Plug into NREL's Resilient CUBE

PRESENTED BY:

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MODERATED BY:

Steve Redifer

2020-05-06

Homeland Defense & Security Information Analysis Center

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https://www.hdiac.org

Consolidated Utility Base Energy "CUBE"

Greg Martin
HDIAC Webinar
May 6, 2020

Presentation Outline

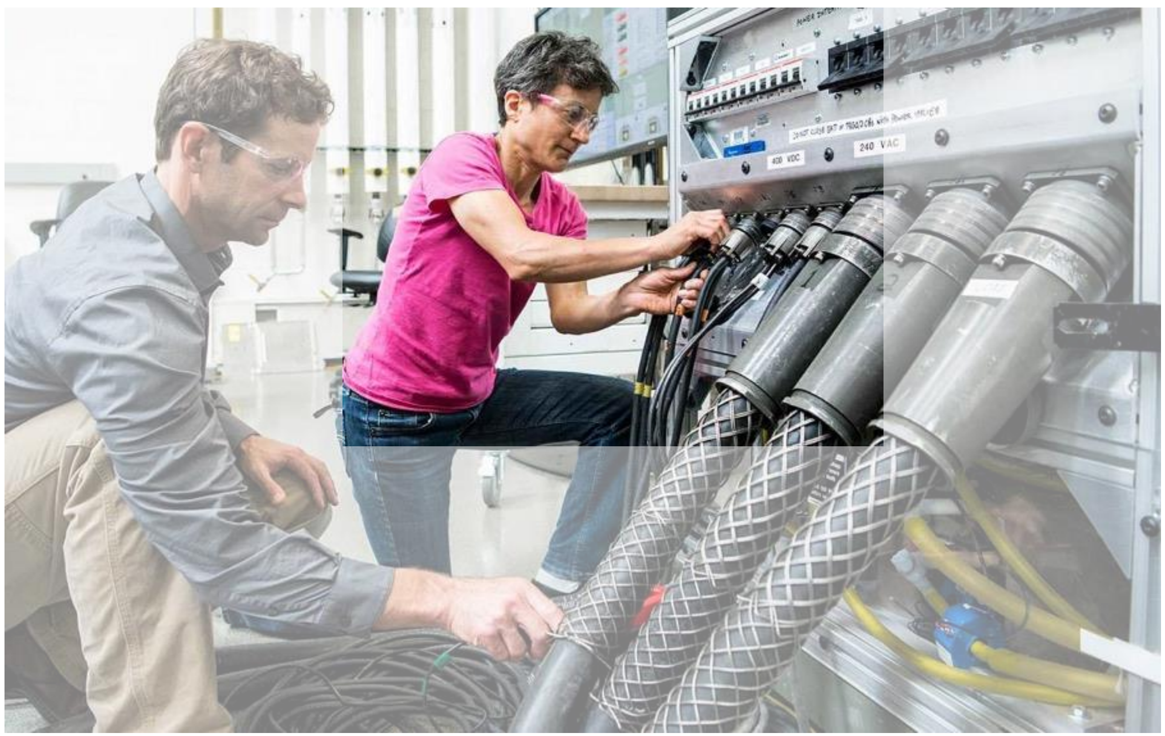
Dedication

Dr. Mari Shirazi

President’s Professor in Energy, University of Fairbanks, Alaska

College of Engineering and Mines - Alaska Center for Energy and Power (ACEP)

(former NREL)



CUBE Project Vision, Leadership and Mentoring

Dr. Bill Kramer, NREL

CUBE Overview

PLUG INTO NREL'S RESILIENT **CUBE**

With the potential to replace diesel-only power generation at forward operating bases for the U.S. military, the National Renewable Energy Laboratory's (NREL's) **Consolidated Utility Base Energy (CUBE)** platform could literally be a lifesaver.

Designed for mobility and flexibility, the CUBE is a hybrid power generation system that converts energy from different sources—solar panels, batteries, diesel generators, and host grid power—into tactical electricity, improving the efficiency and reliability of power for the military's forward operating bases. By reducing dependence on diesel generators, the CUBE also helps reduce the number of soldiers, sailors, airmen and marines shipping fuel across dangerous territory.

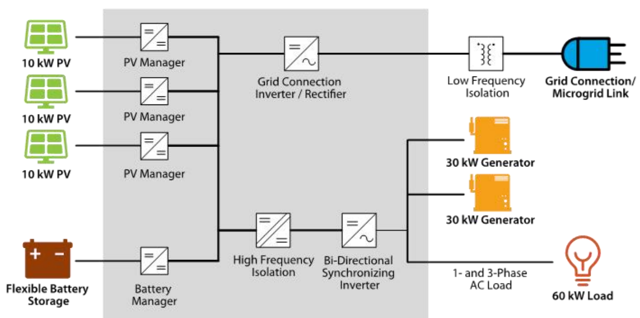
CUBE features:

- Minimized diesel fuel use
- Quiet operations
- Standalone battery and PV operation
- Intelligent dispatch (weather forecast, load forecast)
- NREL-developed power architecture, design, and controls
- Ability to host grid connection and multi-unit chaining for improved resilience and microgrid operations.

Fast, Flexible, and Smart

The CUBE's intelligent power integration platform creates a resilient and flexible 60-kilowatt hybrid power system. It can connect to nearly any photovoltaic (PV) or battery asset, international host grid electricity, and can be configured in parallel operation for scalable microgrid formation. Its control system facilitates the swift transition from one power source to another, enabling uninterrupted energy supply to deliver enhanced power reliability and reserve power standing by. The CUBE is capable of microgrid operations and control, making it ideal for emergency response scenarios when rapid deployment of power is critical.

Flexible | **Intelligent** | **Fast Power**



www.nrel.gov

Research > Publications

SEARCH THE DATABASE for "CUBE"

Fact Sheet is titled:
"Plug into NREL's Resilient CUBE"

Research and Development of the CUBE

The CUBE currently resides at NREL's Energy Systems Integration Facility (ESIF), where validation tests have shown that the technology can achieve up to 30% savings in fuel use, compared to diesel generators alone that serve equal loads. Results in field operations are expected to be similar, with added benefits of improved stealth (when generators are turned down or off) and greater redundancy in power supply options.

The CUBE was originally developed for the Army's Expeditionary Energy and Sustainment Systems, formerly known as Mobile Electric Power. It was further developed through a collaboration between NREL and Wyle Labs, funded by U.S. Department of Defense Rapid Equipping Force.

Software Control for Military and Disaster-Prone Settings

Wide swings in temperature: The CUBE's components can withstand conditions from 140 degrees Fahrenheit to 40 degrees below zero.

Versatility for any scenario: Operates in 18 different power modes with smooth transitioning for uninterrupted supply.

Fast response, rapid recovery: Draws power from any source that's available—including the local grid—and converts to stable, usable electricity.

Compatible and open-source: Designed for plug-and-play use with a standard Tactical Quiet Generator, with a wide range of PV configurations and battery voltages.

CUBE is flexible enough to provide necessary power for disaster relief support or military operations.

Get Connected

Want to know more? We want to hear from you.

Get in touch to learn more about the CUBE's mobile power capabilities by contacting: **Jerry.Davis@nrel.gov**

Learn more about the ESIF's R&D capabilities at www.nrel.gov/esif.

NREL

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/FS-5B00-75550 • January 2020

Project Overview: The Army CUBE

The Challenge

Reduce diesel fuel consumption in standard generators at forward operating bases.

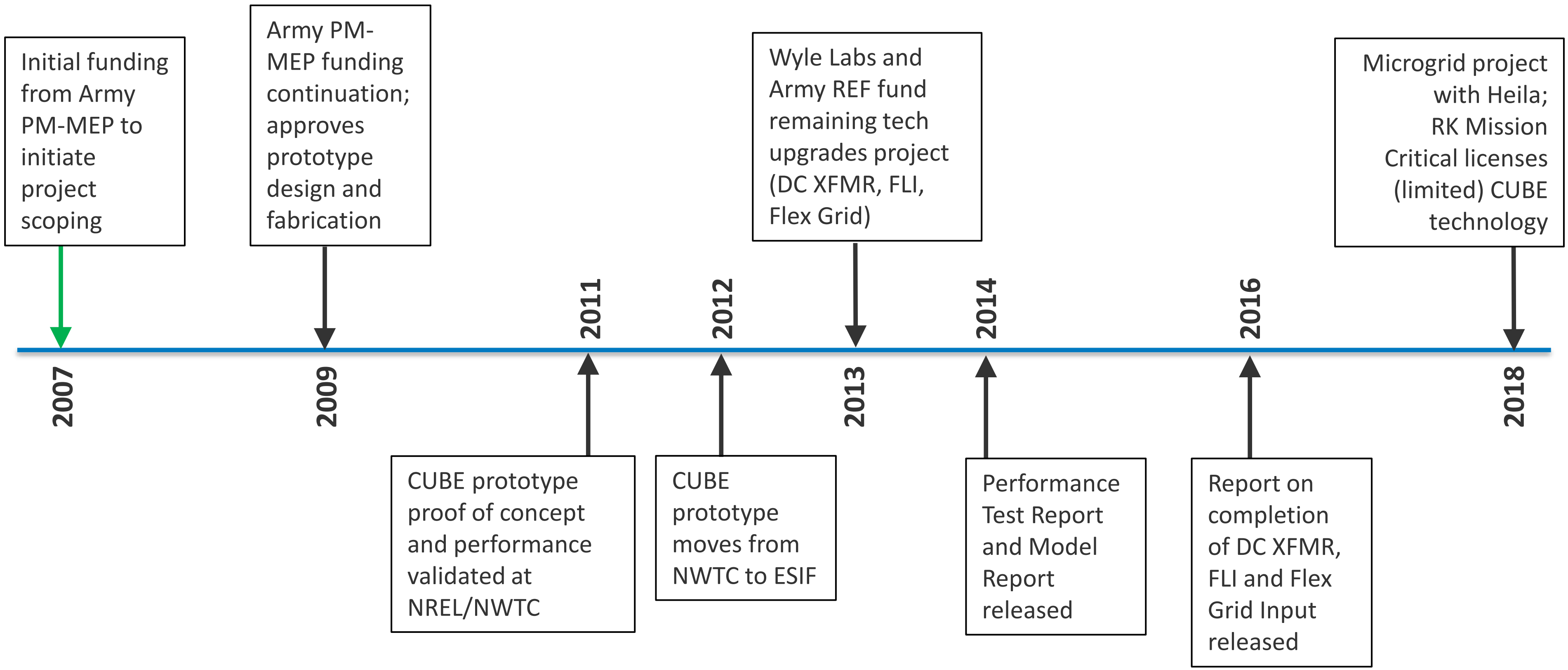
Design Criteria

- Lightweight
- Reliable
- Scalable
- Easily deployed
- Transportable
- Modular

The Solution

Military client engaged NREL to develop and design a containerized power system with a focus on a modular Consolidated Utility Base Energy power interface unit—the CUBE.

