High-MW Electronics – Key to a Future Grid which is Smarter, Greener, more Robust and more Reliable

It is hardly controversial to assert that the fundamental Generation, Transmission and Distribution technology of the US Grid has been relatively unchanged over the last century. As we enter an era of increased renewables, metering, instrumentation, communication and computation applied to the Grid there are some intriguing choices in front of us that can lead to a wide range of outcomes. If these new technologies, particularly renewables, are introduced on the path that has been followed to date they will likely lead to a significantly less reliable grid than we have today, and while large quantities of clean energy may be generated, as non-dispatchable resources this will not save any capital spending on conventional generation technology and will not significantly impact the use of inefficiently operated fossil fuel plants as spinning reserves. Conversely, a different path to grid integration of renewables and the use of these resources to control real and reactive power flows on the Grid could lead instead to an enhanced Grid in terms of reliability, dynamic stability and efficiency. The key is the utilization of the potential of the High-MW electronics that will interconnect the renewable resources to the Grid. High-MW electronics will also be an integral participant in achieving our national policy to modernize the grid. Several key characteristics of the Smart Grid as promulgated by the Energy Infrastructure and Security Act of 2007 Title XIII "Smart Grid" are copied below.

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
(2) Dynamic optimization of grid operations and resources, with full cyber-security.
(3) Deployment and integration of distributed resourcesand generation, including renewable resources.
(4) Deployment of ''smart'' technologies (real-time, automated,interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications, concerning grid operations and status, and distribution automation.
(5) Integration of ''smart'' appliances and consumer devices.
(6) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.

Success in achieving these characteristics will require the use/inclusion of High–MW power electronics, if these goals are to have any relevance to and effectual impact on the actual operation of the nation's future modernized electric power system.

A group of Market Development and Technical leaders have been meeting as the "High-MW Working Group" for the past several years, with focus on developing a Roadmap to achieve high penetration of high power electronics into the US Grid. This work grew originally from the realization that coal gasification efforts, in the Clean Coal initiative, would lead to large quantities of hydrogen that could in turn power large fuel cells which would need to be interconnected to the Grid through appropriate electronics at the Transmission level, whether ac or dc. As wind and particularly solar PV generation has ramped up, this original thrust towards power electronics has only become more relevant. The subsequent NIST hosted workshops and road-mapping effort focused on:

- Advancing Power Electronics for large scale grid integration of Alternative Energy Generation sources, particularly Fuel Cells, Wind and Solar PV, focusing on cost, performance and Controllability (by Utilities)
- Power Systems Architectures and Control for high-penetration of Intermittent Renewables, with High-MW electronics as the key mitigation mechanism for system disturbances
- Modification of regulations and standards to avoid the difficulties encountered with high-penetration of renewables in Europe, where tripping of Inverters under moderate Grid transients caused major problems

The High-MW electronics road mapping effort has brought together representatives of the key Utility and Industry stake holders in addressing the fundamental barriers to successful application of MW scale Grid-connected electronics and the future acceptance and adoption of the same. One particular focus has been to advocate for changes of the IEEE-1547 voltage and frequency trip specifications to avoid the cascading blackouts that Europe experienced in the summer of 2004. At this time these trip points for Grid power electronics are too tight, are orders of magnitude tighter than for conventional thermal power plants, and have the effect that the Inverters trip off at exactly the time they are needed which is when a disturbance has been caused by either a fault or a Power Plant tripping off. This is a fundamental barrier to a high level of penetration of Renewables, and wherever a high penetration has been achieved the Utility concerned has waived compliance with the standard. Post event review of the U.S. Northeast blackout of 2003 also identified lack of dynamic VAR resources as a contributing factor to that major outage. While the frequency-instability on the Eastern Interconnect that led up to the final blackout does not completely support this view, High-MW electronics can play an important ancilliary role as dynamic VAR machines. Another approach being considered to mitigate the effects of intermittency of renewables is to provide through the inverter acceptable ramp-rates under the control of the local Utility, through their SCADA system, to avoid destabilizing the local grid.

Inconsistencies across technical standards also mutes uptake of new technologies and their associated benefits. An example is the inconsistency between anti-islanding requirements of IEEE 1547 and the ride-through requirements of wholesale interconnection standards (FERC Large Generator Interconnection Procedures, LGIP). Large wind projects have been the first to exceed the FERC LGIP threshold (>20MW) and have had to incorporate ride-through capabilities. Other renewable projects that are inverter-interconnected will also be increasingly deployed at these larger magnitudes. Building High-MW inverters for multiple and sometimes conflicting technical criteria is not efficient. “Harmonization” of these and similar inconsistent standards will foster smoother transition of renewable technologies that will be evolving to deployment at much larger scale, connected to the grid as large wholesale generation projects.

With the excitement around the imminent investment into the “Smart Grid” and with attention extending beyond demand-response and metering programs and now also been paid to high-penetration of renewables, and of advanced Power Systems architectures such as Micro-Grids, the High-MW activity seems to offer some pointed solutions. Our contemporary Grid is almost purely an electro-mechanical device with the electronics distributed on the edge of the grid, and largely the consumption edge at that, in the form of meters and instrumentation. Power Electronics connected to the grid in large amounts, as the gateways for alternative energy sources, offer the ability to switch and control power at speeds that are many orders of magnitude faster than today’s grid connected switching and protection devices.

Our vision is of a Future Grid that incorporates renewables as Dispatchable resources, often in Distributed Generation environments where they can form vital components of grid-interactive microgrids. This Future Grid is demonstrably more rugged, reliable and robust than today’s Grid with significantly higher 9’s of availability, is significantly greener, also significantly more efficient and more secure. One key element of this future is the physical layer of the grid, long taken for granted, which must move to be more electronic and so higher speed and more flexibly controlled than the synchronous generators and exciters of today. But, without proactive steps by industry during this major transition period, implementation and delivery of these demonstrable benefits are not assured.

As we examine the major outages of the recent past we find a common thread or theme, excessively slow response time. Instabilities with frequencies significantly longer than 1 sec, lead eventually to complete system collapse because there is nothing on the Grid capable of responding. A moderate amount of grid connected power electronics can and will change this dynamic and we believe that the High-MW group can join with others in bringing this capability forward in a timely manner.

Recently the High-MW group was able to provide valuable advice and knowledge to the NIST led smart grid interoperability effort, particularly as it relates to the physical layer of the Grid. Our community provided much of the expertise at a series of workshops and aided in setting a direction for development of Smart Grid Interoperability Standards that will lead to higher penetration of renewable energy with the inverter acting as a grid stability asset as oppose to a liability, and providing a true reduction of fossil fuel plants operated inefficiently as spinning reserves.

The time has come to reassemble and renew our efforts to advance the cause of High-MW electronics and high-penetration of renewables.

Hi-MW Working Group

Dr. Leo F. Casey, Satcon Corporation

Bob Reedy, Florida Solar Energy Center

Charlie Vartanian, A123 Systems

Dr. Le Tang, ABB Inc.

David Nichols, Altairnano, Inc.

Tarek Abdallah, ERDC-CERL

Madhav Manjrekar, Siemens

High MW Electronics – Industry Roadmap Meeting

December 11th, 2009
8:30am – 3:00pm

Challenges to Growth of Grid Connected Electronics

8:30am	Opening Remarks, High MW Roadmap Committee and NIST Host
9:00 am	David Prend, Rockport Capital, “Barriers to Large Scale Grid Penetration”
9:30am	John Lushetsky, DOE Solar Program, Program Manger
10:00	Colin Schauder, Satcon, Satcon Fellow “Isochronous Grid through Electronics”

10:30 – 10:50 BREAK

10:50	Jeffrey B. Casady, SemiSouth, “ Recent Advancements in SiC power devices & the impact of normally-off SiC JFETs on PV and wind inverter platforms“
11:20	Jerry FitzPatrick, NIST on Smart Grid Interoperability
11:40	Al Hefner, NIST on Energy Storage PAP for Smart Grid Interoperability

12:00 – 12:45 LUNCH

12:45pm	Charlie Vartanian, A123 Systems Energy Solutions Group, “Storage; Smart interfaces for Frequency Regulation & Beyond” “Storage, Storage interfaces, Frequency Regulation”
1:15pm	Madhav Manjrekar, Siemens, “Green Energy and Power Systems”
1:45pm	Le Tang, ABB “Smart Grids and Power Electronics”
2:15pm	Kevin Tomsovic, University of Tennessee “Power System Control Issues for Renewable Integration”

2:45-3:00pm Concluding Remarks and Adjourn

Executive Summary

High MW Electronics – Industry Roadmap Meeting

December 11th, 2009
8:30am – 3:00pm

Challenges to Growth of Grid Connected Electronics

Meeting Agenda

8:30 am	Al Hefner, NIST - Opening Remarks, High MW Roadmap Committee and NIST Host
9:00 am	David Prend, Rockport Capital - Barriers to Large Scale Grid Penetration
9:30 am	John Lushetsky, DOE Solar Program, Program Manger
10:00 am	Colin Schauder, Satcon, Satcon Fellow - Isochronous Grid through Electronics

10:30 – 10:50 am Break

10:50 am	Jeffrey B. Casady, SemiSouth – Recent Advancements in SiC Power Devices and the Impact of Normally Off SiC JFET's on PV and Wind Inverter Platforms
11:20 am	Jerry FitzPatrick, NIST - Smart Grid Interoperability
11:40 am	Al Hefner, NIST - Energy Storage and Priority Action Plans for Smart Grid Interoperability

Noon – 12:45 pm Lunh

12:45 pm	Charlie Vartanian, A123 - Storage, Smart Interfaces for Frequency Regulation and Beyond
1:15 pm	Madhav Manjrekar, Siemens – Green Energy and Power Systems
1:45 pm	Le Tang, ABB, - Smart Grids and Power Electronics
2:15 pm	Kevin Tomsovic, University of Tennessee – Power System Control Issues for Renewable Integration
2:45pm	Concluding Remarks
3:00 pm	Adjourn

Summary of Key Presentation Points

This summary highlights the key points made by each of the individual presenters. Readers are encouraged to view the individual presentations to obtain additional details. Attachment 1 contains a list of meeting attendees

Al Hefner, Opening Remarks, High MW Roadmap Committee and NIST Host

David Prend, Rockport Capital - Barriers to Large Scale Grid Penetration

- The technologies needed for the "smart grid" currently exist
- Based on the experience in other nations (i.e. Spain, Germany) significant increases in market penetration by renewable generation are possible
- The real problem is demand and financing
- Learning curve experience results in significant cost reduction – (i.e. - for every doubling of cumulative capacity, the cost of wind power decreases by 10%)
- Conclusions
    - Deal with demand side and supply will be there
    - Focus on institutional barriers rather than technical barriers

John Lushetsky, DOE Solar Program, Program Manger

- As cumulative installed capacity has increased, the cost of modules based on crystalline and amorphous Silicon and Cadmium Telluride cells have all decreased significantly
- In 2008, California alone installed 158 MW, exceeding the 150 MW growth achieved by entire U.S. in 2007. Outside California, annual installations grew 83% in 2007 over 2006.
- DOE's Office of Energy Efficiency and Renewable Energy accounts for almost 40% of early-stage Cleantech funding
- DOE is funding the development of SEGIS (Solar Electric Grid Integration System) which is focused on new requirements for interconnecting PV to the electrical grid, including intelligent hardware that strengthens the ties of smart grids, microgrids, PV, and other distributed generation.

Colin Schauder, Satcon, Satcon Fellow, - Isochronous Grid through Electronics

- Electronic generators began service in the 1990's as parts of other equipment types for VAR generation, voltage support, flicker reduction, transmission line power flow control, power oscillation damping, and underwater and underground power transmission by cable
- Connected to DC generators, these same designs could serve as very high performance AC generators for the grid
- The capability of an electronic generator could be used for grid control by

emulating a conventional synchronous machine generator in a conventional AC interconnection or establishing an isochronous AC interconnection area under electronic control
- Electronic generators can be used to maintain constant grid frequency, instantaneously absorb real and reactive load/generation differences, provide DC inter-ties for stable power exchange with other AC grid segments, and respond rapidly to control center commands through secure high-speed communications
- The challenges for proponents of utility-scale electronic generators are to achieve high reliability and availability and develop/incorporate suitable energy storage

Jeffrey B. Casady, SemiSouth – Recent Advancements in SiC Power Devices and the Impact of Normally Off SiC JFET's on PV and Wind Inverter Platforms
- SemiSouth SiC (Silicon Carbide) JFETs (Junction Gate Field Effect Transistors) can replace IGBTs (Insulated Gate Bipolar Transistors) and MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) for higher efficiency and higher frequency switching with power dissipation reduced by over 50%
- World record (> 99%) PV inverter efficiency has been demonstrated in the field
- SiC FET devices are suitable up to 3-4 kV, and are being released now

Jerry FitzPatrick, NIST- Smart Grid Interoperability
- Smart grid requirements - accommodate rapid growth in renewable energy sources such as wind and solar, empower consumers with tools to manage and reduce energy use, and enhance reliability and security of the electric system
- 20% of current grid capacity is needed to serve 5% of highest usage hours
- Combining electrical and information infrastructure to create a "smart grid" requires interoperability which requires reliable standards and validated performance
- The NIST role – n cooperation with the DoE, NEMA, IEEE, GWAC, and other stakeholders, NIST has "primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems"
- Smart Grid Interoperability Panel, a public-private partnership formed in November 2009, is a permanent body which supports NIST in setting standards for U.S. smart grid, coordinates but does not develop standards, with over 360 founding member organizations

Al Hefner, NIST - Energy Storage Priority Action Plans for Smart Grid Interoperability
- The current US grid delivers 60 Hz uni-directional AC power produced in large central plants by rotating machines
- As the amount of intermittent, renewable (wind and solar), distributed power generation increases, and the demand side changes to include electric vehicles the character of the grid must change
- The new "smart grid" paradigm requires advanced, high megawatt, cost-effective power conditioning systems
- Meeting energy storage and cyber-security issues is a major challenge

- Development of standards is an enabling requirement
- NIST and the Smart Grid Interoperability Panel will guide and oversee progress on Priority Action Plans (fourteen are currently being developed)

Charlie Vartanian, A123 - Storage, Smart Interfaces for Frequency Regulation and Beyond

- PCS capabilities for full grid benefit include Steady State W power transfer plus:
  - Steady State VAR, *voltage reg.*
  - Transient W, *a/c stall barrier*
  - Transient VAR, *sag mitigation*
  - Dynamic W, *damping, inertia*
  - Dynamic VAR, *voltage stability* \Islanding, *reliability*
- Battery energy storage with frequency response capability is technically reliable today, but the barrier to wide-spread deployment is a viable investment recovery mechanism

Madhav Manjrekar Siemens – Green Energy and Power Systems

- Evolution to a Smart Grid:
  - From control generation and central control to distributed generation and distributed control
    - Penetration of renewables
    - Inclusion of energy storage
  - From load flow by Kirchoff's Law to load flow by power electronics
  - From manual switching, trouble response to automatic switching, anticipatory response with built-in intelligence
  - From periodic maintenance to prioritized, condition-based predictive maintenance

Le Tang, ABB, - Smart Grid and Power Electronics - Why Do We Need High MW Electronics

- A smart grid is the evolved system that manages the electricity demand in a sustainable, reliable, and economic manner built on advanced infrastructure and tuned to facilitate the integration of the behavior of all involved
- The major requirements of a visionary smart grid are
  - Capacity - Upgrade/install capacity economically and provide additional infrastructure (e-cars)
  - Reliability - Stabilize the system and avoid outages and provide high quality power all the time
  - Efficiency - Improve efficiency of power generation and reduce losses in transport and consumption
  - Sustainability - Connect renewable energy to the grid and manage intermittent generation
- Medium voltage variable speed drives are needed because
  - 60 - 65% of industrial electrical energy is consumed by electric motors
  - For each 1 USD spent to purchase a motor, 100 USD are spent for energy cost during its lifetime

- Today, only 5% of these motors are controlled by variable speed drives
- 30% of existing motors can be retrofitted with variable speed drives

- Smart Grid needs high MW electronics
  - Solid-state substation provides current switching, current interrupting current limiting, and transformer
  - Challenges include high reliability, low losses, thermal management/cooling, high switching frequency, high blocking voltage for direct MV connection, high power density/footprint, low cost

Kevin Tomsovic, University of Tennessee – Power System Control Research Issues

- Existing power control systems are:
  - Connected system built upon rotating machines with high inertia and relies on dependable patterns of consumption
  - Very little load is controllable, instead generation tracks daily load curve
  - System has been engineered to meet peak demands
  - Numerous central controls acting largely independently
  - Localized control schemes primarily for protection
- Needed system changes
  - A broader electric grid to include energy end use
  - Increased scheduling capability through local management for existing loads and the addition of new loads
  - New and reconfigurable transmission to improve source diversity
  - Provide effective storage through combination of fast-start units, PHEV's, low-level UPS, and utility-scale storage
  - A flattening of the control structure that replaces the traditional control strategies with simpler local controls operating within a more global context for the system
- Some potential topics for research in the area of control include speed of response, amount of response, need for new transmission and determining transmission limits in real time

Attachment 1

Registration List

High Megawatt Workshop
December 11, 2009
NIST Headquarters, Gaithersburg, MD

Name	Affiliation	E-mail Address
Abdallah, Tarek	US Army	t-abdallah@cecer.army.mil
Atcitty, Stan	Sandia National Laboratories	satcitt@sandia.gov
Bennett, Aaron	North American Electric Reliability Corp. (NERC)	Aaron.bennett@nerc.net
Biondo, Samuel J.	DOE-HQ (Retired)	sjbiondo@verizon.net
Biroschak, Ben	NEMA	Ben.biroschak@nema.org
Casady, Jeff	SemiSouth Labs	jeff.casady@semisouth.com
Casey, Leo	Satcon Technology	Leo.casey@satcon.com
Grider, David	Cree, Inc.	david_grider@cree.com
Johnson, Melanie	US Army CERL	m-johnson@cecer.army.mil
Kub, Fritz	Naval Research Laboratory	fritz.kub@nrl.navy.mil
Lesster, Laban E (Ted)	Satcon Technology Corporation	Ted.Lesster@Satcon.com
Litzinger, Kevin	Siemens	Kevin.litzinger@siemens.com
Lukas, Michael	FuelCell Energy, Inc.	mlukas@fce.com
Lushetsky, John	US Department of Energy Office of Solar, EE-2A	John.lushetsky@ee.doe.gov
Lynn, Kevin	Sentech, Inc.	Kevin.Lynn@ee.doe.gov
Manjrekar, Madhav D.	Siemens Corporate Research	madhav.manjrekar@siemens.com
Munro, James	Satcon technology Corporation	Jim.munro@satcon.com

Pierre, Joe	Siemens Energy, Inc. Stationary Fuel Cells	Joseph.pierre@siemens.com
Prend, David	RockPort Capital Partners	dprend@rockportcap.com
Price, Jack L.	ODDR&E, Research Directorate, Weapons Systems	jack.price@osd.mil
Reedy, Robert Martin	Florida Solar Energy Center at UCF	reedy@fsec.ucf.edu
Reidpath, Maria	US DOE / NETL National Energy Technology Laboratory	maria.reidpath@netl.doe.gov
Roettger, Thomas D.	Northrop Grumman	t.roettger@ieee.org or thomas.roettger@ngc.com
Schauder, Colin D	Satcon Technology Corporation	colin.schauder@satcon.com
Singh, Ranbir	GeneSiC Semiconductor Inc.	Ranbir.singh@genesicsemi.com
Soboroff, Mike	Department of Energy, Office of Electricity Delivery and Energy Reliability	mike.soboroff@hq.doe.gov
Stevanovic, Ljubisa	GE Global Research Center	stevanov@ge.com
Tang, Le	ABB Inc.	le.tang@us.abb.com
Tomsovic, Kevin	University of Tennessee - Knoxville	tomsovic@tennessee.edu
Vartanian, Charles	A123 Systems	cvartanian@a123systems.com
Wolk, Ron	Wolk Integrated Technical Services	ronwolk@aol.com
Wong, Joseph	DOE	Joseph.Wong@hq.doe.gov

Presentations

Opening Remarks

High MW Electronics – Industry Roadmap Meeting

December 11th, 2009
NIST

Hi-MW Roadmap Leadership

- Leo Casey, Satcon Corporation
- Bob Reedy, Florida Solar Energy Center
- Charlie Vartanian, A123 Systems
- Le Tang, ABB Inc.
- David Nichols, Altairnano, Inc.
- Madhav Manjrekar, Siemens
- Sam Biondo, DOE rtd.

- Al Hefner
- Tarek Abdallah, ERDC-CERL

- Ron Wolk
- Colleen Hood

Vision

- Faster Protection & Control
- More robust
- More renewable
- More efficient
- More DC systems
- More electronic
- Higher PQ
- More μGrids
- Improved CF
- More distributed
- Reconfigurable

High MW Electronics

- Technology, Sources and Power Electronics and Systems
- Costs
- Scale
- Integrated/Integration
- Policy
- DC/AC
- Systems
- Safety
- Standards
- Education and Training

- Growth

Agenda

8:30am Opening Remarks, High MW Roadmap Committee and NIST Host

9:00 am David Prend, Rockport Capital, “Barriers to Large Scale Grid Penetration”

9:30am John Lushetsky, DOE Solar Program, Program Manger

10:00 Colin Schauder, Satcon, Satcon Fellow “Isochronous Grid through Electronics”

10:30 – 10:50 BREAK

10:50 Jeffrey B. Casady, SemiSouth, “ Recent Advancements in SiC power devices & the impact of normally-off SiC JFETs on PV and wind inverter platforms“

11:20 Jerry FitzPatrick, NIST on Smart Grid Interoperability

11:40 Al Hefner, NIST on Energy Storage PAP for Smart Grid Interoperability

12:00 – 12:45 LUNCH

12:45pm Charlie Vartanian, A123 Systems Energy Solutions Group, “Storage; Smart interfaces for Frequency Regulation & Beyond” “Storage, Storage interfaces, Frequency Regulation”

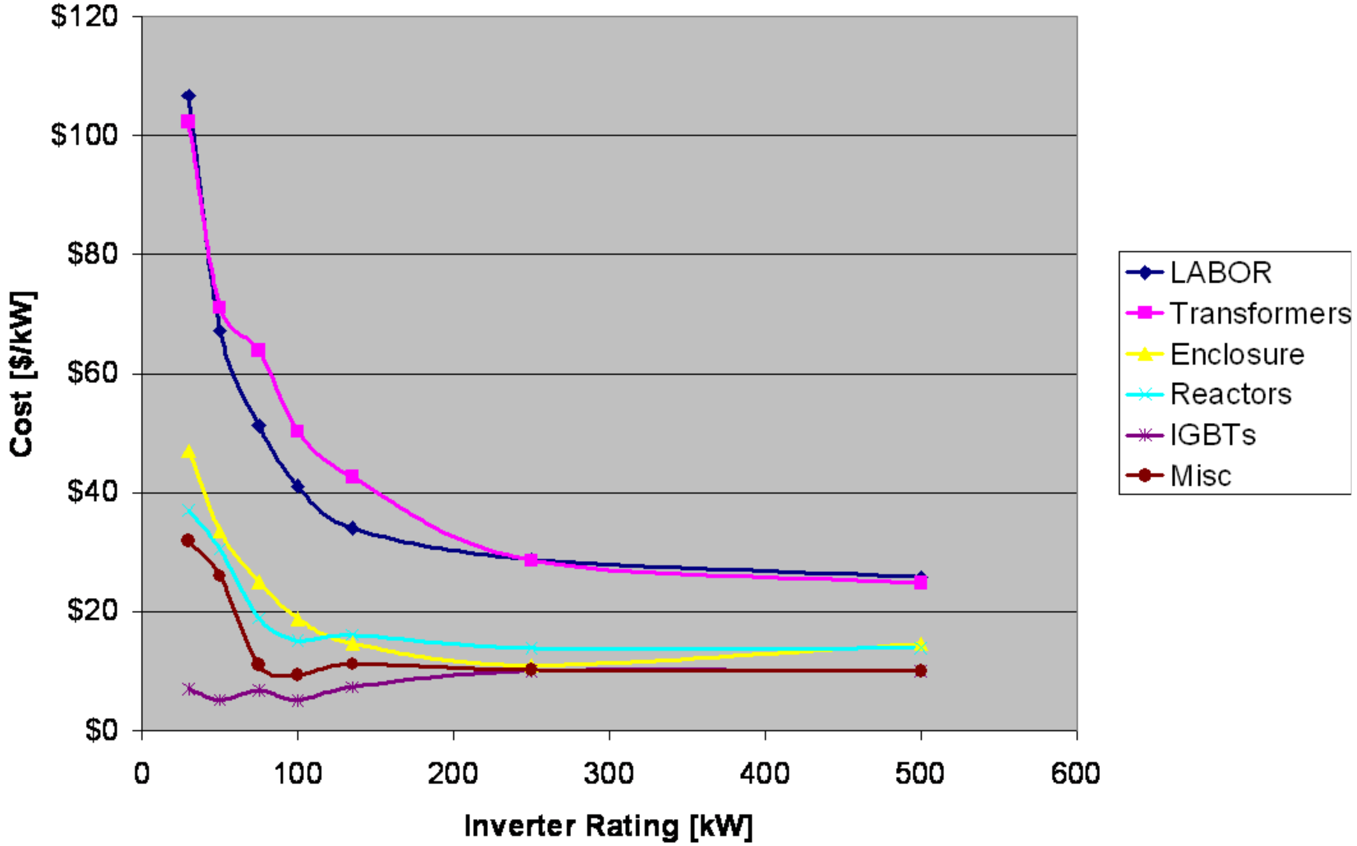
1:15pm Madhav Manjrekar, Siemens, “Green Energy and Power Systems”

1:45pm Le Tang, ABB “Smart Grids and Power Electronics”

2:15pm Kevin Tomsovic, University of Tennessee “Power System Control Issues for Renewable Integration”

2:45-3:00pm Concluding Remarks and Adjourn

SCALE



$/kW flat relatively flat at 135kW and above

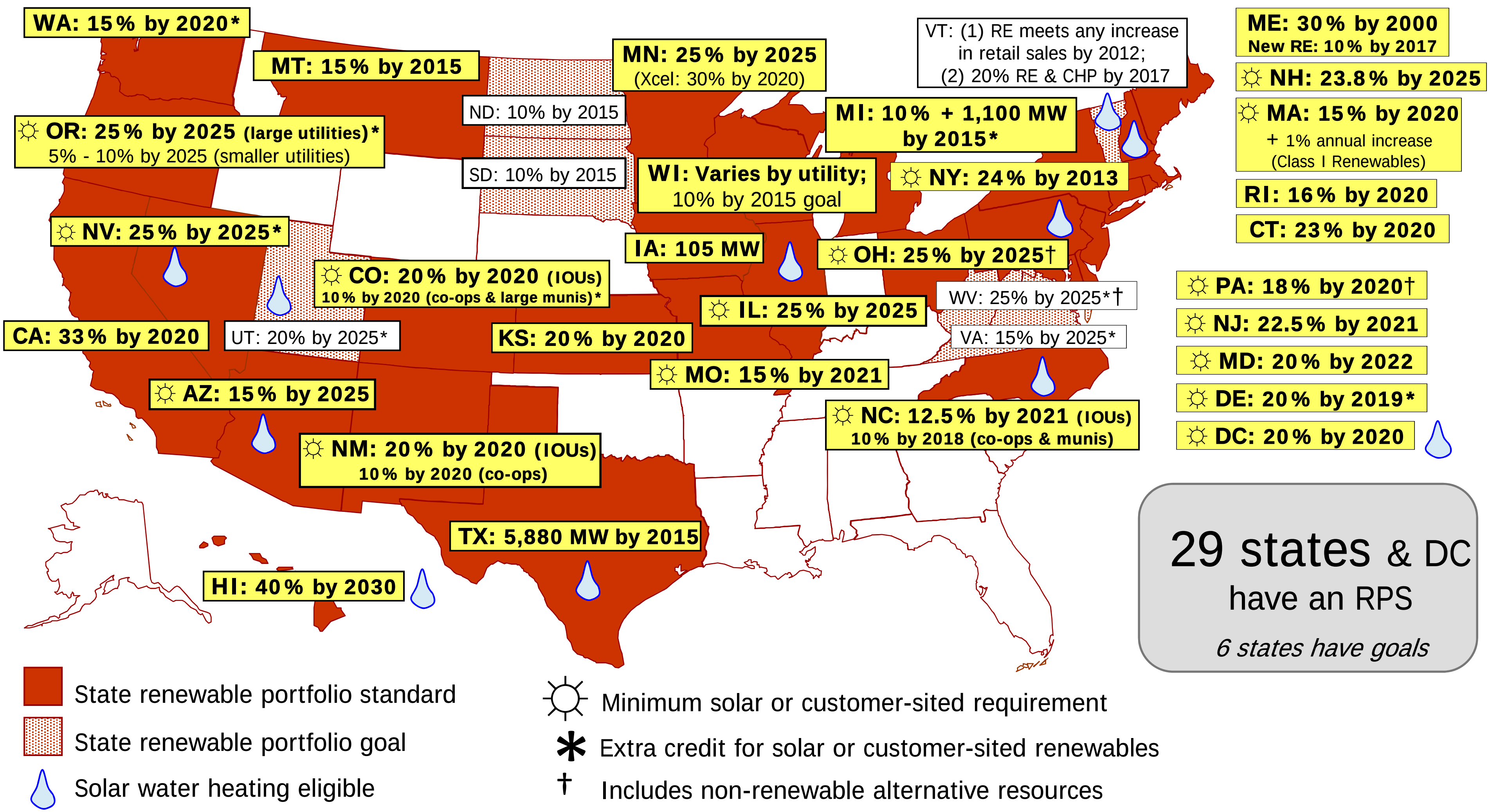
Large Scale

Integrated MV

Policy

Renewable Portfolio Standards

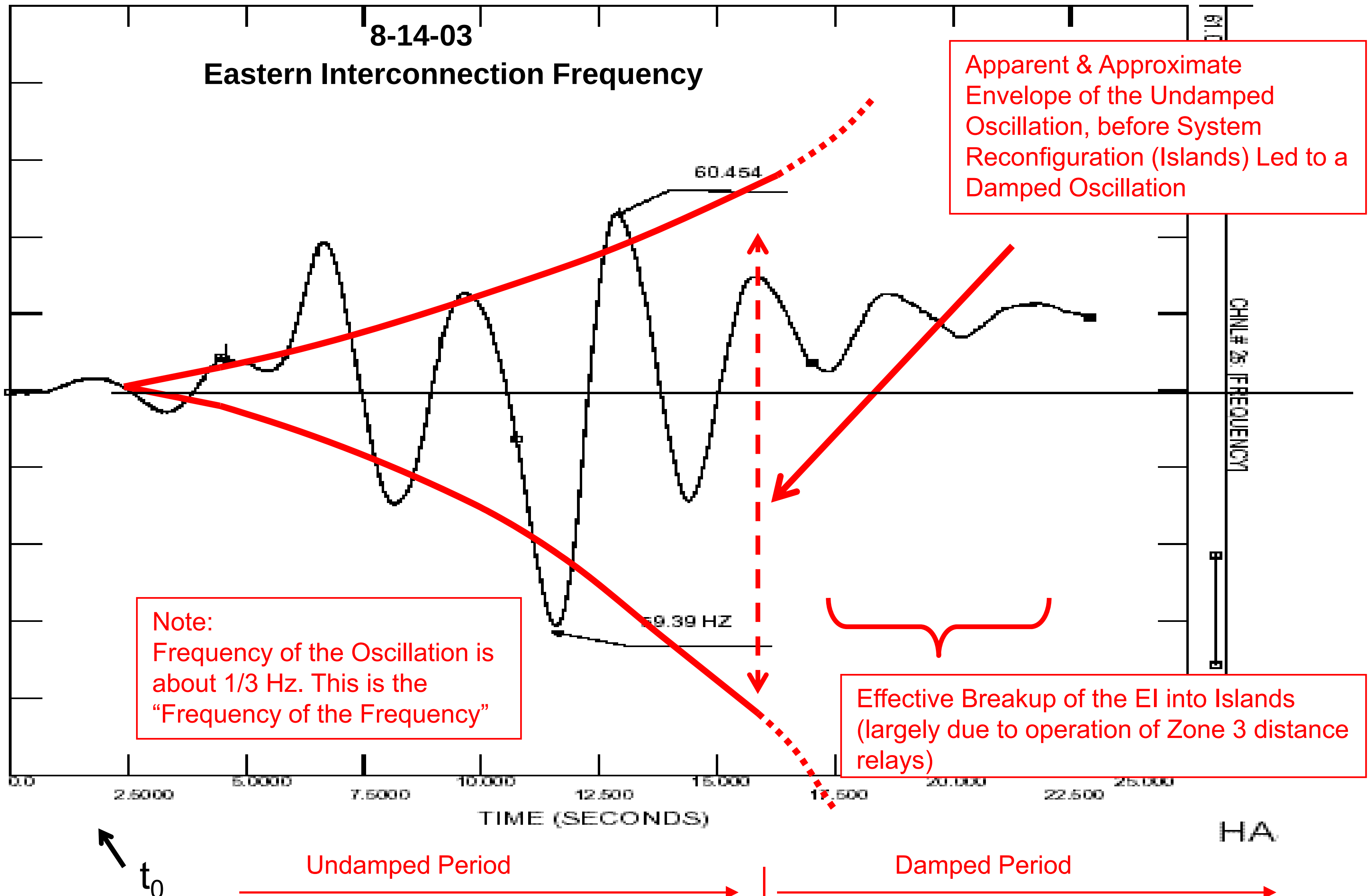
www.dsireusa.org / October 2009



29 states & DC have an RPS

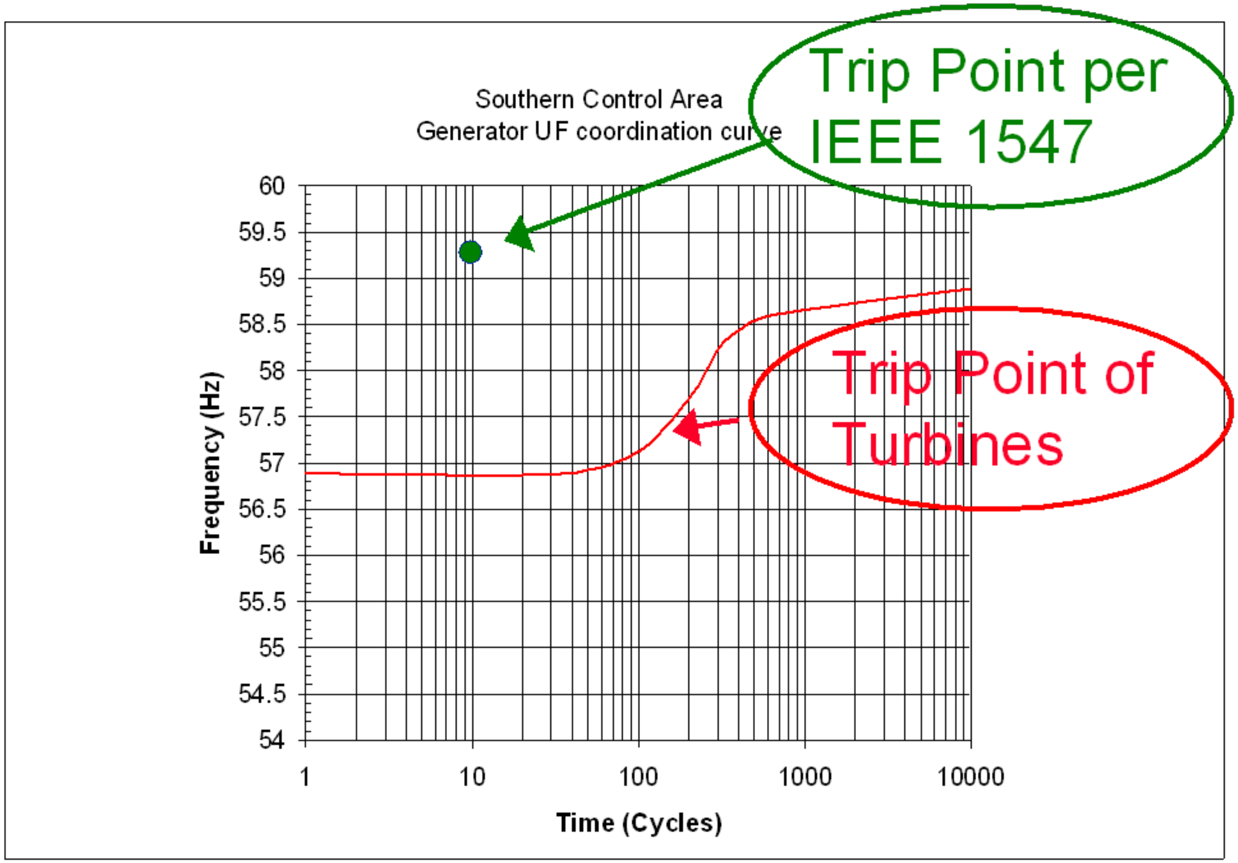
6 states have goals

System – Real Time Control



Variability

STANDARDS


Southern Control Area
Generator UF coordination curve
Trip Point per IEEE 1547
Trip Point of Turbines
60
59.5
59
58.5
58
57.5
57
56.5
56
55.5
55
54.5
54
Frequency (Hz)
1
10
100
1000
10000
Time (Cycles)

Hi-MW Roadmap Leadership

- Leo Casey, Satcon Corporation
- Bob Reedy, Florida Solar Energy Center
- Charlie Vartanian, A123 Systems
- Le Tang, ABB Inc.
- David Nichols, Altairnano, Inc.
- Madhav Manjrekar, Siemens
- Sam Biondo, DOE rtd.

- Al Hefner
- Tarek Abdallah, ERDC-CERL

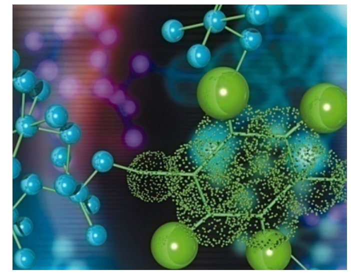
- Ron Wolk
- Colleen Hood

John Prend

Rockport Capital

ROCKPORT CAPITAL




Barriers to Large Scale Grid Penetration of Renewables

High MW Electronics – Industry Roadmap Meeting

December 11, 2009

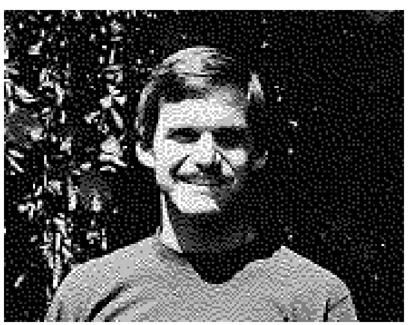
David J Prend

Managing General Partner, RockPort Capital Partners

Let’s step back to late 1970s

Carter – “Moral Equivalent of War”

PV on the White House



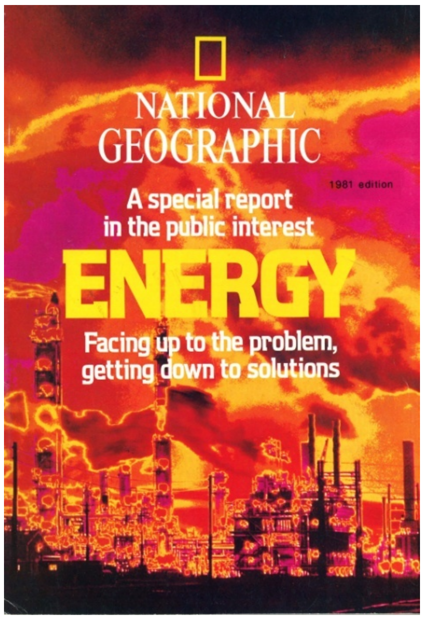
David Prend

Engineer in Advanced Energy Technologies, Bechtel Corporation, 1980

ROCKPORT CAPITAL

Is technology really the problem?

February 1981



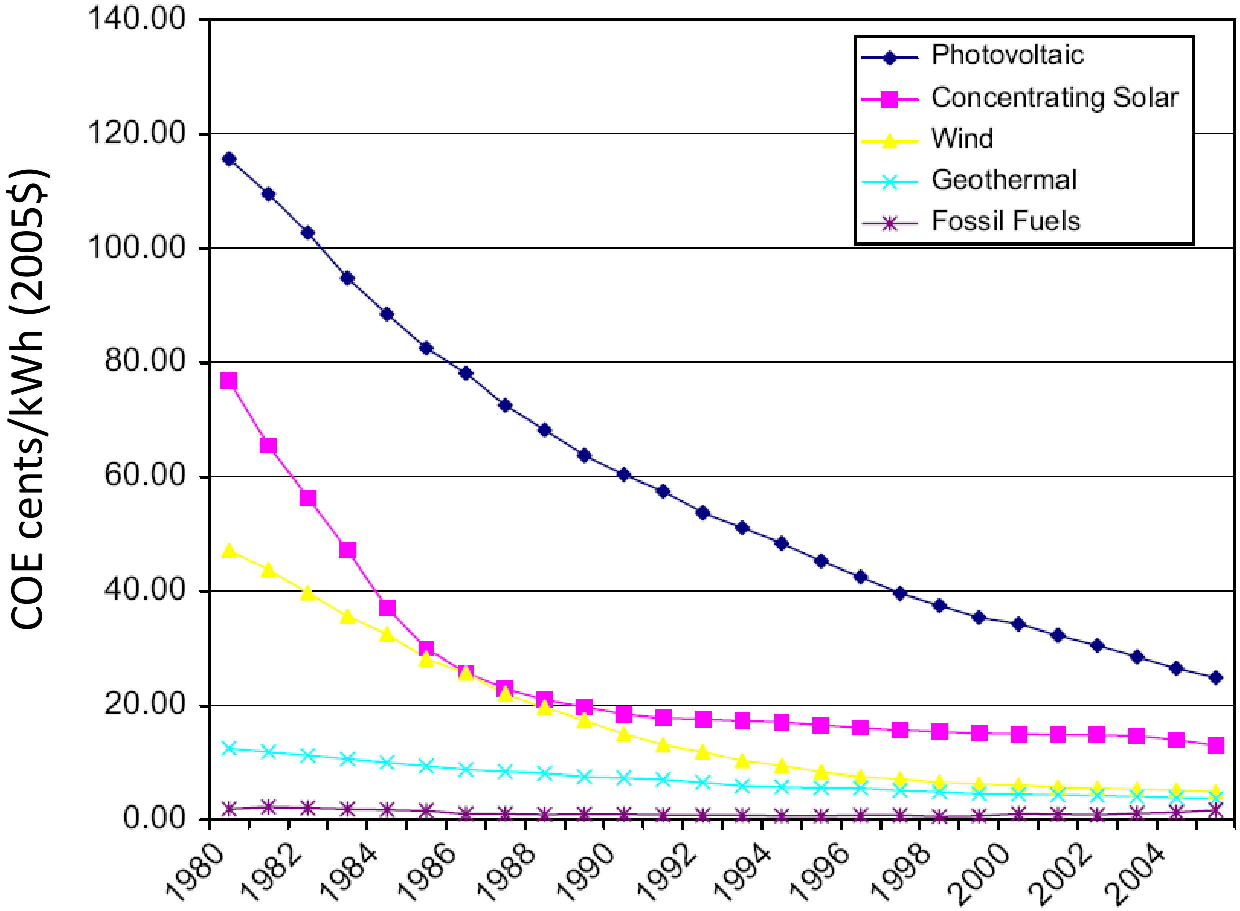
November 2009

"In the case of energy….often the obstacles are not technological but institutional."

"The obstacles are primarily political, not technological."

