MICROGRID KNOWLEDGE
CONFERENCE SERIES

Microgrid 2018
CONFERENCE

Innovations in Generation, Storage & Networks to Improve Efficiency and Ensure Reliability

Moderator:
Daniel Fingleton, Energy Storage and Microgrid Program Manager, *Solar Turbines*

Presenters:
Geoff Slevin, Director, Business Development, *FuelCell Energy*
Dean Tuel, Vice President of America Sales, *Younicos*
Keith Gray, SCADA Project Engineer, *POWER Engineers*
Dan Jones, Electrical System Studies Engineer, *POWER Engineers*

Fuel Cells and Microgrids

Geoff Slevin

May 2018

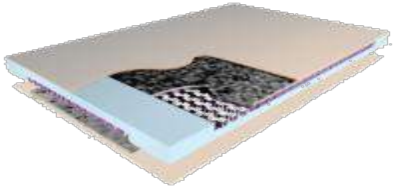
FuelCell Energy In the News

- "FuelCell Energy and Toyota Announce **Renewable Transportation Fuel** Project" – PR Nov 2017
- "FuelCell Energy Announces the Award of Three Fuel Cell Projects Totaling **39.8 Megawatts** by Long Island Power Authority" – PR July 2017
- "Inside this box could be the future of **carbon capture**" – ExxonMobil TV ad Fall 2017

Fuel Cells - What are they?

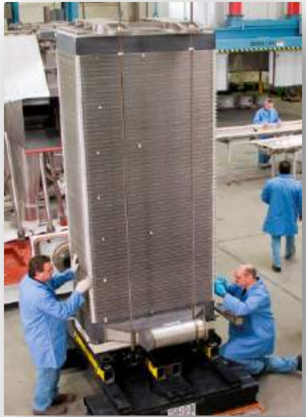
- Generate electricity, and sometimes usable waste heat, by virtue of an electrochemical reaction
- No combustion, no criteria pollutant emissions (NOx, SOx, PM10)
- More efficient than competing baseload technologies, produce lower CO_2 emissions.

Fuel Cell Configuration



Individual fuel cell component

400 components are used to build one 350 kW fuel cell stack



4 stacks are combined to build a 1.4 MW plant

The stacks are enclosed, creating the fuel cell module

Two modules are used for a 2.8 MW power plant

1.4 MW Fuel Cell CHP Plant

Case Study - PFIZER

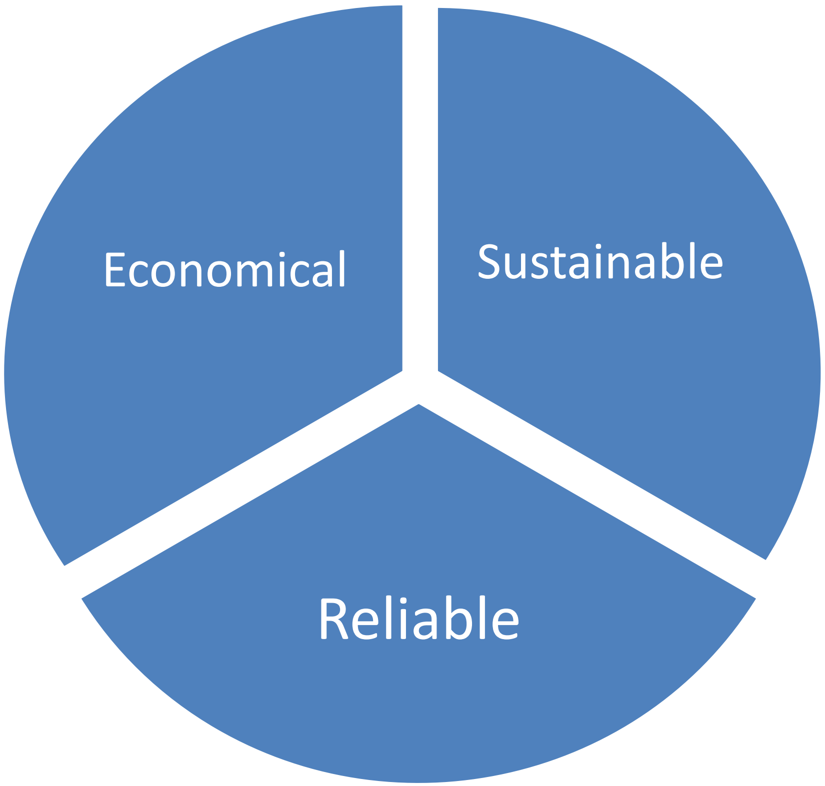
Project Overview

- Grid-connected 5.6 MW fuel cell powered by Natural Gas
- Provides electricity and steam to 160 Acre Pfizer Groton campus
- Seamless grid independent capability
- Private, Critical Facility Microgrid

Benefits

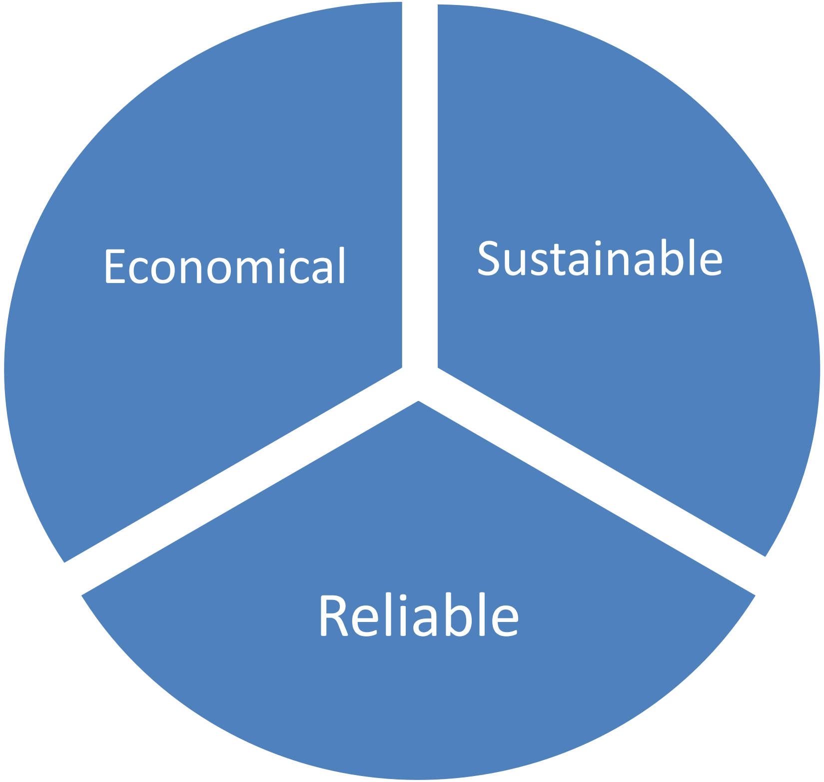
- Closes electrical generation gap with a more reliable source than the commercial grid – makes site independent year round
- PPA structure with no up-front capital cost, delivers energy cost savings to Pfizer
- Enhances site sustainability profile
- Clean profile reduces permitting hurdles

Microgrid Goals



Microgrid Goals

Easily acquired through finance - PPAs



- **0 Criteria Pollutant Emissions**
- **Low CO_2**

Higher availability vis-à-vis other clean baseload generation sources.