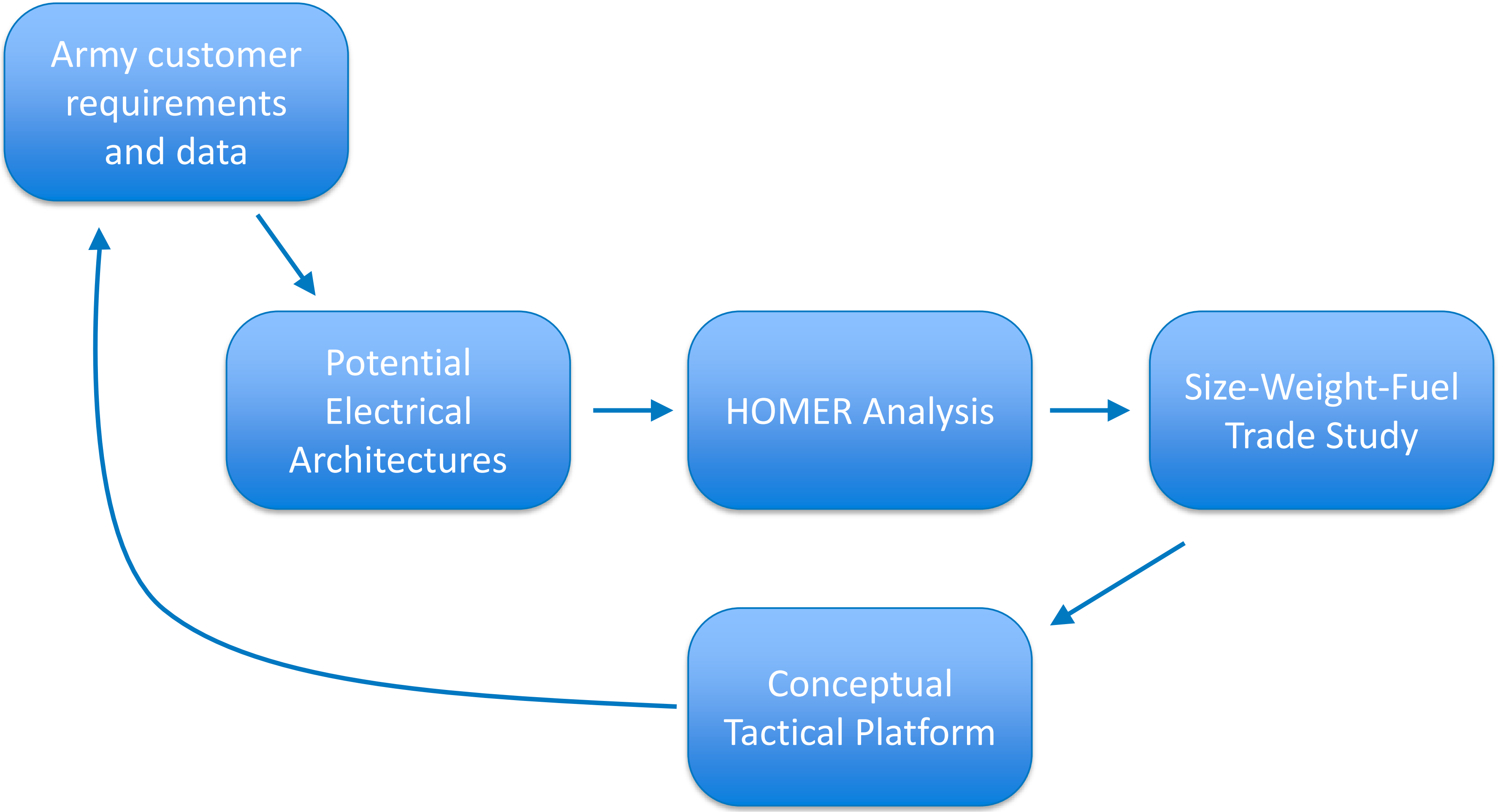
The CUBE Story



CUBE Program Timeline

2007-2018 Major Milestones

Early Analysis

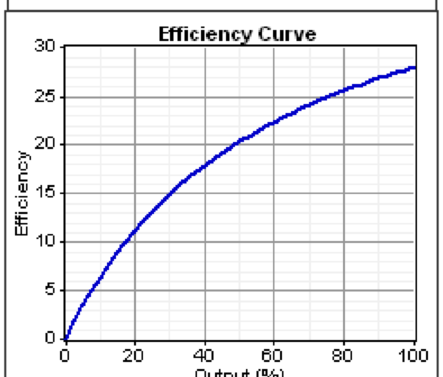


Design Requirements and Constraints

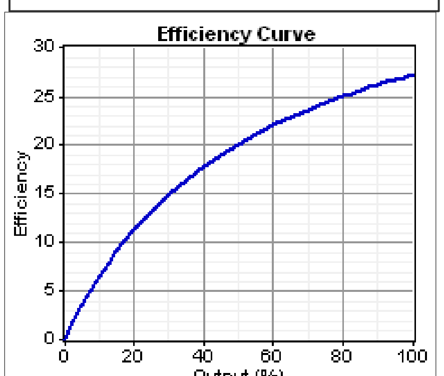
- Must use incumbent TQG with no design modification
- Must be transportable for FOB
- Must be resilient to environment (sand, cold, hot, humid)
- Field deployable by minimally trained soldier
- Approximately 60kW

Tactical Quiet Generator (TQG) Fuel Efficiency Analysis

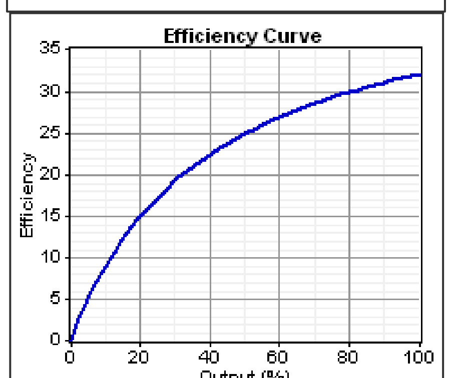
__10 kW TQG__
Weight = 1182 lb.
LxWxH = 62’ x 32” x 37”
3ph, 4-wire Output =
120/208V
= 120/240V
= 60 Hz
Fuel Use= 0.97 gph rated
Fuel Tank= 9 gal



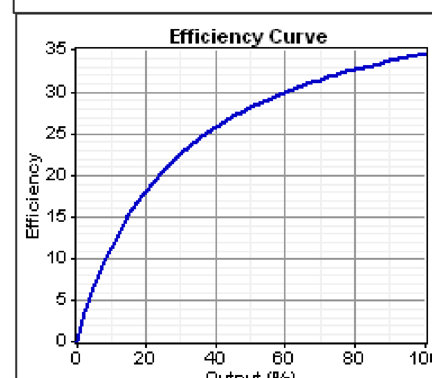
__15 kW TQG__
Weight = 2124 lb.
LxWxH = 70’ x 36” x 55”
3ph, 4-wire Output =
120/208V
= 240/416V
= 50/60 Hz
Fuel Use= 1.5 gph rated
Fuel Tank= 14 gal



__30 kW TQG__
Weight = 3005 lb.
LxWxH = 80’ x 36” x 55”
3ph, 4-wire Output =
120/208V
= 240/416V
= 50/60 Hz
Fuel Use= 2.43 gph rated
Fuel Tank= 23 gal

