

Welcome to this week's presentation and conversation  
hosted by the  
**Canadian Association for the Club of Rome,**  
a Club dedicated to intelligent debate and action on global issues.

## ***Microgrids in the Age of the Anthropocene.***

Our speaker today is Dr. Mahmoud Kabalan, Assistant Professor in and Director of the Center for Microgrid Research (CMR) at U St. Thomas in St. Paul, MN, USA. He received the National Science Foundation CAREER award in 2023. He is the Principal Investigator on a \$5.4 million 5-year grant from the Minnesota Department of Commerce to expand CMR's research, education, and outreach activities. He is a licensed Professional Engineer in Minnesota. Human impact on the planet has reached unprecedented levels of environmental degradation. Scientists are proposing to call this geological epoch the Anthropocene. Electric power systems are a major contributor to the unsustainable human impact on the planet. A major shift in electric power systems is underway to decarbonize and localize the electric grid. This talk will present the status of our planet and how microgrid could play a role in this shift over the next decades.

The presentation will be followed by a conversation, questions, and observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, and Inuit in Canada) and their descendants.



Website: [canadiancor.com](http://canadiancor.com)  
Twitter: [@cacor1968](https://twitter.com/cacor1968)  
YouTube: [Canadian Association for the Club of Rome](https://www.youtube.com/channel/UC...)

# Microgrids in the age of the Anthropocene

Mahmoud Kabalan, Ph.D., P.E.

Founding Director of the

UST Center for Microgrid Research

Assistant Professor

University of St Thomas


[Mahmoud.kabalan@stthomas.edu](mailto:Mahmoud.kabalan@stthomas.edu)

©Mahmoud Kabalan



# Outline

## Introduction

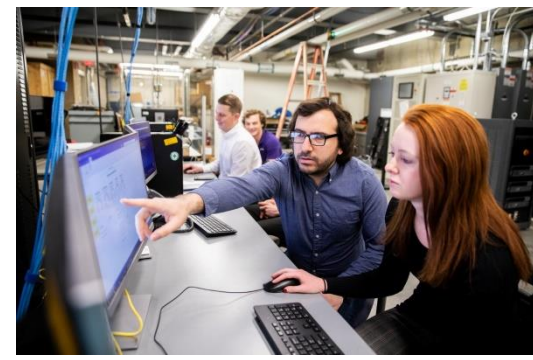
- University of St Thomas
  - Center for Microgrid Research CMR
- 

## Anthropocene



## Microgrids

- Trends in Power Systems
- What is a Microgrid?
- Microgrid Case studies at the CMR
- CMR Expansion



# University of St. Thomas Background

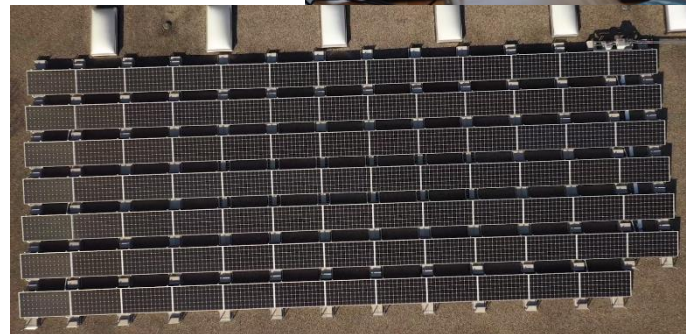
- Minnesota's largest private university with ~10,000 students
- 150 UG and 55 grad program majors and minors
- 6,000 undergrads and 4,000 grad students with growing diversity
- Employ more than 2,500 people in the 4<sup>th</sup> district
- Top 20 Catholic university – Top 10 aspiration
  
- 1 in 6 students are enrolled in the School of Engineering
- Civil, Manufacturing, Mechanical, Electrical, Computer, and Software Engr, & Data Science
- Power Systems Engineering Education: BS, MS tracks + Prof. Education



# UST Center for Microgrid Research

Mission: Be a resource to the power community to transition to carbon free electricity and produce innovative engineers and technology leaders for the 21st century

Vision: To be one of the premier applied engineering research centers in the area of distributed energy resources and microgrids enabling a secure, resilient and carbon-free electric grid for the 21st century.



# UST Center for Microgrid Research - Staff



Mahmoud  
Kabalan, PhD, PE  
Professor and  
Director



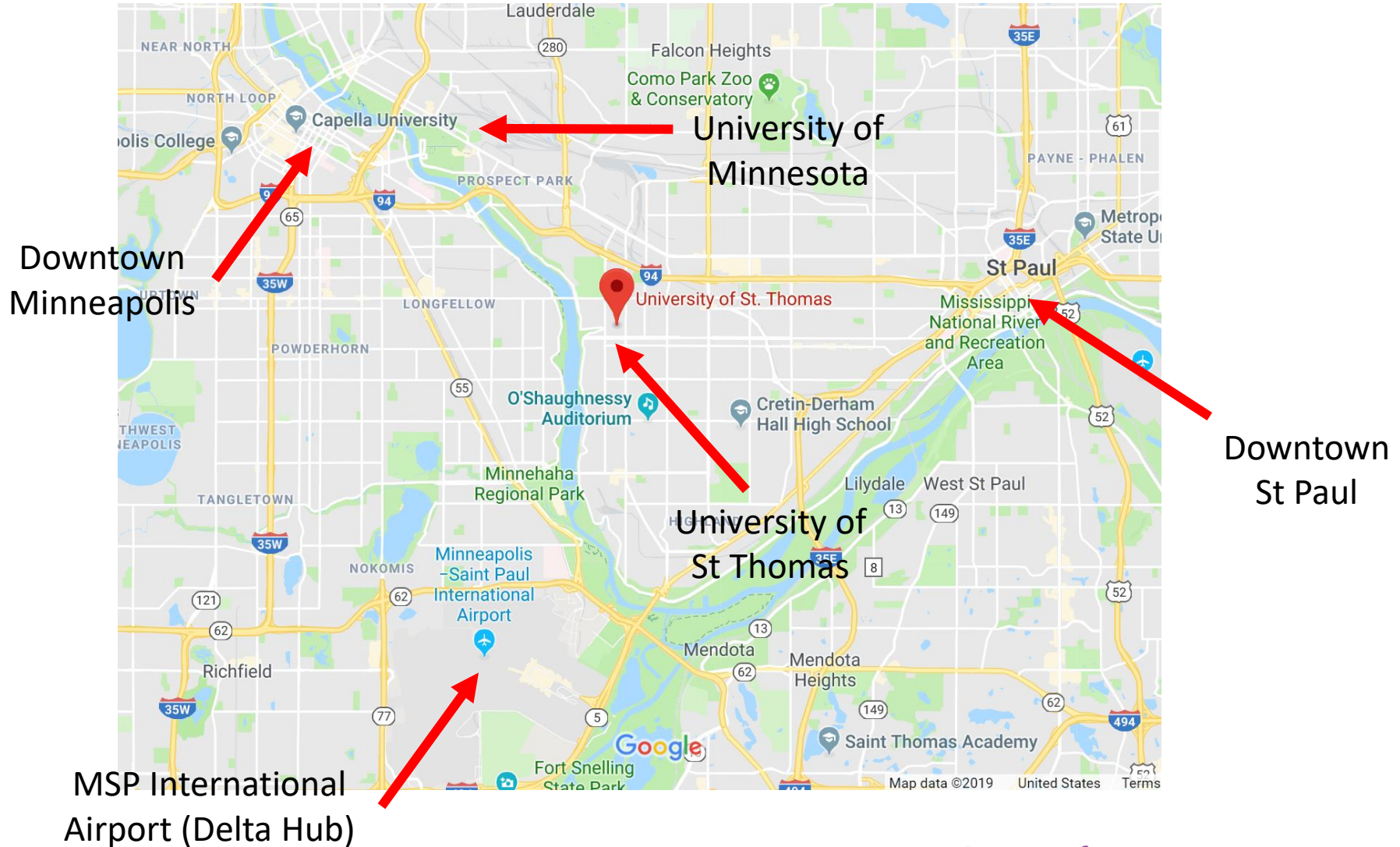
Shree Pandey  
Microgrid  
Engineer



Omid Lorzadeh  
Postdoctoral  
Scholar

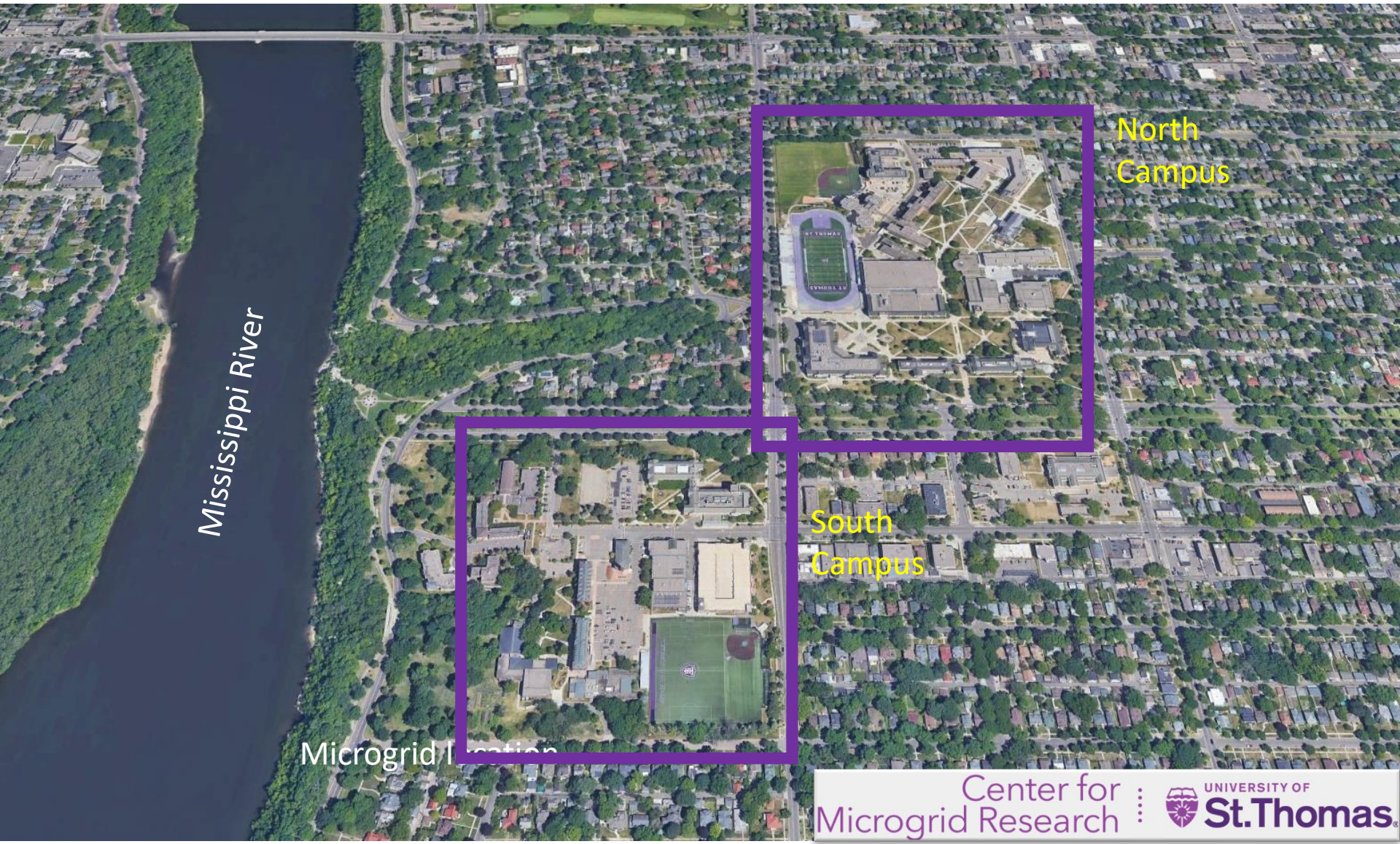
And growing!

# University of St Thomas Location





# Microgrid Location



Mississippi River

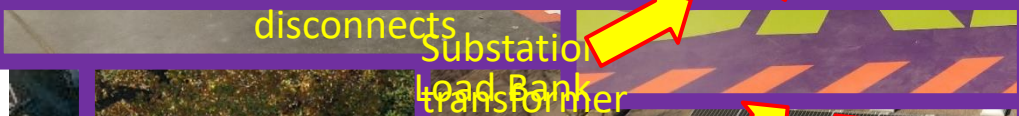
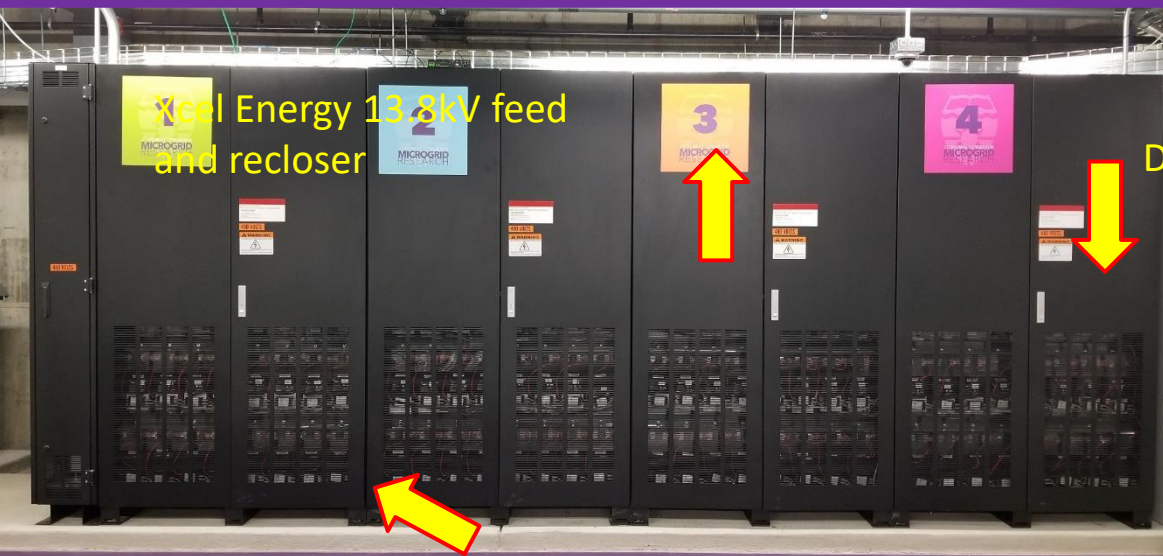
North  
Campus