DOD - SUBASE Groton

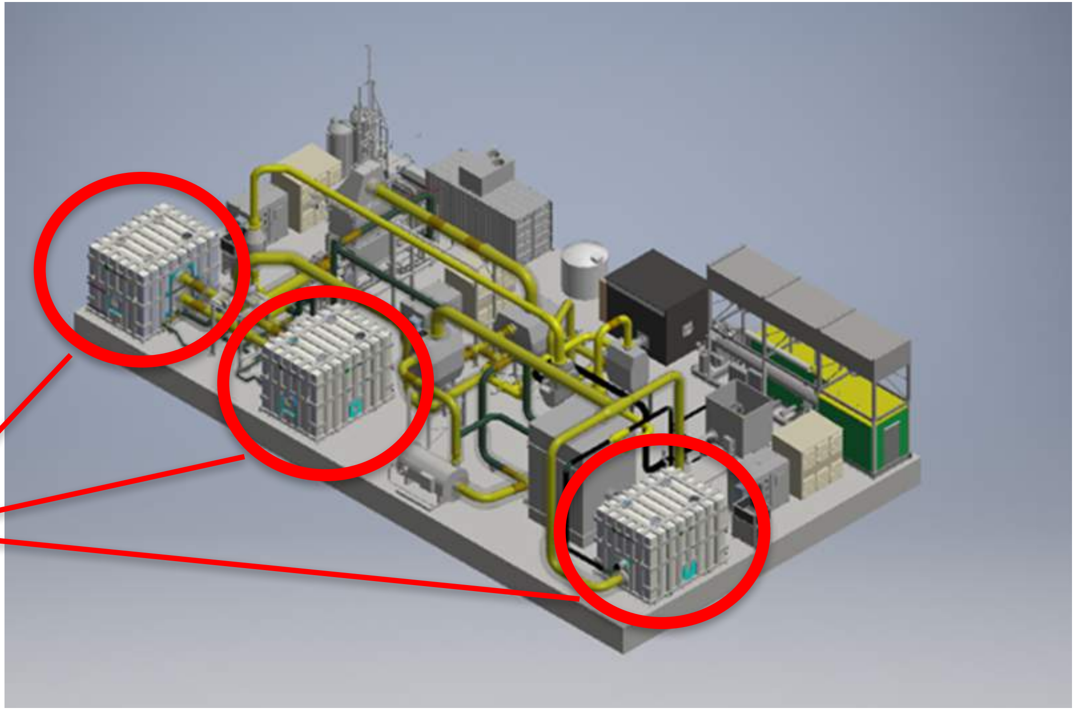
- Naval Submarine Base New London, CT
  - 1st permanent continental sub base
  - Home to 15 attack submarines
  - Employs ~9500 active duty, reserve and civilian personnel

- 20 year PPA with CMEEC (CT Muni Electric Energy Co-op – 6 Munis)

- Design interconnect compatible with the Navy microgrid

- Compliance with DOD directives for resiliency, clean power, operational costs

SureSource 4000™



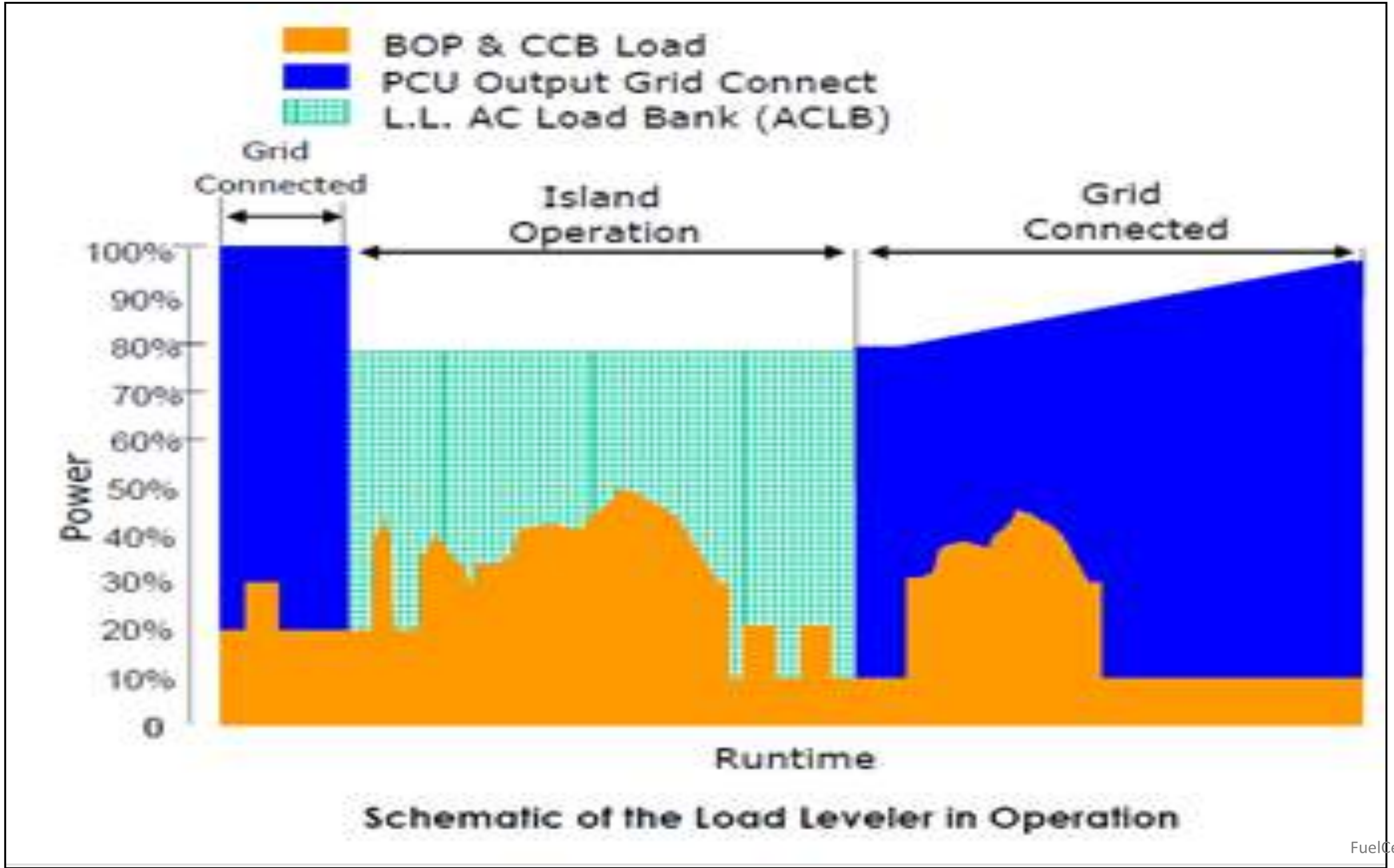
3 Fuel Cell Modules

Delivered Electrical Efficiency: up to 60%

Citing Ease

No transmission losses

Grid Independent Capability



Citing Ease

60’

40’

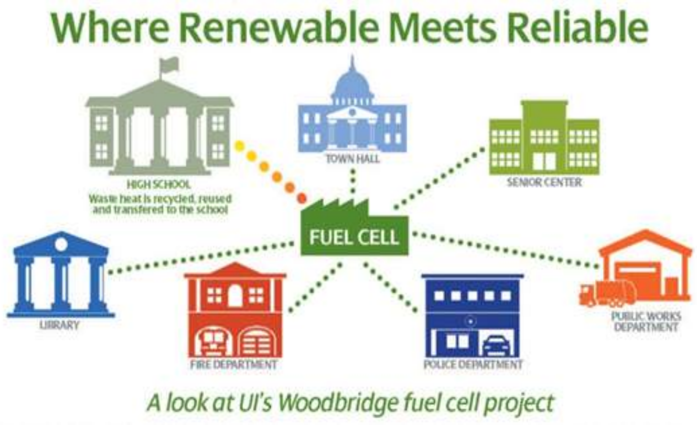
~2500 sq-ft

Carbon Neutral CHP

- 2.8 MW fueled by biogas
- 2nd - 2.8 MW fuel cell installed at the facility
- Savings vs. grid – no upfront costs
- Avoided clean air permitting – challenge in CA

Tulare, CA Wastewater Treatment Plant

Case Study – Town of Woodbridge, CT



Project Overview

- 2.2 MW combined heat & power fuel cell power plant
- Power to UI grid during normal operation
- Supplies 100% of Town microgrid power needs during grid outage
- Heat supplied to Amity High School
- Connecticut Microgrid Program Award

Benefits

- Helps UI achieve its Class I RPS goals
- In a grid outage, power to critical facilities – police, fire, community services
- Savings to Amity High School ~ $100K per year from avoided natural gas
- Enabled upgrade to local gas grid delivery infrastructure

Case Study – UC San Diego

- Grid-connected 2.8 MW fuel cell powered by Directed Biogas providing electricity and absorption chilling to campus grid

BioCycle energy

92% SELF-GENERATED ENERGY

SYMPHONY OF THE MICROGRID AT AN URBAN UNIVERSITY

The University of California San Diego's microgrid produces 92 percent of its annual electricity load and 95 percent of its heating and cooling load. A fuel cell powered by directed biogas is a cornerstone of the operation.