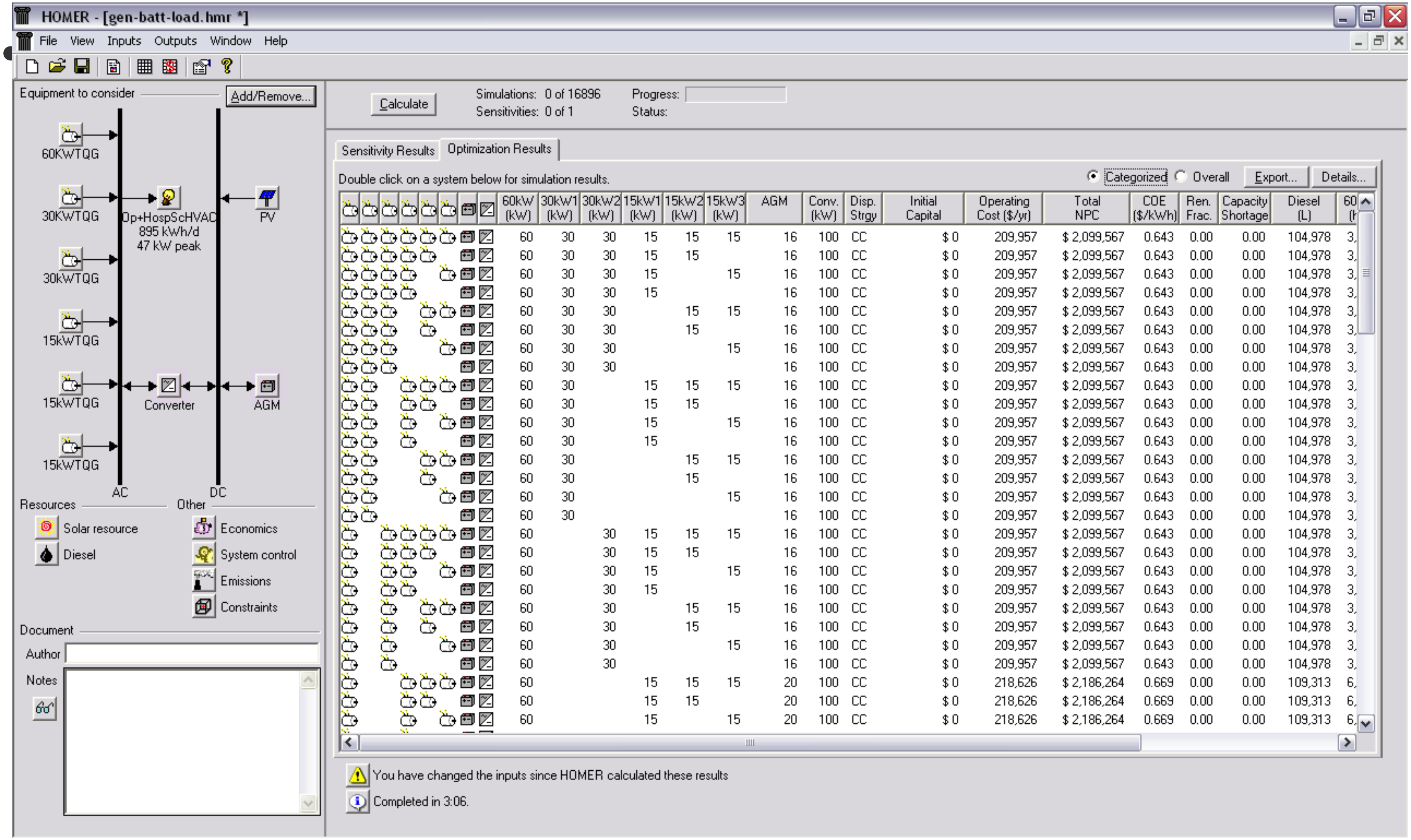


__60 kW TQG__
Weight = 4063 lb.
LxWxH = 87’ x 36” x 59”
3ph, 4-wire Output =
120/208V
= 240/416V
= 50/60 Hz
Fuel Use= 4.51 gph rated
Fuel Tank= 43 gal



Efficiency curves are HOMER-generated graphs using customer-provided fuel consumption vs. power data.

