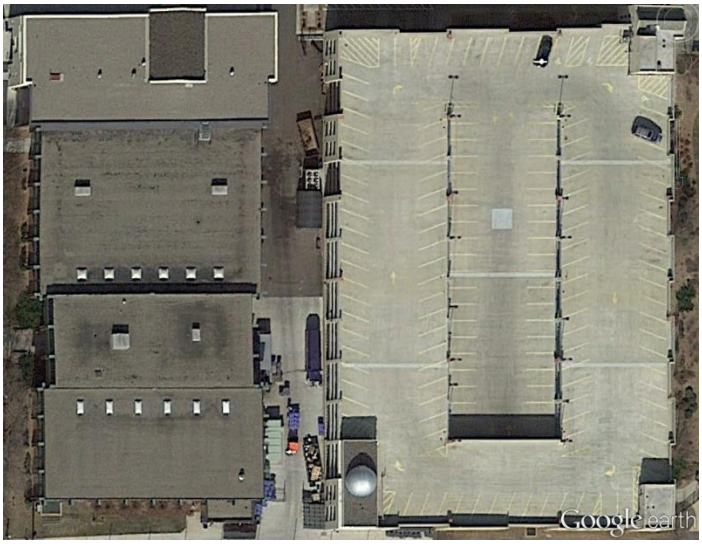


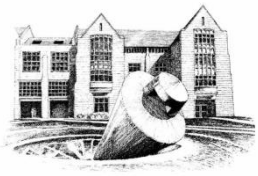

# University of St. Thomas Microgrid Research and Testing Program – HE4-2

## Annual Report (January to December 2016)

Project funding provided by the Xcel Energy Renewable Development Fund (RDF)



UNIVERSITY of ST. THOMAS MINNESOTA



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St Paul, MN 55105

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# Executive Summary

This annual report is submitted in compliance with the Article 7 of the Grant Contract Terms and Conditions covering the project "University of St. Thomas Microgrid Research and Testing Program" supported by the customers of Xcel Energy via a grant from the Renewable Development Fund.

This Annual Report covers the period January to December 2016 and summarizes activities initiated to begin the 'University of St. Thomas Microgrid Research and Testing Program'; the USTREF. This report summarizes actions taken in the January to December 2016 time-frame.

The original site location for the University of St Thomas Microgrid Research and Testing Program (USTREF by reference) was relocated from the Winehaven Winery, Chisago City, Minnesota to the St. Paul campus of the University of St Thomas, located at 2115 Summit Avenue, St. Paul, Minnesota.

Ryan Companies was selected as the general contractor for the USTREF with support from Hallberg Engineering. The development of the one-line diagram for the USTREF was 75% completed in fiscal year 2016.

Research on the USTREF commenced.

Several partners necessary for the success of the research portion of the USTREF were identified.

An oral presentation on HE4-2 for 2016 to NSP and the Renewable Development Fund advisory group was completed.

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# Introduction

The University of St. Thomas (UST) entered into an agreement with the Northern States Power Company (doing business as Xcel Energy in Minnesota) in regard to a $2.1 Million research grant for a period of three years. The funding was allocated from the Higher Education block grant component of the Renewable Development Fund, supported by the ratepayer Xcel Energy's ratepayer and managed by Xcel Energy. Pursuant to the conditions of the said agreement (Section 7; Exhibit C of "REPORTING"), the UST provides this annual report on progress made-to-date in implementing the said research project.

The objective of the "University of St. Thomas Microgrid Research and Testing Program" is to install a sustainable, ~ 0.25 MW peak, multi-purpose microgrid at the St. Paul Campus of the University of St. Thomas. The primary objective of this facility will be to promote industry/academic collaboration in the design/build/test and validation of near commercial concepts in the areas of electricity generation and microgrid/subsystem control. The research will also contribute in the strengthening and expansion of the renewable energy industry in Minnesota through the study of how distributed-energy-resources interact in a microgrid and how this microgrid interacts with the distribution feeder that powers the University of St. Thomas, St. Paul Campus. This project has significant potential for impacting the commercial viability of microgrids and the control of the distributed energy resources contained within a microgrid.

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# Progress in 2016

## Site Relocation

The location of the University of St. Thomas renewable Energy Facility (USTREF) was moved from the Winehaven Winery, Chisago City, Minnesota to the St. Paul campus of the University of St Thomas, located at 2115 Summit Avenue, St. Paul, Minnesota. The change-in-location does not impact or detract from the original scope of the project. In fact, the site relocation has several advantages. These advantages include: (i) improved site control and site security; (ii) enhanced ability to work with 3rd parties and guests due to UST campus proximity; (iii) ability to assess the long term implications of campus microgrids. The site relocation does affect the ability to integrate a traditional wind turbine, as originally proposed, into the research microgrid since zoning restrictions in the vicinity of the UST St. Paul campus do not permit the deployment of the wind turbine initial scoped for the project. Fortunately, the technology exists to cost-effectively emulate the performance of the wind turbine in the USTREF. This can be done in at least two ways; the first using a modern computer controlled power supply; the second using a motor-generator pair under computer control. Both options are being evaluated.

The site location of the USTREF is illustrated in the following two figures. The first is a Google Earth view of UST in West St. Paul.

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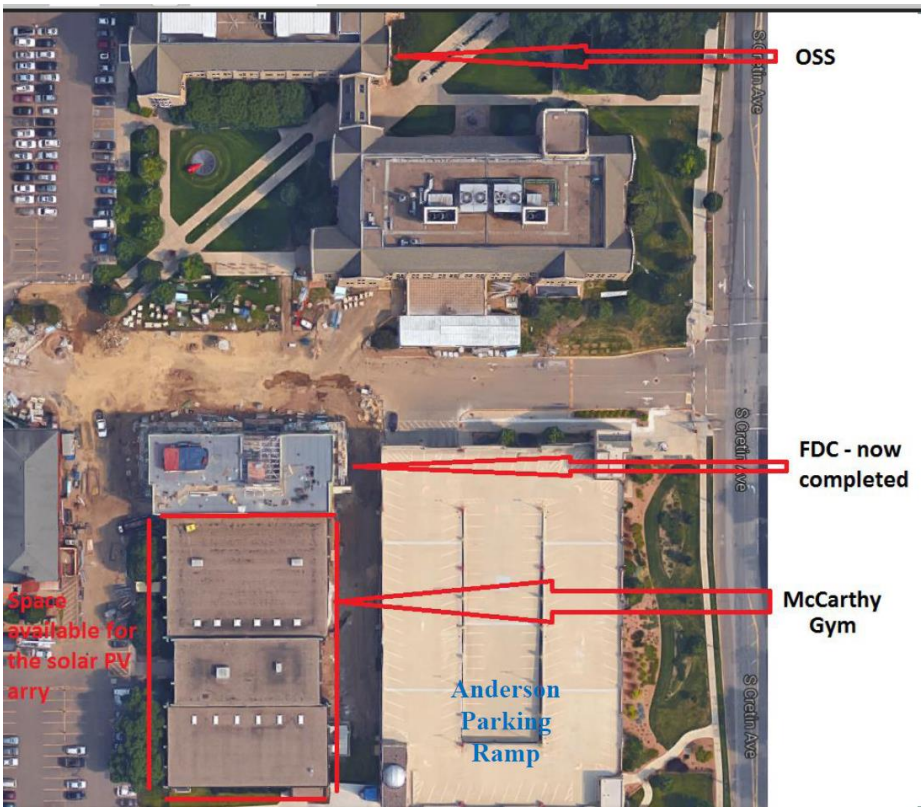
Zooming in on the south-campus region of the satellite view, one can next view the future location of the USTREF.