ROCKPORT CAPITAL

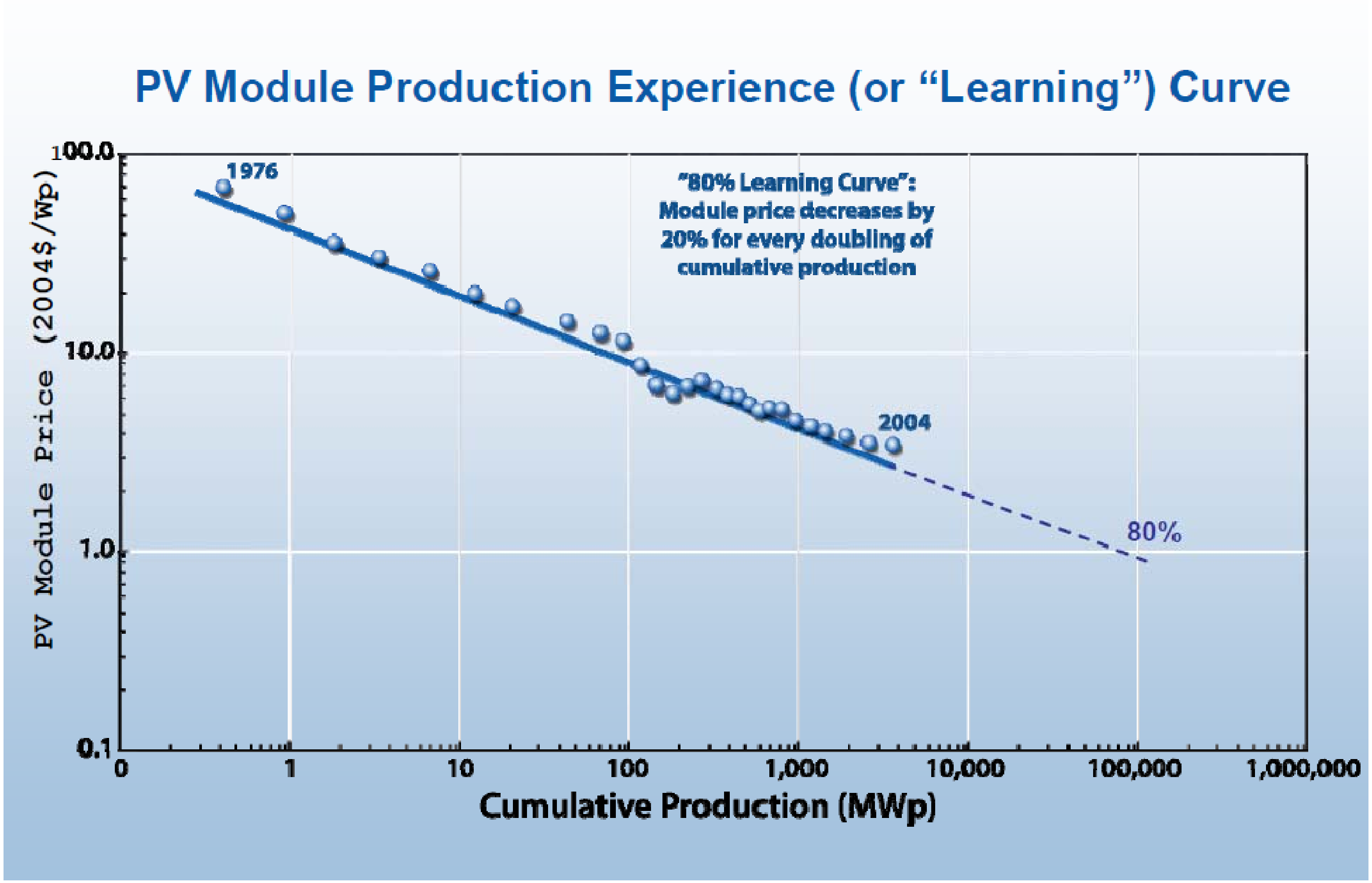
The importance of learning curves



Source: NREL and US Department of Energy

ROCKPORT CAPITAL

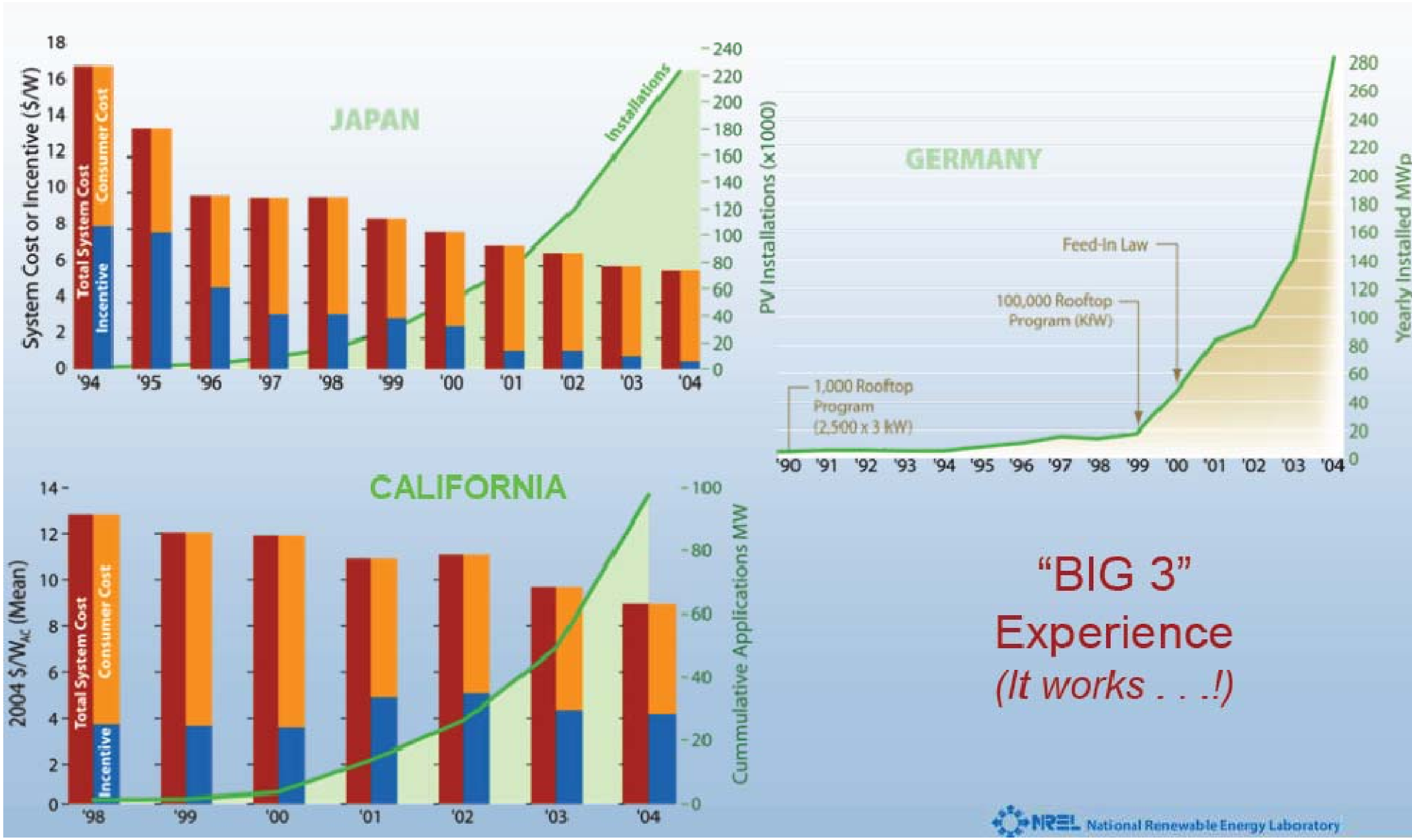
Solar learning curve



Source: NREL

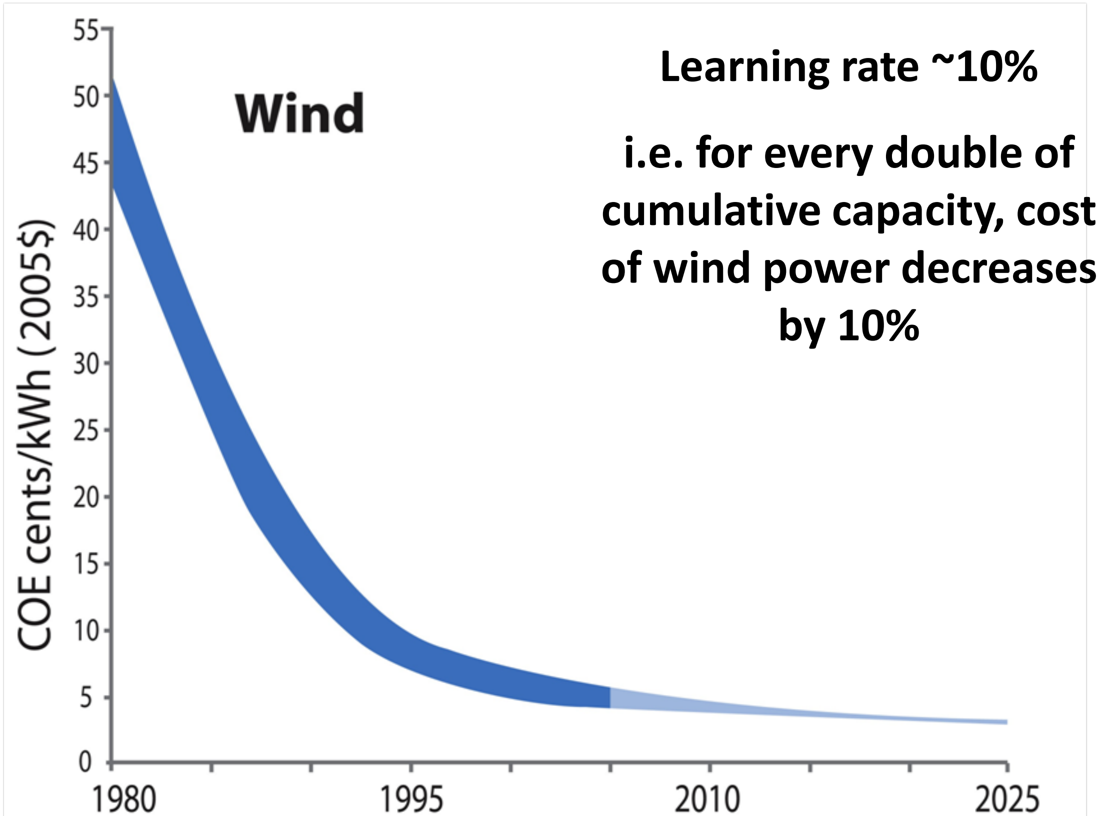
ROCKPORT CAPITAL

The impact of incentives



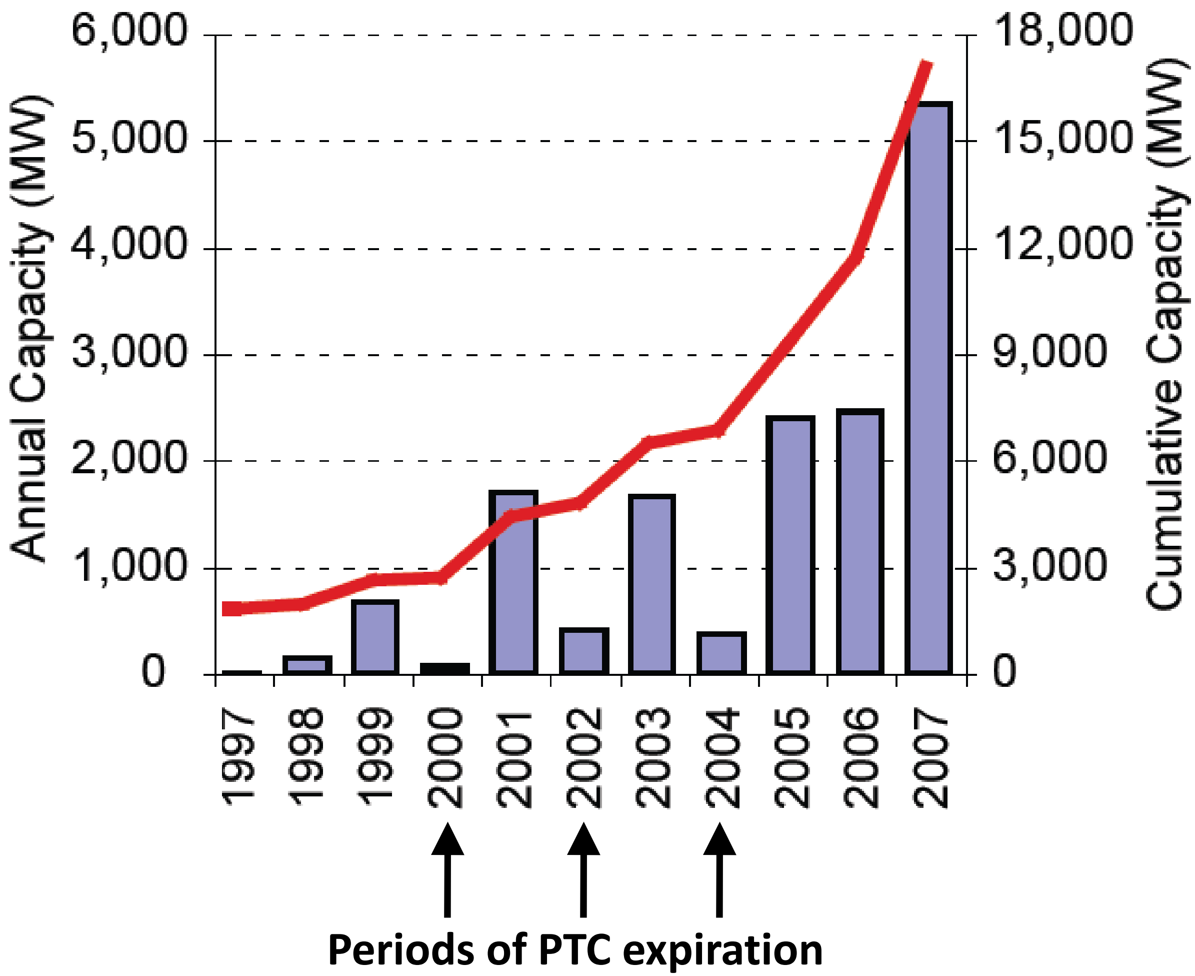
ROCKPORT CAPITAL

Wind learning curve



Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

Incentive effects on US installed wind capacity



Source: AWEA

ROCKPORT CAPITAL

Grid technologies currently exist

Grid

- Wide area networks
- Smart meters
- Substation automation
- Home area networks
- Real time monitoring and control
- Microgrids
- Demand management
- High MW power electronics

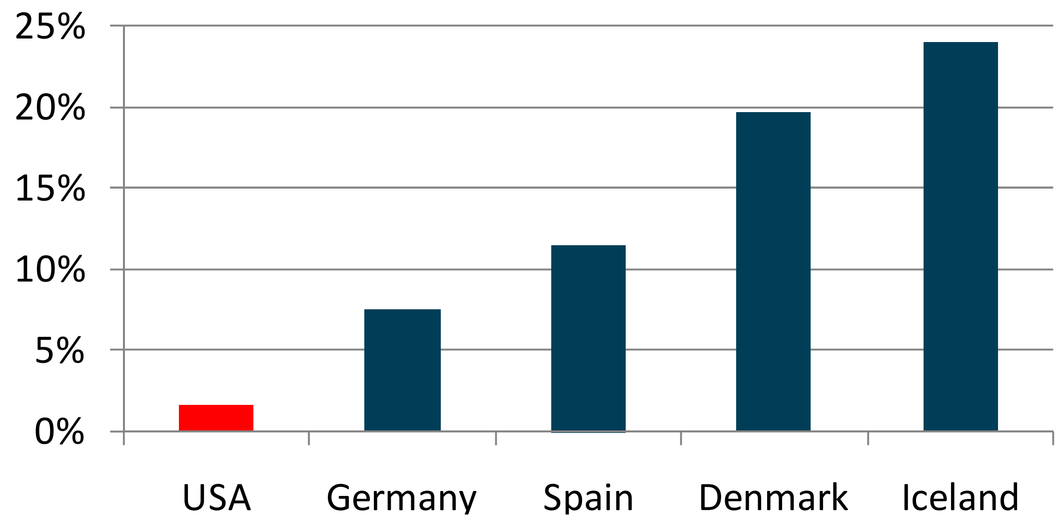
Storage

- Flow batteries
- Pumped hydro
- Compressed air
- Flywheels
- Electrochemical capacitors
- NAS batteries
- Lead-acid batteries
- Li-ion batteries

Large scale penetration is feasible

2008 Renewables Penetration

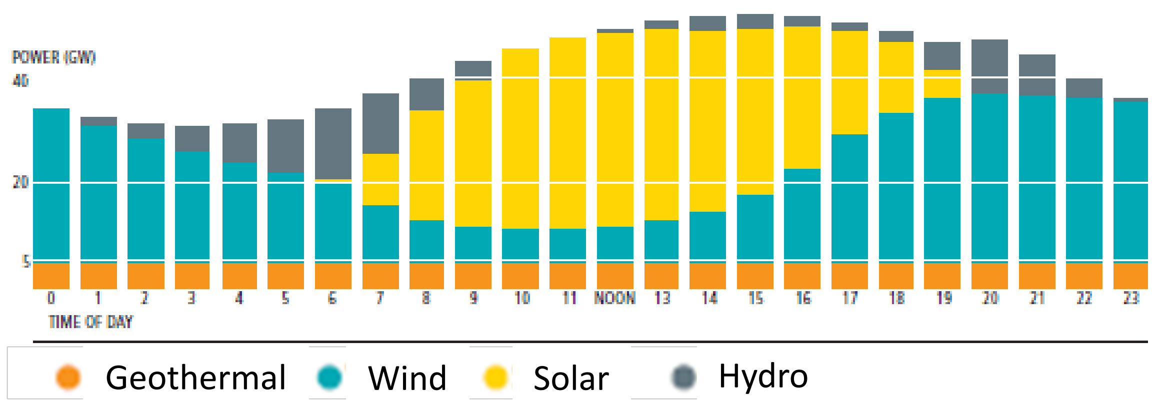
Geothermal/Wind/Solar/Other Generation (GWh)



Source: IEA

2020 Model for California

A Means to Achieve 100% Renewables Penetration

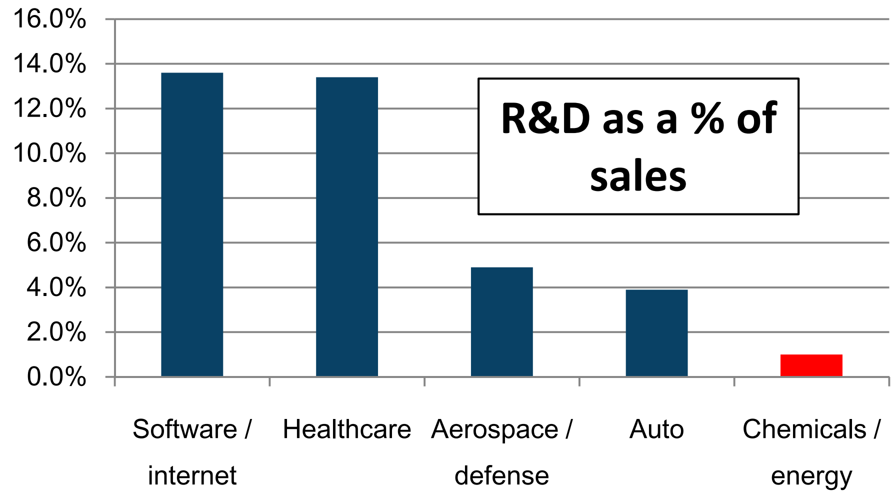


Source: Scientific American, November 2009

ROCKPORT CAPITAL

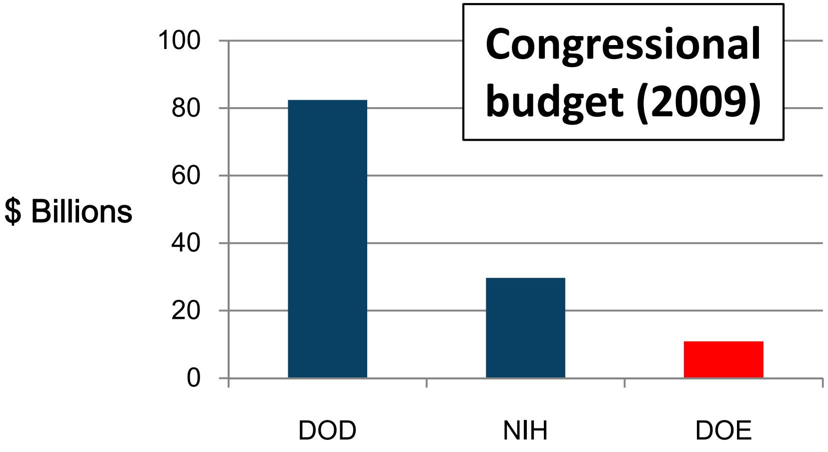
R&D spending on energy vs. other sectors

Industry



Source: Booz & Co

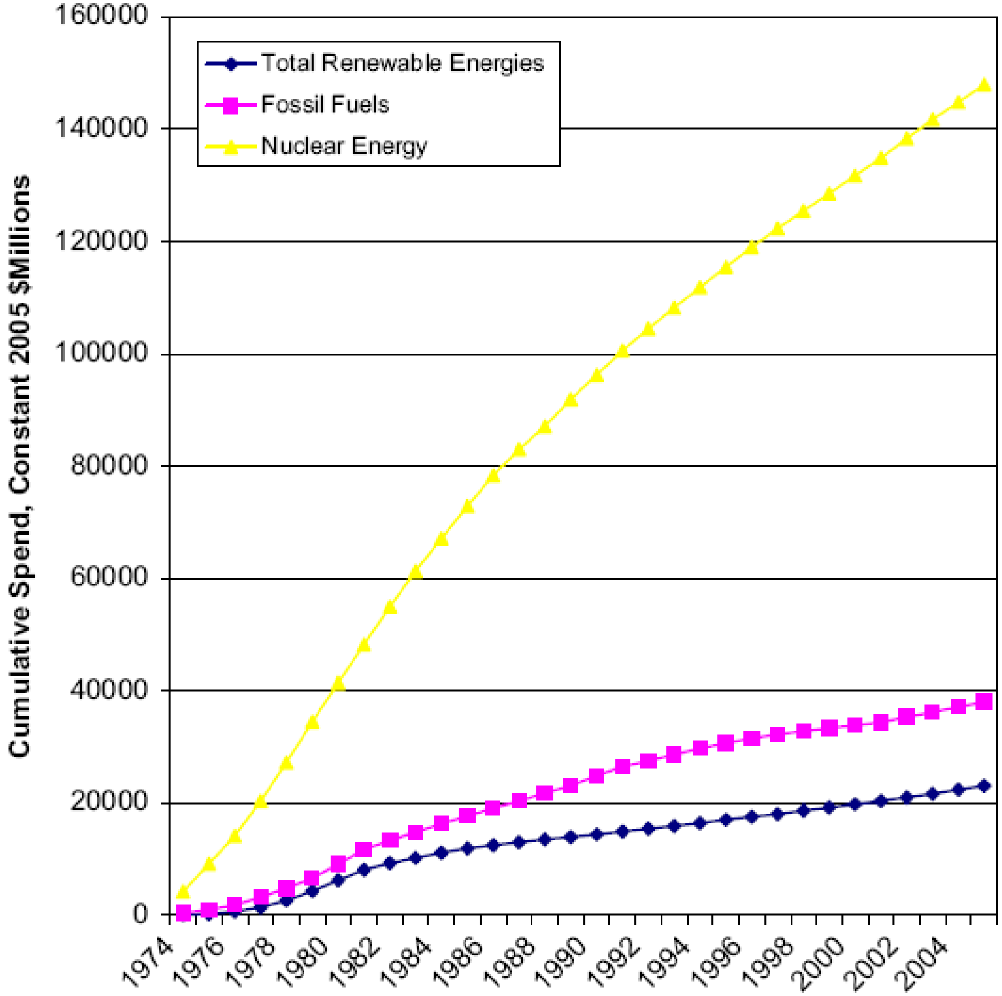
Government



Source: AAAS

ROCKPORT CAPITAL

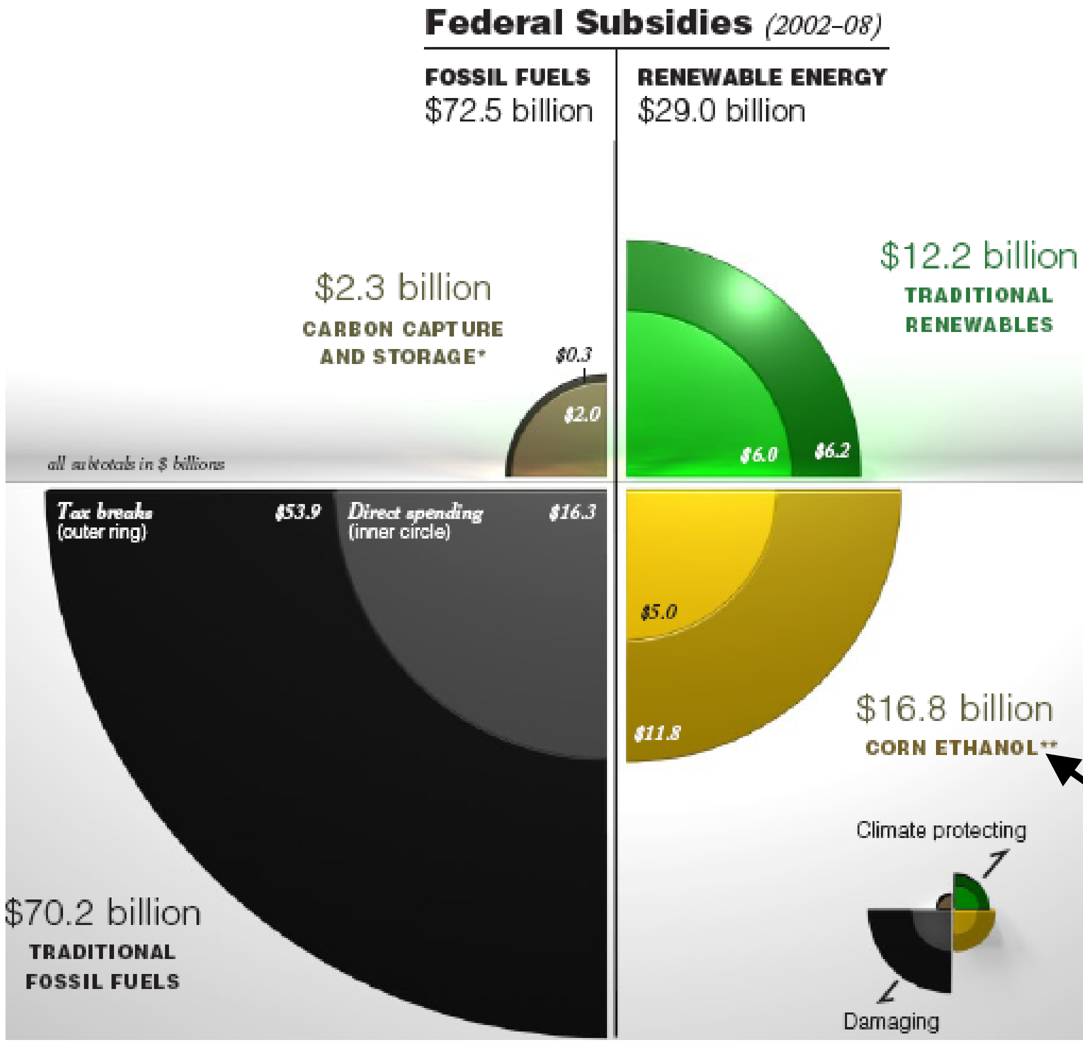
Global government spending on energy R&D



Source: Journal of Energy Policy, Schilling and Esmundo, 2009

ROCKPORT CAPITAL

How level is this playing field?



Corn ethanol!

Source: Environmental Law Institute, 2009

ROCKPORT CAPITAL

How level is this playing field?

$6.4B project in today's dollars

Federal Electricity Subsidies 2002-2007

(Billions of 2007$)

Direct Expenses		Tax Incentives	
Nuclear	$6.2	Nuclear [1]	$0.0
Fossil Fuel R&D	3.1	Fossil Fuel	13.7
Renewables R&D	1.4	Renewables	2.8
Transmission Improvements	0.8	Transmission and Other	1.7
Total:	**11.5**	**Total:**	**18.2**

[1] The GAO report excludes low cost loans, and the federal liability insurance program provided to nuclear operators, which significantly subsidizes their operations.

Source: Federal government statistics and the Government Accountability Office (Report GAO-08-102)

ROCKPORT CAPITAL

The real problem is demand…and financing

- **Question: how much capital investment would it take to increase (non-hydro) renewables from today's level to 20%?**

Total US electricity generation*	3,972,423,000	MWh	
Total (non-hydro) renewable generation*	130,516,000	MWh	3.3%
** Rolling 12 month total as of August 2009 (EIA)*			
20% of Total US electricity generation	794,484,600	MWh	
Additional generation from (non-hydro) renewables	663,968,600	MWh	

Capital investment required to reach 20% target (billions)

		Average capacity factor	
	$ 758	15%	20%
	$2.50	$1,263	$947
Installed Cost ($/W)	$3.00	$1,516	$1,137
	$3.50	$1,769	$1,326

- **Answer: More than a trillion dollars!**

How do we access large pools of capital to fund deployment?

Feed in Tariffs	Utilities
“United States of Gainesville”	Cost recovery through “rate basing”

ROCKPORT CAPITAL

Conclusions

- Deal with demand side and supply will be there
- Focus on institutional barriers rather than technical barriers

John Lushetsky

DOE Solar Program

National Institute of Standards and Technology High-MW Electronics Seminar

"Investments in Power Electronics within the Solar Energy Technologies Program"

John M. Lushetsky
Program Manager
Solar Energy Technologies Program (SETP)
Department of Energy
Office of Energy Efficiency and Renewable Energy

December 11, 2009

Excitement, Leadership, and Opportunity

President Barack Obama

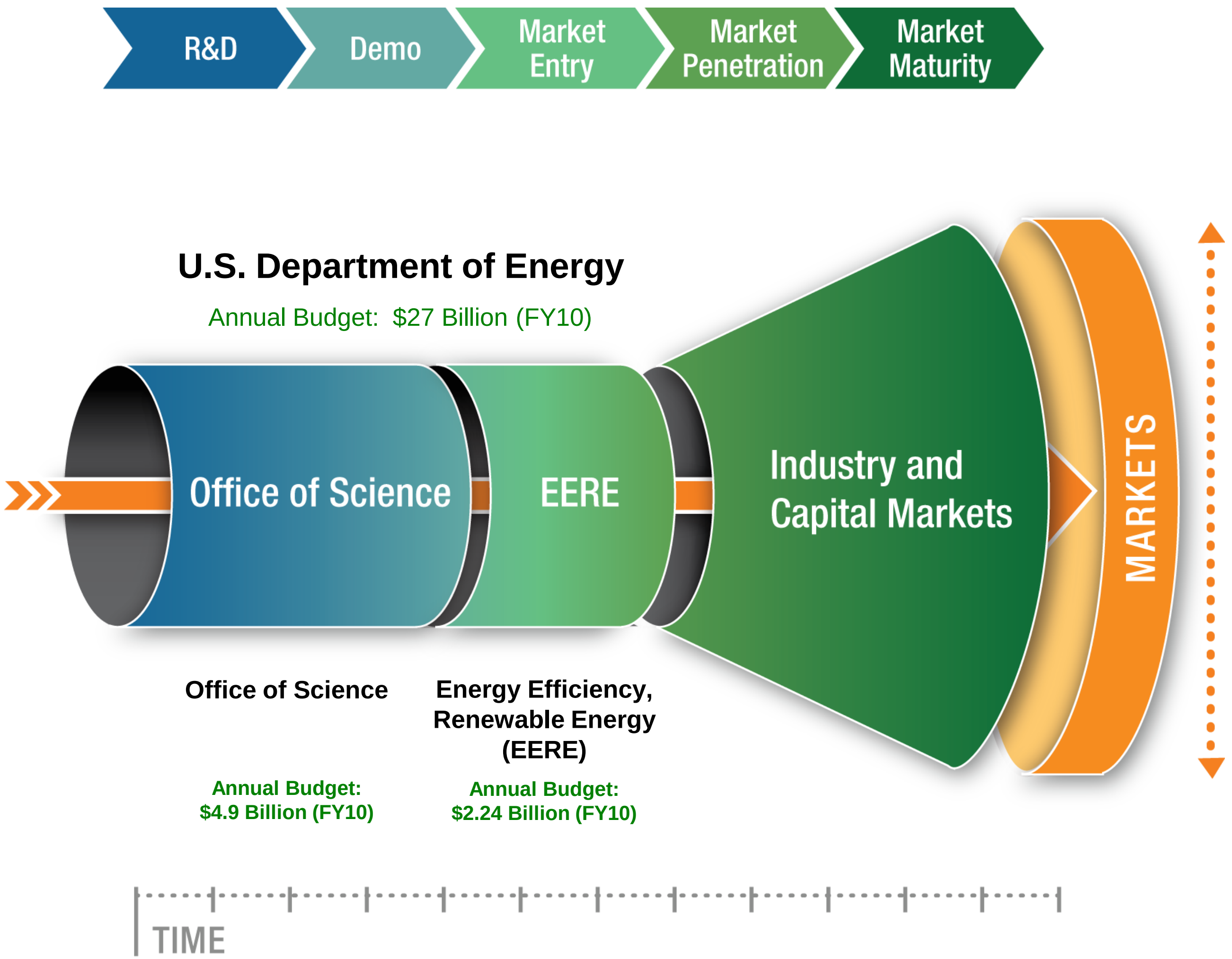
President Obama's Swearing-In Ceremony
January 20, 2009

Dr Steven Chu, Secretary of Energy
Nobel Laureate, Ph.D. Physics,
Former Director of LBNL

"We will harness the sun and the winds and the soil to fuel our cars and run our factories…All this we can do. All this we will do."

President Obama, January 20, 2009

DOE programs address the technology innovation and capital needs across the development pipeline



Office of Energy Efficiency and Renewable Energy Technology Portfolio

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Electric Power Generation

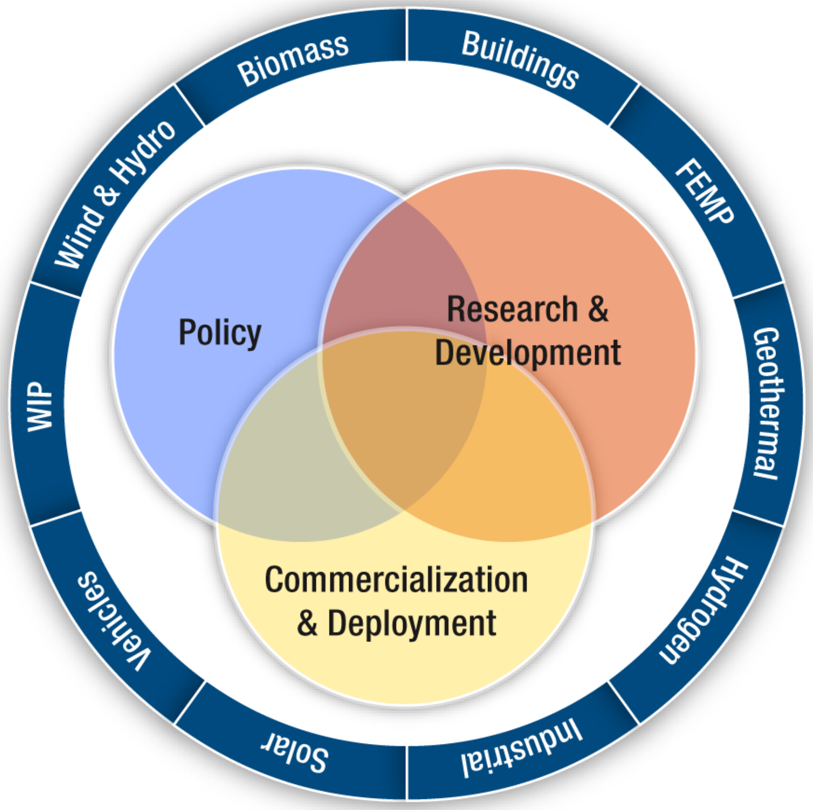
- Geothermal
- Solar
- Wind & Hydropower

Advanced Transportation

- Biomass
- Fuel Cells
- Vehicles

Energy Efficiency

- Buildings
- Industrial
- Federal Energy Management
- Weatherization and Intergovernmental

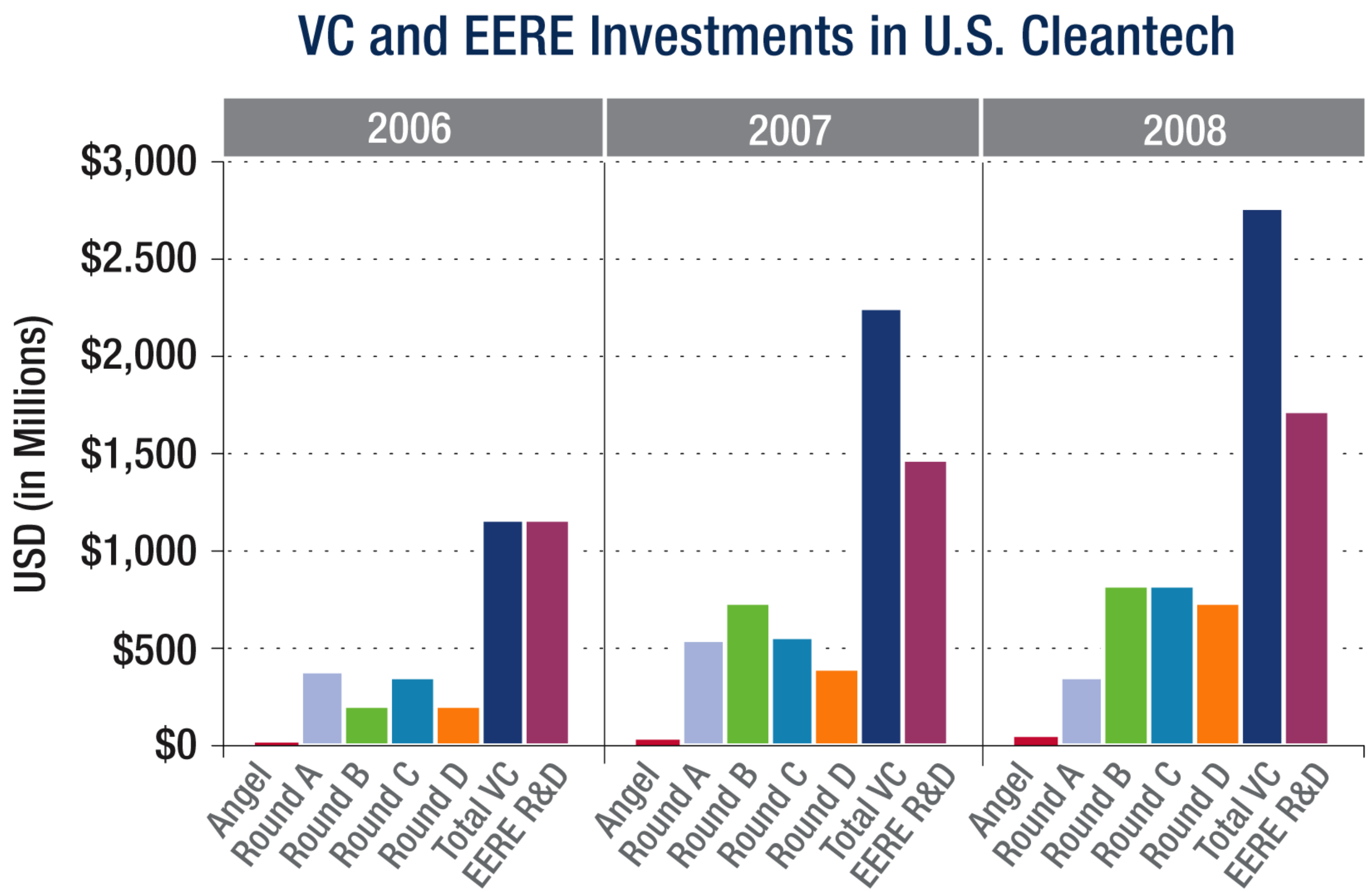


MISSION STATEMENT

Develop cost competitive clean energy technologies and practices and facilitate their commercialization and deployment in the marketplace to strengthen America's energy security, environmental quality, and economic vitality.

Investment in the US Cleantech industry over the past three years

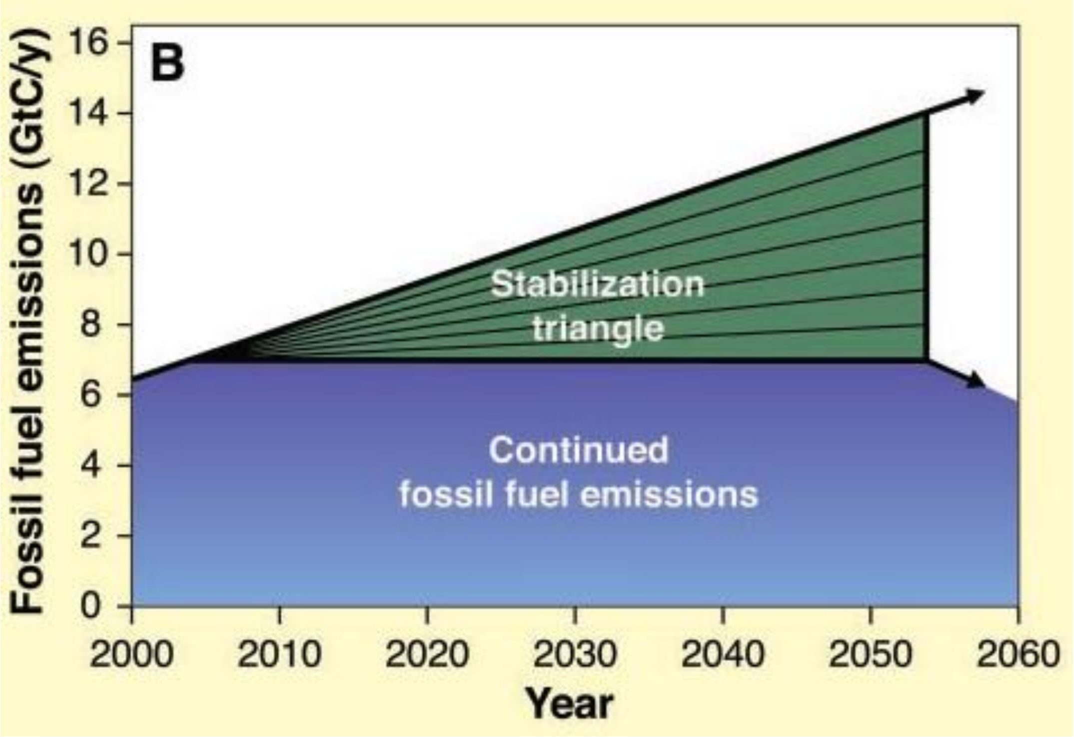
DOE's Office of Energy Efficiency and Renewable Energy accounts for almost 40% of early-stage cleantech funding



Sources:
DOE and New Energy Finance

Scale of the challenge to address climate change

- **Increase fuel economy of 2 billion cars from 30 to 60 mpg.**
- **Cut carbon emissions from buildings by one-fourth by 2050—on top of projected improvements.**
- **With today's coal power output doubled, operate it at 60% instead of 40% efficiency (compared with 32% today).**
- **Introduce Carbon Capture and Storage at 800 GW of coal-fired power.**
- **Install 1 million 2-MW wind turbines.**
- **Install 3000 GW-peak of Solar power.**
- **Apply conservation tillage to all cropland (10X today).**
- **Install 700 GW of nuclear power.**



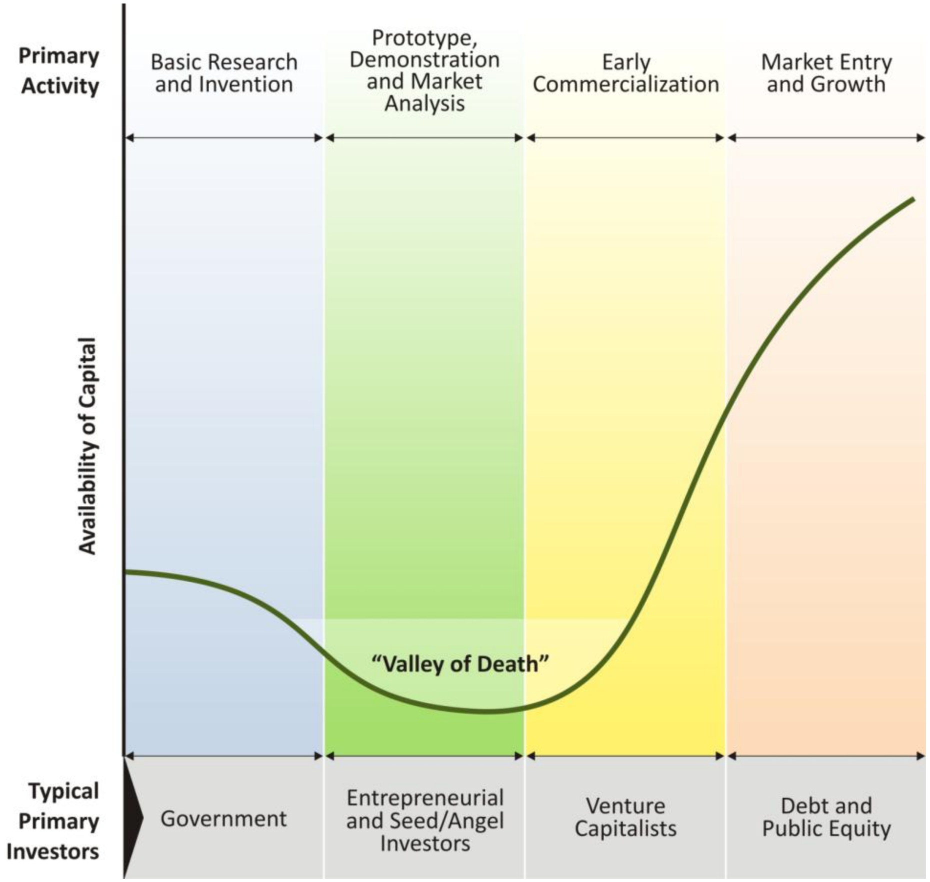
Source: S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technology", Science 13 August 2004, pp.968-972.

