Clean Energy Fund: Advanced Biomass Gasification For Combined Heat And Power Demonstration

Public Project Report
Project F12.016
The University of British Columbia
Vancouver, BC
2015

Acknowledgements

The University of British Columbia (UBC) gratefully acknowledges the financial contribution made by Natural Resources Canada to the construction of the BioEnergy Research and Demonstration Facility (BRDF).

UBC also acknowledges the financial contributions made to the BRDF by other core funders:

- Western Economic Diversification,
- Sustainable Development Canada,
- BC BioEnergy Network,
- The Province of British Columbia
- Corvus Energy
- Alpha Technologies
- FP Innovations,
- Canadian Wood Council,
- GE Canada, and
- Nexterra Systems Corp.,

Report Purpose

This Report is intended to provide information and insights to stakeholders, companies or municipalities that are considering investment in similar Combined Heat and Power (CHP) facilities. The report is a companion public document to the Biomass Combined Heat and Power Options Report which provides more detailed analysis to determine the feasibility of adopting a CHP system having regard to issues such as current fuel costs, heat and power requirements, cost of installation and operation, efficiency of the technology, availability of suitable biomass, and the term of investment. The Options Report is available at https://research.ubc.ca/biomass-combined-heat-power-options-report.

Table of Contents

1. Executive Summary

To meet the university's need for heat and electricity and to reduce its emissions of fossil fuel related CO_2 The University of British Columbia (UBC) embarked, in September 2010 to design and build a "global first" combined heat and power (CHP) facility, at their Point Grey campus located in Metro Vancouver (the Project). The uniqueness of the Project was twofold. First, the fuel input would be, locally sourced, clean woody biomass; and second, the electricity would be generated utilizing an internal combustion, reciprocating engine fueled by conditioned biomass derived synthesis gas (syngas).

In 2011 the Project was expanded to include enhanced heat recovery of planned-vented heat and the incorporation of an advance electro chemical energy storage system (ECES) and energy management system to provide emergency backup power if the event of main electrical supply grid failure. In total 1MWh of lithium-ion based electrical energy storage capacity was installed at three "energy nodes" located on the campus.

In January, 2013 the Project was further expanded to introduce dual-fuel capability to the BRDF. The motivation was threefold. First the mechanical failure, in 2013, of the clean-synthesis gas conditioning system, precluded the generation of engine-quality syngas and thus prevented the generation of electricity or recovery of engine heat from these assets. Second, the desire to designate the facility as a "firm" supplier of power required power production, and therefore fuel, redundancy. And finally the availability, through FORTIS BC, of renewable natural gas (RNG) (http://www.fortisbc.com/NaturalGas/RenewableNaturalGas/Pages/default.aspx).

In operation since October 2012, the performance and availability of the facility has been ever improving. Enabling duel fuel capability has allowed the performance of the facility to exceed the original expectations by 75%. During the period January 1, 2015 – March 31, 2015 the facility realized an availability of 84% and generated approximately 42,000 GJ of steam, 4.1 GWh of electricity and 674 MWh of hot water. The original goal for the BRDF was the displacement of 5,498 tonnes of fossil-fuel based CO2 annually. Currently the facility displaces approximately 6,679 tonnes of emitted fossil fuel based CO2 and the facility is on track to displace over 9,000 tonnes annually by 2017. Third party measurement of emissions, have always realised results that over-achieved the compliance goals pertaining to the facility.

Realizing the social licence to construct and operate a biomass fuel power facility in an urban environment has always been a key goal for the Project. The community's total acceptance of the Project has provided a reference site for others contemplating siting similar facilities in similar environments.

The Project also provided a unique platform for the industrial partners to develop and showcase new products. As an "operational asset" the partners are also ensured that UBC will continue to maintain the functionality of their product. Commercially the BRDF has served as a reference site for Nexterra's successful expansion into the United Kingdom and the development of new product for Corvus and Alpha.

Finally at the outset UBC wanted to integrate teaching and learning opportunities with the operational requirements of the facility. To date research valued at over $500k has been linked to the facility.

UBC will continue to make incremental improvements to the BRDF to enhance its performance. For the ECES the ultimate goal will be to have this technology cited in the UBC Technical Guidelines, as a UBC accepted technology for back-up power generation in plant-scale applications. To date, rectifying the mechanical failure of the syngas conditioning remains an outstanding issue due to financial and other considerations (e.g. the price/availability of renewable natural gas). If conditions change, re-mobilization of the gas conditioning system will be reviewed and appropriate actions will be taken.