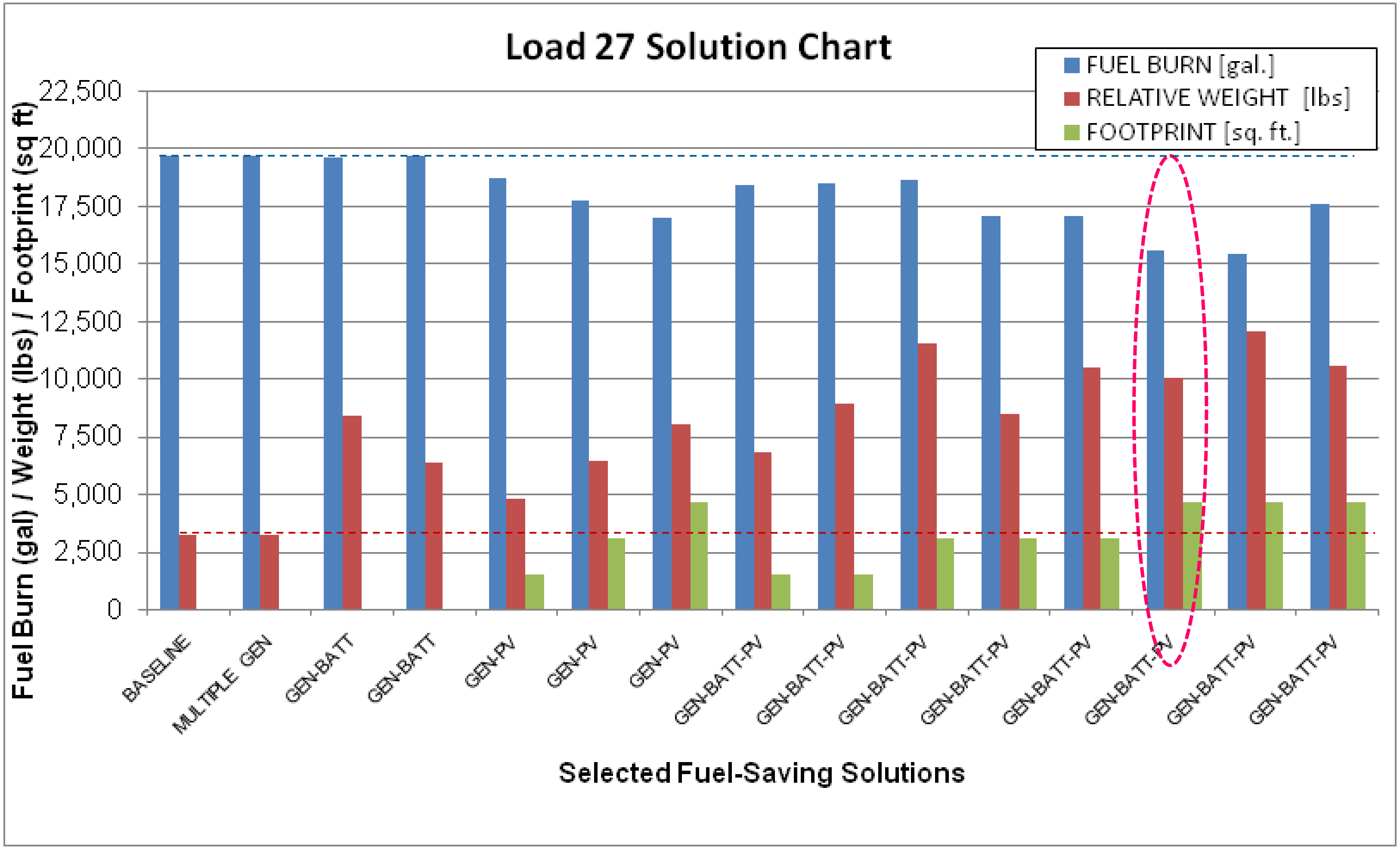
HOMER Software Screenshot



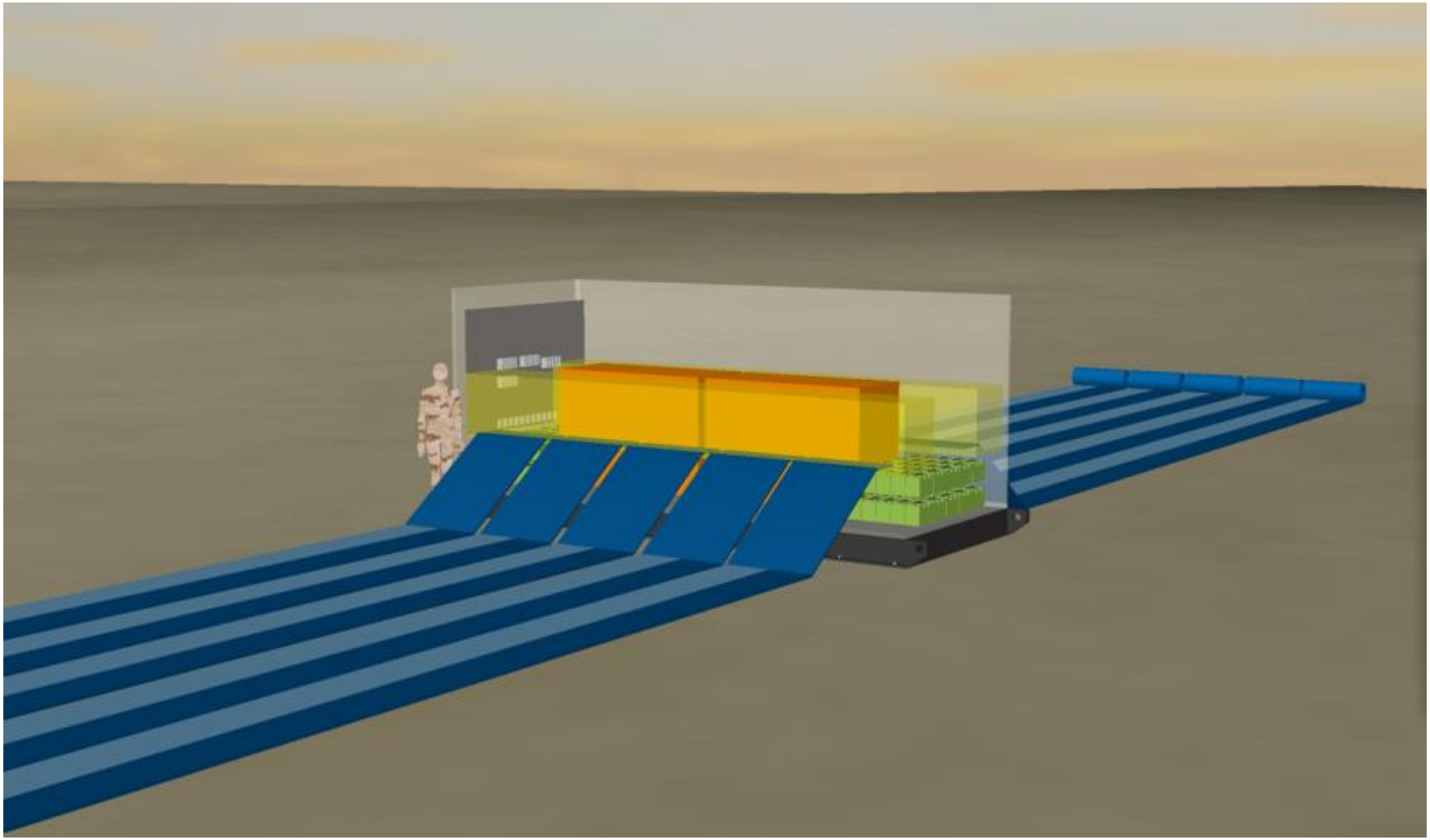
Configuration Optimization

Selected Solution for Load Profile 27

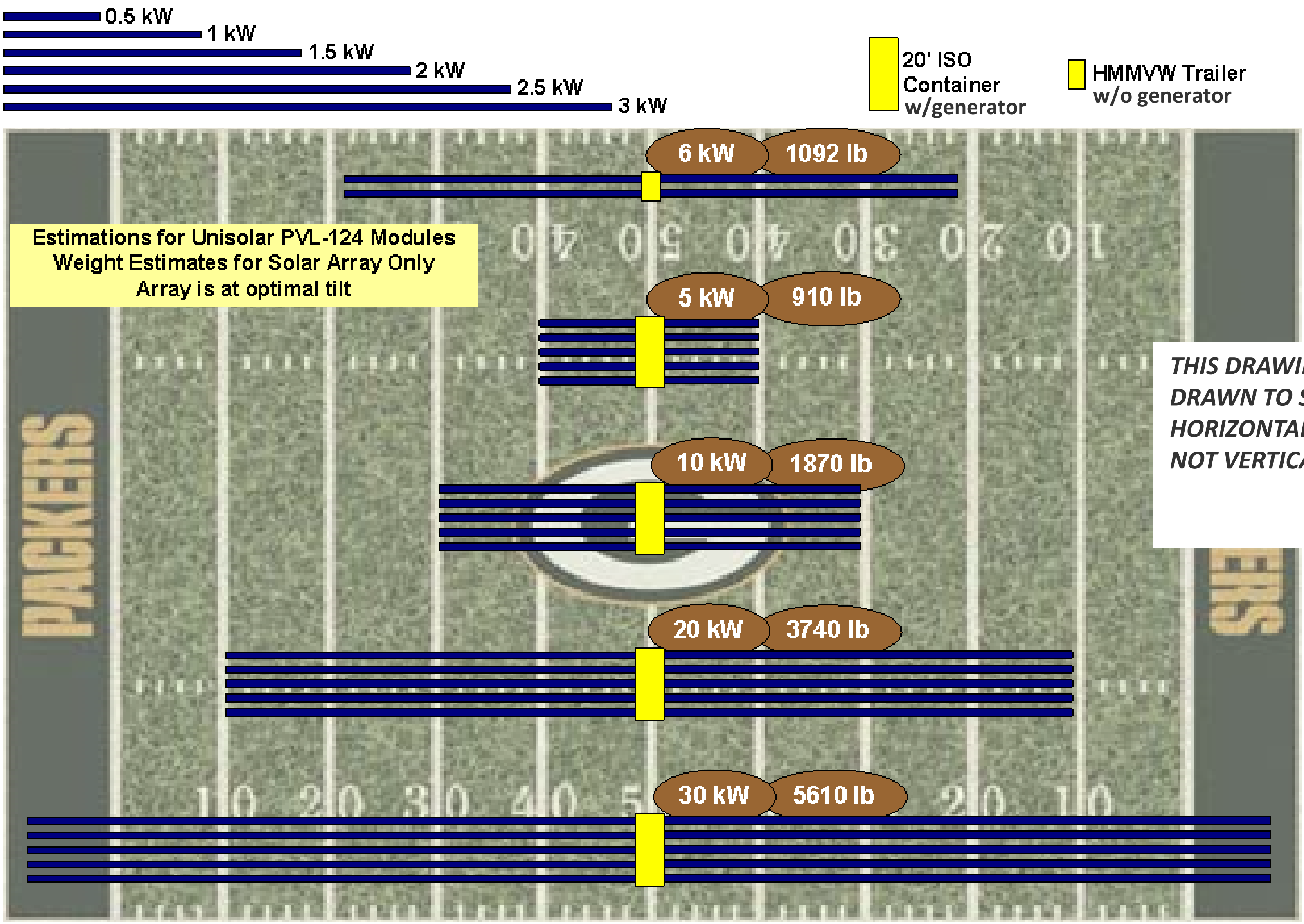
$11.80	GEN CONFIG	LP	BATT	SOLAR	GAL SAVED	COST SAVED	SUMMED WEIGHTS [lbs]	FOOTPRINT [sq. ft.]	$:lb	$:fp
GEN-BATT-PV	30	27	82.8	30	4,083	$48,183	10,031	4,714	4.80	10.22



Large Container Concept



Solar Footprints (2009)



THIS DRAWING IS DRAWN TO SCALE HORIZONTALLY, BUT NOT VERTICALLY!

Small Container Concept

Deployable Solar Prototype

<u>Structure:</u>
Bi-stable composite tube integration from Composite Technology Development, Inc
Lafayette, Colorado

<u>Solar Panels:</u>
Lighweight flexible, high efficiency CIGS from Ascent Solar

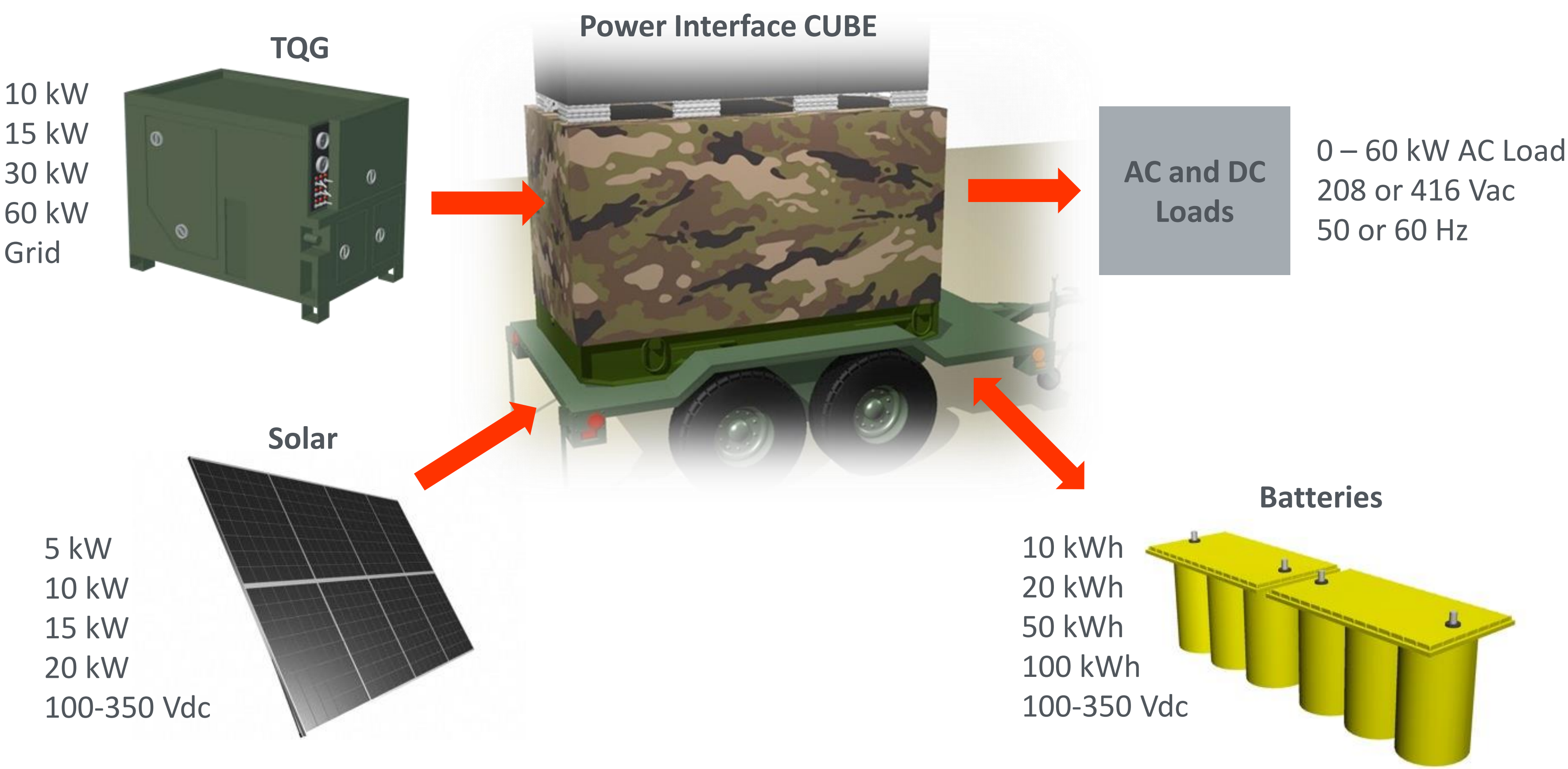
Deployable Solar Concept

Early Concept (movie)

(please switch to movie)

Technology and Design

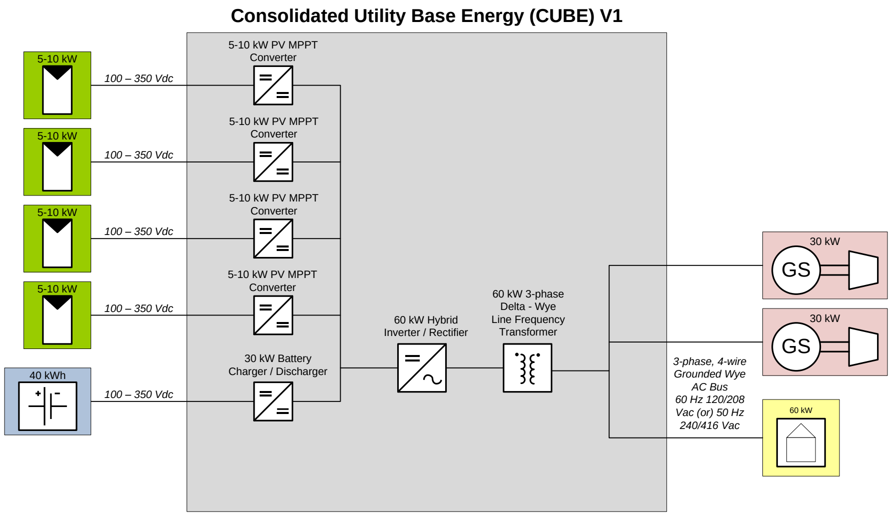
Mission-Adjustable Modular System Design



