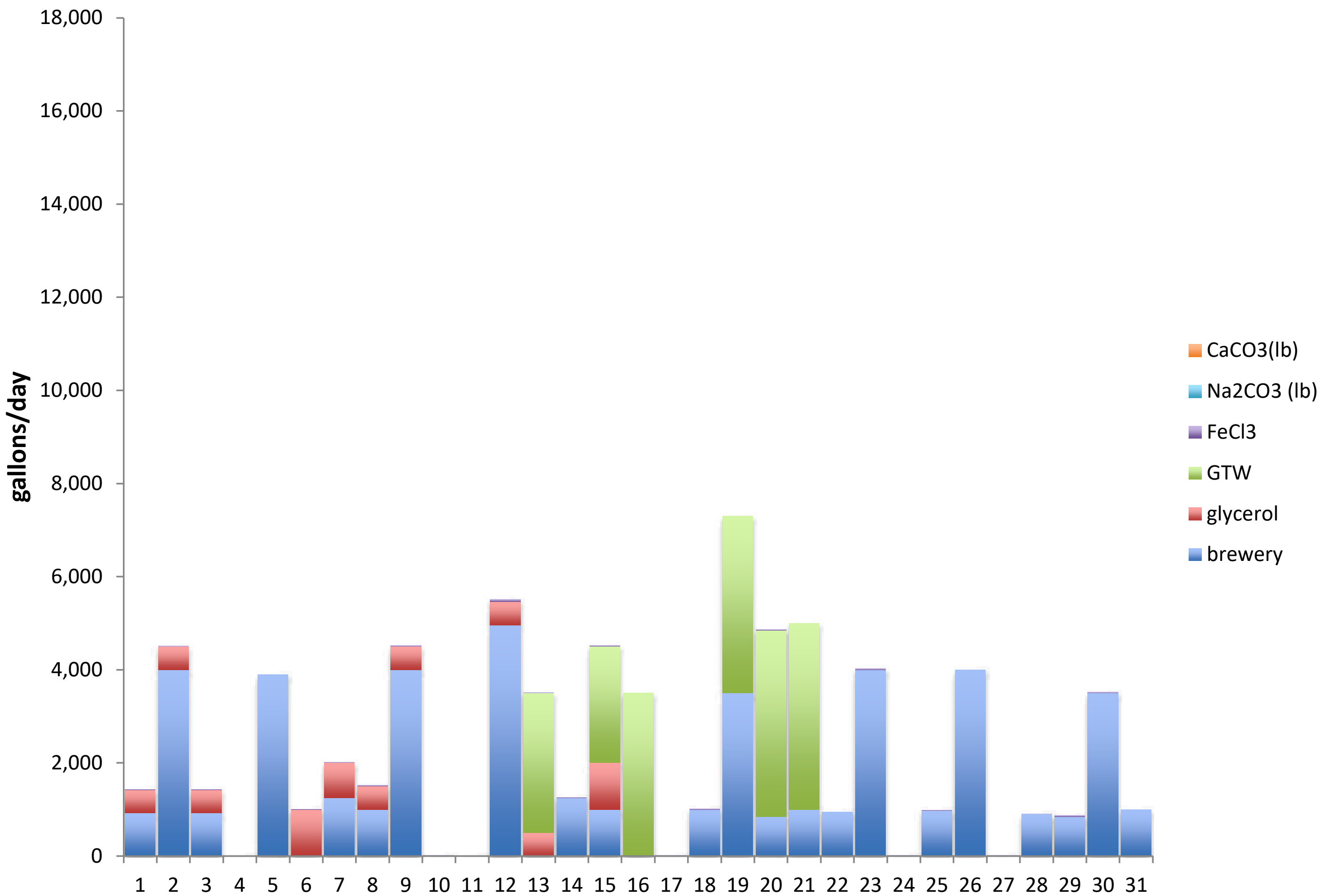
APPENDIX C: DAILY FEEDSTOCK DATA FOR 2015

January 2015

ON-FARM INPUTS

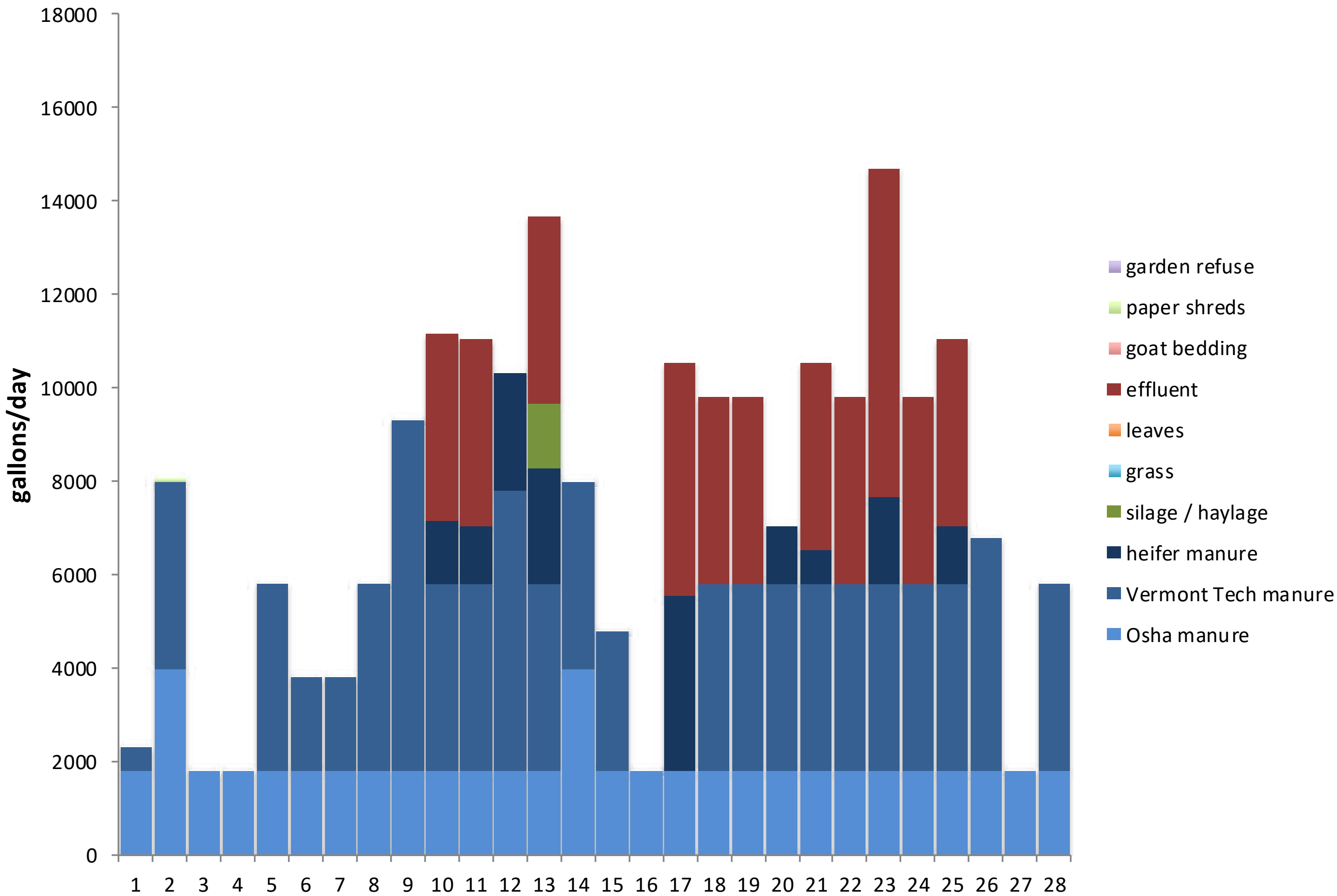


OFF-FARM INPUTS

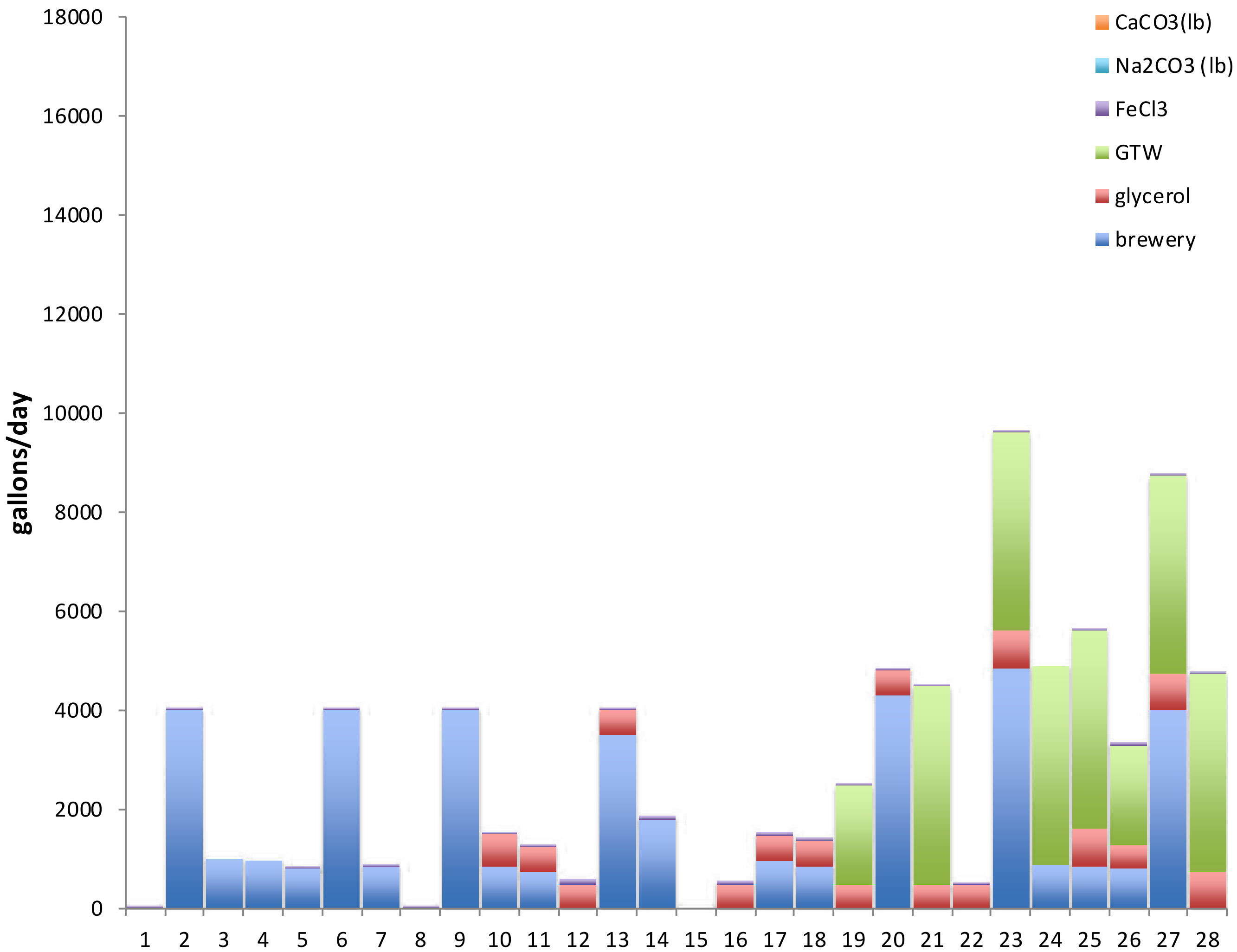


February 2015

ON-FARM INPUTS

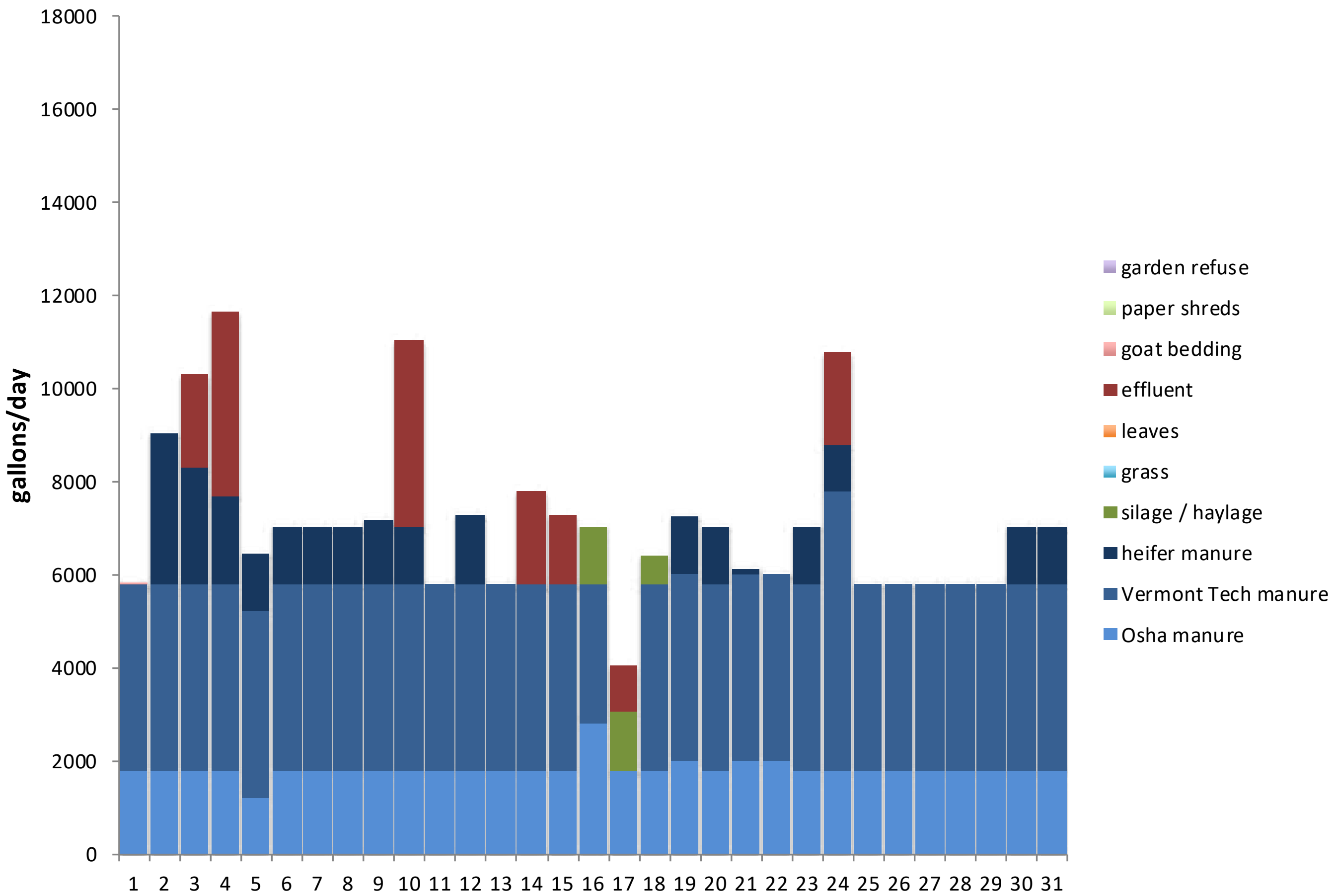


OFF-FARM INPUTS

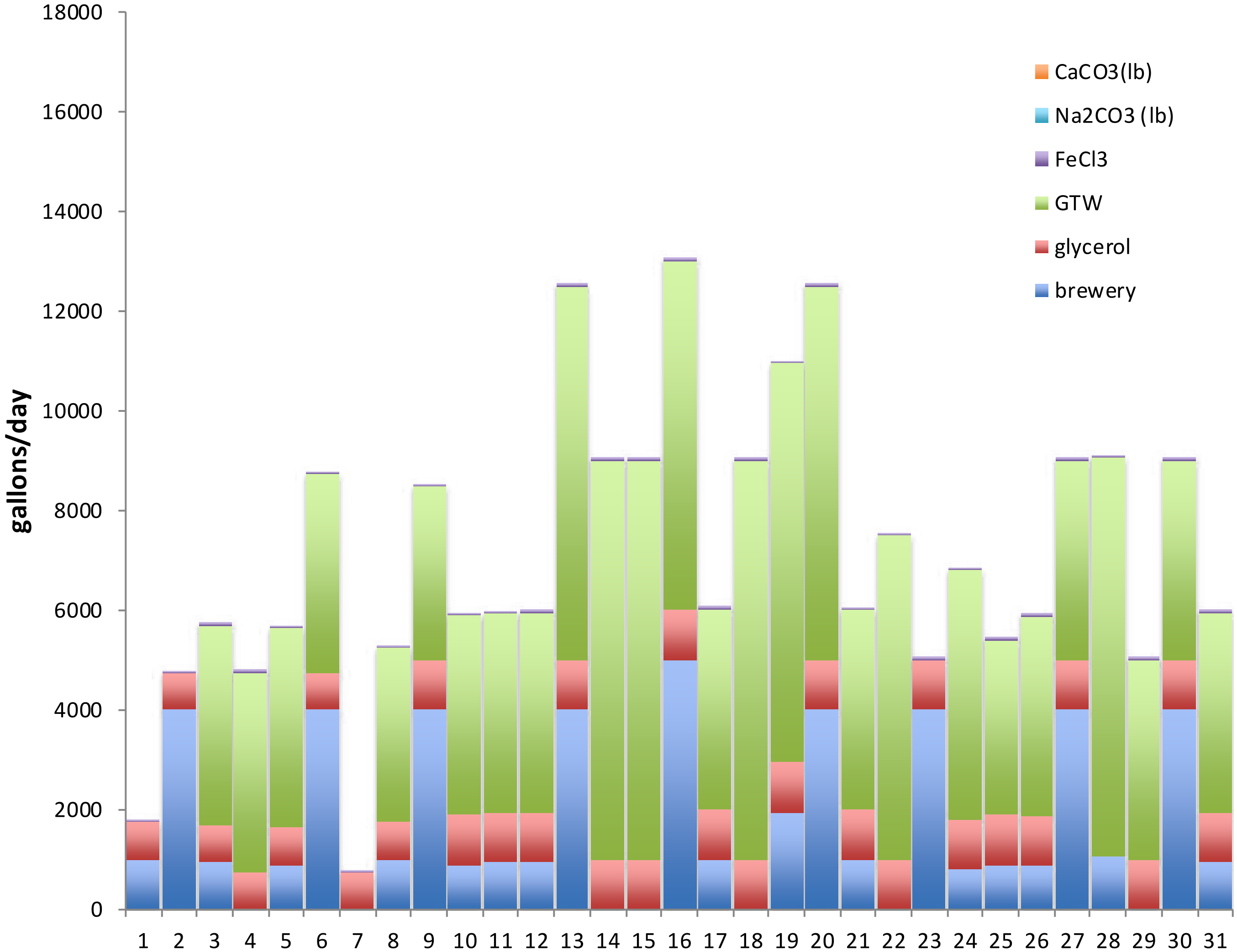


March 2015

ON-FARM INPUTS

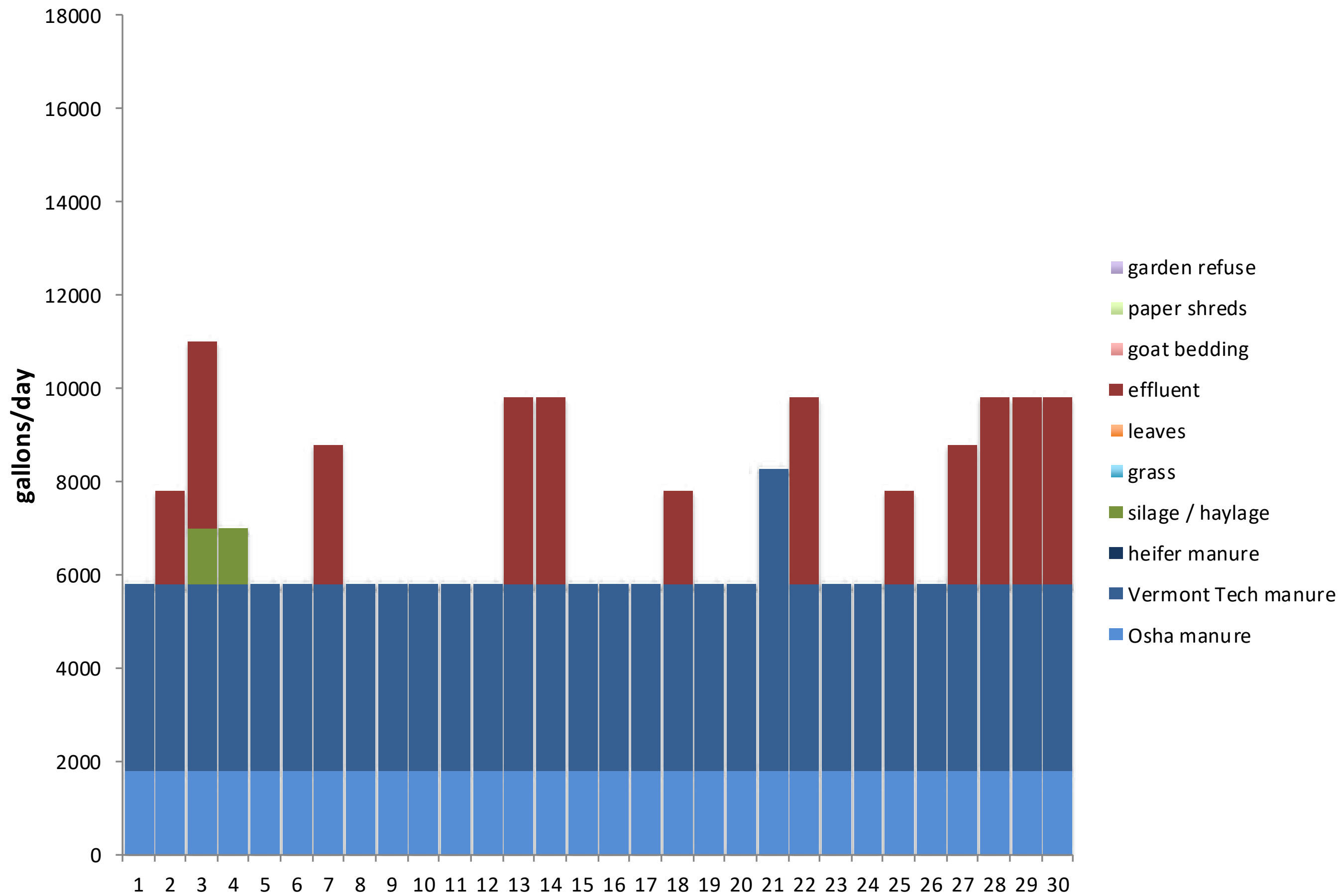


OFF-FARM INPUTS

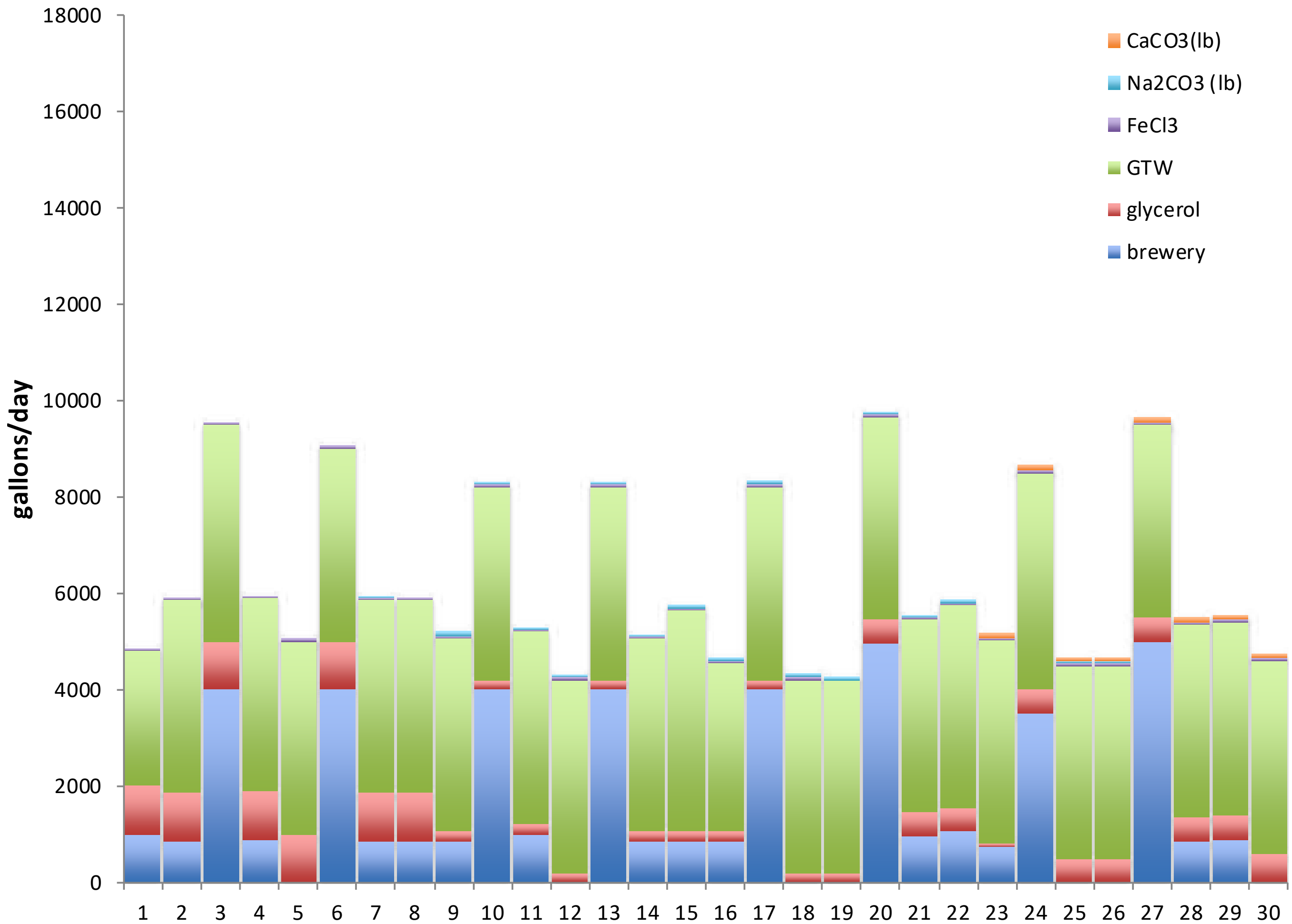


April 2015

ON-FARM INPUTS

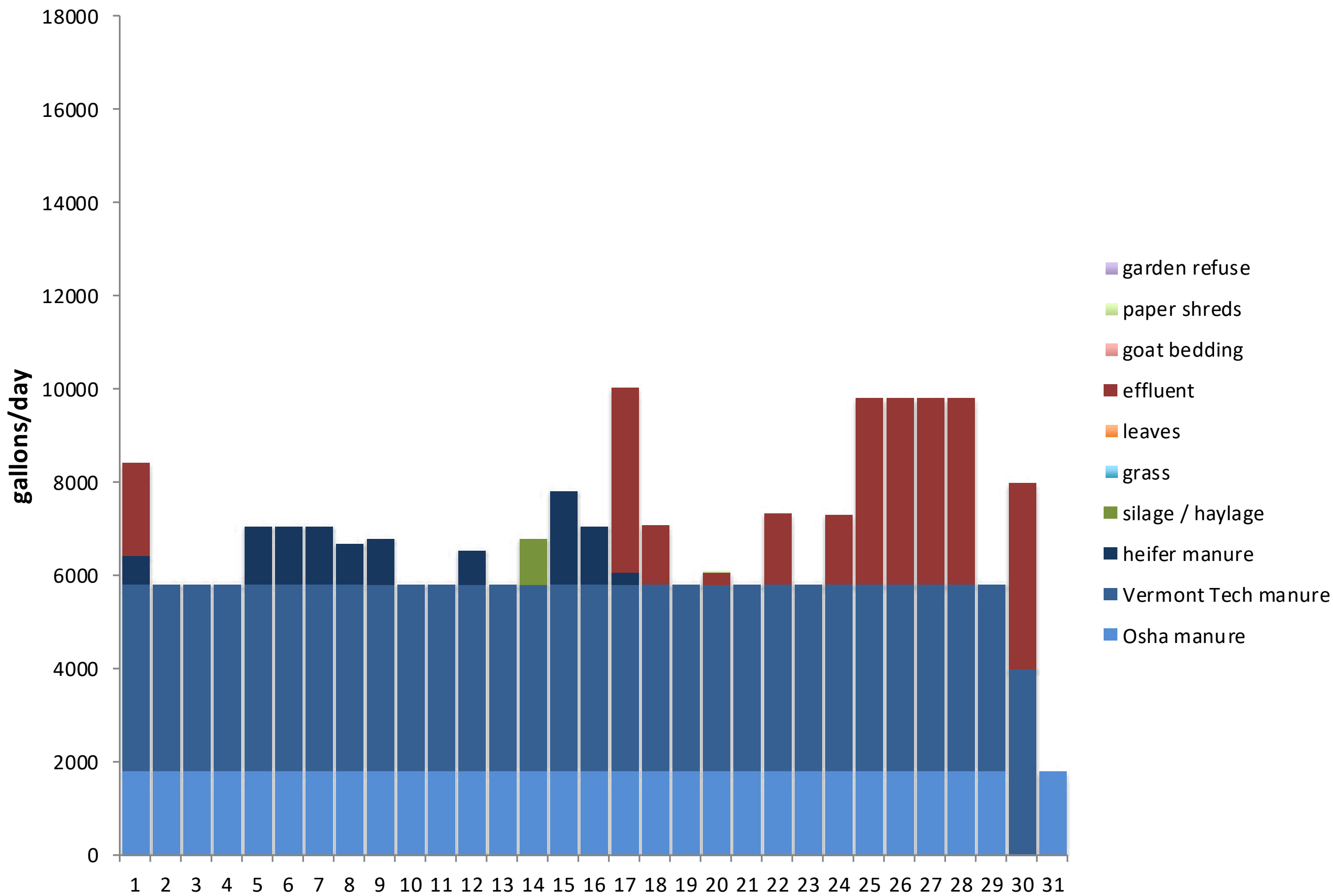


OFF-FARM INPUTS

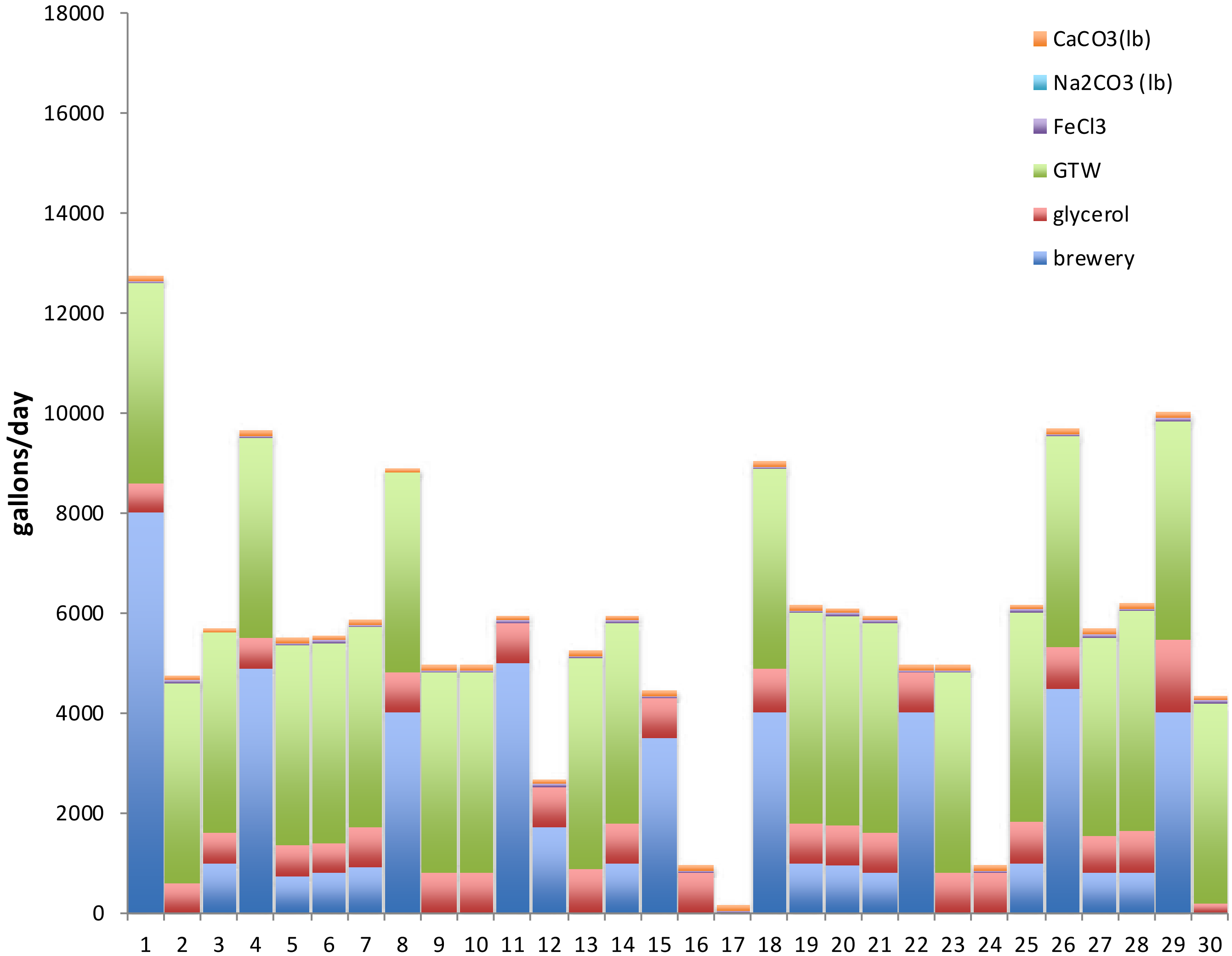


May 2015

ON-FARM INPUTS

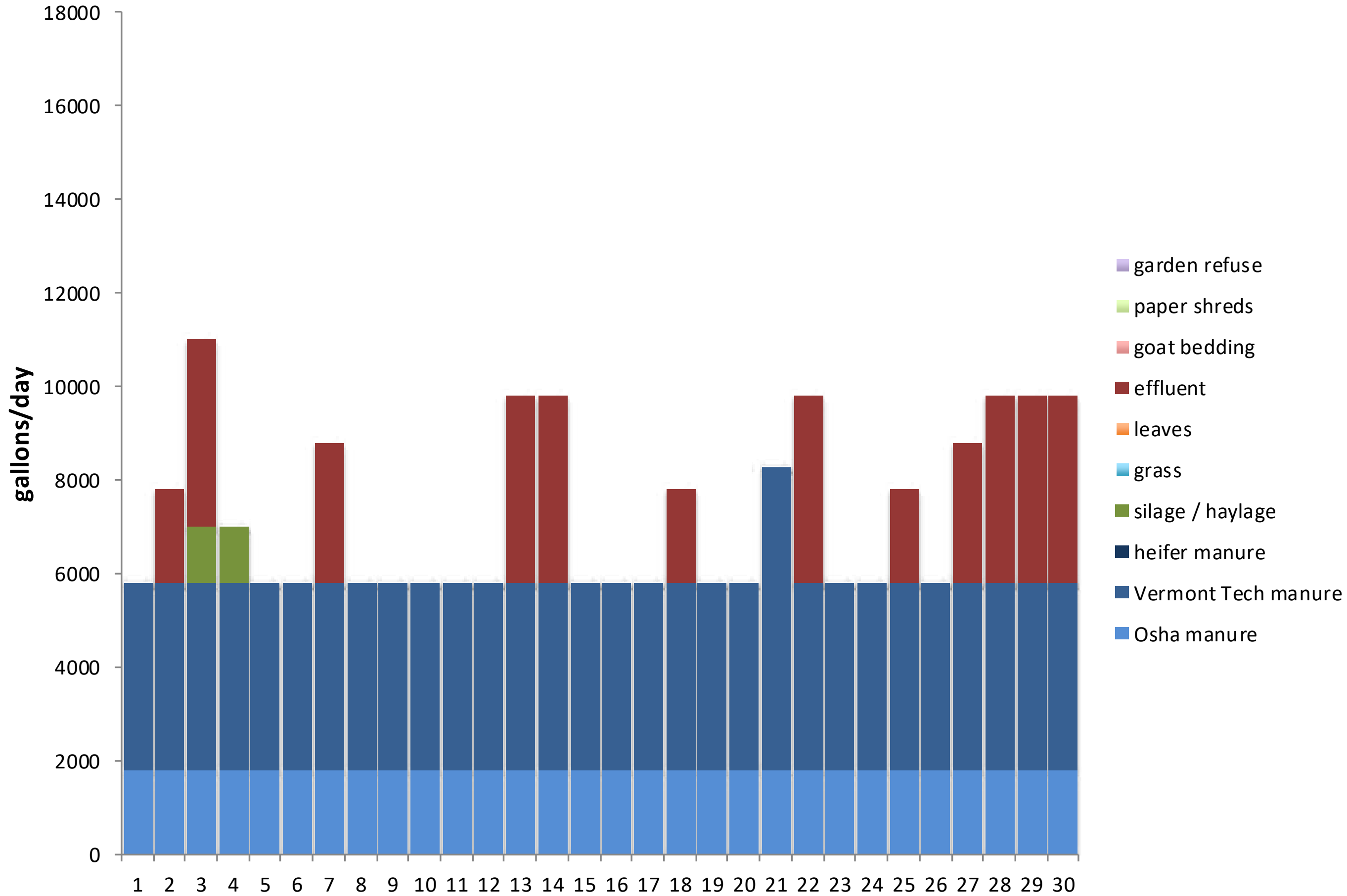


OFF-FARM INPUTS