South  
Campus

Microgrid Location







1 Xcel Energy 13.8kV feed and recloser

3

4

Diesel Generator

Solar PV Array

Substation fuses and disconnects

Substation load bank transformer

Switchgear and controller

Solar PV Inverter

Energy Storage System

**A Versatile Real-Scale, Grid Connected / Islanded Microgrid for Research & Development, Company Partnering, and Education**



13.8 kV  
Xcel Energy  
Feeder

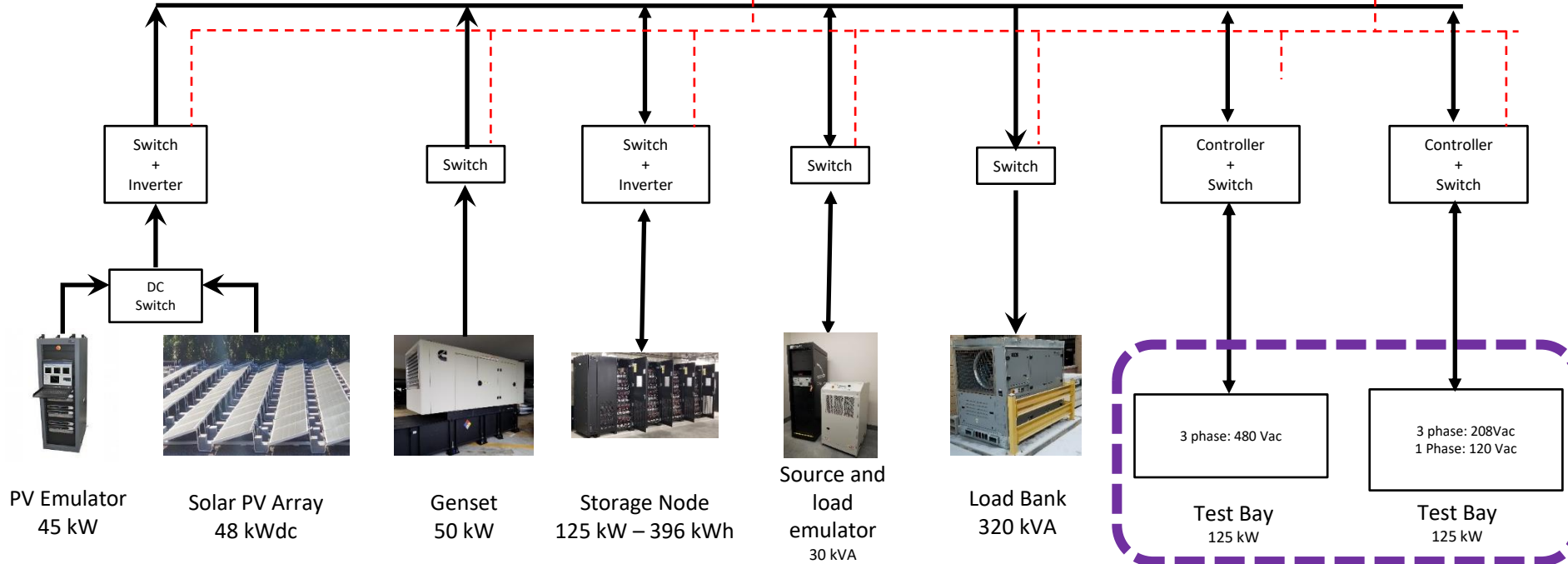
Transformer  
+  
Switch



Control Hardware:  
SEL Relays and Computers



480 V 3-Phase 4-Wire Bus



PV Emulator  
45 kW

Solar PV Array  
48 kWdc

Genset  
50 kW

Storage Node  
125 kW – 396 kWh

Source and  
load  
emulator  
30 kVA

Load Bank  
320 kVA

3 phase: 480 Vac  
  
Test Bay  
125 kW

3 phase: 208Vac  
1 Phase: 120 Vac  
  
Test Bay  
125 kW

# Outline

## Introduction

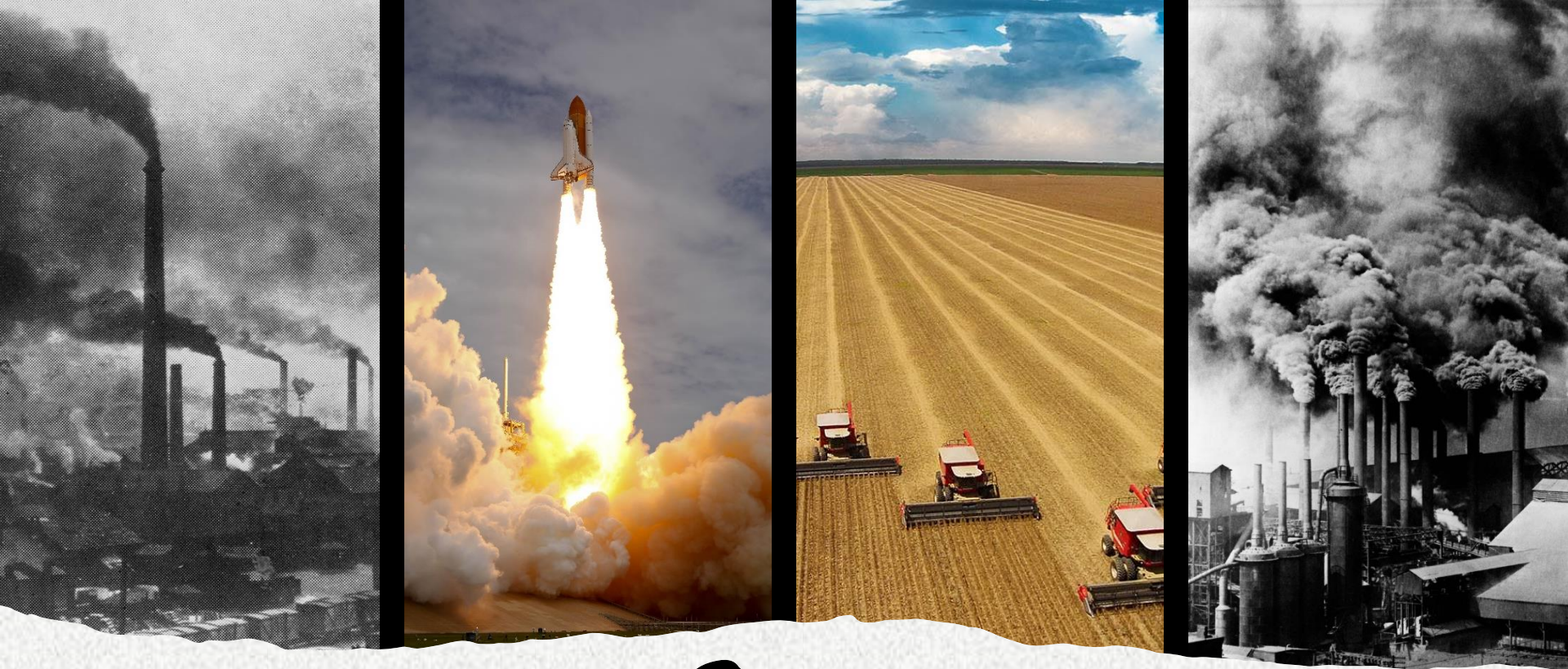
- University of St Thomas
- Center for Microgrid Research CMR

## Anthropocene

## Microgrids

- Trends in Power Systems
- What is a Microgrid?
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The Anthropocene is a proposed epoch starting from the commencement of significant human impact on the Earth's geology and ecosystems

# The Anthropocene? Humans have:

## Land Use

Transformed between a third and a half of the land surface of the planet

## Plastics

Microplastic particles are now virtually ubiquitous

## Nitrogen and Phosphorous Cycles

Doubled the nitrogen and phosphorous in our soils in the past century with fertilizer use. This is likely to be the largest impact on the nitrogen cycle in 2.5bn years

## Geological Record

Left a permanent layer of airborne particulates in sediment and glacial ice such as black carbon from fossil fuel burning

## Extinction rates

The Earth is on course to see 75% of species become extinct in the next few centuries

## $CO_2$

Increased levels of  $CO_2$  in the atmosphere at the fastest rate for 66m years

# The Anthropocene? Humans have:

## Land Use

Transformed between a third and a half of the land surface of the planet

## Extinction rates

The 6<sup>th</sup> Mass Extinction is underway

$CO_2$

Increased levels of  $CO_2$  in the atmosphere at the fastest rate for 66m years

## Plastics

Microplastic particles are now virtually ubiquitous, and plastics will likely leave identifiable fossil records for future generations to discover

## Nitrogen and Phosphorous Cycles

Doubled the nitrogen and phosphorous in our soils in the past century with fertiliser use. This is likely to be the largest impact on the nitrogen cycle in 2.5bn years

## Geological Record

Left a permanent layer of airborne particulates in sediment and glacial ice such as black carbon from fossil fuel burning

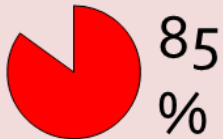


# MASS EXTINCTIONS:

The biggest disasters in history

## ORDOVICIAN

Death Rate:



Time: 445 million years ago

Likely Causes:

- Rapid global cooling
- Falling sea levels

Results:

- Coastal areas destroyed
- Chemical reactions affected by cold



## DEVONIAN

Death Rate:



Time: 340 million years ago

Likely Causes:

- Asteroid impact(s)
- Rapid global cooling

Results:

- Local destruction from debris
- Ocean life affected by temperature



## PERMIAN

Death Rate:



Time: 250 million years ago

Likely Causes:

- Volcanic activity
- Increase in Methane and CO<sub>2</sub>
- Rapid global warming

Results:

- Oxygen removed from oceans
- Desertification of land



## TRIASSIC

Death Rate:



Time: 200 million years ago

Likely Causes:

- Increase in Methane and CO<sub>2</sub>
- Rapid global warming

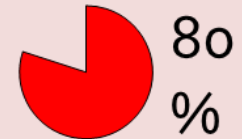
Results:

- Desertification of land
- Frequent heat waves



## K-T

Death Rate:



Time: 65 million years ago

Likely Causes:

- Asteroid impact
- Volcanic activity
- Falling sea levels

Results:

- Widespread fires
- Plants disrupted by global ash cloud
- "Nuclear winter"



Poster by Budjarr Lambeth, Information from [brittanica.com](http://brittanica.com) and [bbc.co.uk](http://bbc.co.uk), Images from Wikimedia Commons - Feel free to redistribute

<https://steemit.com/science/@okan35/five-big-mass-extinctions-our-world-had>

# 6<sup>th</sup> Mass Extinction

## 6<sup>th</sup> Mass Extinction

The Earth is on course to see 75% of species become extinct in the next *few* centuries because of humans

### ORDOVICIAN

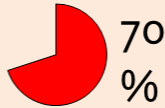
Death Rate:



Time: 445 million years ago

### DEVONIAN

Death Rate:



Time: 340 million years ago

### PERMIAN

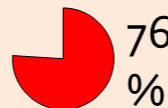
Death Rate:



Time: 250 million years ago

### TRIASSIC

Death Rate:



Time: 200 million years ago

### K-T

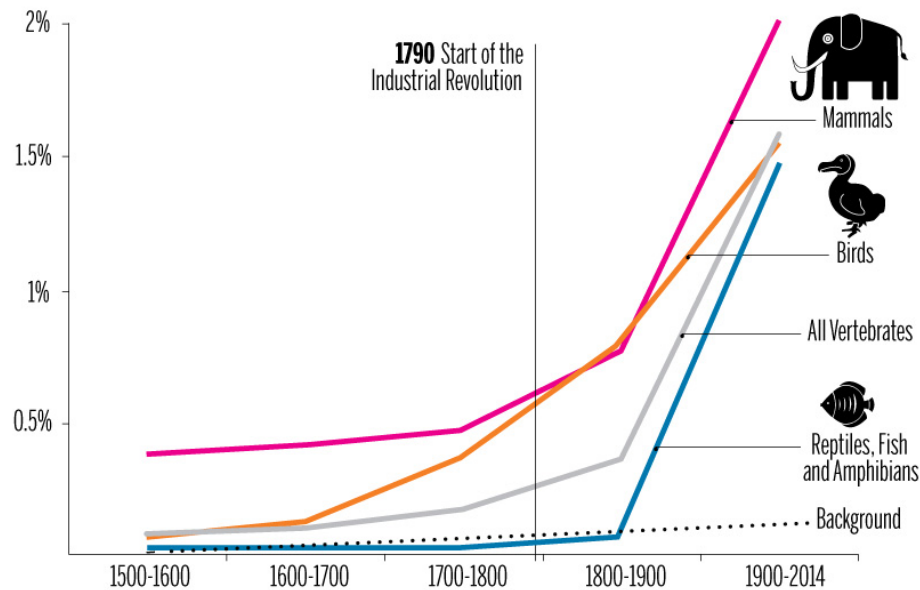
Death Rate:



Time: 65 million years ago

### VERTEBRATE SPECIES EXTINCTION RATES

Cumulative, recorded as "extinct" or "extinct in the wild"



SOURCE: CEballos et al. Sci. Adv. 2015;1:e1400253 | GRAPHIC: Amanda Shendruk

MACLEAN'S

<https://maclean.ca/society/science/infographic-charting-the-worlds-sixth-mass-extinction/>

# The Anthropocene? Humans have:

## Land Use

Transformed between a third and a half of the land surface of the planet

## Extinction rates

The Earth is on course to see 75% of species become extinct in the next few centuries if current trends continue

$CO_2$

Increased levels of  $CO_2$  in the atmosphere at the fastest rate for 66m years

## Plastics

Microplastic particles are now virtually ubiquitous, and plastics will likely leave identifiable fossil records for future generations to discover

## Nitrogen and Phosphorous Cycles

Doubled the nitrogen and phosphorous in our soils in the past century with fertiliser use. This is likely to be the largest impact on the nitrogen cycle in 2.5bn years

