SAND2017-8297PE

Exceptional service in the national interest

Sandia National Laboratories

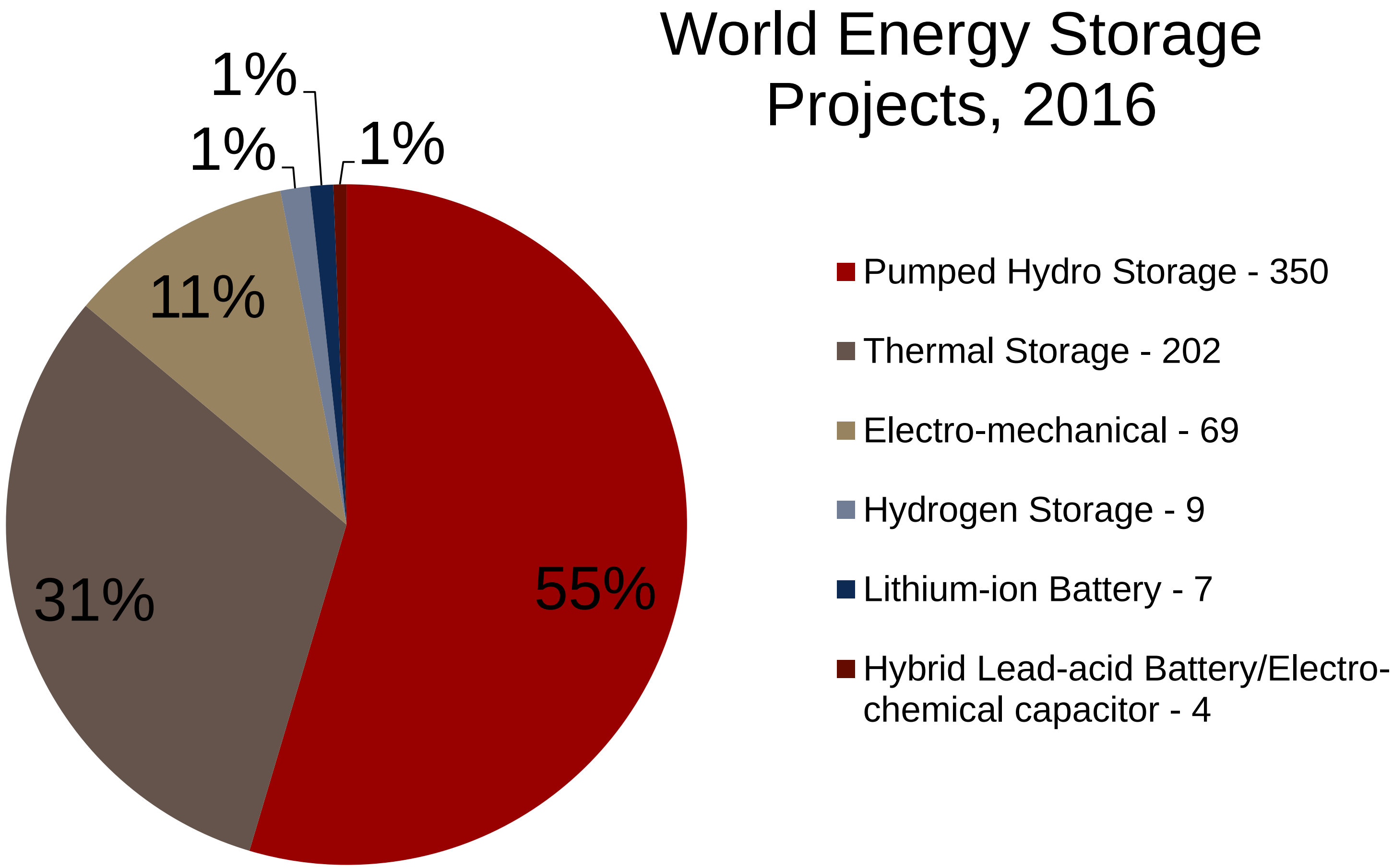
Sandia Grid Energy Storage

Stan Atcitty, Ph.D., Ray Byrne, Ph.D., Ben Schenkman

Why Do We Need Energy Storage?

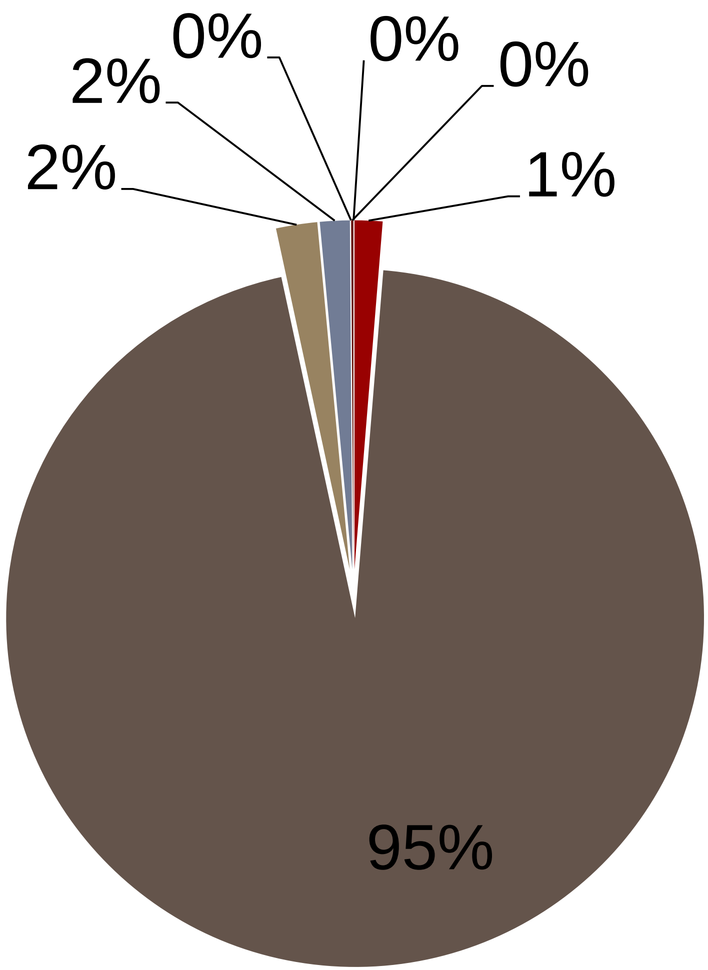
- Major reasons for installing energy storage:
  - Renewable integration
  - Transmission and Distribution upgrade deferral
  - Power quality, e.g., UPS application, microgrids, etc.
  - Improved efficiency of nonrenewable sources (e.g., coal, nuclear)
  - Off-grid applications (not the topic of this presentation)