At the top of this figure is the O'Shaughnessy Science Hall (OSS), were the office of the principle investigator is located with a direct view of 'Facilities and Design Center (FDC)' where much of the USTREF will be located. FDC will house the battery storage system, the USTREF control center, and the main switch gear along with the wind turbine emulator. The south facing 50 kW solar PV array of the USTREF will be located just south of FDC on the roof of the McCarthy Gym. The diesel gensets will be located in the bottom level of the adjacent Anderson Parking Ramp. A Google Earth view showing the completed buildings along with a front view of FDC follow.

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Google Earth view of the UST µGrid location

## FDC – the Facilities and Design Center

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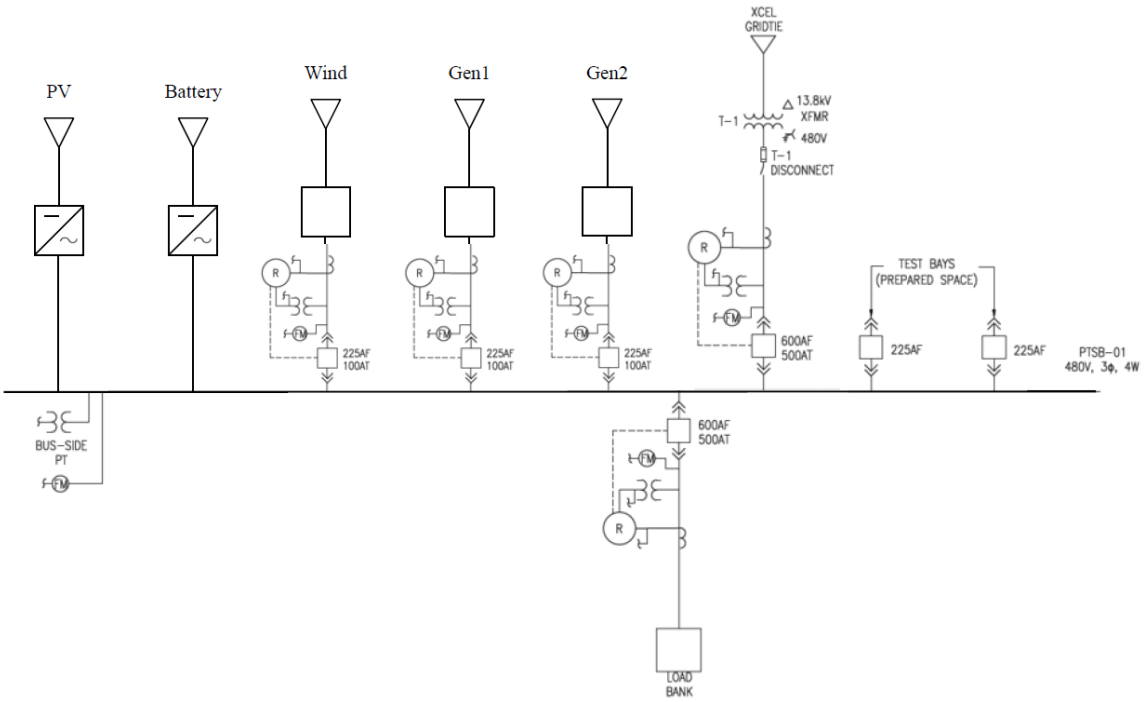
## Contractors and Layout

Ryan Companies was selected as the general contractor for the USTREF with support from Hallberg Engineering. The development of the foundational one-line diagram for the USTREF was 75% completed in fiscal year 2016. The finalized one-line diagram, illustrated next, is projected to be completed toward the end of Q1, 2017 as the precursor for the construction phase of the project.

## Near Final One-Line Diagram of the research Microgrid




Each vertical leg in the one-line diagram represents the various parts of the USTREF along with protection and switch-gear. The grid-tie to the Xcel Energy feeder, along with load banks and provisions for 3rd party hardware are also illustrated. A simplified version of the USTREF one-line diagram is illustrated next. The information in both figures are essentially identical.

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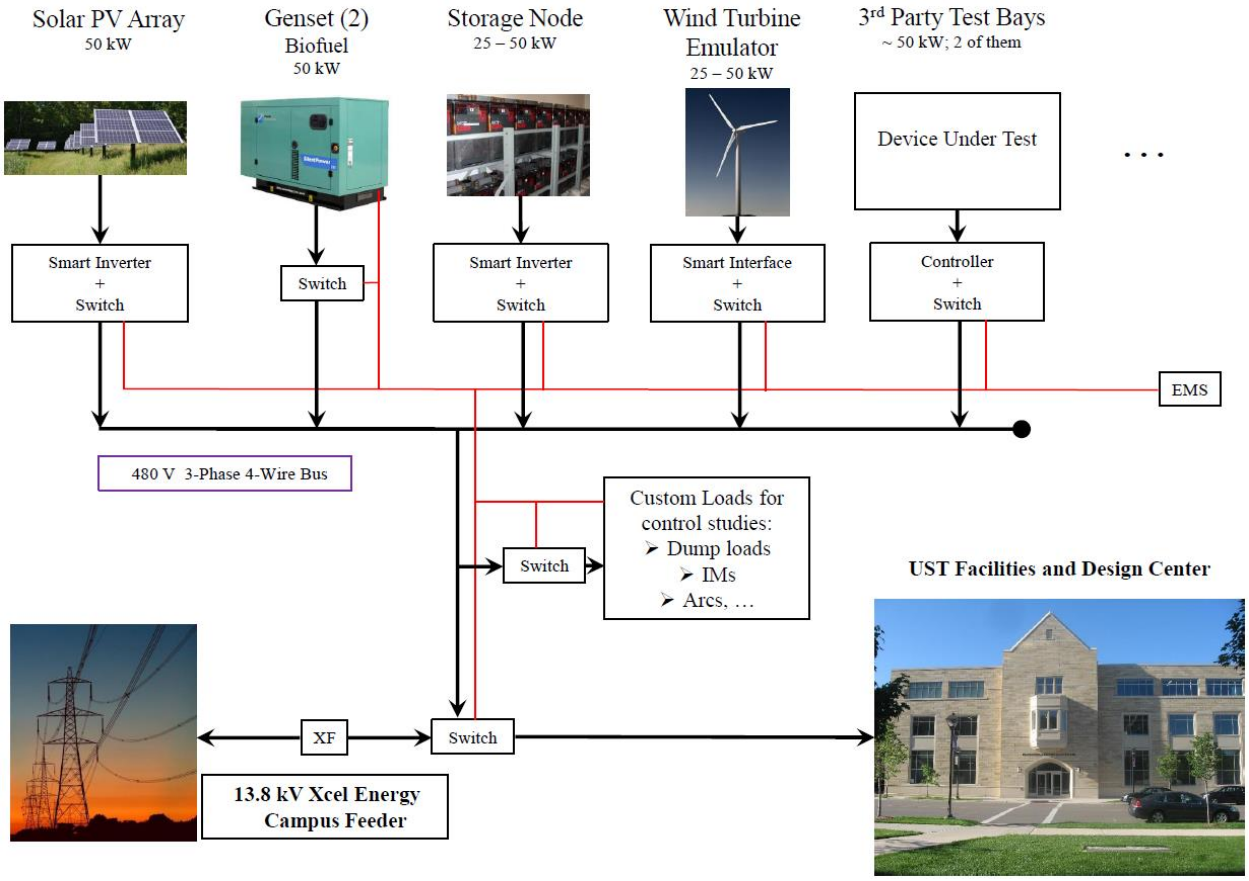