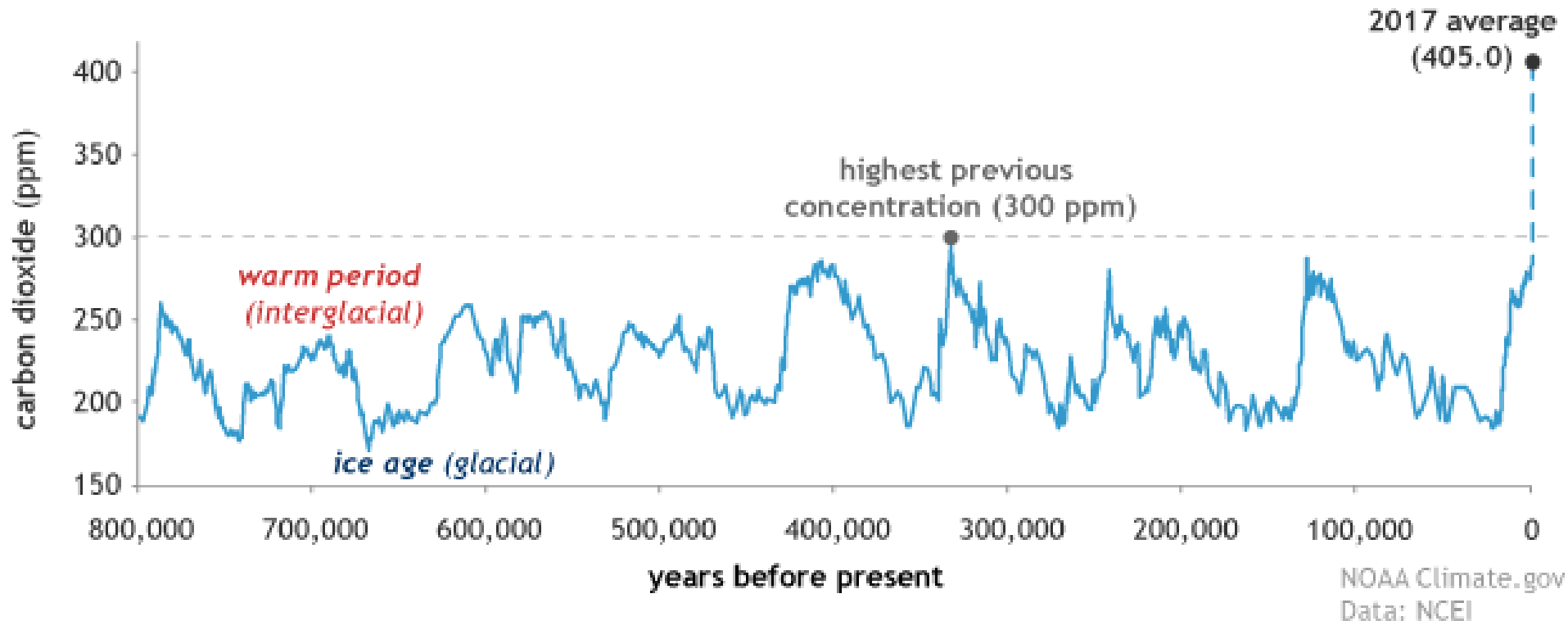
## Geological Record

Left a permanent layer of airborne particulates in sediment and glacial ice such as black carbon from fossil fuel burning

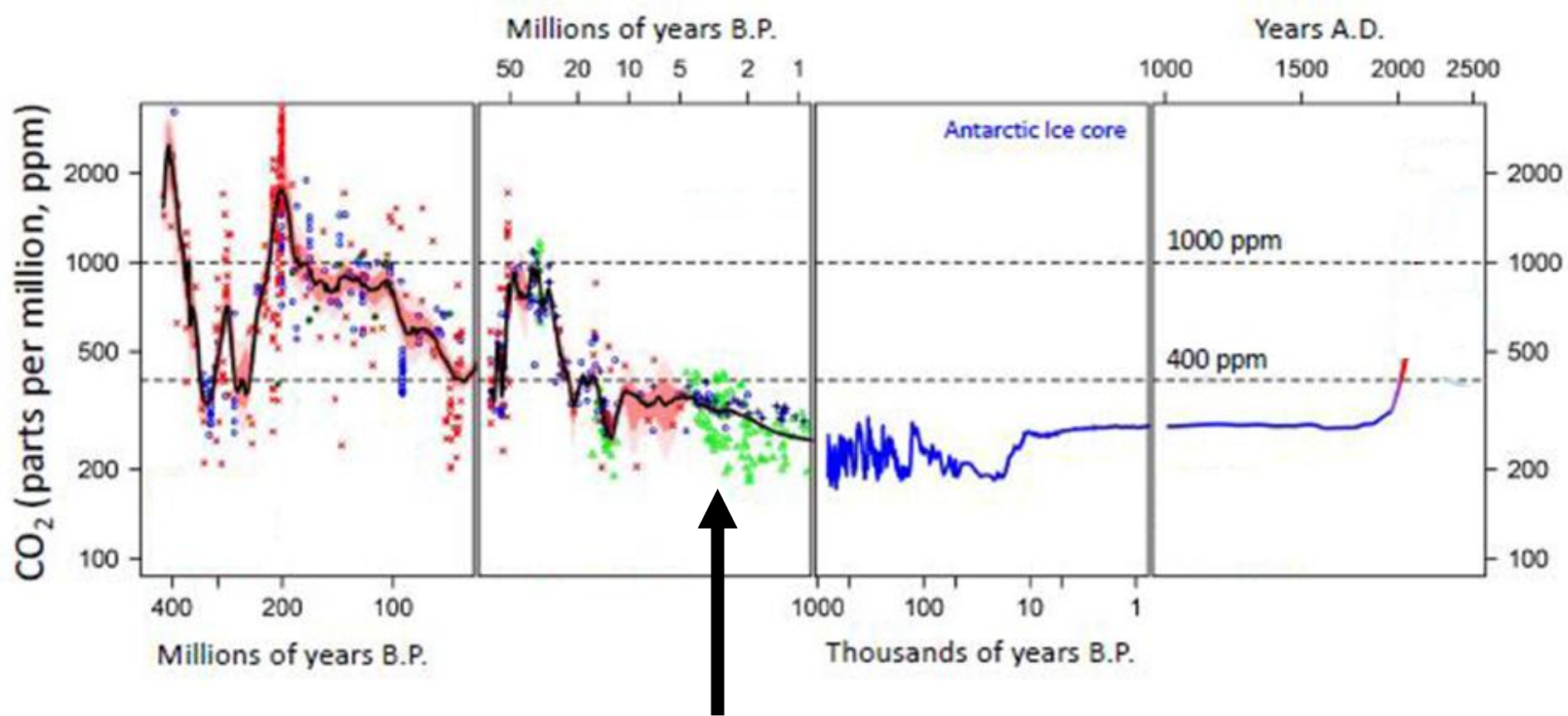


# CO<sub>2</sub> over 800,000 years

CO<sub>2</sub> during ice ages and warm periods for the past 800,000 years



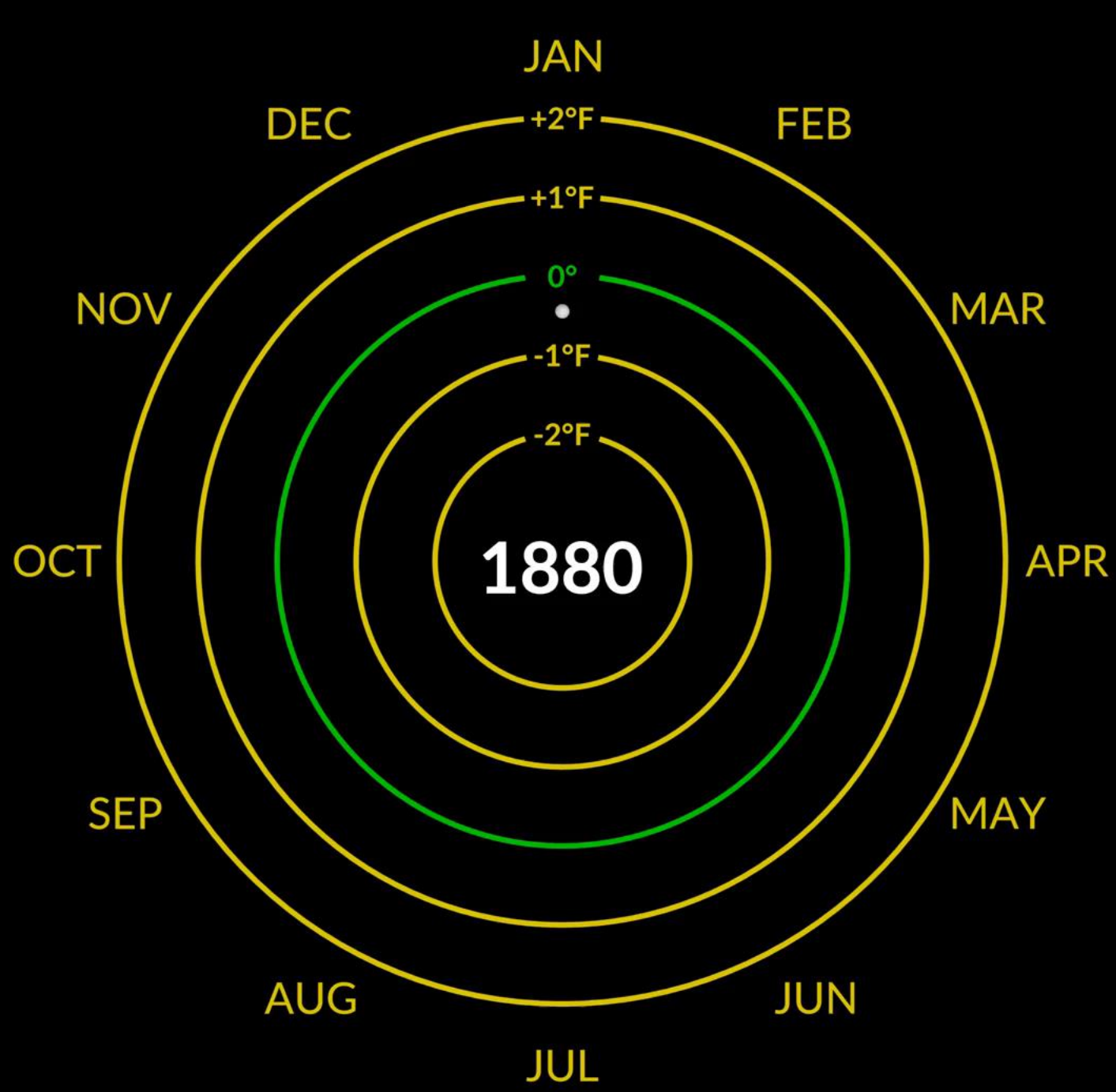
# $CO_2$ over MILLIONS of Years



Last time  $CO_2$  was at 400 ppm was about three to five million years ago

. Foster et al/descent into the icehouse

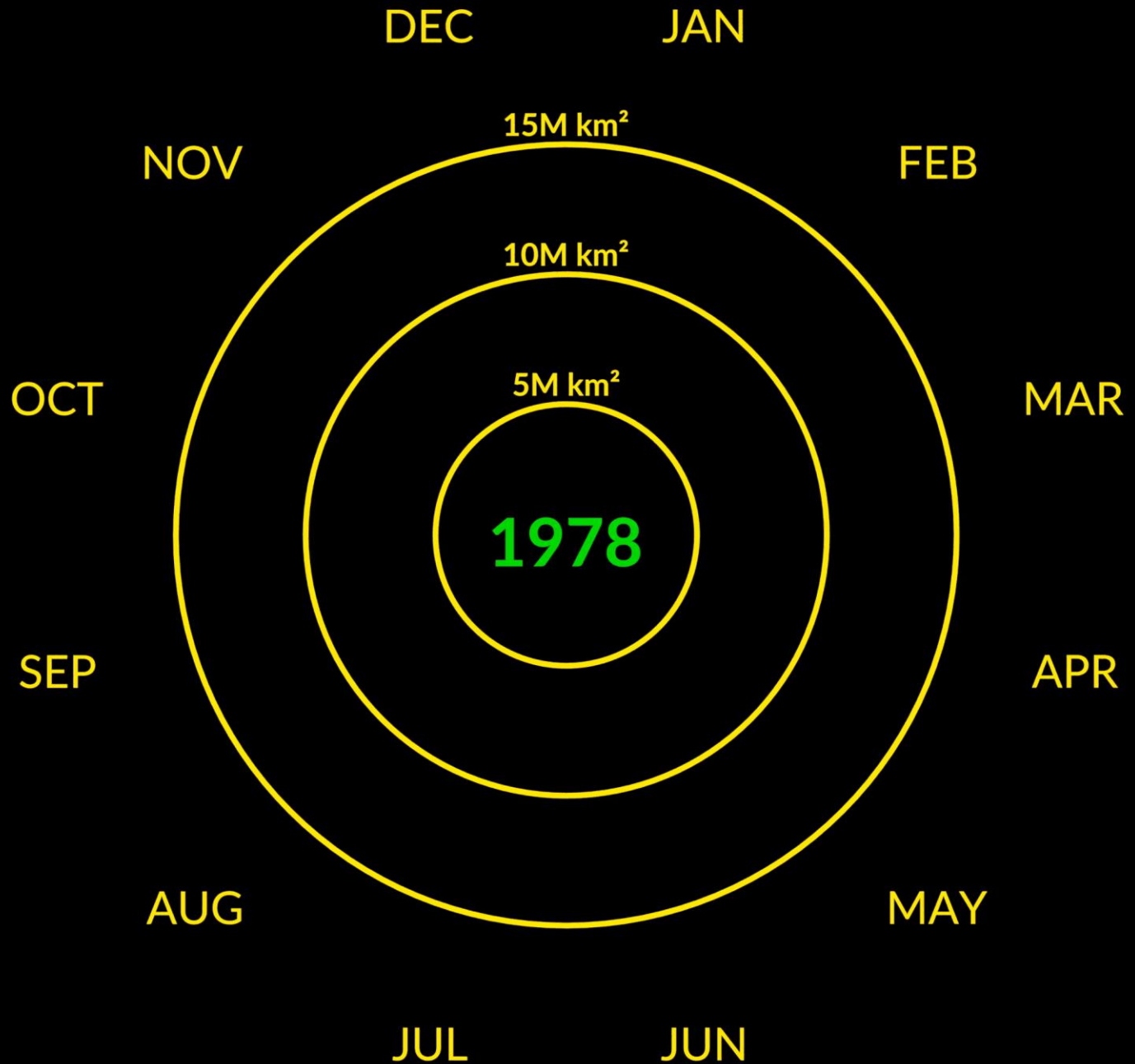
# Global Temperatures



[Video: Climate Spiral \(1880-2022\) – Climate Change: Vital Signs of the Planet \(nasa.gov\)](#)



# Arctic Sea Ice Volume



<https://svs.gsfc.nasa.gov/5028>

Have We Recovered from  
Potential Global  
Catastrophize Before?