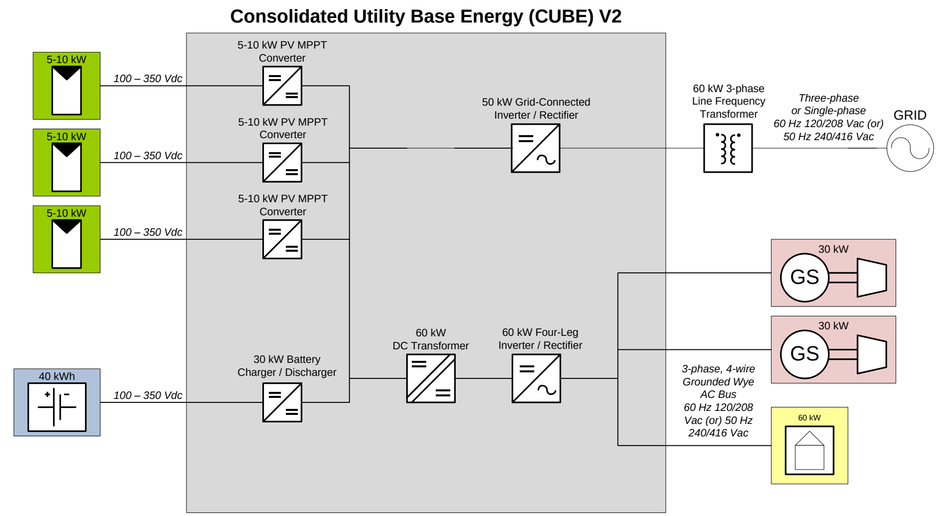
CAD Layout Iteration

Prototype Design Progression

V1



V2



Benefits of high frequency transformer isolation with DC Transformer plus Four-Leg Inverter

- Reduced weight (175 vs. 575 lbs = 70% reduction in weight for non-integrated design)
- Reduced volume (3.6 vs. 8.1 ft^3 = 55% reduction in volume for non-integrated design)
- Ability to provide voltage balancing in presence of significant load imbalance

Benefits of flexible grid input

- Leverage host nation grid power with 120/208, 240/416, or 277/480 V and 50 or 60 Hz
- Clean up host nation grid power

Differentiating Design Features

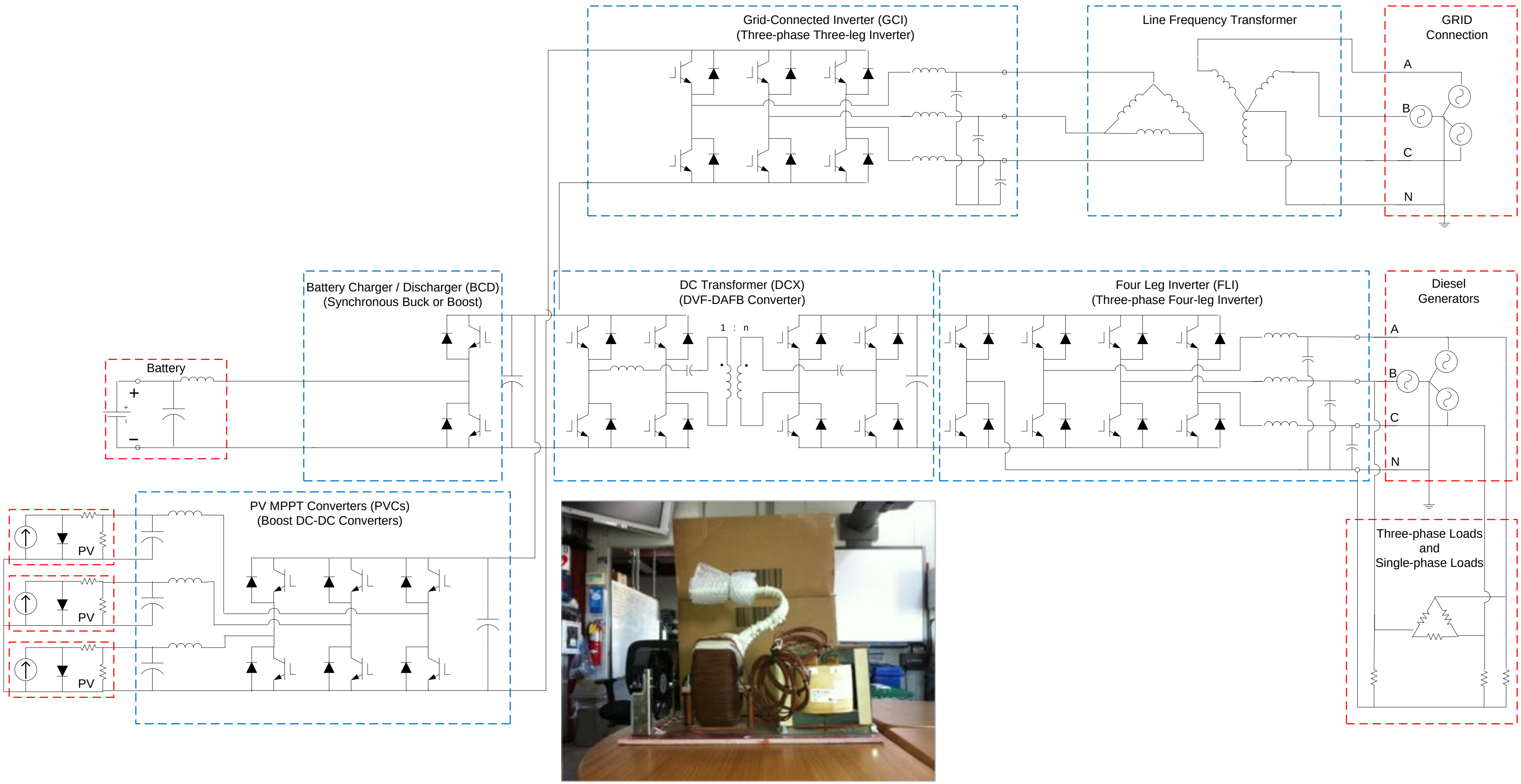
1: Seamless, instantaneous transition to and from diesel generation.

- Allows plug-and-play with any TQG (or isochronous generator)
- Preserves battle short
- No interruption to load even if all diesels are lost

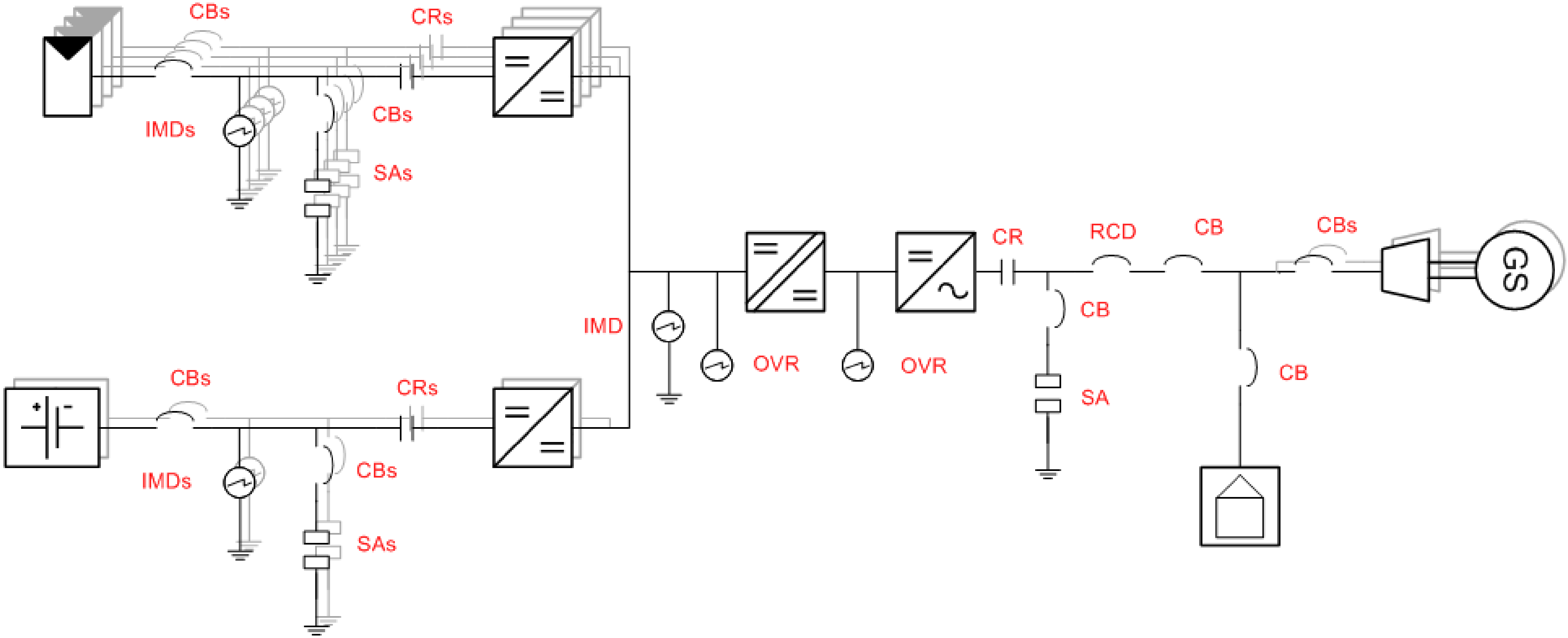
2: Load Balancing via 4-Leg Inverter

3: Lightweight electrical isolation by Dual Active Full Bridge with high frequency liquid cooled transformer – "DC transformer"