## Research

Project research in 2016 centered on two aspects of microgrid control. The first involved preliminary investigations into distributed microgrid control methods (often referred to as peer-to-peer control) and on innovative methods of controlling 3-phase inverters. The second research focus area addressed identifying key microgrid partners capable of supporting the USTREF with the execution of the innovative microgrid and inverter control strategies. It was discovered that via space-vector-pulse-width-modulation (SVPWM) that inverters could be controlled to emulate the terminal characteristics of a synchronous generator. This discovery, combined with investigation into various microgrid control strategies, led to the identification of a key microgrid partner, Rhombus Energy Solutions. Efforts are underway to engage Rhombus Energy Solutions in the development of both advanced inverter and peer-to-peer control methods that have the

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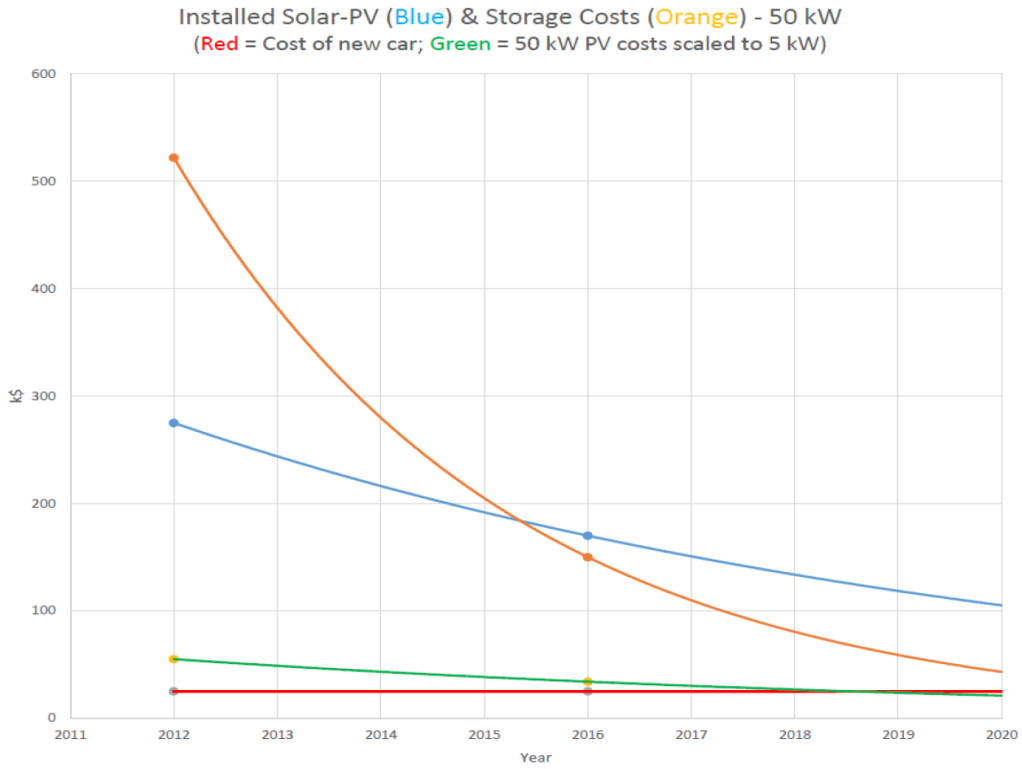
potential to significantly improve the performance of the USTREF and, microgrids in general, while lowering overall microgrid costs.

To date the RDF HE4-2 funding has enabled the engagement of 3 graduate students, 2 undergraduate students, and 2 UST engineering faculty in the USTREF microgrid project.

Microgrid cost analysis over the past 5 years led to the discovery that microgrids (comprised of solar PV, battery, and inverter based technologies) have performance and cost characteristics that appear to be following a Moore's Law type of performance-cost dependency common to solid-state electronic systems; e.g. cell phones, computers, and hard disc drives – to name a few. Extrapolating those trends leads to the prediction that by 2020 (or a bit sooner perhaps) microgrids on the order of 10 – 15 kW will cost less than the average price of a new automobile. These trends are illustrated in the following two graph.



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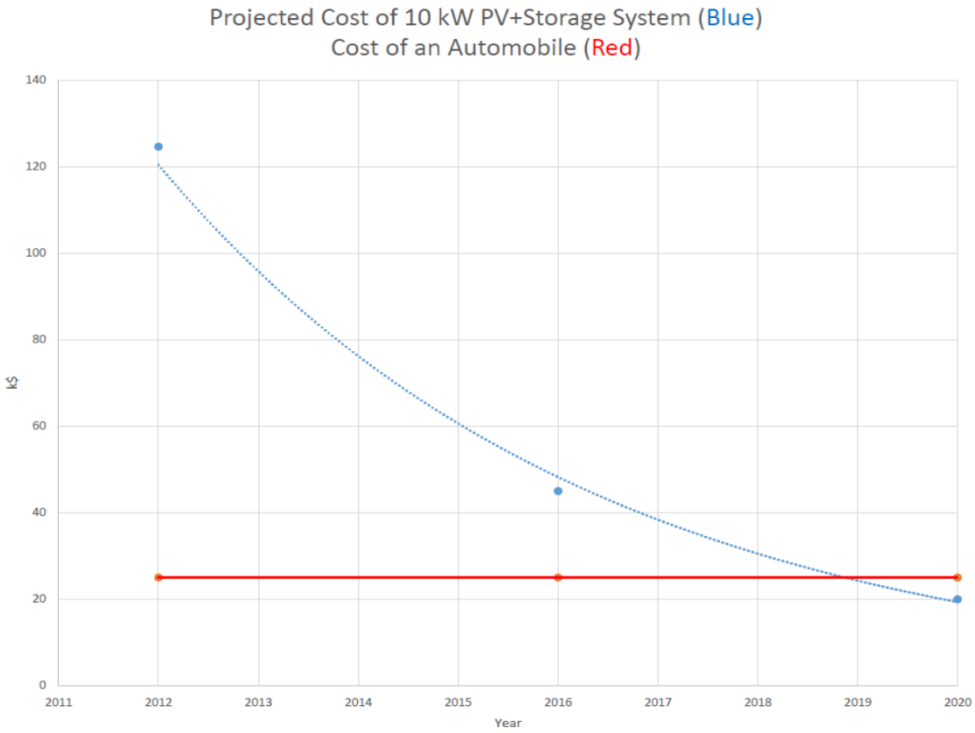


These microgrid cost-performance projections have potentially significant implications for USA based utility companies and for users around the world; since in developing countries microgrids will play a dominant role in years to come. In view of sustainability efforts and century type events such as hurricanes Katrina, Irene, and Sandy, the potential for cost-effective grid resiliency through microgrids is being studied by many groups. The HE4-2 supported research just noted, combined with the potential for grid resiliency via microgrids, has also led to an invited microgrid talk in 2016 with 4 more invited talks already planned for in 2017. Additional information on these presentations may be found in the appendices of this report.