YES!!

By DOING  
SOMETHING

# CFC 1987 Ban and the Ozone Layer

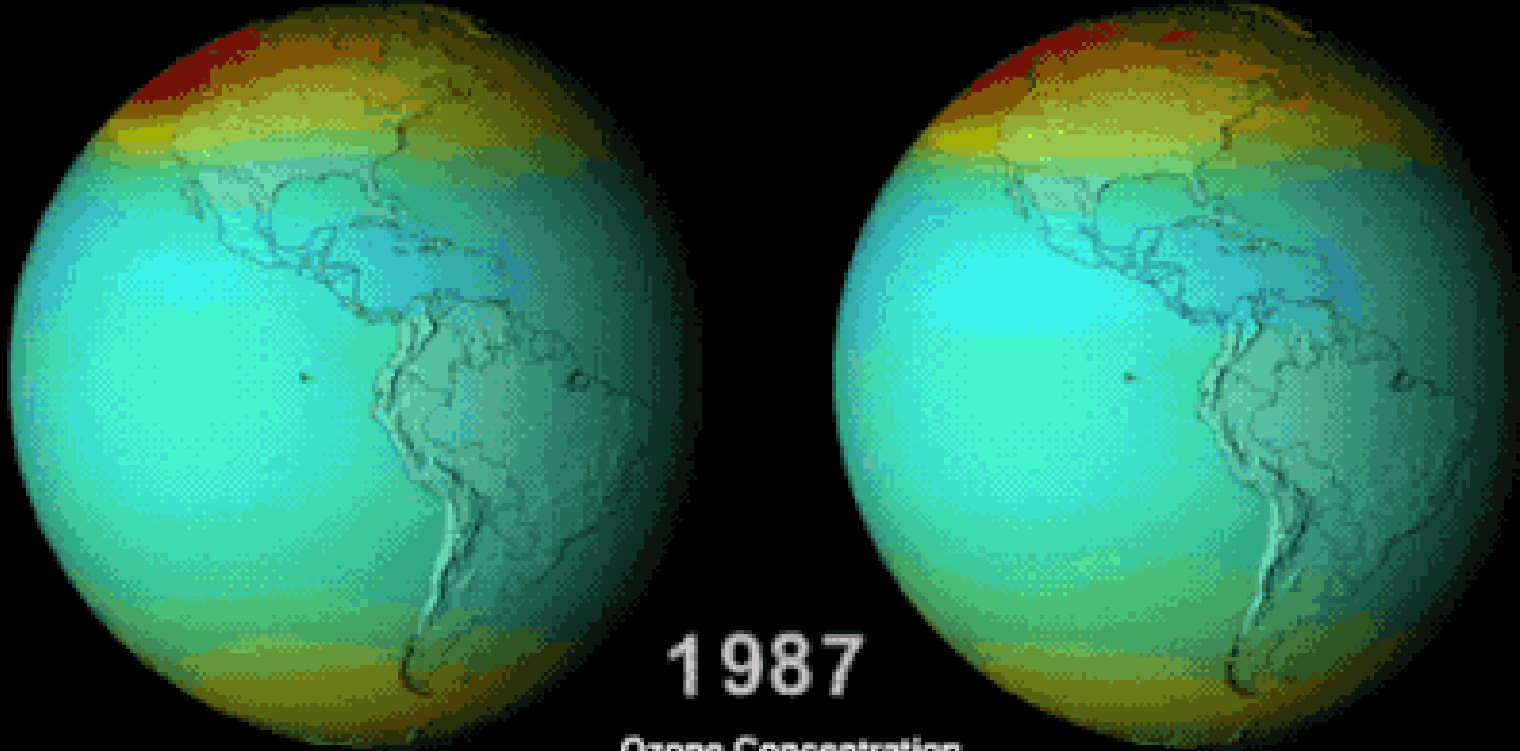
**BECAUSE OF THE BAN ON CFC'S, THE OZONE HOLE IS SHOWING SIGNS OF HEALING ITSELF AFTER YEARS OF EFFORTS.**



# What If We Waited?

With Montreal Protocol

Without Montreal Protocol



We can fix all these  
problems with TODAY'S  
TECHNOLOGY

There is a cost to delayed  
action...

# Outline

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- University of St Thomas
- Center for Microgrid Research CMR

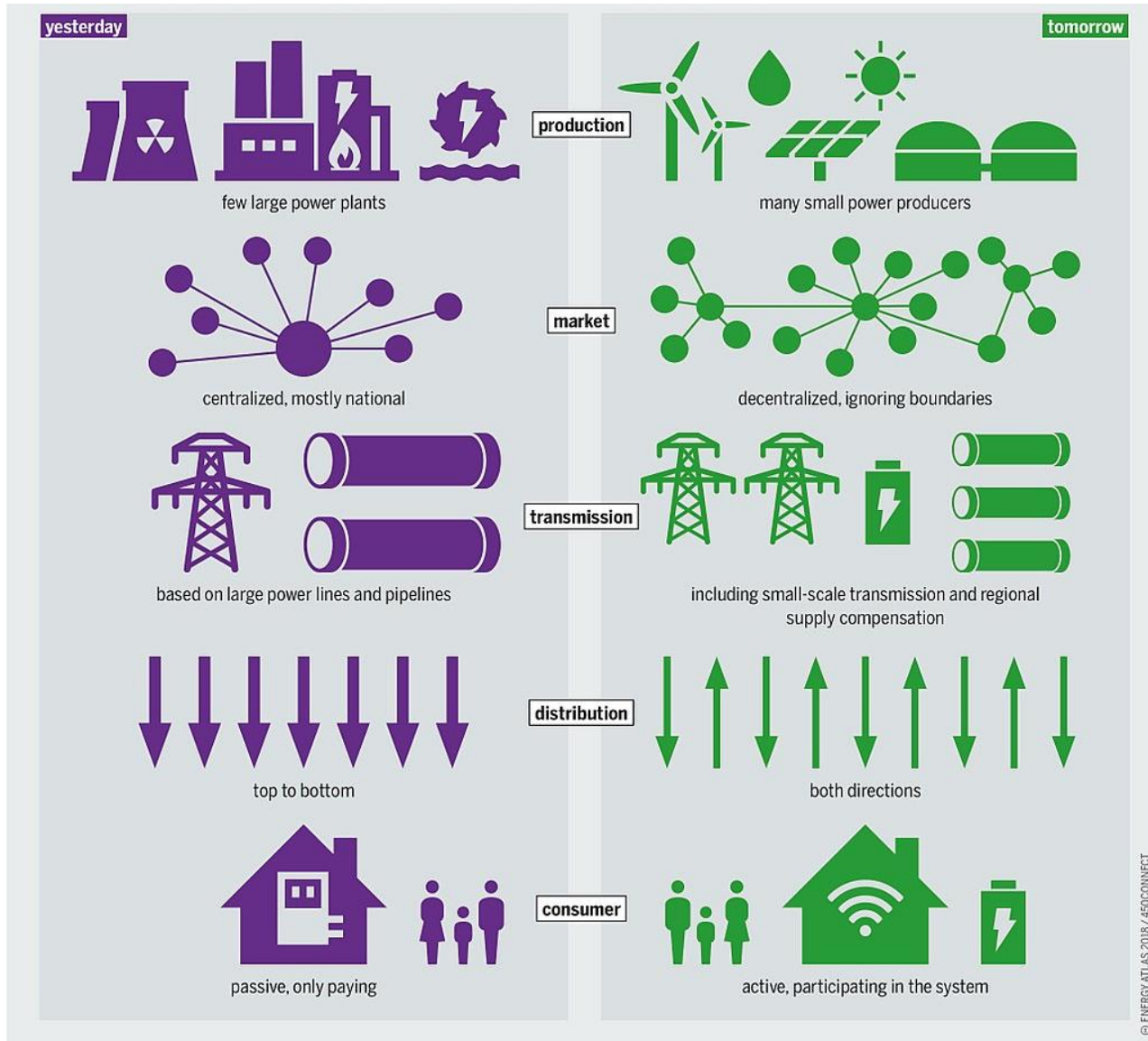
## Anthropocene

## Microgrids

- Trends in Power Systems
- What is a Microgrid?
- Microgrid Case studies at the CMR
- CMR Expansion