Marsha W. Johnston

"A fuel cell powered by directed biogas is the cornerstone of the micro-grid operation"

<u>Benefits</u>

- Cost savings during normal operations
- Microgrid satisfies 90% of campus electric needs
- Carbon neutral by utilizing directed biogas

fuelcellenergy

Summary

- Municipalities, companies, and governments are considering and selecting fuel cells to be a part of their microgrids
- The reliability, environmental, and now economic benefits of fuel cells make them a sound choice
- Watch this space . . . More to follow

Geoff Slevin

Director, Business Development

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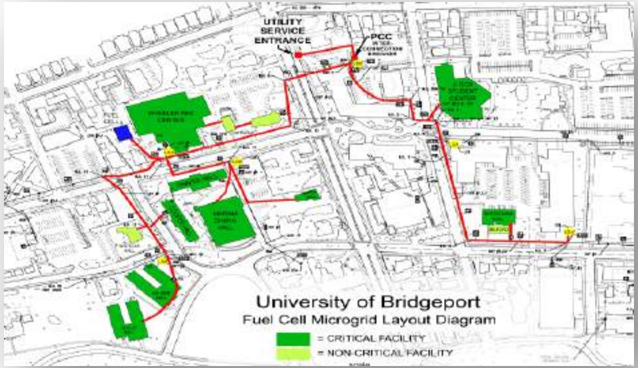
www.fuelcellenergy.com

Backup

Case Study – University of Bridgeport



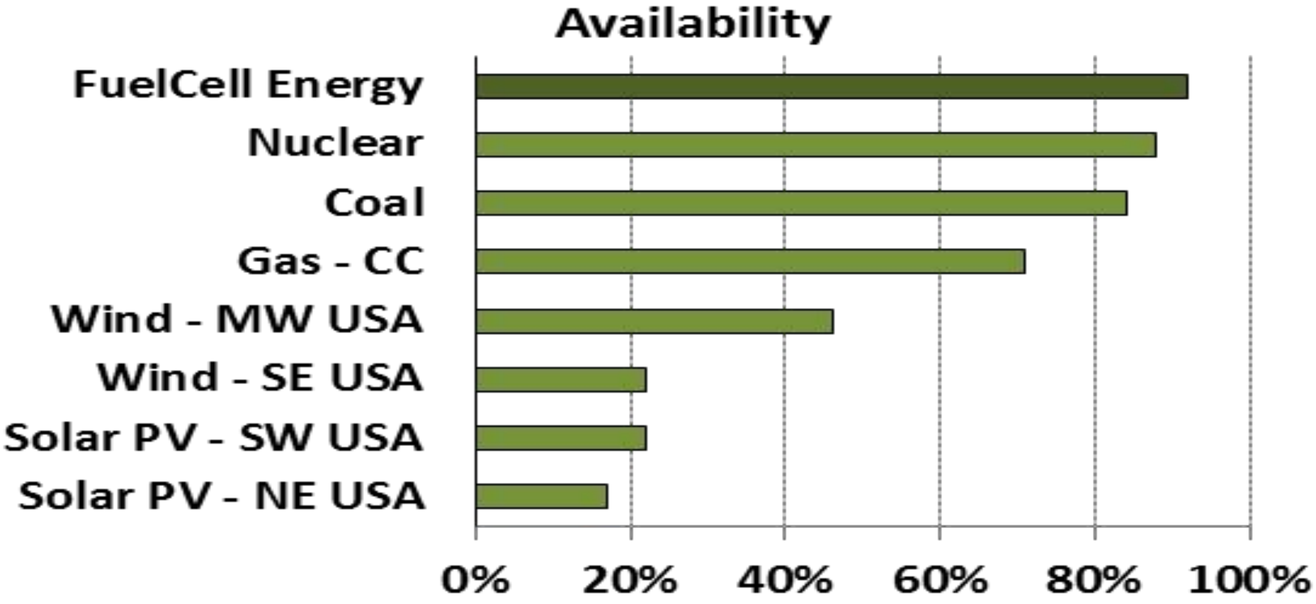
Project Overview

- 1.4 MW combined heat & power fuel cell power plant
- Supplies 80% of campus power needs
- Waste heat converted to hot water and supplied to three locations on campus
- Connecticut Microgrid Program Award

Benefits

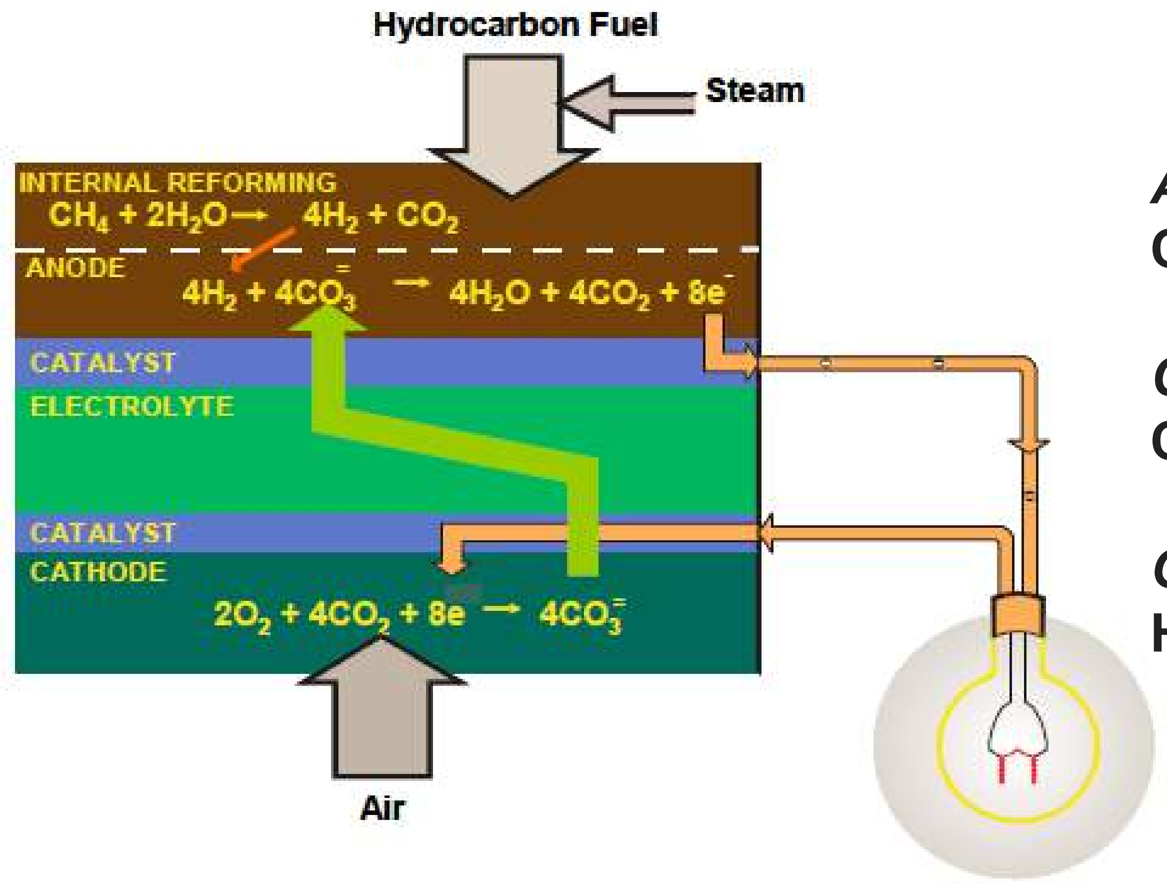
- Cost savings during normal operations
- In a grid outage, power to critical facilities – shelter ~2700 persons, security, dining
- Renewable Energy Research Lab – “practice what we teach”
- Emissions reductions:
  7,000 tons CO_2, 64 tons SO_x, 28 tons NO_x