2. Introduction

This report is based on the operational experience of the BRDF located on the Point Grey Campus of UBC. The BRDF commenced full operation in October 2012 after a two year design, construction and commissioning phase, and is North America's first demonstration of a community-scale internal combustion engine based combined heat and power (CHP) system fuelled by woody biomass and renewable natural gas (RNG). The facility utilizes the proprietary woody biomass gasification technology developed by Nexterra (http://www.nexterra.ca/files/corporate-profile.php) to produce syngas, which is then used to produce thermal or electrical energy. (For a further description of the technology and the facility, see http://sustain.ubc.ca/research/signature-research-projects/bioenergy-research-and-demonstration-facility)

Realizing the opportunity represented by the recovery of vented heat produced by the GE engine, used to power the electrical generator, the Project was expanded, in 2012-13 to include the addition of a heat exchanger and interconnection of the engine's cooling system loop and exhaust with the university's district energy system. At the same time, to meet the requirements for a source of back-up power in the case of a power grid failure, and to provide an "at scale" demonstration of an integrated energy generation and storage system, UBC embarked, with its Partners Corvus and Alpha, in the design and deployment of: 1 MWh of lithium–Ion based energy storage, at three "energy nodes", located on the UBC Point Grey campus, and an overarching Supervisory Management and Control system.

In January, 2013 the Project was further expanded to introduce dual-fuel capability to the BRDF. The motivation was threefold. First the mechanical failure, in 2013, of the clean-synthesis gas conditioning system, precluded the generation of engine-quality syngas and thus prevented the generation of electricity or recovery of engine heat from these assets. Second, the desire to designate the facility as a "firm" supplier of power required power production, and therefore fuel, redundancy. And finally the availability, through FORTIS BC, of renewable natural gas (RNG) (http://www.fortisbc.com/NaturalGas/RenewableNaturalGas/Pages/default.aspx) to maintain the utilization of renewables to fuel the facility.

3. Background

Since 2007 Nexterra had been working with GE, and its subsidiary Jenbacher Ltd. to develop a new generation of biomass fueled combined heat and power systems in the 2 to 10 megawatt (MW) size range. The proposed system would utilize a Jenbacher reciprocating engine fueled by conditioned syngas generated by the Nexterra system. The attributes of the system make the technology ideally suited for "inside-the-fence" thermal and CHP applications for industrial and institutional facilities. Nexterra had also developed, a new gas condition process utilizing high efficiency thermal cracking to overcome any engine fouling issues and had demonstrated this capability at pilot scale. Both Nexterra and GE were keen to undertake a "city scale" demonstration.

On March 24th, 2010, UBC committed to aggressive GHG emissions targets for its core academic buildings on the Point Grey campus:

- reduce GHGs an additional 33 per cent from 2007 levels by 2015
- reduce GHGs to 67 per cent below 2007 levels by 2020
- eliminate 100 per cent of GHGs by 2050

UBC personnel realized that a unique partnership of both internal UBC and external entities would be required in order to meet these targets and therefore committed to take advantage of its unique capacity for project management, asset investment, research and problem solving to embrace and deploy leading-edge technology and concepts. The needs of UBC, to reduce its GHG emissions from, the natural-gas fueled boiler facility, its largest emitter, and the desire of Nexterra and GE, to demonstrate the CHP technology at a “city scale” aligned. And, in 2009, UBC, Nexterra and GE formed a partnership to solidify a demonstration project.

In 2011, UBC embarked upon an $85 million project to convert the Point Grey heating grid from steam to hot water. This change to hot water also allowed for the consideration of the “harvesting” of BRDF-generated low temperature heat. Analysis of the opportunity represented by the GE engine confirmed that it was a prime candidate for recovery of both steam and hot-water grade heat and that by doing so the overall system-energy efficiency would be increased.

Also, in 2011, a safety audit of the BRDF identified the need to supply power to the facility in the case of a power-grid failure. At the same time Vancouver based Alpha and Corvus wished to demonstrate “at scale” an integrated energy generation and storage facility based on newly available Dow Kokum battery technology. Initial discussion identified that again both the needs and desires of UBC, Corvus and Alpha could be met and the team embarked on the design of a 1 MWh distributed energy network and the Supervisory Management and Control system.

The mechanical failure of the clean-synthesis gas conditioning system in 2013, and the subsequent decision not to pursue repair/replacement (estimated cost ~ $1.4 million) negating the generation of electricity or heat with the impact of “orphaning” all the BRDF’s electricity generating assets. Discussions with GE indicated that modification of the engine to operate on either syngas or natural gas seemed viable. And the ability of purchasing RNG would allow UBC to remain true to its GHG reduction commitment. Augmenting the woody biomass fuel with RNG and the installation of an RNG steam-producing boiler also would allow the facility to be identified as a “firm” rather than an “interruptible” source of thermal energy.

4. System Description

4.1. BRDF

The BRDF has two modes of operation, Thermal and CHP. In Thermal Mode the facility produces only heat energy in the form of steam. In CHP Mode, the facility produces both electrical AND thermal energy (Figure 1). (See http://sustain.ubc.ca/research/signature-research-projects/bioenergy-research-and-demonstration-facility for further description of the technology and the facility.)