The 2016 microgrid results summarized above have already resulted in substantively positive visibility for Xcel Energy and its rate payers, the RDF program, and the State of Minnesota. The HE4-2 funding and the USTREF research has led to Minnesota being identified as an innovative leader in the microgrid space.

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## Lessons Learned

The most significant lesson learned to date is that it takes a long time, with a significant amount of effort, to make even incremental progress in the microgrid space. While the research is necessary and essential, the real long-term impact is only realized through commercial adoption of that research. While the promise of microgrids is significant in terms of resiliency and sustainability, it remains to be seen how microgrids will evolve commercially through business models that are still being developed so that microgrids become long-term viable. The HE4-2 funding represents a critical step in the overall success of the microgrid enterprise.

## Budget Summary and the Remaining Disbursement Request

To date a total of $1,438.143.32 has been received from the RDF for the HE4-2 grant. 2016 expenditures include:

- Hallberg Engineering: $24,081.50
- Rhombus Energy Solutions: $6,785.00
- Travel: $1,709.10
- End of 2016 Balance: $1,405,567.72

Out of the total approved RDF HE4-2 grant funding (rounded) of $2,100,000 the projected budget for bringing the USTREF microgrid online is $1,500,000. This remaining 2016 balance is projected to be disbursed by mid-2017 as the USTREF is brought online. The remaining disbursement is needed to bring the USTREF online as well as fund continuing project research. It is the belief of the principle investigator that the performance-to-date justifies the final disbursement totaling approximately $600,000.

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# Conclusion and Next Steps

The site-location of the USTREF has been finalized and accepted by all parties.

Progress was made toward finalizing the one-line diagram of the USTREF with completion expected in early-to-mid 2017.

One of the key vendor-partners was identified for the control system and smart inverters that will be used in the USTREF.

Graduate student research has commenced with several interesting first-year discoveries; namely using SVPWM to allow solid-state inverters to emulate a synchronous generator and microgrid cost-performance trends

Construction of the USTREF is expected to begin in mid-2017 with island mode operation commencing in the fall of 2017.

Grid connection of the USTREF to the Xcel Energy feeder servicing the south-campus of UST is projected to occur toward the end of 2017.

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## Attachments

1. 2016 Quarterly reports

2. 2016 Speaking Events and Presentation Titles

3. NSP Oral Presentation Material

RDF Grant HE4-2

University of St. Thomas Microgrid Research and Testing Program

Q1 2016 Quarterly Report covering 1 January 2016 to 31 March 2016

**PI:** Dr. Greg Mowry

**Date:** 31 March 2016

## Planning

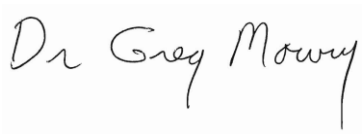
The land use agreement between the University of St Thomas and Winehavens Winery for the University of St. Thomas Microgrid Research and Testing Program was placed on hold. A site-location-change (SLC) request was prepared and submitted to Xcel Energy to relocate the HE4-2 microgrid project from Winehavens Winery to the University of St Thomas St. Paul, MN campus. The SLC proposal was approved. Legal documentation reflecting the SLC is in progress. Anticipate agreement completion and funding release by end of FYQ2 2016.

## Technical

Two graduate students, Nathan Webster & Naga Guddeti, have begun development of the peer-to-peer control methodology for the microgrid project for their MSEE thesis. Development of the peer-to-peer control (Nathan Webster), inverter modeling (Naga Guddeti), and communication scheme continues. The block diagram of the hardware and software, common to any distributed energy resource (DER) attached to a microgrid, was developed.

Prototype control and switching hardware for the intelligent switching function continues being defined. Hoang Ngo, graduate student, is developing this as part of his thesis work.

Hardware identification with coordinated vendor support was initiated for the smart inverters necessary for the peer-to-peer controls, communication systems, and microgrid interconnects has started. CREE & Wolfspeed have consented, and confirmed, that they will supply state-of-art wide-bandgap switch modules for the high-performance smart inverters that will be used in the microgrid project. Projected delivery of the state-of-art wide-bandgap switch modules for the high-performance smart inverters estimated for July 2016.



RDF Grant HE4-2

University of St. Thomas Microgrid Research and Testing Program

Q2 2016 Quarterly Report covering: April – June 2016

**PI:** Greg Mowry, Professor

**Date:** 1 July 2016

## Planning

A site-location-change (SLC) request was prepared and submitted to Xcel Energy to relocate the HE4-2 microgrid project from Winehavens Winery to the University of St Thomas St. Paul, MN campus. The SLC proposal was approved. The final agreement between Xcel Energy and the University of St Thomas, which reflects the SLC, has been signed by both parties and filed with the Minnesota Public Utilities Commission. The invoice for initial funding release has been delivered to Xcel Energy. Anticipate receiving initial funding by the end of FYQ3, 2016.

## Technical

In anticipation of funding arrival, the vendor selection process has begun with discussions being actively engaged with the following companies:

| | |
|---|---|
| Storage subsystem | Enersys |
| Switch gear | Schneider-Electric |
| | GE |
| Energy Management System (EMS) | OATI, MN |
| | Siemens, MN |
| | GE, MN |
| | Emerson, MN |
| | OSI (contacted but no response yet) |
| Inverters | Rhombus |
| Gensets | Cummins |
| | Caterpillar |
| SiC wide band-gap inverter switches | CREE/Wolfspeed |

Preliminary modeling (Nathan Webster) shows that it is possible to control an inverter such that it operates (emulates) the performance of a synchronous generator. This has significant system implications.

Prototype control & switch-gear for the intelligent switching function of the research microgrid has been defined (Hoang Ngo). Selections are being reviewed by the research team (consisting of the graduate students working on the project).

RDF Grant HE4-2

University of St. Thomas Microgrid Research and Testing Program

Q3 2016 Quarterly Report covering: July – September 2016

**PI:** Greg Mowry, Professor

**Date:** 1 Oct 2016

## Planning

The Q2 2016 site-location-change (SLC) request was approved by Xcel Energy to locate the HE4-2 microgrid project at the University of St Thomas St. Paul, MN campus. Initial funding for the HE4-2 grant has been received. Project planning with the general contractor, Ryan and Hallberg Engineering, is now underway. A preliminary project build schedule is projected to be ready for review by mid-Q4 206. Joel Limoges and Brian Amundson, Xcel Energy Distribution, have been added to the project distribution list and have been alerted to initiate the planning process with Xcel Energy for connecting the UST microgrid to the south campus Xcel Energy feeder circa Q3 2017.