Energy Storage in the Grid Today



Source: DOE Energy Storage Database, 2016

Energy Storage in the Grid Today



World Energy Storage
MW, 2016

- Electro-chemical - 2,446 MW
- Pumped Hydro Storage - 180,627 MW
- Thermal Storage - 3,615 MW
- Electro-mechanical - 2,611 MW
- Hydrogen Storage - 6 MW
- Lithium-ion Battery - 196 MW
- Hybrid Lead-acid Battery/Electro-chemical capacitor - 0 MW

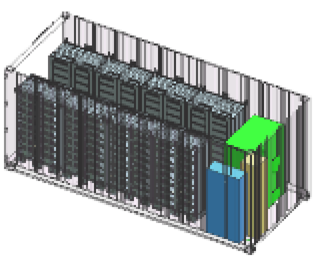
Source: DOE Energy Storage Database, 2016

Elements of Energy Storage System

Sandia National Laboratories

Storage

- Cell
- Battery Management & Protection
- Racking



Integration

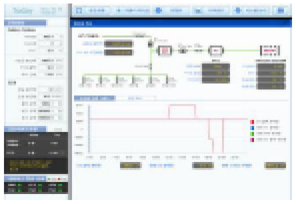
- Container / Housing
- Wiring
- Climate control

PCS

- Bi-directional Inverter
- Switchgear
- Transformer
- Skid

EMS

- Charge / Discharge
- Load Management
- Ramp rate control
- Grid Stability



Cost Structure of Storage System

Storage
Racks+BMS

+

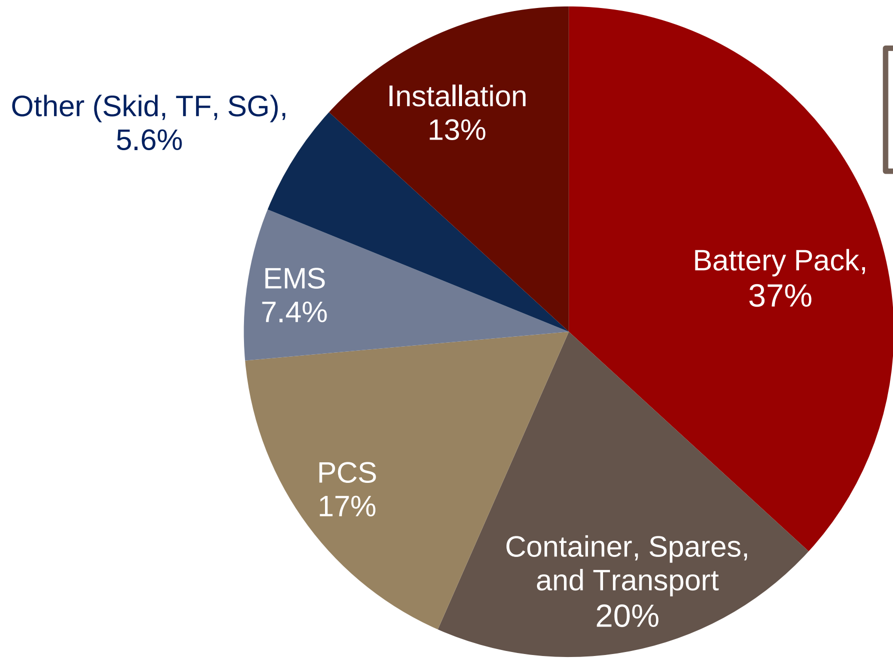
Product
Integration

+

Power
Conditioning
(PCS)

+

Field EPC
Grid Integration



1MW/1MWh
LIB ESS

Projected cost line items for a 1MW/1MWh Li-ion energy storage system ($600/kWh and above depending on the system configuration)

Almost 60% of storage system cost is outside the Battery Pack

Data: 2016 Multiple industry sources

Energy Storage at Sandia

Energy Storage is a major Crosscut at the lab.

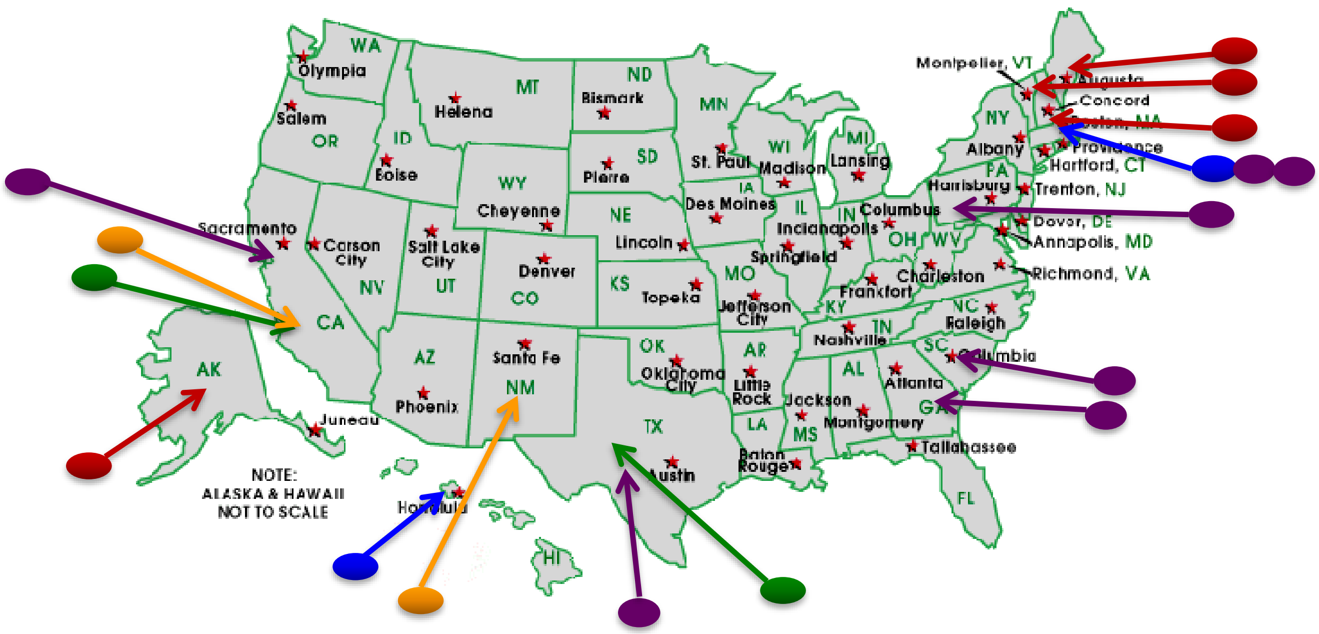
Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