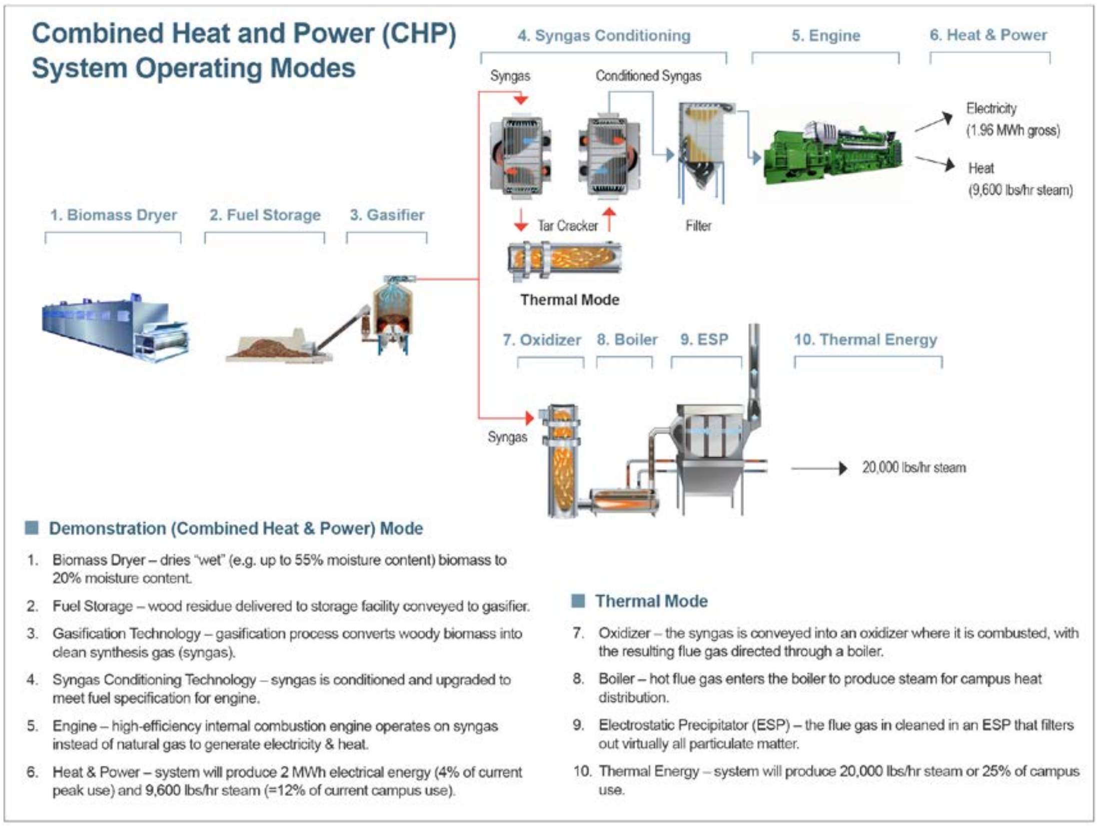

Figure 1 The BRDF was initially designed to operate in one of two modes – Thermal or CHP.

4.2. ECES

The ECES is a unique combination of battery (Corvus – see http://corvus-energy.com/) and Energy Management (Alpha – see http://www.alpha.ca/web2/) technologies. The deployed network has facilities located at three “energy nodes” located on the campus (Table 2).

Node Location	Designed Capacity[1]	Primary Purpose
BDRF	312 kWh (1 hour backup)	Power to energize fans and other equipment required for controlled shut down of facility.
NCE Lab	416 kWh (4 hour backup)	Power required for controlled shutdown of laboratory equipment Power required to “smooth” base- community grid power supply
Kaiser Lab	273 KWh (8 hour backup)	Power required to “smooth” base- community grid power supply Integration with existing DC circuit/equipment Research and demonstration of advanced ECES applications

Table 1 The NCE energy node has the largest energy storage capacity.

Capable of operating independently the “nodes” are linked via an energy management system (EMS) to enable both autonomous and manual/automated central control.

[1] The ECES technology is Lithium–ion based battery manufactured by Dow Kokam

5. Objectives and Outcomes

5.1. Construct and commission a 2MWe biomass CHP system at UBC's Point Grey campus

Figure 2 Interior view of the BRDF.

The BRDF (Figure 2) commenced full operation in October 2012 after a two year design, construction and commissioning phase, and remains North America's first demonstration of a community-scale internal combustion engine based combined heat and power (CHP) system fuelled by woody biomass and RNG. The "design" energy-production capacity of the BRDF is summaries in Table 1.

DESIGNED ENERGY PRODUCTION CAPACITY		
Operating Mode	Thermal Energy	Electrical Energy
Thermal[2]	20,000 lbs/hr = 21 GJ/hr = 5.8 MW	0
CHP	9,600 lbs/hr = 10 GJ/hr = 2.8 MW	1.94 MWe (Gross)

Table 2. In CHP the BRDF is designed to produce 10 GJ/hr of thermal and 1.94 MW of electricity.

[2] Three processes within the BRDF generate thermal energy: the boiler, engine exhaust, and engine water jacket.

5.2. Achieve and document operating costs and performance

5.2.1. First 12 Months Pre Dual Fuel Conversion

During the first 12 months of operation the facility consumed over 7k tonnes of oven-dry woody bio mass fuel (Table 3).

Biomass (ODMT)	Plant Uptime (%)	Thermal Mode Hours	Steam Production (GJ)	CHP Mode Hours	Engine Runtime Hours	Electricity Generated (MWh)
7,523	69%	5,654	63,871	406	223	205

Table 3 In its first 12 months of operation the BRDF realized 69% availability.