## Technical

The vendor selection process has commenced. RFQs for the microgrid subsystems is planned for release in mid-Q4 2016. The vendors for the energy storage subsystem and the microgrid inverters have been identified. They are:

- Storage subsystem: Enersys
- Inverters: Rhombus

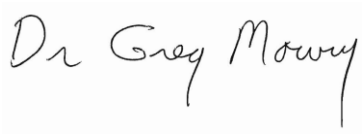
The remainder of the microgrid subsystems will be selected during the RFQ process; e.g.

| | |
|---|---|
| Switch gear | Schneider-Electric, Square-D, GE |
| Energy Management System (EMS) | OATI, MN; Siemens, MN; GE, MN; OSCO/Emerson, MN; OSI |
| Gensets | Cummins, Caterpillar |
| PV array | TBD |

Preliminary modeling (Nathan Webster) shows that it is possible to control an inverter such that it operates (emulates) the performance of a synchronous generator. The software for the Rhombus inverters used in HE4-2 will be upgraded with this capability to enable the inverters to operate as a synchronous generator in addition to the traditional manner in which inverters are

operated. The grid is largely powered through the use of the synchronous generators. Control of the rotor DC magnetic field enables a synchronous generator to run in-phase, over-excited (source Q), or under-excited (sink Q). In addition, the operation of the synchronous generator in the grid may be controlled using droop methods. Finally, the mass in the rotor of the synchronous generator enables voltage ride through during faults. If a solid state inverter can be controlled to operate in a manner analogous to a synchronous generator, then the attributes just noted naturally follow; i.e. an inverter so controlled appears to operate like an electric machine. Additionally, if solid-state inverters are operated in a manner analogous to a synchronous generator, then standard grid-control-software may be used to control microgrids; largely eliminating the need to develop new microgrid control strategies.

The process of selecting the project research team is underway.



RDF Grant HE4-2

University of St. Thomas Microgrid Research and Testing Program

Q4 2016 Quarterly Report covering: October – December 2016

**PI:** Greg Mowry, Professor

**Date:** 31December 2016

"In the past quarter construction planning and scheduling of the microgrid components was conducted with the general contractor, Ryan and Hallberg Engineering is now underway. The microgrid is to be functional in island mode during the third quarter of 2017 and interconnected to the Xcel Energy's distribution feeder by the end of the year. Models have shown that it is possible to control an inverter such that it emulates the performance of a synchronous generator. Recent research indicates that it is possible to extend inverter performance so that a microgrid can be self-synchronizing without any communications structure. Inverter control methods may also permit intrinsic load sharing among inverters and hot-plugability and load-sharing adaptability of inverter-based microgrid energy sources. This model will be a primary driver of the microgrid research. Software for the Rhombus inverters will be upgraded with this capability to enable the inverters to operate in the manner described. The first 60 kW Rhombus inverter has been ordered."

# II. 2016 Speaking Events and Presentation Titles

Minnesota Society of Professional Engineers

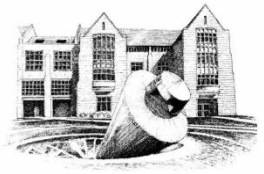
St Paul, MN

"An introduction to microgrids and University of St Thomas renewable Energy Facility Update"

1 November 2016

**2017 Invitations for Speaking: All presentations generally planned on being titled as, "Introduction to Microgrids and the USTREF"**

- North Central Electrical League Inc. – 7 Feb 2017, St Paul, MN
- Xcel Engineering Technical Conference – 9 February 2017, St Paul, MN
- 7th Microgrids & Distributed Generation for public and Private Sectors – March 2017, Boston, MA
- National Society of Professional Engineers – July 2017, Atlanta, GA

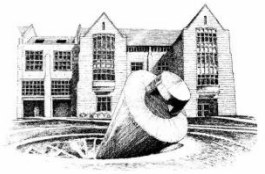


# The University of St. Thomas Renewable Energy Facility (USTREF)

HIGHER EDUCATION BLOCK GRANT CONTRACT
WITH THE MINNESOTA STATE COLLEGES AND UNIVERSITIES
RENEWABLE DEVELOPMENT FUND – CYCLE 4
GRANT CONTRACT WITH UNIVERSITY OF ST. THOMAS HE4-2

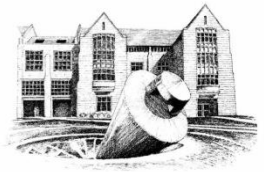
PI: Dr. Greg Mowry

17 Feb 2017



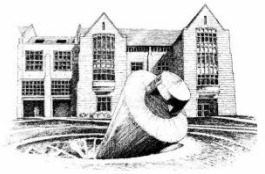
# Grateful Acknowledgements

Project funding provided by customers of Xcel Energy through a grant from the Renewable Development Fund.

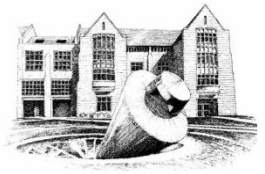


# Outline

- Intro and Program Review
- Accomplishments
- Program Benefits
- Budgets and Schedule
- Questions??



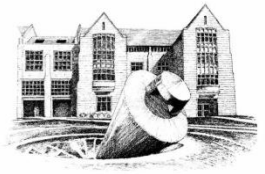
# Intro and Program Review



## **Executive HE4-2 Summary** (1)

- Install a multi-purpose microgrid which is now referred to as the, “USTREF”

- The primary objective of this facility will be to promote industry/academic collaboration in the design/build/test and validation of near commercial concepts in the areas of electricity generation and microgrid/subsystem control.



## **Executive HE4-2 Summary** (2)

- Incorporate real scale distributed energy resource and microgrid modeling experience into graduate and undergraduate electrical engineering curriculum;

- Develop an educational portal and curriculum for the K-12 grades showcasing sustainability and alternative energy systems in action.

Solar PV Array
50 kW

Genset (2)
Biofuel
50 kW

Storage Node
25 – 50 kW

Wind Turbine Emulator
25 – 50 kW

3rd Party Test Bays
~ 50 kW; 2 of them

Device Under Test

. . .

Smart Inverter + Switch

Switch

Smart Inverter + Switch

Smart Interface + Switch

Controller + Switch

EMS

480 V 3-Phase 4-Wire Bus

Switch

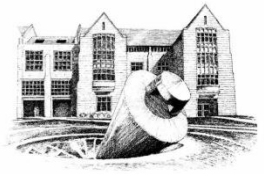
Custom Loads for control studies:
- Dump loads
- IMs
- Arcs, …