Major R&D Thrust Areas

- Materials and Systems Development
  - Development of next-generation technologies
  - Improving current technology (flow batteries, flywheels, membranes, etc.)
- Power Electronics
  - Development of power electronics and power conversion systems.
- Energy Storage Systems Safety and Reliability
  - Fundamental Safety R&D of utility class storage systems
  - Laboratory testing and analysis from individual cells to 1MW systems
- ES Systems Demonstrations and Testing
  - Field deployments; State-Initiated Demonstration Project Development
- Grid Analytics and Policy
  - Providing assessments of the impact of storage placement
- Outreach - publications and meetings to help educate the Grid Energy community
  - EESAT and DOE Energy Storage peer review
  - US DOE Global Energy Storage Database
- Microgrid design

Field Demonstrations

To assistance regulators and utilities in determining how to utilize storage systems to maximize return on investment (ROI). Field demonstrations and pilot projects help to ensure ROI and facilitate adoption via improving confidence in safety, reliability, performance and cost effectiveness.



Legend: DoD, Commercial End User, State, Academia, Industry

DOE-OE Industry Acceptance and ESS Demonstration Program: Ongoing Projects

State Projects (CESA):
- Alaska – Cordova Electric Co-Op
- Connecticut DEEP
- Massachusetts DOER/CEC – Sterling Power, Cape and Vineyard, Holyoke
- NYSERDA
- Oregon Dept. of Energy/Eugene Water & Electric Board
- Vermont – GMP, Burlington Electric
- New Mexico – EMNRD, PNM

California/Hawaii:
- California CEC
- HECO
- HELCO
- NELHA
- Sunpower
- UCSD

Other Projects:
- DCICON (DoD)
- Group Nire, TX
- Los Alamos County

Industry Support
- GS Yuasa
- Helix
- Primus Power
- UET
- Transpower
- East Penn/ECOULT
- Aquion Energy
- MegaAmp (S. Africa)

International support:
- Pacific Rim
- WEICan (Canada)

Energy Storage Analytics

- Estimating the value of energy storage
  - Production cost modeling (vertically integrated utility)
  - LP Optimization (market area)
  - Stochastic unit commitment/planning studies (vertically integrated utility)
- Control strategies for energy storage
  - Wide area damping control
  - Control and architectures for MWh-GWh storage plants
- Model development (e.g. for dynamic simulation)
- Public policy: identifying and mitigating barriers
- Standards development and DOE Protocols
- Project evaluation
  - Technical performance
  - Financial performance

Estimating Value – Vertically Integrated Utility

- Sandia has performed studies for the following
  - Nevada Energy [1]
  - Southern Company [2]
  - Maui Electric Company [3]
- A study is currently under way for the Hawaiian Electric Company
- Typical cost savings come from being able to turn off expensive “must run” units (spinning reserve, regulation) and replace with energy storage

[1] J. F. Ellison, D. Bhatnagar, N. Saaman *et al.*, *NV Energy Electricity Storage Valuation,* SAND2013-4902, Sandia National Laboratories, Albuquerque, NM 87185, 2013.

[2] J. Ellison, D. Bhatnagar, C. Black *et al.*, *Southern Company Energy Storage Study: A Study for the DOE Energy Storage Systems Program,* SAND2013-2251, Sandia National Laboratories, Albuquerque, NM 87185, 2013.

[3] J. Ellison, D. Bhatnagar, and B. Karlson, *Maui Energy Storage Study,* SAND2012-10314, Albuquerque, NM 87185, 2012.

Maximizing Revenue – Market Area

- Recent case studies:
  - CAISO [1] (included sensitivity analysis to parameters)
  - ERCOT [2,3]
  - PJM [4]
  - ISO-NE (in progress – 2017 IEEE PES GM)
  - Singapore (in progress)
  - MISO (in progress – 2017 IEEE PES GM)

[1] R. H. Byrne, and C. A. Silva-Monroy, *Estimating the Maximum Potential Revenue for Grid Connected Electricity Storage: Arbitrage and Regulation,* SAND2012-3863, Sandia National Laboratories, Albuquerque, NM 87185, 2012.

[2] R. H. Byrne, and C. A. Silva-Monroy, "Potential Revenue from Electrical Energy Storage in the Electricity Reliability Council of Texas (ERCOT)," in IEEE Power and Energy Society (PES) General Meeting, Washington, DC, 2014.

[3] R. H. Byrne and C. A. Silva-Monroy, Potential revenue from electrical energy storage in ERCOT: The impact of location and recent trends," in Proceedings of the 2015 IEEE Power and Energy Society (PES) General Meeting, Denver, CO, July 2015, pp. 1-5.

[4] R. H. Byrne, R. Concepcion, and C. A. Silva-Monroy, \Estimating potential revenue from electrical energy storage in PJM," Proceedings of the 2016 IEEE Power and Energy Society (PES) General Meeting, Boston, MA, July 2016, pp.1-5.