Time Constants for Change

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

• **Political consensus building**	**~ 3-30+ years**
• **Technical R&D**	**~10+**
• **Production model**	**~ 4+**
• **Financial**	**~ 2++**
• **Market penetration**	**~10++**
• **Capital stock turnover**	
– Cars	~ 15
– Appliances	~ 10-20
– Industrial Equipment	~ 10-30/40+
– Power plants	~ 40+
– Buildings	~ 80
– Urban form	~100's
• **Lifetime of Greenhouse Gases**	**~10's-1000's**
• **Reversal of Land Use Change**	**~100's**

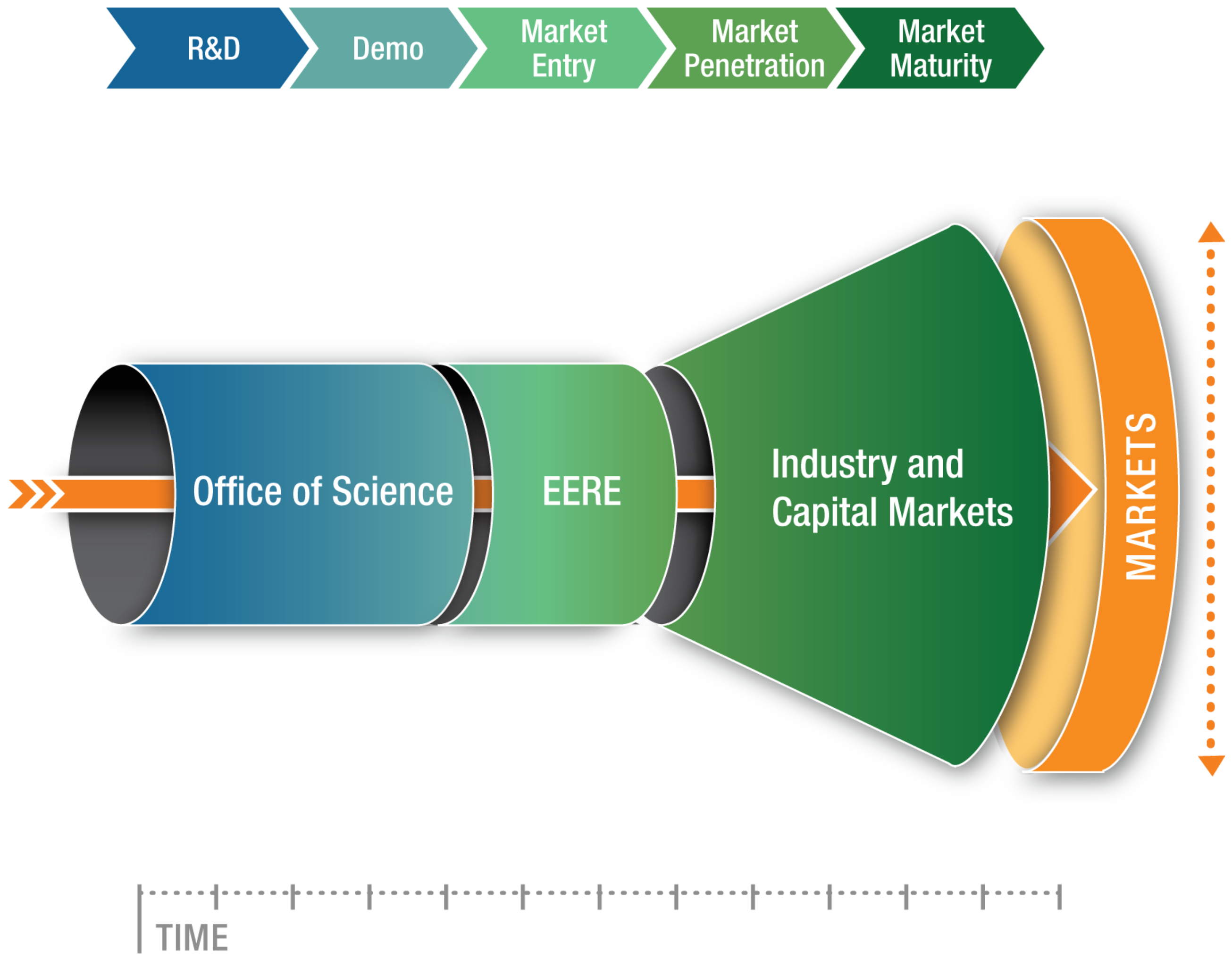
Problem for Cleantech Entrepreneurs: How to cross the "Valley of Death"



- **Significant government and university sources for Basic R&D – venture capital and public markets available for growth and expansion.**
- **Cleantech requires significant capital required for Prototype, Demonstration, and Market Validation.**
- **Cleantech is material intensive - requires higher capital levels than IT, biotech, or software.**
- **Cleantech subject to significant market risk due to government policy.**
- **Present economic and financial conditions have constrained conventional funding and "widened" the valley.**

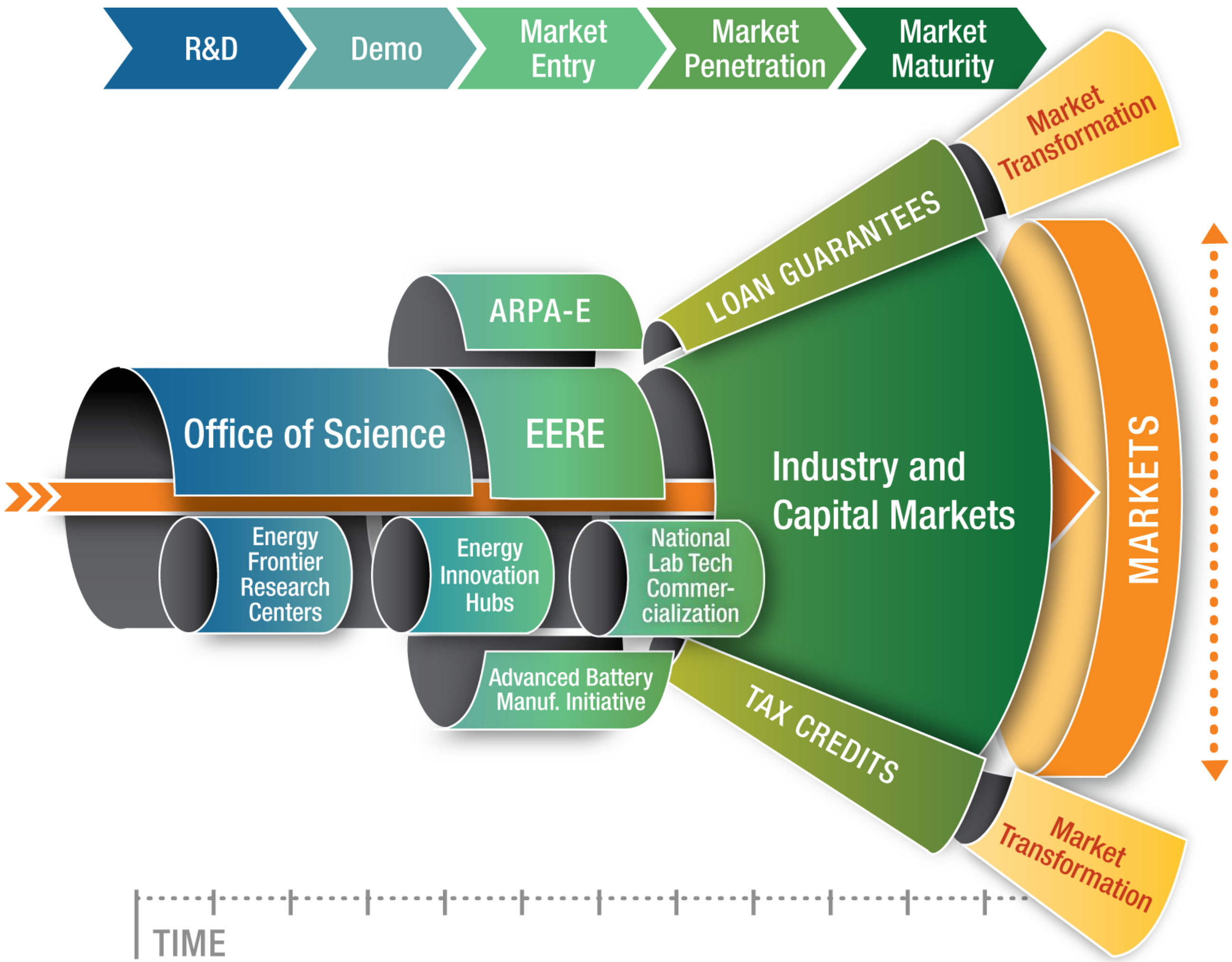
Significant need for new and novel sources of capital and partnerships to accelerate Cleantech through commercialization

DOE programs address the technology innovation and capital needs across the development pipeline



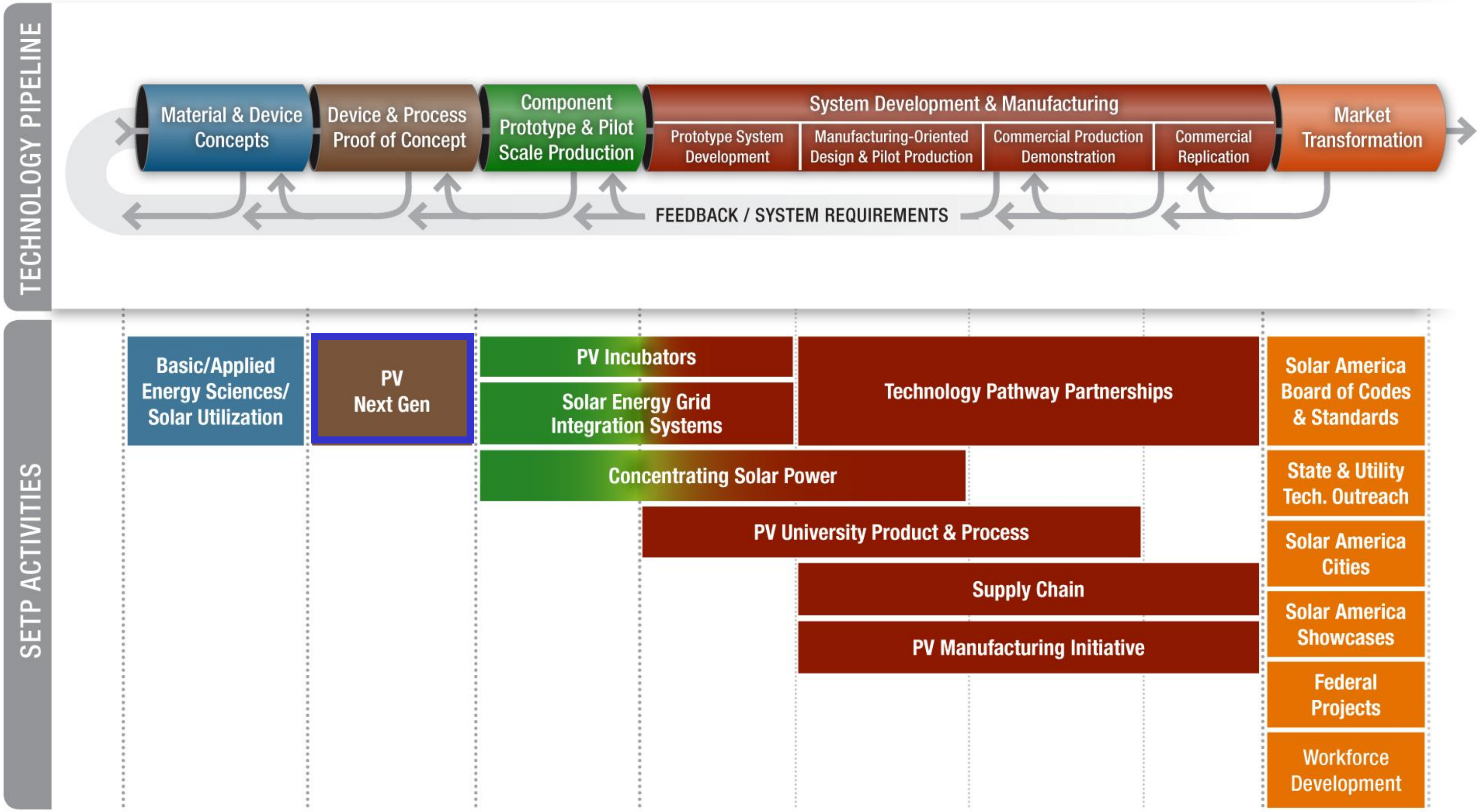
DOE programs address the technology innovation and capital needs across the development pipeline

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

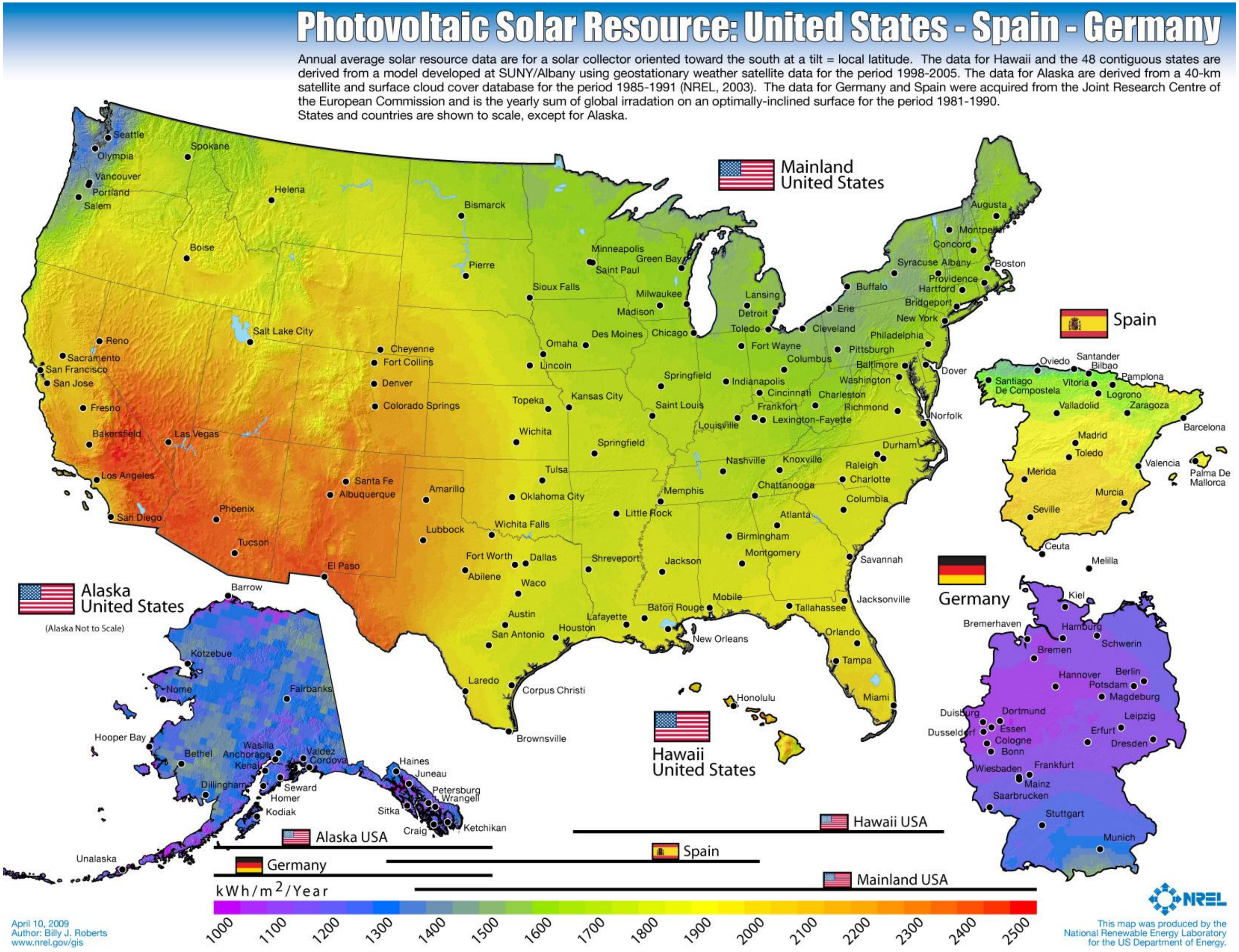


The mission of DOE's Solar Program is to accelerate the wide-spread adoption of solar electric technologies across the United States

SETP's pipeline approach aims to balance near and long term research



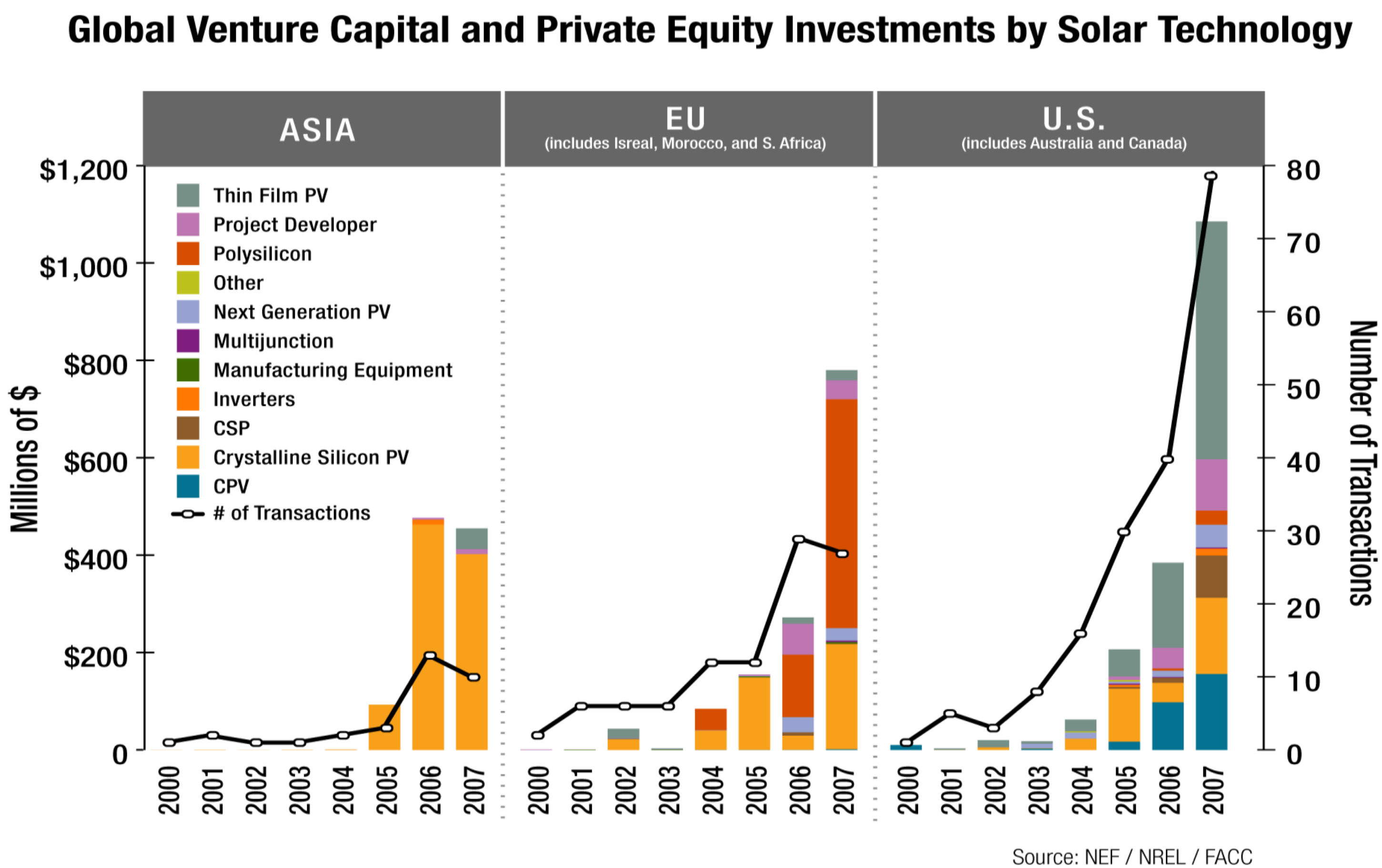
The US has a tremendous solar resource relative to current leading markets



The U.S. is rich in PV technology innovation

The US is the most diversified in solar technologies receiving VC and PE financing, with substantial investment in thin film PV, as well as CPV and CSP

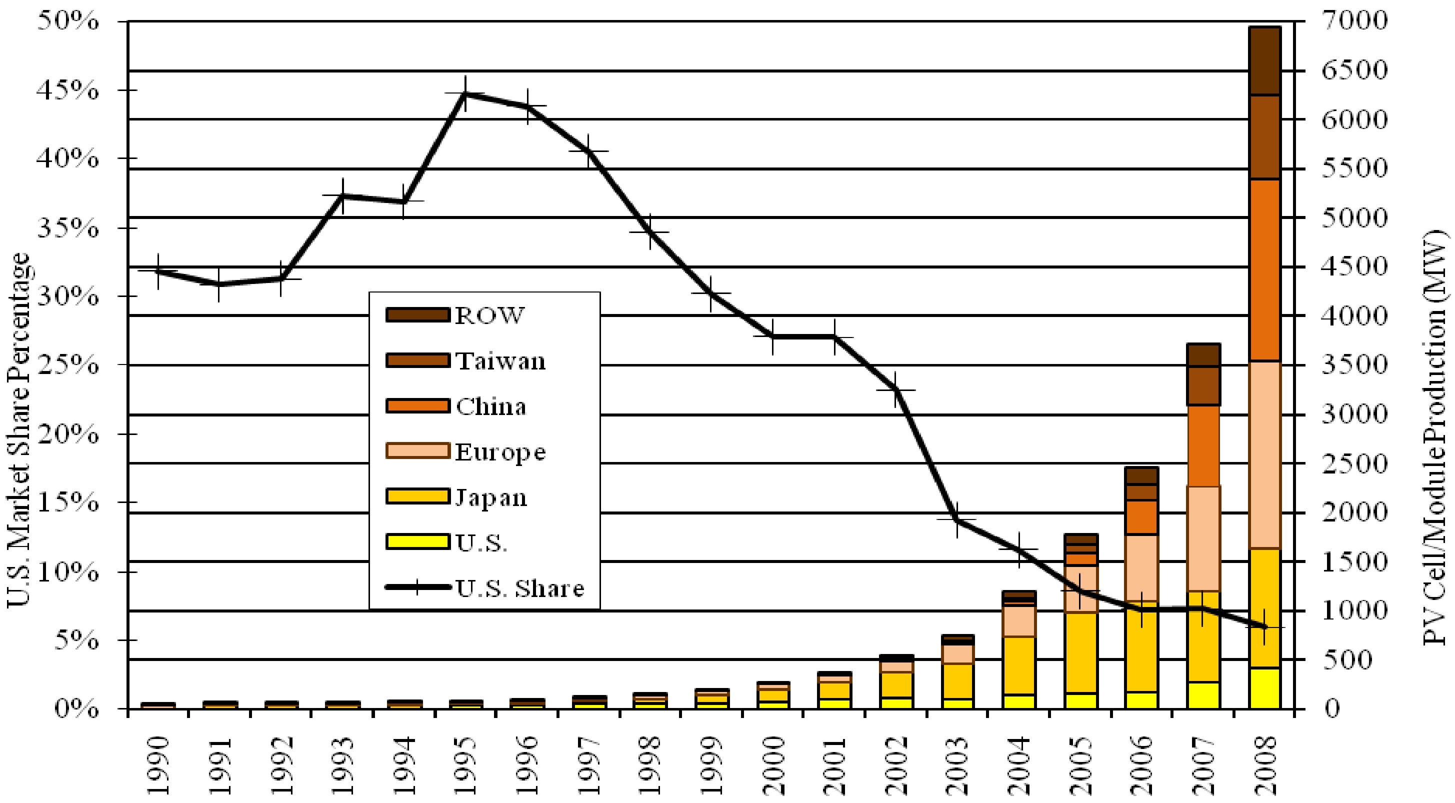
- **In Europe, most of the funding has been to polysilicon and c-Si PV companies**
- **In Asia, almost all investment has gone to c-Si PV**



The U.S. share of worldwide PV cell/module production has fallen drastically

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

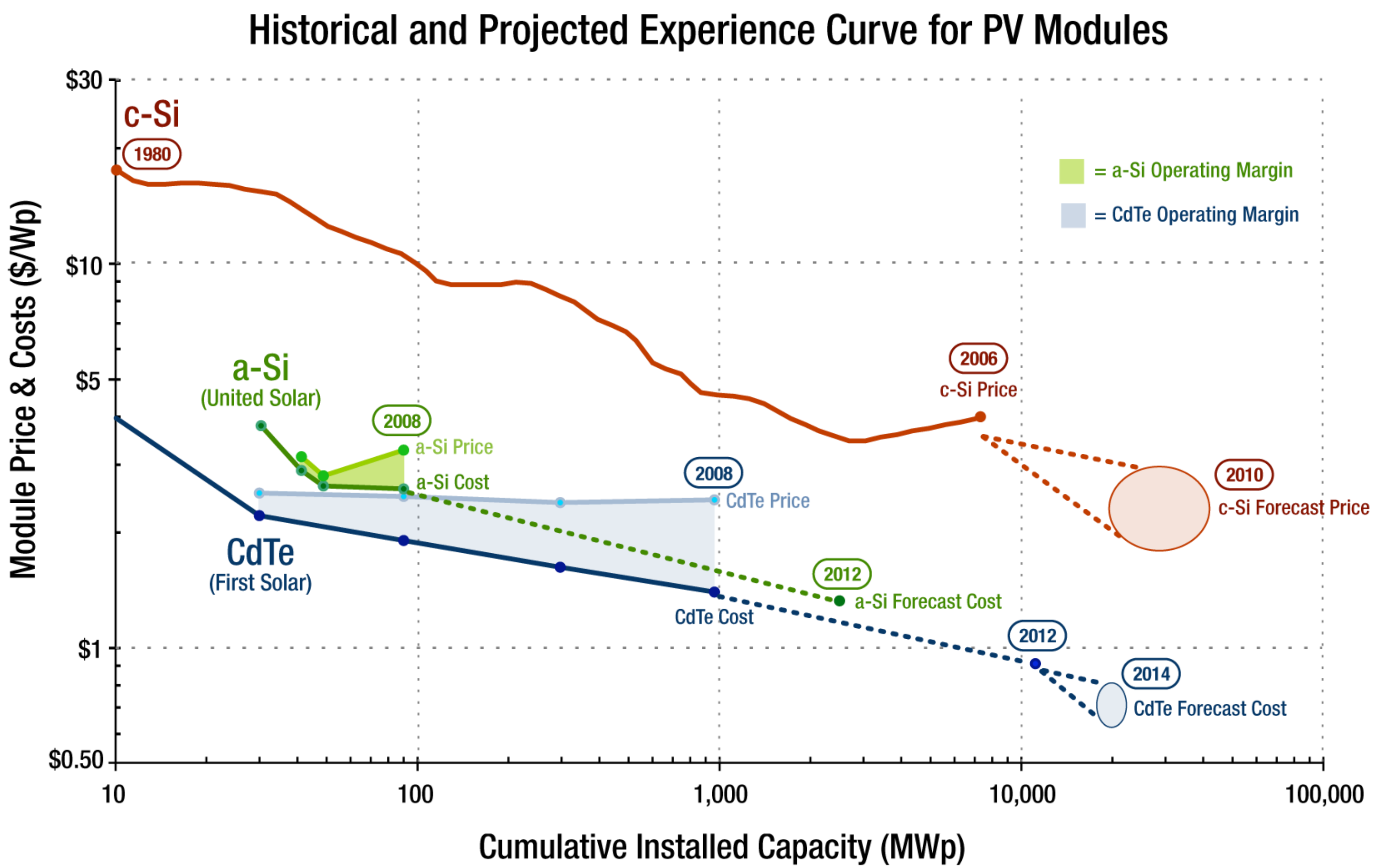
- China's PV cell/module production has been outpacing global growth during the past 5 years (with 5-yr CAGR through 2008 of 170% vs. global 5-yr CAGR of 56%).
- China took the lead in global production in 2008 with 1.8 GW of production (tied with Europe at 27% market share of 6.9 GW global production).



Prometheus/PV News 1993 - April 2009

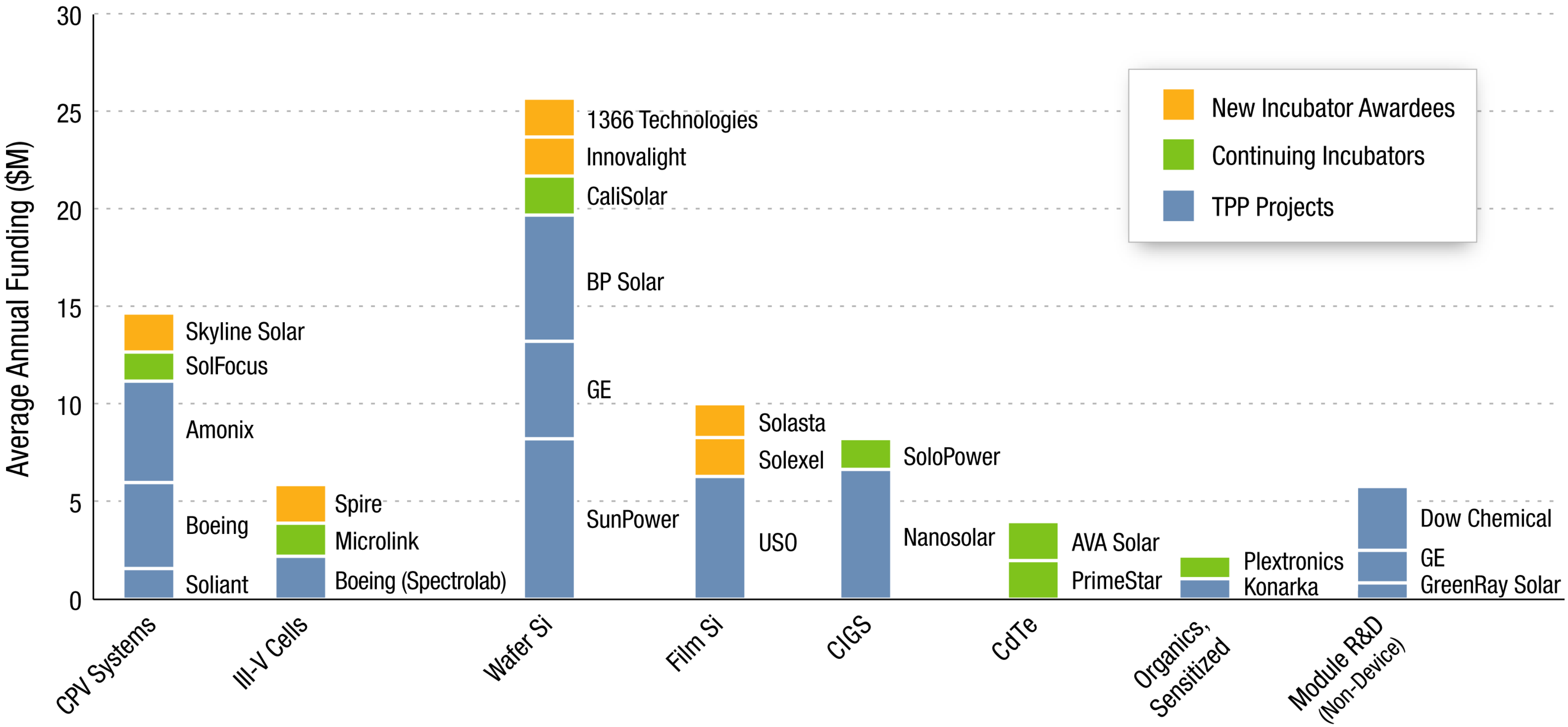
PV costs have been dramatically reduced across different technologies

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

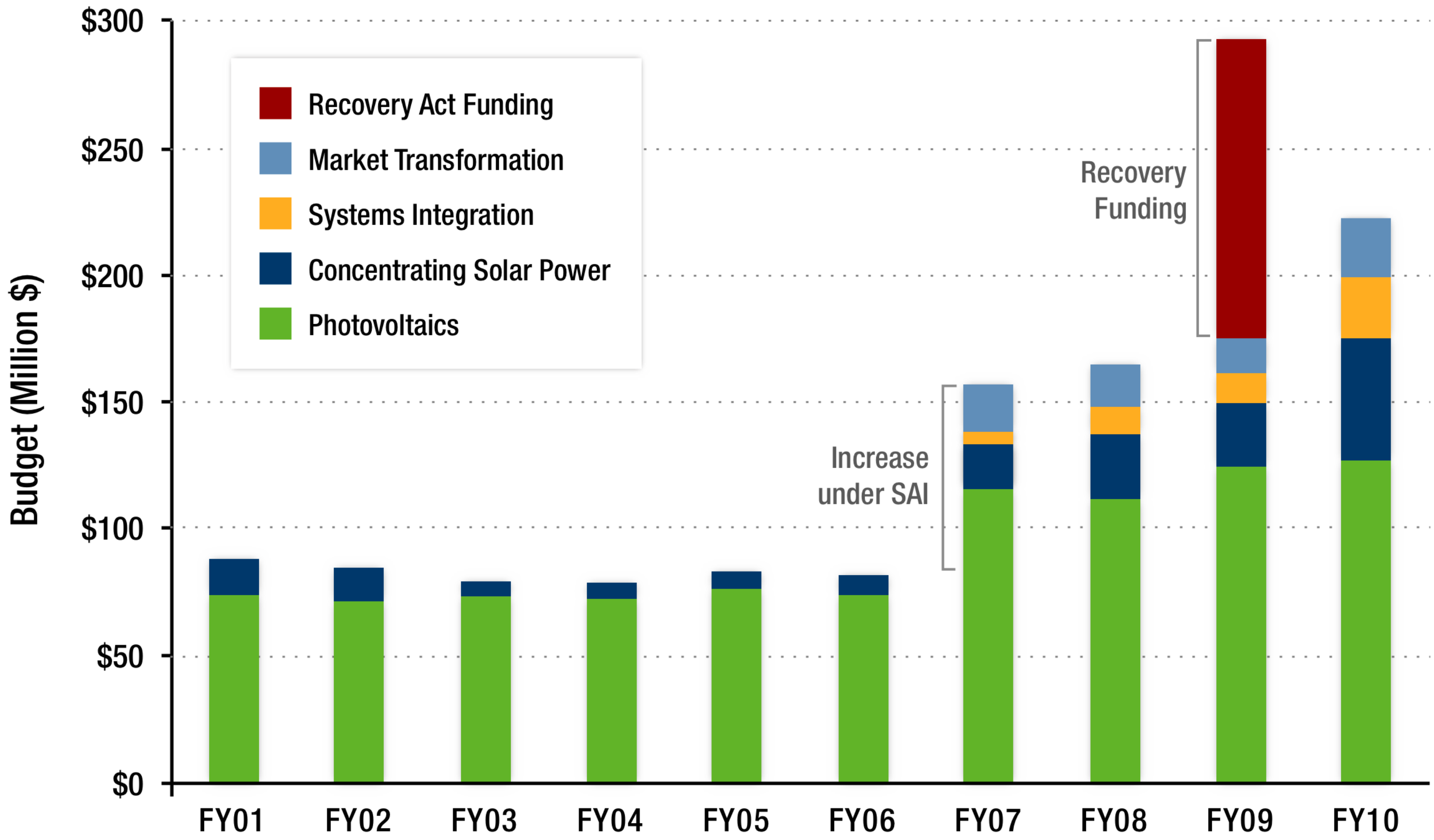


DOE's industry R&D programs include diverse technologies

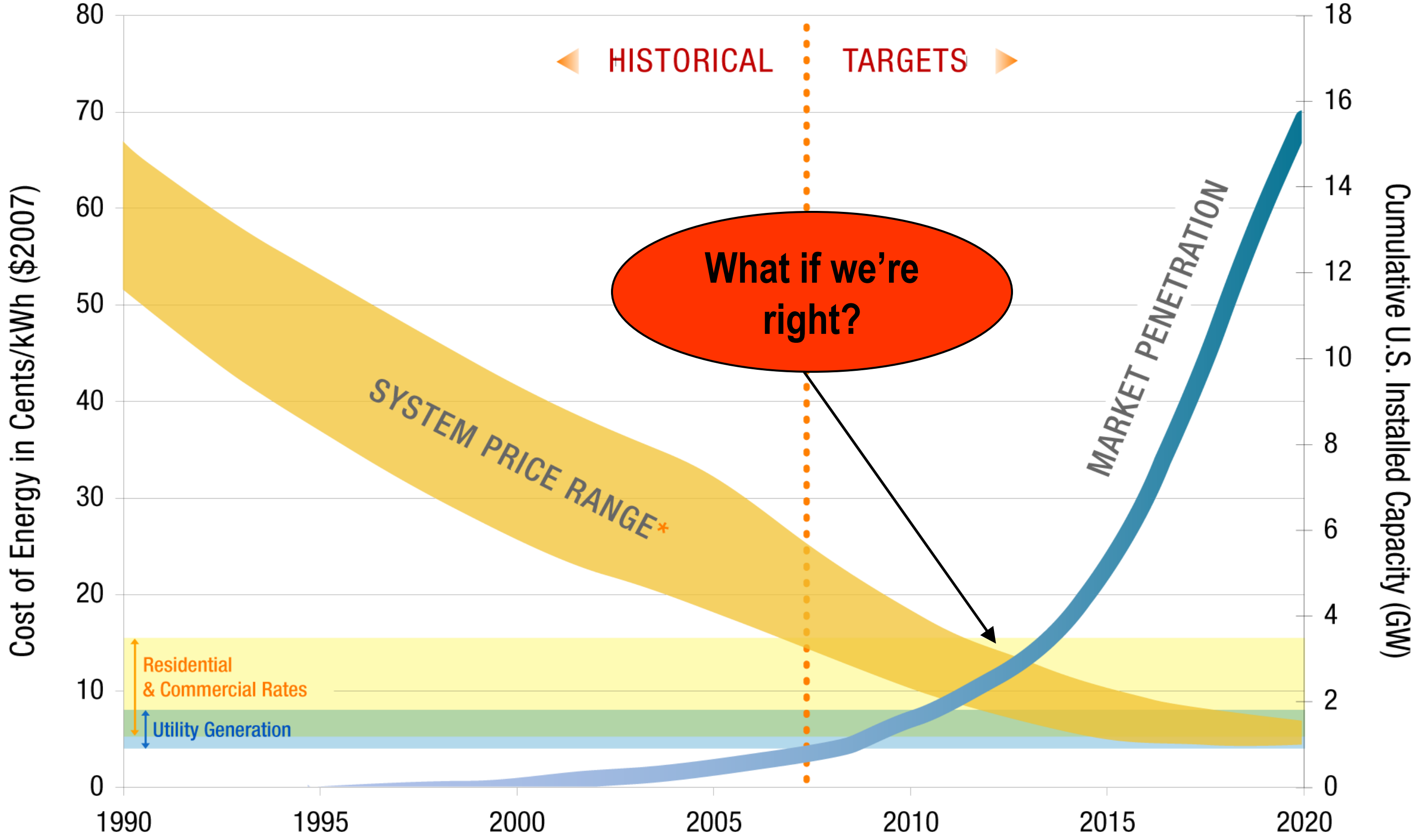
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



SETP budget


Budget (Million $)
$300
$250
$200
$150
$100
$50
$0
Recovery Act Funding
Market Transformation
Systems Integration
Concentrating Solar Power
Photovoltaics
Recovery
Funding
Increase
under SAI
FY01
FY02
FY03
FY04
FY05
FY06
FY07
FY08
FY09
FY10

The SETP is focused on enabling high penetration of solar energy technologies and achieving grid parity by 2015

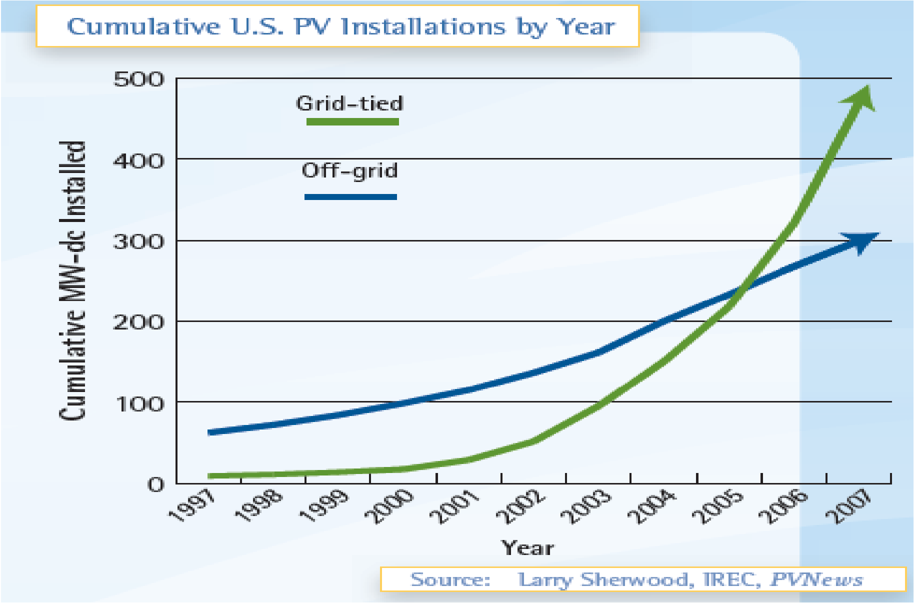


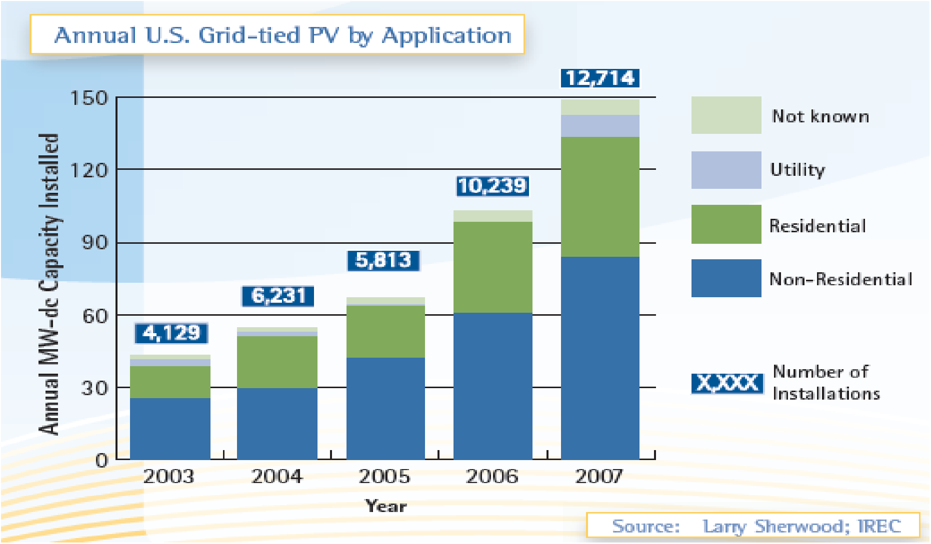
Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8 - 16.7	23 - 32	13 - 18	8 - 10
Commercial	5.4 - 15.0	16 - 22	9 - 12	6 - 8
Utility	4.0 - 7.6	13 - 22	10 - 15	5 - 7

Growth of Grid-Tied PV at a Fast Clip

- **Based on latest industry information on grid-tied PV:**
  - 45% growth rate in U.S. PV installations in 2007 over 2006
  - Annual installed capacity more than doubled since 2005
  - In 2008, CA alone installed 158MW, exceeding the 150MW growth achieved by entire U.S. in 2007
  - Outside CA, annual installations grew 83% in 2007 over 2006

- **High-penetration PV will inevitably become more prevalent in foreseeable future, based on growth trajectory**



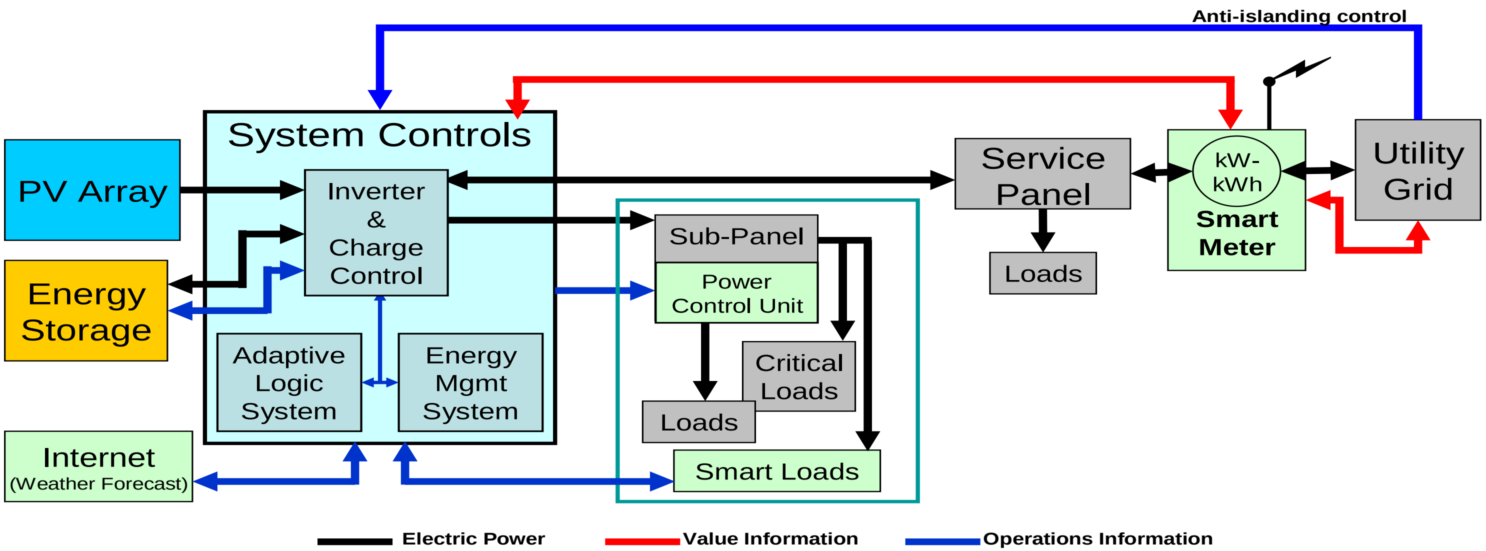


Technical Challenges for High-Penetration PV

- Ensure safe and reliable two-way electricity flow
- Develop smart grid interoperability
- Develop advanced communication and control functionalities of inverters
- Integrate renewable systems models into power system planning and operation tools
- Integrate with energy storage, load management, and demand response to enhance system flexibility
- Understand high-penetration limiting conditions
- Understand how various climates and cloud transients affect system reliability

SEGIS Development Efforts

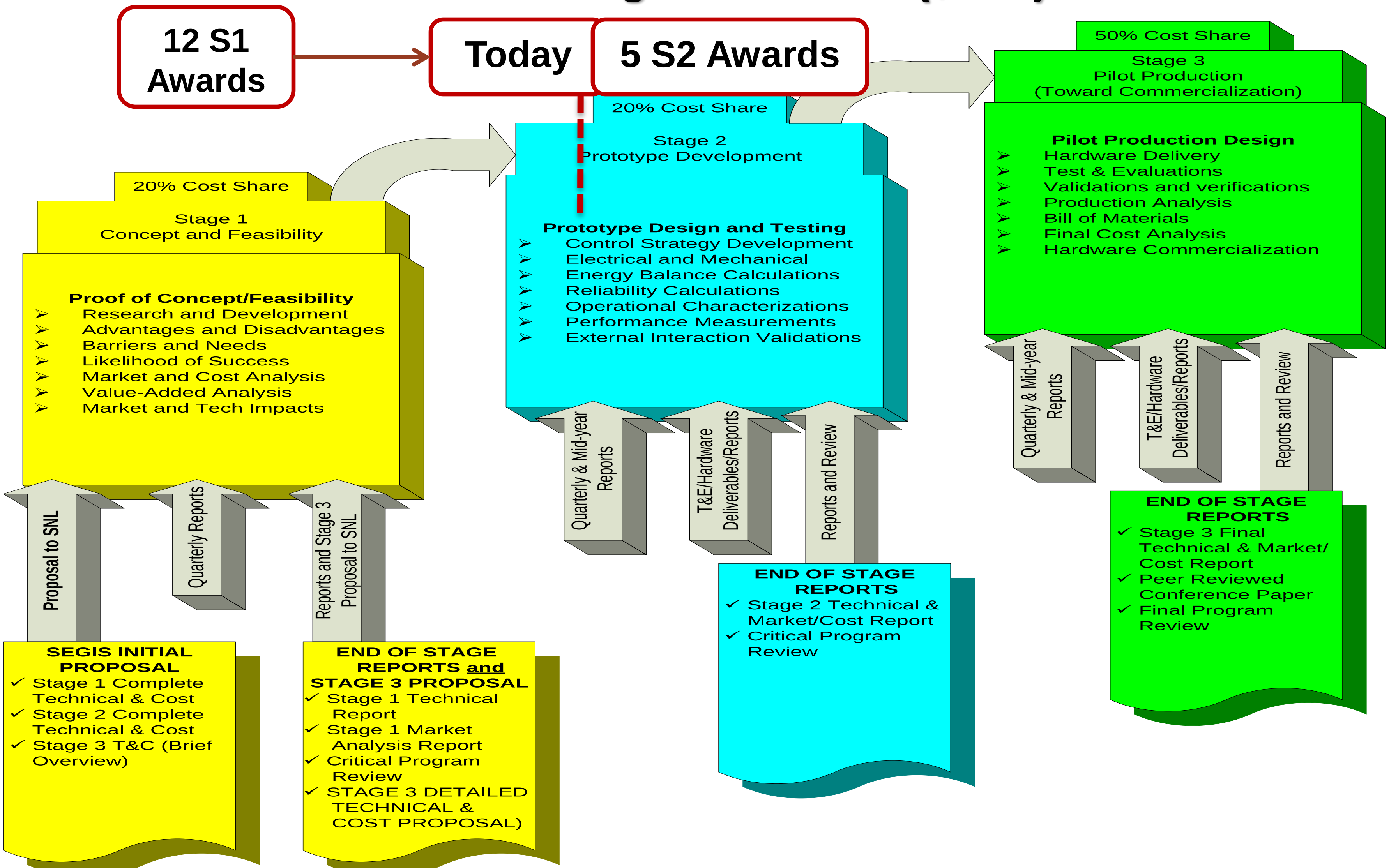
- SEGIS is a “system” development program focused on new requirements for interconnecting PV to the electrical grid.
- SEGIS develops intelligent hardware that strengthens the ties of smart grids, microgrids, PV, and other distributed generation.