XF

Switch

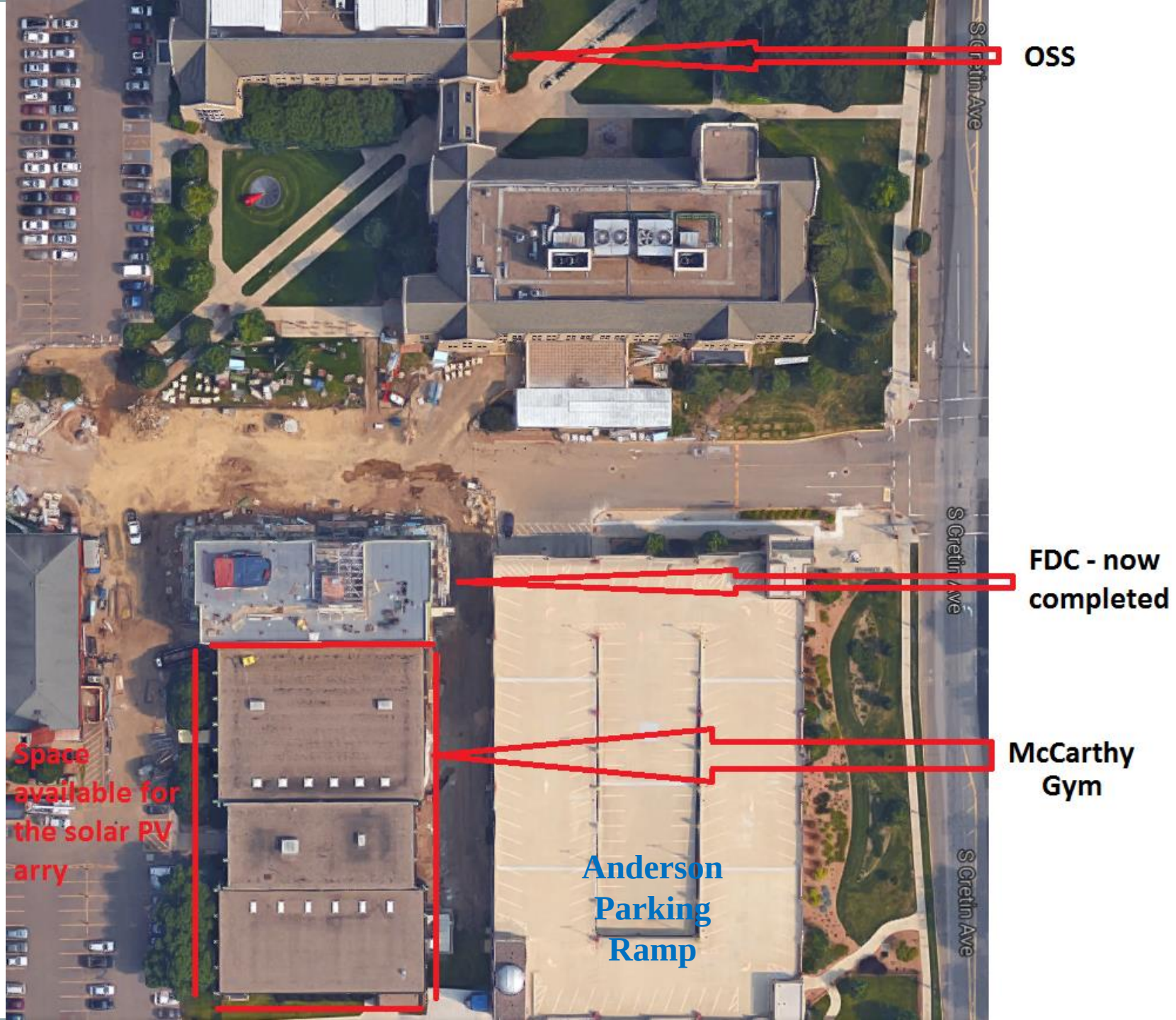
**13.8 kV Xcel Energy Campus Feeder**

**UST Facilities and Design Center**



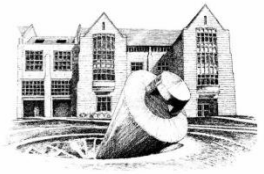
# Accomplishments


UST
North
Campus
Summit Avenue
UST
South
Campus
© 2016 Google
Google Earth
1991
Imagery Date: 3/11/2016 44°56'24.89" N 93°12'04.66" W elev 732 ft eye alt 5043 ft


OSS
FDC - now completed
McCarthy Gym
Space available for the solar PV arry
Anderson Parking Ramp
S Cretin Ave

Google Earth view of the UST µGrid location

# FDC – the Facilities and Design Center

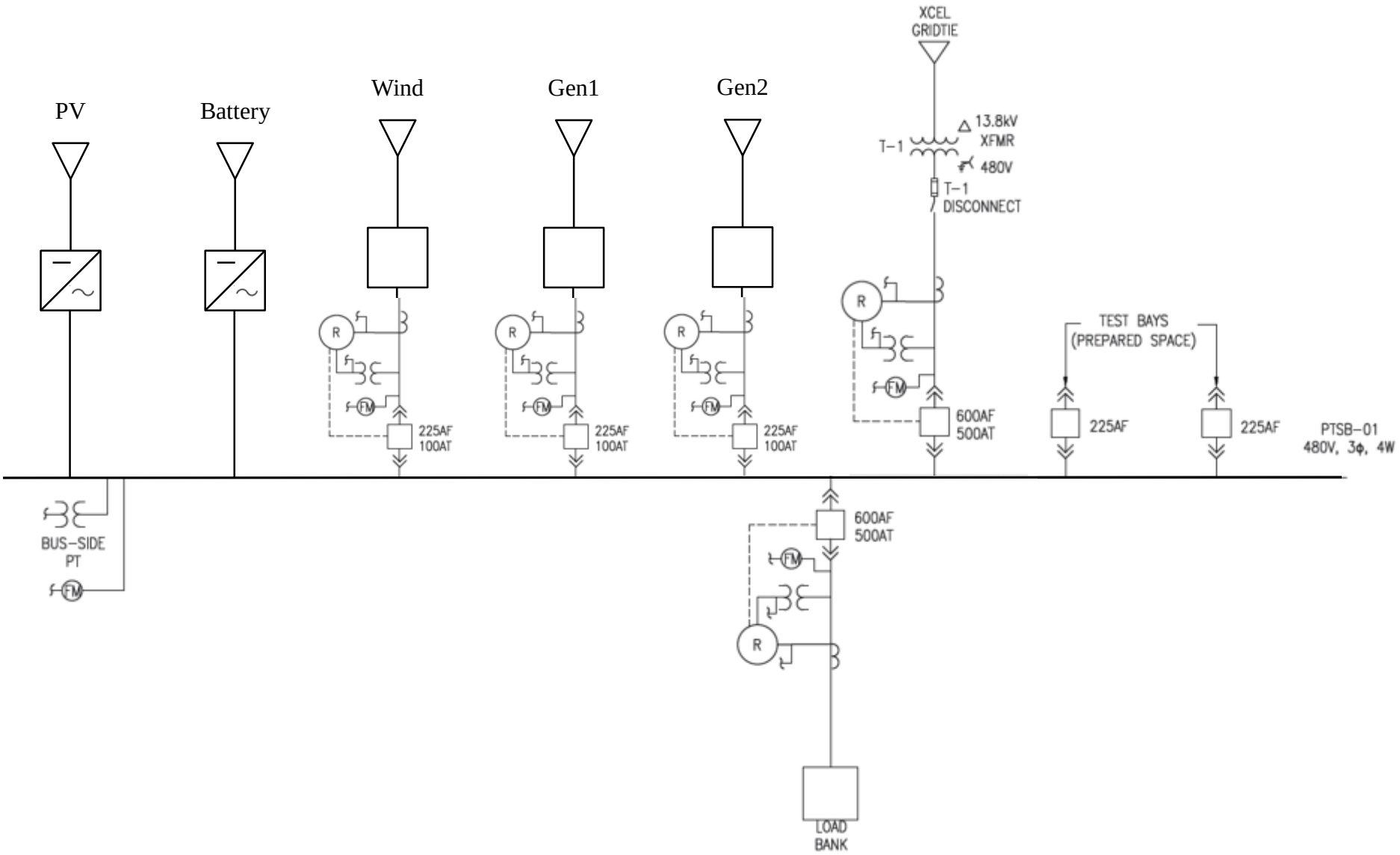


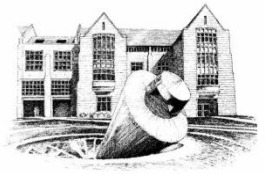
## **Accomplishments** (1)

- Full funding release has occurred

- Nearing the finalization of the one-line diagram that will be used to drive all RFQs, procurements, and asset deployments