High fuel cell plant availability



Source: FCE & NREL

Fuel Cell – How it Works



***Anode Reaction*:**

$$CO_3^{2-} + H_2 \rightarrow H_2O + CO_2 + 2e^-$$

***Cathode Reaction*:**

$$CO_2 + \frac{1}{2}O_2 + 2e^- \rightarrow CO_3^{2-}$$

***Overall Cell Reaction*:**

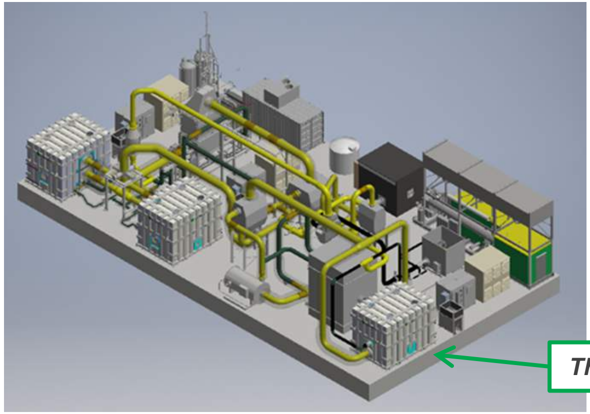
$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Latest Solution: SureSource 4000

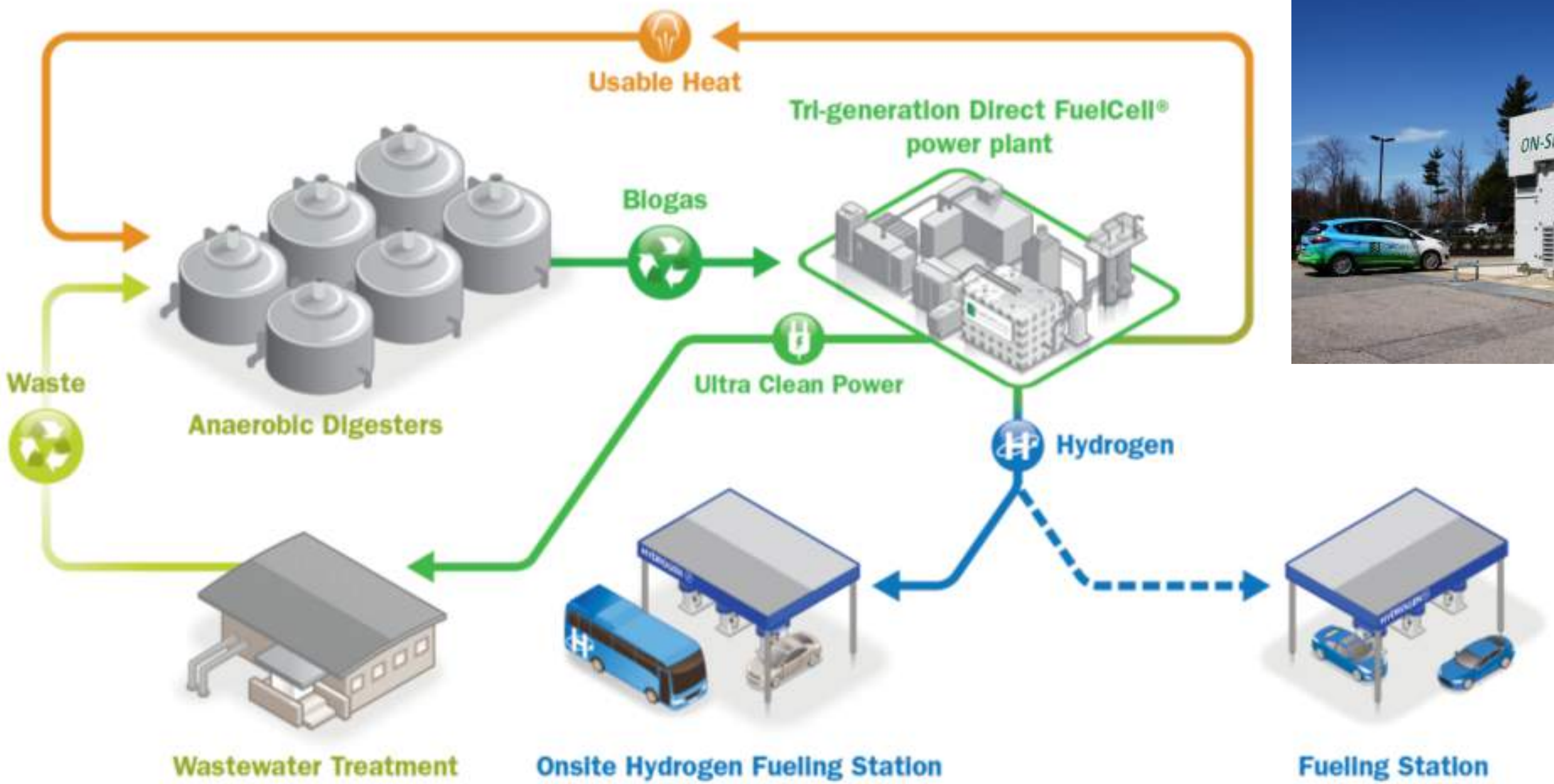
MW-Class Distributed Generation with Combined Cycle Electrical Efficiencies

	FuelCell Energy	Combined cycle gas plant
Size	1.4 MW to 100 MW	400+ MW *(scale req'd for high efficiency)*
Construction/Siting	Months; site WITHIN cities	Years; site AWAY FROM cities
Electrical Efficiency	Plant efficiency: 47-60% Transmission losses: *None!* **Delivered efficiency: 47-60%**	Plant efficiency: 55-60% Transmission losses: *(6-9%)* **Delivered efficiency: 46-54%**
Clean Emission Profile (virtually zero NO_x, SO_x, or PM)	Yes ✓	No ⊘
Renewable Fuel Option/REC's	Yes ✓	No ⊘
Combined Heat & Power	Yes ✓	Limited ⊘
Scalable	Yes ✓	No ⊘
Support Urban Redevelopment	Yes ✓	No ⊘
Affordable Carbon Capture	Yes ✓	No ⊘

3.7 MW Enhanced- Efficiency Fuel Cell Power Plant Configuration



Clean Fuel Production



Fitting the Application

	MW - Class	Sub-MW-Class	
Technology	Carbonate	Phosphoric Acid	Solid Oxide
System Size Range	1.4 MW - 3.7 MW	400 kW	200 kW
Typical Application	Utilities, campuses, industrial - baseload	Commercial buildings - baseload	Commercial buildings - baseload
Fuel	Natural gas, Biogas, others	Natural gas	Natural gas
Advantages	High efficiency, scalable, fuel flexible & CHP	CHP	High Efficiency
Electricial Efficiency	47-60%	40% - 42%	50% - 60%
Combined Heat & Power (CHP)	Steam, hot water, chilling	Hot water, chilling	Depends on technology used

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Younicos
an aggreko company

Microgrid 2018 Conference

ABOUT YOUNICOS AND AGGREKO

Global leader in mobile power solutions with expertise in hybrid and microgrid system integration

- **220MW+ of energy storage deployments**
- **Power electronics - intelligent software - hybrid functionality.**
- **3000 MW+ Distributed energy generation**
- **Round the clock service/remote monitoring**
- **100 countries worldwide**

What is a Microgrid

MICROGRID 101

Reliability

Islanding: Enhances local resilience

Service loads in case of emergencies

Access to Energy

Remote communities

Industrial parks, mines.

Flexibility

Parallel operations; provide grid services

Sustainability

Distributed assets typically renewable resources

WHAT IS A MICROGRID?