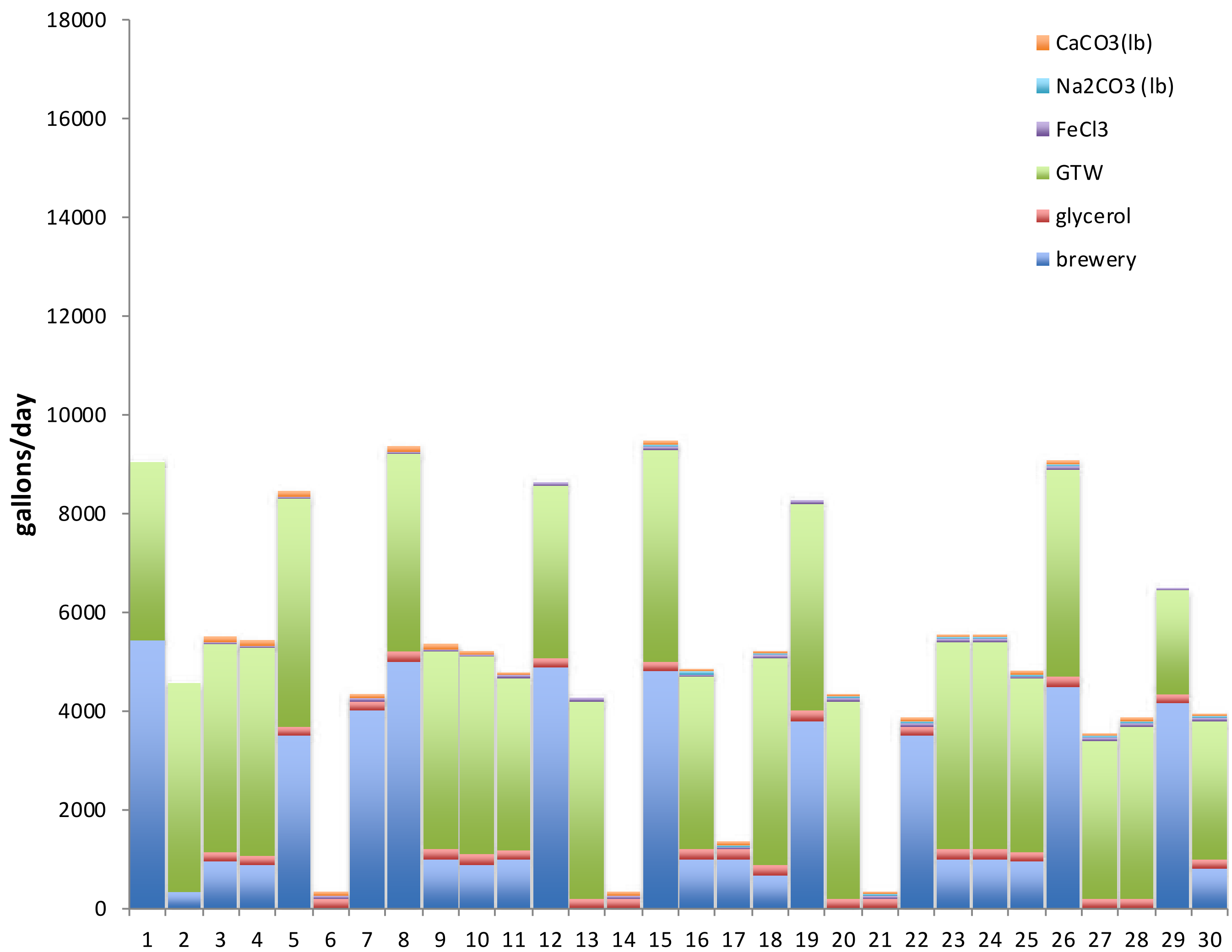


June 2015

ON-FARM INPUTS

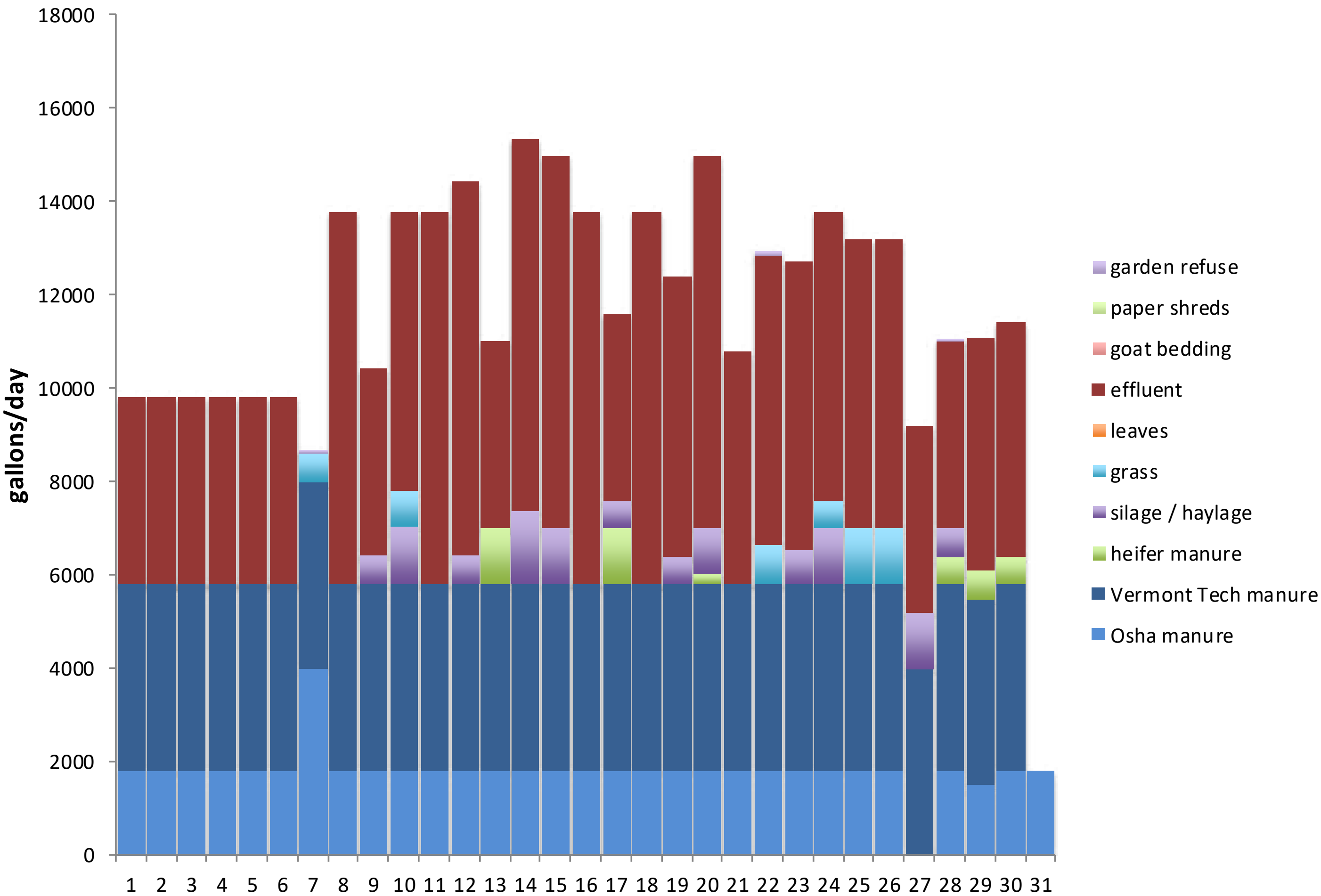


OFF-FARM INPUTS

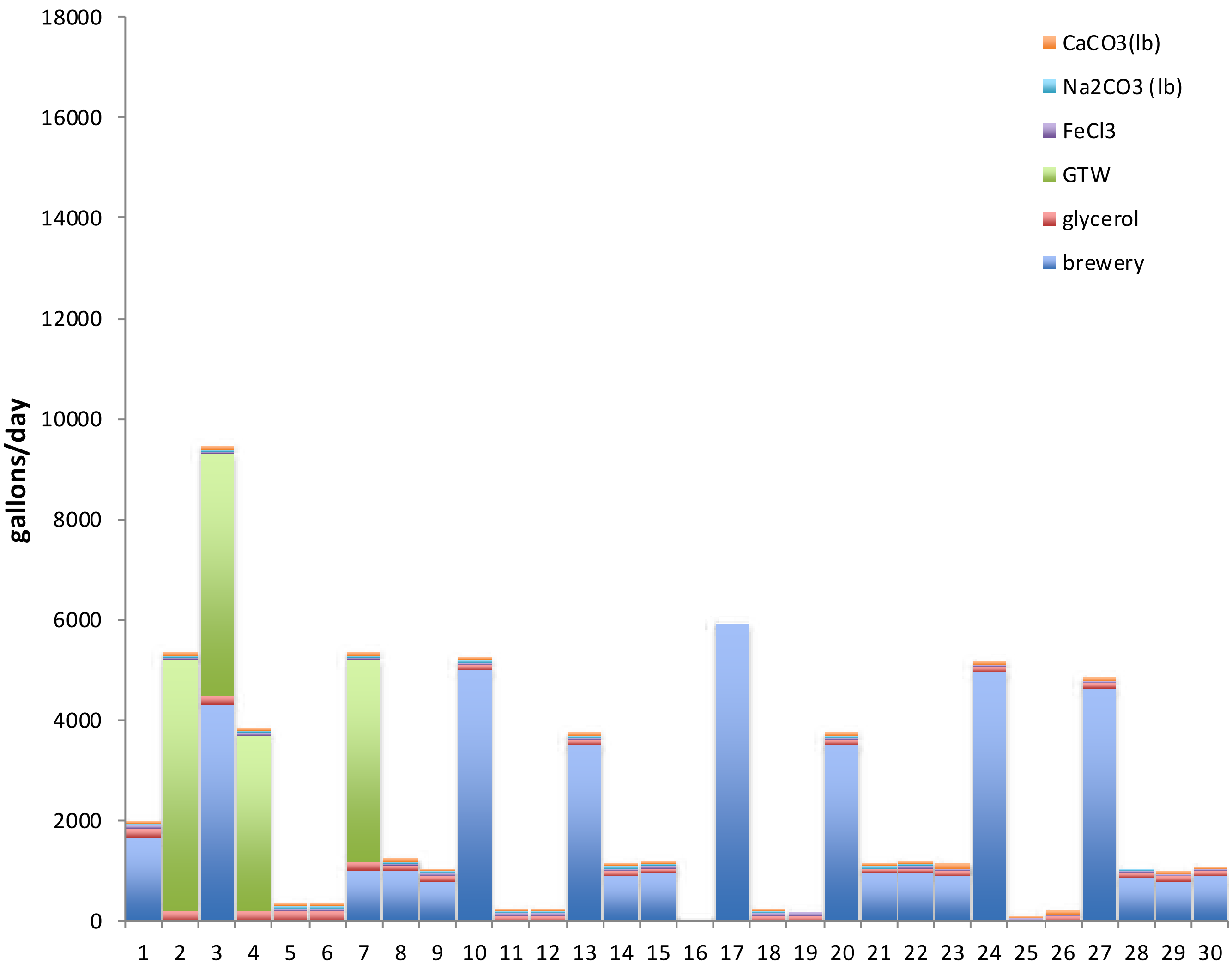


July 2015

ON-FARM INPUTS

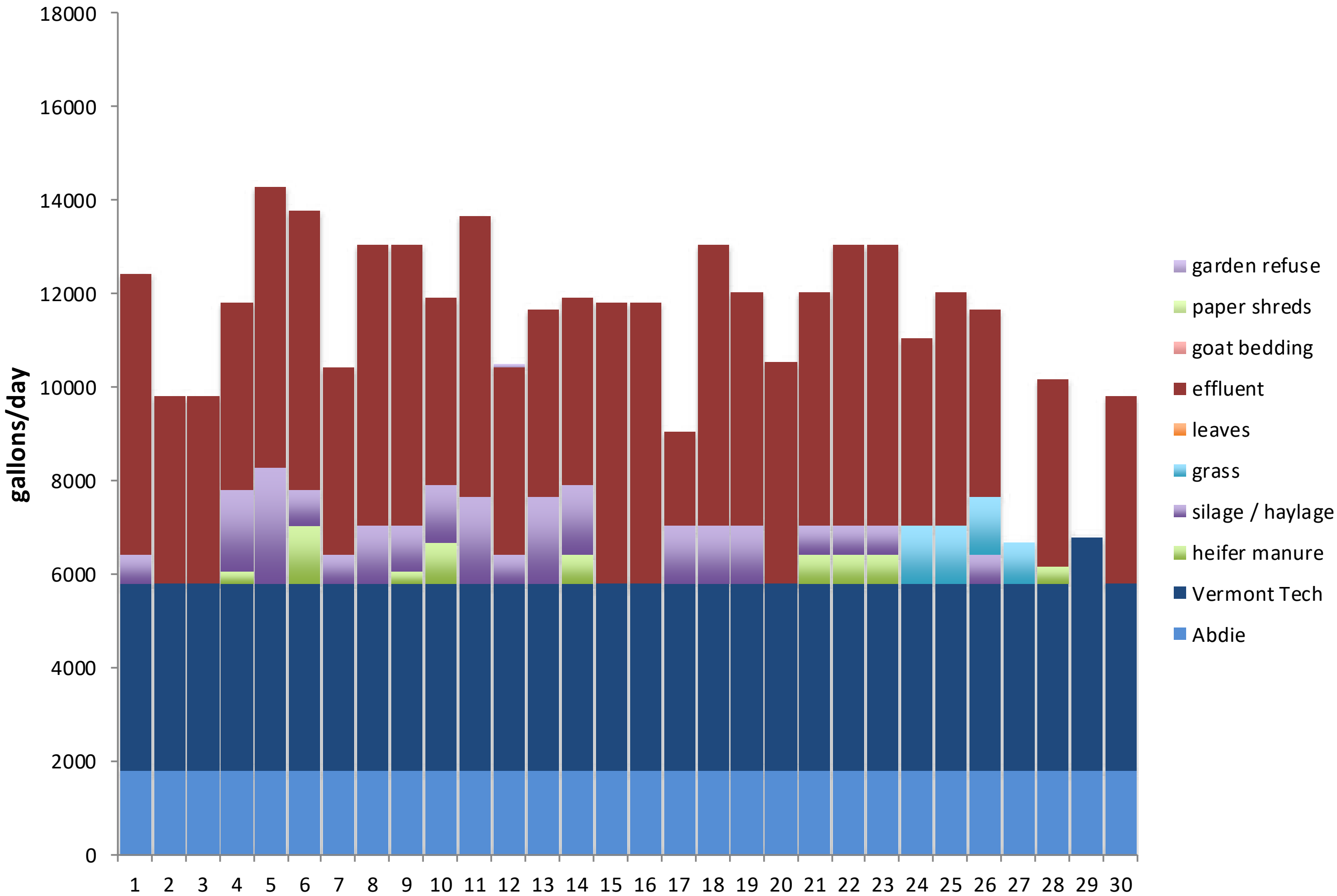


OFF-FARM INPUTS

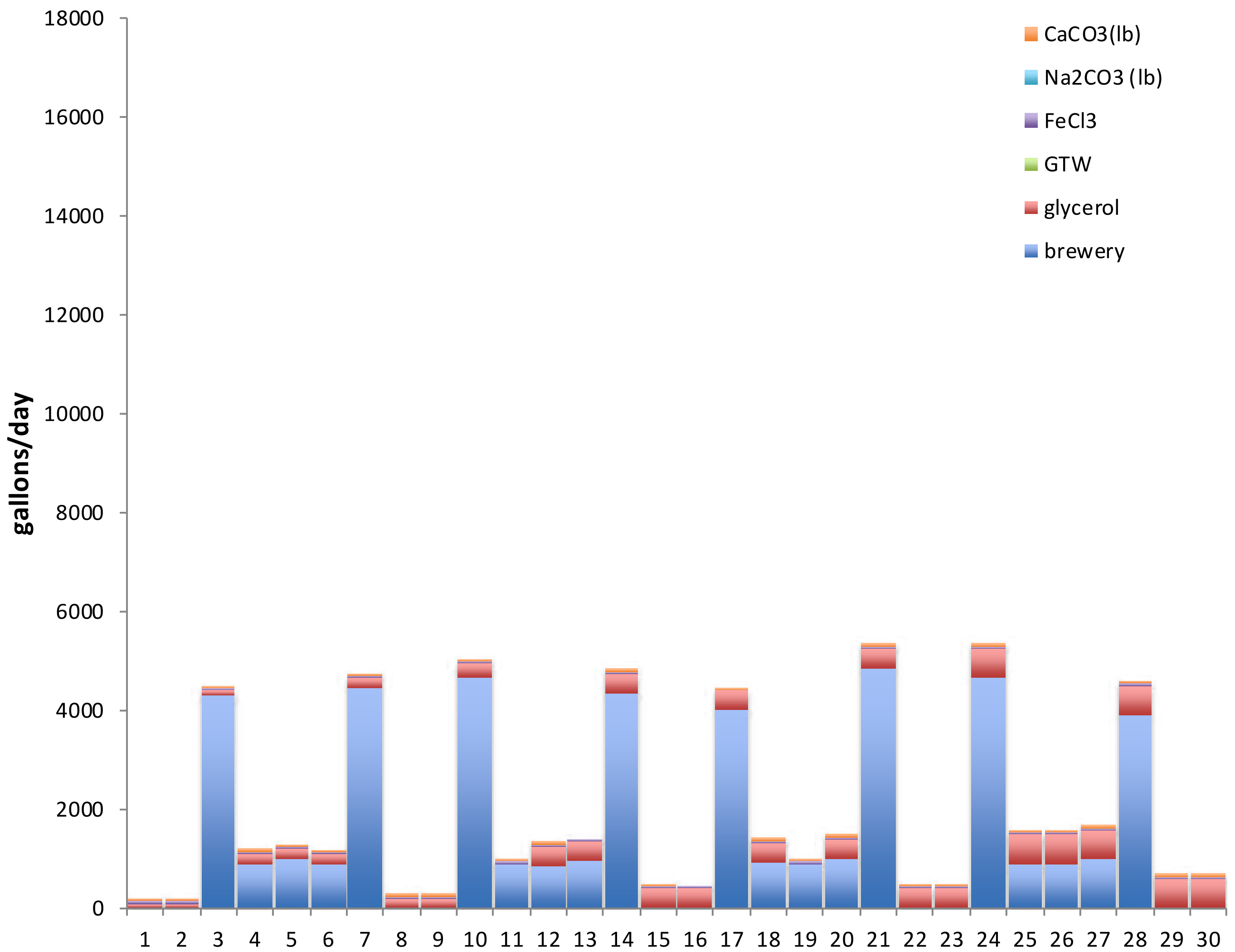


August 2015

ON-FARM INPUTS

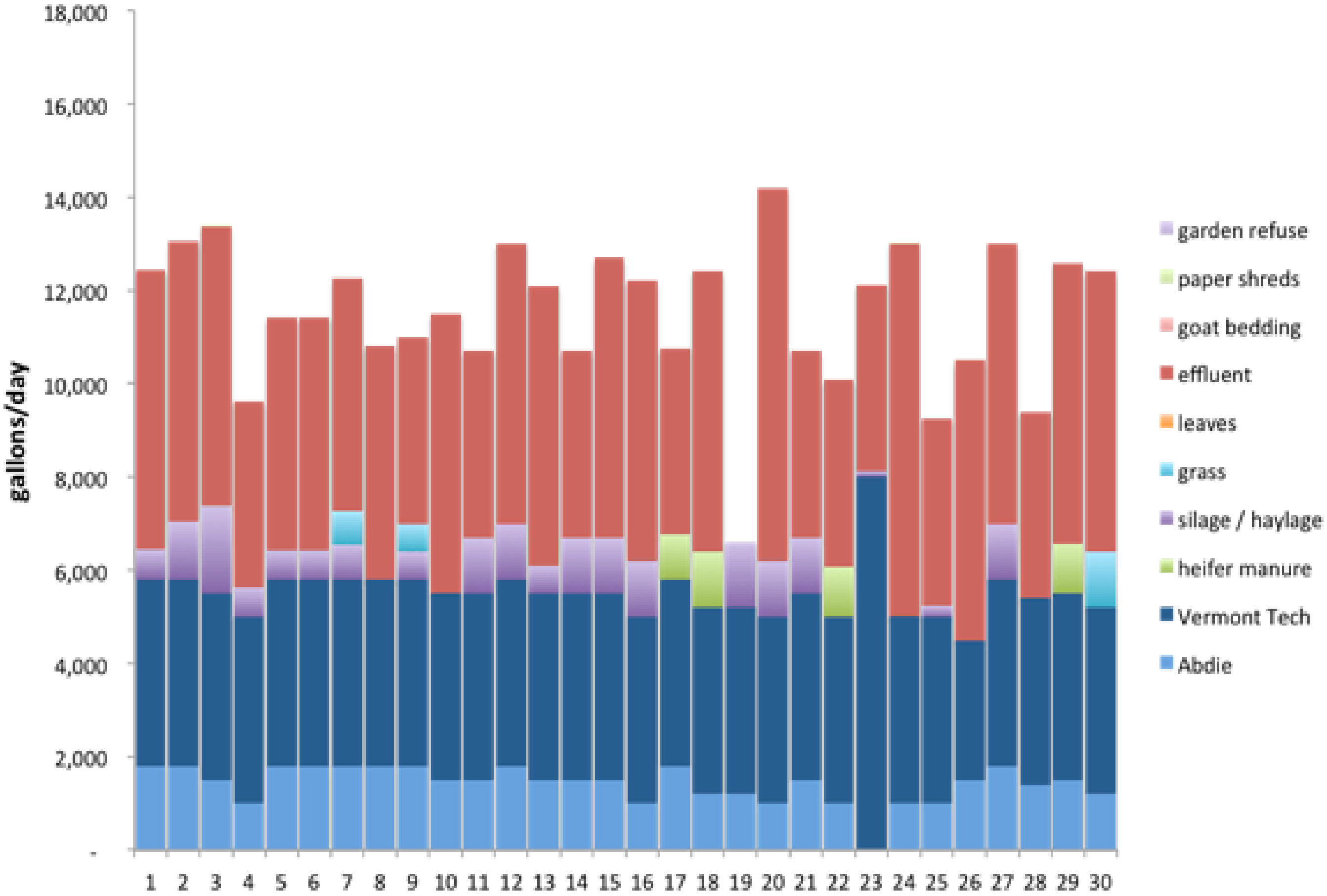


OFF-FARM INPUTS

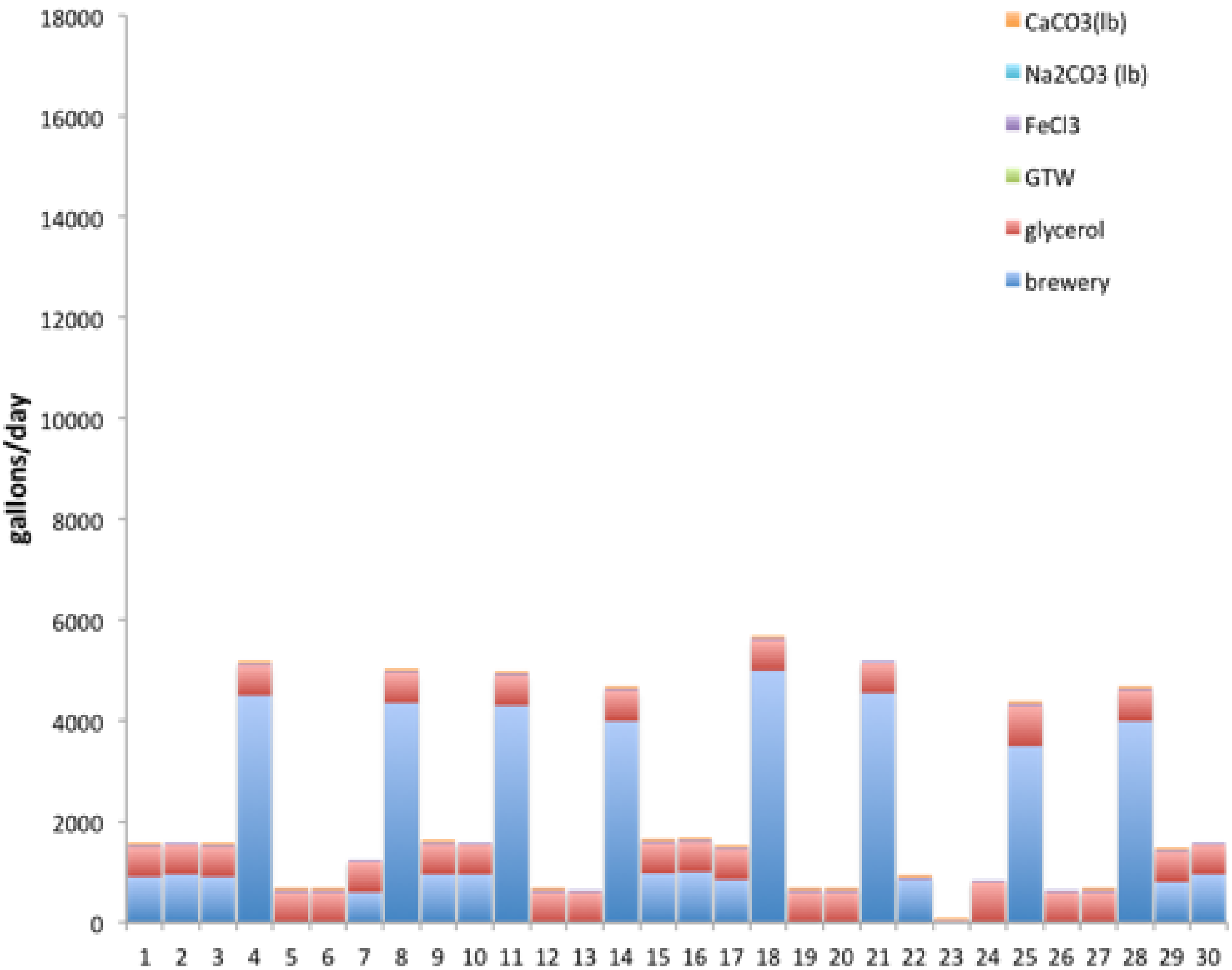


September 2015

ON-FARM INPUTS

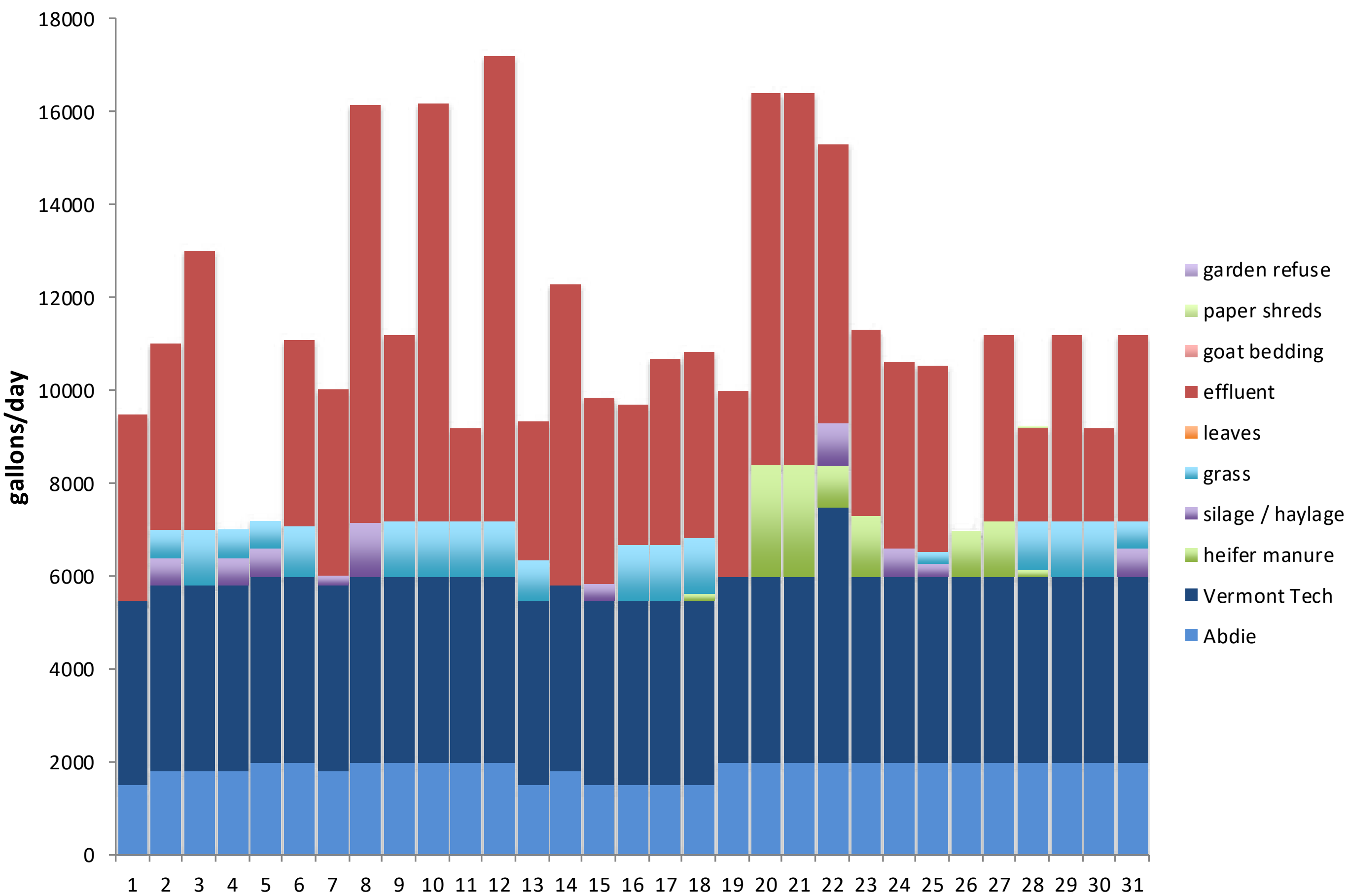


OFF-FARM INPUTS

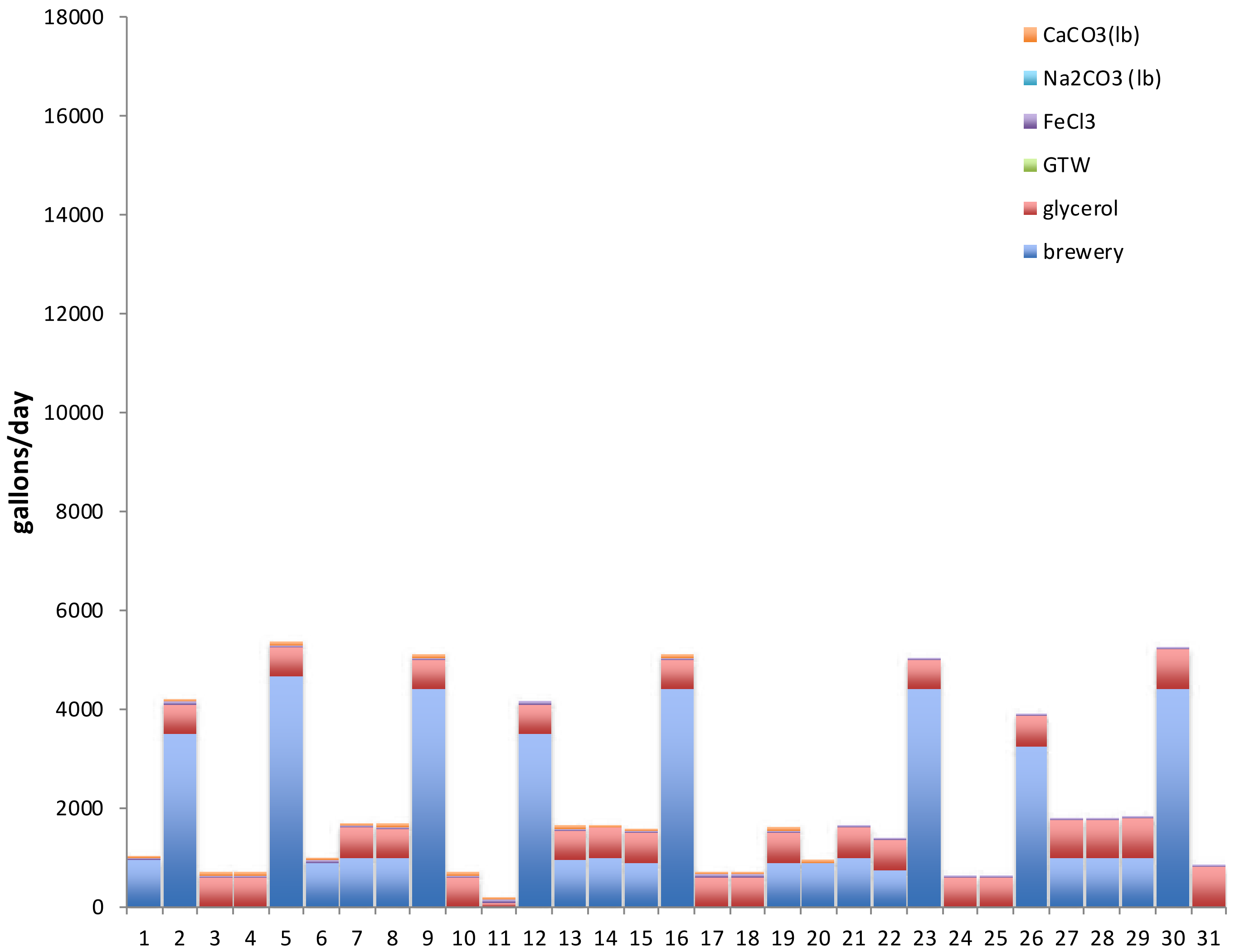


October 2015

ON-FARM INPUTS

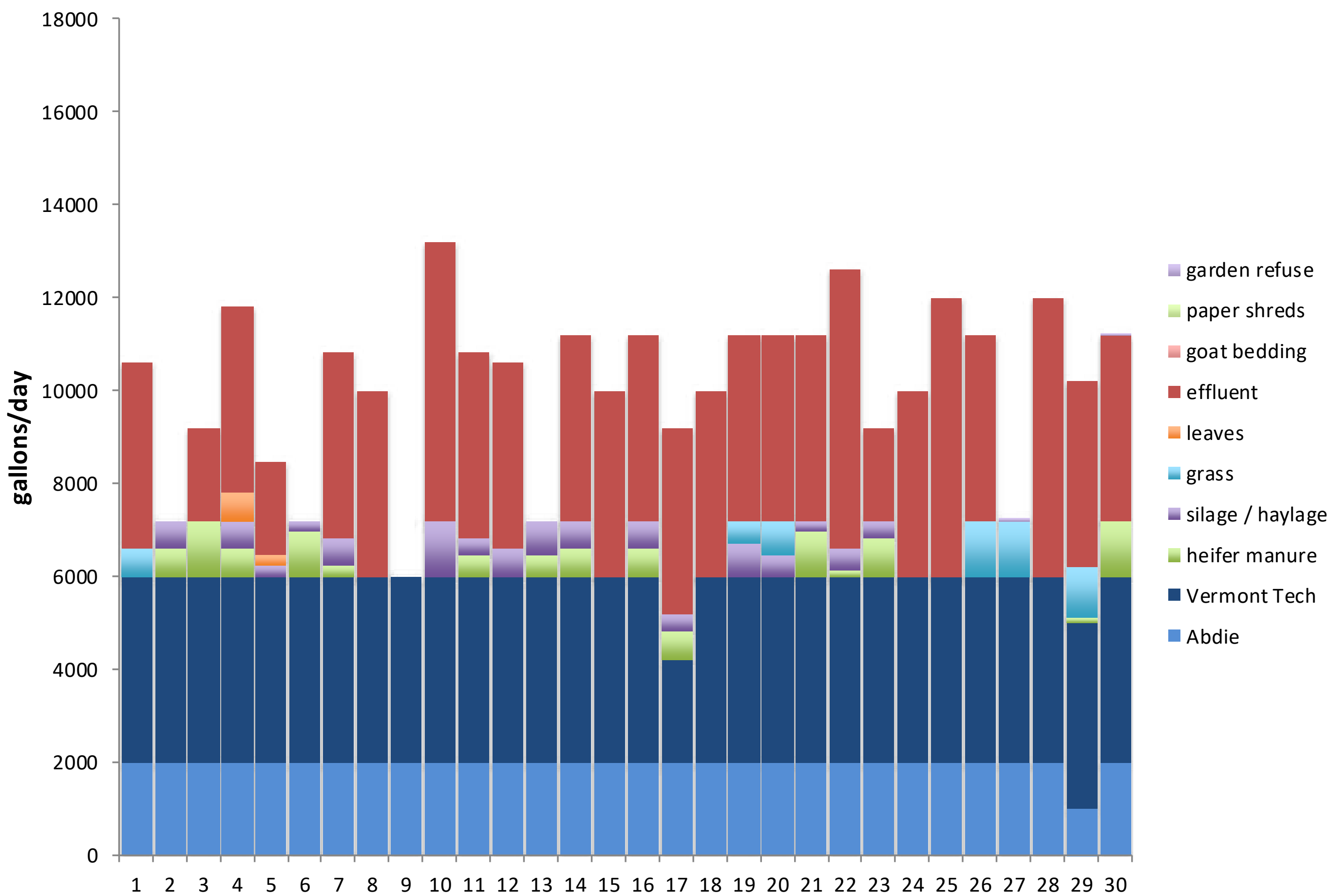


OFF-FARM INPUTS

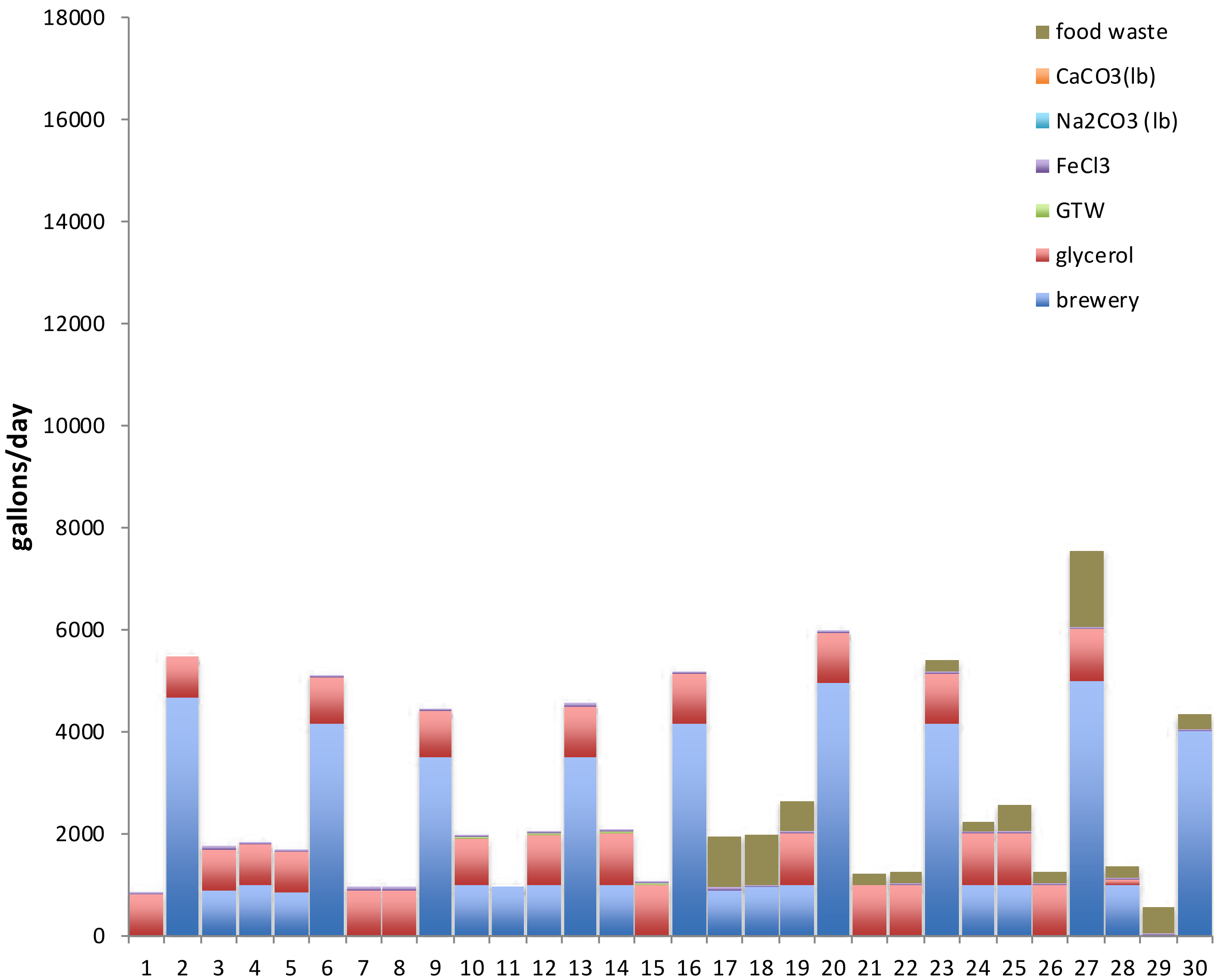


November 2015

ON-FARM INPUTS