Three-line diagram

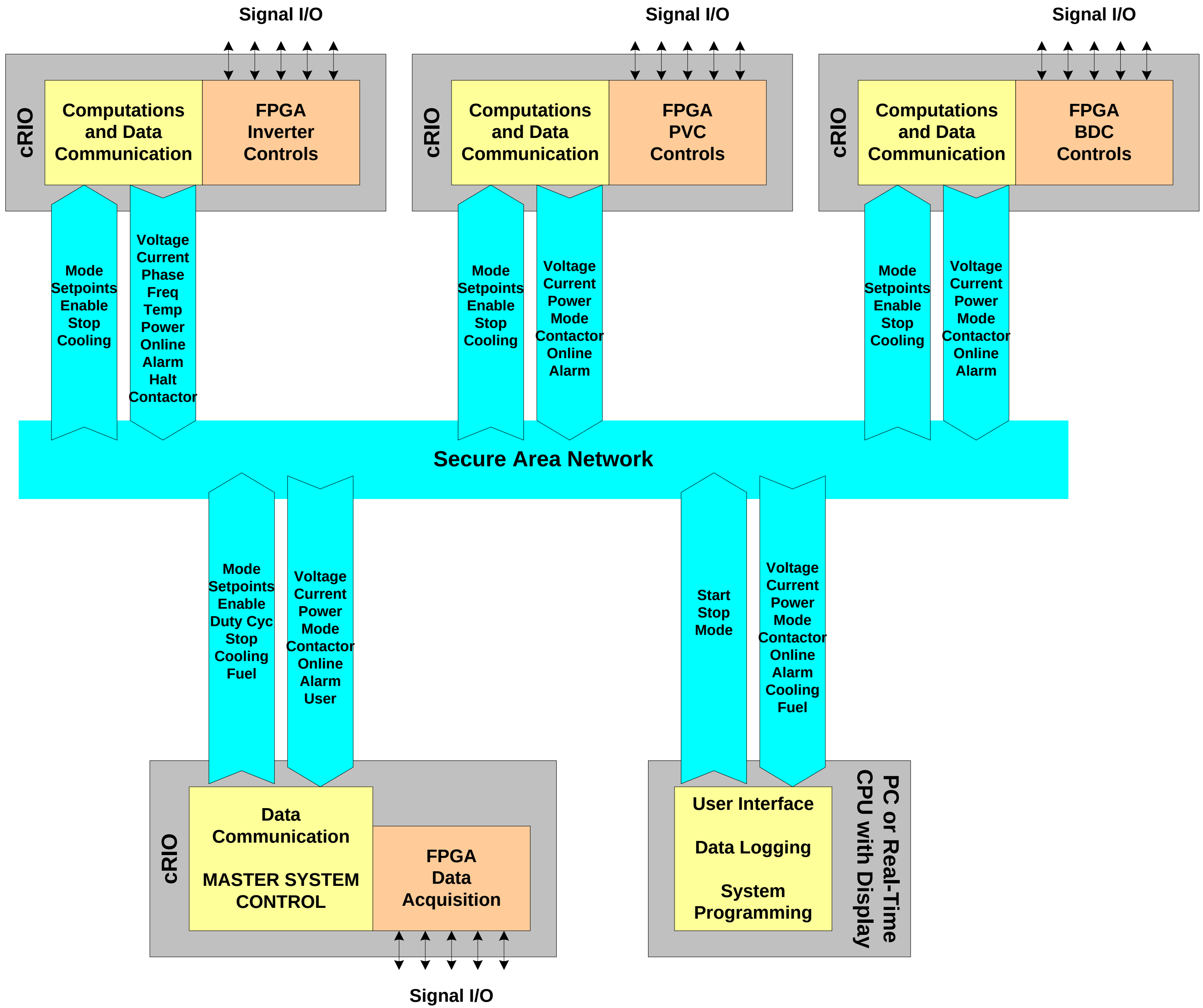


Isolation and Protection



CB: Circuit Breaker
IMD: Insulation Monitoring Device
SPD: Surge Protection Device
OVR: Over Voltage Relay
RCD: Residual Current Device
CR: Contactor

Control and Signal Architecture



Operating Modes and Bus Control

Mode \ Component	TQG	FLI	PVC	BCD	GCI	DAB
OFF	OFF	OFF	OFF	OFF	OFF	OFF
Diesel Only	ACV	OFF	OFF	OFF	OFF	OFF
Diesel + PV MPPT	ACV	DCV	MPPT	OFF	OFF	MREG
PV Only	OFF	ACV	DCV	OFF	OFF	MREG
Diesel + Battery Current	ACV	DCV	OFF	CC	OFF	MREG
Diesel + Battery Voltage	ACV	DCV	OFF	BV	OFF	MREG
Battery Only	OFF	ACV	OFF	DCV	OFF	MREG
Diesel + PV MPPT + Battery Current	ACV	DCV	MPPT	CC	OFF	MREG
Diesel + PV MPPT + Battery Voltage	ACV	DCV	MPPT	BV	OFF	MREG
PV + Battery	OFF	ACV	MPPT	DCV	OFF	MREG
Grid Only	OFF	ACV	OFF	OFF	DCV	MREG
Diesel + Grid	ACV	DCV	OFF	OFF	CC	MREG
Diesel + PV MPPT + Grid	ACV	DCV	MPPT	OFF	CC	MREG
PV + Grid	OFF	ACV	MPPT	OFF	DCV	MREG
Diesel + Battery Current + Grid	ACV	DCV	OFF	CC	CC	MREG
Diesel + Battery Voltage + Grid	ACV	DCV	OFF	BV	CC	MREG
Battery + Grid	OFF	ACV	OFF	DCV	CC	MREG
Diesel + PV MPPT + Battery Current + Grid	ACV	DCV	MPPT	CC	CC	MREG
Diesel + PV MPPT + Battery Voltage + Grid	ACV	DCV	MPPT	BV	CC	MREG
PV + Battery + Grid	OFF	ACV	MPPT	DCV	CC	MREG

CUBE Prototype

Rugged Versatile Controllers

Real-Time Processor
- Stable, fast computing
- Communications
- Data Logging

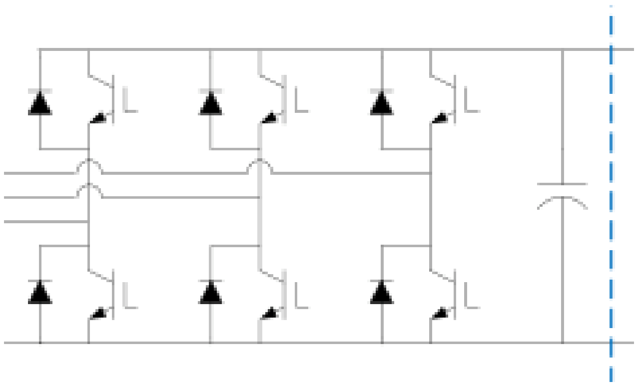
FPGA Backplane
- Extremely fast and reliable electronics control
- Versatile signal I/O

Signal Interface Modules

Single-Board RIO
- Integrated circuit board
- Configurable

Hardened Power Electronics Packages

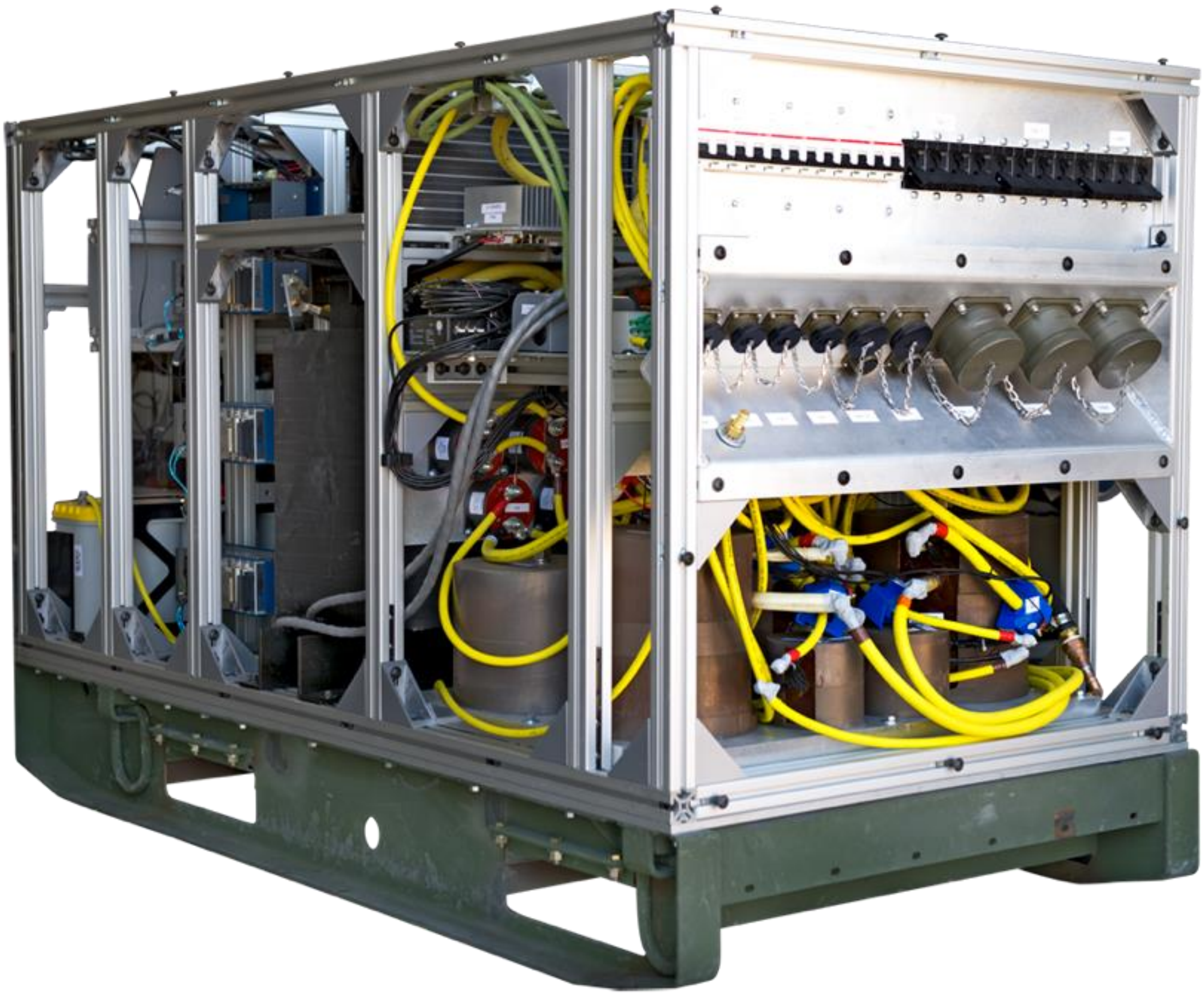
SEMIKRON
innovation+service



Key Prototype Features

- Liquid cooling for compact package
  - Power electronics
  - Magnetics
  - Internal air cooler for controller cooling
  - High Frequency Transformer
- Mil-spec connectors and as many other components as feasible
- Operator interface
- Intelligent dispatch algorithm that is adjustable for the mission
- The design and implementation is open source owned by the Army sponsor