Reports available at: http://www.sandia.gov/ess/

Standards Development

- Working with PNNL to develop performance protocols for the energy storage industry
  - Micro-grids (completed)
  - Frequency regulation (completed)
  - Peak shaving (completed)
  - PV smoothing (in progress)
- Working to generate a U.S. standard based on the protocols
  - ANSI
  - NEMA
  - IEC
- Industry user group is test driving the protocols

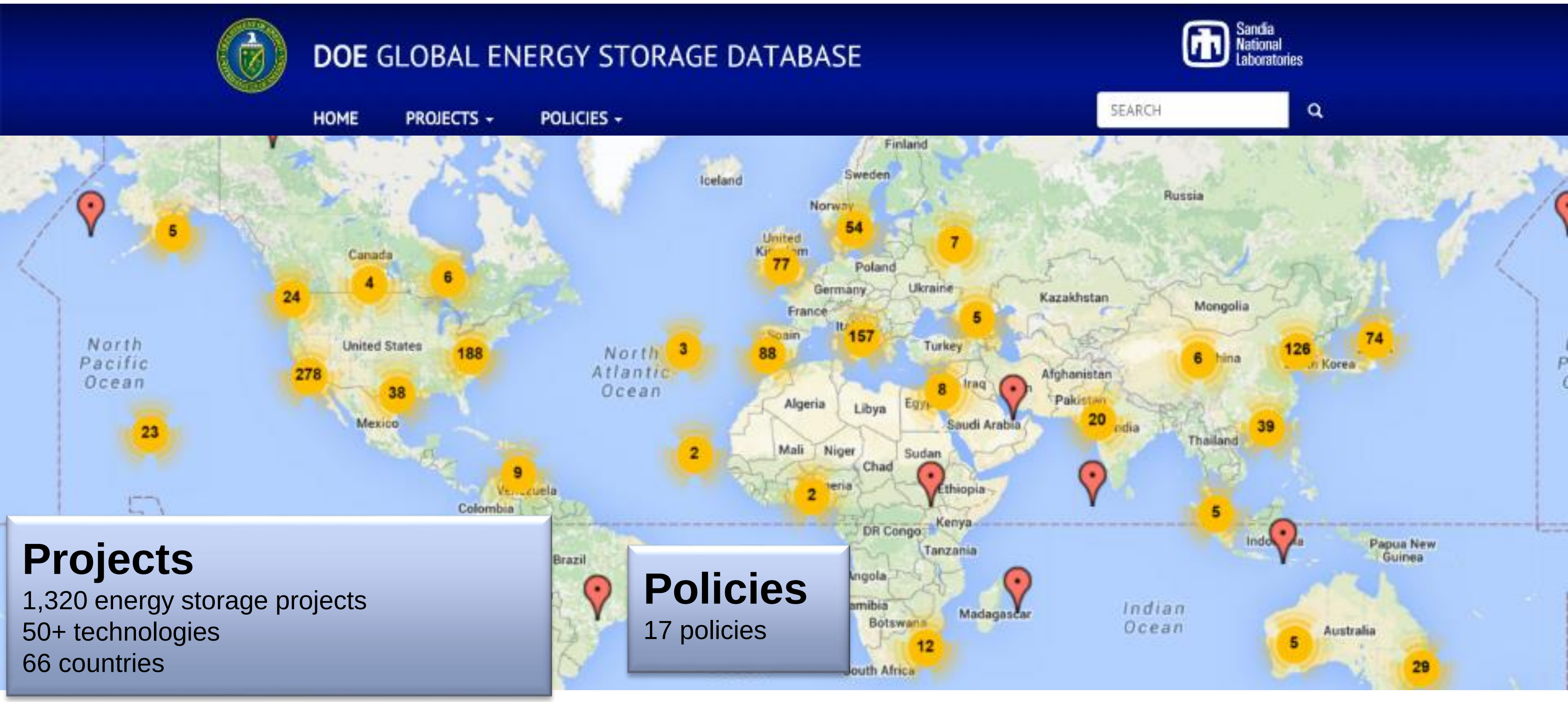
Outreach and Industry Tools

- ***DOE/EPRI Electricity Storage Handbook*** is a how-to guide for utility and rural cooperative engineers, planners, and decision makers to plan and implement energy storage projects safety in communities
- ***DOE Global Energy Storage Database*** provides free, up-to-date information on grid-connected energy storage projects and relevant state and federal policies.
- ***DOE Performance Protocol*** focuses on developing uniform methods of measuring ESS performance for specific applications.

Grid Storage – Installed Capacity

Sandia National Laboratories

Sandia maintains a comprehensive online resource of energy storage projects and policies.



Projects

1,320 energy storage projects
50+ technologies
66 countries

Policies

17 policies

Li batteries in storage: 900 projects, 2400 MWh
Compare that to 60GWh of PV that got installed in 2015 alone

Discussion Topics

- Emerging energy surety (safety, security, reliability) and resiliency drivers
  - Use of advanced microgrids for energy surety
  - Use of advanced microgrids to support DOE Smart Grid goal
  - Scales of advanced microgrid operations
- Summary of Sandia advanced microgrid capabilities and efforts – approach, analysis, testing, and training
- Sandia advanced military microgrid design efforts
  - Many CONUS and several OCONUS efforts
- Army advanced microgrid operational lessons learned study
- DoD Host Nation Power and advanced microgrid integration for energy assurance

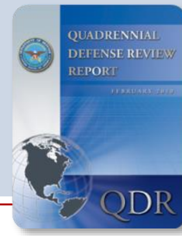
Energy Security Challenges

Goals Defined by stakeholders' authorities & responsibilities

DEPARTMENT OF ENERGY

2006 Strategic Plan

DEPARTMENT OF DEFENSE



Quadrennial Defense Review Report

DEPARTMENT OF HOMELAND SECURITY

2008 Strategic Plan Protecting Critical Infrastructure

Department of Energy goals:

- Diversify energy mix & reduce dependence on foreign petroleum
- Reduce green house gas emissions & other environmental impacts
- Create a more flexible, more reliable & higher capacity US energy infrastructure
- Cost-effectively improve energy efficiency of US economy

Department of Defense goals:

- Improve operational effectiveness
  - -Reduce energy demand
  - -Increase use of renewable energy supply
- Increase energy efficiency & protect against energy price fluctuations
- Reduce greenhouse gas emissions in support of US climate change initiatives

Department of Homeland Security goals:

- Decrease vulnerability of critical infrastructure to bad actors both physical & cyber
- Improve national power grid mod/sim capability to address national scale threats
- Improve port and coastal security – climate change impacts
- DHS concerned with interdependencies: Transportation, Energy, Defense