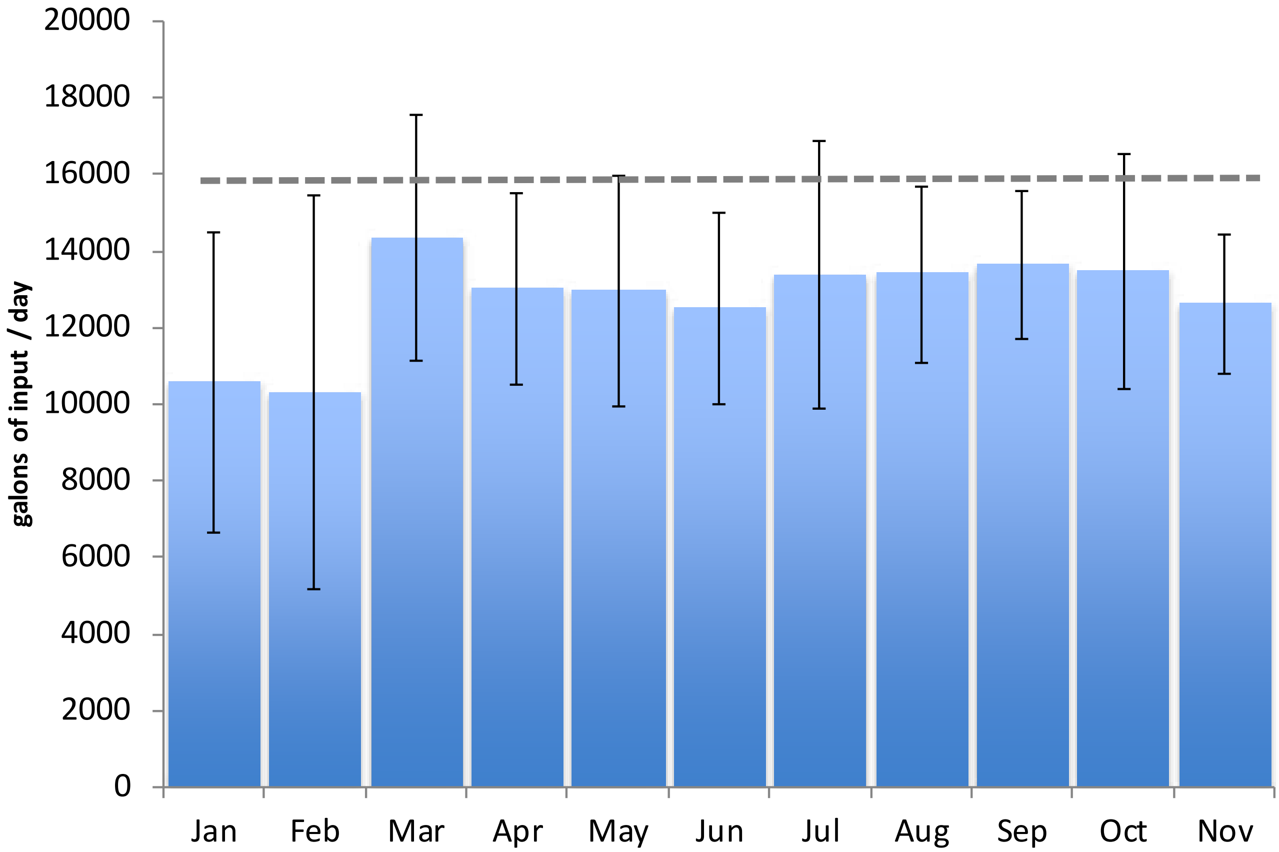


OFF-FARM INPUTS

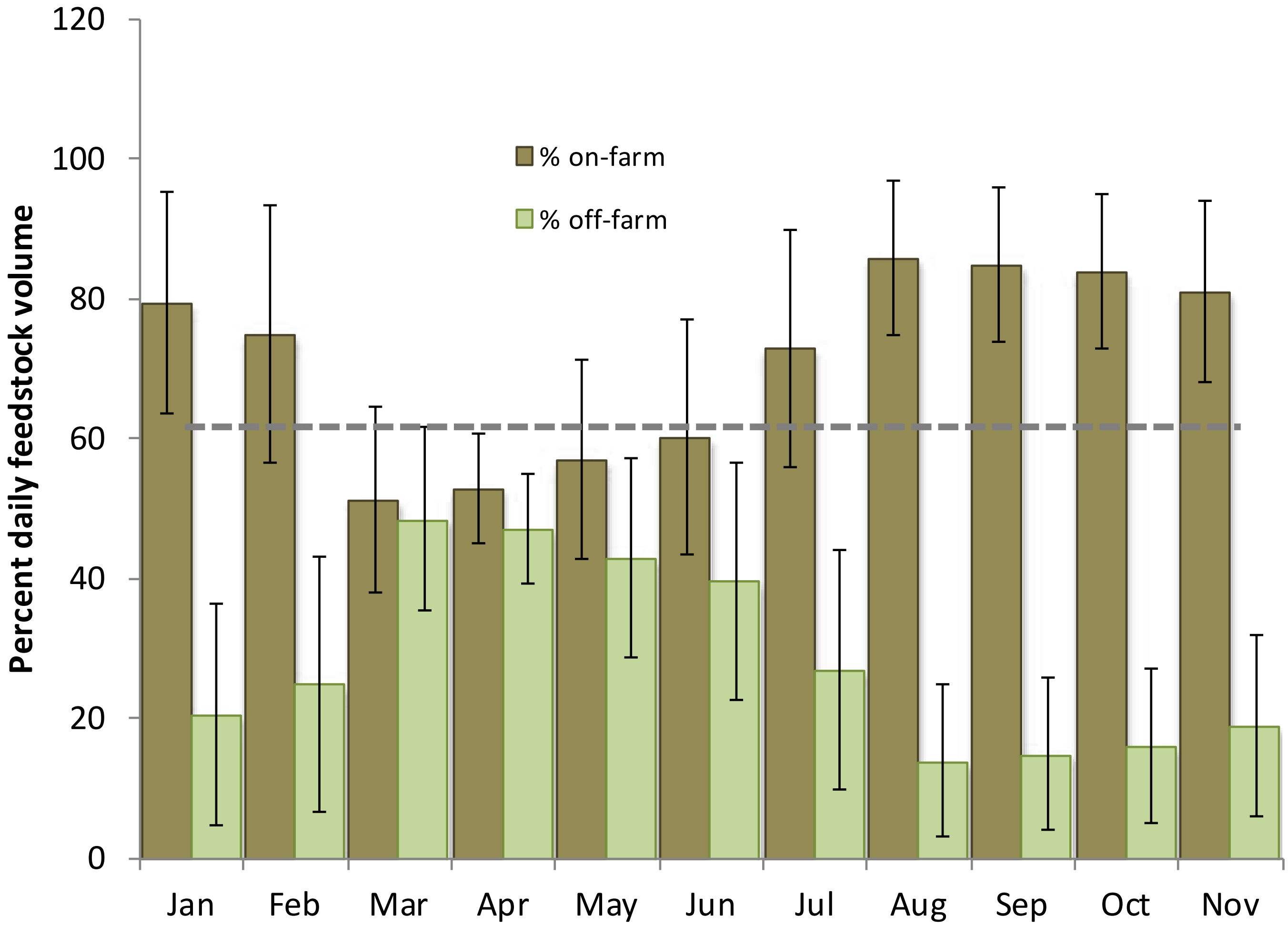


APPENDIX D: MONTHLY FEEDSTOCK SUMMARIES

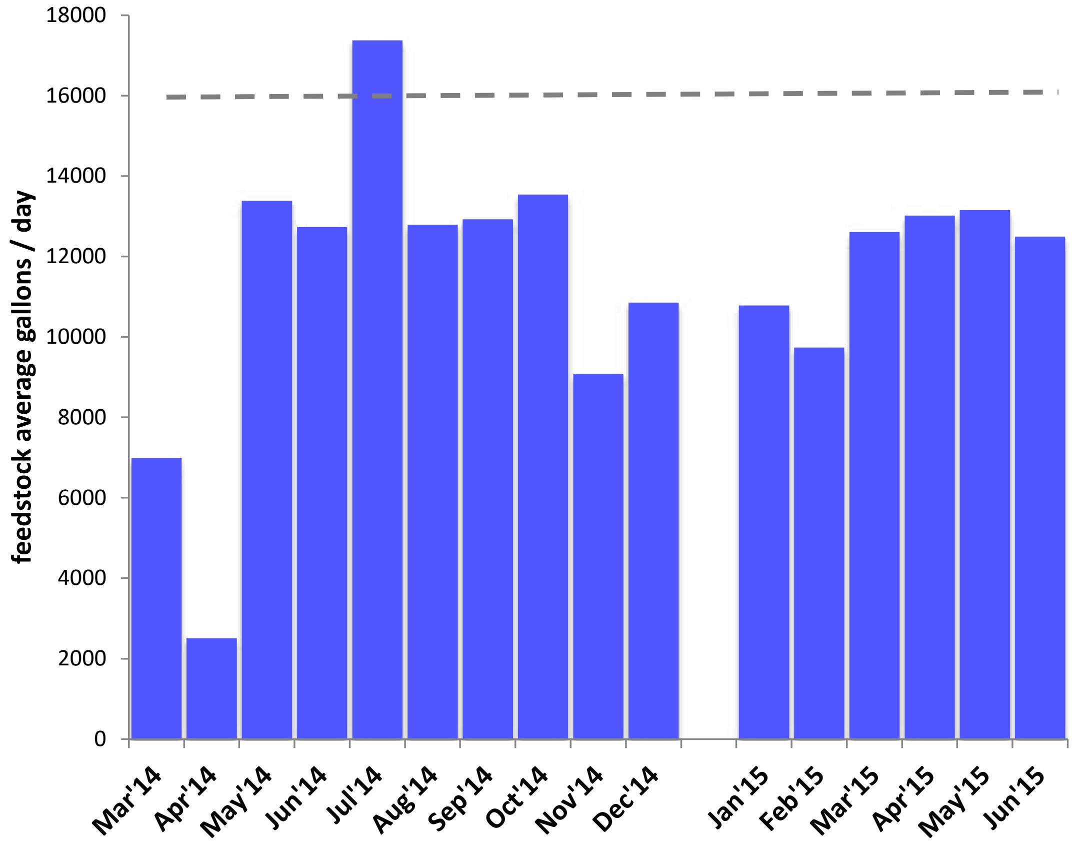
Monthly Input Volumes

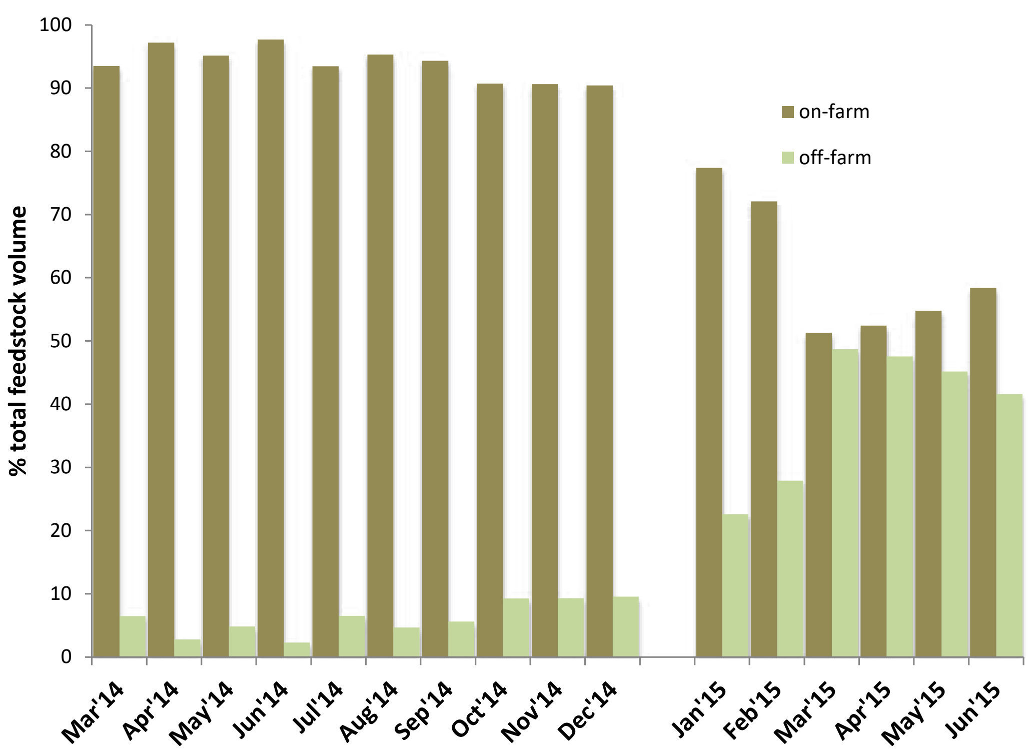


Percent On- and Off-Farm Feedstock



2014—2015 Total





APPENDIX E: FEEDSTOCK SUMMARY 2014-2015

ON-FARM FEEDSTOCK (GALLONS/MONTH)										
Date	**Osha Manure**	**Vermont Tech Manure**	**Heifer Manure**	**Silage / Haylage**	**Grass**	**Leaves**	**VTCAD Effluent**	**Goat Bedding**	**Paper Shreds**	**Garden Refuse**
3/1/2014	40,000	156,000	-	-	-		-			
4/1/2014	-	73,250	-	-	-		-			
5/1/2014	312,000	70,000	-	-	-		-			
6/1/2014	231,800	131,300	10,000	-	-		-			