Advanced Distribution Infrastructure with SEGIS Functionalities

SEGIS Stages & Timetable

SEGIS is a 3-Stage Solicitation ($24M)



Apollo Solar

Apollo Solar

- **Smart Grid Inverter provides the capability for energy storage.**
  - The battery storage can be installed during initial system installation or at a later date.

- **Smart Grid Inverter topology provides increased efficiency and high reliability.**
  - Due to low-part-count and minimal internal heat.

- **The communication system allows monitoring and control by the individual system owner, by the ISO's, or by the electric utilities via IEC 16850-7-420 and other developing protocols.**

Florida Solar Energy Center

Florida Solar Energy Center

- **The FSEC team is working to develop new grid integration concepts for PV that utilize:**
  - optional battery storage
  - utility control
  - communication and monitoring functions
  - building energy management systems

Petra Solar

Petra Solar

The company's SEGIS system architecture is achieved through a number of technological innovations, including:

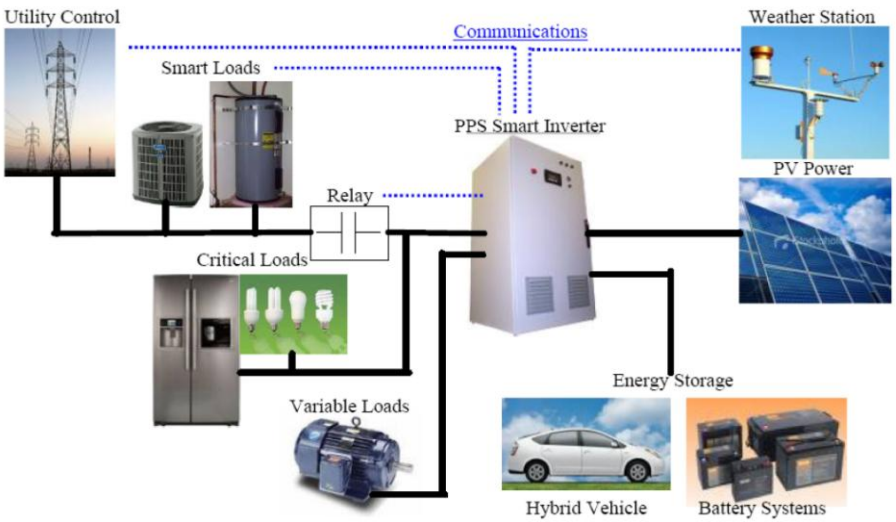
- **Easy-to-install, modular and scalable solar power system architecture based on PV AC modules.**
- **Multi-layer control and communication system that provides electric utilities with the tools to deploy a smart grid communications network and manage distributed generation assets.**
- **Cutting-edge power management platform, which provides tools and functionality to achieve a reliable two way distribution grid architecture.**

Princeton Power Systems

Princeton Power Systems

- **Building an advanced Demand Response Inverter ("DRI") incorporating nanocrystalline materials, that will lower energy cost.**

- **The DRI should achieve a lower LCOE through the following attributes:**
  - Small nanocrystalline magnetics and low-voltage silicon contribute to high efficiencies, with a California Energy Commission (CEC) weighted efficiency of 98%.
  - Simplicity of design and reduction of parts counts reduces initial capital cost.
  - Verified highly reliable components (15 year service life; ~400k hours Mean Time Between Failures).



PV Powered

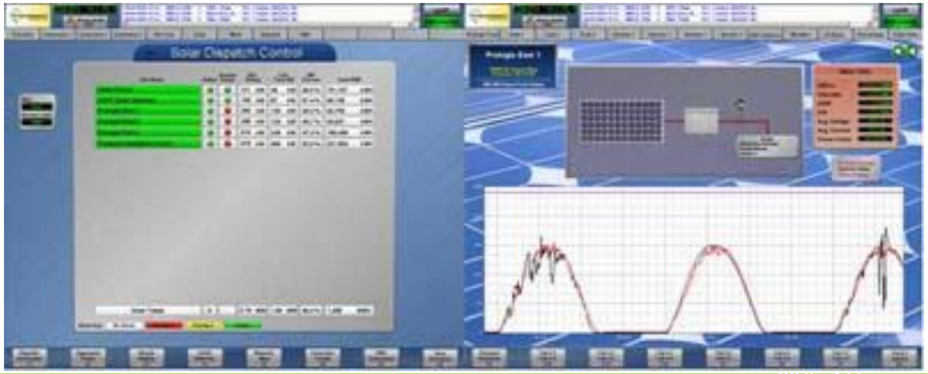
Focus is on two key areas:

1) Solving utility systems integration problems

- Two-way Utility Communications and Control.
- Smart Power Islanding Detection.
- Site Demonstration.

2) Improving the energy economics of PV systems

- Energy Harvest.
- Energy Management Systems Integration.
- Improved Power Plant Balance of System Components.



Thank You

Contact Information:

John Lushetsky
Solar Energy Technologies
Program Manager
U.S. Department of Energy

Email**:**
john.lushetsky@ee.doe.gov
Phone**: 202-287-1685**
on the web:
www.solar.energy.gov

Sign up for SETP quarterly newsletter by emailing: solar@ee.doe.gov

Courtesy: Castle & Cooke

Colin Schauder

Satcon

Workshop on High Megawatt Electronics

December 11, 2009

An Isochronous Grid Through Electronics

Colin Schauder
Satcon Technology Corporation

Satcon

The Grid is a Wonderful Thing – But …

- The US electric power grid is a modern wonder.
- We are
  - Usually it's ***BENEFICIARIES*** – everything is electrical
  - Sometimes it's ***VICTIMS*** – suffer through power outages
  - But always it's ***CAPTIVES*** – almost impossible to change
    - Huge capital investment in equipment and infrastructure
    - Entrenched bureaucracy and operating procedures
    - No financial incentive to do anything differently
    - Nothing changes unless legislation forces it
- Given the technology and hindsight available today, Edison and Westinghouse might come to different conclusions about how to deliver electricity.

Satcon™

The Utility-Scale Electronic Generator

- A static or other electronically-controlled sinusoidal 3-phase voltage source
- *<u>Self-commutated</u>* (i.e. independent of ac line voltage)
- High power rated
  - Multi-megawatts to hundreds of MW
- Capable of real power flow in one (or both) directions from (or to) a real power source (or sink, or energy storage) – analogous to the “prime mover”
- Capable of connection at transmission voltage levels
- Capable of generating (and absorbing) reactive power
- High Efficiency
  - Expected power losses < 1%

Satcon™

Electronic Generators Arrived Quietly in the 1990's - In Disguise

- Not billed as generators, but disguised as part of other equipment types – up to 320 MVA
  - STATCOM – Static Compensator
    - Westinghouse, Mitsubishi, ABB, Alsthom – US installations TVA, AEP, PG&E, NYPA, SDG&E, VELCO, NU, Austin
  - UPFC – Unified Power Flow Controller
    - Westinghouse (Siemens) – AEP, NYPA, Korea
  - SSSC – Static Synchronous Series Compensator
    - Westinghouse (Siemens) – AEP, NYPA
  - IPFC – Interline Power Flow Controller
    - Westinghouse (Siemens) - NYPA
  - Arc Furnace Flicker Compensator
    - Westinghouse, Mitsubishi
  - Back-to-back asynchronous intertie
    - ABB – US installation at AEP
  - HVDC Lite
    - ABB worldwide

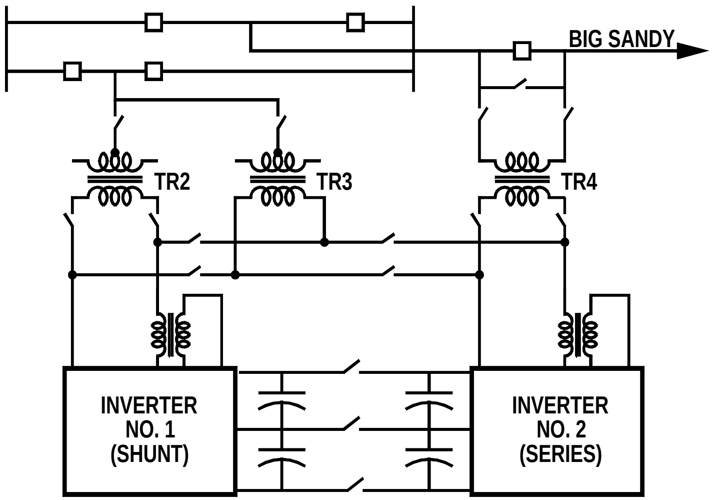
Satcon™

Various High-Power Equipment Has Been Built Around Large Electronic Generators

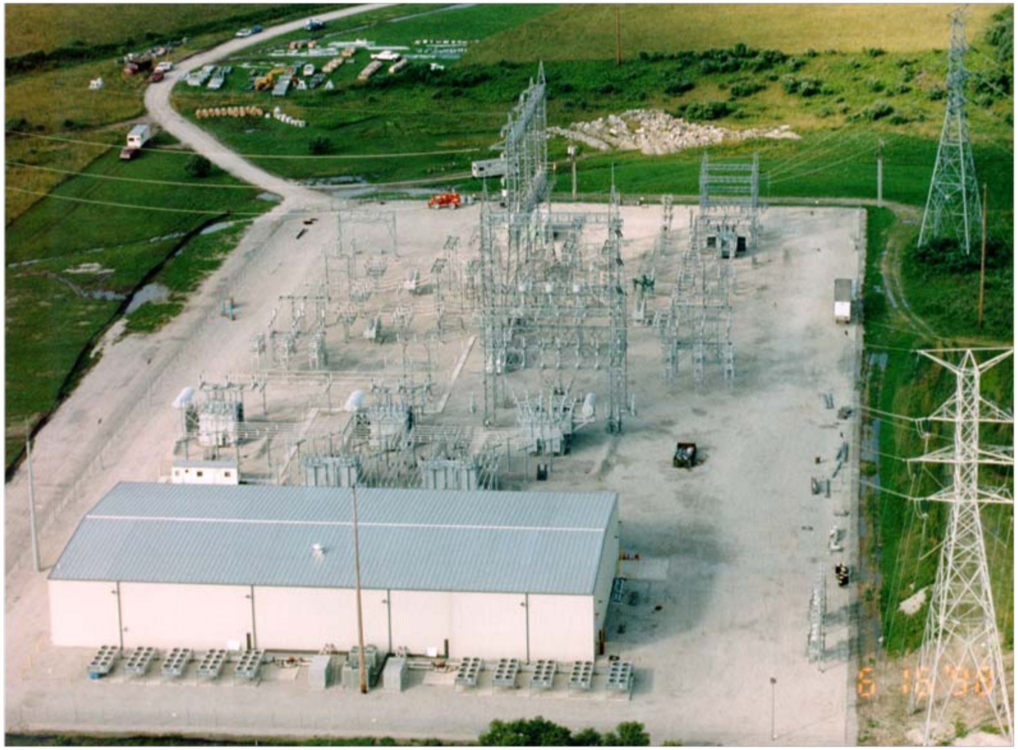
- All of these types of equipment qualify as electronic generators as defined here.
- The power ratings achieved are comparable with moderately large utility generating units
- None of the equipment types has typically been associated with a built-in capability to produce electrical power from fuel or renewable sources or to and from bulk energy storage.
- They were designed to serve different purposes from conventional utility power generation
  - Var generation – Voltage support – Flicker reduction
  - Transmission line power flow control – Power oscillation damping.
  - Underwater and underground power transmission by cable
- But .. Connected to suitable dc power sources or energy storage the same designs could serve as very high performance ac generating units for the grid.

WESTINGHOUSE (SIEMENS) UNIFIED POWER FLOW CONTROLLER
AEP INEZ SUBSTATION, KENTUCKY.
320 MVA (2 x 160 MVA) INVERTER - DEDICATED JUNE 1998

- First back-to-back inverter installation
- Largest inverter installation in the world (when dedicated)
- First high power 3-level pole installation
- First demonstration of series connected inverter-based compensation
- First demonstration of UPFC with automatic power flow control



ACKNOWLEDGEMENT TO AEP FOR USE OF PICTURE



Satcon™

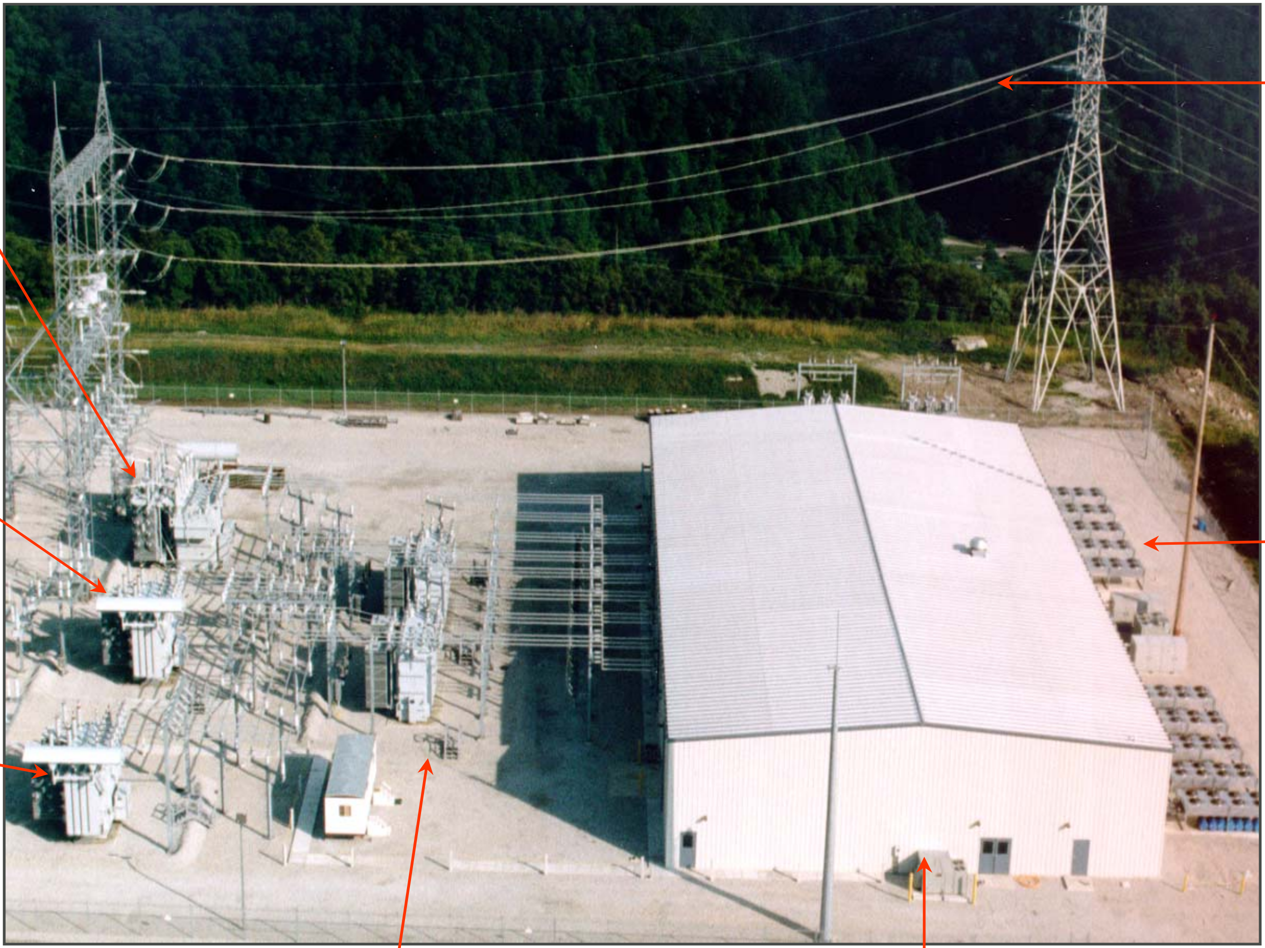
UPFC Installation at AEP Inez Substation

ACKNOWLEDGEMENT TO AEP FOR USE OF PICTURE

Series Transformer

Spare Shunt Transformer

Main Shunt Transformer



Big Sandy Line

Cooling System Heat Exchangers

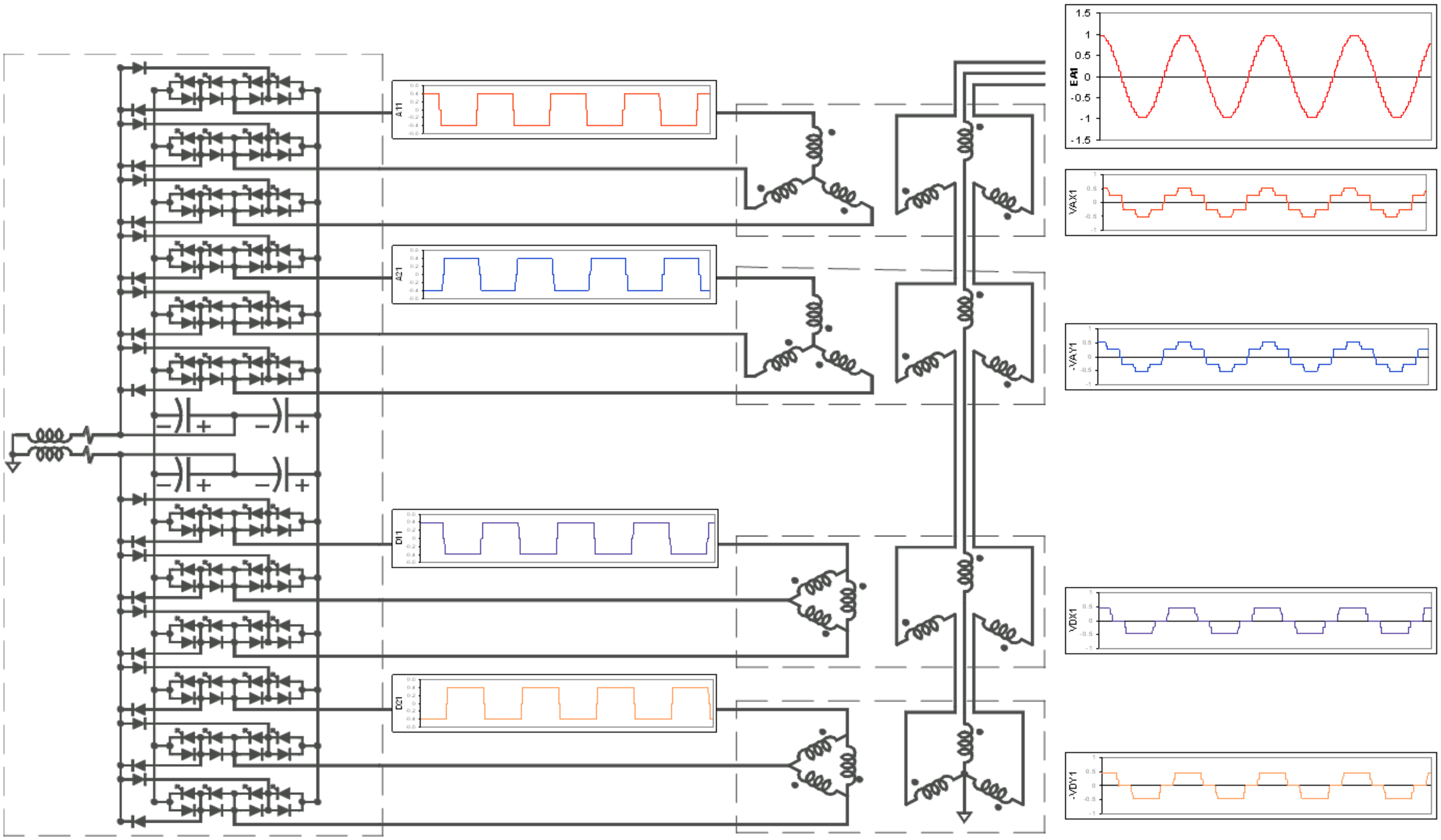
Shunt & Series Intermediate Transformers

UPFC Building (Inverters & Controls)

Satcon

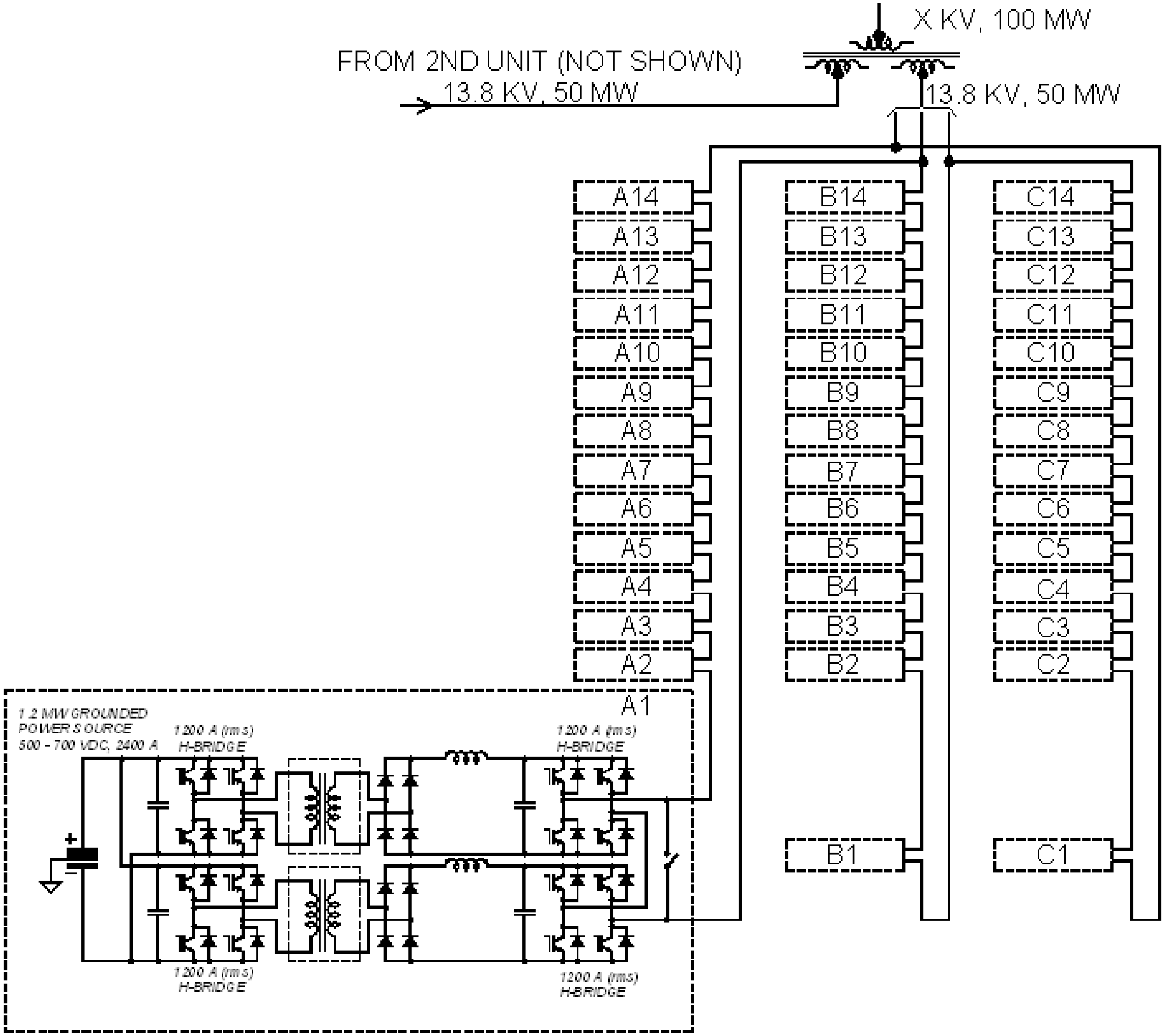
View of the 320 MVA (2 x 160 MVA) GTO-Based Inverter at AEP Inez Substation

Example of Electronic Generator Waveform Synthesis
- AC Series Cascade - 60 Hz Switching - 48-Pulse Output Voltage
- Practical Design in Service at 150 MVA



Satcon™

Example of a Hypothetical 100 MW Electronic Generator
- H-Bridge Series Cascade - Low Voltage IGBT's
- Multiple Grounded Power Sources



Satcon™

Large-Scale Self-Commutated Electronic Generators Failed in Some Markets – Succeeded in Others

- After many successful demonstration projects established the technical viability, commercial reality set in.
  - Failed in transmission compensator market
    - Utilities prefer alternative line-commutated thyristor-based equipment for var generation - Lower performance, lower cost.
    - Little interest in power flow control or oscillation damping
  - Succeeded in underwater and underground cable transmission market.
    - HVDC Lite (ABB) (and very recently HVDC Plus (Siemens))
    - DC cable beats AC cable transmission.
    - Self-commutated beats line-commutated on weak AC bus

Satcon™

Return of the Electronic Generators – No Disguise

- Electronic generators are returning to the grid, with a new raison d’être as the grid connection interfaces for renewable and alternative energy sources and storage
  - Lower unit power ratings (1MW - 3MW typical) – but sometimes aggregated to tens of MWs per site
  - Often connected to the *distribution system at MV levels* rather than a transmission bus
  - With built-in power sources / sinks:
    - Renewable energy (PV storage (x 1 MW)
    - Grid interface for wind turbines (x 3 MW DFIM)
    - Energy storage
  - Usually not owned and operated by utilities

Electronic Generators Have Been Relegated to Menial Duty Providing an Interface with the AC Grid

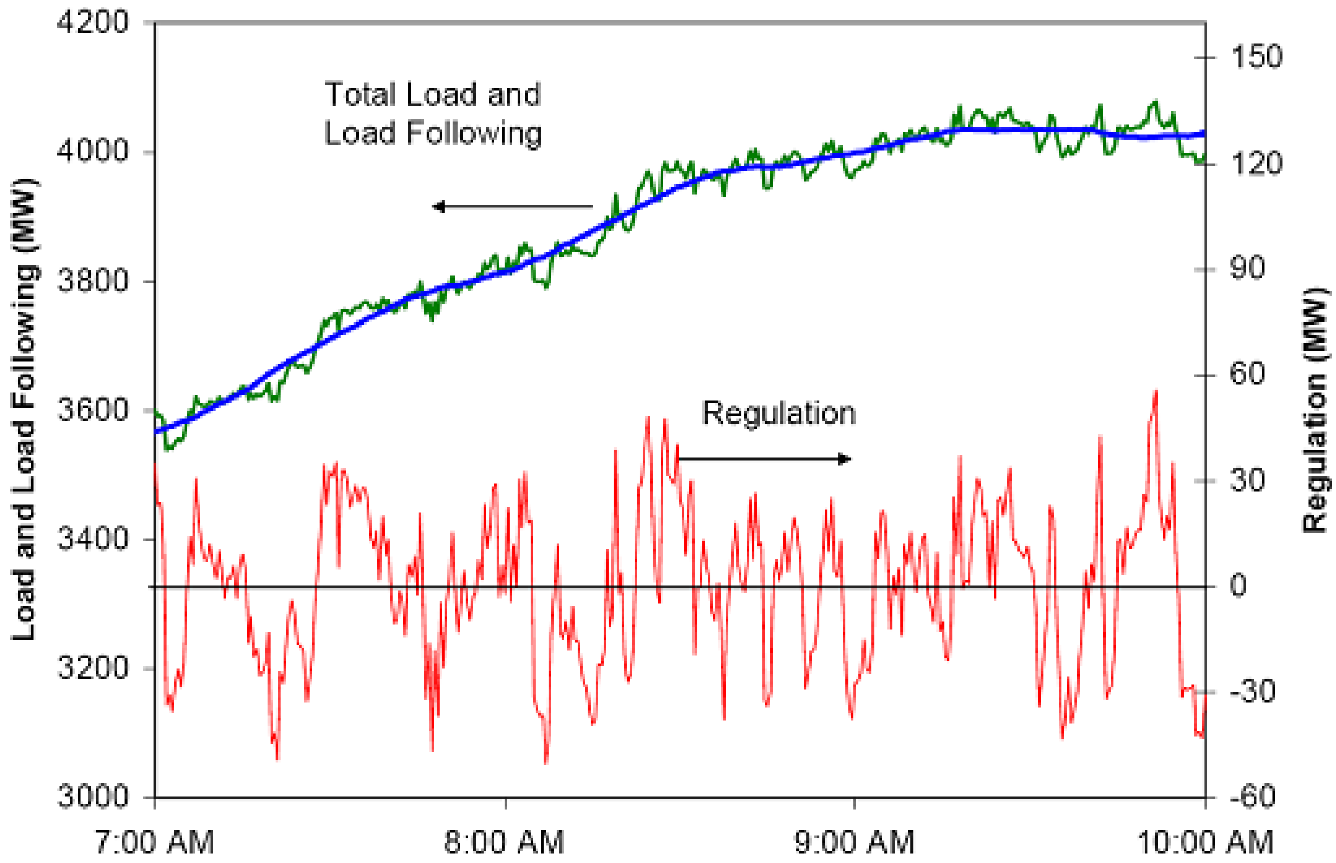
- Presently electronic generators act as simple low-tech power sources connected to the grid.
  - Allowed to push current into the grid for various purposes
  - Regulate voltage at transmission buses and ride through disturbances
  - Regulate nothing on distribution buses - get out of the way during disturbances and let the big boys handle it

Control of the AC Interconnected Grid Has Evolved Around Synchronous Machine Generators

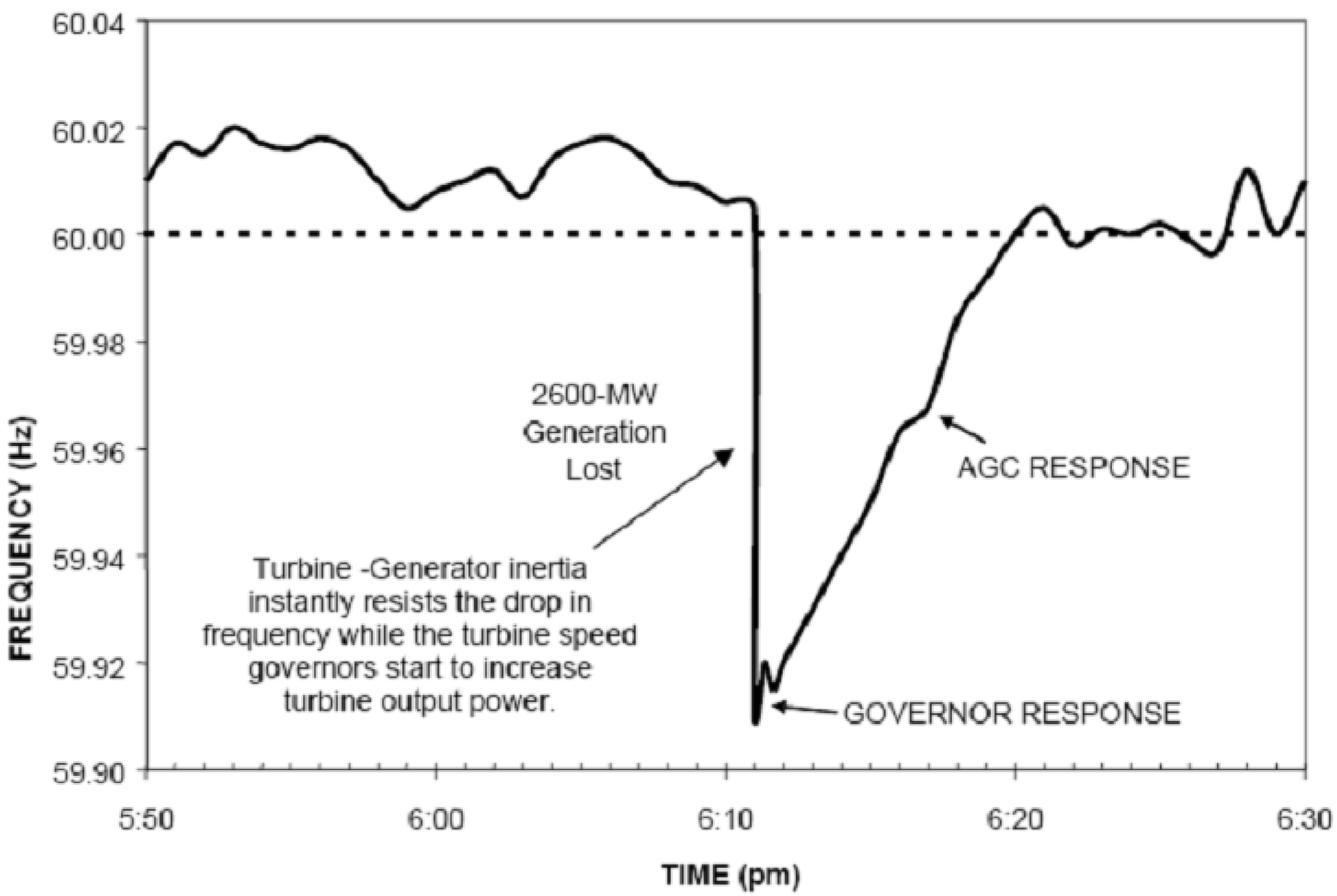
- Frequency is used as a global control variable
  - Effectively establishes a form of communication between generating units.
- Grid control *depends* on frequency change.
- Generator governor action provides a power/frequency droop characteristic that establishes equitable load sharing.
- Sudden load changes are transiently supplied from the collective stored energy (inertia) until governor action stabilizes the grid at a new frequency.
- Secondary control from a control center slowly adjusts the droop characteristics so that the load/generation equilibrium point returns to 60 Hz.

Satcon™

Control is Based on Frequency Deviation and Correction – Power Used For Correction is Expensive



Stored Energy (Inertia) Supplies Load Excess Until Governor Action Stabilizes Frequency – AGC Corrects



Satcon™

How Would You Utilize The Capability of An Electronic Generator to Control a Grid?

- Emulate a conventional synchronous machine generator in a conventional ac interconnection

OR

- Establish an isochronous ac interconnection area under electronic control

Satcon™

How Should Electronic Generators Be Incorporated Into A New Modern Grid Architecture?

- Electronic generators can be forced to suppress their fast control capability, and mimic the behavior of their rotating synchronous machine counterparts.
  - Frequency/Power droop with slow secondary frequency correction – Business as usual – Same power system stability issues.
  - This is the basis of the CERTS approach to microgrid control

OR

- Electronic generators can be used to
  - Maintain constant grid frequency
  - Instantaneously absorb real and reactive load/generation differences
  - Provide dc interties for stable power exchange with other ac grid segments
  - Respond rapidly to control center commands through secure high speed communications.

Satcon™

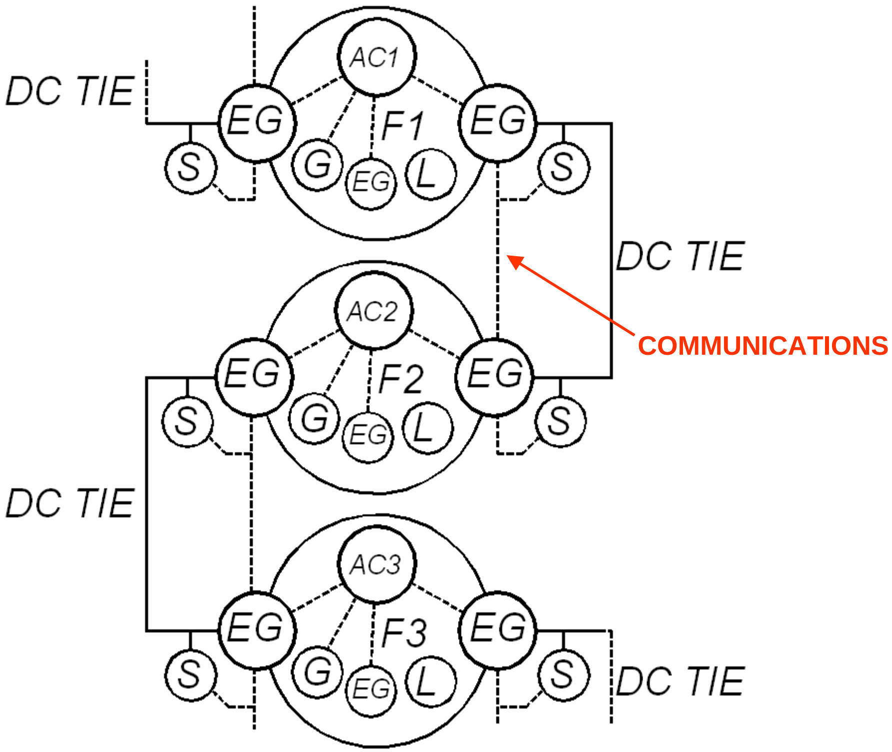
Electronic Generators Can Be More Than Just Grid Interfaces – They Can Control The Grid Frequency

- An electronic generator of sufficient rating can support a quasi-infinite ac “swing” bus, defining the frequency of the entire ac interconnection in an absolute sense.
  - An electronic generator provides a nearly ideal Thevenin voltage source behind a finite tie impedance
  - Frequency and phase of the controlled voltage source is not dependent on load
  - The electronic generator supplies or absorbs all of the differential real and reactive power for the grid (i.e. the difference between other generation and loads) – virtually instantaneously.

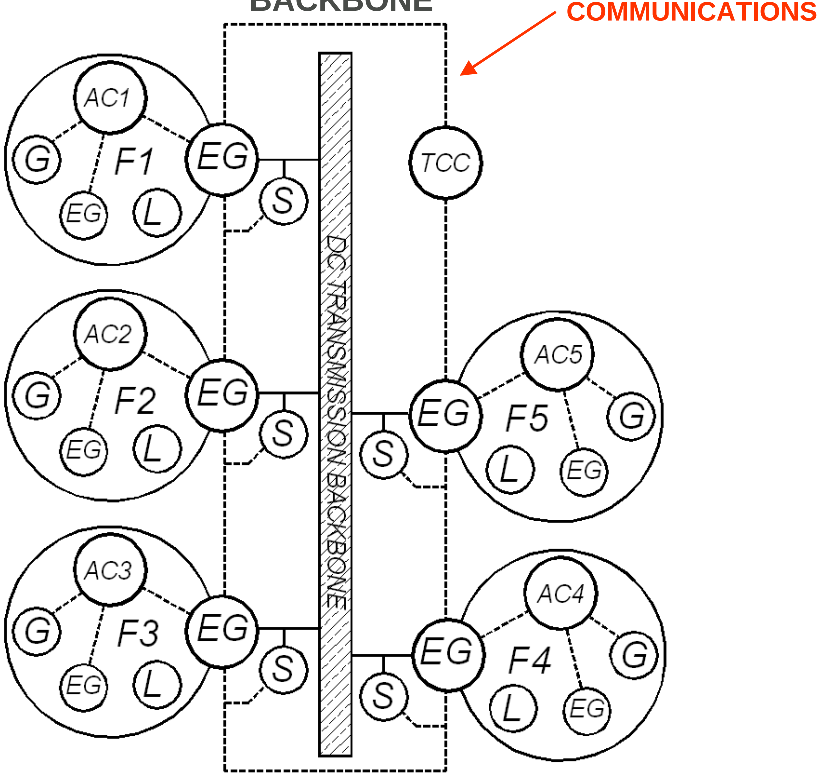
Satcon™

Two Hypothetical Electronic Grid Architectures

DC TIES BETWEEN
ADJACENT AREAS



DC TRANSMISSION
BACKBONE



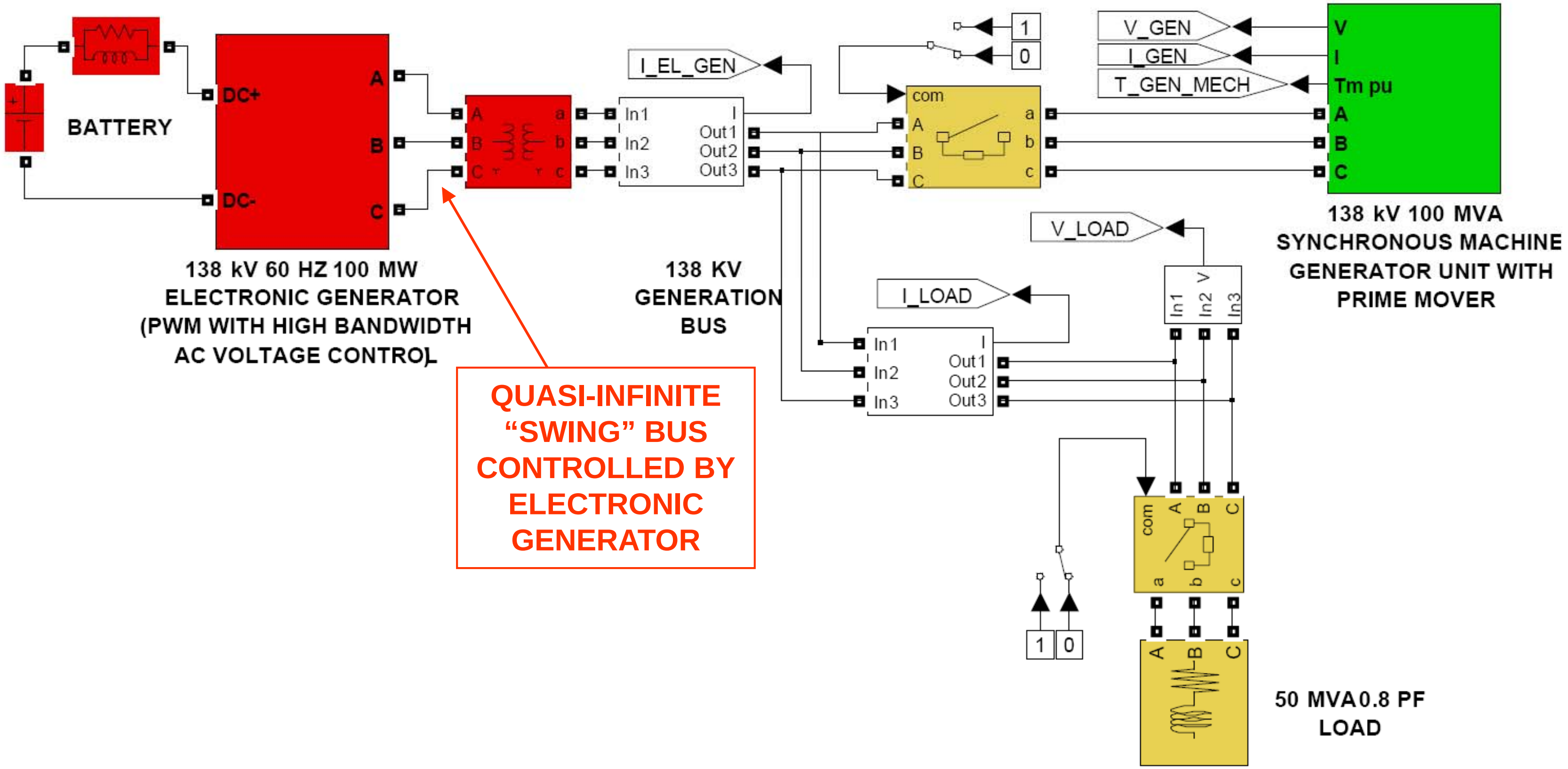
AC - AREA CONTROL
G - SYNCHRONOUS M/C GENERATION
EG - ELECTRONIC GENERATION
L - LOAD
S - ENERGY STORAGE
F - FREQUENCY
TCC - TRANSMISSION CONTROL

Satcon™

An Isochronous Grid With Electronic Generator Control

SIMULINK MODEL FOR HYPOTHETICAL GRID CONTROLLED ISOCHRONOUSLY BY AN ELECTRONIC GENERATOR

- Battery feeds electronic generator serving as isochronous swing generator , controlling voltage and frequency
  - Electronic generator supplies or absorbs transient real power and continuous reactive power as needed
- Rotating synchronous machine generator unit supplies continuous load with prime mover under dispatch control

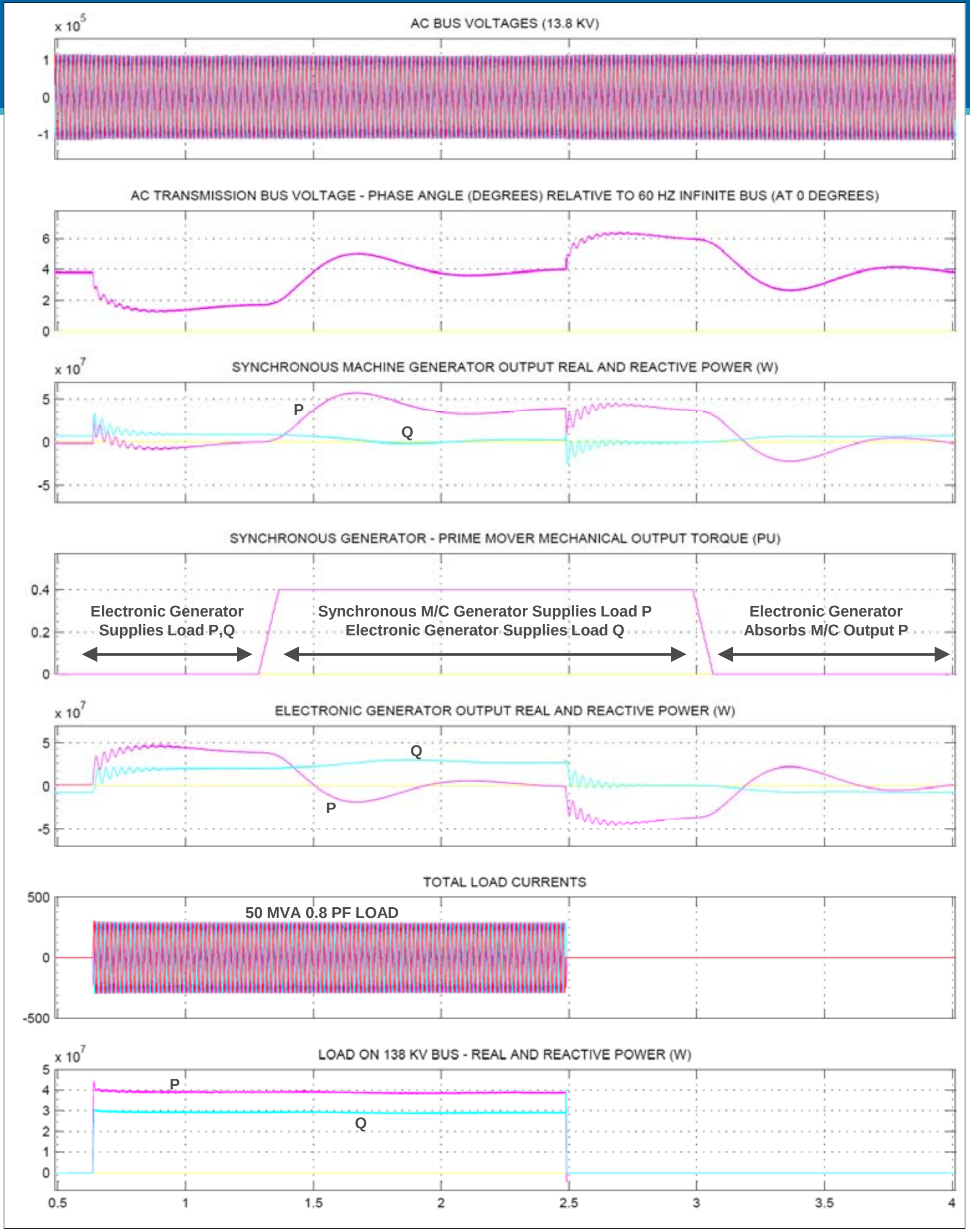


Satcon

An Isochronous Grid With Electronic Generator Control

Average Frequency Constant At 60 Hz

100 MW Electronic Generator Supports Isochronous Grid With Instantaneous P and Q



100 MW Synchronous M/C Generator Supplies Real Power On Command

Satcon™

The Challenges For Proponents of Utility Scale Electronic Generators

- Achieve high reliability and availability
  - Essential for equipment controlling a grid
  - Should be easier with electronics than rotating machines
- Develop/incorporate suitable energy storage (High MW – short or long term) and/or power sources to enhance the capability of electronic generators to absorb, store, and deliver energy
- Gain acceptance through large “island” grid projects incorporating synchronous machine generators
- Fight the good fight – Work to revise standards that impede the progress of new forms of generation
- Establish a sound commercial basis for the use of electronic generators – Otherwise they will disappear!