Although operation in Thermal Mode exceeded the pro forma the facility was not able to meet the target for CHP operation. The CHP Equipment was commissioned and synthesis gas production commenced July 20th, 2012 (under the control of Nexterra). In Fall 2012 a failure mode was identified in the soot blower and a new soot blower assembly was installed. This facilitated additional trials in the beginning of 2013. In June, 2013, at the beginning of the first 100hrs endurance trial, a high temperature alarm on the syngas cooler required the syngas conditioning system to be taken offline. After progressive examination of the unit and eventual disassembly of the hot end of the heat exchanger it was clear that this unit had failed. Since that time there have been extensive discussions with the equipment supplier, but no practicable/financially viable resolution has been identified. The objective for long term/sustainable operation in CHP mode using conditioned syngas remains unmet. However the basis for the un-met objective is due to mechanical failure and the associated cost for mitigation. It is NOT due to technological failure.

5.2.2. Performance to date

Availability or uptime of the facility continues to consistently improve (Table 4). Since coming on line, the facility has consumed almost 23,000 oven dry metric tonnes (ODMT) of woody biomass. Concurrent operation of all assets, realized by achieving dual-fuel capability, has produced an ~75% increase in energy production (Table 5).This significant increase in energy output, has maintained the financial viability of the facility allowing it to function within the economic expectation of UBC despite the substantial cost reduction of natural gas.

.

	Biomass Consumed (ODMT)	Plant Uptime (%)	Thermal Mode (Hours)	Thermal Mode Steam to Campus (GJ)
FY2012/13 Total	**5,491**	**66%**	**4,112**	**41,582**
FY2013/14 Total	**9,390**	**86%**	**7,411**	**108,074**
FY2014/15				
Q1 Apr-Jun	1,579	71%	1,540	23,147
Q2 Jul-Sep	1,827	88%	1,954	25,112
Q3 Oct-Dec	2,257	98%	2,157	32,809
Q4 Jan-Mar	2,192	84%	1,836	34272
FY2014/15 Total	**7,854**	**85%**	**7,487**	**115,339**
Grand Total	**22,736**	**80%**	**19,010**	**264,995**

Table 4 Thermal Mode Performance - the BRDF achieved 85% availability for April 1, 2014-March 31, 2015.

	Biomass Consumed for Engine (ODMT)*	Biomass CHP Mode Hours	Engine Runtime Hours	Electricity Generated (MWh)
FY2012/13 Total	**92.3**	**262**	**154**	**151**
FY2013/14 Total	**32.8**	**144**	**69**	**54**
FY2014/15 Total	**0**	**0**	**0**	**0**
Grand Total	**125.1**	**406**	**223**	**205.3**

***Estimate based on mass and energy balance**

Table 5 Biomass Syngas CHP Mode Performance - the BRDF produced 205.3 MWh on biomass syngas prior to the mechanical failure of the clean-synthesis gas conditioning system in 2013

	RNG Mode Gas Input (GJ)	Engine Uptime (%)	Engine Runtime Hours	Steam to Campus (GJ)	Electricity to Campus (MWh)	Hot Water to Campus (MWh)
Q1 Apr-Jun	0	0%	0	0	0	0
Q2 Jul-Sep	25,973	70%	1539	5,149	2209	524
Q3 Oct-Dec	41,834	93%	2062	9,162	3802	553
Q4 Jan-Mar	44,468	98%	2116	7,683	4134	674
FY2014/15 Total	**112,274**	**65%**	**5717**	**21,993**	**10145**	**1751**

Table 6 Renewable Natural Gas Cogen Mode Performance

Source	Measured Power Output (MW)		
	Biomass Thermal	Biomass CHP	Dual Fuel CHP
Steam Boiler	6.0	1.5	6.0
Steam Heat (engine recovery - exhaust)		1.4	1.4
Hot Water (engine recovery - water jacket)		1.0	1.0
Electricity generator		2.0	2.0
TOTAL	**6.0**	**5.9**	**10.4**

Table 7 Achieving dual-fuel capability has resulted in a 75% increase in the energy output of the BRDF.

5.3. Demonstrate a highly replicable application that will potentially increase the value of Canadian biomass

The recently produced Options Report (http://research.ubc.ca/vpri/biomass-combined-heat-power-options-report) provides the information required to allow institutions, industry and communities to determine the feasibility of adopting a Combined Heat and Power (CHP) system in their particular circumstances. Issues to be considered include: current fuel costs, heat and power requirements, cost of installation and operation, efficiency of the technology, availability of suitable biomass, and the term of investment.

5.4. Demonstrate Canadian leadership in clean energy technology innovation and commercialization

As part of the outreach responsibility for the Project the facility has hosted over 1,200 persons to view and gain information on the process and facility. The facility has received numerous awards and recognitions including: LEED Gold Building Award (2012), KPMG Infrastructure 100 Award: Outstanding efforts in urban infrastructure (2012), and the Canadian Wood Council Wood Building & Design Award: In recognition of excellence in architectural design using wood for commercial large projects (2013).