Any interconnected series of load and distributed generation assets that can operate fully independent from a centralized grid

INCLUDES MULTIPLE RESOURCES

BESS

Natural Gas Generators

Diesel Generators

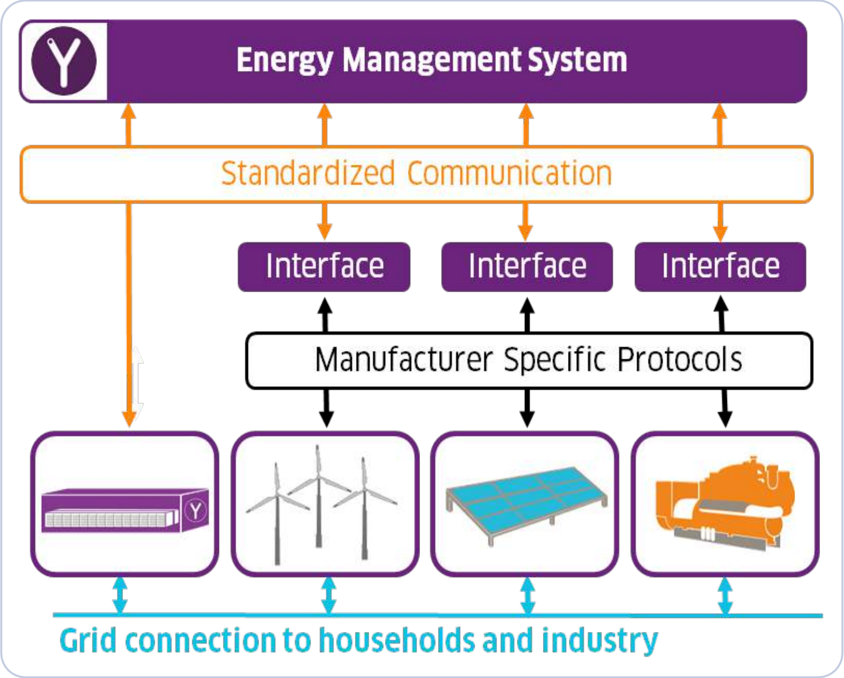
Y.Q
Intelligent Software

PV/Wind

Transformer
Balance of Plant

THE BRAINS – OPTIMIZES AND CONTROLS

THE INTERACTION OF DIFFERENT GENERATION UNITS

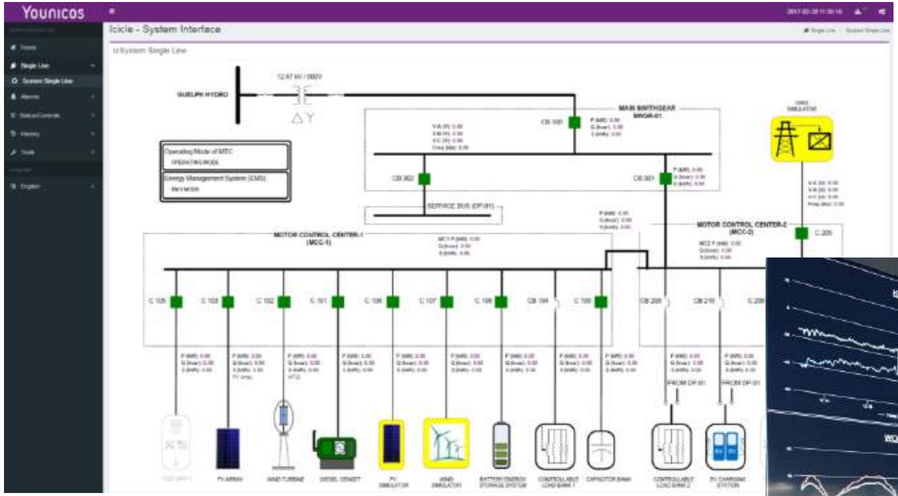


- **Short-term forecasting of Renewable generation and load (power and energy)**
- **Optimized power limits and set-point for WPP/PVPP and BPP**
- **Triggers diesel if necessary**
- **Power balance of DG/BESS can be maintained at all times by the primary controls of the contributing units**
- **Maintains the voltage and frequency stability**