# Near Final One-Line Diagram of the research Microgrid

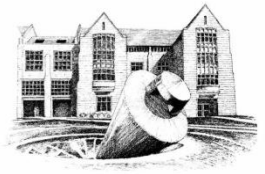




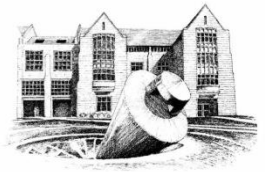
# **Accomplishments** (2)

- Several key vendor/partners:
  - Xcel Energy: grid tie and smart-substation interactions
  - Rhombus Energy Solutions: inverters & distributed EMS
  - Enersys: storage node

- Integration of preliminary R&D into both undergrad and graduate engineering curriculum at UST



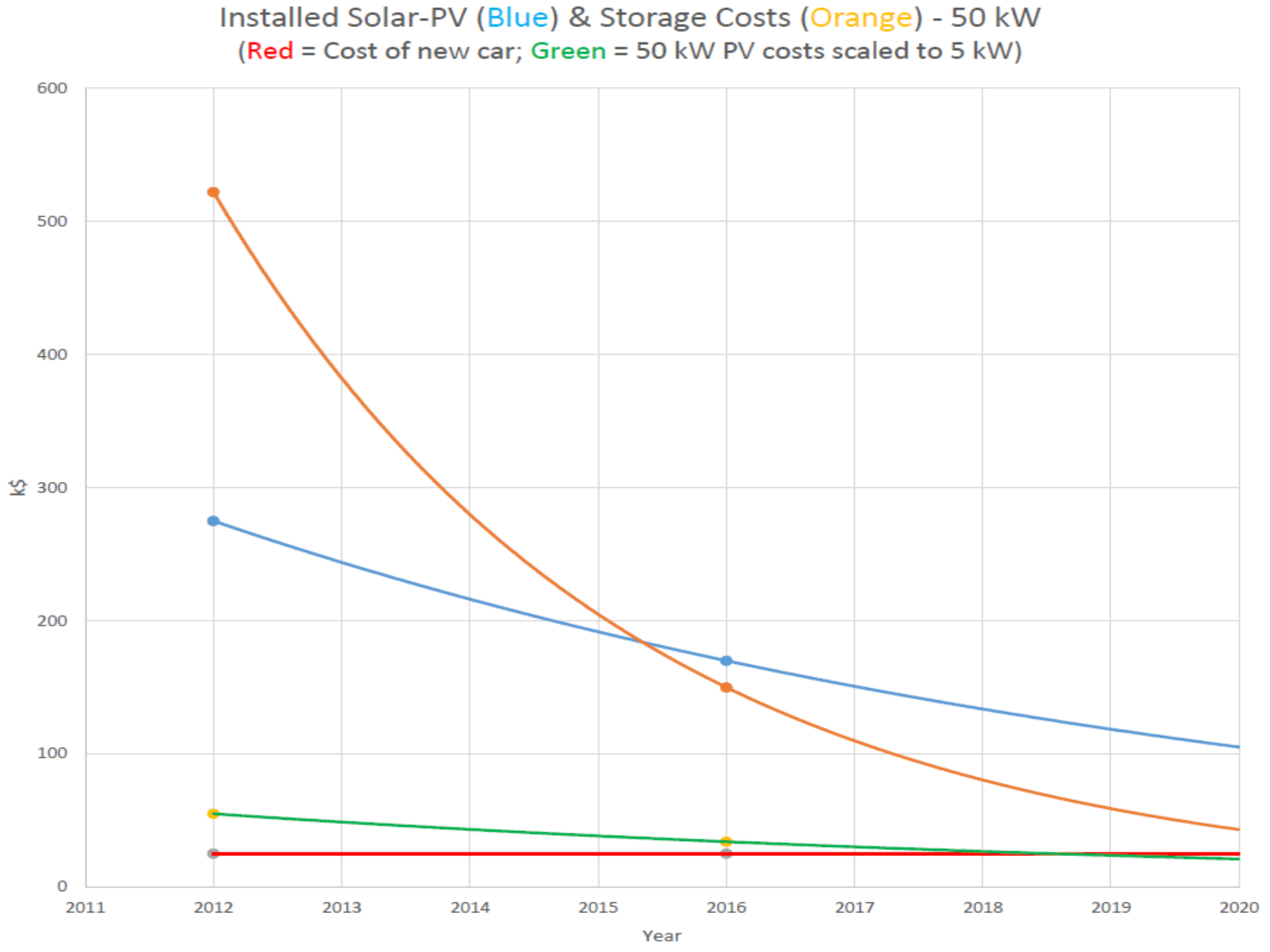
# Program Benefits

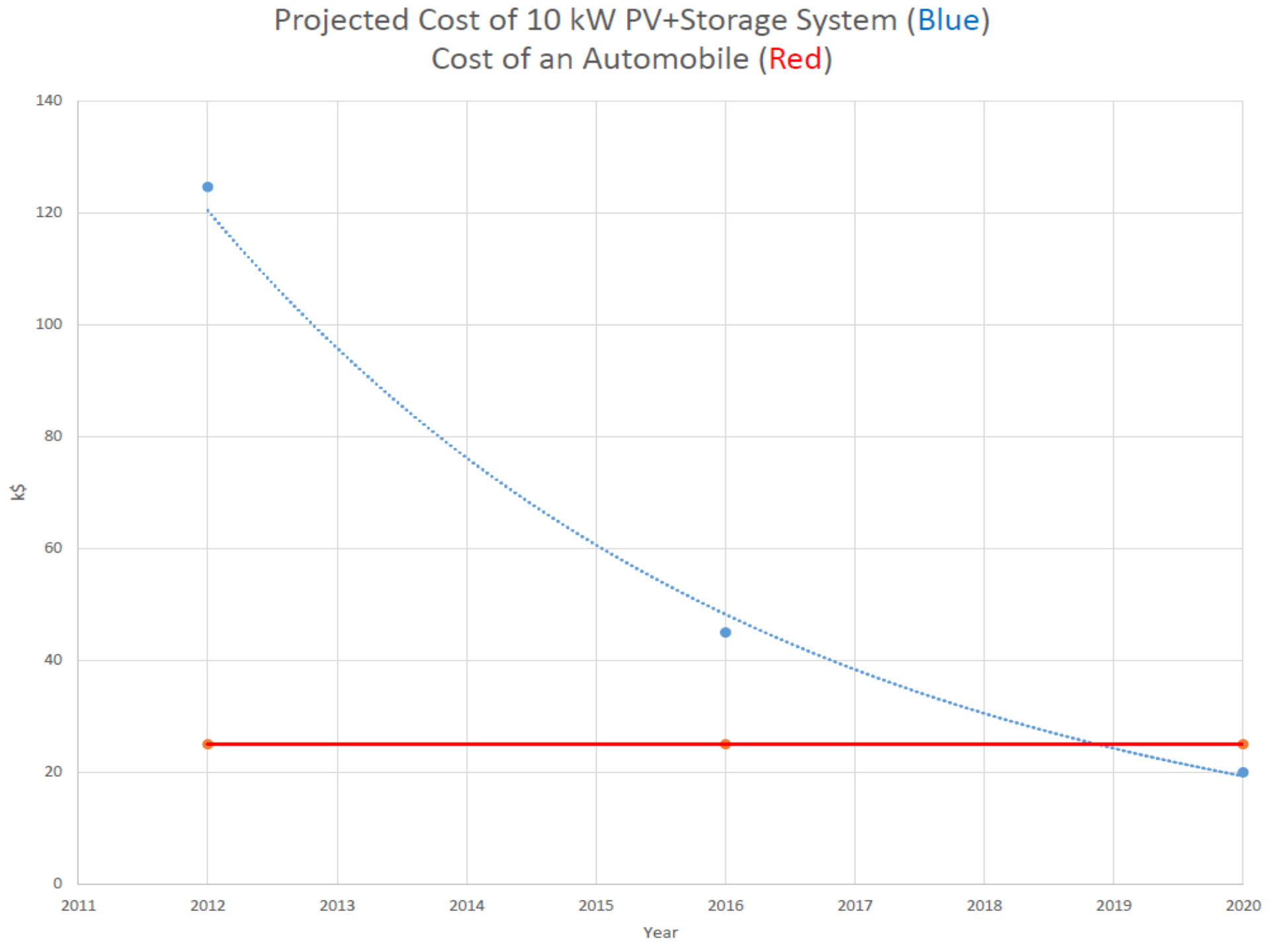


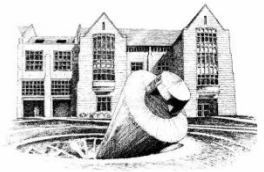
# **Program Benefits** (1)

- Xcel Energy is being recognized as leading-edge and proactive in microgrid technology and deployment

- 4 invited microgrid presentations (completed or pending) with national visibility
  - National Society of Professional Engineers (done)
  - North Central Electrical League (done)
  - Xcel Engineering 2017 Technical Conference (done)
  - 7th Microgrids & Distrib. Gen. for Public & Private Sectors (pending)


Installed Solar-PV (Blue) & Storage Costs (Orange) - 50 kW
(Red = Cost of new car; Green = 50 kW PV costs scaled to 5 kW)
600
500
400
300
200
100
0
k$
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year

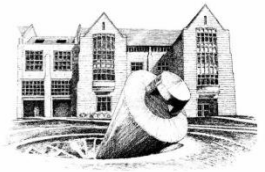

Projected Cost of 10 kW PV+Storage System (Blue)
Cost of an Automobile (Red)
140
120
100