5.5. Enable UBC, and partner institution, faculty members and students, to conduct research on renewable energy applications

Research activities, valued at over $500k, have been linked to the facility. A sampling includes:

- **Catalytic Tar Cracking - Primary Investigator**: Dr. John R Grace, Dr. Tony Bi
- **High Temp. Hydrogen Membrane Extraction**- Primary Investigator: Dr. John R Grace, Dr. Jim Lim
- **CLT Life Cycle Study - Primary Investigator**: Dr. Alberto Cayuela

- **MetroVancouver Fuel Study** - Primary Investigator: Dr. Shahab Sokhansanj, Dr. Anthony Lau
- **Implication on testing of pipeline materials exposed to hydrogen** - Primary Investigator: Dr. Chad Sinclair, Dr. Matt Roy
- **Added Value Ash Study** - Primary Investigator: Dr. Tom Troczynski
- **Examination of Corrosion Mechanisms in Steel Vessels** - Primary Investigator: Dr. Akram Alfantazi
- **Metallurgical Investigation of Materials Issues at the BRDF** - Primary Investigator: Dr. Steve. Cockcroft
- **B2H Advanced Gas Program - Primary Investigator**: Nexterra/UBC/Fortis/Quadrogen
- **Electro-Chemical Energy Storage (ECES)** - Primary Investigator: Dr. Martin Ordonez
- **Advanced Integrated AC-DC Systems** - Primary Investigator: Dr. Juri Jatskevich

5.6. Demonstrate demand and supply side opportunities and document benefits resulting from implementation of an ECES network and a CHP facility

At the outset four main value-based opportunity areas were identified for energy storage. Within these categories, specific energy storage functions were also identified as ones that could demonstrate tangible value, whether that be financial or otherwise (such as research value, or steps towards the achievement of future goals). These categories and functions were:

1. Peak Shaving
    a. Campus scale peak reduction for capital deferral
    b. Local peak shaving for feeder level load relief
2. Uninterruptible Power Supply (UPS)
    a. BRDP shutdown backup power
    b. Facility UPS for critical loads and sensitive equipment
3. Islanded Micro-Grid Stabilization
    a. Power quality stabilization
    b. Extended supply capacity
4. Product Development and Academic Research
    a. Practical experience for EMS research and modeling
    b. Partnership access to fundamental R&D

The results (Table 6), verified by the 3rd party Powertech Labs, indicate that the performance requirements for this objective were realized in at least one, if not multiple, nodes on the ECES network.

Facility	Backup Power	UPS Power	Power Quality	Peak Shaving	Renewables Integration	Load Management (Facility)	Load Management (Feeder)
BRDF	✓			✓		✓	✓
NCE Lab		✓	✓*	TBD		✓	
Kaiser Lab		TBD	TBD	TBD	✓	✓	
Integrated System				✓			✓

Table 8 The performance abilities of an ECES demonstrated a variety of opportunities.

* Previously at NCE, power quality issues existed in the form of lower than normal voltage levels at the point of utilization due to undersized conductors throughout the building.

5.7. Recover energy via engine heat recovery (EHR) system

Heat energy is recovered from both the engines water cooling system and its exhaust (Table 7).

Source	Measured Thermal Power (MWt)	% Increase of Whole System
Steam Heat recovery (engine exhaust)	1.4	14%
Hot Water Heat Recovery (engine water jacket**)**	1.0	9.6%

Table 9 Steam and hot water grade heat is recovered from previously "vented" sources.

5.8. Demonstrate BRDF as a "base load" supplier of thermal energy to the campus heating grid

Redundancy of power supply is required to be considered as a "firm" supplier to UBC's base energy load. The installation of a natural gas/RNG fueled boiler at the facility and access to the ability to draw on the BC Hydro supply, if the BRDF does not generate electricity, has realized redundancy for both thermal and electrical power confirms the BRDF as a "firm" supplier of energy to the campus.

6. Results

6.1. Project Achievements

6.1.1. Financial

Based on UBC's initial capital investment of $8.35m the "break even" point is forecasted for 2028. Delivery of an operable CHP facility at this investment level without additional 3rd party funding assistance, or supportive government policies, makes the investment in this technology difficult to justify financially. See Options Report (http://research.ubc.ca/vpri/biomass-combined-heat-power-options-report) for more discussion on this topic.

As is always the case, there exists a variance between the predicted and actual values for the business case (Table 8). Fuel Input cost is are considerably higher due to the use of renewable natural gas, as the primary fuel for CHP, and simultaneous operation in both the thermal and CHP modes.

The break-even forecast is extended by 2 years due to the delayed completion of the project, and the unsuccessful efforts to reliably produce electricity from syngas.

Factors	Business Case	
	Predicted	**Actual**
UBC Invested Principle	$8.35M	$8.15M
Annual Operating & Maintenance Costs	$1.4M	$1.1M
Annual fuel input cost	$0.8M	$2.6M
Price of Natural Gas (2015)	$11.1/GJ	$8.5/GJ
Revenue generated	$3.2M	$3.9M
Break-Even forecast	2026	2028

Table 10 The price of natural gas has dropped by ~23% during the term of the Project

This represents UBC's capital cost investment for the BRDF initial phase only. It does not include expenses for the add-on Projects that were recovered from UBC's annual operating budget.