Satcon™

Jeffrey Casady

SemiSouth

Recent Advancements in SiC power devices & the impact of normally-off SiC JFETs on PV inverter platforms

Jeffrey B. Casady, CTO & VP Bus Dev

SemiSouth Laboratories Inc.

www.semisouth.com

High MW Electronics – Industry Roadmap Meeting
December 11th 2009

SemiSouth

SemiSouth

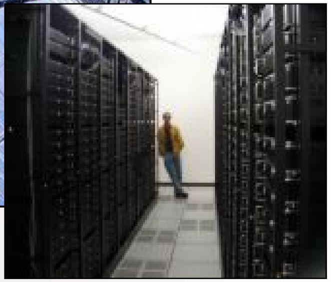
Introduction

SemiSouth Laboratories is a clean energy enabler

specializing in the design & manufacture of silicon carbide (SiC) power devices used to harvest and transfer power in renewable energy systems, telecom server farms & hybrid electric vehicles.

SemiSouth silicon carbide based devices offer higher efficiency, greater power density and higher reliability than comparable silicon-based devices

Solar



Servers

HEV

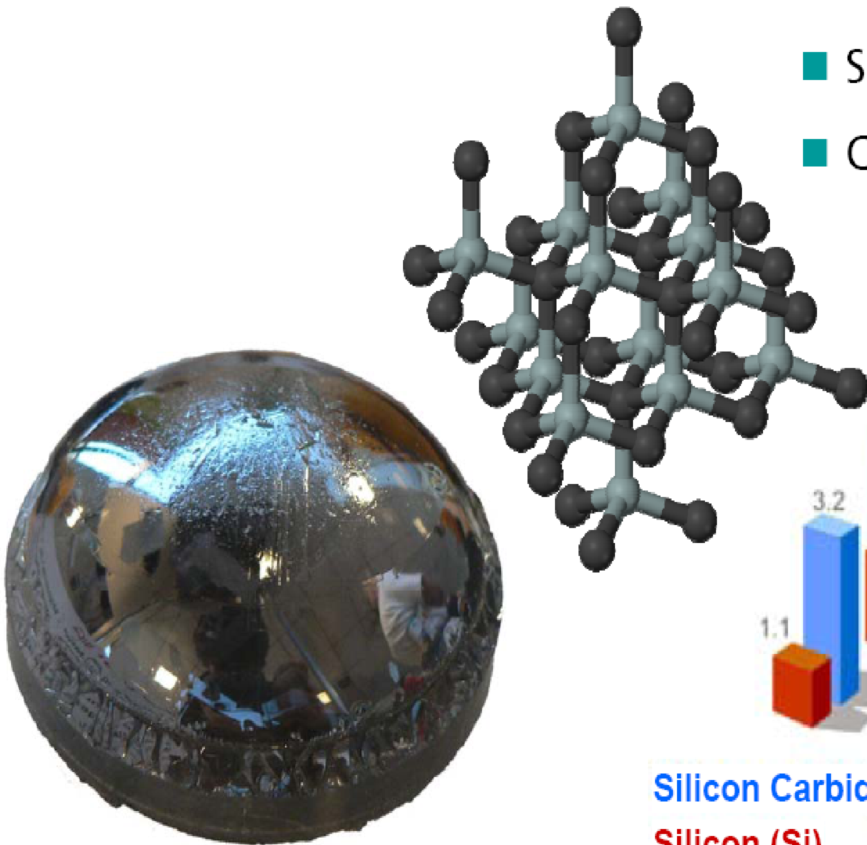
Wind

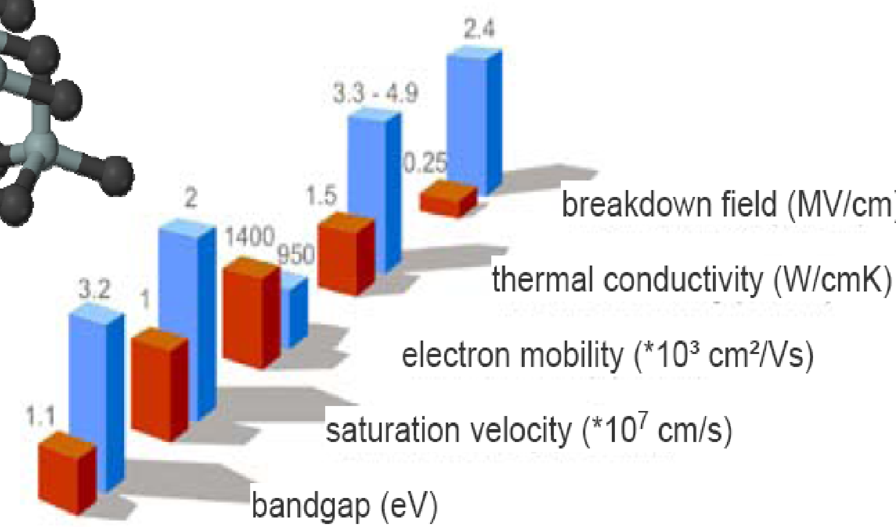
SiC Wafer

World record PV inverter efficiency

SiC Properties

- Silicon and Carbon
- Cubic and hexagonal structure (4H)





Source: www.wikipedia.de

Source: www.siced.de

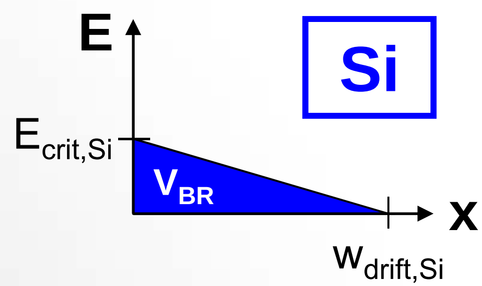
SemiSouth

SiC Advantages

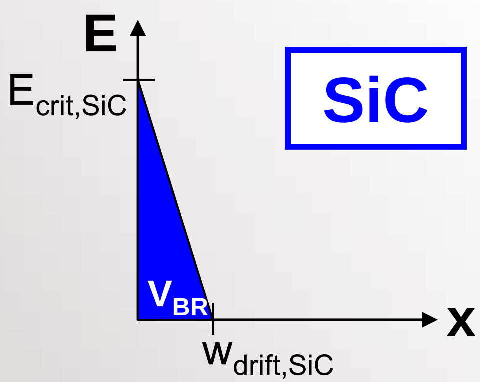
Material property	Si	4H-SiC	GaN
Bandgap	1.12 eV	3.25 eV	3.4 eV
Breakdown field	0.25 MV/cm	~3 MV/cm	~3 MV/cm
Thermal conductivity	1.5 W/cm•K	4.9 W/cm•K	1.3 W/cm•K
Electron mobility	1200 cm^2/V•s	800 cm^2/V•s	900 cm^2/V•s
Dielectric constant	11.7	9.7	9

- Silicon carbide is the ideal power semiconductor material
- Most mature "wide bandgap" power semiconductor material
- Electrical breakdown strength ~ 10X higher than Si
- Commercial substrates available since 1991 –
  - **now at 100 mm dia; 150 mm dia soon**
- *Defects up to 1,000 times less than GaN*
- *Thermal conductivity ~ 3X greater than Si or GaN*

Thinner Devices, Lower Losses



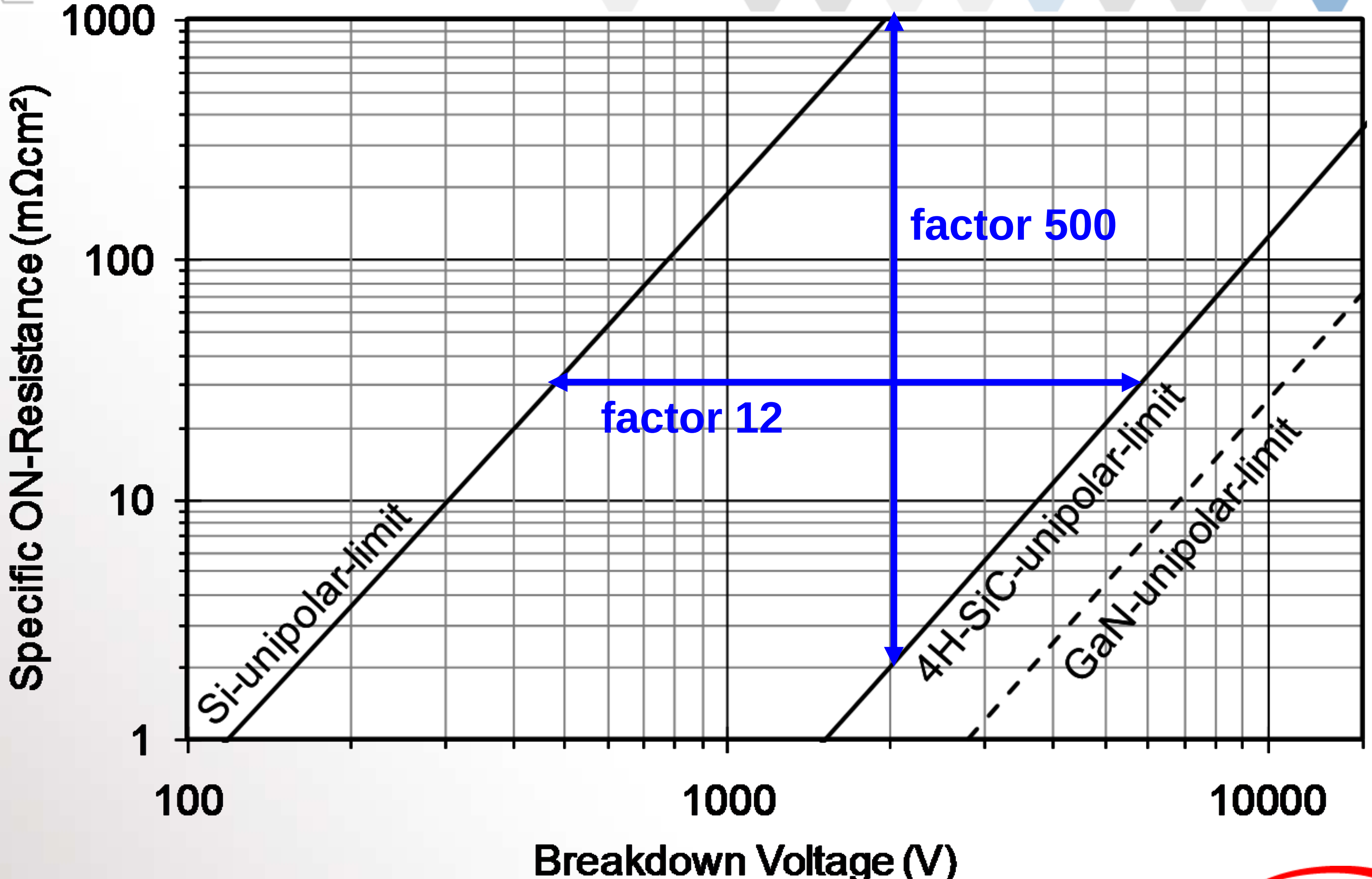
$E_{crit,SiC} \approx 10 \cdot E_{crit,Si}$



unipolar devices	bipolar (plasma) devices
$r_{on} \sim w_{drift} / N_D$	$q_{st} \sim w_{drift}^2$
$w_{drift,SiC} \approx w_{drift,Si} / 10$ $N_{D,SiC} \approx 100 \cdot N_{D,Si}$	$w_{drift,SiC} \approx w_{drift,Si} / 10$
$r_{on,SiC} \approx r_{on,Si} / 1000$	$q_{st,SiC} \approx q_{st,Si} / 100$

N. Kaminski, EPE2009

ON-Resistances: Theoretically



N. Kaminski, EPE2009

SemiSouth

A Note on Device Size

- SiC devices can not be 500 times smaller
  - 500 times higher current densities are tough
  - 500 times higher loss densities are deadly (same losses on 500 times smaller area)
- Rather: Design on the same loss density
  - Area and losses reduced by the same factor
  - Benefit would be $\sqrt{\text{BFoM}}$, i.e. still factor 22
- Note: Threshold voltages do not scale!

N. Kaminski, EPE2009

IALB

SemiSouth

Material Properties

Parameter		Silicon	4H-SiC	GaN	Diamond
Band-gap E_g	eV	1.12	3.26	3.39	5.47
Critical Field E_{crit}	MV/cm	0.23	2.2	3.3	5.6
Permitivity ε_r	–	11.8	9.7	9.0	5.7
Electron Mobility μ_n	$cm^2/V \cdot s$	1400	950	1500	1800
BFoM: $\varepsilon_r \cdot \mu_n \cdot E_{krit}^3$	rel. to Si	1	500	2400	9000
Intrinsic Conc. n_i	cm^{-3}	$1.4 \cdot 10^{10}$	$8.2 \cdot 10^{-9}$	$1.9 \cdot 10^{-10}$	$1 \cdot 10^{-22}$
Thermal Cond. λ	$W/cm \cdot K$	1.5	3.8	1.3	20

- Low leakage currents (at least theoretically)
- High temperature operation possible (packaging!)
- Better cooling and temperature homogeneity

N. Kaminski, EPE2009

IALB

Device Concepts for WBG

Functionality / Conductivity	**Diodes**	**Switches** junction controlled	**Switches** MOS-controlled ➡ poor & instable interface props.
unipolar ➡ $r_{on} \sim V_{BR}^{2,5}$			
bipolar (plasma) ➡ crystal degradation (SiC) low plasma lifetime (GaN) ➡ $V_T \approx E_g / q - 0.5V$			

N. Kaminski, EPE2009 IALB

Device Concepts for WBG

Functionality / Conductivity	**Diodes**	**Switches** — junction controlled	**Switches** — MOS-controlled ➡ poor & instable interface props.
unipolar ➡ $r_{on} \sim V_{BR}^{2,5}$	[Schottky, JBS]	JFET (✓)	MOSFET ?
(unipolar / bipolar boundary)	MPS ✓	BJT (✓)	
bipolar (plasma) ➡ crystal degradation (SiC), low plasma lifetime (GaN) ➡ $V_T \approx E_g/q - 0.5V$	pin (✓)	bipolar JFE… ? Thyrist…	

1:1 replacement for Si IGBTs

not a real plasma device: high … V_T c…

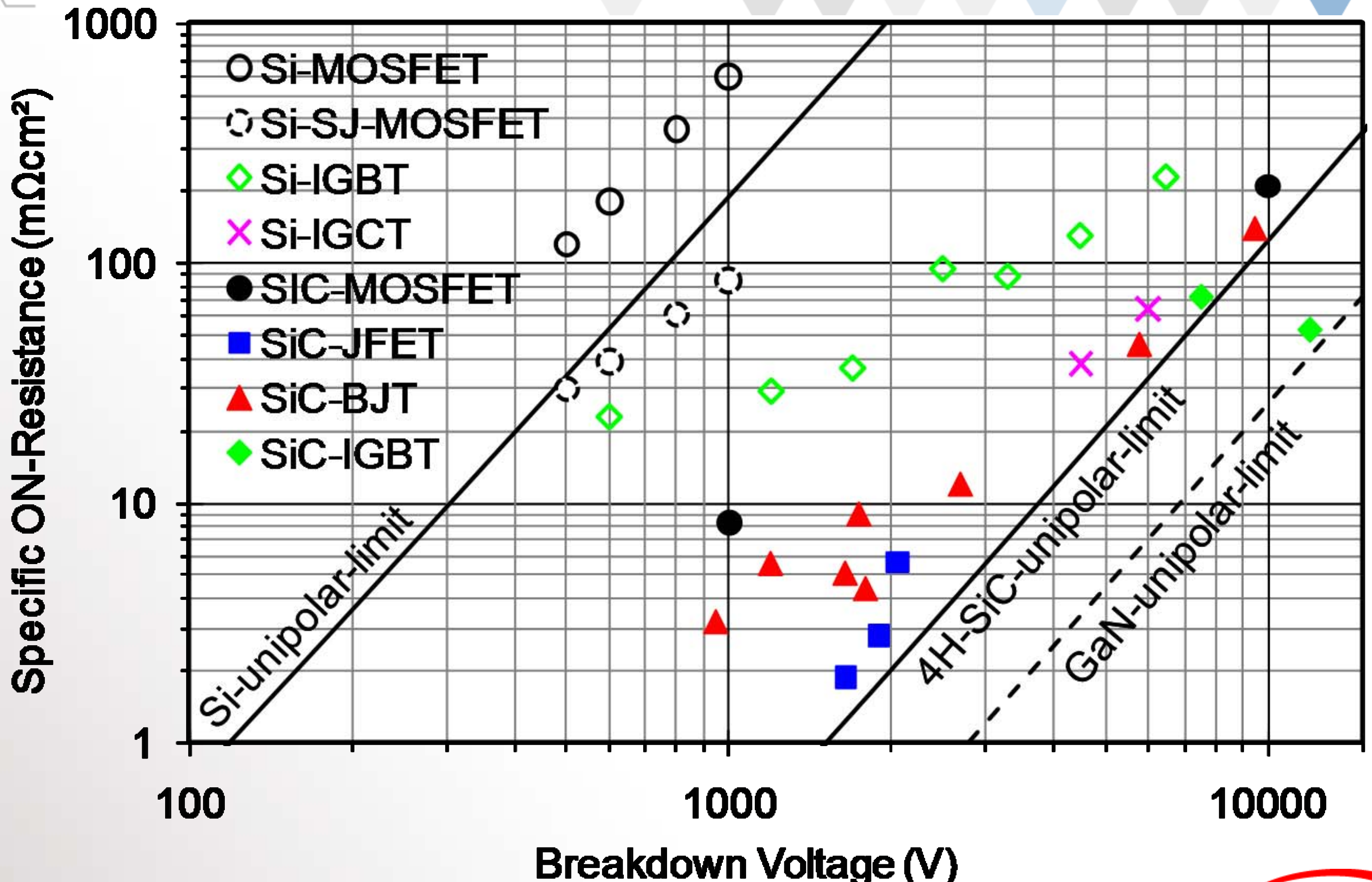
for very high voltages?

N. Kaminski, EPE2009

IALB

SemiSouth

ON-Resistances: State of the Art

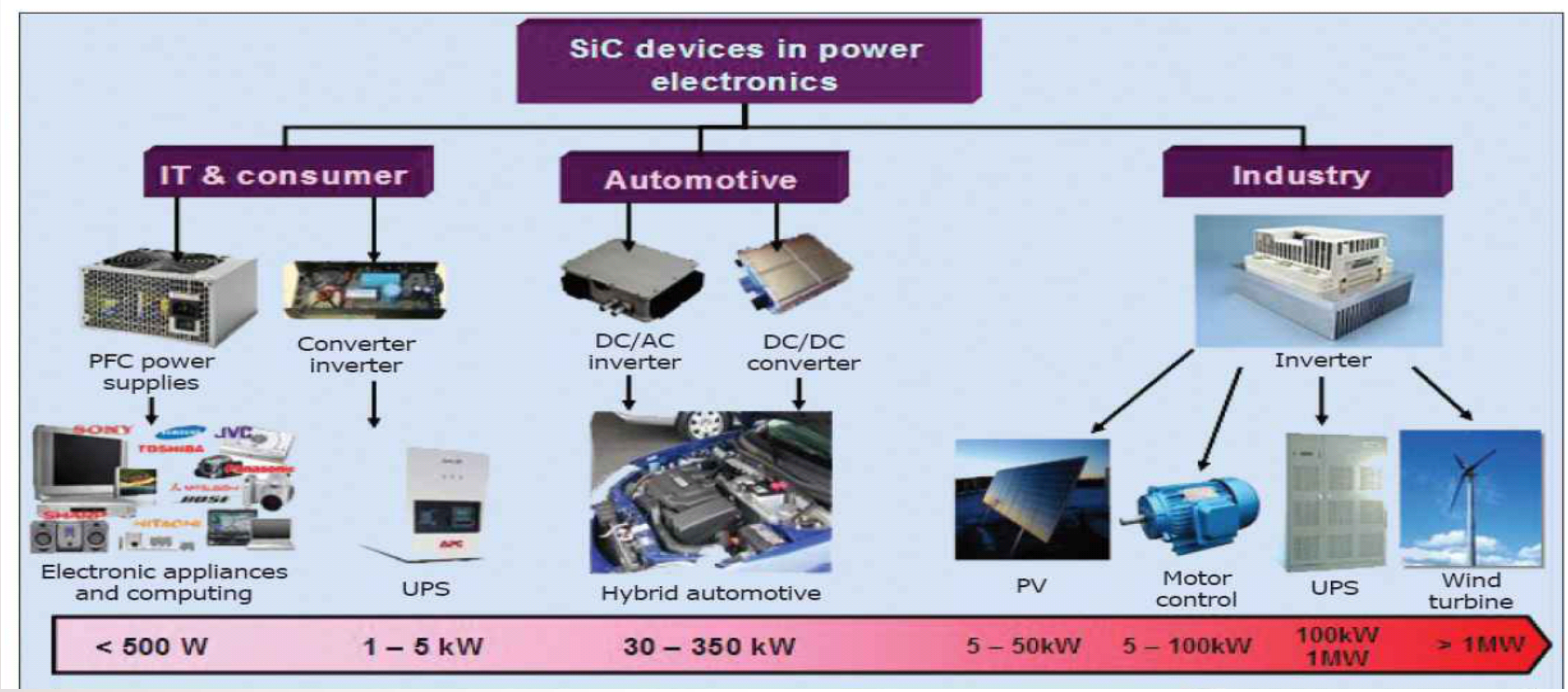


N. Kaminski, EPE2009

IALB

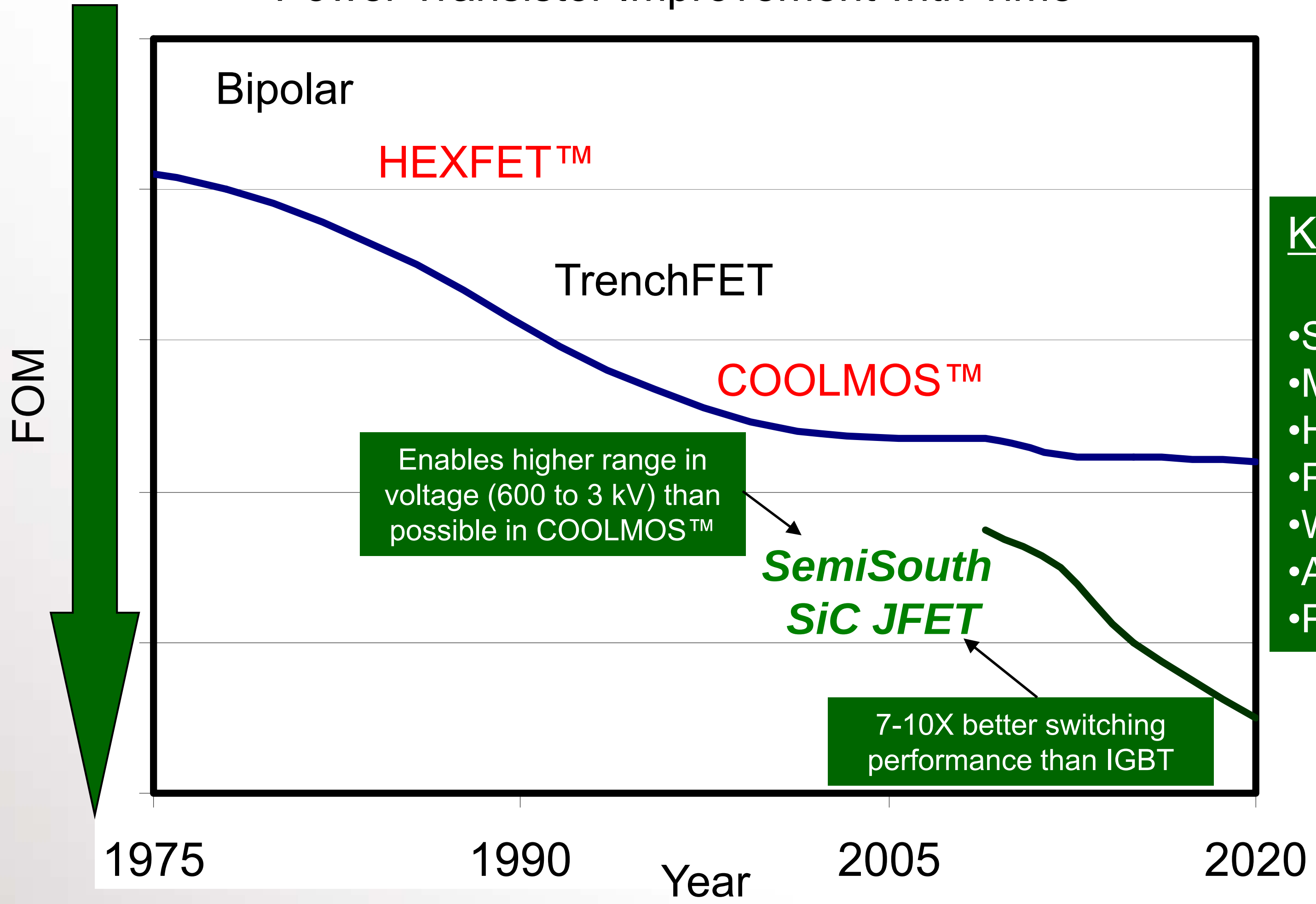
SiC is the Ideal Power Device Technology

SemiSouth JFETs can Replace IGBTs and MOSFETs for Higher Efficiency and Higher Frequency Switching
….Power Dissipation can be reduced by over 50%



SemiSouth

Power Transistor Improvement with Time



Key markets

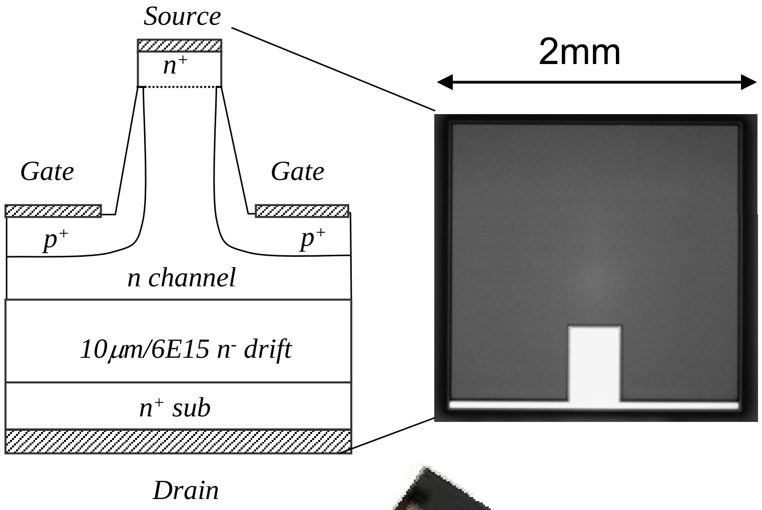
- Solar
- Medical
- Hi-Rel / Aero
- Power Supply
- Welding
- Automotive
- Protection

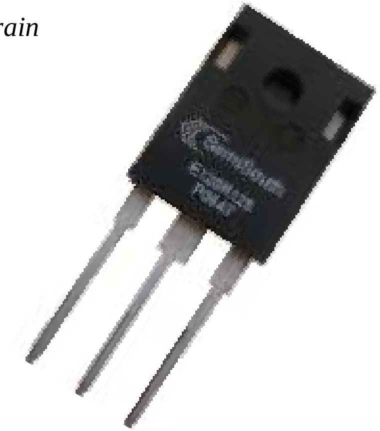
JFET Technology

SemiSouth JFET advantages

- All benefits of SiC
- Normally-off
- Low process complexity
- No degradation issues (bipolar, MOS, etc.)
- No body diode
- Easily paralleled for high power modules
- Demonstrated stable operation at 350C+
- Lowest Rds(on),sp of EM SiC devices
- fast switching / low switching energy

SemiSouth Vertical-Channel JFET





SemiSouth

Competitiveness against IGBTs

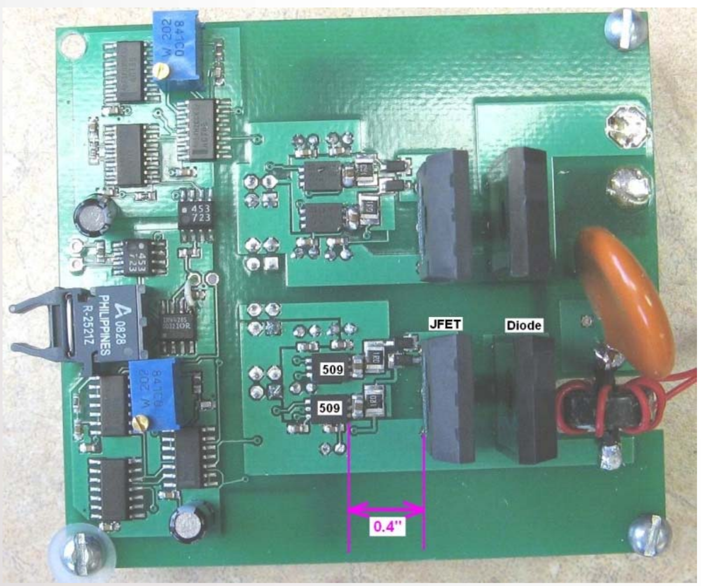
Critical Parameter		Fairchild ***NPT IGBT*** ***FGL40N***	SemiSouth ***VJFET*** ***SJEP120R063***	***Performance Improvement***
Technology		Silicon – IGBT	Silicon Carbide	
Breakdown Voltage	V_{DS}	1200V	1400V	**Higher breakdown margin**
On Voltage (conduction)	Von	2.5V	Unipolar	**Reduced losses at low I …higher light load Efficiency**
Input Capacitance	Ciss	1700 pF.	1220pF	**Reduced Gate Power Loss**
Effective Output Cap Energy Related	$C_{O(ER)}$	260 pF	100 pF	**2.5X Lower Switching Losses**
Operating Temperature	Tj	-55°C to 150°C	-55°C to 175°C	**Safe Operation at higher Temp**
Thermal Impedance	Rthj-c	0.25K/W	0.6K/W	**X2 worse but offset by overall lower dissipation losses**
Turn-On Losses	Joules	550uJ	110uJ	**X10 Lower Switching Energy**
Turn-Off Losses		1000uJ	70uJ	
Total Losses		1550uJ	180uJ	

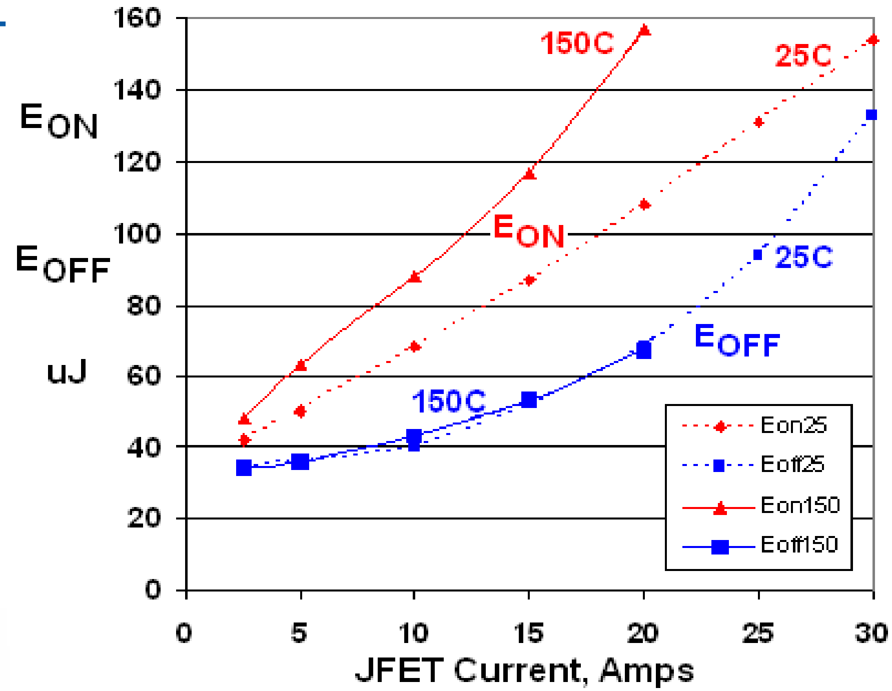
SS JFETs HAVE 50% LOWER LOSSES

Smallest Switching Energy

• Allows high-frequency, high-efficiency, higher power density solutions!

Half-Bridge Configuration:
•SJEP120R063: 1200V / 63mΩ VJFET
•SDP20S120: 1200V / 20A SBD





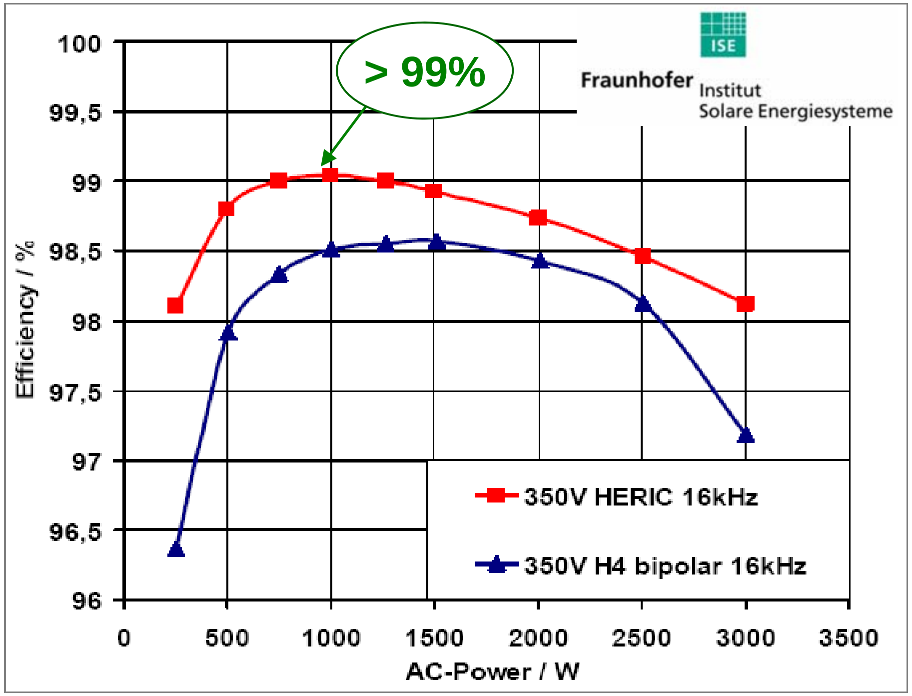
Performance Validation

WORLD RECORD Power Conversion Efficiency*

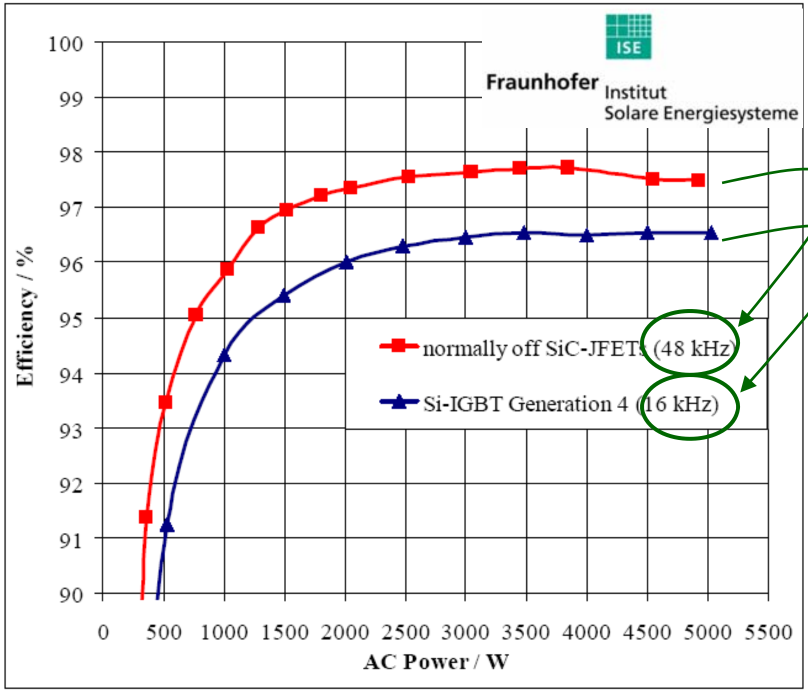
SemiSouth

"We now use junction field-effect transistors (JFETs) made of silicon carbide (SiC) manufactured by SemiSouth Laboratories Inc.. This is the main reason for the improvement", - Prof. Bruno Burger, leader of the Power Electronics Group at Fraunhofer ISE, July 2009 press release.

- Single phase Heric®
- Commercial inverters @ 98%
- SemiSouth's JFET lowers losses ~ 50%



- Three phase full bridge inverter
- SemiSouth JFET *boosts efficiency* 1.2%
- SemiSouth JFET operates *3X higher freq.*



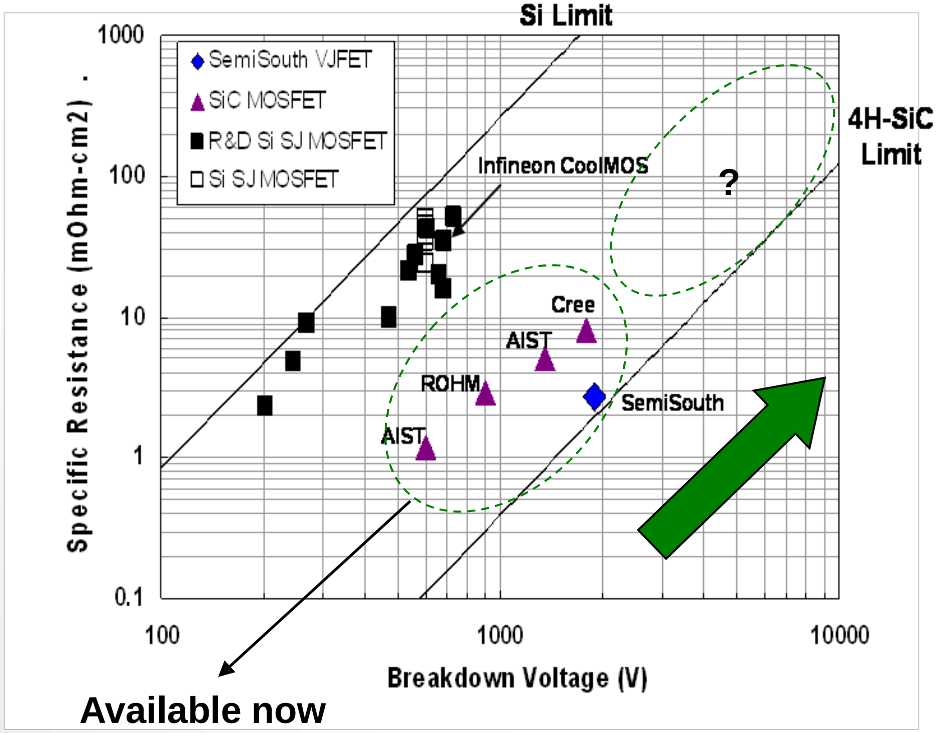
* Bruno Burger, Dirk Kranzer, "Extreme High Efficiency PV-Power Converters," EPE, Barcelona, Spain, 8-10 September 2009

SemiSouth

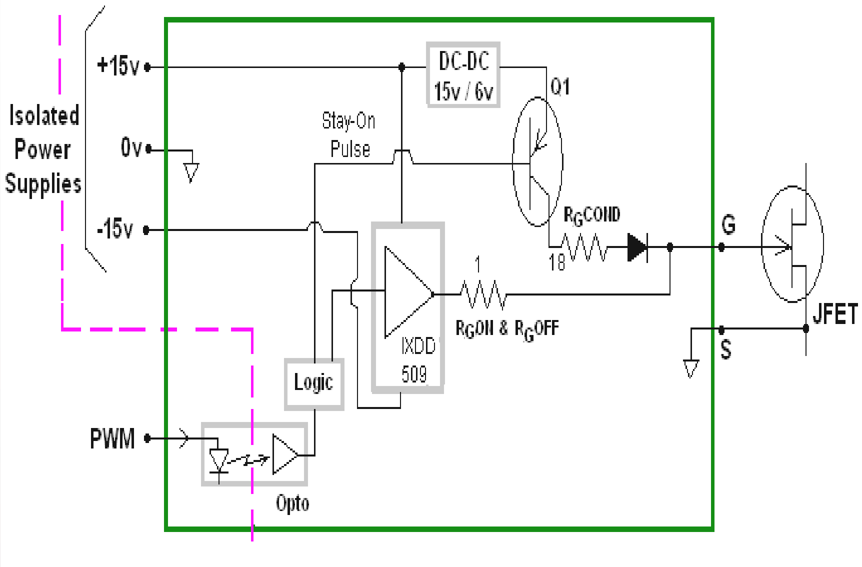
Normally-off JFET Performance

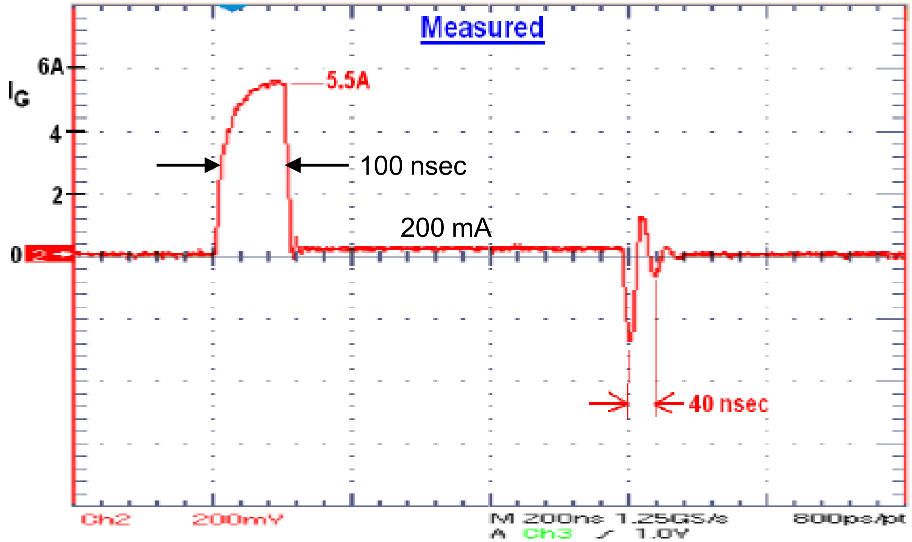
Trench JFET Technology Evolution:

- **Initial demonstration in 2007**
- **Compact design leads to ultra-low specific on-resistance**
- **Initial product release in 2008**



SJEP120R063 JFET Driver Scheme





Opto Coupler: This reference design uses the HP "wide body" HCHW4503 high speed opto coupler enabling fast switching speeds while allowing layout spacing to meet safety isolation requirements.

509 Gate Driver: The IXYS IXDD509 high speed Driver is used to provide a high current Turn-on and Turn-off gate pulse through Rg(on/off) for very fast switching and low switching losses.

Q1 Conduction Driver: Q1 is a small PNP transistor used to provide the ON-state gate current of 200mA to maintain a low Rds(on) in the SJEP120R063 or 050 JFET during the conduction period.