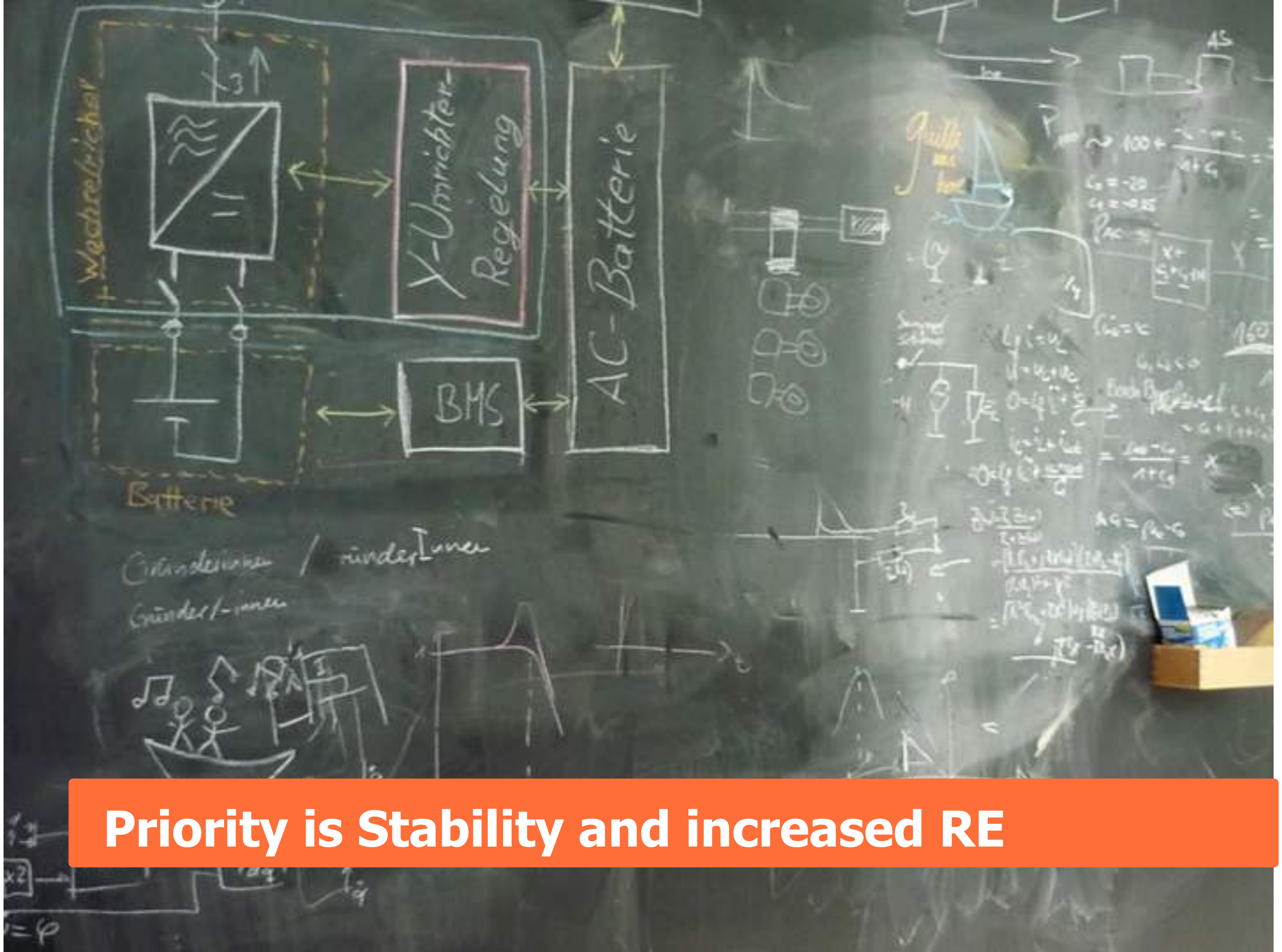
SERVICES: REMOTE MONITORING & MAINTENANCE

Data analytics and historical trends – Preventative maintenance – Uptime %

WebUI

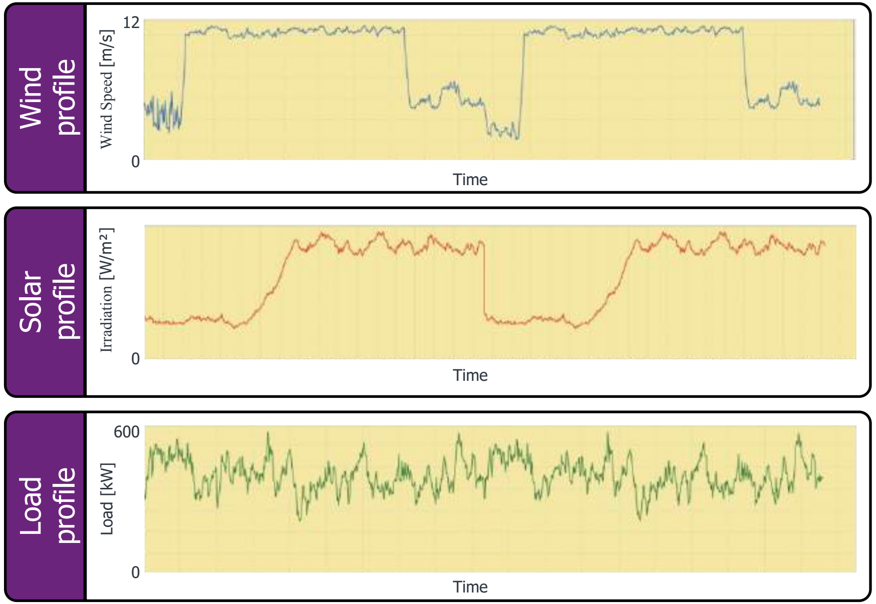


24/7 manned Operation center



Priority is Stability and increased RE

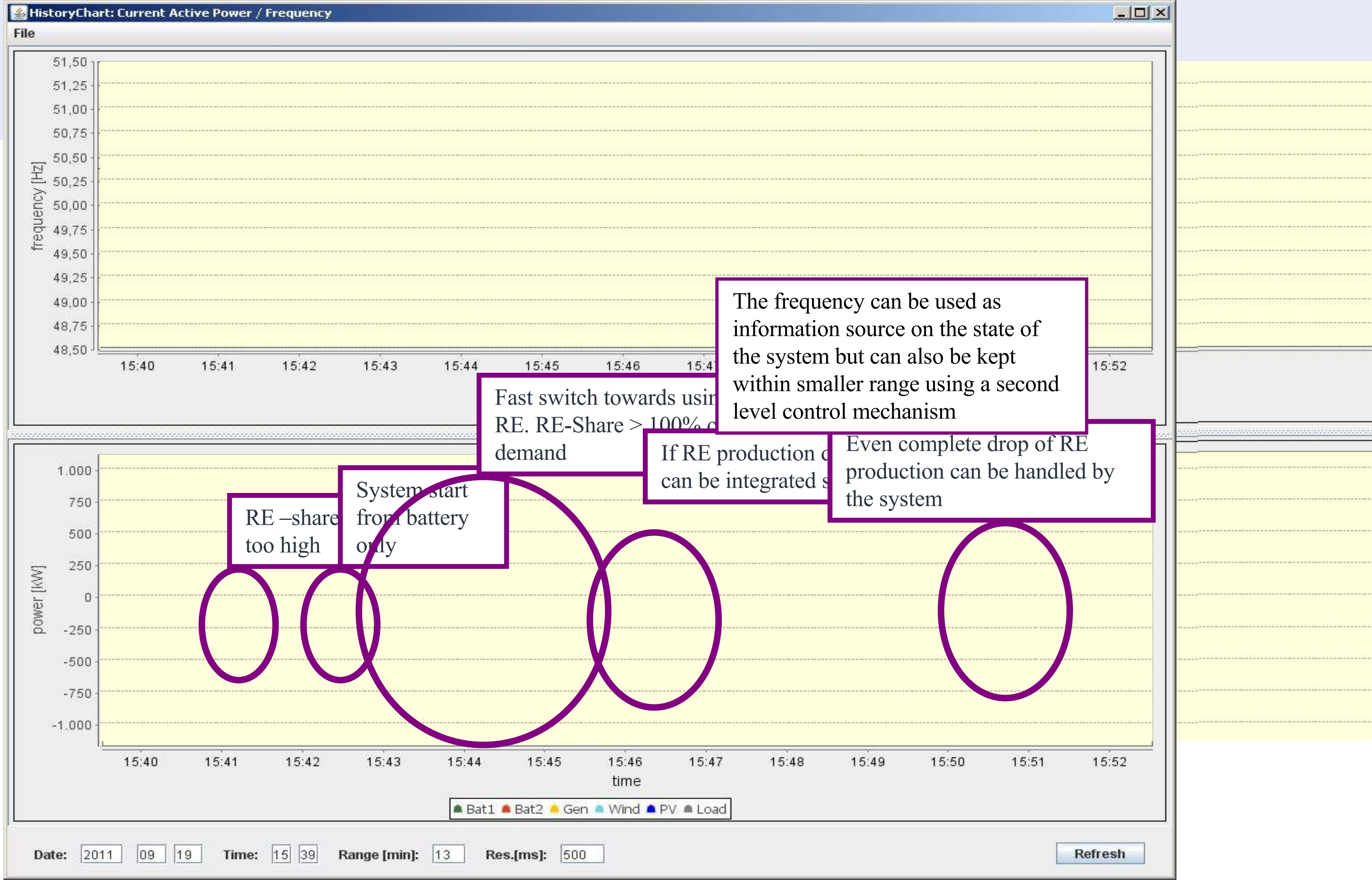
WE CREATED A "WORST-WORST-CASE" SCENARIO TO SHOW OUR SOLUTION'S ABILITIES



Extreme conditions

- Wind profile with strong changes
- Irradiation profile with strong changes
- High and very variable Load
- All profiles were measured on Graciosa but did not coincide

A situation with very unlikely combination of extreme conditions is chosen to test the solutions' robustness



HistoryChart: Current Active Power / Frequency
File
frequency [Hz]
51,50
51,25
51,00
50,75
50,50
50,25
50,00
49,75
49,50
49,25
49,00
48,75
48,50
15:40
15:41
15:42
15:43
15:44
15:45
15:46
15:52
The frequency can be used as information source on the state of the system but can also be kept within smaller range using a second level control mechanism
Fast switch towards usin
RE. RE-Share > 100% o
demand
If RE production c
can be integrated s
Even complete drop of RE production can be handled by the system
System start
from battery
only
RE –share
too high
power [kW]
1.000
750
500
250
0
-250
-500
-750
-1.000
15:40
15:41
15:42
15:43
15:44
15:45
15:46
15:47
15:48
15:49
15:50
15:51
15:52
time
Bat1
Bat2
Gen
Wind
PV
Load
Date:
2011
09
19
Time:
15
39
Range [min]:
13
Res.[ms]:
500
Refresh