Focus on energy security, reliability, flexibility, and sustainability

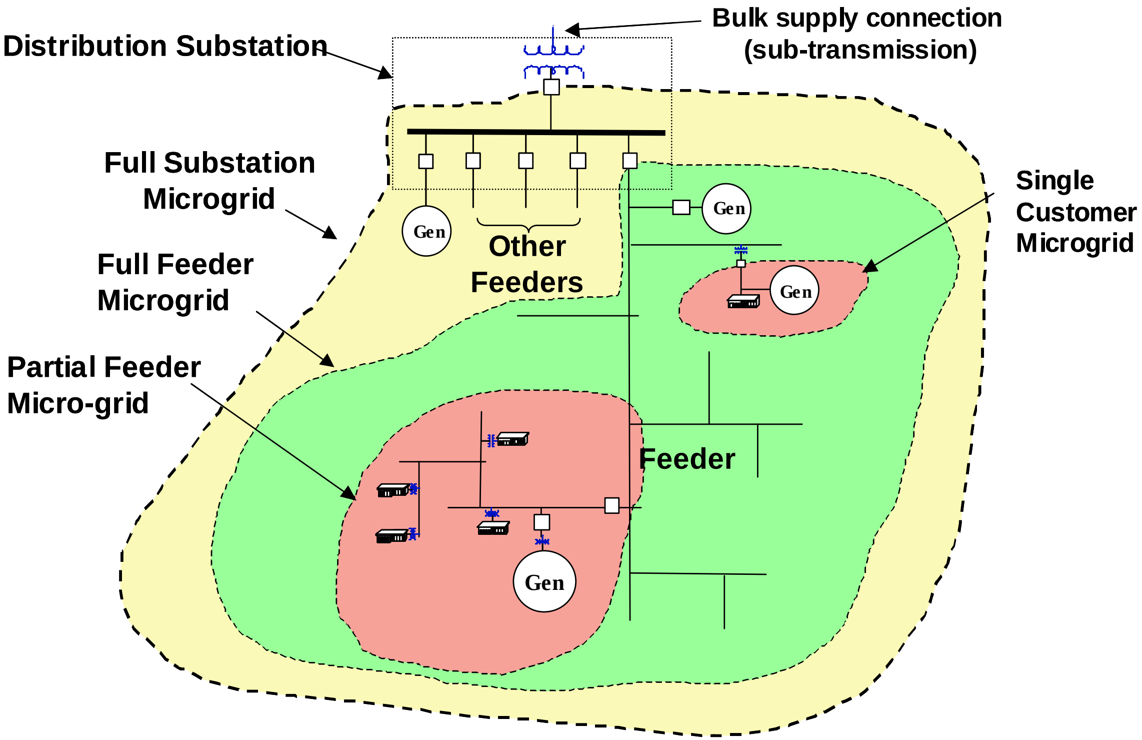
Advanced Microgrids – Smart Grid Building Blocks

STANDARD MICROGRID	• Operates where there is no large grid or operates generally islanded from the larger grid • Often used with a central power plant or CCHP plant to balance power and steam or cooling demand locally • Minimal grid interaction or support
ADVANCED MICROGRID	• Can integrate distributed generation and manage and control power demand and distributed resource allocation • Can operate islanded or grid-tied • Allow optimum use of energy resources during both power outages and for grid support
SMART GRID NODE	• Same functional capabilities as an advanced microgrid • Control capabilities to federate with other microgrids, if needed • Grid-tied operations are aggregated at microgrid level and coordinated with the grid operator to support grid operations

Advanced microgrids are the building blocks for Smart Grid Nodes, which in turn is one of the major power utility building blocks for the Smart Grid.

Advanced Microgrids Support Smart Grid and Energy Assurance Initiatives

- Allows distributed and renewable generation to operate grid-tied and islanded through point of common coupling (PCC)
- More efficient, cost effective, and reliable use of renewables and distributed generation
- Uses advanced control and monitoring vs. manual control



Ref EPRI

Nanogrid	Less than 10-kW, single-phase, residential
Small microgrid	From 100-kW to 500-kW, three phase
Commercial microgrid	Greater than 1 MW up to 20MW