# Changes in Power System



# Three Trends shaping the future of power systems:

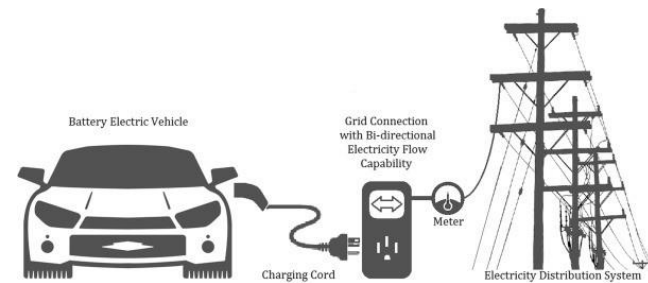
Renewable energy sources



Energy Storage

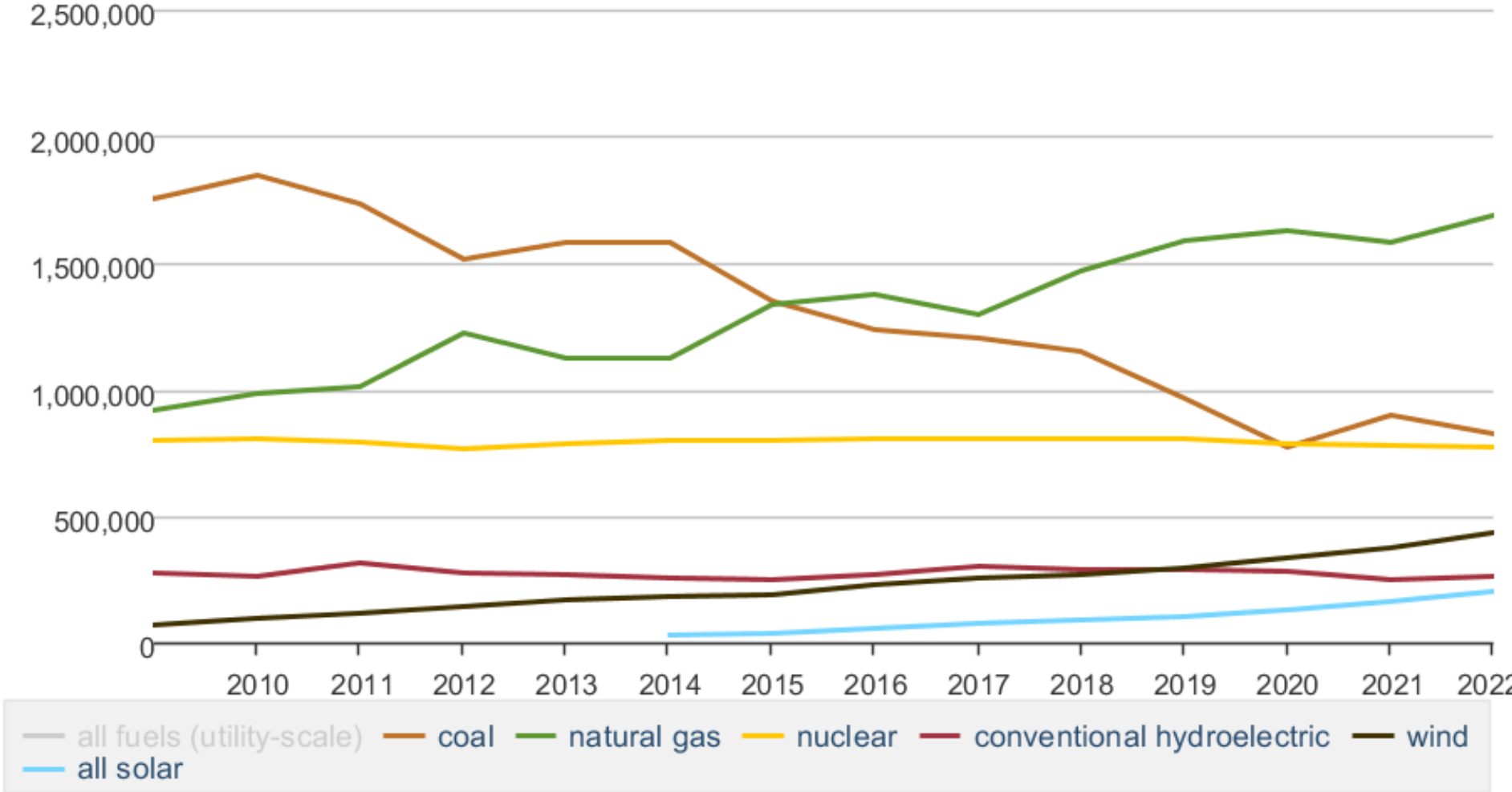


Electric Vehicles



# Net generation, United States, all sectors, annual

thousand megawatthours



Data source: U.S. Energy Information Administration

# Energy Storage: Game Changer

## Near-term lithium-ion battery cell and pack price forecast

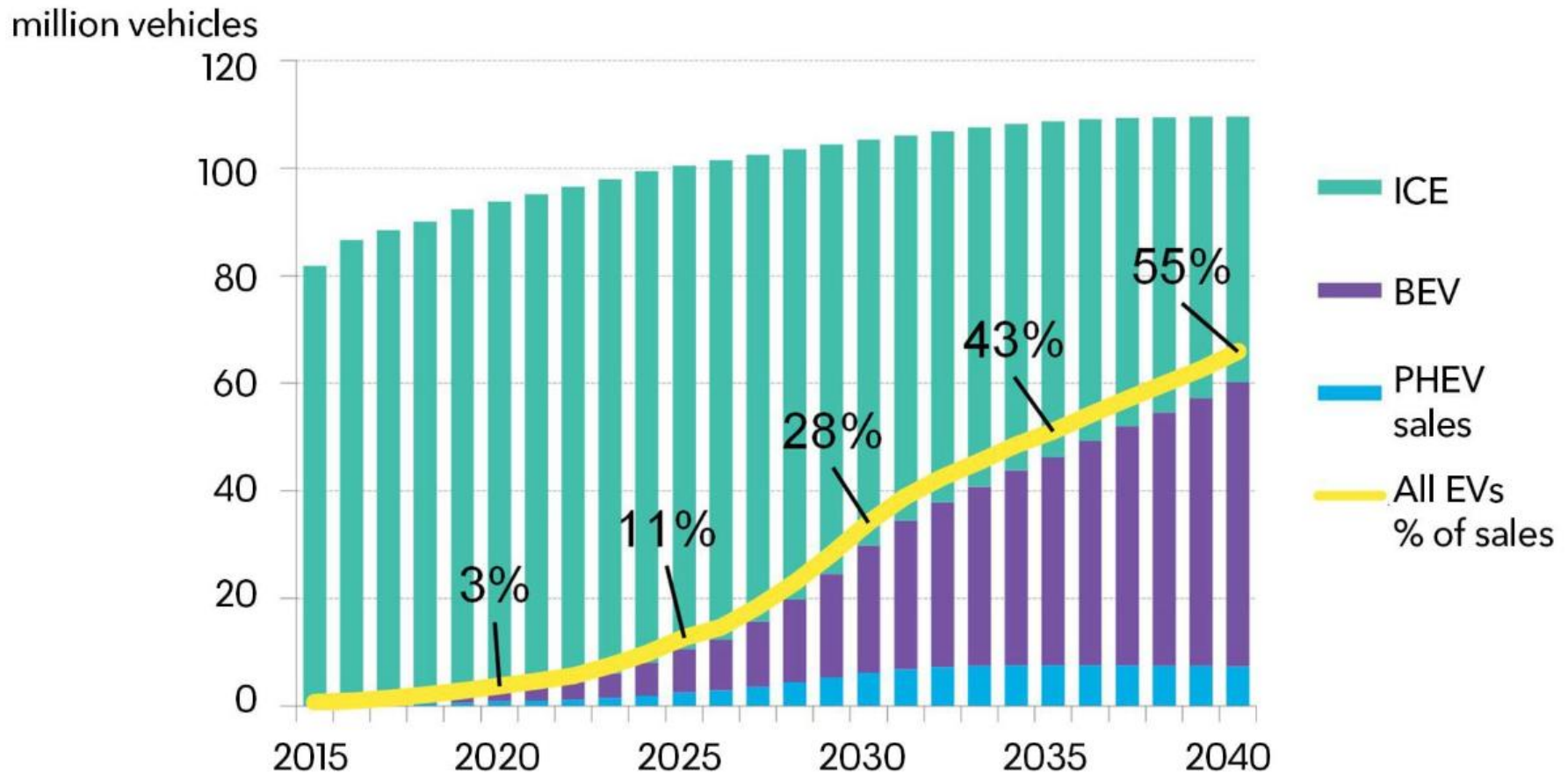


Source: BloombergNEF



# Electric Vehicles are here...

## Annual global light duty vehicle sales

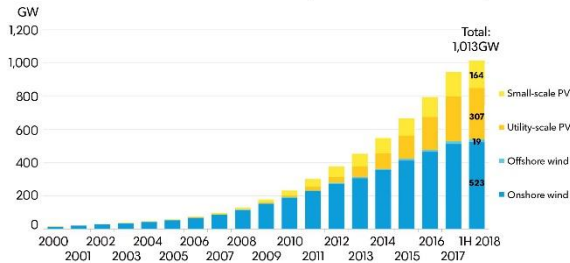


Source: Bloomberg New Energy Finance

<https://about.bnef.com/electric-vehicle-outlook/#toc-download>

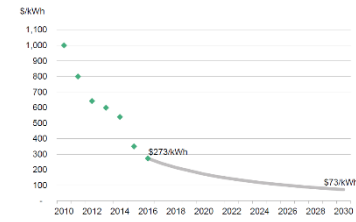
<https://www.greentechmedia.com/articles/read/bevs-vs-phevs-peaceful-coexistence-or-life-or-death-battle#gs.pJ2Hzgl>

Global wind and solar installations, cumulative to June 30, 2018



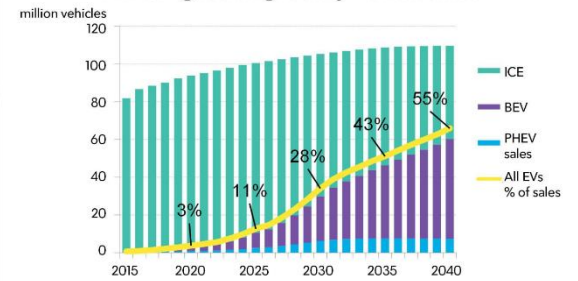
Source: Bloomberg NEF. Note: 1H 2018 figures for onshore wind are based on a conservative estimate; the true figure will be higher. BNEF typically does not publish mid-year installation numbers.

Li-ion battery prices to fall another 73% to 2040



Source: Bloomberg New Energy Finance

Annual global light duty vehicle sales



Source: Bloomberg New Energy Finance

Trend 1 Lower Renewable Energy Cost

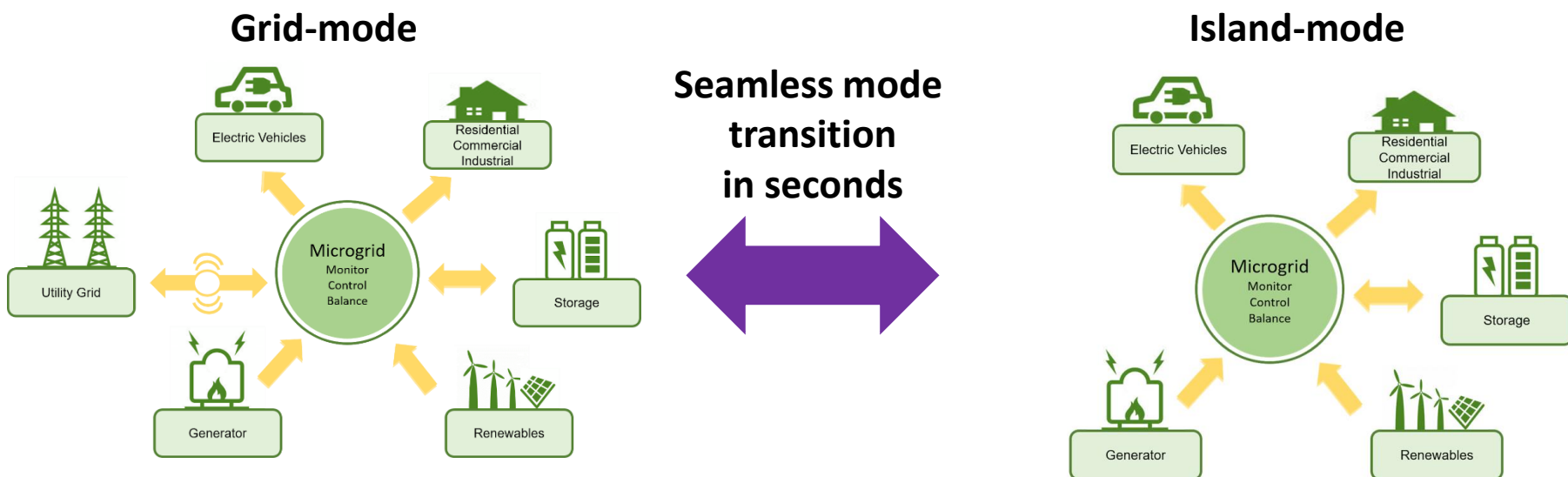
Trend 2 Lower Energy Storage

Trend 3 Higher Electric vehicles adoption

The future of power is extremely exciting and fluid

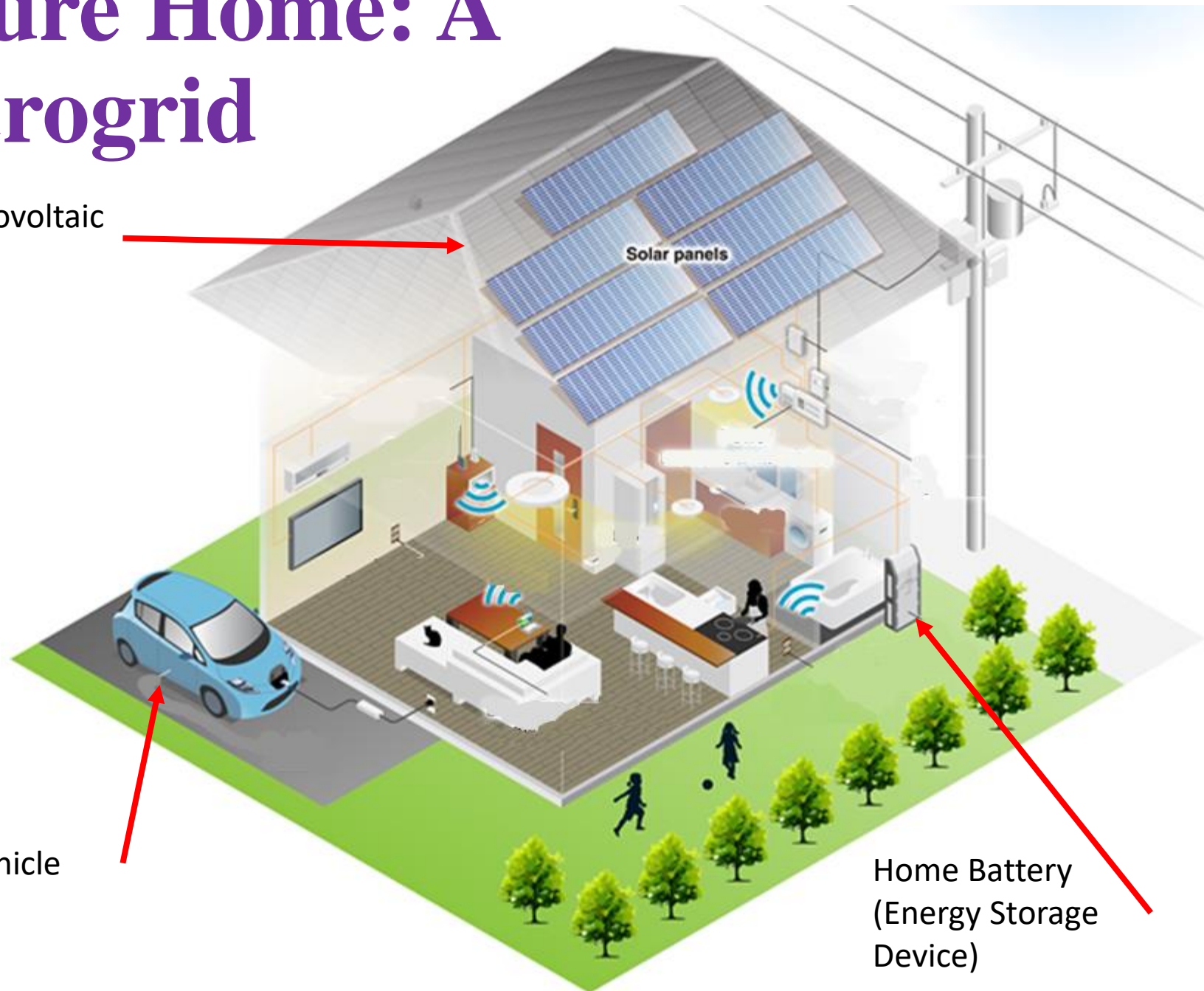
# What is a microgrid?

- A microgrid is a localized energy system and is greater than the sum of its parts
- A microgrid can operate with the grid or without the grid and seamlessly transition between those two “modes”
- A microgrid enables the integration of all types of energy sources to maximize the benefits of each energy technology
- A microgrid enables a more resilient, robust, and stable grid via an active and safe interaction with the grid



# Future Home: A Microgrid

Solar Photovoltaic System



Solar panels

Electric Vehicle

Home Battery  
(Energy Storage Device)



# Not too Distant Future...

## California to require solar panels on most new homes

It's the first state where the renewable energy is mandatory.