7/1/2014	348,000	125,100	3,688	2,875	5,250		-	2,500		
8/1/2014	168,024	189,400	-	750	7,375		-			135
9/1/2014	160,000	169,500	-	3,000	9,125		22,000			2,221
10/1/2014	116,000	115,100	4,000	5,625		2,375	125,500			
11/1/2014	16,000	117,900	13,750	2,375	11,000		86,200			
12/1/2014	36,600	114,300	11,700	5,000			127,000			
1/1/2015	50,600	116,200	12,500	2,125			69,000			
2/1/2015	54,800	90,000	16,520	1,375			48,000		30	
3/1/2015	47,800	105,000	21,625	3,125			16,500		30	
4/1/2015	52,000	121,500	25,188	2,125			4,000		30	
5/1/2015	52,200	120,000	10,500	1,000			32,600		50	
6/1/2015	54,000	122,500		2,400			40,000			
Running Total	**1,739,824**	**1,937,050**	**129,471**	**31,775**	**32,750**	**2,375**	**570,800**	**2,500**	**140**	**2,356**

APPENDIX E: FEEDSTOCK SUMMARY 2014-2015

OFF-FARM FEEDSTOCK (GALLONS/MONTH)						
Date	**Brewery**	**Glycerol**	**Grease-Trap Waste**	**$FeCL_3$**	**Na_2CO_3 (Lb)**	**$CaCO_3$ (Lb)**
3/1/2014	9,600	-	4,000			
4/1/2014	2,100	-	-			
5/1/2014	19,500	-	-			
6/1/2014	8,400	440	-			
7/1/2014	12,350	-	21,500			
8/1/2014	11,725	2,140	4,000			
9/1/2014	11,575	1,700	8,500			
10/1/2014	12,900	4,050	19,800			
11/1/2014	10,950	545	13,500			
12/1/2014	13,025	6,610	11,200			
1/1/2015	49,225	6,265	17,300			
2/1/2015	40,000	9,150	31,500			
3/1/2015	42,975	24,000	116,000			
4/1/2015	46,775	15,400	120,500		1,000	700
5/1/2015	53,450	22,430	98,000			3,100
6/1/2015	55,025	5,600	91,700		700	1,600