First Prototype (minus coolers)



Final Prototype

Walk-Around

- **Advanced Liquid-Cooled Power Electronics**
- **FPGA and Real-Time Computer Controls**
- **Intelligent Dispatch Strategy to Decrease Diesel Fuel Burn**

Diesel Dispatch

- Objective: Minimize fuel consumption while ensuring the primary load is always met
- Steps:
  - Diesel Capacity Dispatch: Determine the minimum amount of diesel generating capacity that must be on-line to ensure the primary load is always met, called *Diesel Capacity Required*
  - Diesel Configuration Dispatch: Select the most fuel efficient combination of diesel generators to provide *Diesel Capacity Required*
- Challenges:
  - Load and PV power fluctuations
  - Diesel capacity cannot be added instantaneously

System Prototyping and Testing

CORE EXPERTISE

- In-house design and build of complex systems, involving electrical controls and thermal management
- Embedded controls using microcontrollers, FPGA and microprocessors
- High speed data acquisition
- System control and visualization (e.g., LabView/LabWindows)
- System evaluation using PHIL at ESIF and NWTC

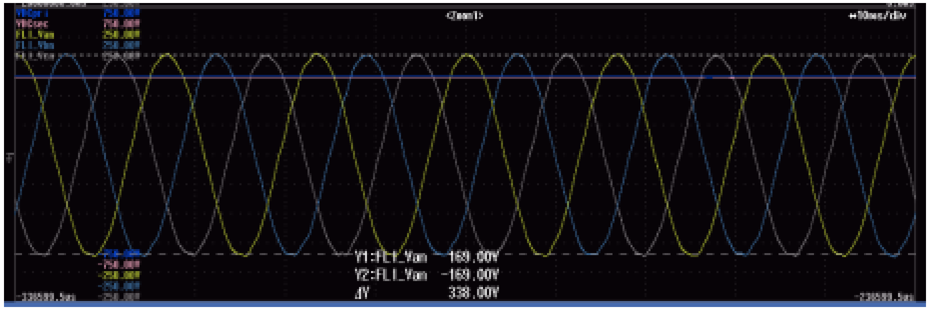
KEY APPLICATION: CONSOLODATED UTILITY BASE ENERGY (CUBE) SYSTEM

NREL staff worked with the US Army Mobile Electric Power (MEP) program to design an energy management system for Forward Operating Bases with the goal of using renewable energy and storage to minimize the use of diesel fuel

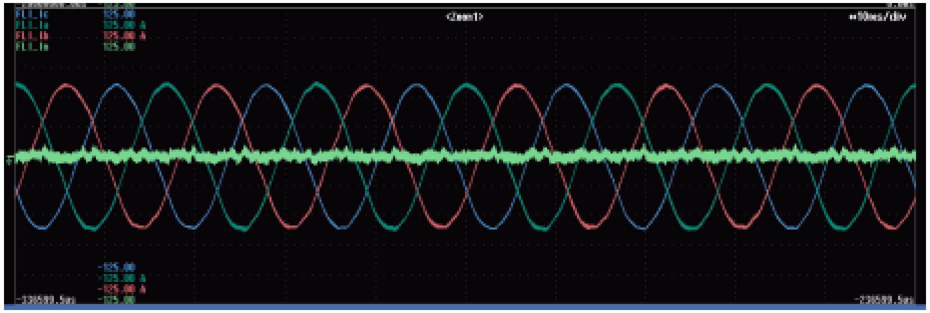
FLI waveforms - voltage balancing (Experimental)

Ph A = Ph B = Ph C = 5 kW

Voltage

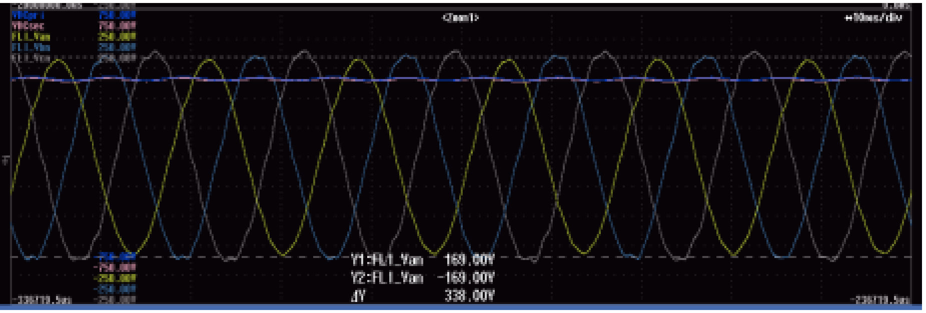


Current

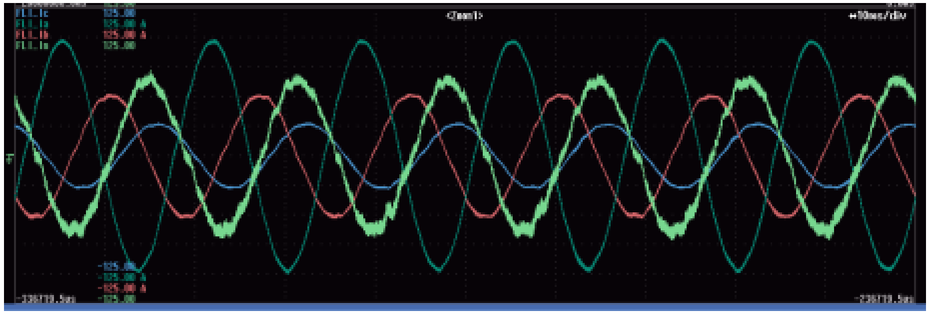


Ph A = 8 kW, Ph B = 4 kW, Ph C = 2 kW

Voltage

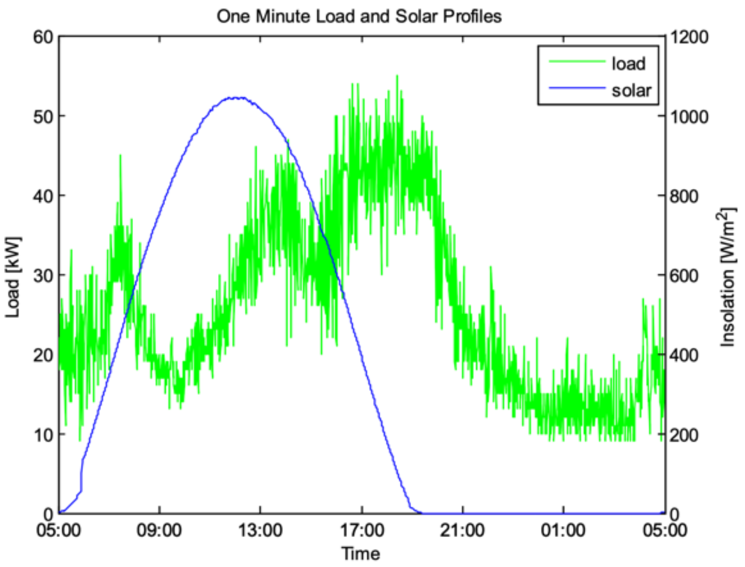


Current



Voltage scale = 150 V/div
Current scale = 25 A/div
Time scale = 10 ms/div

Key Results – 24 Hour Test and Modeling



	Test	Model
Fuel used, diesel-only system	67.8 gallons	68.04 gallons
Fuel used, hybrid system	46.6 +/- 0.1 gallons	46.99 gallons
Fuel reduction	21.2 +/-0.1 gallons 31%	21.1 gallons 31%
Total runtime for two diesel generators	28 h	26 h
Diesel generated electricity	495 kWh	519 kWh
Battery input energy	9 kWh	33 kWh
Battery discharge energy	8 kWh	31 kWh

…we can therefore conclude that about 63% of the fuel savings was achieved by using the battery to prevent starting another TQG, while about 37% was the direct result of PV power displacing TQG power.

CUBE Reports in NREL.gov Publications Database

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Publications Database

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Subject
- Cube (5)
- PV (2)
- ESIF (2)
- Energy Systems Integration Facility (2)
- REopt (1)
- More options

Author/Creator
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- Niebylski, C (2)
- Simpkins, T (1)
- Bolton, C (1)
- Martin, G (1)
- More options

Publication Date

From [ ] To [ ] Refine

2013 – 2020

More options

8 Results for NREL Publications Sorted by: Relevance

TP Technical Report
Consolidated Utility Base Energy (CUBE) Model Report
NREL/TP-7A40-62792
Dan Olis, Travis Simpkins, Mariko Shirazi 2014
15 pp. External Note: Produced under direction of Wyle Laboratories, Inc. by the National Renewable Energy Laboratory (NREL) under TSA number TSA-13-566 and Task No WTFA.1000.
Online access
View Online Details

TP Technical Report
Integration of a DC Transformer, Four-Leg Inverter, and Flexible Grid Input Into the Consolidated Utility Base Electrical (CUBE) System
NREL/TP-5D00-66612
Mariko Shirazi, Christopher Niebylski, John Deplitch 2016
41 pp.
Online access
View Online Details

TP Technical Report
Consolidated Utility Base Energy (CUBE) Performance Test Report
NREL/TP-5B00-62768
Mariko Shirazi, Gregory Martin, Christopher Niebylski, Christopher Bolton 2014
68 pp. External Note: Produced under direction of Wyle Laboratories, Inc. by the National Renewable Energy Laboratory (NREL) under TSA number TSA-13-566 and Task No. WTFA.1000.
Online access
View Online Details

FS Fact Sheet
Plug into NREL's Resilient CUBE
NREL/FS-5B00-75550
2020
2 pp.
Online access
View Online Details

TP Technical Report
Heila Microgrid Controller Validation Using CUBE: Cooperative Research and Development Final Report, CRADA Number CRD-17-663
NREL/TP-5D00-72294
Mariko Shirazi, Barry Mather 2018
5 pp. Author Role: NREL Technical Contacts
Online access
View Online Details

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Steven Silwa – US Army REF
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John Deplitch – Wyle Laboratories

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Blake Lundstrom – NREL Engineer
Bob Hansen – NREL Technician
Kyle Tangler – NREL Technician
Dan Olis – NREL Analyst
…and many others!