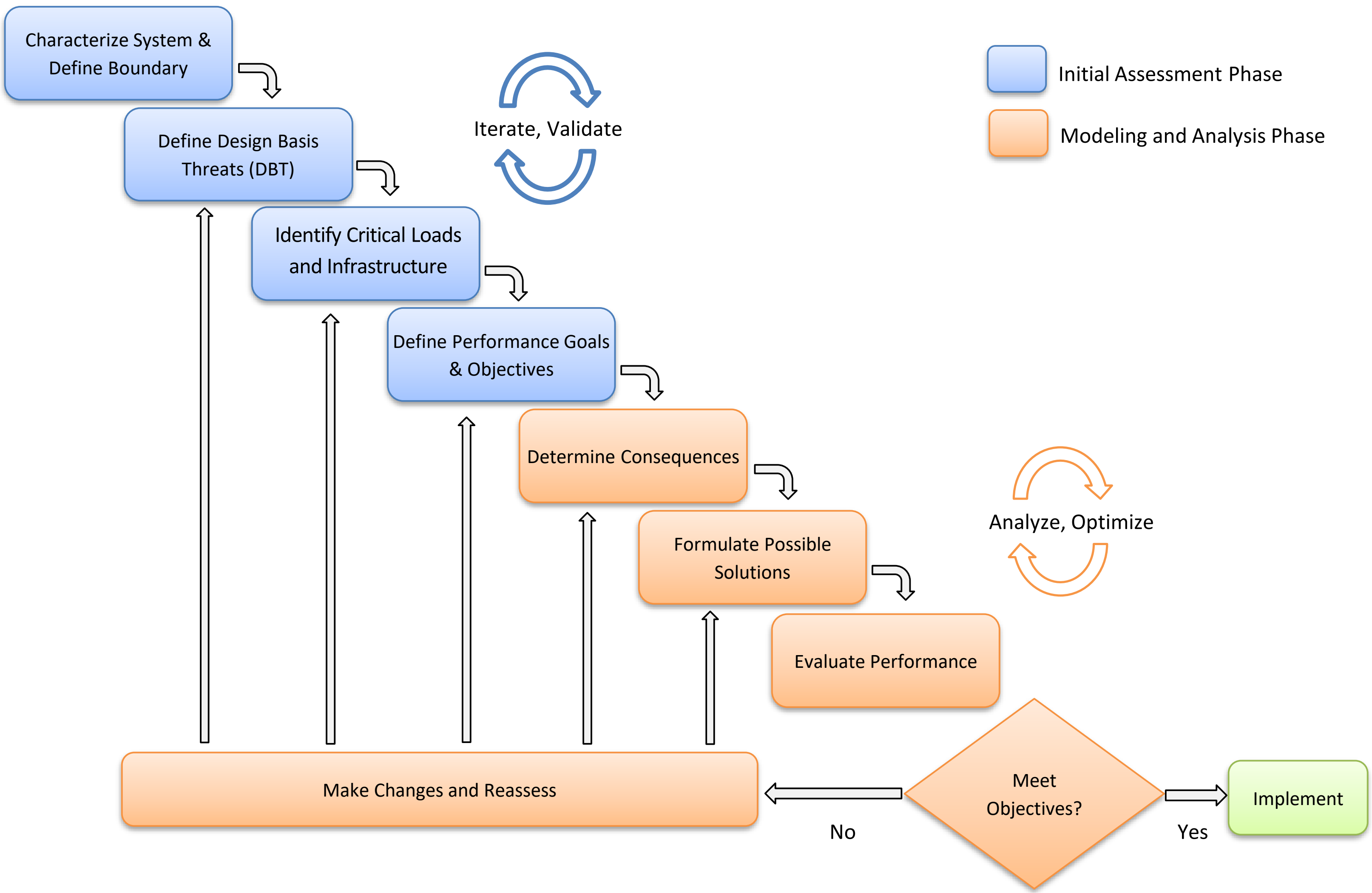
Capabilities and Benefits of Microgrid

- Emergency Power
- Power Quality
- Enhanced renewable, storage and CHP integration
- More efficient and cost effective than diesel standby
- Peak Shaving
- Demand Response
- Load Shedding

Sandia Advanced Microgrid Analysis, Modeling and Testing Capabilities

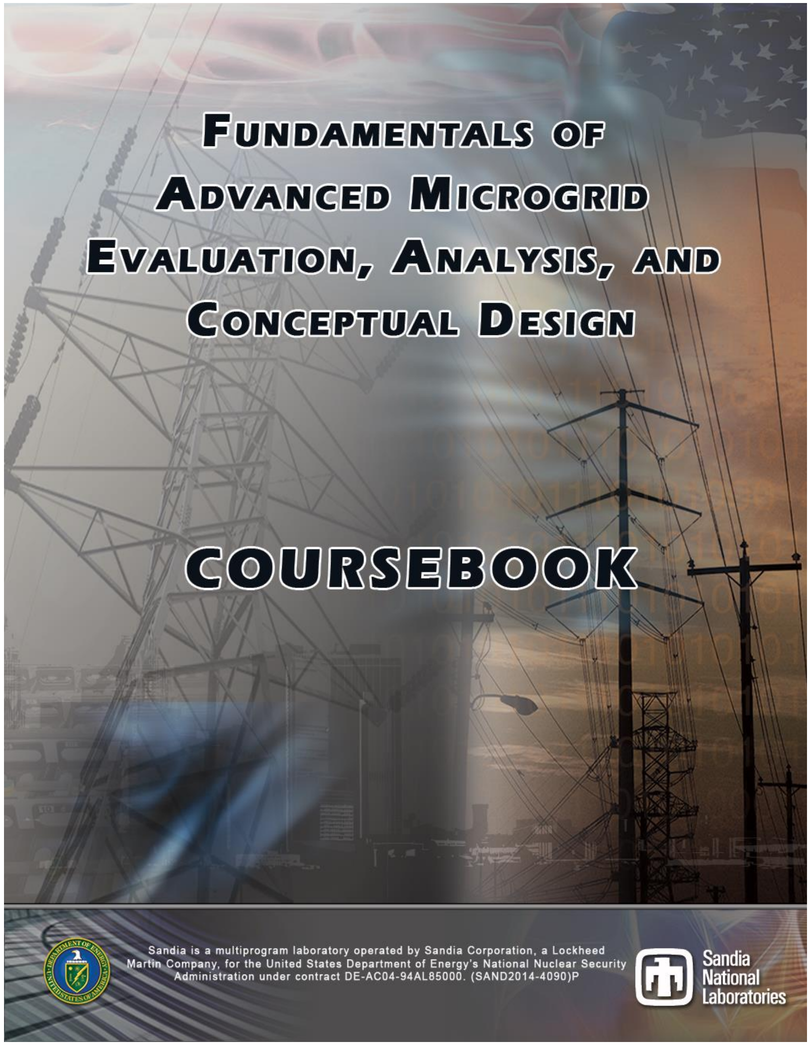
- Energy Surety Design Methodology
  - initiated in 2001 to provide performance-based, risk informed designs for energy infrastructures
  - Applied to electric power, energy pipeline, marine and railroad energy transport, and energy refineries
  - Used since 2006 for microgrid designs
- Distributed Energy Technology Laboratory
  - Operational 500 kW microgrid test facility with diesel, PV, microturbine, and energy storage resources to test power and load management and control approaches
- Scalable-Secure Microgrid Testbed
  - Laboratory testbed focused on control and integration of multiple microgrids
  - Agent-based and Hamiltonian DC and AC control research and cyber security protection
- Microgrid Design Toolkit
  - Series of user friendly energy reliability, consequence, risk, cost, and optimization models developed for DOE to support universal microgrid analysis and design

Energy Surety Design Methodology And Use for Advanced Microgrids



Advanced Microgrid Evaluation & Design Course

- Developed as a 3-day course
- 200 page course book
  - Background info, vugraphs, appendices of detailed data
- 50 page work book
  - Example problems and worksheets
  - Final microgrid design demo of full design and analysis process
- Course book and work book to keep as future reference
- Designed to be used by key stakeholders and technical users
- Organized to directly follow Sandia ESDM process