6.1.2. Social

The BRDF has become a fixture in the infrastructure of the campus community. Its building design and siting has made it a positive contribution to the building stock of UBC. The community receives regular updates on the performance of the system and are very much accepting of its presence. Initial concerns on building siting, truck traffic and air/sound emissions were dealt with at the outset by significant community engagement and education and confirmed with follow-up measurements or implementation of protocols. The gaining of "social license" continues to be a key positive outcome of the project which has been shared with others contemplating similar facilities in urban environments.

6.1.3. Environmental

Emissions, subject to 3rd party measurement, are well below permitted levels (Table 9).

Permit Requirements	Measured Source					
	Dryer		Boiler		Engine	
	Permit	Actual	Permit	Actual	Permit	Actual
Particulate Matter (PM) (mg/m3)	15	3.9	15	2.1	15	1.3
Nitrogen Oxides (NO_X) (mg/m3)	-	-	209	183	249.7	105
Volatile Organic Compounds (VOC) (mg/m3)	10.4	9.6	10.5	2.2	40.9	31
Opacity (%)	5	<5	5	0	5	<5

Table 11 Boiler and Engine measurements are based on 8% 02. The BRDF continues to conform to the permitted emissions requirements for bio-mass fueled facilities.

The original goal for the BRDF was the displacement of 5,498 tonnes annually of fossil-fuel based CO_2 (a 9% GHG reduction from 2007 levels). Due to the increased availability of the facility it now displaces over 7k tonnes of emitted fossil fuel based CO_2 annually.

3rd Party measurement of noise levels taken during full operation of the facility confirmed that it achieved or bettered the design level - 55dba (daytime) and 45 dba (night time) measured at the adjacent residence building.

6.1.4. Demonstration at Scale

The major benefit of the BRDF and add-on Projects has been the successful demonstration of the associated technologies' viability both individually and when operating as a system. The ongoing opportunity to demonstrate the conditioning of synthesis gas and utilization of the ECES for back-up power remain unmet objectives due to mechanical failure and operator "hesitancy" respectively - not technical issues. Reconnection of the ECES to the BRDF is planned for the Spring 2015 (to correspond with a scheduled maintenance shut-down of the BRDF equipment). UBC will continue to verify the reliability of, and cost saving generated by, the ECES systems. This continued verification will build operator confidence in the system and justify the potential expansion of the network.

Given the appropriate financial conditions (e.g. availability of replacement components at a significant cost discount, access to 3rd party funding, unavailability/increased cost of RNG etc. both UBC and Nexterra are prepared to revisit the opportunity to continue operation in CHP mode utilizing on-site generated and conditioned synthesis gas. The opportunity to rectify the equipment failure has been exacerbated with the reduction in natural gas prices since the projects inception to present day - $11.1/GJ to $8.51/GJ respectively

The BRDF served as the reference site for Nexterra's successful bid to build a thermal system in the United Kingdom. The facility has also become an integral part of UBC's energy generation infrastructure and is cited in UBC's Climate Action Plan as one of the key enablers for meeting UBC's GHG targets.

Specific Benefits relating to the ECES include:

1) Demonstrated ongoing development relationship and projects with UBC, inclusive of those beyond the Electrical and Computer Engineering faculty

2) The ECES network allows Alpha, in partnership with its customers, the development and commercialization of further smart grid management applications. Outcomes will be key learnings of the impact of these applications thus enabling focused development of additional products and strategies. Of specific interest is the ability to demonstrate to their customers applications for realizing peak shaving and load sharing on a facility, feeder and campus levels.

6.1.5. Moving from Demonstration to Firm Status

Operation in "demonstration" mode gave the UBC operations team the confidence to achieve "firm" power status for the facility. Implementing dual-fuel capacity, redundancy (in thermal, electrical generation and supply of back-up energy) achieved this goal. The BRDF and ECES network have become integral components of the energy generation capacity of the campus. With implementation of the original technology and the various add-ons the total energy generation of the facility has increased by 75% provided 22% of UBC's District Energy heating requirements and over 4% of UBC's core electrical use. Due to the ongoing campus requirement for steam, the BRDF will become the primary source of this energy. Incorporation of further ECES capacity on campus will proceed as identified.

6.1.6. Ongoing Contributor to Environmental Improvement

Currently the facility displaces approximately 7,240 tonnes of emitted fossil fuel based CO_2 (Table 10). Given the improving and stable "up time" of the plant, UBC is confident that it will achieve an annual displacement of over 9,000 tonnes by 2017.

Term	Performance	
	Actual	**Forecast**
FY 2013/14	6,679 tonnes	
FY 2014/15	7,240 tonnes	
FY 2015/16		8,910 tonnes
FY 2016/17		9,434 tonnes

Table 12 Tonnes of displaced fossil fuel based CO2 continues to increase in step with the facilities availability.