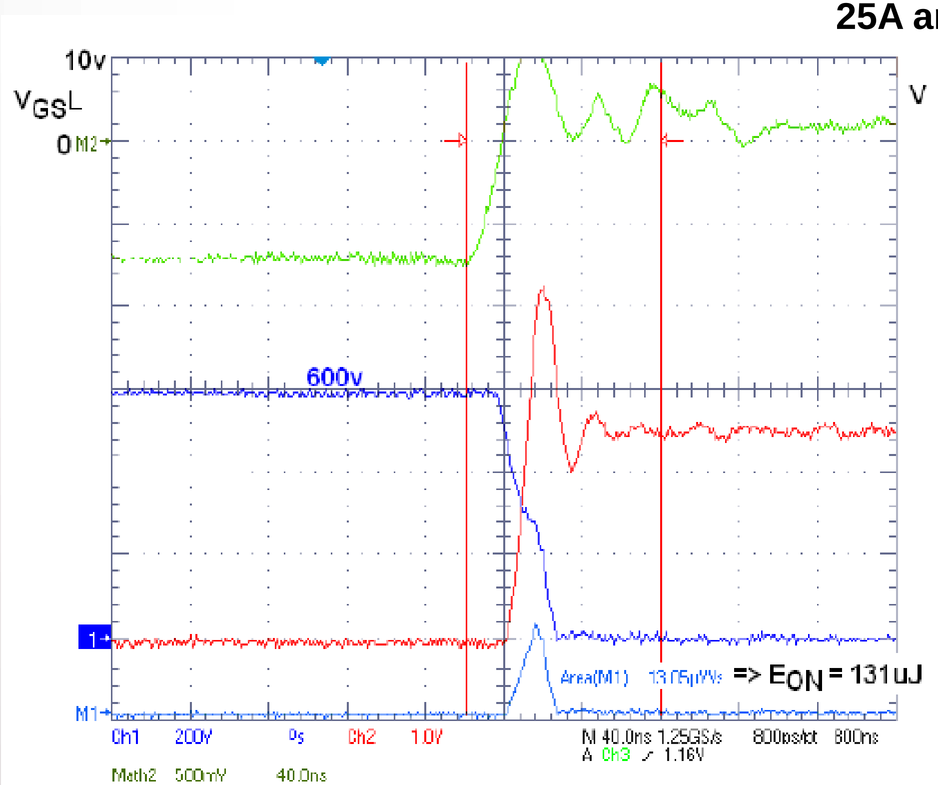
15V to 6V DCDC: This step down (85% eff) DCDC converter IC is used as the power source for Q1 and enables a reduction in gate power loss during the conduction period. (optional).

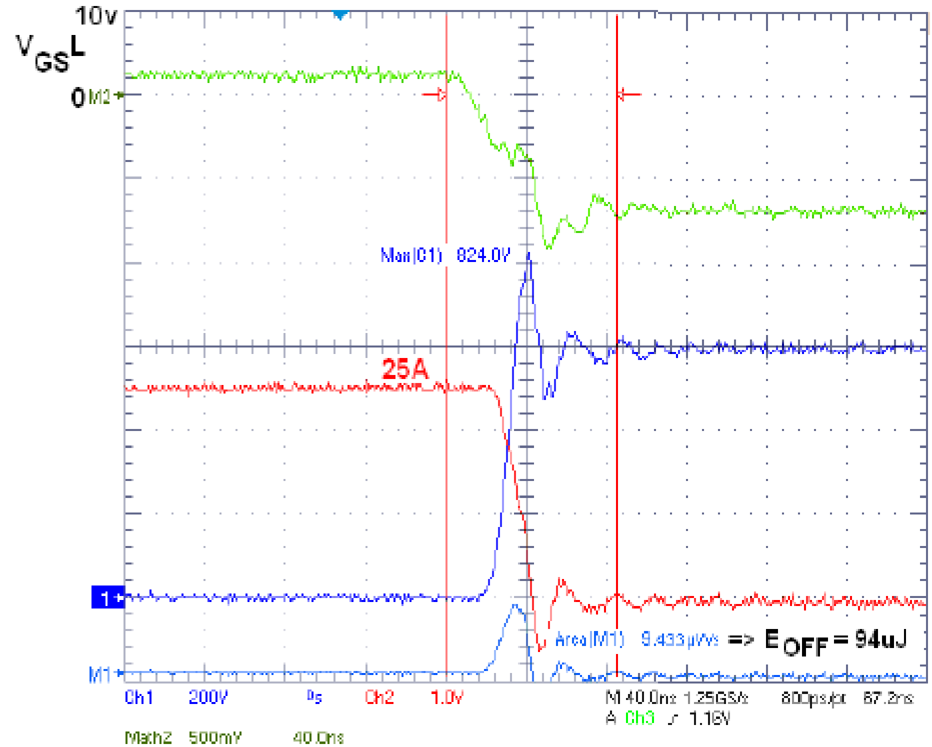
Timing Logic: The logic / timing circuit generates the required timing signal for the IXDD509 gate Driver and Q1. The timing is set to achieve a 100nsec turn on high I pulse and then maintain the 200mA conduction pulse.

SemiSouth

Typical Switching Waveforms – with SJEP120R063 JFET

25A and 600V



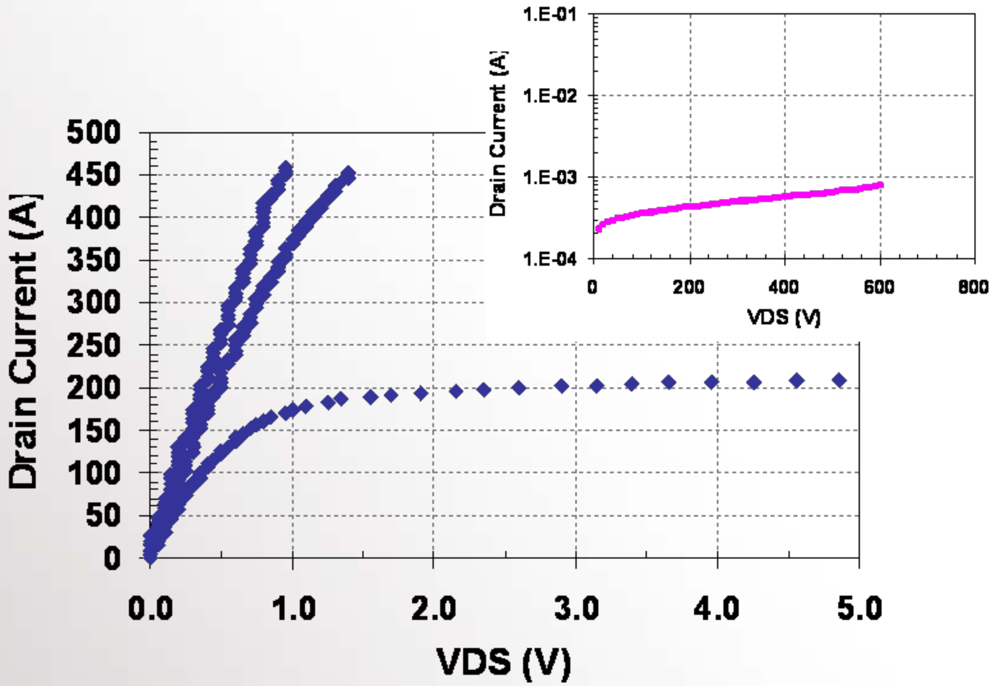


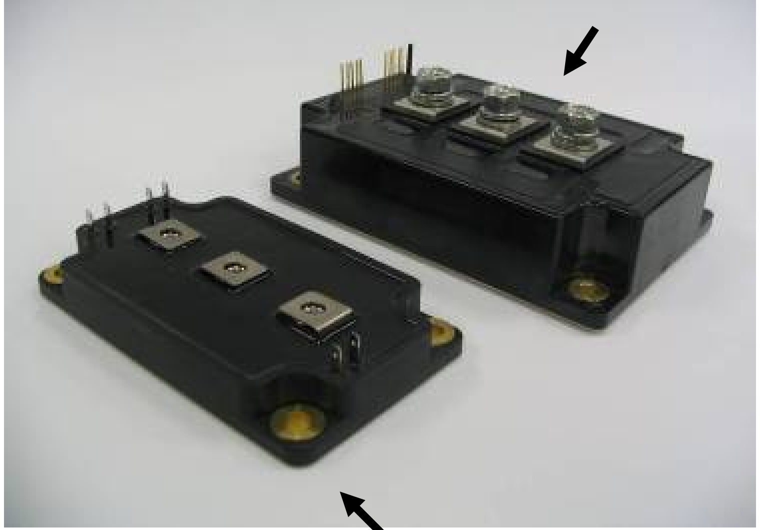
Comments:

1. These switching losses are in line with the data sheet and the higher temperature (150C) switching loses would be similar to the data sheet as well and only 10% higher.

Demo Module Example

- 600 V / 450 A SiC Normally-off JFET module
- Up to 57% reduction in conduction losses possible at 1200 V level (~2.2mΩ @ 1V)





600 V Si IGBT / diode module

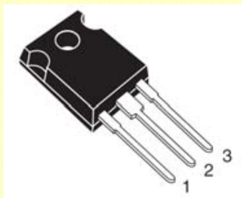
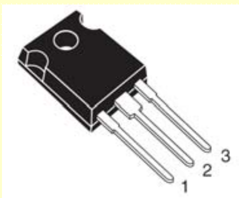
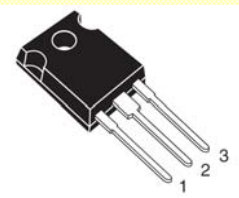
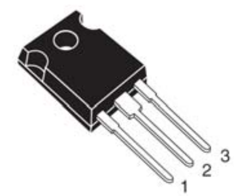
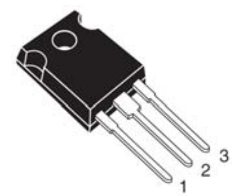
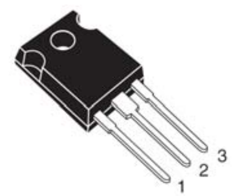
1200 V SiC JFET / diode module
(SemiSouth enhancement-mode JFET)

SemiSouth

Vertical Trench JFET Roadmap

Products Released in Sept 2008

Improved "125" to "100" (SJEP120R125 → SJEP120R100) | **Dual Die** (SJEP120R063)

Part	SJEP120R125	SJEP120R100	SJEP120R063	SJEP120R050	SJEP120R025	SJEP170R550
Package	 3L TO-247	 3L TO-247	 3L TO-247	 3L TO-247	 3L TO-247	 3L TO-247
Voltage (V)	1200	**1200**	**1200**	**1200**	**1200**	**1700**
Rds(on)	125 mΩ	**100 mΩ**	**63 mΩ**	**50 mΩ**	**25 mΩ**	**550 mΩ**
Ciss Tr*/Tf* (ns) Die size	576 pF 50 /50 4 mm^2	**TBD TBD 4.5 mm^2**	**2 x 576 pF 50 /50 2 x 4 mm^2**	**1168 pF 50 /50 9 mm^2**	**2320 pF 50 /50 15 mm^2**	**167 pF 50 /50 2 mm^2**
Co-Pak Options	5A SBD Q2 09	**5A SBD TBD**	**-**	**10A SBD Q3 09**	**-**	**-**
Samples	Now	**Now**	**Now**	**Q3 09**	**Q1 10**	**Q2 09**
Production	Now	**Now**	**Now**	**Q4 09**	**Q2 10**	**Q4 09**

Latest Datasheets at http://www.semisouth.com/products/powersemi.html

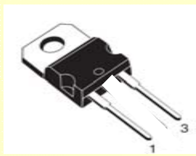
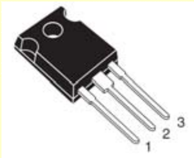
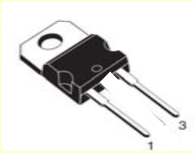
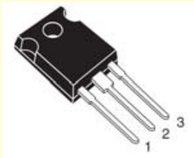
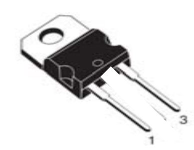
[yellow box] **Accepting Sample and Production orders**

[*] **30-50 ns typical**

UPDATED 11 Aug 2009

SemiSouth

SiC Schottky Diode Roadmap

Part	SDA05S120	SDP10S120D	SDA10S120	SDP20S120D	SDA30S120	SDP30S120
Package	 **2L TO-220**	 **3L TO-247**	 **2L TO-220**	 **3L TO-247**	 **2L TO-220**	 **2L TO-247**
BV (V)	**1200**	**1200**	**1200**	**1200**	**1200**	**1200**
I_F (A)	**5A**	**10A (2 x 5A)**	**10A**	**20A (2 x 10A)**	**30A**	**30A**
V_{Fmin} (V) V_{Fmax} (V)	**1.6** **1.8**	**1.6** **1.8**	**1.6** **1.8**	**1.6** **1.8**	**1.6** **1.8**	**1.6** **1.8**
Samples	**Now**	**Q1 09**	**Now**	**Now**	**Q3 09**	**Now**
Production	**Q2 09**	**Q2 09**	**Now**	**Now**	**Q4 09**	**Q2 09**

Accepting Sample and Production orders

SemiSouth

Summary of SemiSouth JFET

- ***SiC is maturing, cost declining***
  - ***100 mm dia wafers now; 150 mm dia wafers soon***
  - ***SiC FET devices suitable up to 3-4 kV, and being released now***
  - ***SiC bipolar (BJT, IGBT, …) for > 3 kV still being developed***
  - ***MOS controlled devices still challenging***

- **Released first normally-off SiC JFET in 2008**
  - **High reliability, easily paralleled for high power modules**
  - **Small die + High Performance + Low process complexity**
  - ***Low $ for SiC level performance expectations***

- ***World record (> 99%) PV inverter efficiency***
- ***Enables higher power density inverters***

Jerry FitzPatrick

NIST

Setting Standards for the Smart Grid: The NIST Interoperability Framework - Overview -

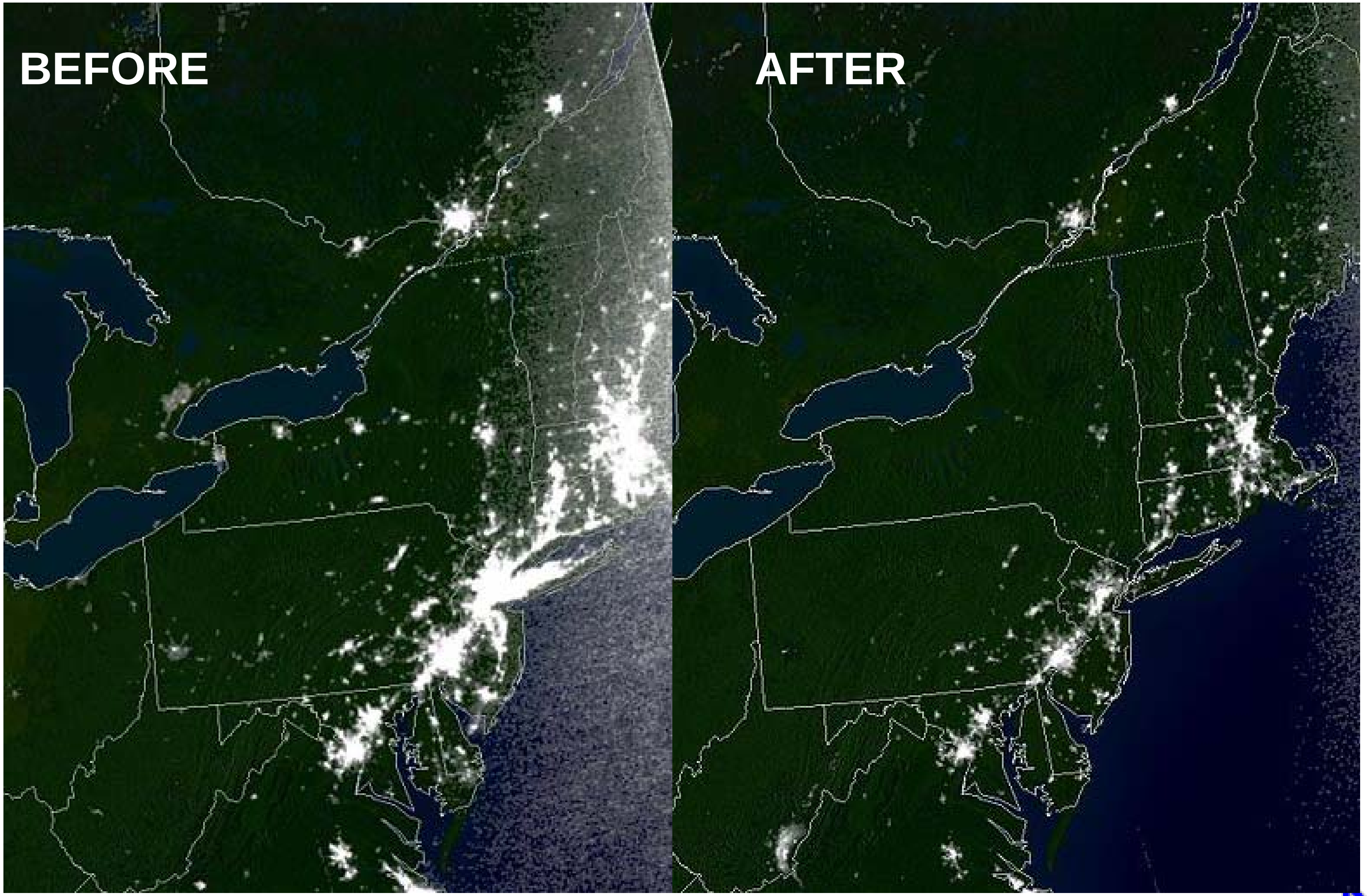
Jerry FitzPatrick
Smart Grid Team Member
National Institute of Standards and Technology
fitzpa@nist.gov

December 11, 2009

Outline

- Introduction
  - Why do we need a Smart Grid?
  - 2007 EISA – why NIST is a key player Smart Grid
- NIST Interoperability Framework and Roadmap, Release 1.0
- Smart Grid Interoperability Panel (SGIP)

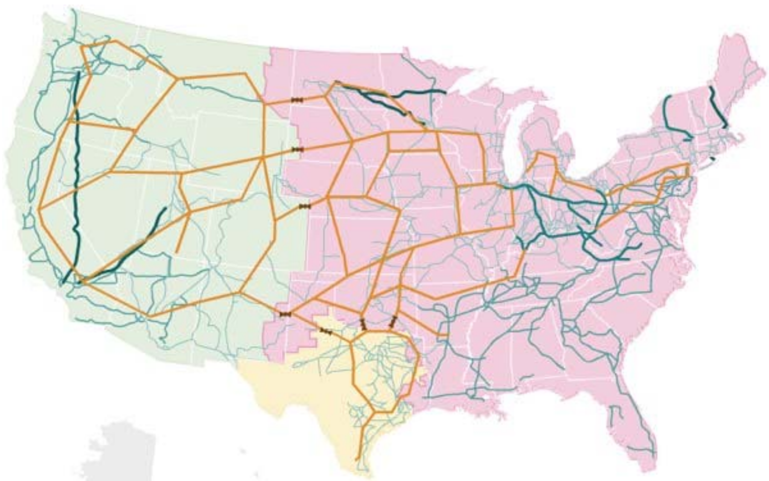
Why do we need a Smart Grid?



National Institute of Standards and Technology

Why Do We Need Smart Grids?

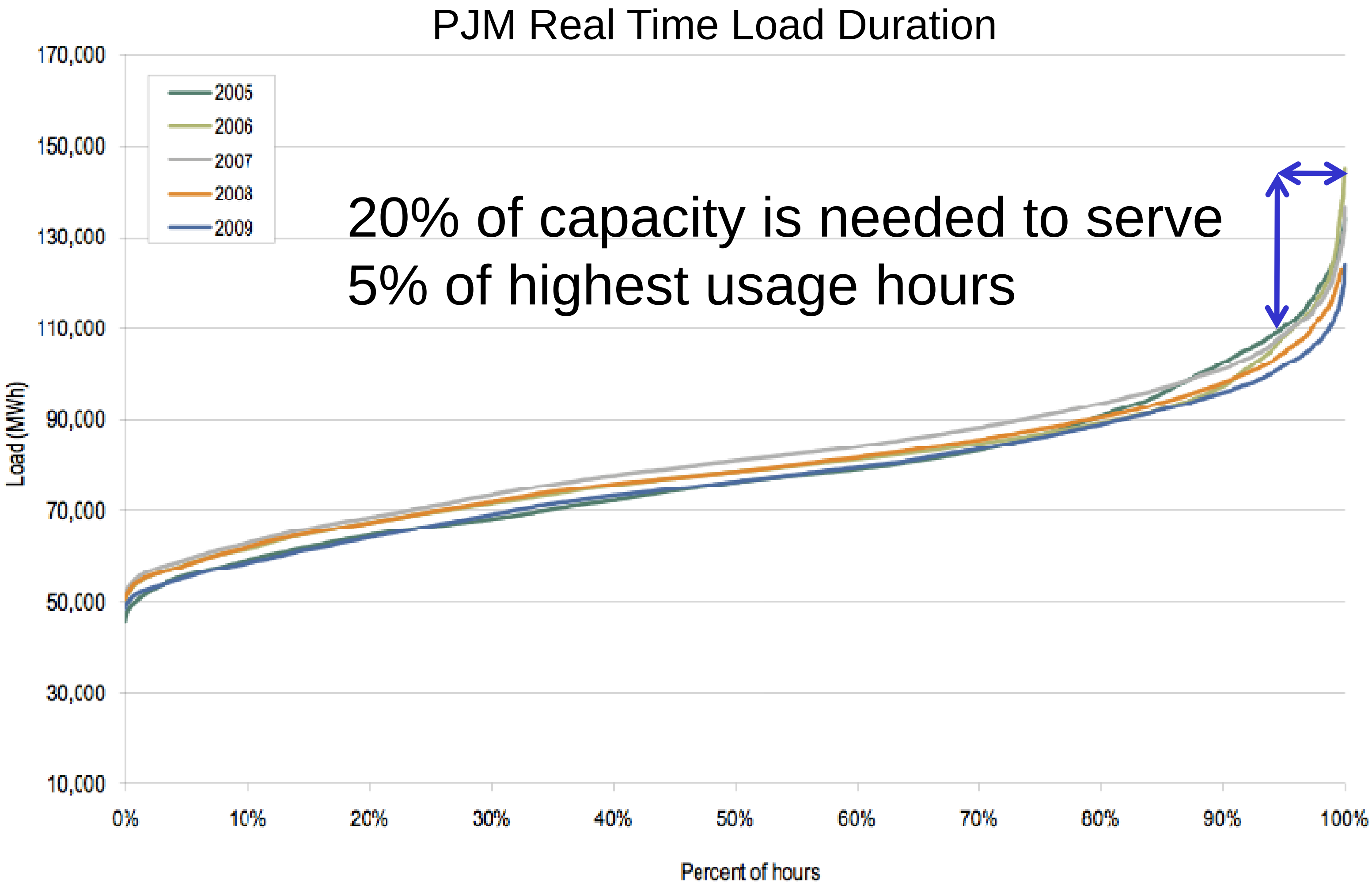
- **Imperatives**
  - Climate change
  - Energy security
  - Sustainable economic growth



- **The 21st Century Economy Requires a 21st Electric System**
  - Accommodate rapid growth in renewable energy sources such as wind and solar
  - Empower consumers with tools to manage and reduce energy use
  - Enhance reliability and security of the electric system

NIST National Institute of Standards and Technology

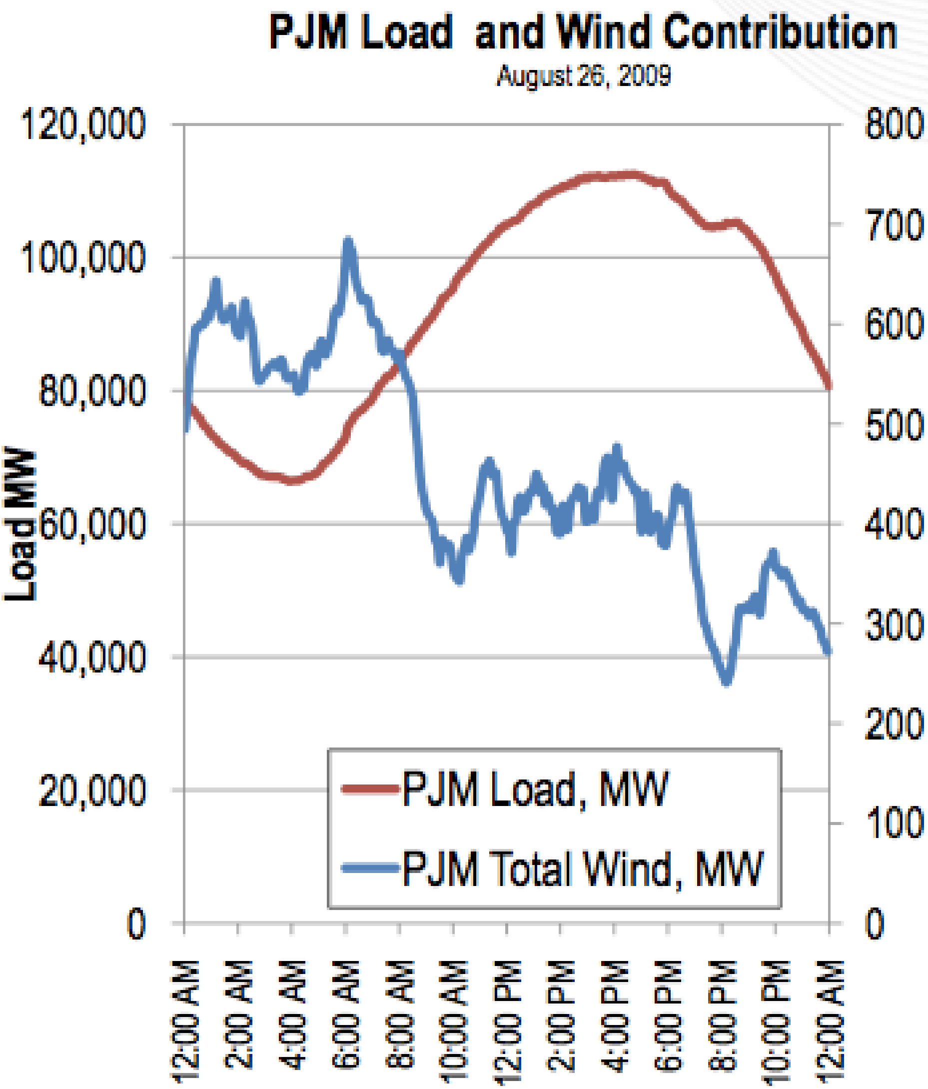
Current Grid is Inherently Inefficient

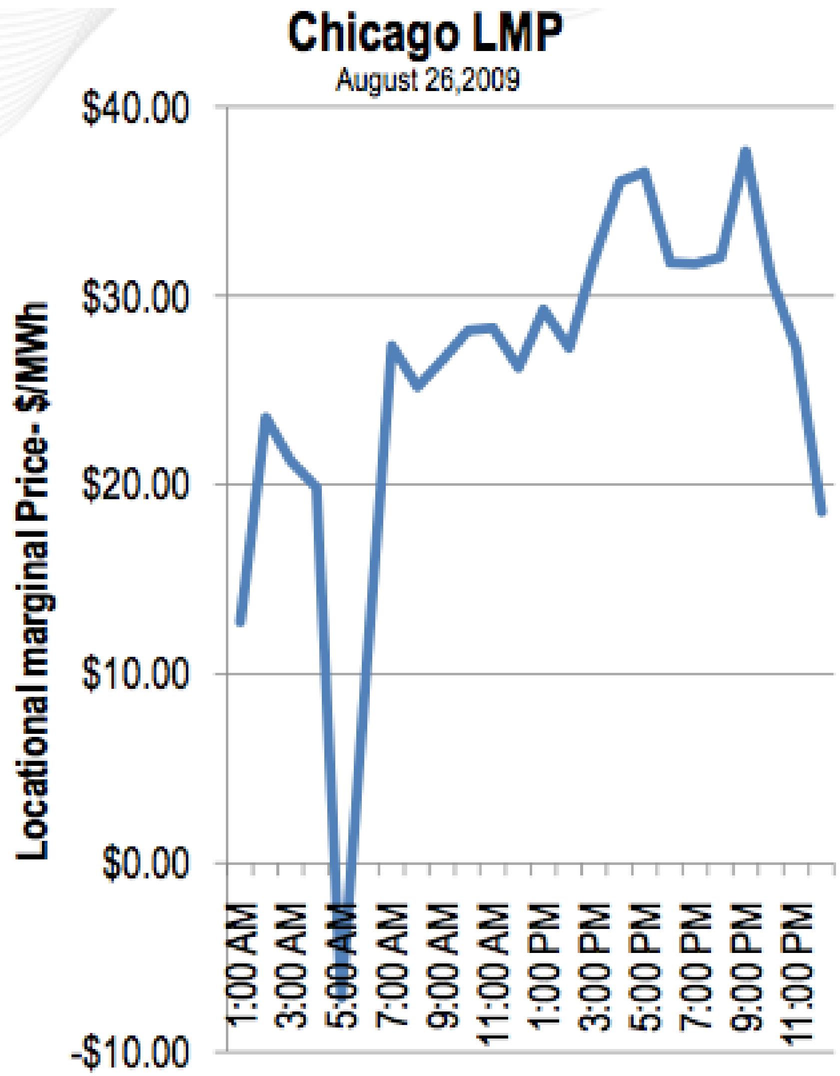


Source: PJM

NIST
National Institute of Standards and Technology

Integration of Renewables Presents New Challenges due to Variability





Source: PJM

National Institute of Standards and Technology

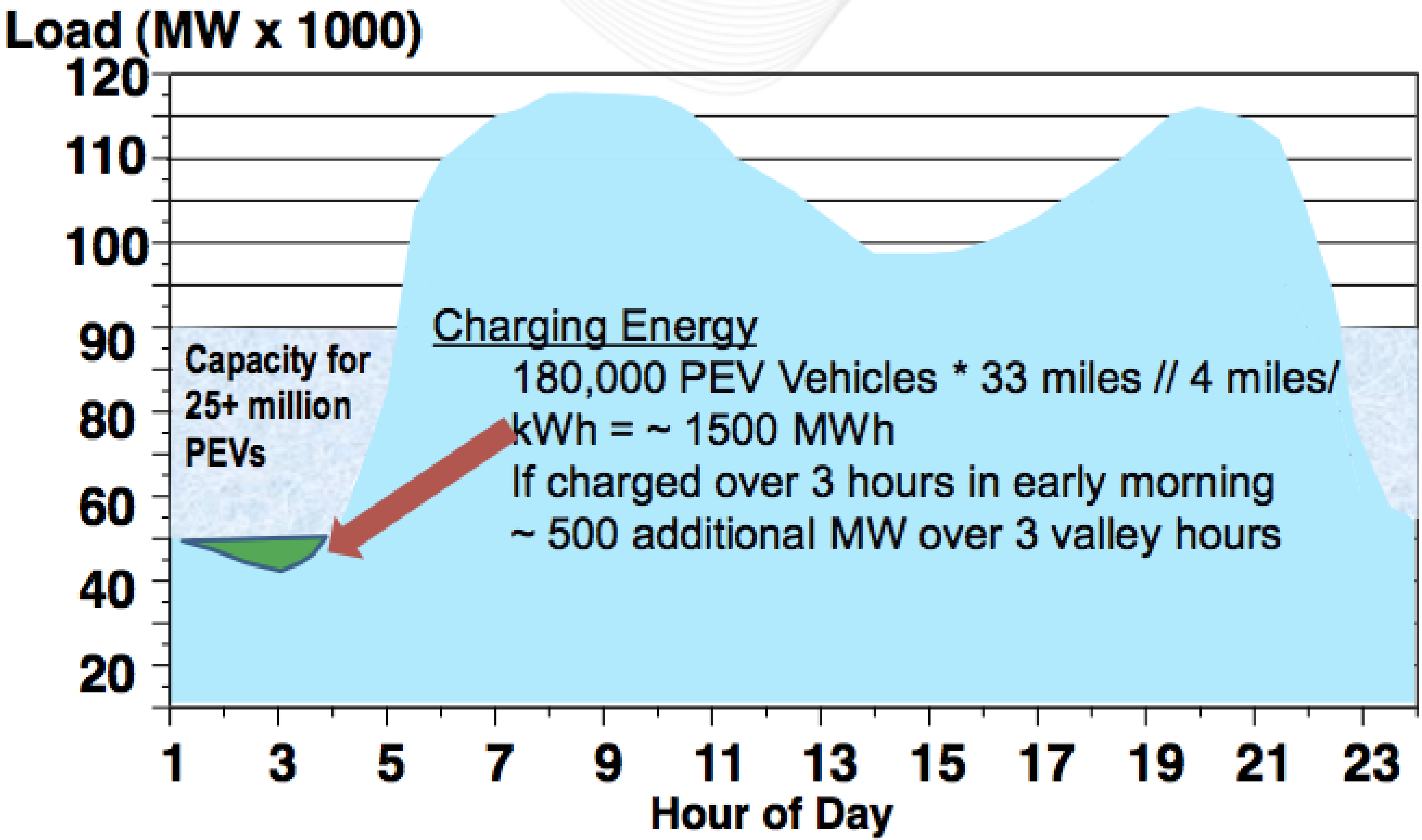
Why Electric Vehicles?

Electrification of transportation could

- Displace half of US oil imports
- Reduce CO_2 20%
- Reduce urban air pollutants 40%-90%
- Idle capacity of the power grid could supply 70% of energy needs of today's cars and light trucks

NIST National Institute of Standards and Technology

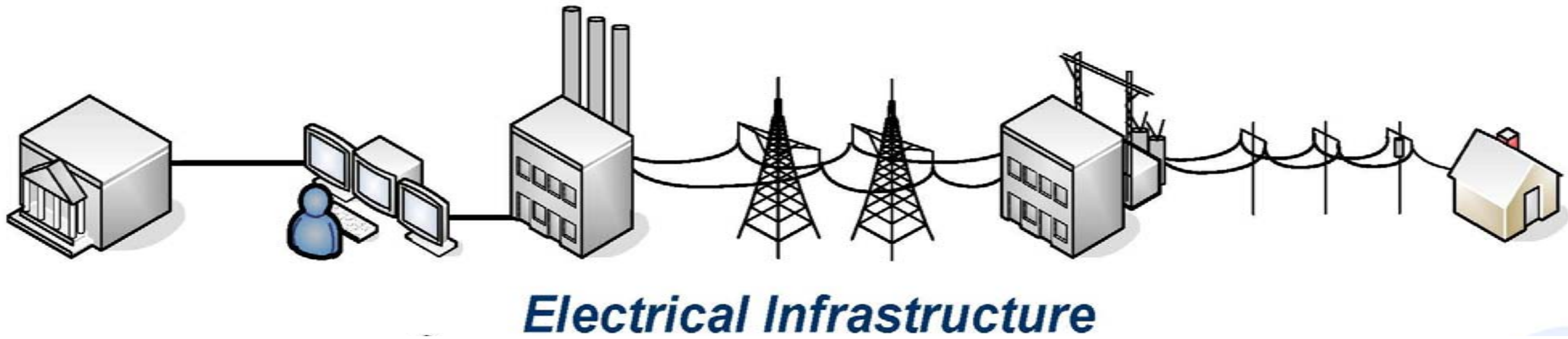
Grid Can Handle PEV Demand – if Charging is Managed



Source: PJM

NIST National Institute of Standards and Technology

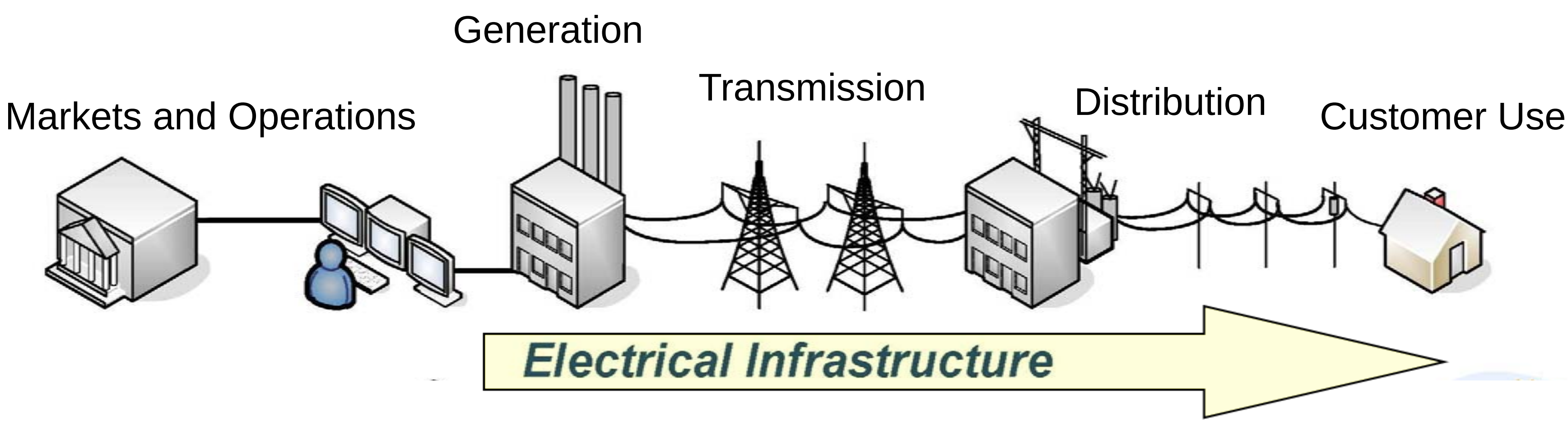
Today's Electric Grid



Power grid/electrification is "the most significant engineering achievement of the 20th century" and the most complicated, interconnected machine on Earth

Graphics courtesy of EPRI

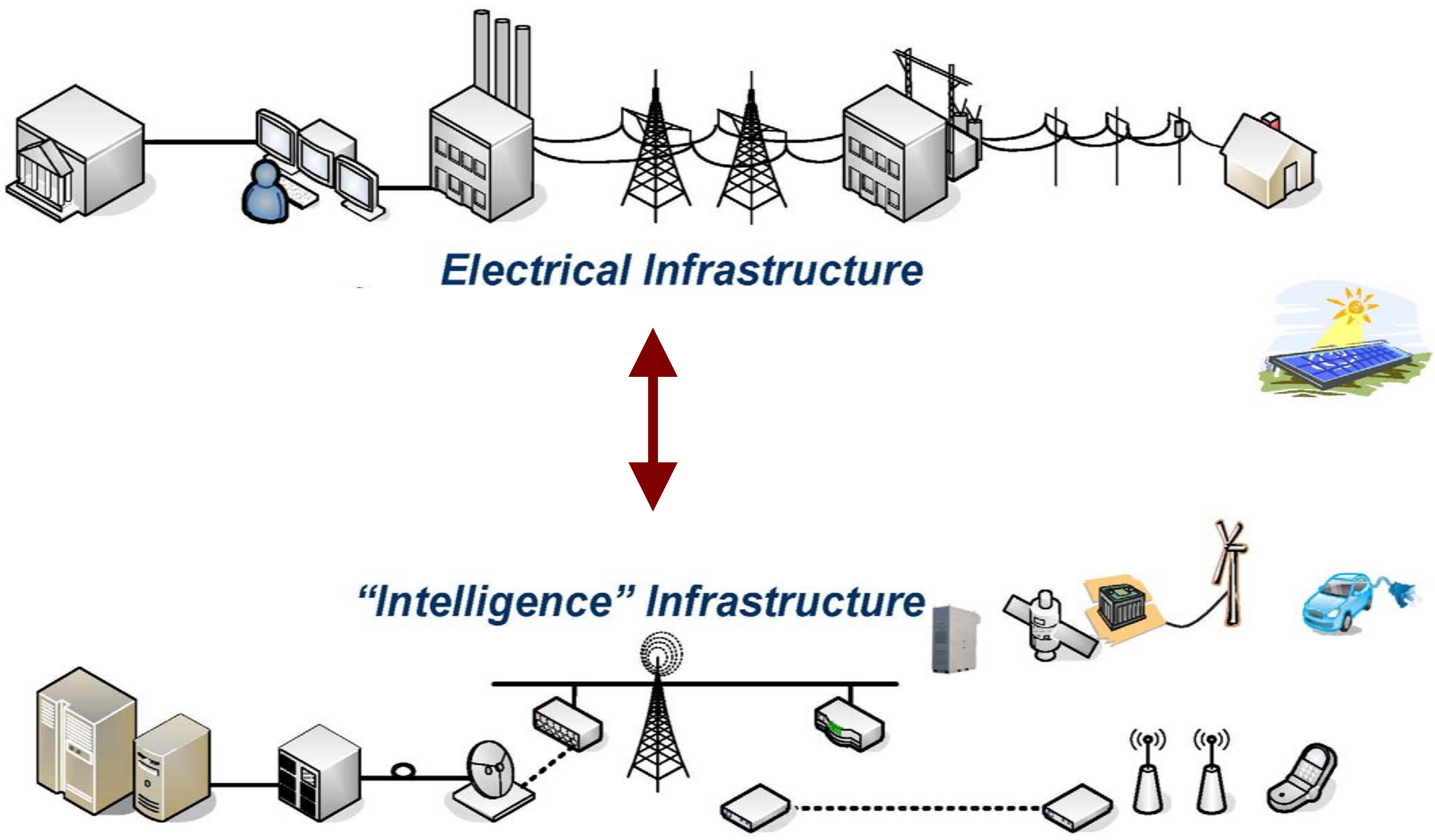
Today's Electric Grid



Power grid/electrification is "the most significant engineering achievement of the 20th century" and the most complicated, interconnected machine on Earth

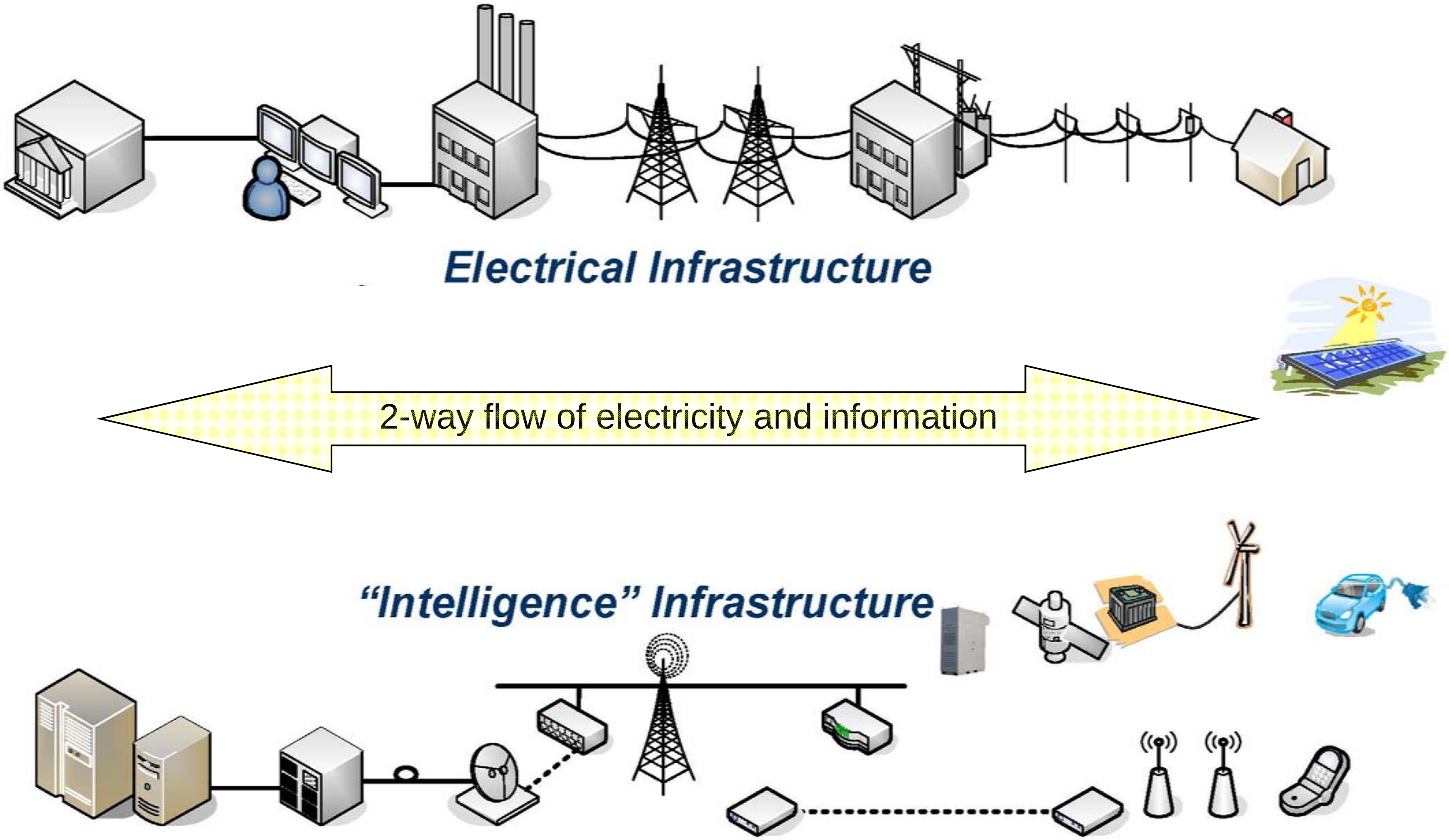
Graphics courtesy of EPRI

"Smart Grid" = Electric Grid + Intelligence



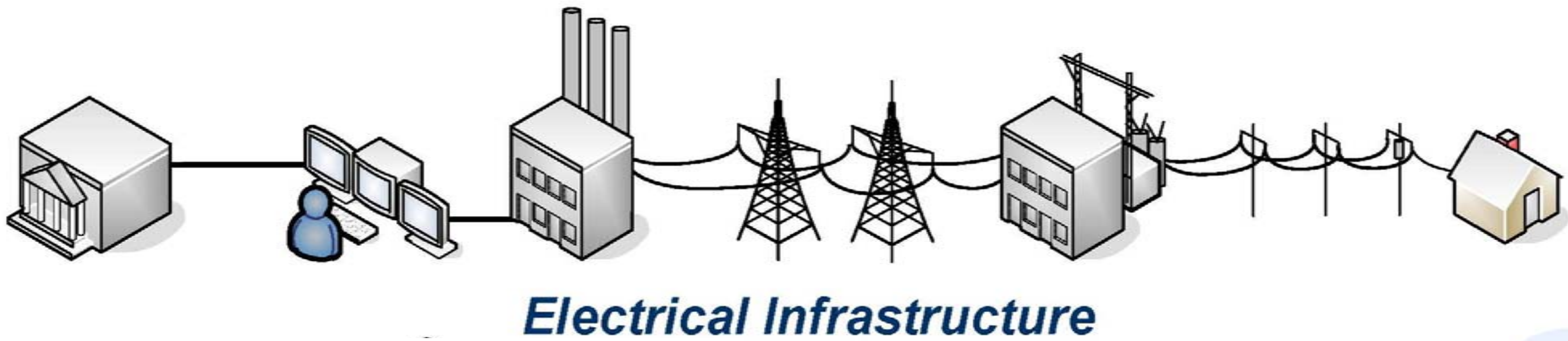
Graphics courtesy of EPRI

"Smart Grid" = Electric Grid + Intelligence



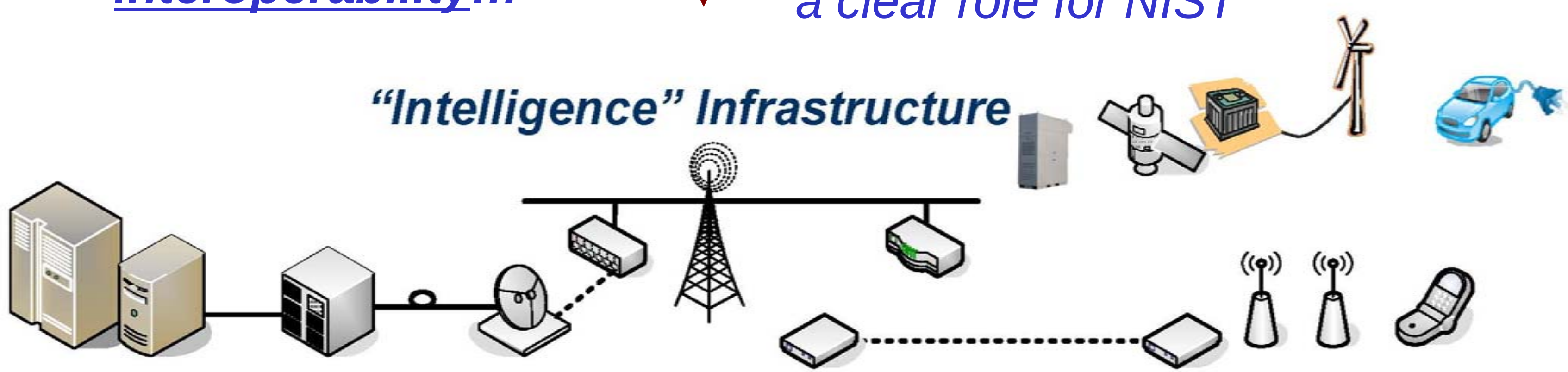
Graphics courtesy of EPRI

"Smart Grid" = Electric Grid + Intelligence



Combining electrical and information infrastructure requires <u>interoperability</u>…

Interoperability requires reliable <u>standards</u> and validated performance – *a clear role for NIST*



Graphics courtesy of EPRI

National Institute of Standards and Technology

Presidential Priority

- "To build an economy that can lead this future, we will begin to rebuild .. and retrofit America for a global economy. ..That means **updating the way we get our electricity by starting to build a new smart grid** that will save us money, protect our power sources from blackout or attack, and deliver clean, alternative forms of energy to every corner of our nation."
  President-Elect Barack Obama, January 8, 2009

- Direct personal involvement of Secretary of Energy (Steve Chu) and Secretary of Commerce (Gary Locke)

Government Roles in Smart Grid

Federal

U.S. DEPARTMENT OF ENERGY

National Institute of Standards and Technology
U.S. Department of Commerce

Federal Energy Regulatory Commission

State

Public Utility Commissions

Energy Independence and Security Act

Defines ten national policies for the Smart Grid:

1. Use digital technology to improve reliability, security, and efficiency of the electric grid
2. Dynamic optimization of grid operations and resources, with full cyber-security
3. Integration of distributed renewable resources
4. Demand response and demand-side energy-efficiency resources
5. Automate metering, grid operations and status, and distribution grid management
6. Integrate `smart' appliances and consumer devices
7. Integrate electricity storage and peak-shaving technologies, including plug-in electric vehicles
8. Provide consumers timely information and control
9. Interoperability standards for the grid and connected appliances and equipment
10. Lower barriers to adoption of smart grid technologies, practices, and services.