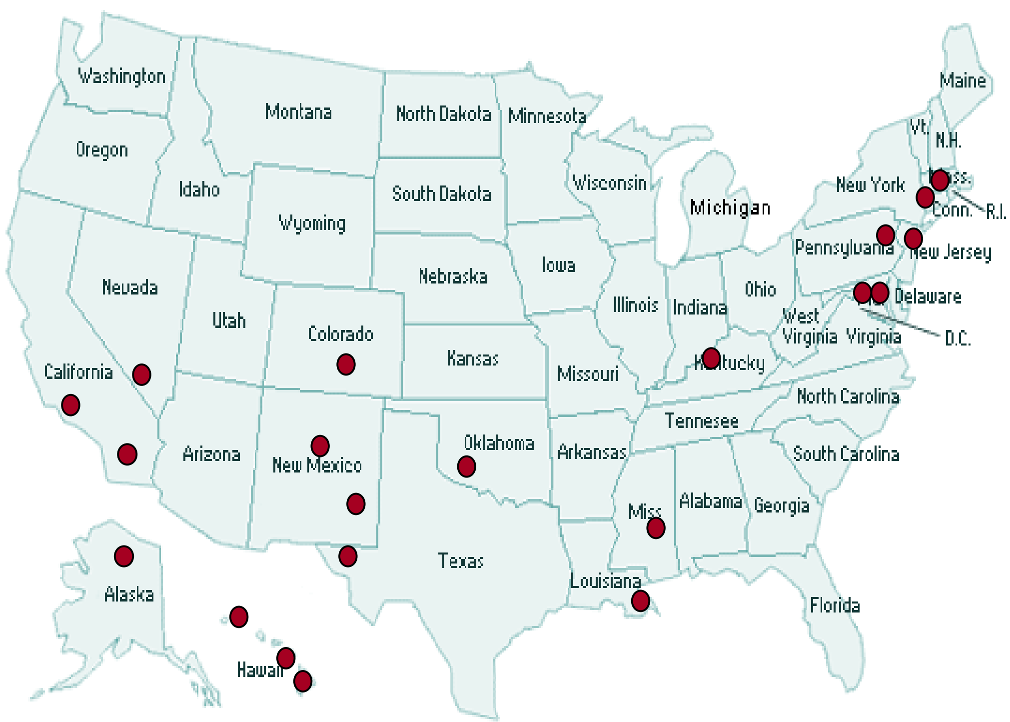
Advanced Microgrid Course Organization

- Module 1 – Introduction to Electric Power and Energy Surety
- Module 2 – Introduction to Microgrids
- Module 3 – Energy Surety Design Methodology
- Module 4 – Defining Energy System Boundaries
- Module 5 – Ranking Critical Assets and Services
- Module 6 – Identify Design Basis Threats
- Module 7 – Developing Performance Goals and Objectives
- Module 8 – Performance Risk Analysis
- Module 9 – Load Estimation Techniques
- Module 10 – Formulating and Evaluating System Reliability and Availability Options
- Module 11 – Design Option Cost Estimation

Energy Surety Microgrid Efforts

Conceptual Designs/Assessments	Small Scale Microgrid Demos	Large Scale Microgrid Demos	Operational Prototypes

• Creech AFB – FY12 DoD
• Soto Cano – FY12 DoD
• West Point FY12, DoD/DOE
• Osan AFB, FY 12, DoD
• Philadelphia Navy Yard – FY11, DOE OE/PIDC
• Camp Smith – FY10, DOE FEMP
• Indian Head NWC – FY09, DOE OE/DoD
• Ft. Sill – FY08, Sandia LDRD
• Ft. Bliss – FY10, DOE FEMP
• Ft. Carson – FY10, DOE FEMP
• Ft. Devens (99th ANG) – FY09, DOE OE/DoD
• Ft. Belvoir – FY09 DOE OE/FEMP
• Cannon AFB – FY11, DOE OE/DoD
• Vandenberg AFB – FY11, DOE FEMP
• Kirtland AFB – FY10, DOE OE/DoD
• Maxwell AFB – FY09, DoD/DOE
• Alaska Villages– FY12, DOE
• Bagram – FY13, DoD
• Kuwait – FY15, DoD
• 29 Palms – FY14, DoD
• Korea Naval Academy – FY16, DoD
• Kaui – FY15, DOE
• Northhampton, MA – FY14, DOE
• New Orleans – FY17, DOE
• UPS in KY – FY17, DOE
	• Maxwell AFB – FY09, DoD
	• Ft. Sill – FY09, DoD w/ SNL serving as advisor
		• SPIDERS JCTD – FY11, DOE/DoD
		  • Camp Smith
		  • Ft Carson
		  • Hickam AFB
			• H.R. 5136 National Defense Authorization Act



Army Advanced Microgrid Lessons Learned Study Goals

Sandia National Laboratories

- Evaluate and document current Army advanced microgrid operations and use
- Identify performance capabilities and limitations
- Identify benefits and best practices
- Provide recommendations on strategies and policies to improve the use of advanced microgrids to address energy security and costs more effectively

NYC After Tropical Storm Sandy -
Local microgrids provided energy reliability, security, and mission assurance

Evaluation criteria and site selection were developed and coordinated with ESTCP, MIT/LL, USACE/CERL, Army Installations-Energy and Environment, ORNL on CHP, LBNL on Unified Facility Guide integration, and Army EITF Program.

Summary of Advanced Microgrid Operations

Sandia National Laboratories

MICROGRID	CIRCA	POINT OF COMMON COUPLING	INTERCONNECTED GENERATION AND LOAD		DISCONNECT /RECONNECT[3] sec	POWER RELIABILITY	POWER SECURITY	ANCILLARY BENEFITS USED		
			GEN	LOAD				DEMAND SUPPORT	UTILITY BACKFEED	RENEWABLES INTEGRATION
Ft. A	1960	Substation	8MW	3MW	Man, <60 sec	x	x	x	x	-
Ft. B	1985	Feeder	4MW	2MW	Man, <60 sec	x	x	x	-	-
Ft. C	2005	Feeder	10MW	3MW	Man, <60 sec	x	x	-	-	-
Ft. D[1]	2005	Feeder	5MW	3MW	Auto, <10 sec	x	x	X	-	-
Ft. E	2012	Feeder	1.5MW	1MW	Auto, <10 sec	x	x	X	-	25%
Ft. F	2012	Feeder	4MW	2MW	Auto, <10 sec	x	x	-	-	-
Ft. G	2013	Feeder	3MW	1.5MW	Auto, <10 sec	x	x	-	-	30%
Ft. D[2]	2015	Feeder	5MW	3MW	Auto, <10 sec	x	x	x	-	-
Ft. G[2]	2016	Feeder	20MW	15MW	Auto, <10 sec	x	x	x	-	40%
H AFB	2000	Substation	80MW	15MW	Man, <90 sec	x	x	-	x	-
P/H Navy	2013	Feeder	1.2MW	1MW	Auto, <10 sec	x	x	X	-	20%
J Marines	2014	Feeder	8 MW	5 MW	Auto, <10 sec	x	x	-	-	20%