Running Total	**399,575**	**98,330**	**557,500**		**1,700**	**5,400**

APPENDIX E: FEEDSTOCK SUMMARY 2014-2015

SUMMARY						
	On-Farm	Off-Farm	Volume		On-Farm	Off-Farm
Date	Total Gallons/ Month	Total Gallons/ Month	Total Gallons/ Month	Average Gallons/Day	% (v/v)	% (v/v)
3/1/2014	196,000	13,600	209,600	6,986.67	93.5	6.5
4/1/2014	73,250	2,100	75,350	2,512	97.2	2.8
5/1/2014	382,000	19,500	401,500	13,383	95.1	4.9
6/1/2014	373,100	8,840	381,940	12,731	97.7	2.3
7/1/2014	487,413	33,969	521,382	17,379	93.5	6.5
8/1/2014	365,684	17,964	383,648	12,788	95.3	4.7
9/1/2014	365,846	21,907	387,753	12,925	94.4	5.6
10/1/2014	368,600	37,693	406,293	13,543	90.7	9.3
11/1/2014	247,225	25,457	272,682	9,089	90.7	9.3
12/1/2014	294,600	31,181	325,781	10,859	90.4	9.6
1/1/2015	250,425	73,157	323,582	10,786	77.4	22.6
2/1/2015	210,725	81,506	292,231	9,741	72.1	27.9
3/1/2015	194,080	184,205	378,285	12,610	51.3	48.7
4/1/2015	204,843	185,835	390,678	13,023	52.4	47.6
5/1/2015	216,350	178,430	394,780	13,159	54.8	45.2
6/1/2015	218,900	156,025	374,925	12,498	58.4	41.6
Running Total	**4,449,041**	**1,071,369**	**3,981,741**	**318,539.30**		

APPENDIX F: ENERGY POTENTIAL ESTIMATES OF FEEDSTOCK MATERIALS

Gas Yields Table

This table is only intended to provide indicative results. All values are approximate and can vary extremely. Gas yields depend highly on dry matter content, storage feedstock, handling feedstock. For an exact calculation feedstock testing is definitely necessary.