NIST
National Institute of Standards and Technology

Energy Independence and Security Act

Defines ten national policies for the Smart Grid:

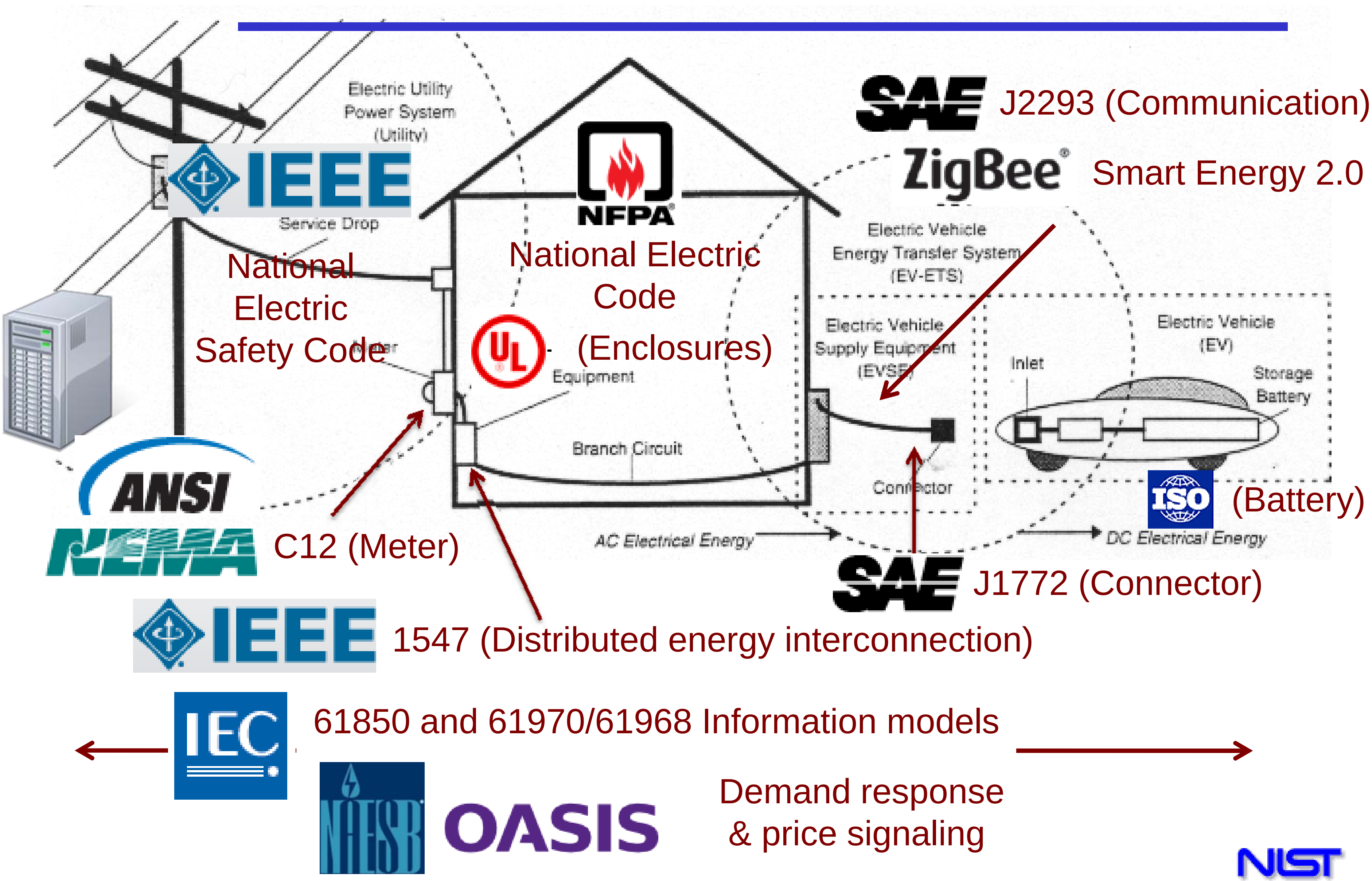
1. Use digital technology to improve reliability, security, and efficiency of the electric grid
2. Dynamic optimization of grid operations and resources, with full cyber-security
3. **Integration of distributed renewable resources**
4. Demand response and demand-side energy-efficiency resources
5. Automate metering, grid operations and status, and distribution grid management
6. Integrate `smart' appliances and consumer devices
7. **Integrate electricity storage** and peak-shaving technologies, including plug-in electric vehicles
8. Provide consumers timely information and control
9. Interoperability standards for the grid and connected appliances and equipment
10. Lower barriers to adoption of smart grid technologies, practices, and services.

The NIST Role

Energy Independence and Security Act (EISA) of 2007
Title XIII, Section 1305.
Smart Grid Interoperability Framework

- In cooperation with the DoE, NEMA, IEEE, GWAC, and other stakeholders, **NIST** has "primary responsibility to **coordinate development of a framework** that includes protocols and model standards for information management **to achieve interoperability of smart grid devices and systems**…"

Electric Vehicles Require Many Standards



NIST
National Institute of Standards and Technology

NIST Three Phase Plan

PHASE 1
Identify an initial set of existing consensus standards and develop a roadmap to fill gaps

PHASE 2
Establish public/private Standards Panel to provide ongoing recommendations for new/revised standards

PHASE 3
Testing and Certification Framework

2009

2010

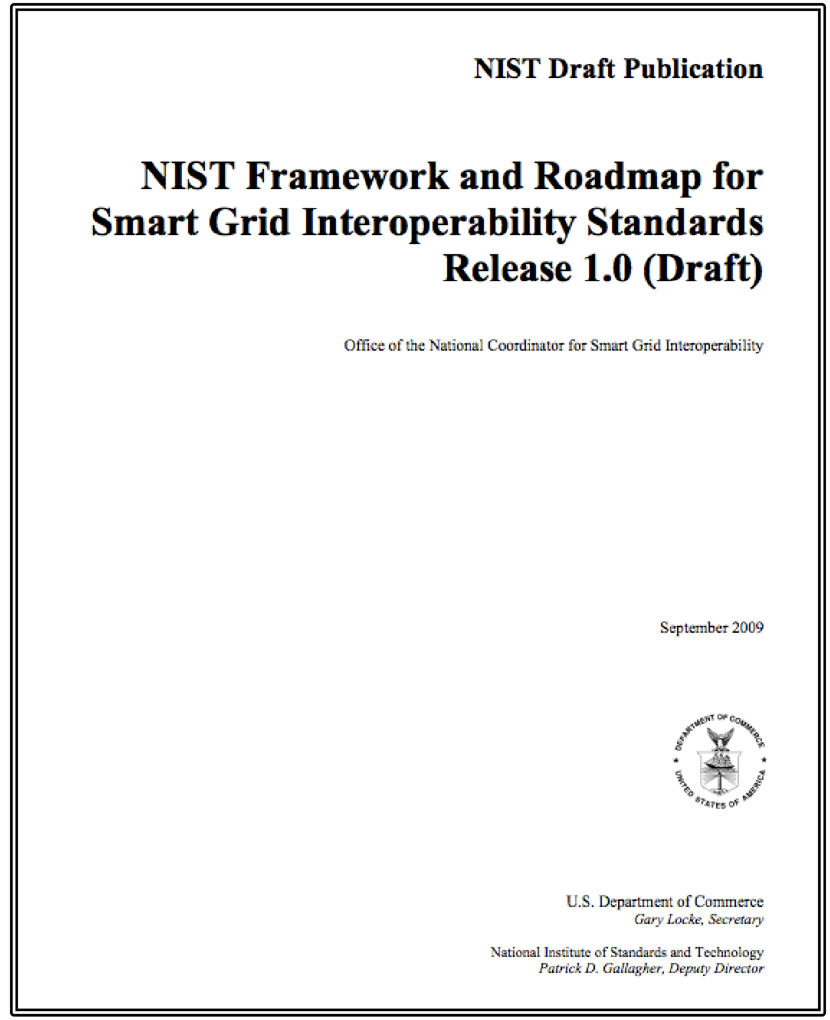
March

September

NIST
National Institute of Standards and Technology

Draft Release 1.0 Framework

- SG Vision
- Reference Model
- 77 standards identified
- 14 priority action plans to fill gaps
- Cyber security strategy
- Next steps


NIST Draft Publication

NIST Framework and Roadmap for Smart Grid Interoperability Standards Release 1.0 (Draft)

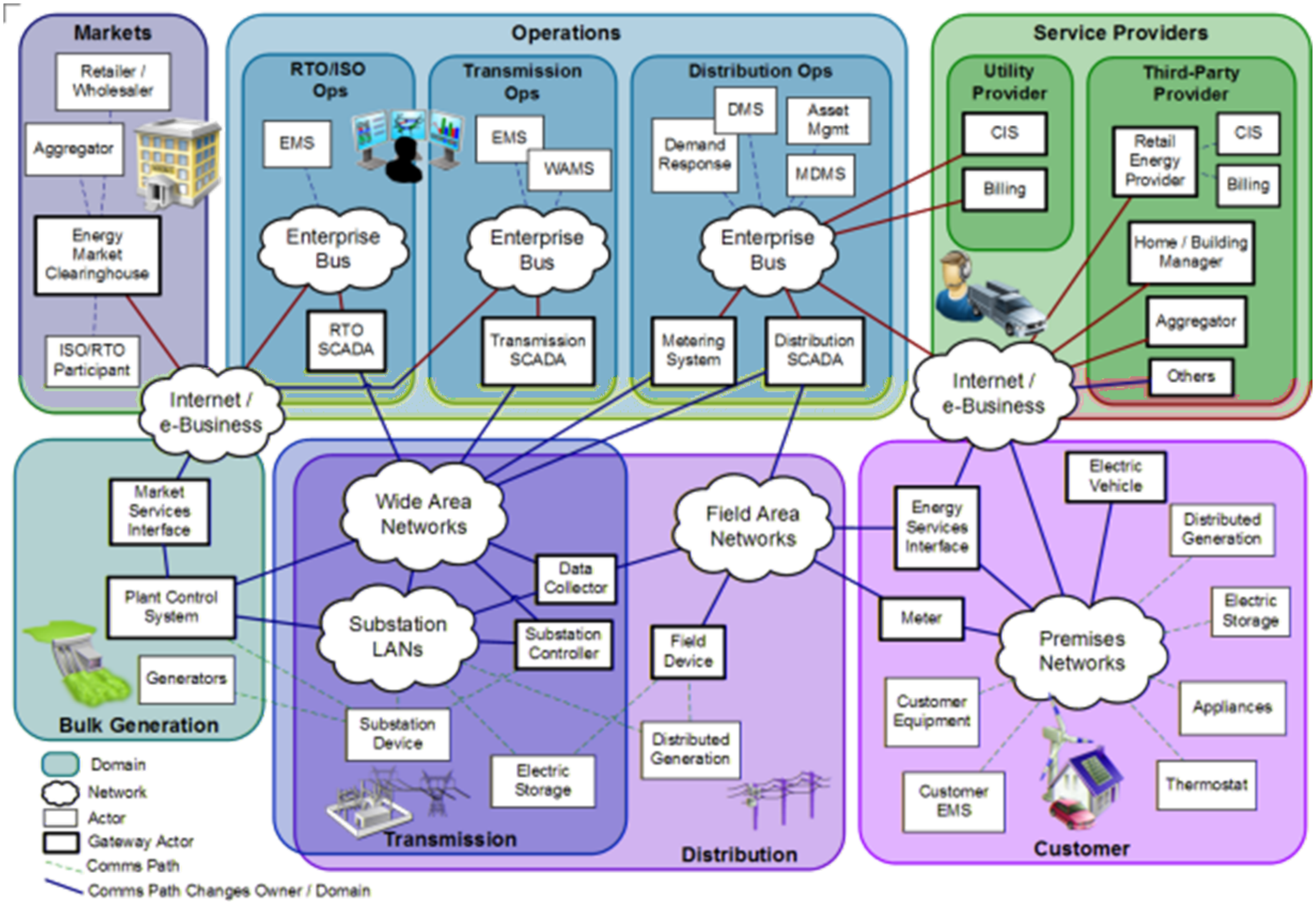
Office of the National Coordinator for Smart Grid Interoperability

September 2009

U.S. Department of Commerce
Gary Locke, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Deputy Director

NIST Smart Grid Reference Model



National Institute of Standards and Technology

Smart Grid Cyber Security Strategy

DRAFT NISTIR 7628

Smart Grid Cyber Security Strategy and Requirements

DRAFT

The Cyber Security Coordination Task Group
Annabelle Lee, Lead
Tanya Brewer, Editor
Advanced Security Acceleration Project – Smart Grid

September 2009

NIST National Institute of Standards and Technology • U.S. Department of Commerce

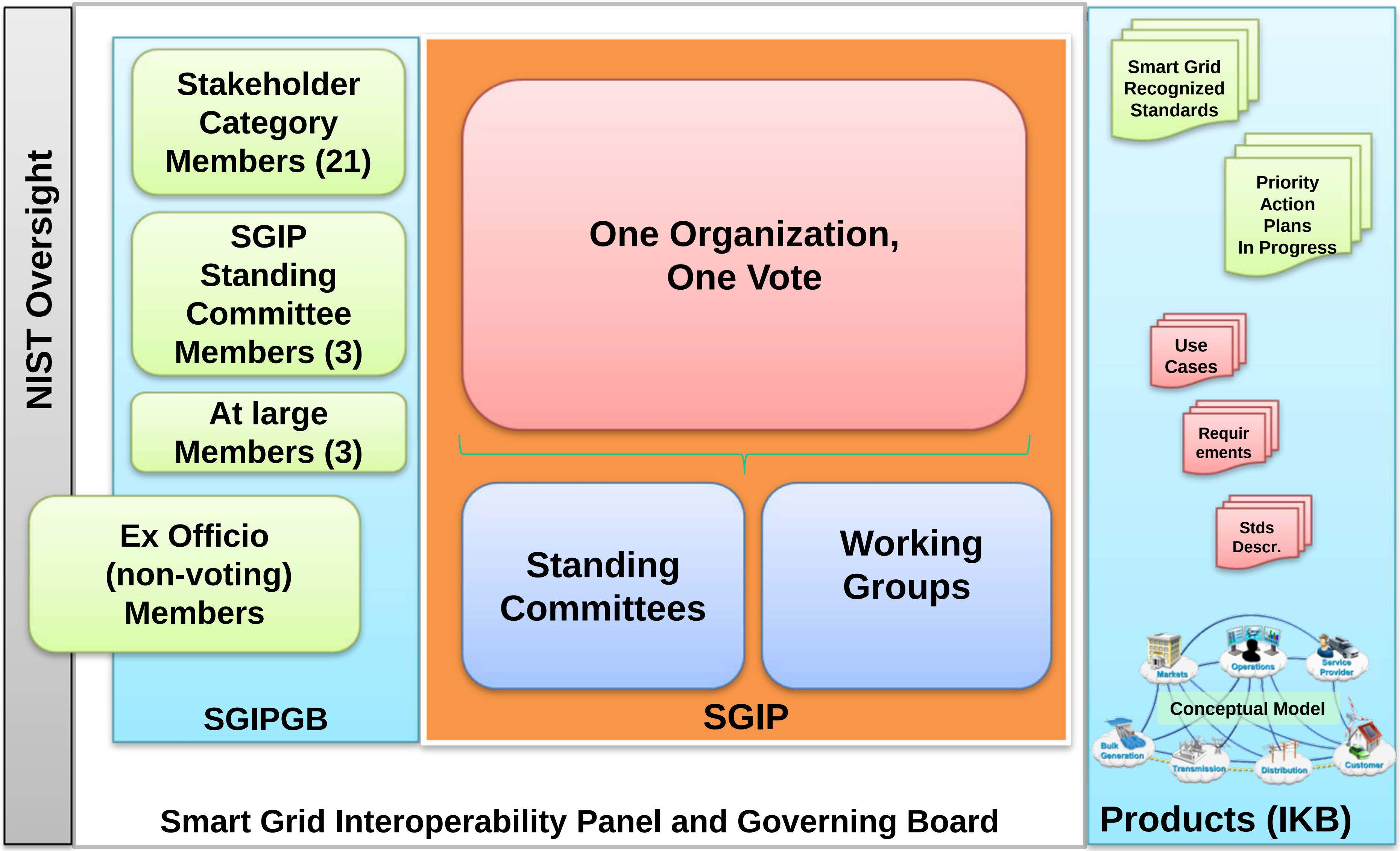
- Use Case Analysis
- Risk Assessments
  - Vulnerabilities
  - Threats
  - Impacts
- Security Architecture
- Security Requirements
  - AMI included in draft
- Standards
- Conformance

NIST National Institute of Standards and Technology

Smart Grid Interoperability Panel

- Public-private partnership formed November 2009
- Permanent body
- Supports NIST in setting standards for U.S. smart grid
- Coordinates, does not develop standards
- Over 360 member organizations at founding
- 22 stakeholder categories – utilities, renewable power suppliers, electric equipment suppliers, ICT, appliance makers, automation suppliers, standards developers, regulators, venture capital, …
- Open, transparent process
- International participation welcome

SGIP Structure



National Institute of Standards and Technology

Smart Grid Stakeholders

1	Appliance and consumer electronics providers
2	Commercial and industrial equipment manufacturers and automation vendors
3	Consumers – Residential, commercial, and industrial
4	Electric transportation industry Stakeholders
5	Electric utility companies – Investor Owned Utilities (IOU)
6	Electric utility companies - Municipal (MUNI)
7	Electric utility companies - Rural Electric Association (REA)
8	Electricity and financial market traders (includes aggregators)
9	Independent power producers
10	Information and communication technologies (ICT) Infrastructure and Service Providers
11	Information technology (IT) application developers and integrators

12	Power equipment manufacturers and vendors
13	Professional societies, users groups, and industry consortia
14	R&D organizations and academia
15	Relevant Federal Government Agencies
16	Renewable Power Producers
17	Retail Service Providers
18	Standard and specification development organizations (SDOs)
19	State and local regulators
20	Testing and Certification Vendors
21	Transmission Operators and Independent System Operators
22	Venture Capital

Smart Grid Stakeholders

1	Appliance and consumer electronics providers
2	Commercial and industrial equipment manufacturers and automation vendors
3	Consumers – Residential, commercial, and industrial
4	Electric transportation industry Stakeholders
5	Electric utility companies – Investor Owned Utilities (IOU)
6	Electric utility companies - Municipal (MUNI)
7	Electric utility companies - Rural Electric Association (REA)
8	Electricity and financial market traders (includes aggregators)
9	Independent power producers
10	Information and communication technologies (ICT) Infrastructure and Service Providers
11	Information technology (IT) application developers and integrators
12	Power equipment manufacturers and vendors
13	Professional societies, users groups, and industry consortia
14	R&D organizations and academia
15	Relevant Federal Government Agencies
16	Renewable Power Producers
17	Retail Service Providers
18	Standard and specification development organizations (SDOs)
19	State and local regulators
20	Testing and Certification Vendors
21	Transmission Operators and Independent System Operators
22	Venture Capital

References

NIST Smart Grid Site	http://www.nist.gov/smartgrid/
NIST Collaboration Site	http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/WebHome
EPRI Roadmap Report	http://www.nist.gov/smartgrid/Report%20to%20NISTIAugust10%20(2).pdf
Framework 1.0 Draft	http://www.nist.gov/public_affairs/releases/smartgrid_interoperability.pdf
Grid-Interop Conference	http://www.grid-interop.com/2009/
DOE Smart Grid Site	http://www.oe.energy.gov/smartgrid.htm
DOE System Report	http://www.oe.energy.gov/DocumentsandMedia/final-smart-grid-report.pdf

Questions?

- Contact info:
  Jerry FitzPatrick
  fitzpa@nist.gov
  301-975-8922
- More info, NIST website:
  http://www.nist.gov/smartgrid/

Allen Hefner

NIST

Setting Standards for the Smart Grid: The NIST Interoperability Framework - Interconnection Standards -

Al Hefner

Smart Grid Team Member

National Institute of Standards and Technology

hefner@nist.gov

October 30, 2009

Energy Today

- **Today's electric power grid:**
  - **Electricity is generated at large central plants by rotating machines that produce 60 Hz AC**
  - **Electricity is delivered through a unidirectional, passive grid where conversion is achieved using 60 Hz transformers**
  - **Not much storage: Generation must instantaneously match loads using only load shedding at large facilities**
  - **Fault clearing requires large excess grid capacity**
- **Today's fossil energy consumption:**
  - **Transportation is large fraction of fossil energy consumption using low efficiency variable torque combustion engines**
  - **Large central coal plants have lowest energy cost but emit CO2**
  - **Natural Gas (NG) is used at central plants and is delivered through the existing pipeline infrastructure**

NIST
National Institute of Standards and Technology

U.S. Electricity Production

2005

Including CO2 Concern !!!

EIA/DOE AEO2009

Annual Energy Outlook

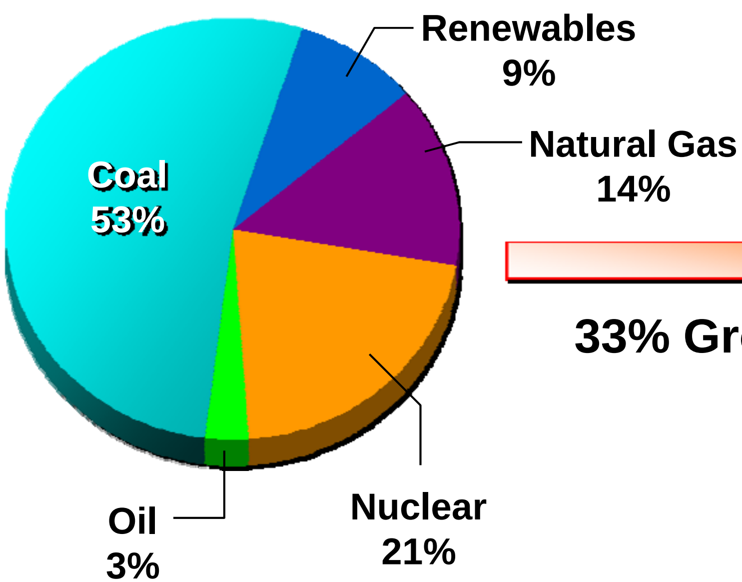
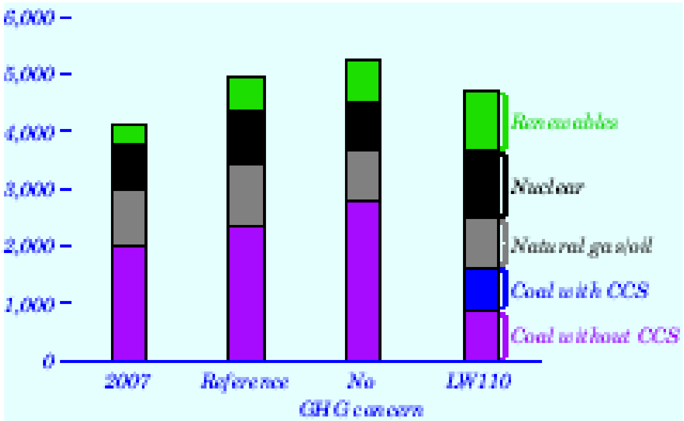


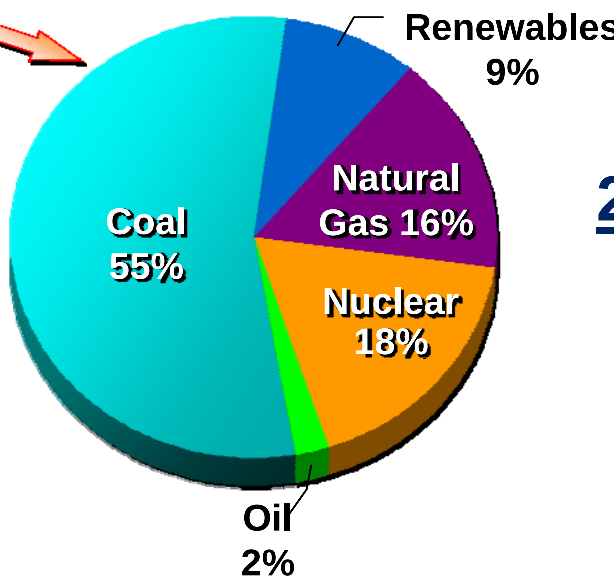
Figure 24. U.S. electricity generation by source in three cases, 2007 and 2030 (billion kilowatthours)



2030

33% Growth

2025



Without CO2 Concern !!!

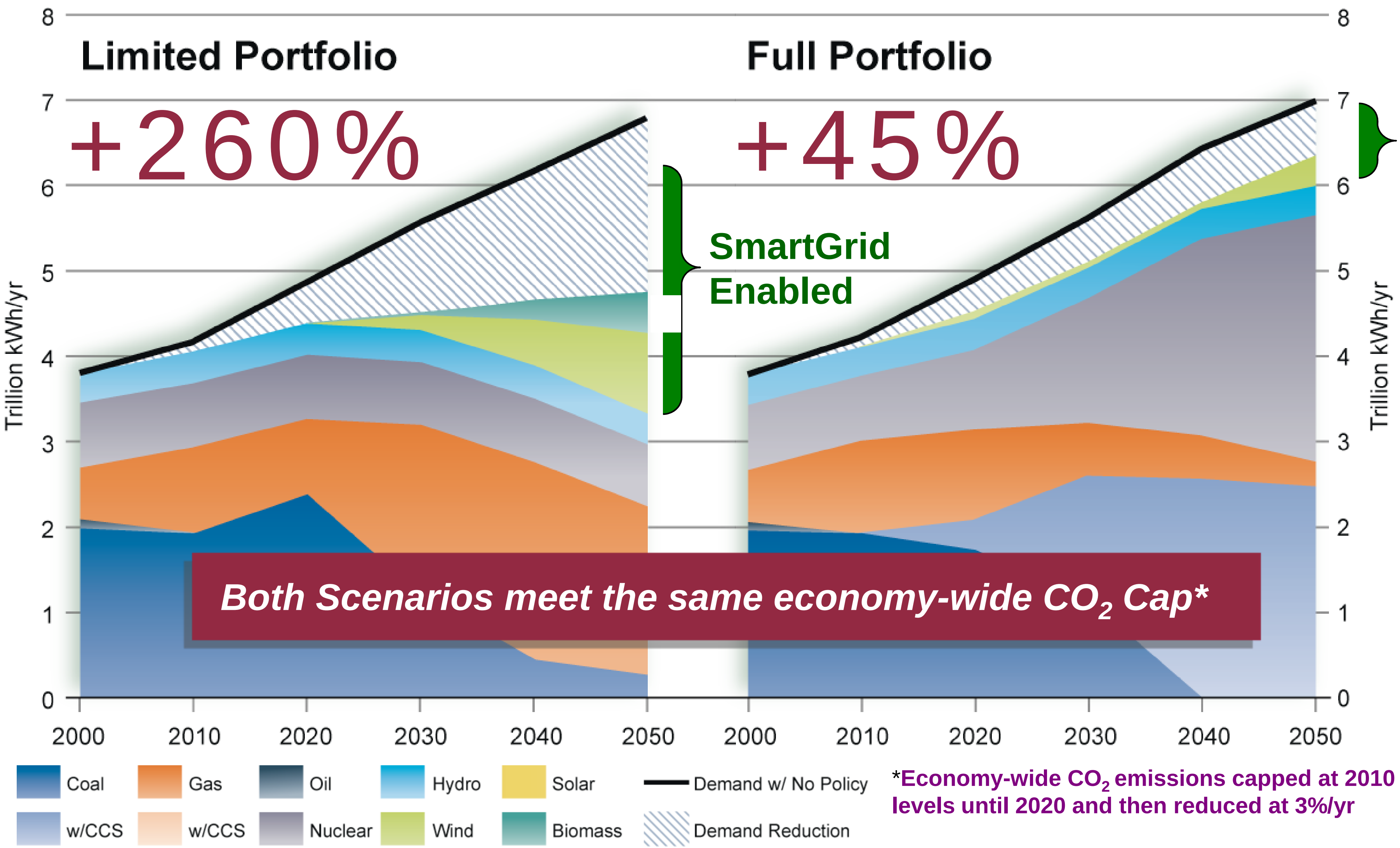
EIA/DOE AEO2004

Annual Energy Outlook

Table A2

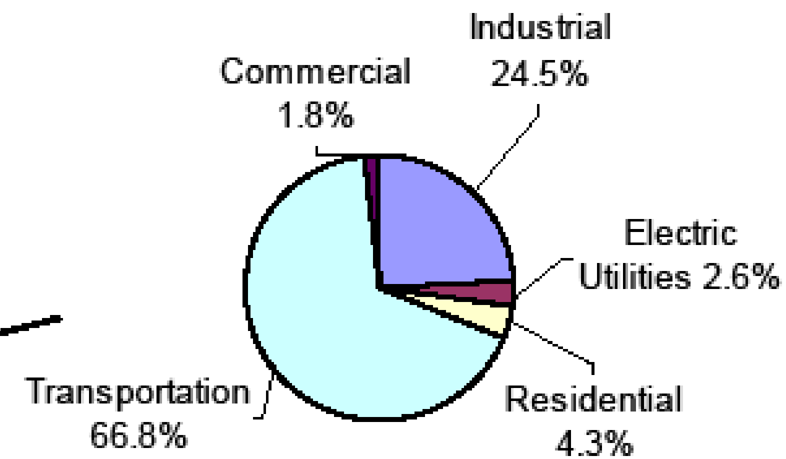
EPRI MERGE Analysis (2008 Revision)

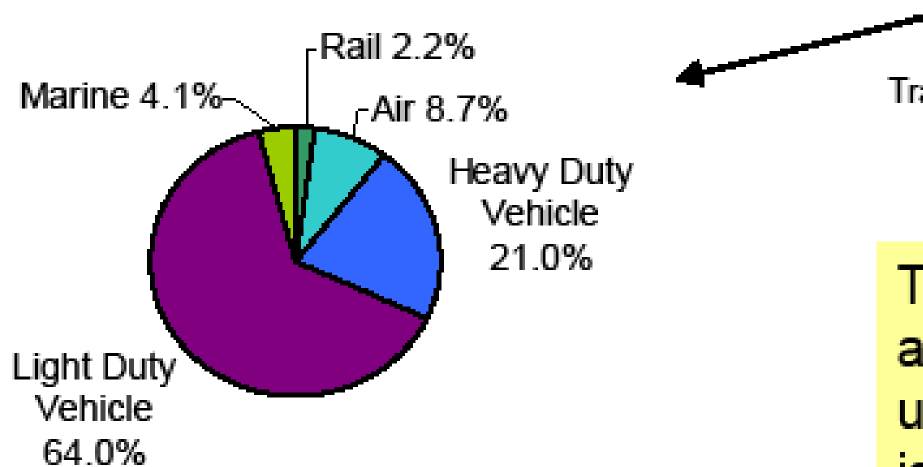
Increase in Real Electricity Prices…2000 to 2050



*Economy-wide CO_2 emissions capped at 2010 levels until 2020 and then reduced at 3%/yr

Transportation Accounts for the Majority of US Oil Consumption





The transportation sector accounts for 67% of the oil use in the United States and is the fastest growing petroleum consuming sector.

Future Energy Transition

- **Renewable and Clean power generation/transportation:**
  - **Gasified coal enables higher efficiency and CO_2 capture**
  - **High-megawatt electric drive compressors enable efficient CO_2 sequestration at large central coal and NG plants**
  - **Electric power delivery grid is enhanced to enable integration of dispatchable renewable energy sources**
  - **Grid storage is introduced to improve grid stability and larger amounts of variable/intermittent renewable energy sources**
  - **Dispatachable loads and micro-grids enhance grid capacity**
  - **Plug-in vehicles increase efficiency, provide additional grid storage, and use diverse (non petroleum) low CO_2 sources**
  - **LNG refrigeration enables long distance transport**

- ***This new paradigm requires advanced cost effective High-Megawatt Power Conditioning Systems (PCS)!***

NIST
National Institute of Standards and Technology

What Will the Smart Grid Look Like?

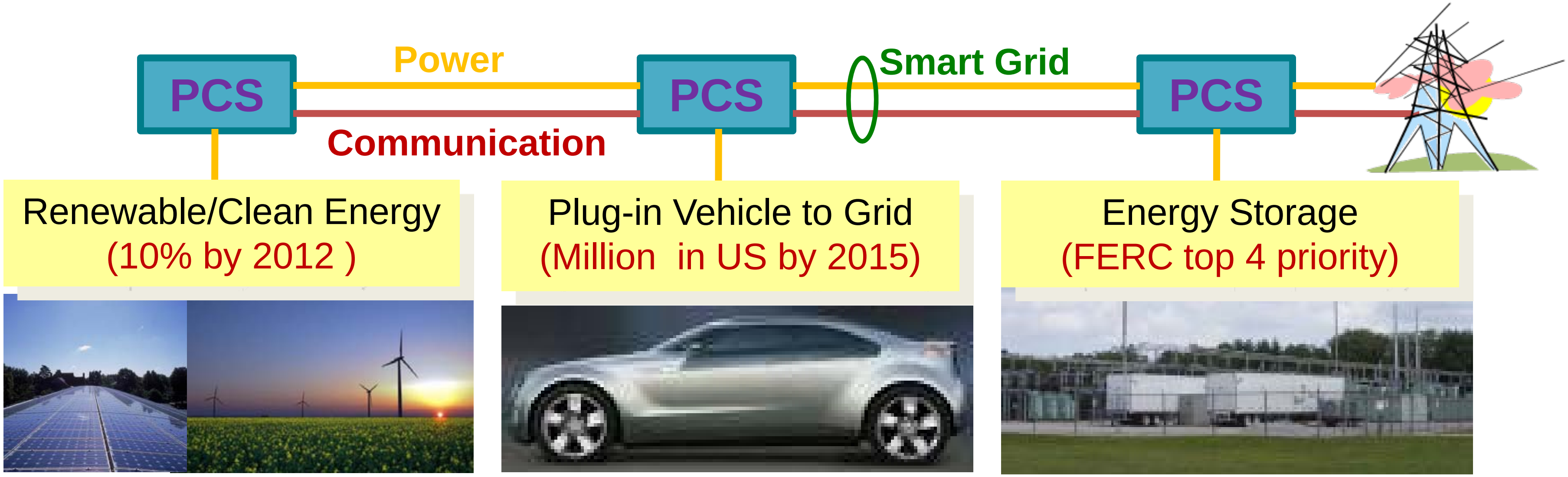
- High use of renewables – 20% – 35% by 2020
- Distributed generation and microgrids
- “Net” metering – selling local power into the grid
- Distributed storage
- Smart meters that provide near-real time usage data
- Time of use and dynamic pricing
- Ubiquitous smart appliances communicating with the grid
- Energy management systems in homes as well as commercial and industrial facilities linked to the grid
- Growing use of plug-in electric vehicles
- Networked sensors and automated controls throughout the grid

Accelerated Standards Process

- Executives meeting with Secretaries Locke and Chu in May
- Workshops with more than 1500 participants
  - April 28-29, 2009
  - May 19-20, 2009
  - SDO Workshop, August 3-4, 2009
- EPRI Report, Priority Action Plans, Standards Organizations
- Comments through two Federal Register Notices
- On September 24, 2009, Secretary Locke announces availability of NIST Smart Grid Interoperability Framework and Roadmap, Release 1.0 (Draft) – GridWeek 2009
  - Request for public comment period open
  - Final version November 2009
- First meeting of Smart Grid Interoperability Panel (SGIP): November 16-19 at Grid Interop

NIST
National Institute of Standards and Technology

High Penetration of Renewables and PEVs



- Power Conditioning Systems (PCS) convert to/from 60 Hz AC for interconnection of renewable energy, electric storage, and PEVs

- "Smart Grid Interconnection Standards" required for devices to be utility controlled operational asset and enable high penetration:
  - **Dispatchable real and reactive power**
  - **Acceptable ramp-rates to mitigate renewable intermittency**
  - **Accommodate faults faster, without cascading area-wide events**
  - **Voltage/frequency control and utility controlled islanding**

Priorities for Standardization

- Demand Response and Consumer Energy Efficiency
- Wide Area Situational Awareness
- Electric Storage
- Electric Transportation
- Advanced Metering Infrastructure
- Distribution Grid Management
- Cyber Security
- Network Communications

What are Priority Action Plans (PAPs)

- NIST workshops identified priority standards issues
  - many standards require revision or enhancement
  - and new standards need to be developed to fill gaps
- 70 standards gaps and issues were identified
- NIST determined which issues require most urgent resolution and selected top 14 to initiate PAPs
- The August SDO Workshop was used to develop the action plan for each priority issue.
- Current status for each PAP is posted on the NIST website
  - broad SDO and stakeholder support and participation
  - aggressive milestones in 2009 or early 2010 established
- NIST and the Smart Grid Interoperability Panel will guide and oversee progress on PAPs and development of new PAPs.

Priority Action Plans	Target Date
Smart meter upgradeability standard	completed
Common specification for price and product definition	early 2010
Common scheduling mechanism for energy transactions	year-end 2009
Common information model for distribution grid management	year-end 2010
Standard demand response signals	January 2010
Standard for energy use information	January 2010
IEC 61850 Objects / DNP3 Mapping	2010

Priority Action Plans (continued)	Target Date
Time synchronization	mid-2010
Transmission and distribution power systems models mapping	year-end 2010
Guidelines for use of IP protocol suite in the Smart Grid	mid-year 2010
Guidelines for use of wireless communications in the Smart Grid	mid-year 2010
Electric storage interconnection guidelines	mid-2010
Interoperability standards to support plug-in electric vehicles	December 2010
Standard meter data profiles	year-end 2010

NIST National Institute of Standards and Technology

Electric Storage Interconnection Guidelines

SG Standards Need

- Interconnection and object model standards needed for:
  - DER grid operational interface with dispatchable: VAR, V, F, etc.
  - support for energy storage devices (ES), including PEV
  - and hybrid generation-storage systems (ES-DER)

PAP Major Objectives

- Revised and updated consistent guidelines and standards:
  - Involve broad set of **Stakeholders**: SDOs, utilities, vendor, etc.
  - **Scoping Document** to determine priorities and timeline for standards development for spectrum of applications (Oct. 09)
  - **IEEE 1547 revisions** for urgent applications (mid-2010)
  - Consistent **object models** for DER, ES, ES-DER in IEC 61850-7-420
  - UL, NEC-NFPA70, SAE **guidelines for safe, reliable implementation**

http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/PAP07Storage

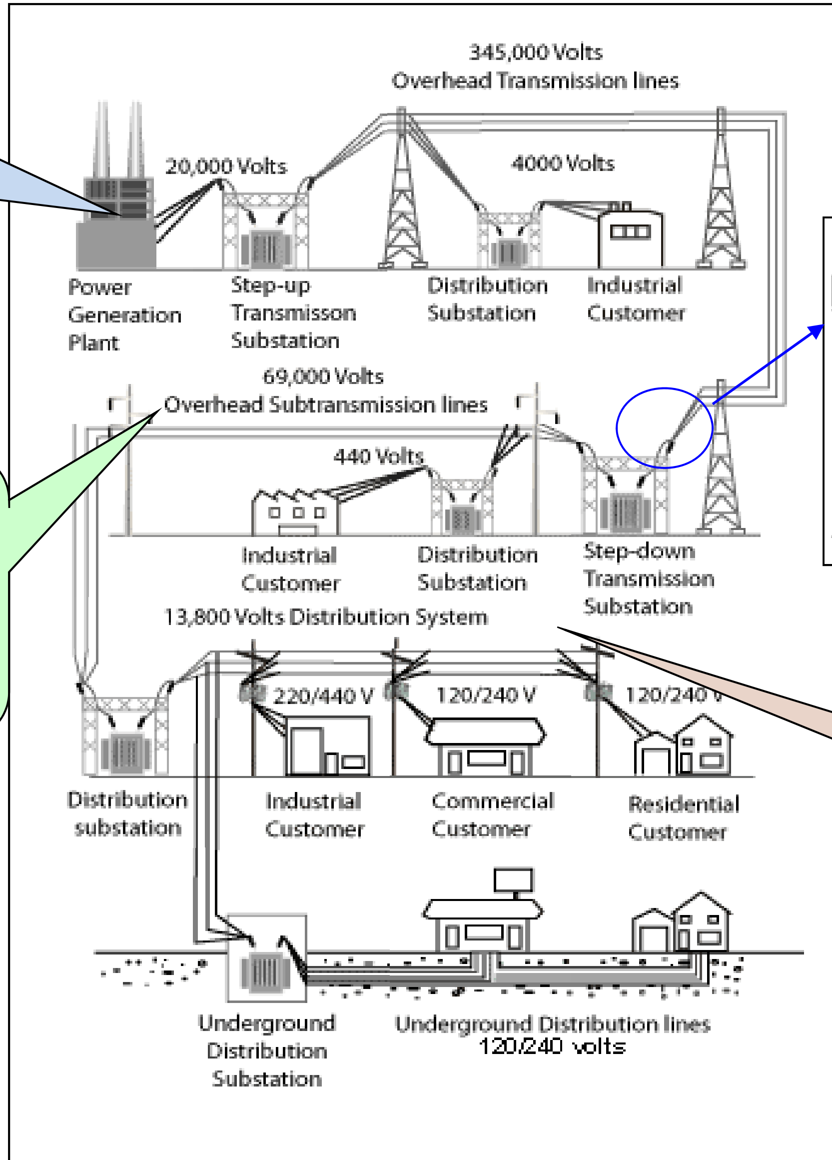
Renewable/Clean Energy Interconnects

Central Station

Clean Coal
(IGFC)
> 300 MW

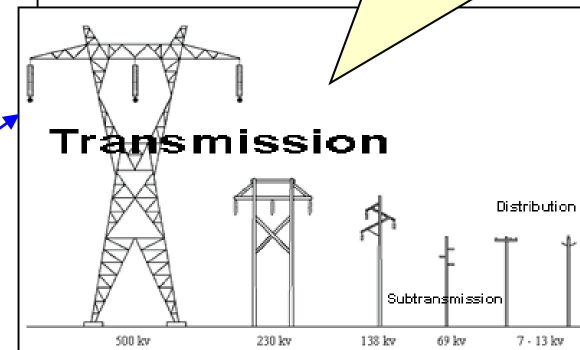
Transmission, sub-transmission

Large wind farms, central PV, biopower, hydro, geothermal, hydrokinetic



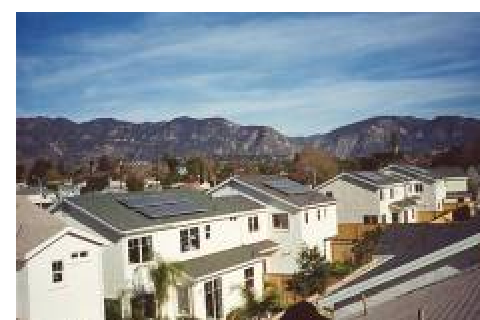
Transmission

HVDC, FACTS,
Smart Grid, Islanding



Distribution + Consumer

PV, small wind, fuel cells, and Plug-in EV



National Institute of
Standards and Technology

Storage PAP Task Interactions

Task 0: Scoping Document

Prioritized timeline for ES-DER standards

Task 1: Use Cases

Define requirements for different scenarios

Task 2: IEEE 1547.4 for island applications and IEEE 1547.6 for secondary networks

Task 3: Unified interconnection method with multifunctional operational interface for range of storage and generation/storage.