Jon Fingas, @jonfingas  
05.06.18 in Green

9302  
Shares

CA new energy standards would require solar panels on the roofs of nearly all new homes by 2020

The plan doesn't require that a home reach net-zero status

Plan provides "compliance credits" for homebuilders who install storage batteries like Tesla's Powerwall

Increase construction costs by \$25,000 to \$30,000

Energy savings of \$50,000 to \$60,000 over 25-year lifespan

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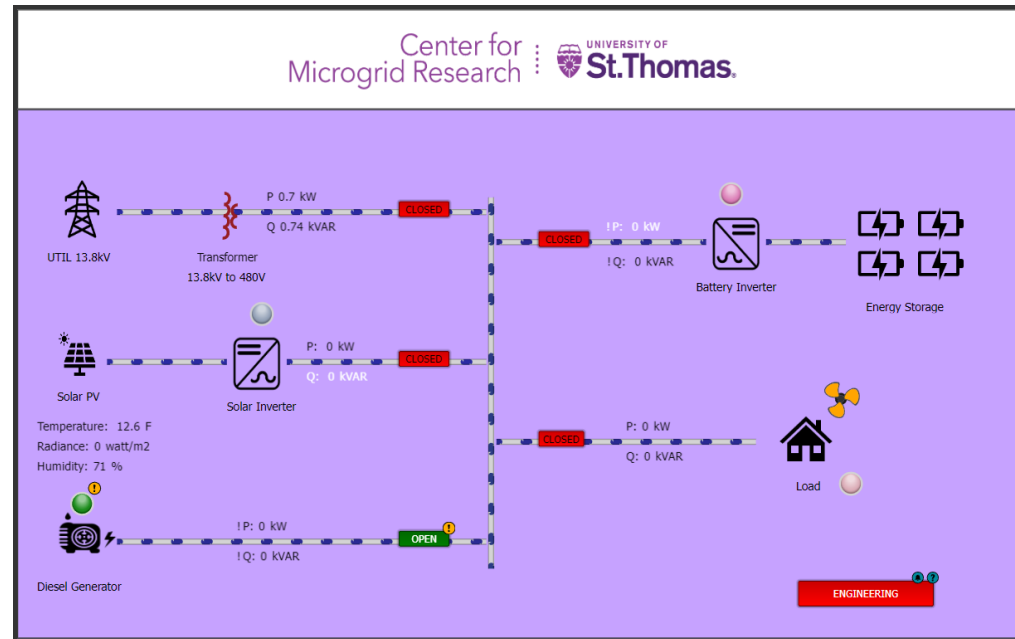
## Anthropocene

## Microgrids

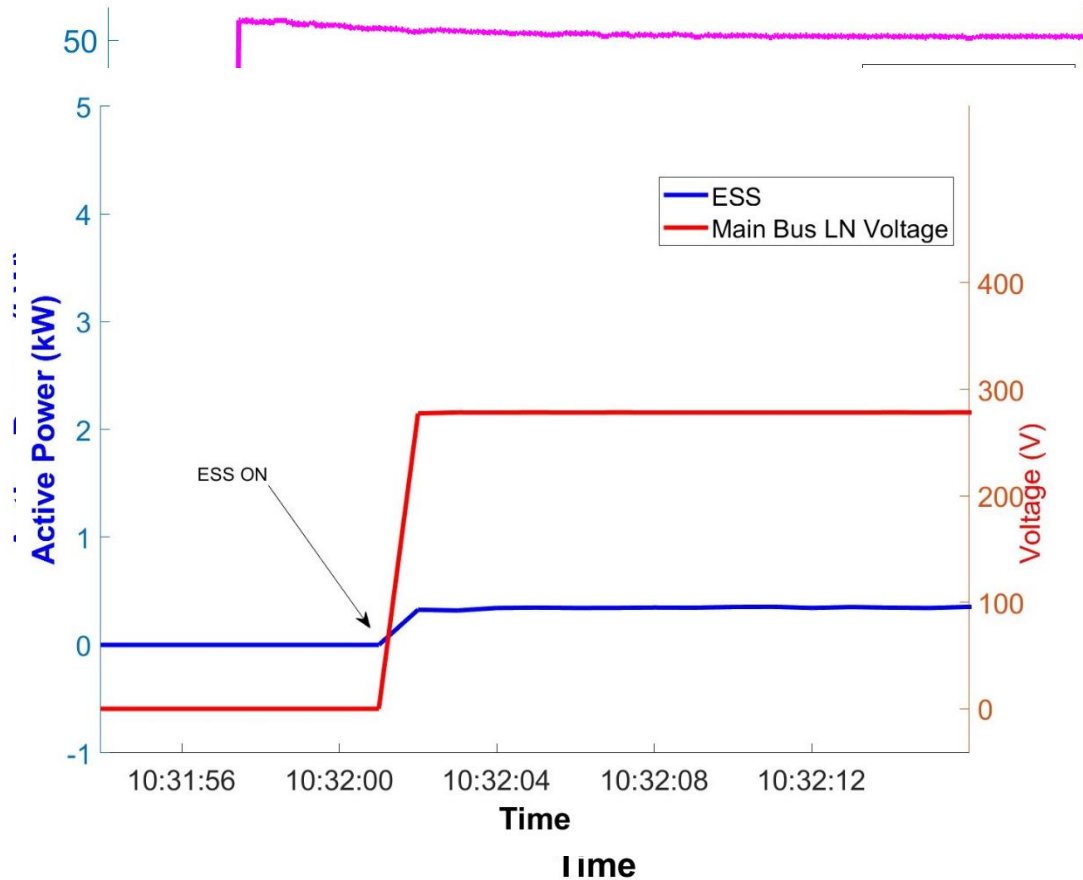
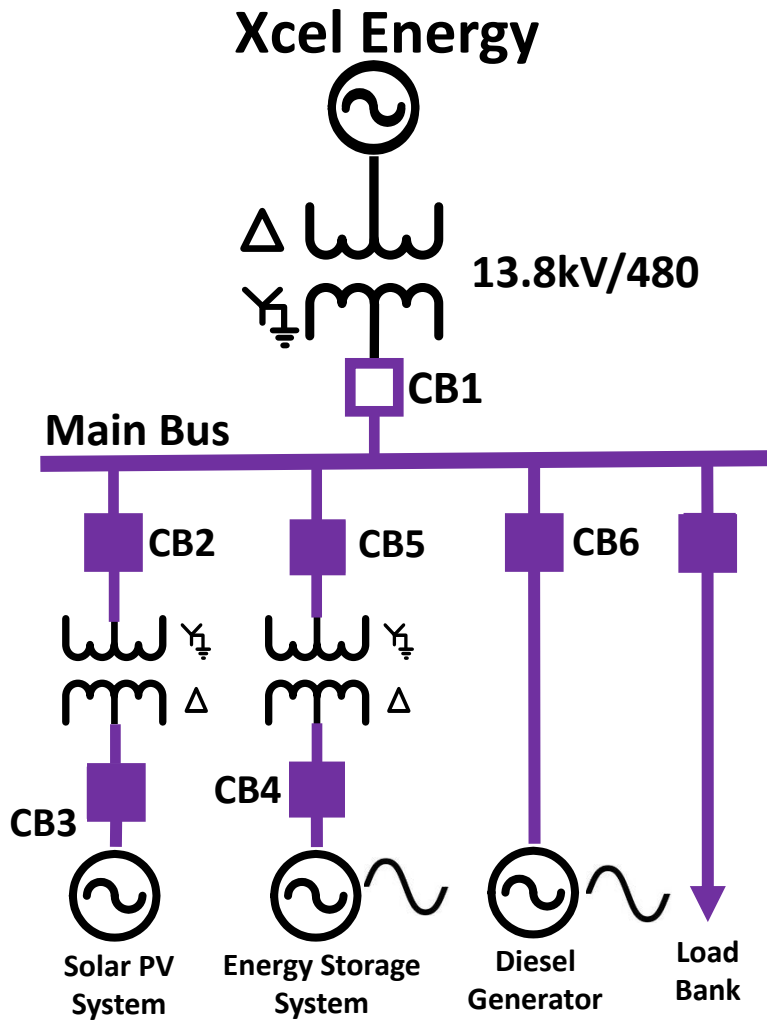
- Trends in Power Systems
- What is a Microgrid?
- Microgrid Case studies at the CMR
- CMR Expansion

# Microgrid Controller

- In development and testing phase:
  - Alpha version completed\*
  - Beta version ongoing
  - Written in IEC 61131-3
  - Implemented in SEL RTAC 3555
- Capabilities:
  - Grid-connected operation
  - Grid-to-island
  - Island-to-grid
  - Island-mode operation
  - Operational Optimization
    - Economic
    - Environmental
    - Volt/Var



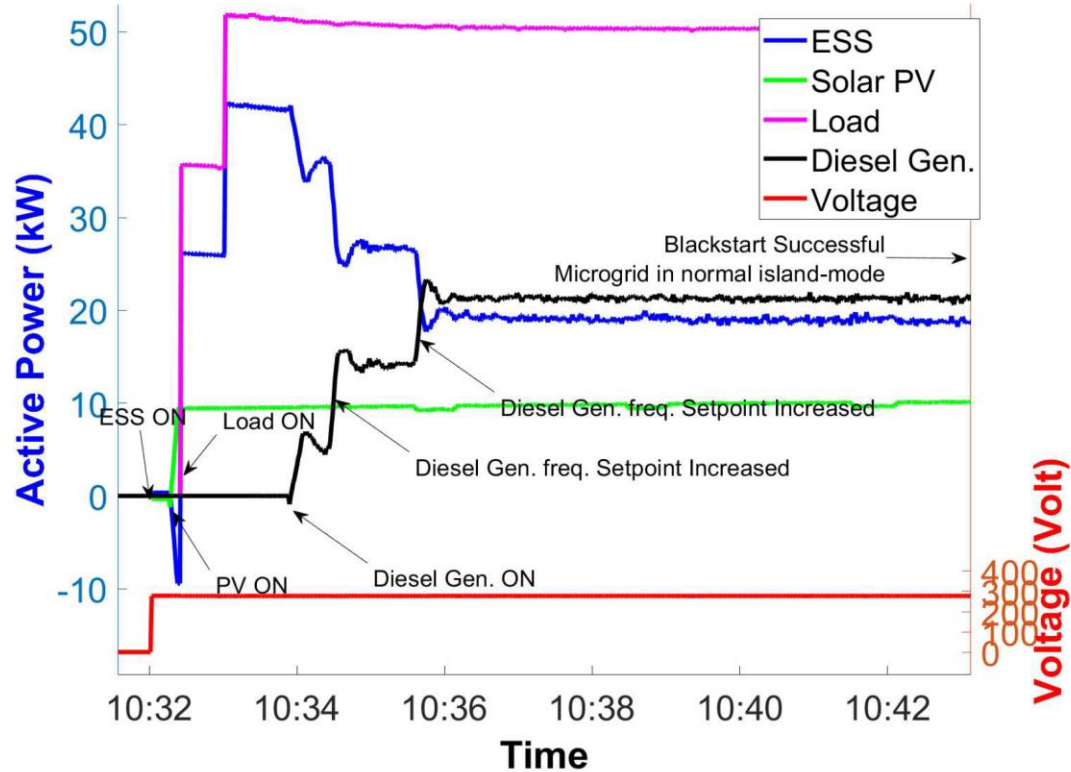
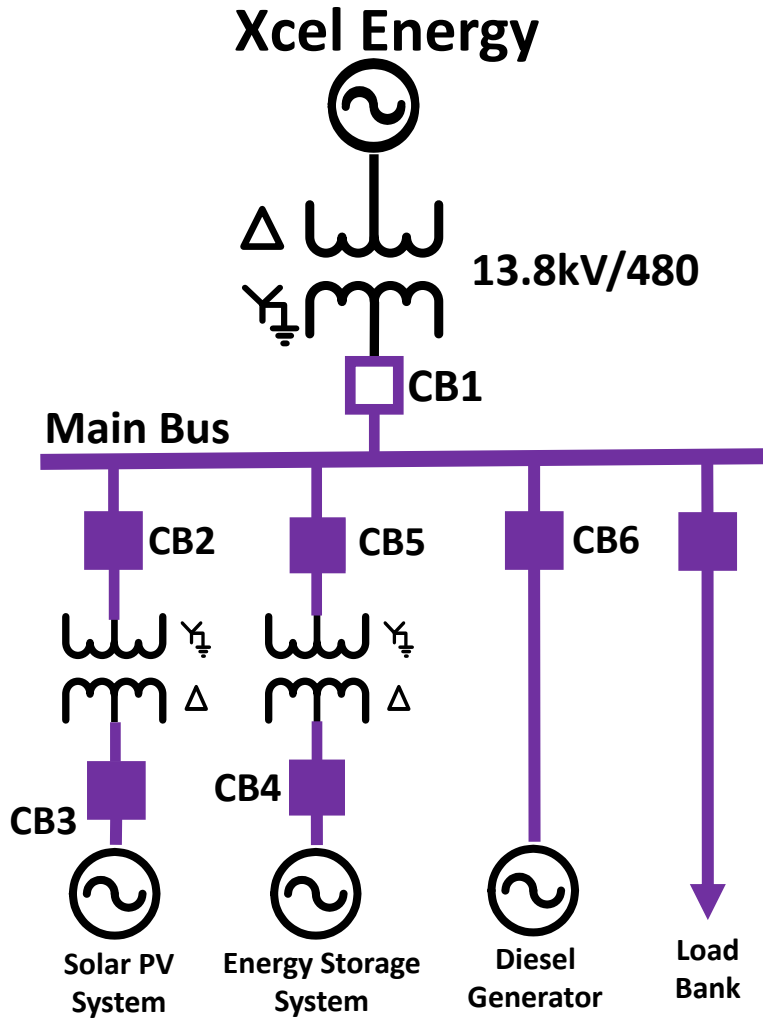
# Blackstart