All data approximate and can vary for exact data further samples are necessary	Dry solids (data can vary)	Organic dry solids (data can vary)	Specific gas production per oDS (data can vary)	Gas-production per tonne fresh material (data can vary)	Produced kilowatt-hours per t FM (35 % electrical efficiency CHP, Heating value 21 MJ/m3, 55 % Methane content, 3.6 MJ/kWh)	Kilowatt per tonne fresh material and day
Unit	% of Fresh material	% of DS	m3 /t oDS	m3/t FM	kWh/t FM	kW/t FM d
Animal carcasses (homogenised	30.0	90	900	243.0	496.1	20.7
Animal fat*	90.0	90	850	688.5	1405.7	58.6
Beet top	12.0	70	420	35.3	72.0	3.0
Canteen waste/ food waste	20.0	85	700	110.0	224.6	9.4
Cattle-dung	25.0	80	300	60.0	122.5	5.1
Cattle-slurry	8.0	80	320	20.5	41.8	1.7
Cereal slop (alcohol production)	6.0	90	480.0	25.9	52.9	2.2
Cereals/grains	85.0	95	650	524.9	1071.6	44.7
Chaff	85.0	90	350	267.8	546.7	22.8
Chicken litter/ dung	40.0	75	420	126.0	257.3	10.7
Chip fat	95.0	87	1000	826.5	1687.4	70.3
Clover	15.0	88	520	68.6	140.1	5.8
Concentrated whey	15.0	90	800	108.0	220.5	9.2
Corn Cob maize (CCM)	60.0	95	600	342.0	698.3	29.1
Draff from beer production	20.0	80	500	80.0	163.3	6.8
Fat	95.0	87	1000	826.5	1687.4	70.3

All data approximate and can vary for exact data further samples are necessary	Dry solids (data can vary)	Organic dry solids (data can vary)	Specific gas production per oDS (data can vary)	Gas-production per tonne fresh material (data can vary)	Produced kilowatt-hours per t FM (35 % electrical efficiency CHP, Heating value 21 MJ/m3, 55 % Methane content, 3.6 MJ/kWh)	Kilowatt per tonne fresh material and day
Fermentation slops	1.8	98	750	13.2	27.0	1.1
Food waste (disinfected)	20.0	85	700	110.0	224.6	9.4
Fruit Pomace	20.0	90	520	93.6	191.1	8.0
Fruit residuals	20.0	80	350	56.0	114.3	4.8
Fruit slop	2.0	95	450.0	8.6	17.5	0.7
Fruit wastes	15.0	90	550	74.3	151.6	6.3
Glycerine*	100.0	95	750	712.5	1454.7	60.6
Grass fresh	18.0	90	450	72.9	148.8	6.2
Grass silage	25.0	85	550	116.9	238.6	9.9
Grease trap	13.0	95	800	98.8	201.7	8.4
Gut + Stomach/ Intestines content	15.0	80	400	48.0	98.0	4.1
Hemp cake	88.0	93	105	85.9	175.4	7.3
Horse manure	28.0	80	250	56.0	114.3	4.8
Maize silage	32.0	95	660	200.6	409.6	17.1
Municipal solid waste	35.0	50	580	101.5	207.2	8.6
Old bread	65.0	95	700	432.3	882.5	36.8
Pig slurry	4.5	80	320	11.5	23.5	1.0
Potato top	12.8	87	420	46.8	95.5	4.0
Potato pulp	15.0	95	650	92.6	189.1	7.9
Potatoes	25.0	92	680	156.4	319.3	13.3
Pure fat (rendering plants)*	99.0	100	750	742.5	1515.9	63.2
Rape seed-silage	16.0	80	500	64.0	130.7	5.4
Rapeseed cake	85.0	93	680	537.5	1097.5	45.7
Residuals from vegetables	20.0	80	450	72.0	147.0	6.1
Sewage sludge	12.0	80	490	47.0	96.0	4.0
Silage effluent*	1.4	95	800	10.6	21.7	0.9

All data approximate and can vary for exact data further samples are necessary	Dry solids (data can vary)	Organic dry solids (data can vary)	Specific gas production per oDS (data can vary)	Gas-production per tonne fresh material (data can vary)	Produced kilowatt-hours per t FM (35 % electrical efficiency CHP, Heating value 21 MJ/m3, 55 % Methane content, 3.6 MJ/kWh)	Kilowatt per tonne fresh material and day
Silage from grain (whole plant)	28.0	90	550	138.6	283.0	11.8
Sugar beet chopped	25.0	85	580	123.3	251.6	10.5
Sugar beet leaves siliert	22.0	75	450	74.3	151.6	6.3
Whey*	5.0	90	750	33.8	68.9	2.9
Sources: FNR (Biogashandreichung), KTBL-website, LfL-website, Big East Biogas handbook						

Average biogas yields of some important materials are presented in the list above. These indicated yields are approximate values. For exact gas yields further analysis is necessary. With the gas yield the possible produced kWh by the cogeneration unit can be calculated (see complete list with more substrates).

Explanations for list:

Abbreviations			
%	**Percent**	**kW**	**Kilowatt**
CHP	**Combined Heat Power**	**kWh**	**Kilowatt hours**
D	**Day**	**m^3**	**Cubic Meter**
DM	**Dry Matter = dry solids**	**MJ**	**Megajoule**
DS	**Dry Solids = dry matter**	**oDM**	**Organic Dry Matter**
FM	**Fresh material**	**oDs**	**Organic dry solids = organic dry matter**
kg	**kilogramm**	**t**	**Tonne = 1000 kg**

APPENDIX G: PREDICTION OF FEEDSTOCK ENERGY PRODUCTION, 2014-2015

ON-FARM FEEDSTOCK (GALLONS/MONTH)										
PREDICTED BIOGAS VOLUME (M3/MONTH)										
Date	**Osha Manure**	**Vermont Tech Manure**	**Heifer Manure**	**Silage / Haylage**	**Grass**	**Leaves**	**VTCAD Effluent**	**Goat Bedding**	**Paper Shreds**	**Garden Refuse**
3/1/2014	3,182	12,409	-	-	-	-	-	-		-
4/1/2014	-	5,827	-	-	-	-	-	-		-
5/1/2014	24,818	5,568	-	-	-	-	-	-		-
6/1/2014	18,439	10,444	3,247	-	-	-	-	-		-
7/1/2014	27,682	9,951	1,197	1,991	2,071	-	-	1,015		-
8/1/2014	13,366	15,066	-	519	2,909	-	-	-		53
9/1/2014	12,727	13,483	-	2,078	3,600	-	833	-		876
10/1/2014	9,227	9,156	1,299	3,896	-	937	4,754	-		-
11/1/2014	1,273	9,378	4,464	1,645	4,339	-	3,265	-		-
12/1/2014	2,911	9,092	3,799	3,463	-	-	4,811	-		-
1/1/2015	4,025	9,243	4,058	1,472	-	-	2,614	-		-
2/1/2015	4,359	7,159	5,364	952	-	-	1,818	-		-
3/1/2015	3,802	8,352	7,021	2,165	-	-	625	-		-
4/1/2015	4,136	9,665	8,178	1,472	-	-	152	-		-
5/1/2015	4,152	9,545	3,409	693	-	-	1,235	-		-
6/1/2015	4,295	9,744	-	1,662	-	-	1,515	-		-
7/1/2015	-	-	-	-	-	-	-	-		-

APPENDIX G: PREDICTION OF FEEDSTOCK ENERGY PRODUCTION, 2014-2015

OFF-FARM FEEDSTOCK (GALLONS/MONTH)			
PREDICTED BIOGAS VOLUME (M3/MONTH)			
Date	**Brewery**	**Glycerol**	**Grease-Trap Waste**
3/1/2014	2,909	-	1,500
4/1/2014	636	-	-
5/1/2014	5,909	-	-
6/1/2014	2,545	357	-
7/1/2014	3,742	-	8,063
8/1/2014	3,553	1,735	1,500
9/1/2014	3,508	1,378	3,188
10/1/2014	3,909	3,283	7,425
11/1/2014	3,318	442	5,063
12/1/2014	3,947	5,358	4,200
1/1/2015	14,917	5,078	6,488
2/1/2015	12,121	7,417	11,813
3/1/2015	13,023	19,455	43,500
4/1/2015	14,174	12,483	45,188
5/1/2015	16,197	18,182	36,750
6/1/2015	16,674	4,539	34,388
7/1/2015	-	-	-

APPENDIX G: PREDICTION OF FEEDSTOCK ENERGY PRODUCTION, 2014-2015

PREDICTED BIOGAS VOLUME (M3/MONTH)				
Date	**Predicated Biogas (M3/Month)**	**Predicted Biogas (M3/Day)**	**Actual Average Biogas (M3/Day)**	**Actual as % Predicted**
3/1/2014	20,000	667		
4/1/2014	6,463	215		
5/1/2014	36,295	1,210		
6/1/2014	35,032	1,168		
7/1/2014	55,712	1,857		
8/1/2014	38,701	1,290		
9/1/2014	41,670	1,389		
10/1/2014	43,885	1,463		
11/1/2014	33,187	1,106	508	45.9
12/1/2014	37,581	1,253	546	43.6
1/1/2015	47,895	1,596	815	51.0
2/1/2015	51,003	1,700	1,029	60.5
3/1/2015	97,942	3,265	2,107	64.5
4/1/2015	95,448	3,182	1,772	55.7
5/1/2015	90,163	3,005	1,802	60.0
6/1/2015	72,818	2,427	1,032	42.5

APPENDIX H: BIOCHEMICAL SCREENING OF FEEDSTOCK MATERIALS

ON-FARM FEEDSTOCK							
Parameter	Optimal or Stimulatory	Moderate Inhibition	Problematic or Inhibitory	Vermont Tech manure 7/10/2013	Vermont Tech heifer manure 2/10/2015	"Bad" silage 2/10/2015	Grass 2/10/2015
				UMaine	CVAS	CVAS	CVAS
pH	> 5		< 5	4.7	7.86	8.44	5.38
% TS	~ 8			62.4	21.8	48.97	59.48
% VS	> 80						
BOD, 5-day (mg/L)							
COD (mg/L)							
Nitrite N (mg/L)							
Nitrate N (mg/L)							
Ammonia N (mg/L)	50 - 200	1,500 - 3,000 pH > 7.4	> 3,000	995	1,015	1,391	272
TKN (mg/L)				1,893	7,083	9,494	10,293
organic N				899			
P, total (mg/L)				695	2,918	4,429	4,072
K, total (mg/L)	200 - 400	2,500 - 4,500	12,000	2,900	5,965	18,328	14,108
Na, total (mg/L)	100 - 200	3,500 - 5,500	8,000	767	618	370	266
Cl (mg/L)							
B, total (mg/L)			2	2			
Ca, total (mg/L)	100 - 200	2,500 - 4,500	8,000	1,318	2,860	9,343	5,698
Cu, total (mg/L)			1 - 10		10	6	8
Fe, total (mg/L)			5	853	677	514	938
Mg, total (mg/L)	75 - 100	1,000 - 1,500	3,000	695	1,262	1,685	1,217
Mn, total (mg/L)				38	71	73	84
Zn, total (mg/L)				10	35	20	18
Sulfide (mg/L)			50				

APPENDIX H: BIOCHEMICAL SCREENING OF FEEDSTOCK MATERIALS

OFF-FARM FEEDSTOCK							
Parameter	Optimal or Stimulatory	Moderate Inhibition	Problematic or Inhibitory	Ayers Brook Bedding 2/10/2015	Effluent 2/10/2015	Alchemist Sludge 2/10/2015	Long Trail Yeast Slurry 6/25/2013
				CVAS	CVAS	Endyne	Endyne
pH	> 5		< 5	7.97	7.88	4.3	4.6
% TS	~ 8			27.29	4.65	8.1	
% VS	> 80					96.6	
BOD, 5-day (mg/L)							119,000
COD (mg/L)						153,900	NA
Nitrite N (mg/L)						9	4.7
Nitrate N (mg/L)						0	
Ammonia N (mg/L)	50 - 200	1,500 - 3,000 pH > 7.4	> 3,000	2,271	1,150	24	
TKN (mg/L)				10,627	4,220	1,539	5,200
organic N							
P, total (mg/L)				9,271	872	259	1,300
K, total (mg/L)	200 - 400	2,500 - 4,500	12,000	9,401	2,113	591	1,700
Na, total (mg/L)	100 - 200	3,500 - 5,500	8,000	1,203	585	19	130
Cl (mg/L)						219	310
B, total (mg/L)			2				
Ca, total (mg/L)	100 - 200	2,500 - 4,500	8,000	8,355	1,182		
Cu, total (mg/L)			1 - 10	14	6		
Fe, total (mg/L)			5	413	300		
Mg, total (mg/L)	75 - 100	1,000 - 1,500	3,000	3,705	458		
Mn, total (mg/L)				97	19		
Zn, total (mg/L)				87	13		
Sulfide (mg/L)			50				

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