80
60
40
20
0
k$
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year



## **Program Benefits** (2)

- Significant boon to the University of St Thomas's School of Engineering power program: at both the graduate and undergraduate level

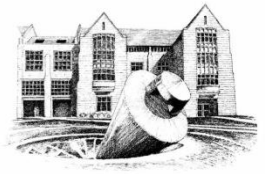
- The first graduate student with thesis/project work related to the USTREF has already graduate; Nathan Webster. He is now at ASU working on his PhD with a power focus



## **Program Benefits** (3)

- Multiple grad and undergraduate research students will starting on the project in Spring 2017 semester as we move into the RFQ phase of the project.

- Significant recognition by 3rd party businesses in & moving into microgrid related markets



## **Program Benefits** (3)

- Opportunities pending for other RDF recipients for Multiple grad and undergraduate research students will starting on the project as we move into the RFQ phase of the project.

- World-wide recognition of humanitarian microgrid outreach.

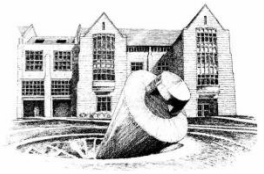
# Will Steger – Ely, MN



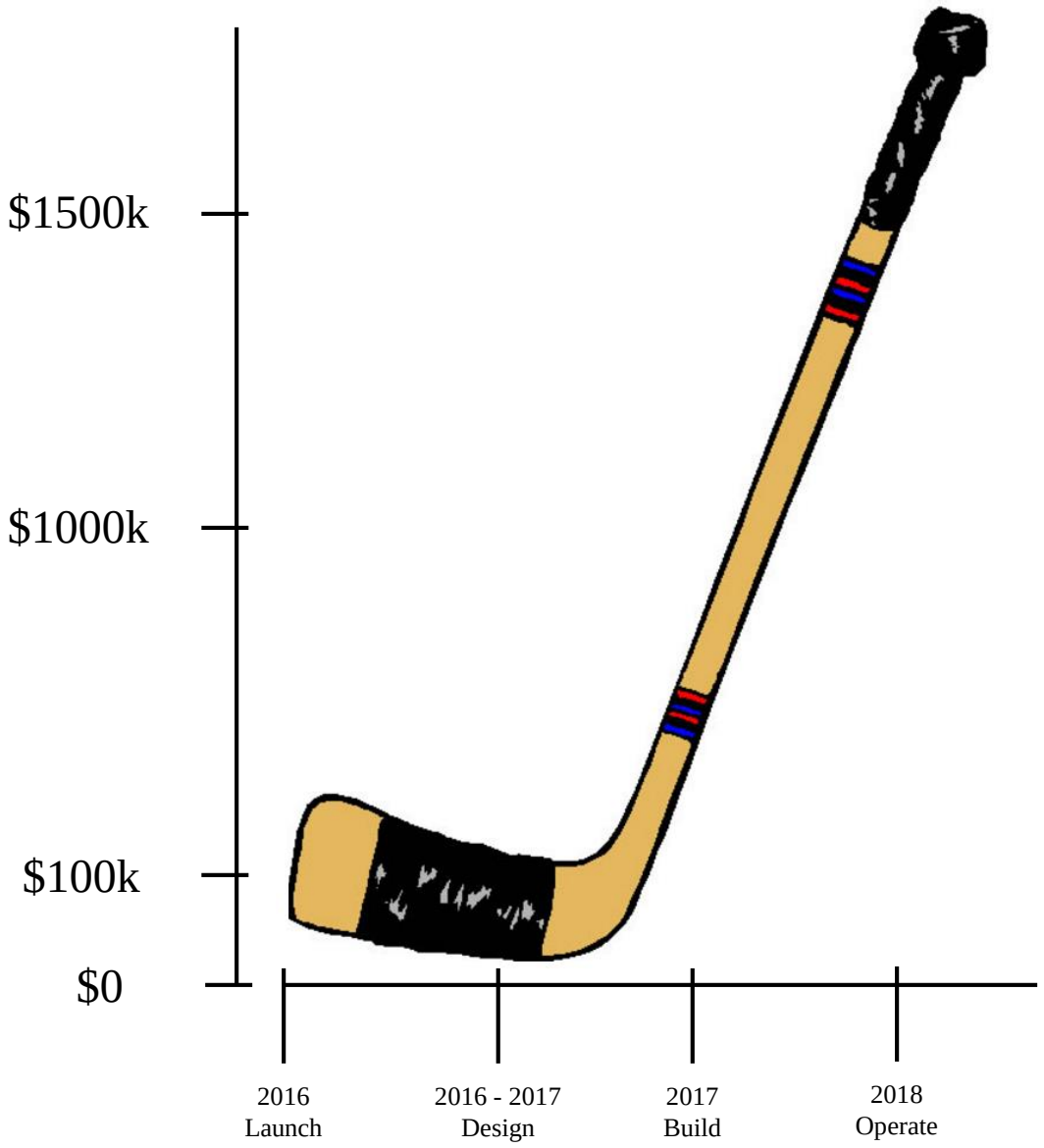
The Steger Wilderness Center is made of glass, native timber and stone, and recycled wood.

# Will Steger – Ely, MN

# Will Steger – Ely, MN



# Budgets and Schedule


$1500k
$1000k
$100k
$0
2016
Launch
2016 - 2017
Design
2017
Build
2018
Operate

# Questions??