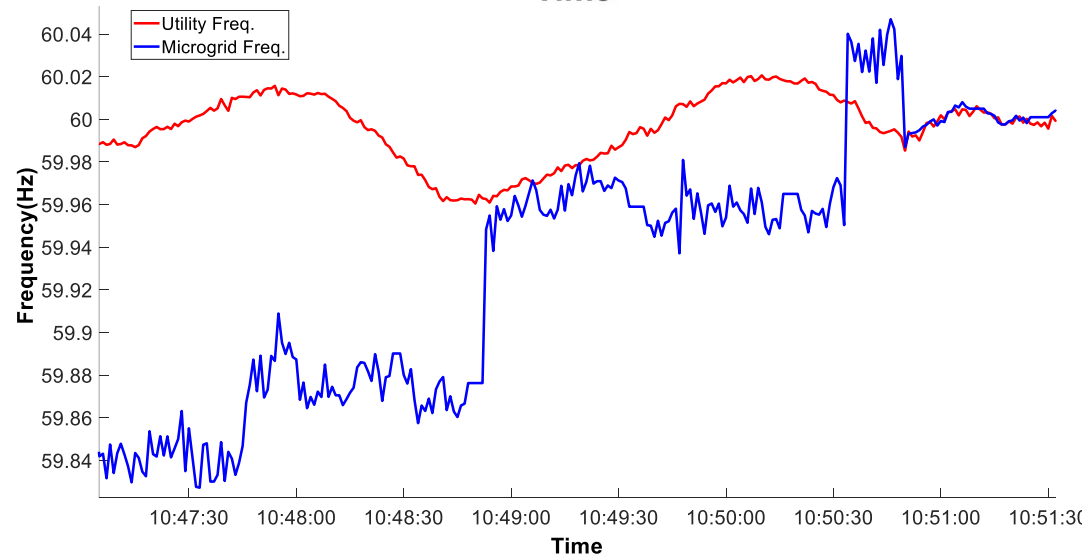
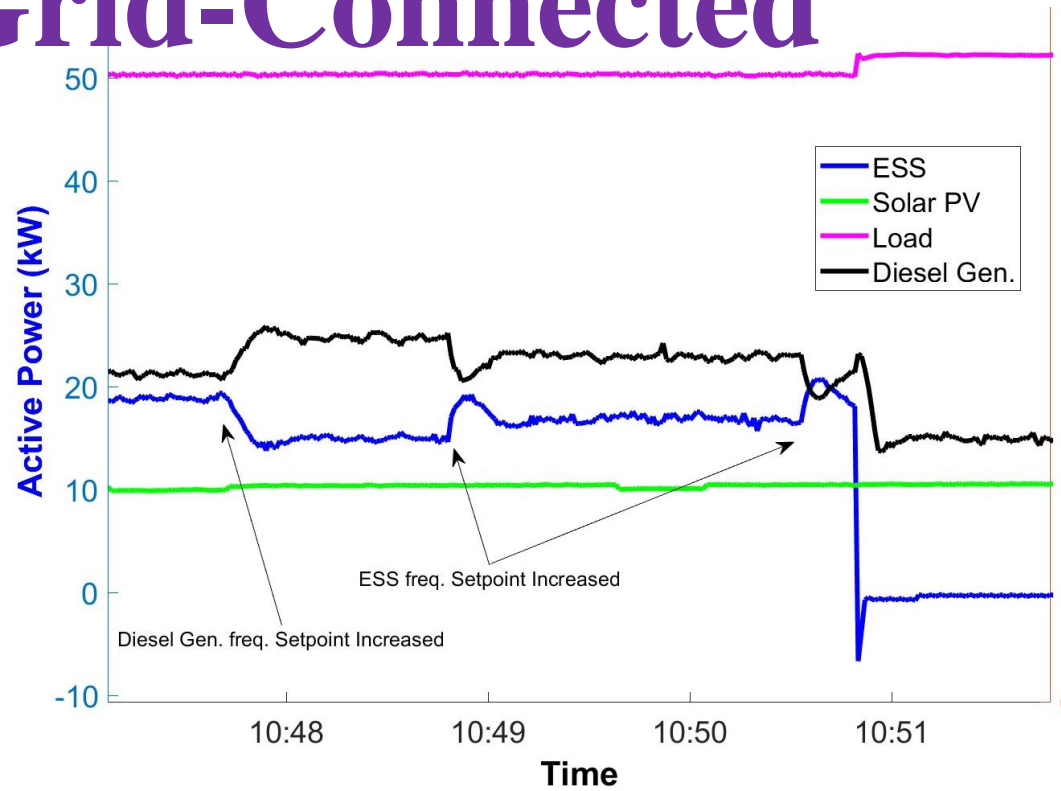
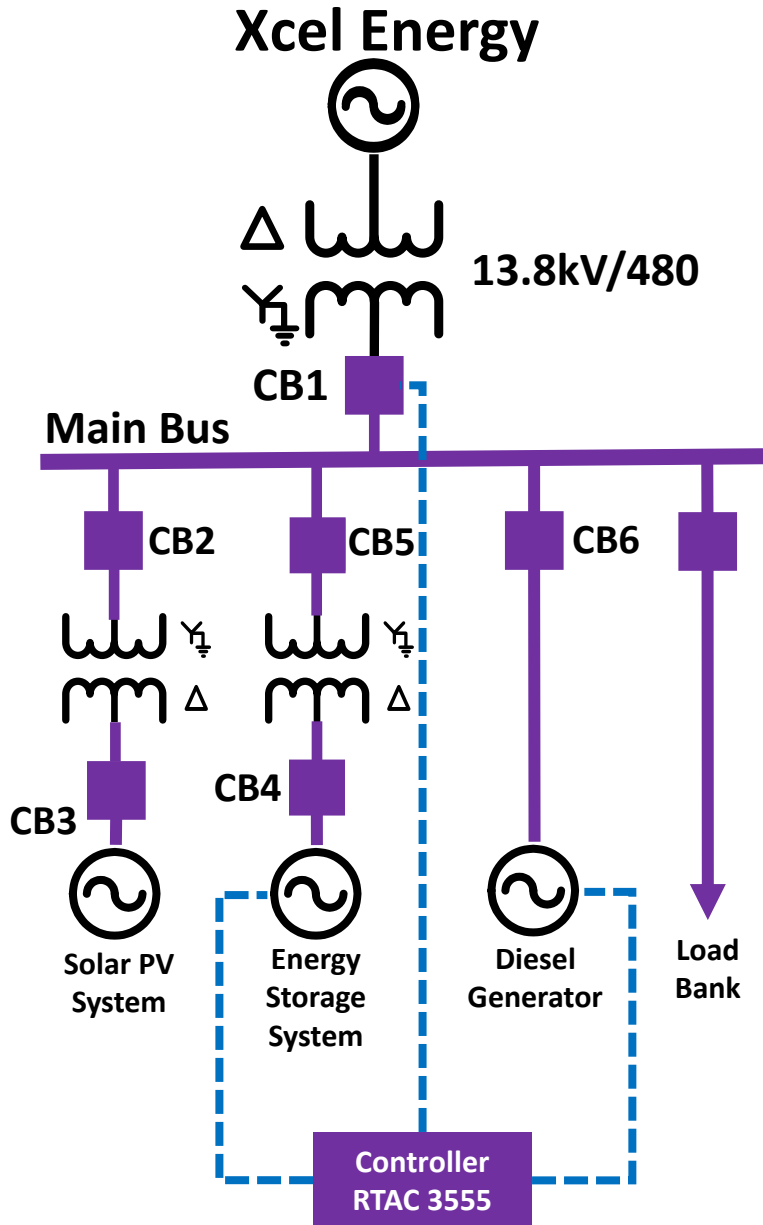
Solar PV system turned ON as grid-following asset	Energy Storage System starts as Grid-forming asset (droop control)	Diesel Gen started as grid-forming asset (droop control)	Load applied
---------------------------------------------------	--------------------------------------------------------------------	----------------------------------------------------------	--------------



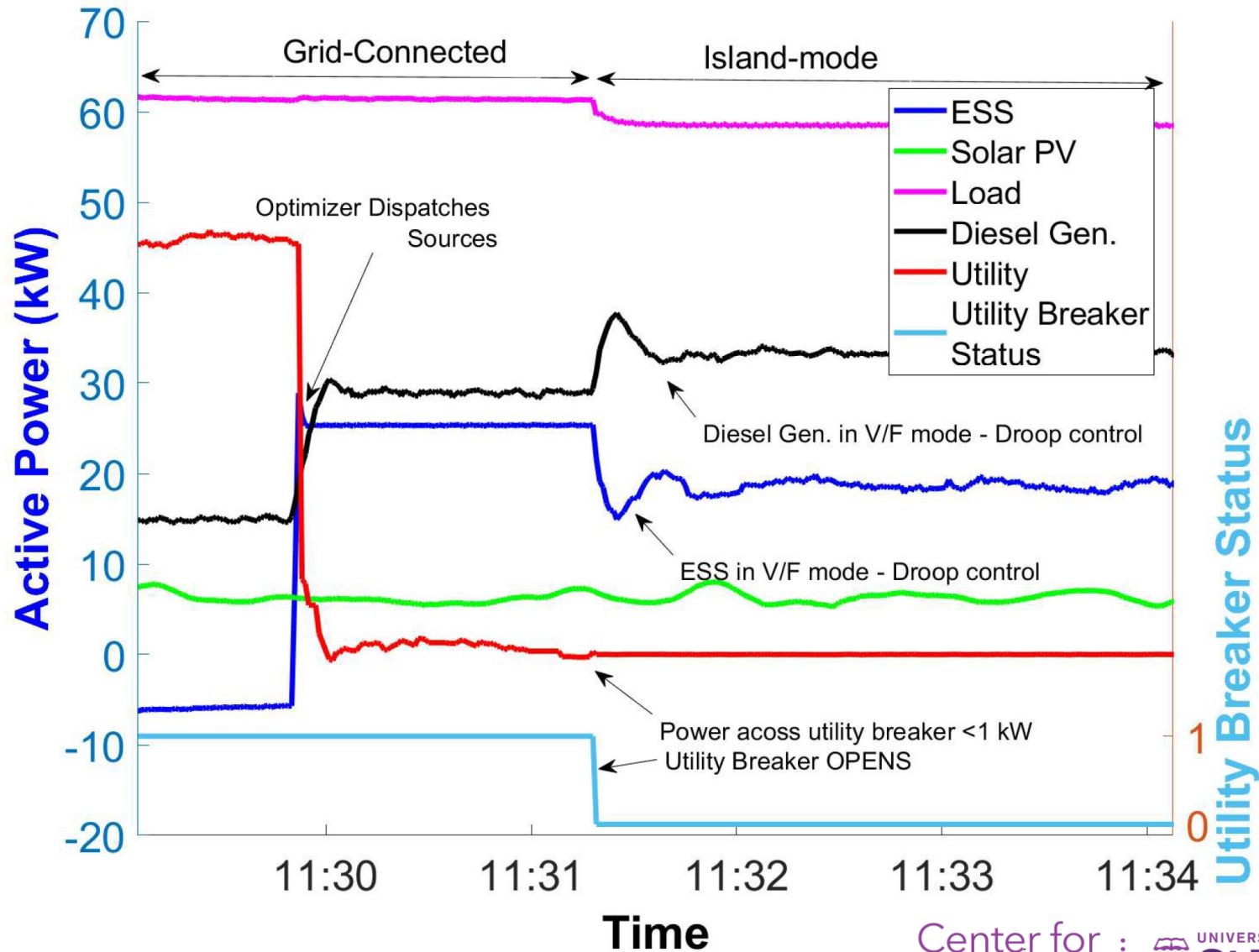
# Blackstart



# Island to Grid-Connected




# Intentional Islanding (Grid-to-Island)



# Outline

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- 

## Anthropocene

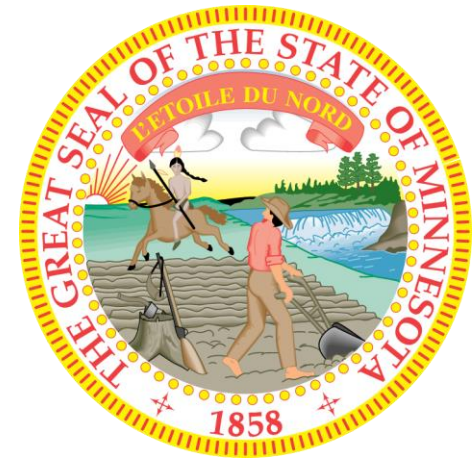


## Microgrids

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# \$5.4 million Renewable Development Account (RDA) Grant from State of Minnesota 2021-2026

1. Increase on-site power assets to above 1MW
2. Connect microgrid to multiple buildings on campus via 13.8 kV loop
3. Expand Hardware-in-the-loop capabilities
4. Expand hands-on educational opportunities





# Research, Prototyping, and Development Capabilities

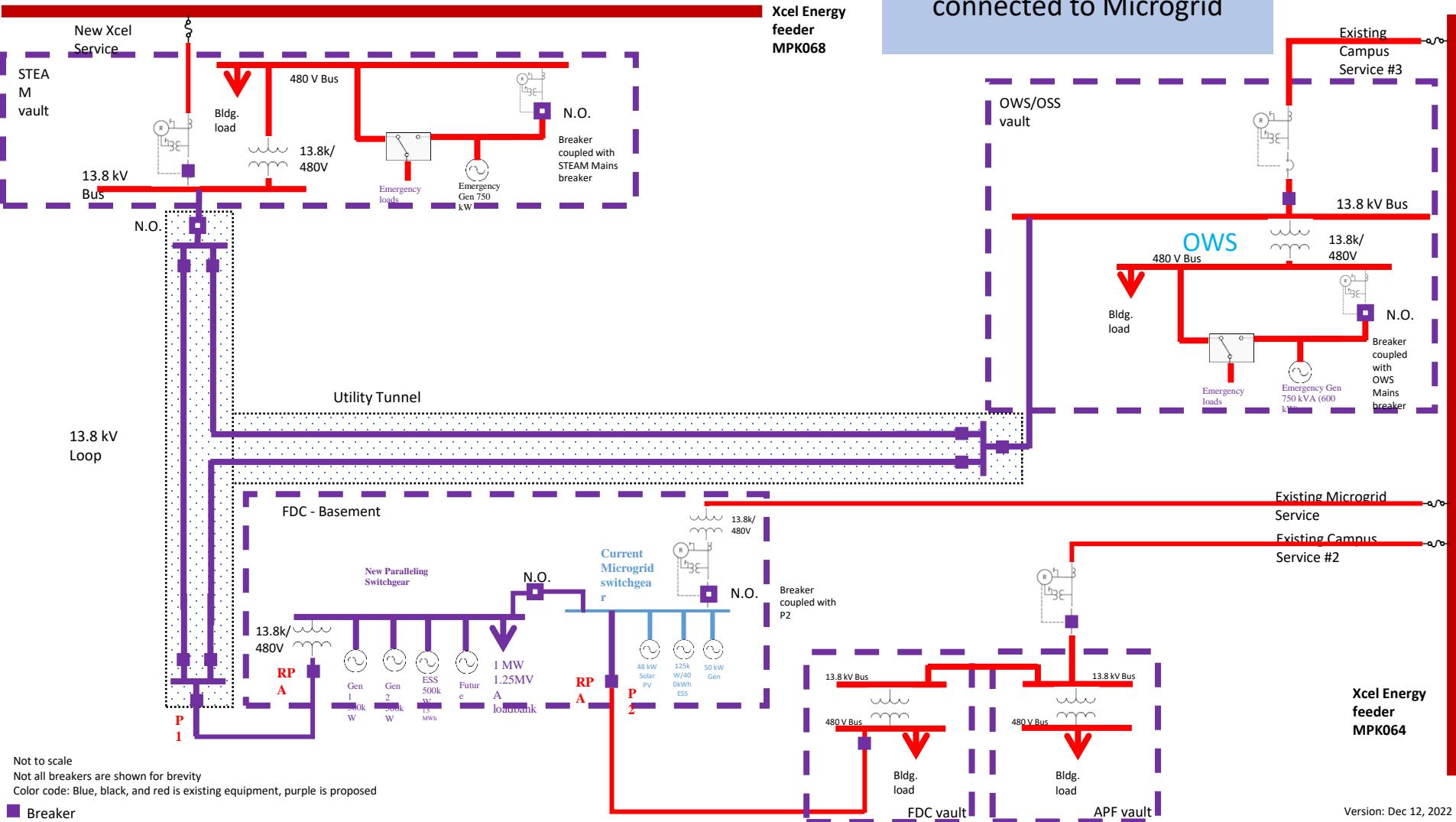
**Hardware-in-the-Loop  
HIL testbeds arriving  
May 2023**