Diesel Efficiency

MICROGRID : DIESEL EFFICIENCY CASE

DG ACTS AS SPINNING RESERVES

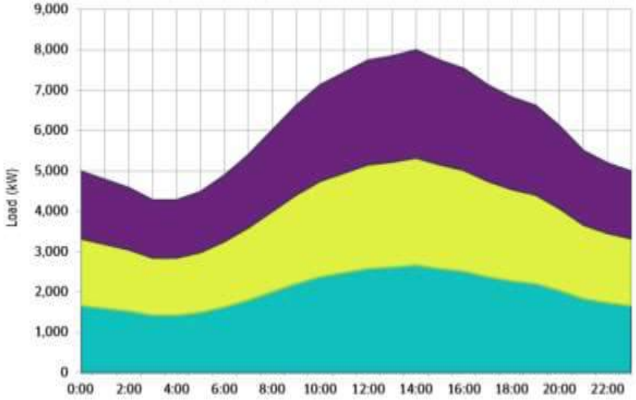
INCREASED FUEL CONSUPTION

ESS PROVIDES SPINNING RESERVES

HIGHER LOADING INCREASES EFFICIENCY

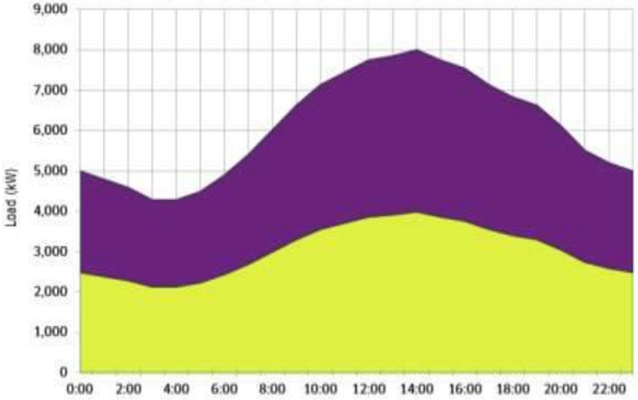
Operation without ESS

Load Shared Across 3 Generators



Operation with ESS

Load Shared Across 2 Generators



PROJECT IN DEVELOPMENT: AMAZONAS
DIESEL PLUS ENERGY STORAGE APPLICATION IN REMOTE COMMUNITIES

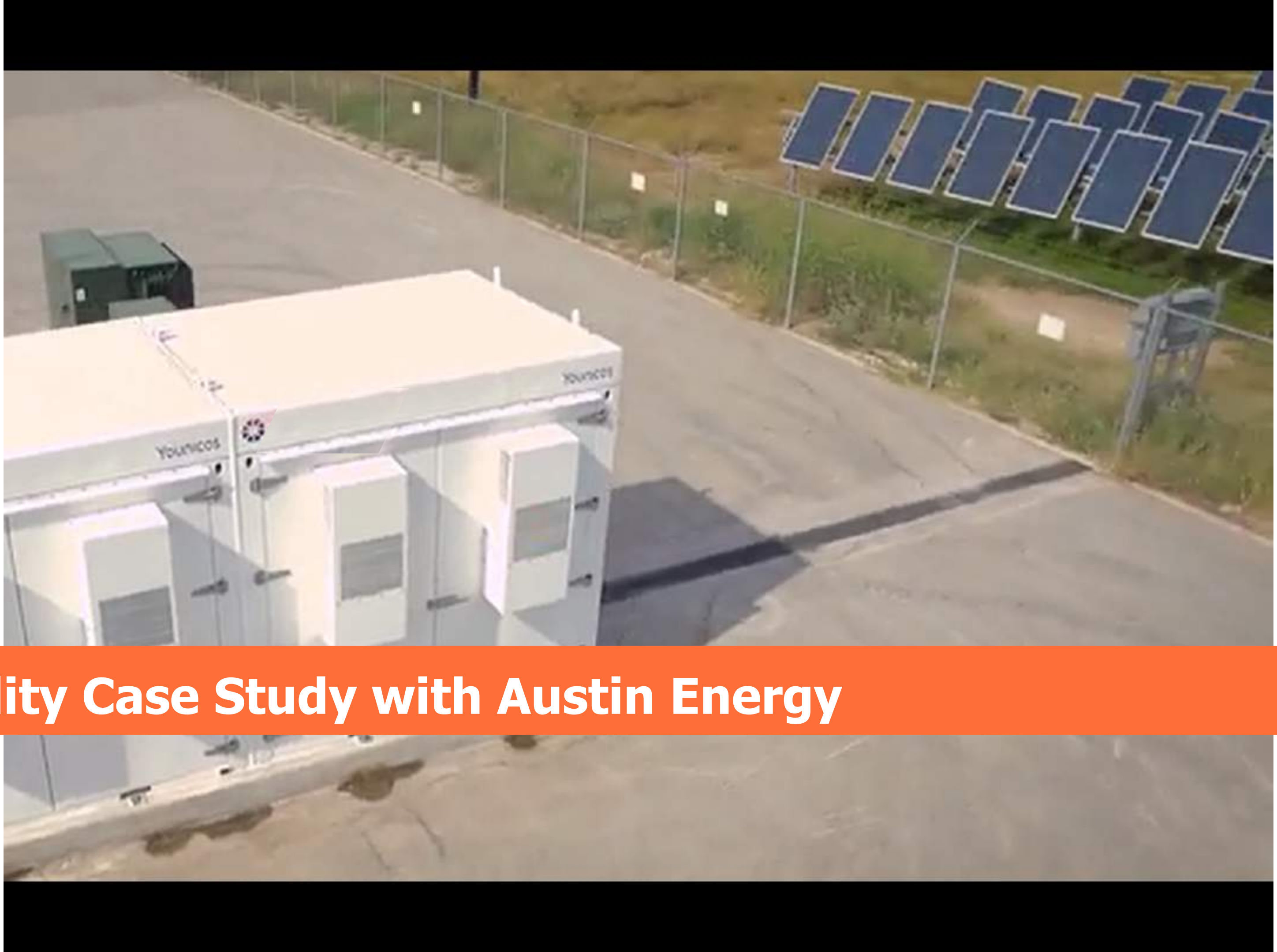
Amazon, Brazil

ELECTROBRAS AMAZONAS

PROJECT STILL IN DEVELOPMET

- **1 MW/0.5 MWh Lithium Ion**
- **8MW Diesel**
- **Spinning reserve displacement, Fuel savings, Diesel efficiency**

	Recommended Battery Power (MW)	GENSET	Total Load (kWh/year)	Fuel Consumption with battery (L/y)	Cost of fuel ($/y) @ $1/L	Fuel Savings	Capex Battery	**Indicative Payback Period**
Site 1	1000	G3+	32,221,544	8,259,676	8,259,676	$126,639	$430,000	**3.6**
Site 2	-	DC16	29,544,327	-	-	$0	-	**-**
Site 3	1000	G3+	110,481,184	27,926,998	27,926,998	$22,215	$430,000	**31.6**
Site 4	1000	G3+	36,740,218	9,361,045	9,361,045	$160,501	$430,000	**2.8**
Site 5	1000	G3+	82,271,995	20,797,595	20,797,595	$98,605	$430,000	**4.8**
						$385,745 per year for viable sites		
							$1,600,000	
						$5,786,175 over 15 years		



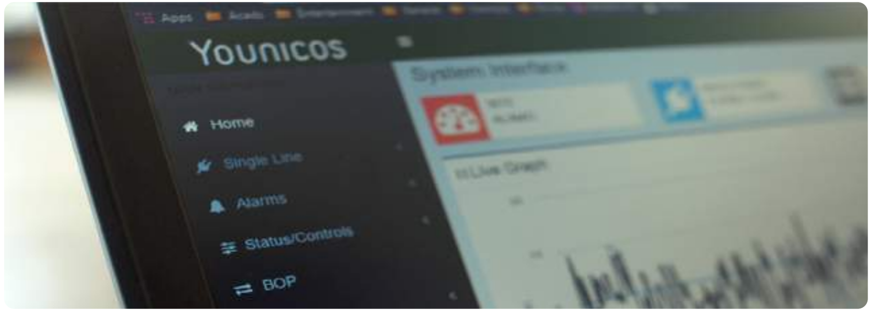
Utility Case Study with Austin Energy

UTILITY: INTEGRATION OF LOCAL DISTRIBUTED PV GENERATION TO PROVE 14¢/KWH

▪Austin, Texas, United States

AUSTIN ENERGY SHINES PROJECT

- 1.75 MW/ 120 min Lithium Ion
- 2MW Rooftop PV
- Frequency response, back-up power, PV integration
- Commissioning: Q1/2018
- Goal: demonstrate a credible pathway LCOE of 14¢/kWh for solar energy when augmented by storage



C&I Case Study with Panasonic

PANASONIC HQ
SOLAR PLUS STORAGE FOR COMMERICIAL AND INDUSTRIAL CUSTOMERS

Denver, Colorado, United States

PANASONIC HEADQUARTERS

- **1 MW/120 min Lithium Ion**
- **1.8 MW PV**
- **Commissioning: Q1/2017**
- **Grid Connected providing multiple functions (See next slide)**

REVENUE STACKING (BEYOND UPS)

Multi-Use Storage for Greater Market Impact

- **Frequency Regulation** as an ancillary service to the grid
- **Solar Firming & Shifting** for both collocated solar & solar penetration on feeder
- **Peak Shaving** to reduce peak demand on the feeder deferring distribution upgrades
- **Back-up Power** capability to create islanded microgrid for 24/7 operation of the Panasonic NOC
- **Energy Arbitrage** charge a low prices and discharge at high prices

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Island Detection in Microgrids

A Case Study

POWER ENGINEERS

Presented by: Dan Jones, P. E., Keith Gray, P. E.
Coauthor: Heath Lessard, P.E.