6.1.7. Social License

The process for realizing and maintaining the "social license" required to site and operate such a facility in an urban environment remains a key commitment of UBC. The community's support for the facility's ongoing operation is a testament to UBC's commitment to "walk the talk". The UBC facility and its community acceptance has, and will continue to be, used as a reference site for those proposing to locate woody biomass fueled energy facilities in urban areas (e.g. the BRDF serves as the local reference site for a proposed facility at Children's & Women's Health Centre in Vancouver.)

6.2. Technology Development

6.2.1. Enabling Dual Fuel Capability for GE J 620 engine

As installed, the J 620 had been extensively modified to operate on conditioned syngas. Enabling dual-fuel capability for the engine required extensive re-modification not just to its original configuration but to one that allowed fuel switching. GE undertook the design, fabrication and installation utilizing input from their sites globally. Post re-modification operation has confirmed that these modifications have been successful and the engine is performing as/better than predicted.

6.2.2. Increase Power Rating for ECES Components

The requirement for providing back-up power at the BRDF stimulated ALPHA to develop, install test/monitor an enhanced AMPS system with a power rating, of 225kVA product. Prior to the project their product offering limit was 80 KVA. Successful operation supported further analysis including the definition of additional market opportunities for this technology and assessment of the commercial viability, and effort required, to develop even higher power technologies.

6.2.3. Commercial Deployment of new CORDEX HP Controller & Pre-Commercial availability of Arm@da

The development, testing and implementation of two new Alpha products, the CORDEX HP Controller and Arm@da was required to enable the tracking of energy flows and to be aware of multiple energy sources at both the "energy node" and network scale respectively. At the node level the project stimulated the control and integration/communications between the Alpha equipment and the Corvus Li-ion battery modules. Both companies therefore can offer to the market an integrated solution that was not available pre Project.

6.2.4. Demonstrate the Corvus product in a grid support application

Prior to the Project, Corvus's major market focus was the marine sector with limited experience in material handling & transportation. Integration of their technology with Alpha has expanded their technology/product offering into the Stationary Power/Renewable Integration sectors. Corvus now offers a fully integrated storage solution with select products from OutBack Power, a member of the Alpha group.

6.2.5. Certifications Approvals

The UBC installation represented the first stationery deployment of the Corvus related technologies. CSA approval for the Lithium ion modules and Engineered Certified approval of the bus bar reinforcements were both realized. Having approval "in hand" now allows CORVUS to offer a CSA approved product into this market.

6.3. Challenges and Barriers

6.3.1. Biomass Sourcing

At Project inception there was not a well-developed "sophisticated" source of "specified" biomass material. UBC has worked closely with the biomass aggregator, to develop a stream of fuel that is consistent in moisture content, size and free of contaminants. Throughout the project the aggregator has implemented numerous improvements including additional screening of the fuel prior to shipment to UBC, and tenting to reduce the uptake of moisture during storage. Although the ultimate goal of fuel characterization has yet to be consistently met UBC has seen an improvement in the quality of the fuel material being received. As fuel quality has a direct impact on the facility's performance and its maintenance costs UBC will continue to monitor the fuel delivered and react accordingly.

The impact of this activity is the availability of more "graded" material stream then was previously available. The outcome will be that operators, of other woody biomass energy systems, in south-western BC, have the opportunity to "optimize" their fuel supply depending upon price and the process they employ and have a ready supplier capable of delivering the specified fuel.

6.3.2. Social License

Successfully demonstrating the acceptability for integrating these types of biomass fuelled CHP facilities into the community fabric was an important aspect of this project. Realizing Social License was therefore critical. Three issues, Building Siting, Truck Traffic and Emission were identified as the major public concerns. The ultimate success of gaining favourable community support, was realized through numerous meeting occurring with the general public (Open House Meetings), specific presentations to the University Neigbourhoods Association and one-on-one meeting with concerned individuals. Throughout, the approach was to educate about, and build confidence in, the technology. The legacy of the BRDF is the tangible demonstration that these types of biomass "energy plants" and ECES systems can be deployed and operated in an urban and building environment with minimal impact upon either.

6.3.2.1. Building Siting

Campus and Community Planning staff in consultation with the proponents conducted a thorough analysis of potential sites for this facility. Six sites were initially evaluated. Attributes which supported the ultimate site location include: greater on-site manoeuvering room for trucks, reduced truck traffic impacts on residential buildings, compatibility with existing and draft campus plans, opportunity for on-site facility expansion, and its proximity to utility tie-ins.

6.3.2.2. Truck Traffic

Concerns regarding the increase in tuck traffic due to fuel delivery included the following:

Concern	Mitigation
Safety impacts on students due to trucks maneuvering to unload/load	• Truck movement maneuvering will take some time due to the size of the trucks. These movements will be obvious to pedestrians and truck movement will be slow. Trucks will be fitted with an auditory signal providing further warning when trucks are backing up.
Truck traffic impacts along route to facility	• The precise truck routes will be dependent on the location of the fuel sources. Because the biomass facility is located at the edge of the campus, there will be no movements within the campus itself except for the short journey from Marine Drive along Agronomy Road to Lower Mall. • Trucks will arrive from either the east or west from Marine Drive through parts of the UEL and Vancouver depending on the origin of their trips.