**Allows for state-of-the-art  
low/no risk R&D  
efforts and accelerates  
prototyping efforts**



# Microgrid Expansion – South Campus

Over 400,000 SF of building electrical infrastructure connected to Microgrid



# Microgrid Expansion – South Campus



Anderson Parking Facility (APF)

Owens Science Hall (OWS)

Facilities & Design Center (FDC)

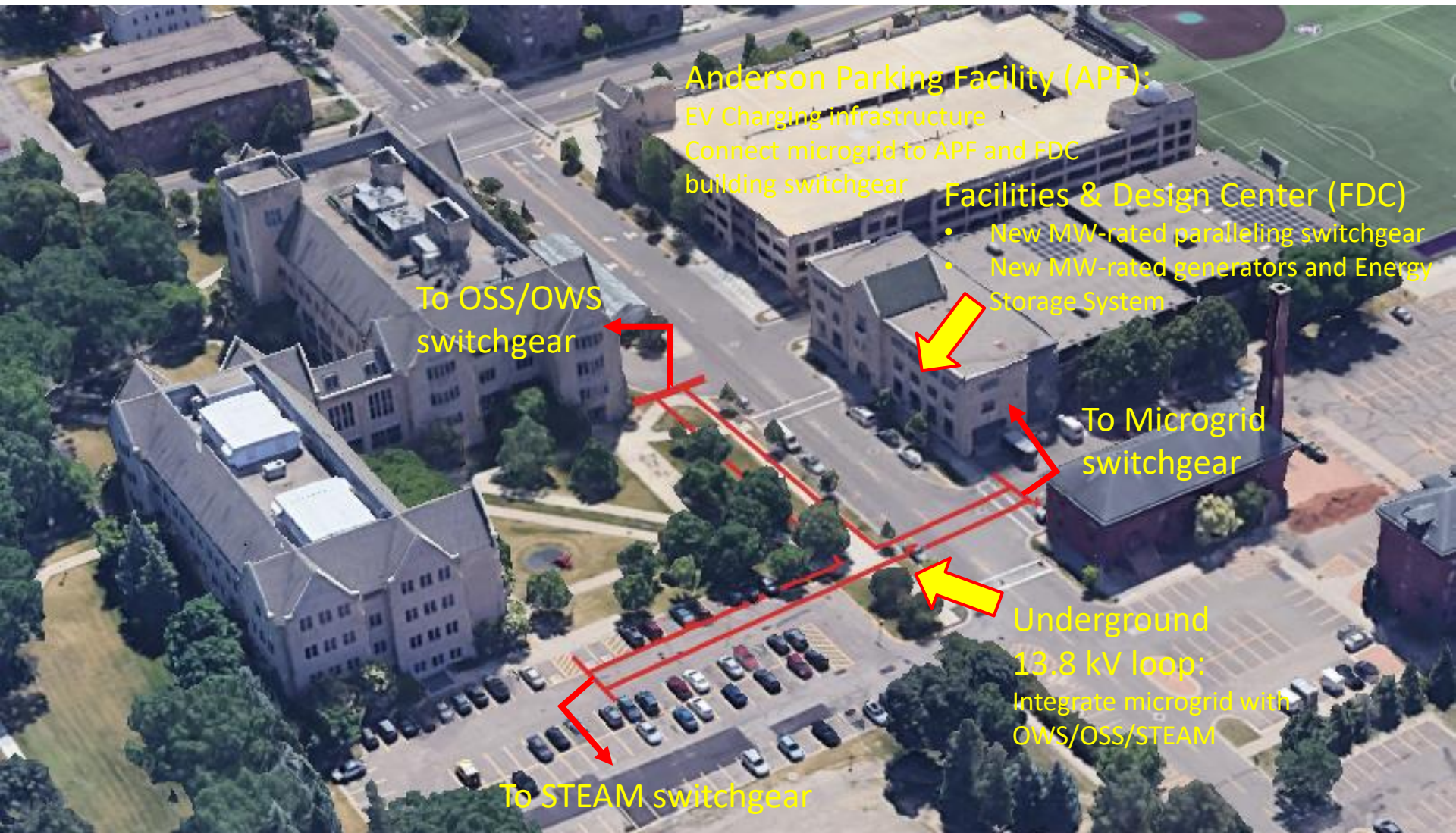
O'Shaghnessy Science Hall (OSS)

Schoenecker Center (STEAM) site:

- 130,000 square feet arts, engineering, and sciences building
- Opening Spring 2024



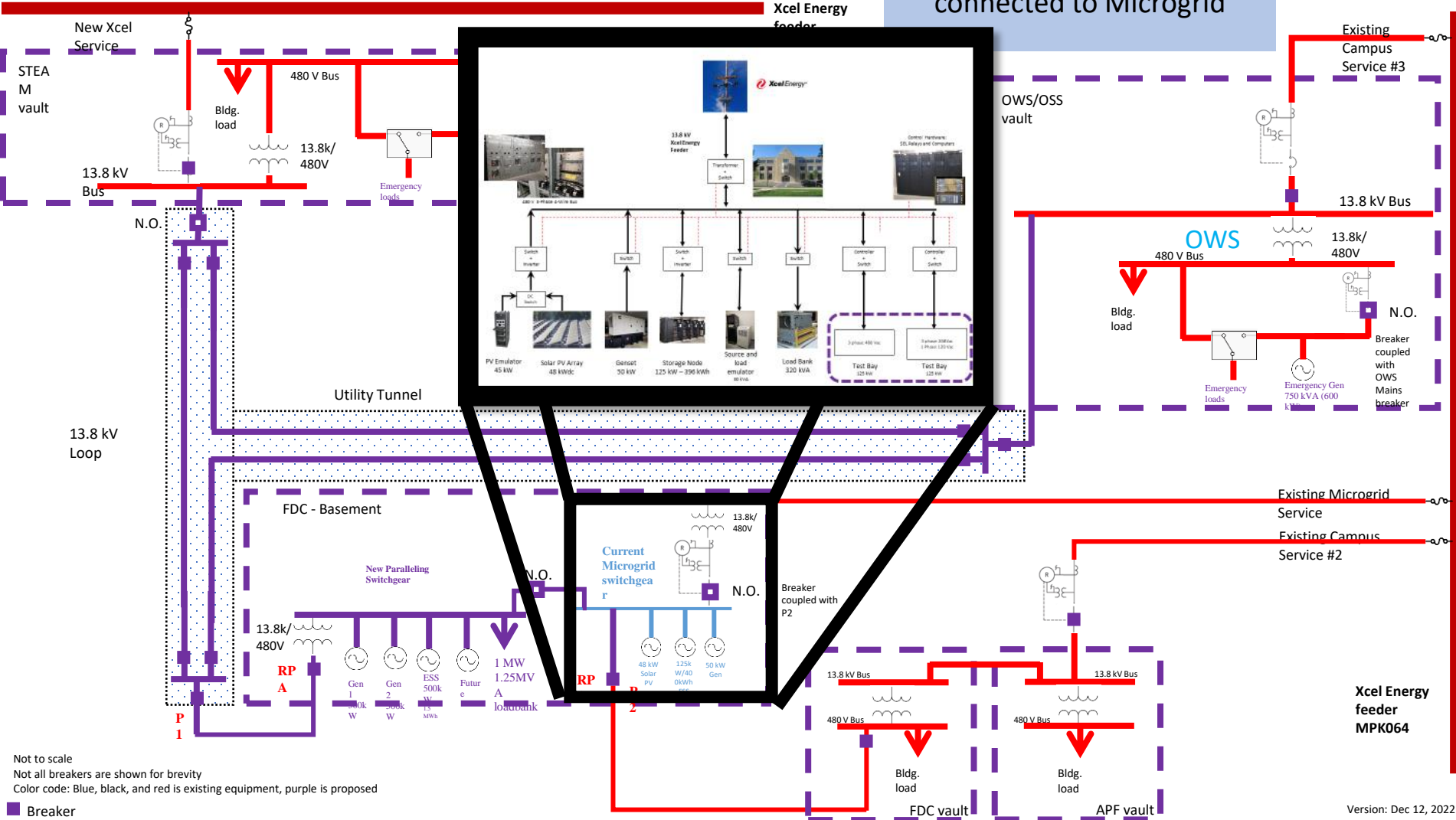
# Microgrid Expansion – South Campus



\*As of August 2022

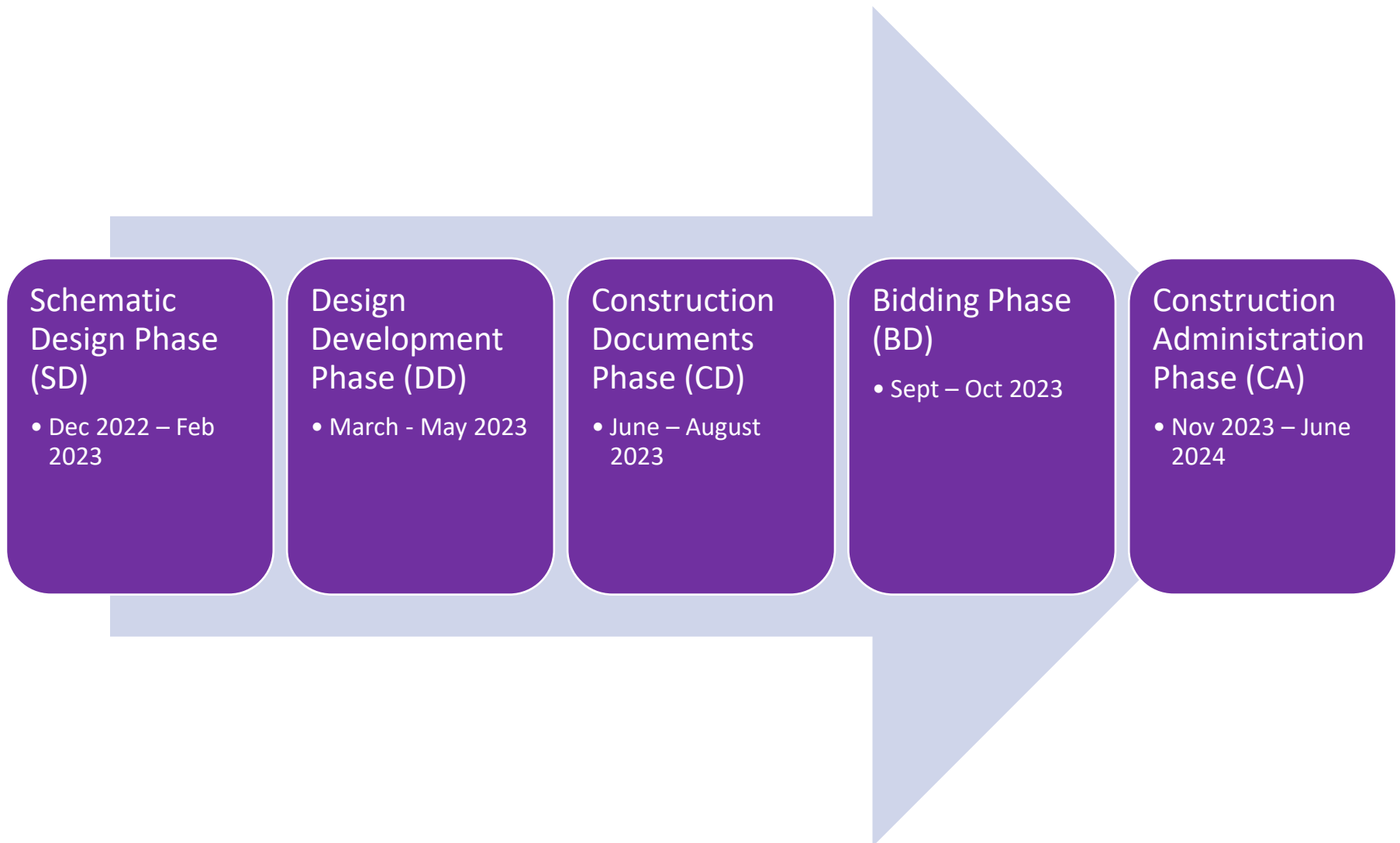
# Microgrid Expansion – South Campus

Over 400,000 SF of building electrical infrastructure connected to Microgrid





# Microgrid Expansion - Timeline



# Job Openings

- At CMR:
  - Postdoctoral scholars (2 openings)
    - [Postdoctoral Microgrid Controls and Modeling \(Term Assignment\) in St. Paul, Minnesota | Careers at St Paul \(icims.com\)](#)
  - Research Engineer (4 openings)
    - <https://staffemployment-stthomas.icims.com/jobs/6563/research-engineer/job>
  - Graduate (Masters) Research Assistant (4 openings)



# 'We are last generation that can stop climate change' - UN summit

Big cuts in carbon emissions and a rise in protection from extreme weather urgently needed

“We are clearly the last generation that can change the course of climate change, but we are also the first generation with its consequences,”

- Kristalina Georgieva, the ***CEO of the World Bank***
- December 2 2018

We need Earth, Earth doesn't need us

We can fix all these problems with TODAY'S  
TECHNOLOGY

There is a cost to delayed action...

The 2020s and 2030s could be the most  
exciting and important decades for humanity...

# Contact info

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Mahmoud  
Kabalan, Ph.D., P.E.

Director:  
Center for Microgrid Research

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[Mahmoud.kabalan@stthomas.edu](mailto:Mahmoud.kabalan@stthomas.edu)

Connect with me on  
**LinkedIn**

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651-962-5598

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<https://engineering.stthomas.edu/industry/microgrid-research-center/index.html>

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