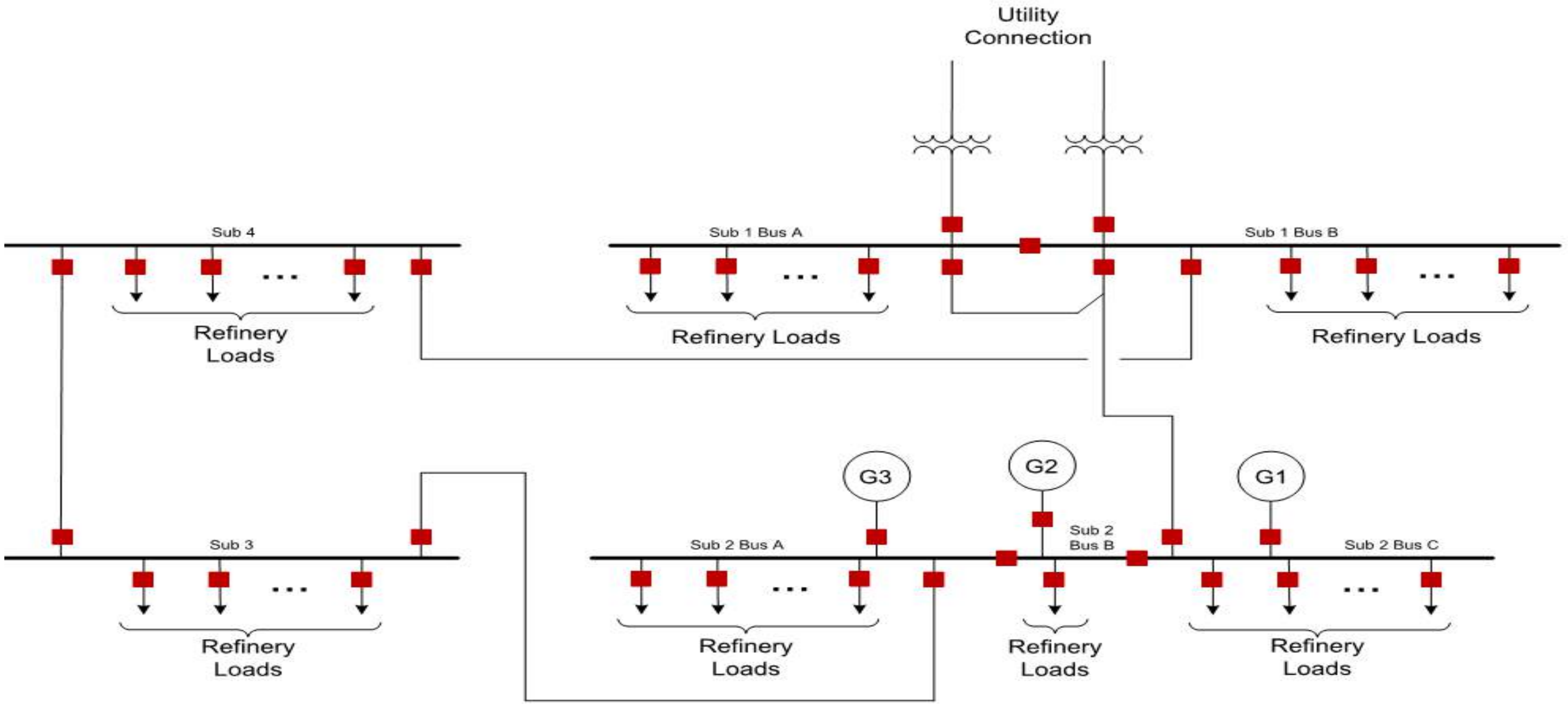
May 9, 2018

Introduction

- Oil refinery with cogeneration plant
  - *Refinery uses electricity and steam from cogeneration*

- Refinery-wide outage potential
  - *Generators could not stay online in the event the refinery electrical system was islanded from the utility*

System One-Line



Generator Control Systems

- **Normal Condition:** Generators operate in parallel with the utility
  - *Generator control systems take their frequency reference from the utility (droop mode of operation)*

- **Islanded Condition:** Frequency reference is lost
  - *The control system of one generator needs to become the new frequency reference for the other generators (Isochcronous mode of operation)*

Island Detection Goals

- **Detect** an island condition and change generator control mode to keep refinery loads online
  - *Must be fast, otherwise generator frequency may drift and trip offline on under or over frequency conditions depending on the generation to load mismatch at the moment of islanding*

- **Leverage** greater use of existing cogeneration to provide system reliability

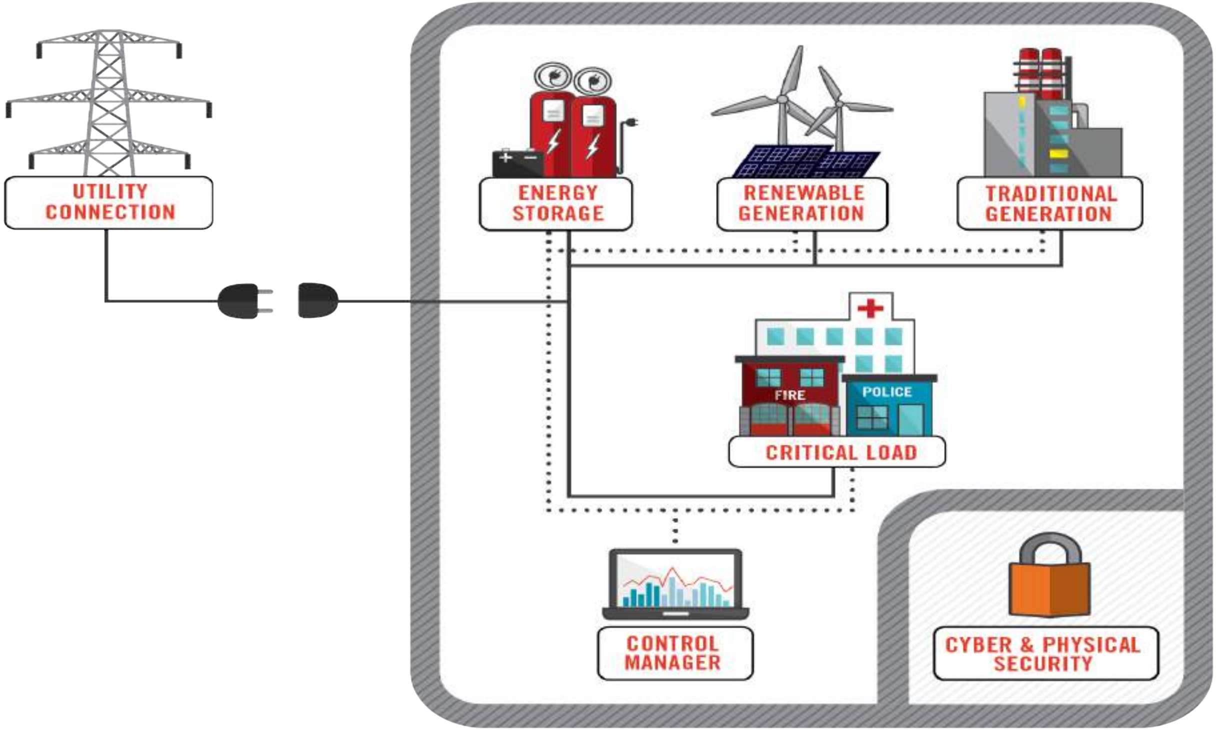
Island Detection Development Process

- Create Functional Specification
  - *Describes how the system is supposed to operate*
- Develop island detection logic
  - *Breaker statuses provided to Logic Processor by IEDs via IEC 61850 messages*
- Develop IEC 61850 configuration
- Develop settings for Logic Controller
- Bench Test Logic Controller settings
- Field Commission and Test System

Application to Other Microgrids

- Island detection applies to other microgrid generation types/control systems
  - *Inverter-based generation (PV, BESS, wind turbine)*
  - *Synchronous generators (Gas turbines, reciprocating machines, steam turbines, hydro)*
- Depending on the mix of generation control types, all of these control systems may benefit from being told the system is islanded
- Can be used to trigger load shedding

Questions?


UTILITY CONNECTION
ENERGY STORAGE
RENEWABLE GENERATION
TRADITIONAL GENERATION
FIRE
POLICE
CRITICAL LOAD
CONTROL MANAGER
CYBER & PHYSICAL SECURITY