Acknowledgements

Other Recent NREL Initiatives

NREL Support of Installation and Operational Energy Missions

	Installation	Operational
Fuel	Non-Tactical Vehicles and Spot Gen	Primary Energy Source
Electricity	Dependence on utility grid	Diesel Generation, Soldier Electronic Systems and Batteries
Approach	• Smart microgrids • Renewable integration and storage • Enterprise-level management • Replicable, modular process and systems • Load reduction/management • Vehicle electrification and grid integration	• Demand-side management • Energy Efficiency • Hybrid diesel/renewable generation systems • Microgrid design and implementation • Logistics optimization • Battery/renewable hybrid soldier electronic systems • Renewable generation (e.g., waste to energy, PV)

Background

New military microgrid testbed capability builds upon years of successful strategic partnership projects.

Relevant DOD projects included hardware-in-the-loop (HIL):

- Army "Consolidated Utility Base Energy" (CUBE) project
  - Developed advanced diesel genset integration with renewables
- Navy "Energy Resource Planning Tool" (ERPT) project
  - Proved energy resource planning algorithms are valid in HIL
- Air Force / Eaton "Modular Expeditionary Technology Evaluation Resource" (METER) project
  - Pioneered machine learning for multi-energy system controls
- DOD ESTCP "Large Scale Energy Storage Microgrids" project
  - Strategic program contributing advanced equipment to NREL

New Research Capability

Advanced Research of Integrated Energy Systems (ARIES)

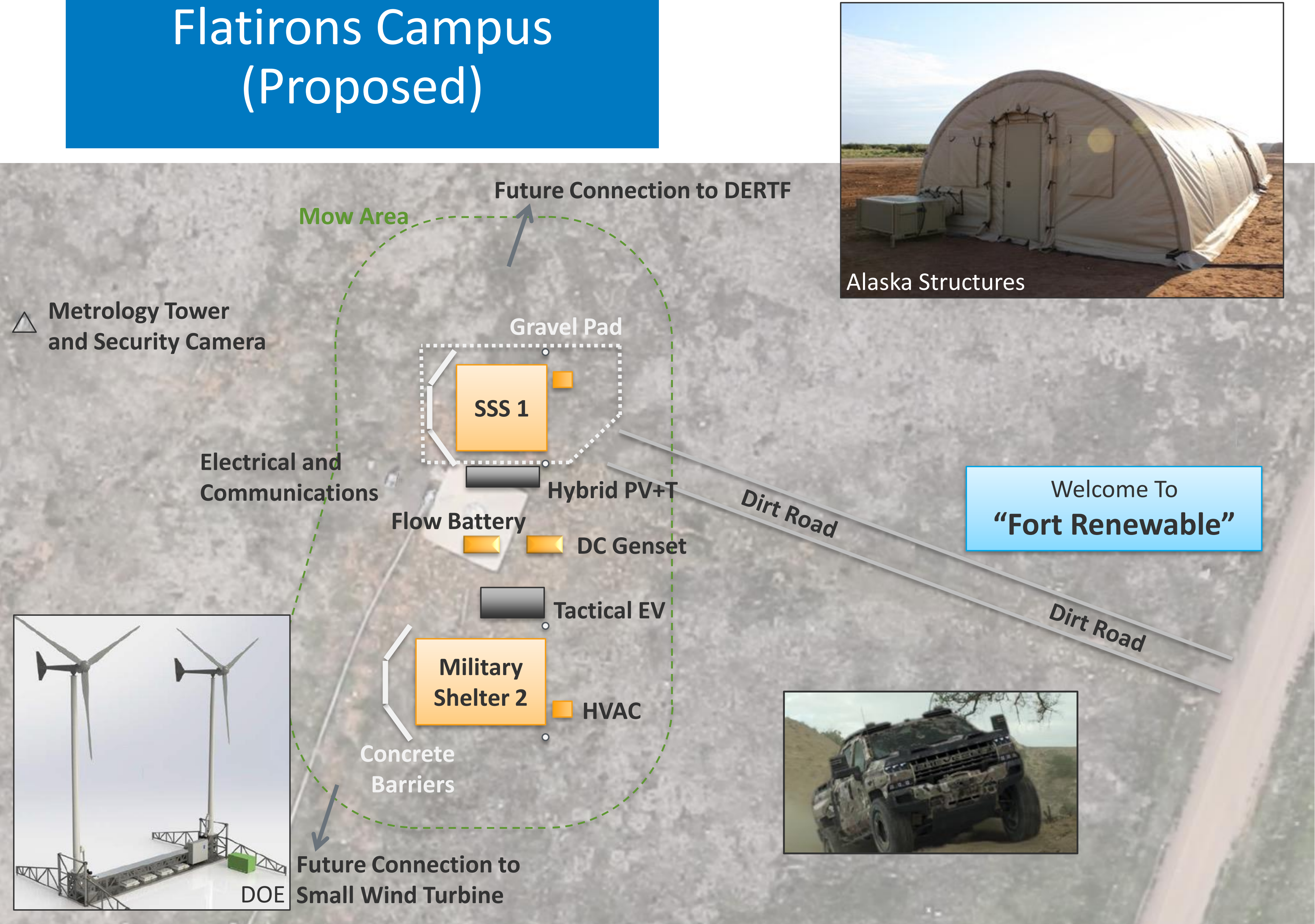
New site with **significant interconnectivity** between ESIF and Flatirons

- Intended **for live simultaneous research** operations
  - Link to existing ESIF real time simulation platforms
  - Newly created Cyber Energy Emulation Platform (CEEP) at ESIF
  - Connection to wide variety of ESIF assets (PHIL, SCADA, etc)

Military-style tent structures built at Flatirons

- Initial DER equipment located both external and inside the structures:
  - Regenerative grid simulator
  - Military diesel generator with load bank
  - **Variety of controllers and sensors associated with all equipment**
- Coming projects gradually add equipment:
  - Vanadium flow battery with bidirectional multi-port inverter
  - Advanced diesel generator
  - Solar array simulator and PV inverter

Flatirons Campus (Proposed)



Nexus-E

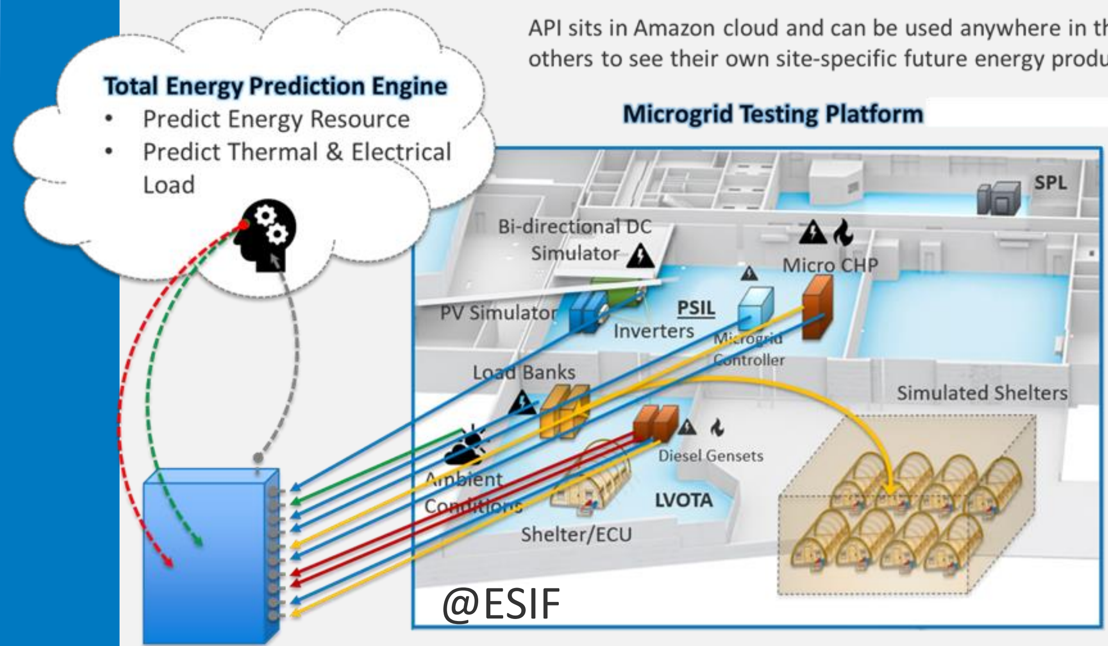
Nexus-E brings modularity and flexibility to predictive control on multiple energy domains

Enables reduction in energy consumption, enhancing resiliency in microgrids such as forward operating bases.

Scalable cloud-computing with machine learning for predicting total energy requirement to better utilize advanced controllers *anywhere*

Contact:
Richard Bryce, NREL
Richard.Bryce@nrel.gov

API sits in Amazon cloud and can be used anywhere in the country to enable others to see their own site-specific future energy production and loads



Thermal Loads
Electrical Loads
Renewables
Fossil Fuels

Multiple microgrids connected to Nexus-E with NREL development at ESIF & Flatirons

Islands

Desert

Mountains

Thank You. Questions?

www.nrel.gov

Plug into NREL's Resilient CUBE

PRESENTED BY:

Greg Martin

Engineering Group Manager, Energy Systems Integration Facility, National Renewable Energy Labs (NREL)

MODERATED BY:

Steve Redifer

2020-05-06

Homeland Defense & Security Information Analysis Center

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https://www.hdiac.org