1 – Decommissioned
2 – Under planning/construction - Ft. D (ESTCP), Ft.G (IMCOM)
3 - ~ 60 sec needed for high value ancillary services

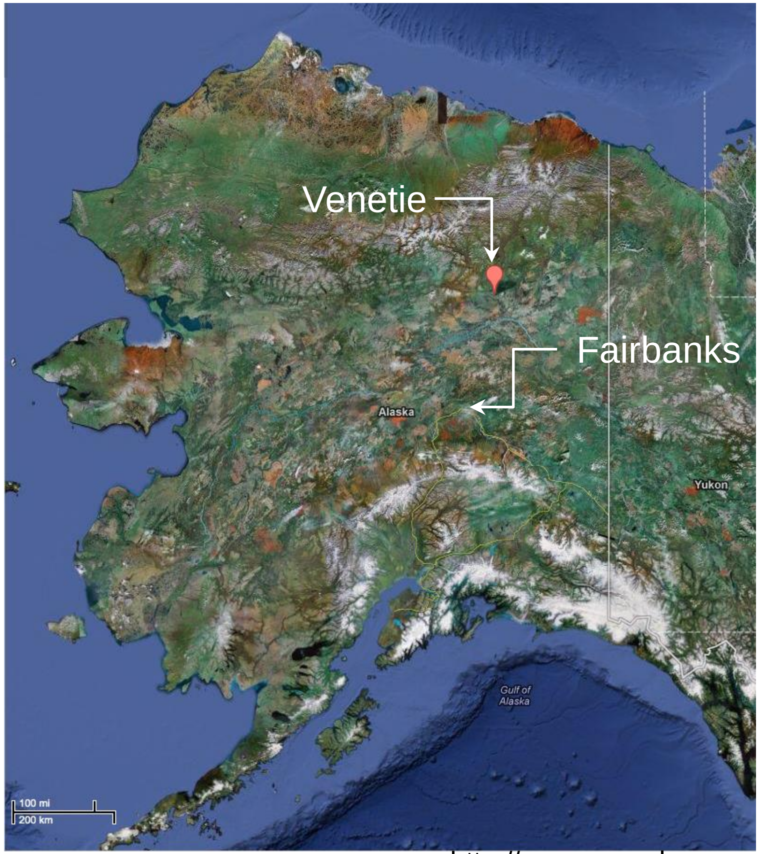
Current advanced microgrid operational focus is on energy security and reliability, but not taking full advantage of ancillary use and associated cost benefits.

Army Advanced Microgrid Lesson Learned Conclusions

- Army advanced microgrids are fundamentally designed and effectively operated to enhance critical mission energy security, safety, and reliability
- Most Army advanced microgrids are currently not operated in ways that enhance benefits of renewables integration or the cost effectiveness benefits of microgrid ancillary services
- Recommendations and strategies to improve and accelerate the cost-effective use of advanced microgrids include:
  - *Standardize microgrid evaluation, design, implementation,*
  - *Improve utility collaboration and operation coordination,*
  - *Increase microgrid metering, control, and associated training,*
  - *Establish microgrid operational training and testing requirements, and*
  - *Standardize renewable and energy storage integration approaches.*

Description of Venetie

- Village ~160 miles north of Fairbanks, Alaska
  - Located along the Chandalar River, a tributary of the Yukon River
  - In the foothills/base of Brooks Range
- Population: 166 (2010 census)
- Subsistence economy
- Access to village is exclusively by air transport
  - http://commerce.alaska.gov/cra/DCRAExternal/community/Details/916b06db-23c9-4c32-9ea2-2ab0b342199b



http://maps.google.com

Electrical System

- Generation: Three diesel generators
  - 180 kW (operational)
  - 190 kW (newly rebuilt and put into service in January 2013)
  - 125 kW (failed and probably will not be put into service in the foreseeable future)
  - Fed from external 1500 gallon tank adjacent to building
- Powerhouse
  - Old, wood-sided building on stilt foundation
  - Poorly ventilated and poorly lit interior
  - Undersized
  - Waste heat from generator is piped to adjacent washeteria
- Distribution System
  - Three single phase, pole-mounted 75 kVA transformers
  - 12.47/7.2 kV overhead
- On the AEA Rural Power Systems Upgrade List (September 2013, projects remaining category)

Venetie Conclusions

- The village of Venetie, Alaska is in need of a new electric power generating station
- Upgrading the existing station with new generators that match the given loads would result in annual operating cost savings due to greater operation efficiencies
- The surrounding area has few renewable resources – PV is currently best bet
- PV systems can be installed and savings will be seen
  - a 23 kW system that achieves 20% penetration
    - Simple payback payback ranges from 9.7 years to 13.6 years for cost of installation ranging from $10/watt to $14/watt, respectively
    - LCOE is 5% less than current costs (assuming $10/W install and CF of 10%)
  - 46 kW system that achieves 40% penetration (needs energy storage)
    - Simple payback payback ranges from 14.9 years to 20.4 years for cost of installation ranging from $10/watt to $14/watt, respectively
    - LCOE is 14% greater than current costs (assuming $10/W install and CF of 10%)
  - 92 kW system that achieves 80% penetration (needs energy storage)
    - Simple payback payback ranges from 24.6 years to 32.6 years for cost of installation ranging from $10/watt to $14/watt, respectively, for
    - LCOE is 66% greater than current costs (assuming $10/W install and CF of 10%)
- Consequences of increasing the size of the PV systems and the correlating penetration
  - Forces the need of an energy storage system
  - Pushes the simple payback further out into the future
  - Drives the internal rate of return negative and unfavorable LCOE
- A 20 kW PV system has the best return on investment
- Need more complete load data in order to produce a more robust set of options to evaluate potential savings

Contact

Stanley Atcitty (Stan), Ph.D.
Distinguish Member of Technical Staff
Energy Storage Technology and Systems Dept. 06111
Sandia National Laboratories

Phone: 505-284-2701
Email: satcitt@sandia.gov

Ray Byrne, Ph.D.
Distinguish Member of Technical Staff
Energy Storage Technology and Systems Dept. 06111
Sandia National Laboratories

Phone: 505-844-8716
Email: rhbyrne@sandia.gov

Ben Schenkman
Senior Member of Technical Staff
Energy Storage Technology and Systems Dept. 06111
Sandia National Laboratories

Phone: 505-284-5883
Email: blschen@sandia.gov