6.3.2.3. Emissions

6.3.2.3.1.1. Air

UBC committed at the outset to meeting or bettering Metro Vancouver standards for Biomass fueled facilities by achieve emissions normally associated from natural gas combustion and the installation and operation of an air shed monitoring system. UBC also committed to ongoing monitoring and reporting for the full operating-life of the BRDF.

6.3.2.3.1.2. Noise

The impact on ongoing ambient noise from operations and some intermittent noise generated from trucks delivering fuel were identified as concerns. UBC committed to achieving 55dba (daytime) and 45 dba (night time) at the adjacent residence building. Further, UBC committed to limiting fuel delivery times to an established range of day time hours only.

7. Conclusion and Follow-up

The first positive impact the project is the public's perception and acceptance of locating woody biomass fueled power generation facilities in an urban environment. The UBC project, throughout its operating lifetime, will provide tangible proof that "Yes in my back yard" is a viable and logical point of view for these types of facilities. Long term, for jurisdictions embarking on commissioning similar facilities, the existence of the UBC facility advances and enhances their ability to engage the community and to ultimately gain the critical social license.

The second positive impact has been on the UBC own organization. Prior to the BRDF project UBC had not, within their operations group, undertaken a seemingly "risky" endeavour. The project has required many to operate "outside of their comfort zone" to embrace and enable the opportunity to integrate new technologies and processes that would not normally be chosen. To a great degree the Project can be seen as the initiator of an "innovation culture" – a legacy that will allow UBC to lead in the "city scale" demonstration of new and immerging technologies.

Finally the Project provided a unique platform for the industrial partners: Nexterra, GE, Alpha and Corvus to develop new products and showcase their capabilities. Undertaking the Project has also forged inter-partner and partner-UBC relationships that support joint marketing (e.g. Alpha-Corvus) and student/research collaboration opportunities. As a public institution, the "open" nature of UBC makes it a perfect location to bring existing and potential customers to see "first hand" the application of their technologies. As an "operational asset" the partners are also ensured that UBC will continue to maintain the functionality of their product.

7.1. Potential for Replication

Given the current and anticipated Canadian economic situation and the global outlook for the price of natural gas it appears that the conditions for replication of the technologies, as a packaged network, will not present themselves in the near to midterm. (See Options Report (http://research.ubc.ca/vpri/biomass-combined-heat-power-options-report).

To quote Nexterra[3]:

"To promote the use of bioenergy, many developed countries have implemented incentive programs that enhance the economics of biomass energy. This will be a major driver promoting the biomass industry provided that investors believe that they can rely on these incentives over the promised term. A key market for Nexterra will be the United Kingdom as the Department of Energy and Climate Change (DECC) have stated that gasification qualifies as an Advanced Conversion Technology (ACT) and qualifies for 2.0 Renewable Obligation Certificates (ROC) which is the highest level of subsidy available."

The opportunity for replication of thermal only systems seems more likely, or larger facilities where Nexterra units are "ganged" and electricity produced via steam turbine (see http://www.bbc.com/news/uk-england-birmingham-31850813). An added complexity for the application of "city scale" CHP is the need for the establishment/existence of a district energy system to distribute the heat energy produced. Again the pre existence of such district energy systems is more likely to occur in Europe than North America.

Given Nexterra's BRDF experience they now estimate, at a generation scale of <10 MWe, the installed cost for an industrial grade power system, built to developed world standards, is approximately $5 – 8 million dollars per MWe potentially 50% of the cost experienced at UBC.

7.2. Next Steps

7.2.1. UBC

UBC will continue to make incremental improvements to the BRDF to enhance its performance. Undertaking a pre-feasibility study of expanded biomass operation to meet the UBC's 2020 GHG reduction target is a recommended next step. For the ECES the ultimate goal will be to have this technology cited in the UBC Technical Guidelines, as a UBC accepted technology for back-up power generation in plant-scale applications.

[3] Commercialization Plan for Gasification to Internal Combustion Engine, Internal Nexterra document, March 2013.

7.2.2. Nexterra

Nexterra will continue to identify and act upon opportunities that would allow demonstration of the CHP mode of operation. Given current economic and policy realities it appears that Europe represents the best location/market for their technologies.

7.2.3. Alpha and Corvus

Although there appears to be no immediate opportunity for sales, due to the current economic climate and system's cost, it does appear that the energy storage market is emerging (technology costs reducing). It is very likely that, in the next 2 years, Alpha and Corvus may have revenue generating products that were developed as part of the UBC ESS project.

7.2.4. Government

Supportive Governmental Policies (e.g. BC Greenhouse Gas Reduction Targets Act, BC Carbon Tax and UK Department of Energy and Climate Change Regulations etc.) have been identified as key enablers for the installation and replication of these types of technologies. Where such supporting legislation does not exist the only financially viable opportunity for replication appears to be where it offsets the costs associated with generating power via diesel or another fossil fuels AND a system capable of distributing the thermal energy generated pre-exists. (See Options Report (http://research.ubc.ca/vpri/biomass-combined-heat-power-options-report for further discussion.)