- Task 3a: IEEE 1547.8.1 – Operational interface
- Task 3b: IEEE 1547.8.2 – Storage without gen
- Task 3c: IEEE 1547.8.3 – PV with storage
- Task 3d: IEEE 1547.8.4 – Wind with storage
- Task 3e: IEEE 1547.8.5 – PEV as storage

Task 4: Develop and Harmonize Object Models

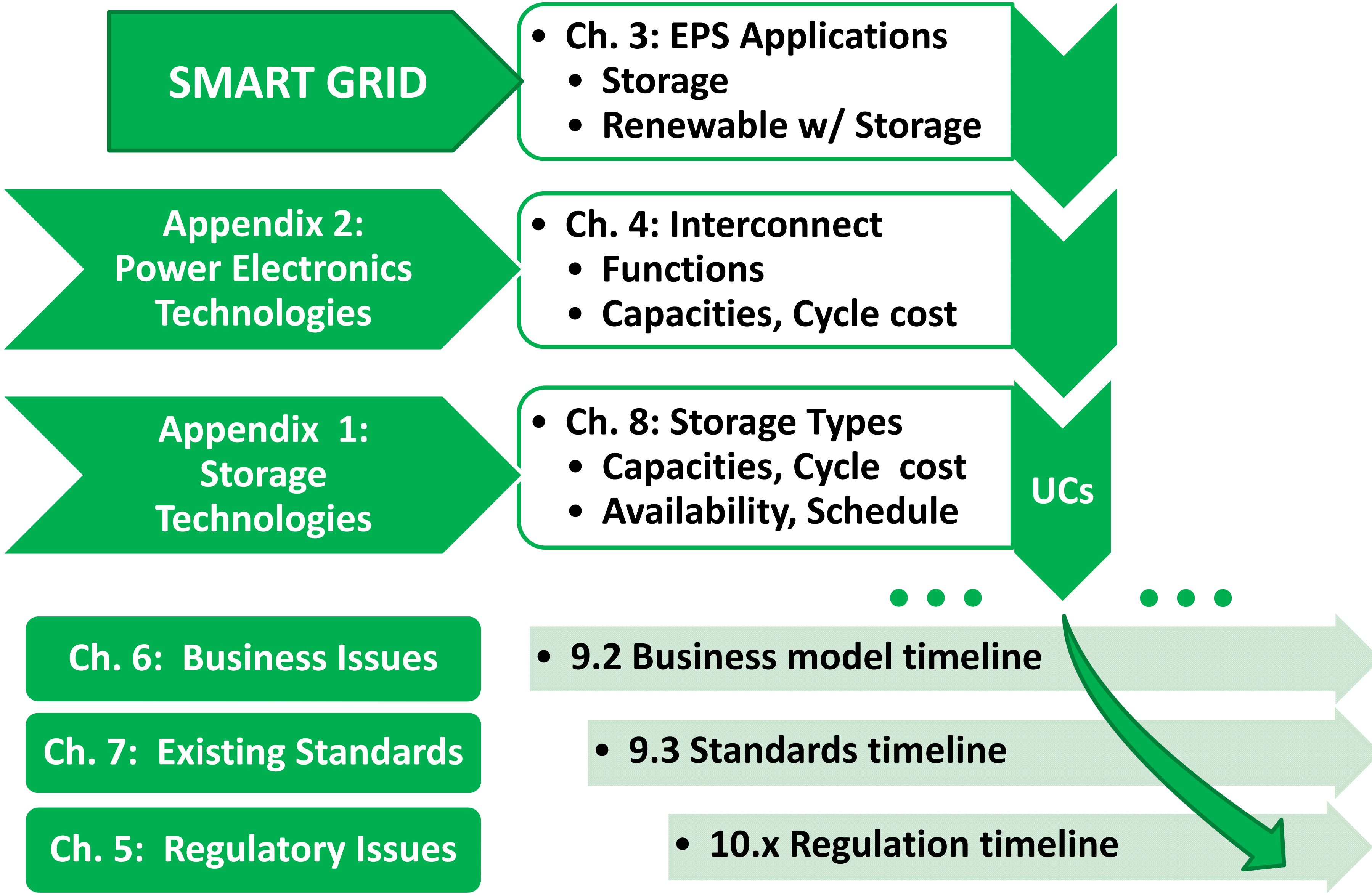
IEC61850-7-420 : Expanded to include multifunctional ES-DER operational Interface; harmonized with SEP, CIM, MultiSpeak

PAP 11,12

Task 5: Safe and Reliable Implementation

UL, NEC-NFPA70, SAE, and CSA

Task 0: Scoping Study Document



Scoping Study Outline (Page 1)

1. **Executive Summary**

2. **Introduction**
   - *NIST Smart Grid Interoperability Framework and Panel*
   - *Storage PAP*
   - *Goals of this Scoping Study*
   - *Discussion*

3. **EPS Applications for Dispatchable ES-DER**
   - *Domain and Location Specific Requirements*
   - *Applications*
   - *EPS Control Parameters*

Scoping Study Outline (Page 2)

4. Electrical Interconnection of ES-DER

- *Role of Mechanical Rotating Machinery as the grid operational interface for generation and storage*
- *Role of Electronic Power Conditioning Systems (PCSs) as the grid operational interface for generation and storage*
- *Dispatchable DER generation with multifunctional grid operational interface*
- *Dispatchable ES-DER generation-storage with multifunctional grid operational interface*

5. Regulatory Issues for ES-DER

- *Wholesale Regulation*
- *FERC Wholesale Market Deregulation*
- *Retail Regulation*

Scoping Study Outline (Page 3)

6. **Business Issues for ES-DER**
    - *Wholesale / System Markets*
    - *Renewable Integration*
    - *Utility T&D Grid Support*
    - *Commercial and Industrial*
    - *Distributed Storage near pad mounted transformer sites*
    - *Residential Applications*

7. **General Standards and Implementation Guidelines for ES-DER**
    - *Electrical Interconnection Standards*
    - *Standards and guidelines for safe and reliable implementation*
    - *Information/Object Model Standards*

SGIP

Scoping Study Outline (Page 4)

8. **Specific Standards needs for ES-DER Technologies/Applications**
   - *Summary of Storage Technology Data considered in this Scoping Study (details in Appendix 1)*
   - *Comparing Technology with Application Requirements (physical/logical)*
   - *Parameters/Relationships that define capacity/availability/cycle cost for storage technologies/applications*
   - *Examples of companies providing storage technologies*

9. **Detailed Timeline and Specifications for High Priority Standards**
   - *Prioritization of Standards for Development*
   - *Detailed specifications for high Priority Interconnection*

Scoping Study Outline (Page 4)

10. Summary and Recommendations to SDOs/Regulators

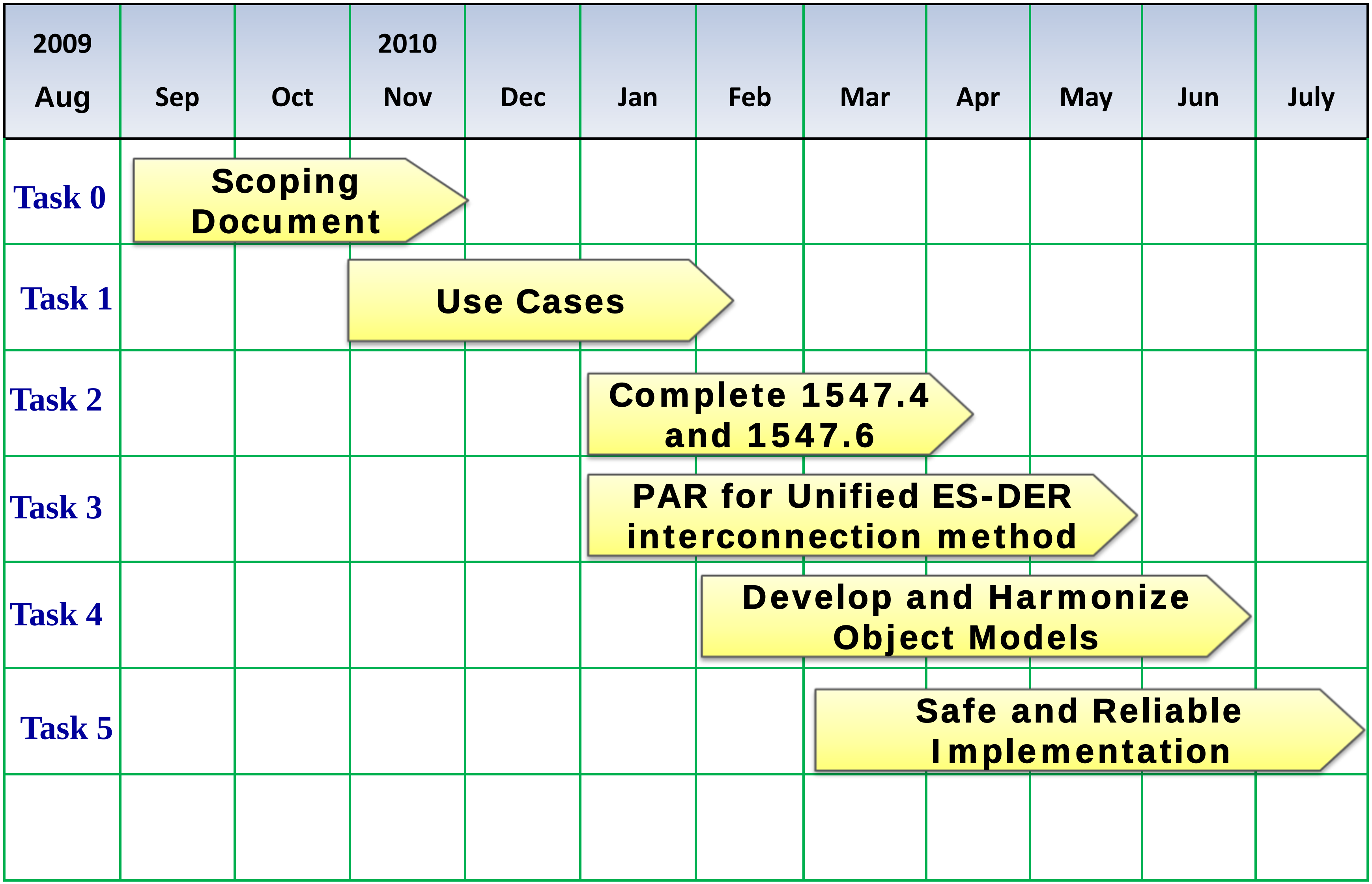
Appendix 1: Storage Technology Type Data and Classification

- *Storage Type data used for the Scoping Study*
- *Classification of Types of Storage*
- *Examples of Companies providing Storage*

Appendix 2: Types of Power Conditioning Systems

- *Battery charger for battery bank energy storage system*
- *Community/residential energy storage*
- *Battery fast charging (filling) station for electric vehicles*
- *STATCOM with energy storage*
- *Storage in wind applications*
- *Solar parks*
- *Renewable power plant monitoring and control*

Use Case Analysis and Other Tasks



Charlie Vartanian

A123 Systems

Storage, Storage Interfaces, Frequency Regulation, and Beyond

High MW Electronics – Industry Roadmap Meeting

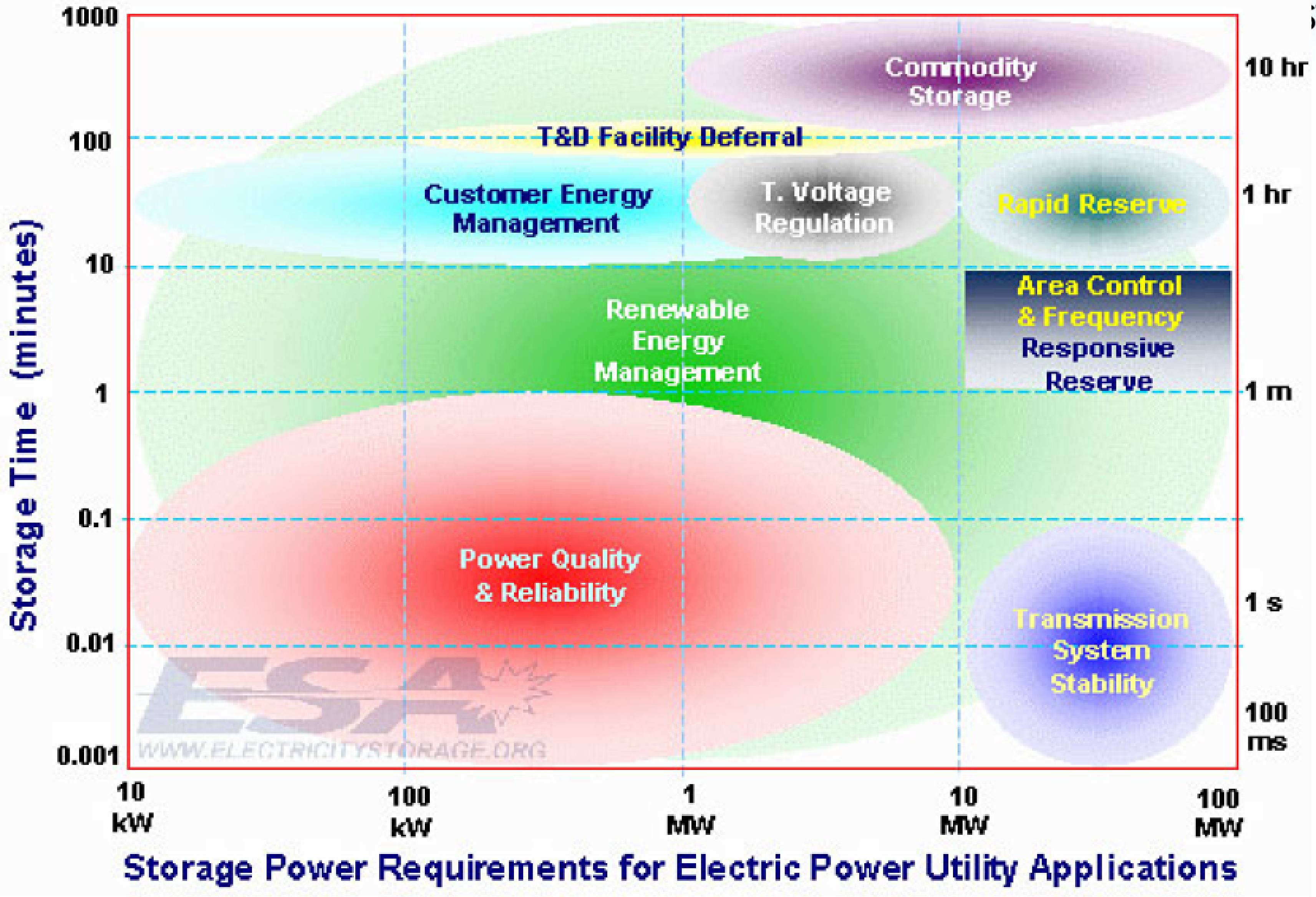
Challenges to Growth of Grid Connected Electronics

National Institute of Standards & Technology

December 11th, 2009

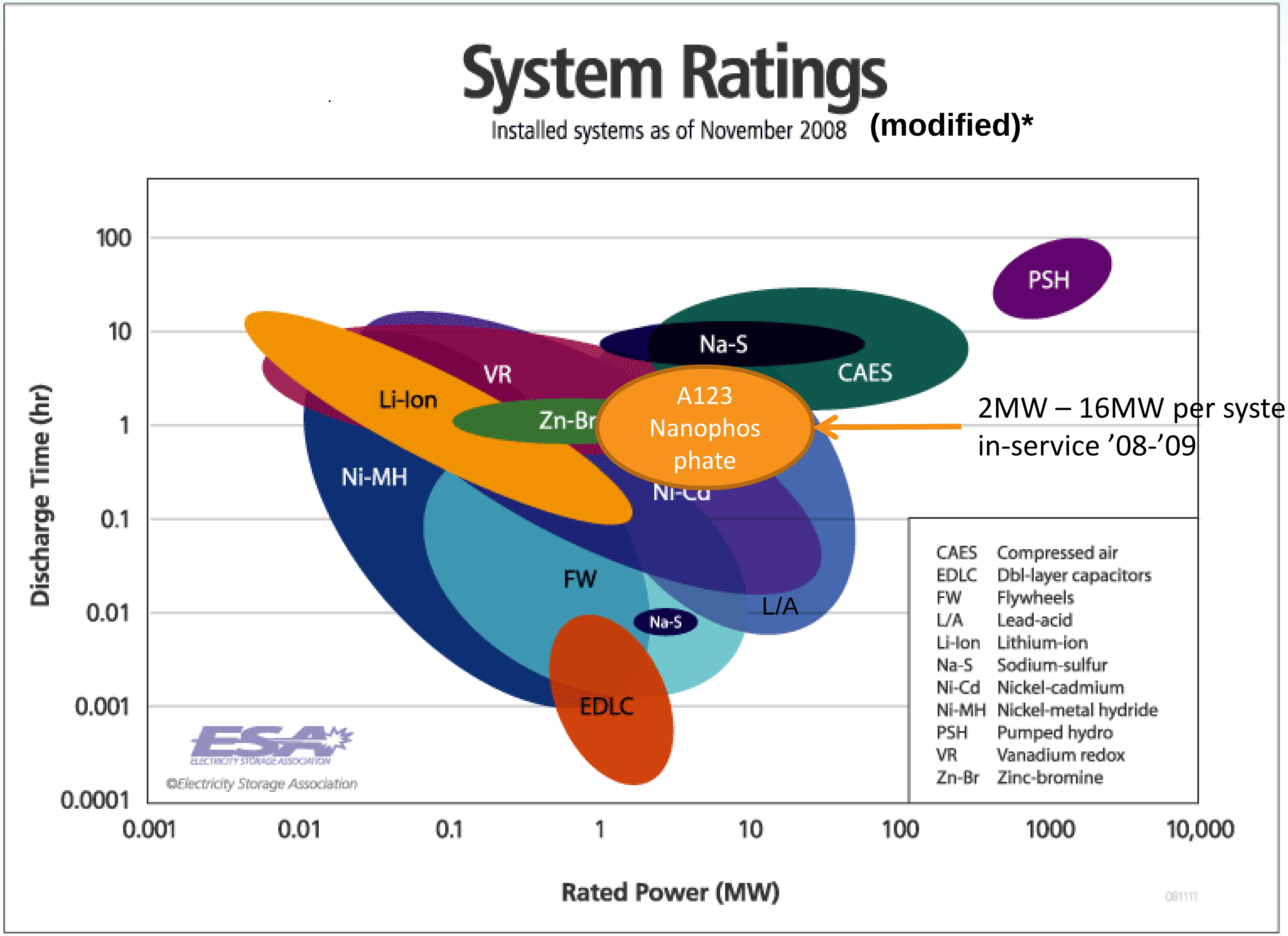
power. safety. life.™

Storage, Grid Applications



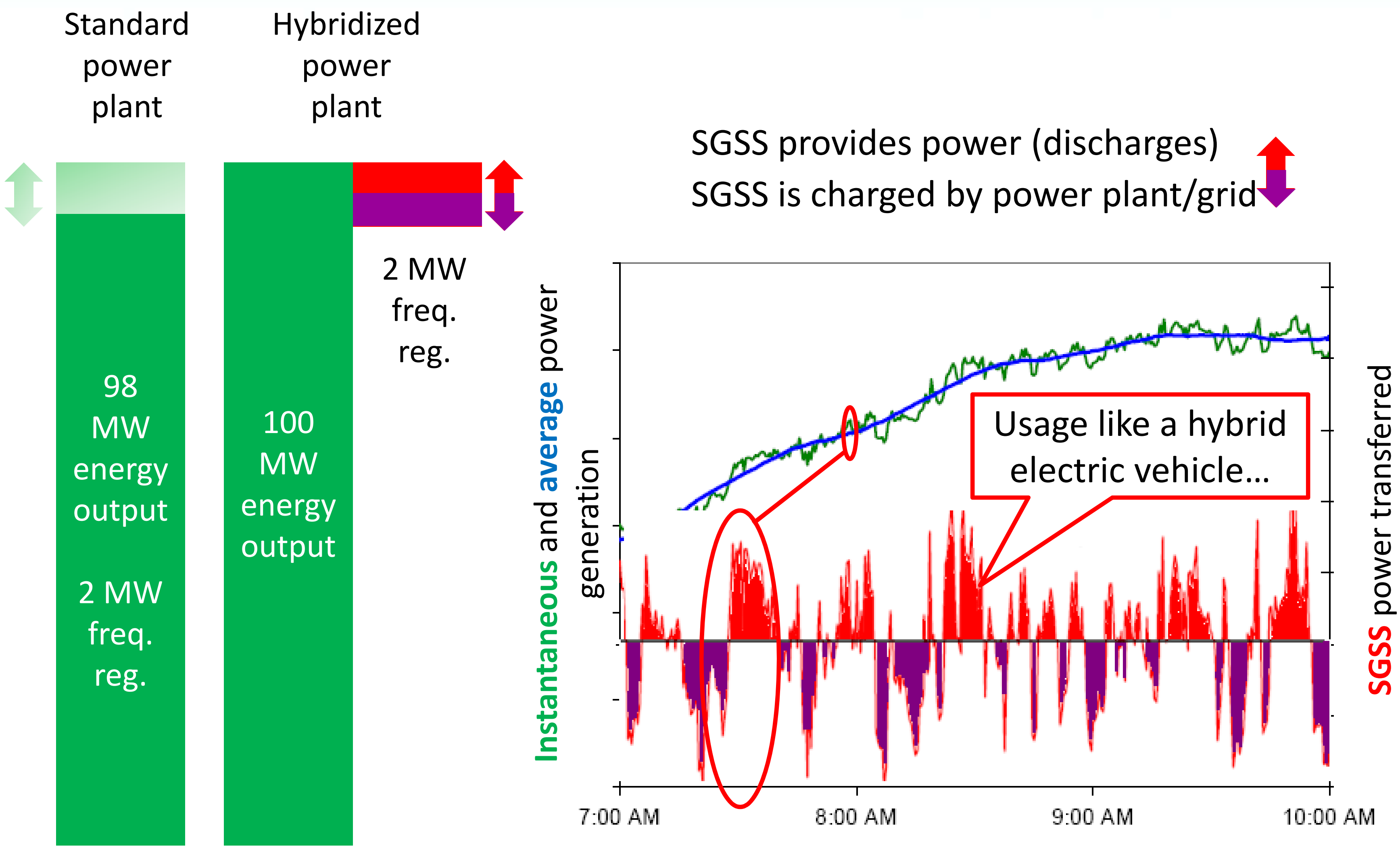
Source: ESA

Storage, System Characteristics Comparison



Source: ESA, * **modified** to include A123 in-service and proposed

Frequency Regulation with Storage (SGSS*)



* SGSS is A123's Smart Grid Stabilization System

Frequency Regulation, What's Delivered by PCS? Per CAISO Tariff, Controlled MW Output Level

A 1.2.1.2 the Generating Unit power output response (in MW) to a control signal must meet the minimum performance standards for control and unit response which will be developed and posted by the ISO on its internet "Home Page." As indicated by the Generating Unit power output (in MW), the Generating Unit must respond immediately, without manual Generating Unit operator intervention, to control signals and must sustain its specified ramp rate, within specified Regulation limits, for each minute of control response (MW/minute);

A 1.2.2 **Monitoring:**

the Generating Unit must have a standard ISO direct communication and direct control system to send signals to the ISO EMS to dynamically monitor, at a minimum the following:

A 1.2.2.2 high limit, low limit and rate limit values as selected by the Generating Unit operator; and

A 1.2.2.3 in-service status indication confirming availability of Regulation service.

★	** Point of Delivery Megavars is not required for AGC Regulation Units. However, it may be required in the future if a voltage market is established.

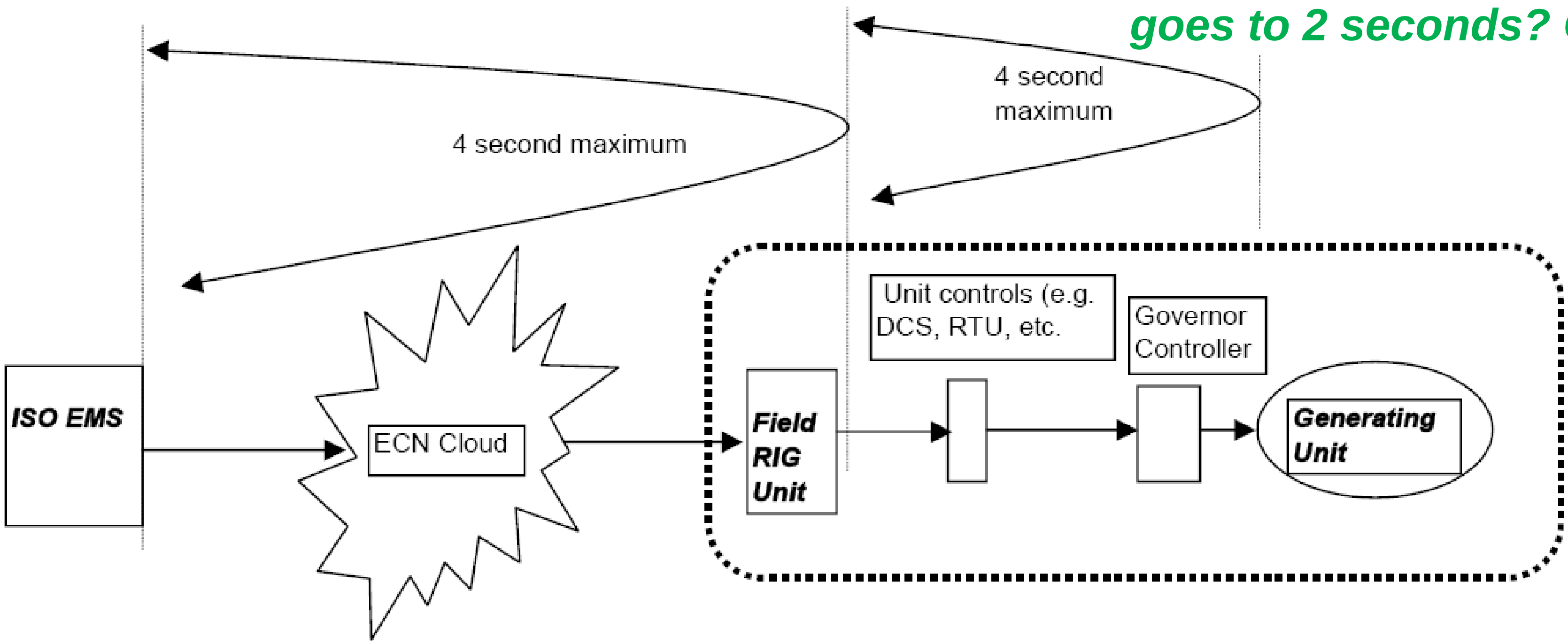
Delivering the Product, PCS Control and Tempo

A123 SYSTEMS

California ISO — Your Link to Power	Technical Standard	Revision Date Revision No.	2/20/2007 4.6
ISO Generation Monitoring and Control Requirements for AGC/Regulation Units		Print Date	2/26/2007
		Effective Date	11/8/2004

Figure 1 - Timing of Telemetered Data for Generators Providing AGC through the RIG

What happens when tempo goes to 2 seconds? CMU



#1 Driver – Storage F/R Commercially Viable

INDICATIVE COST OF PRODUCTION

42 mills CT Production Cost, 12 mills capacity, 30 mills variable cost

22 mills Battery Production Cost, 12 mills capacity, 10 mills variable cost

MARKET PRICE

10 – 50 mills Frequency Regulation average market clearing price

How can the PCS interface impact the "#1 Driver " for deploying this solution?

Lower cost, increase efficiency, and improve reliability

… and also expand compensable capabilities.

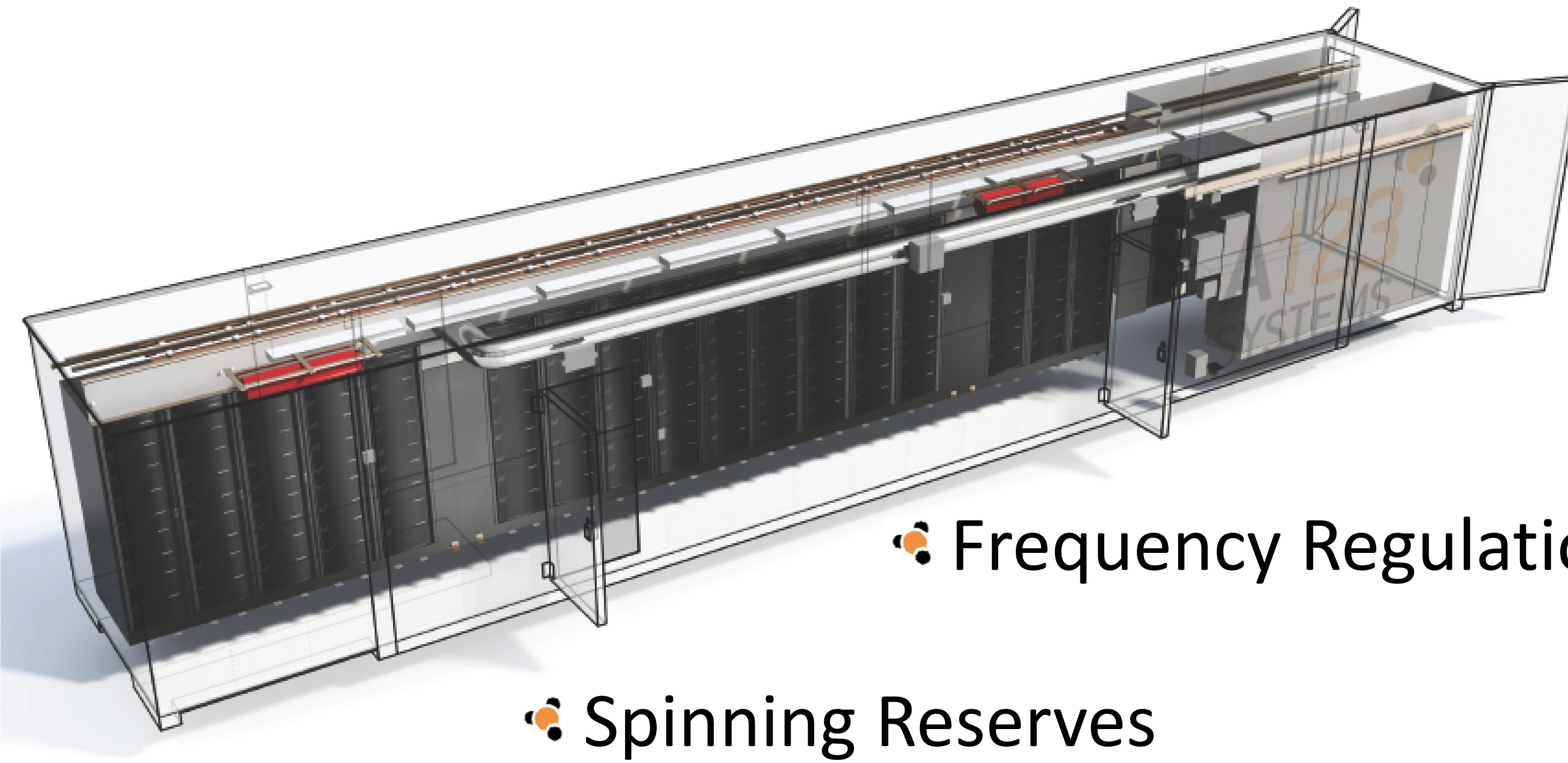
But, barrier is not technology, it's lack of investment recovery mechanisms

See Slide 11

Industry research supports additional potential "drivers", including emission reduction, renewable integration, system asset efficiency improvement . Once again, barrier is lack of investment recovery mechanism, not technology gaps.

One Implementation
A123's Smart Grid Stabilization System (SGSS)

A123 SYSTEMS



- Frequency Regulation
- Spinning Reserves

Grid Deployed SGSS's, Multi-MW Scale

California

Chile

Grid Interface, Parker-Hannifin

A123 SYSTEMS

AC890PX Power Entry Types

TOP POWER ENTRY/EXIT

BOTTOM POWER ENTRY/EXIT

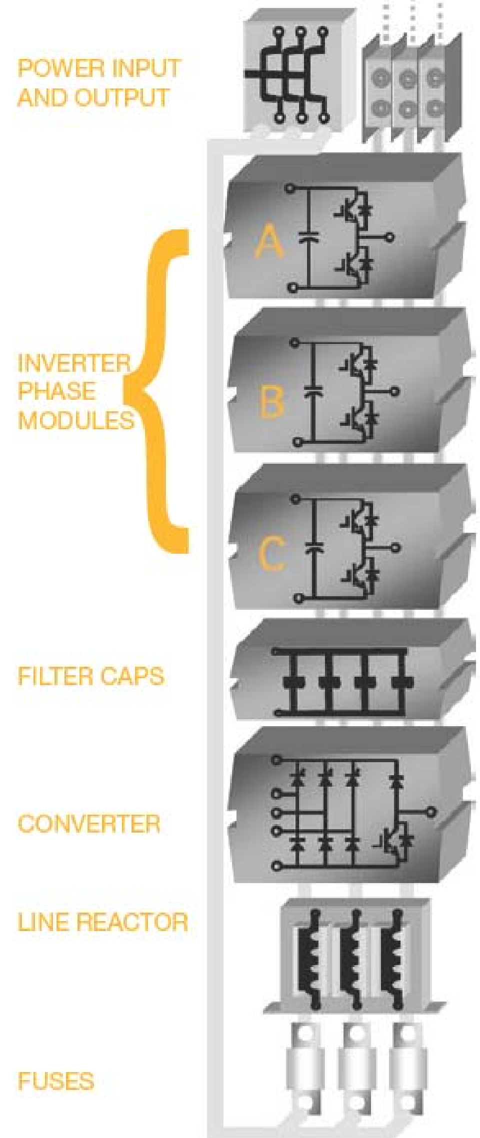
Four Operating Modes

- **Volts/Hertz**
- **Sensorless vector**
- **Full flux vector**
- **Servo (PMAC)**

Four Feedback Options

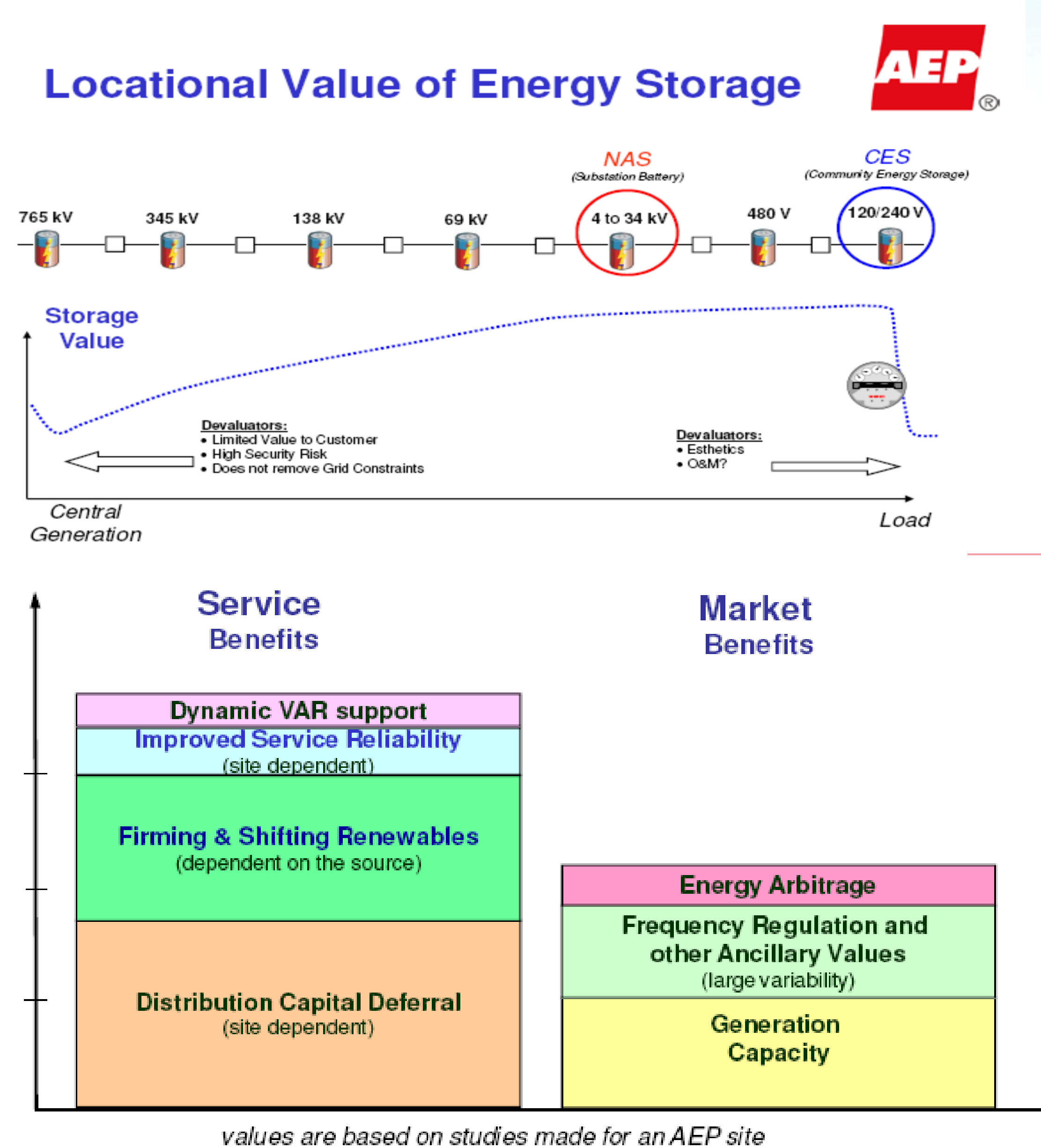
- **Incremental encoder**
- **Sin/Cos encoder**
- **Endat absolute encoder**
- **Resolver**

Runs induction, torque motors, or PMAC Servo



power. safety. life.™

AEP's Vision of Robust Storage Benefits



PCS Capabilities
For Full Grid Benefit

Steady State W, power transfer

Plus:

Steady State VAR, *voltage reg.*
Transient W, *a/c stall barrier*
Transient VAR, *sag mitigation*
Dynamic W, *damping, inertia*
Dynamic VAR, *voltage stability*
Islanding, *reliability*

Can this be delivered <$3/watt?
First U.S. Retail Rate Case

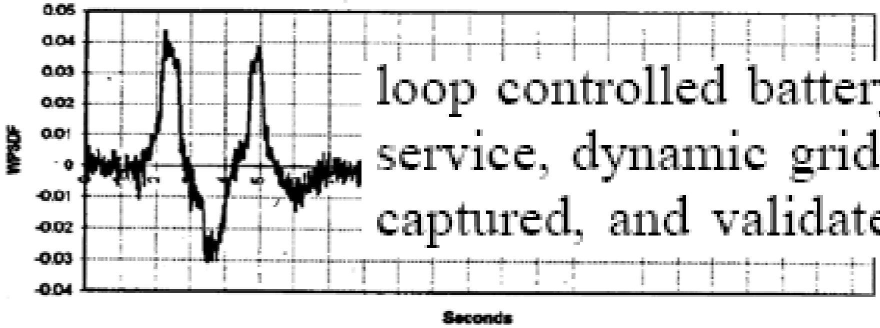
SCE's Utility's Vision of Storage Benefits (FOA 36)

Transmission	1	Provide Voltage Support/Grid Stabilization
	2	Reduce Outage Frequency/Duration (islanding)
	3	Reduce Transmission Losses
	4	Reduce Congestion
	5	Relax Reliability Limits (Defer Load Shed/Provide Generation under N-2 Contingency)
	6	Transmission Access
	7	Defer Transmission Investment
	8	Renewable Energy Transmission
System	9	Provide System Capacity/Resource Adequacy
	10	Renewable Energy Integration (smoothing)
	11	Renewable Energy Integration (daily output shifting)
ISO Markets	12	Provide Frequency Regulation
	13	Provide Spin/Non-Spin/Replacement Reserves
	14	Provide Ramp
	15	Provide Black Start
	16	Energy Price Arbitrage

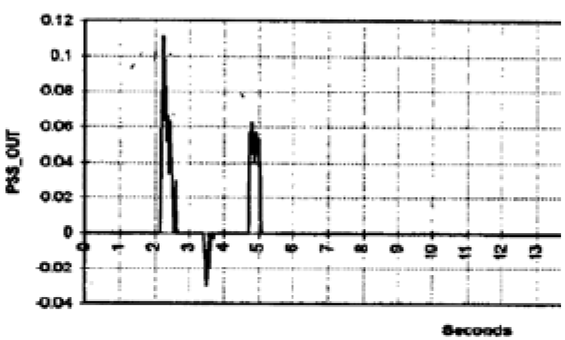
SCE Chino - Back to the Future - SCE Tehachapi

B. Chino Battery Energy Source Power System Stabilizer

In 1994 an Energy Source Power System Stabilizer (ESPSS) was designed and built by GE, and added to the Chino Battery and put into operation by SCE.



loop controlled battery output. Within two days of going into service, dynamic grid-supportive response by the battery was captured, and validated, through project metering.



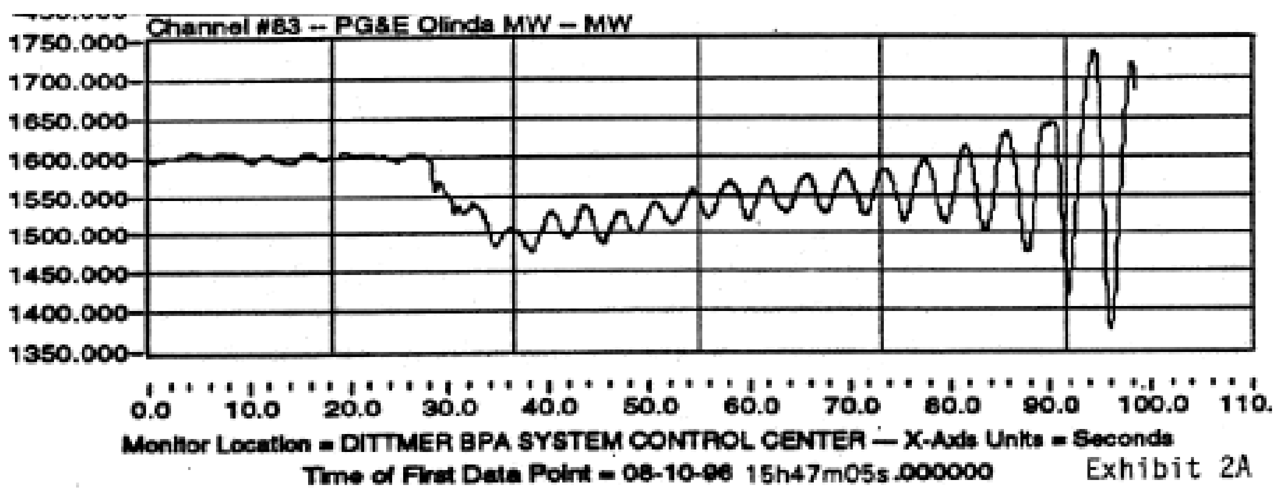
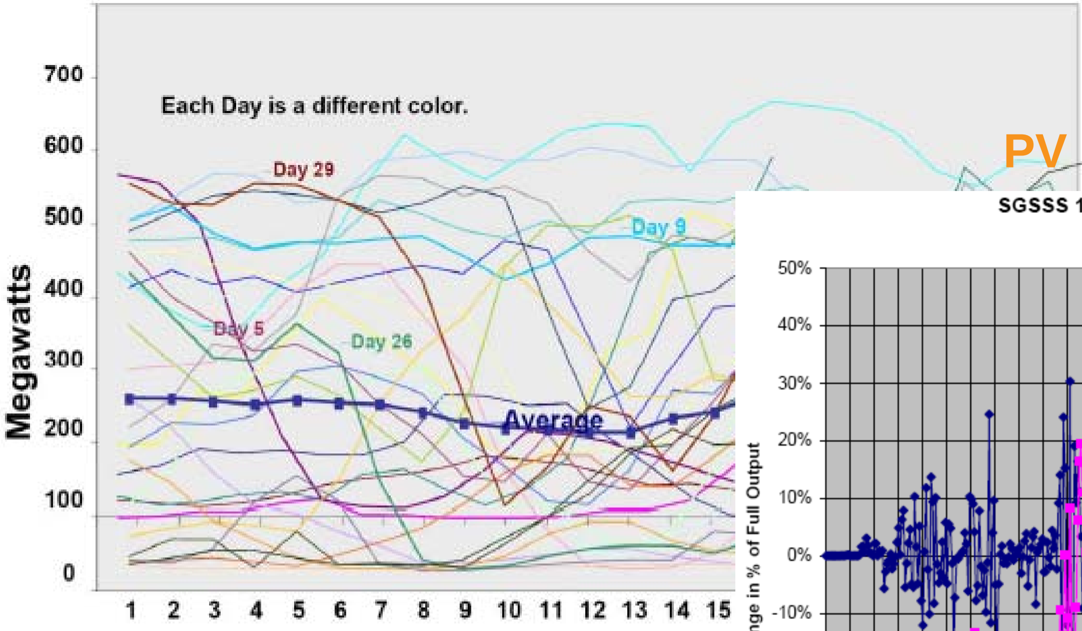


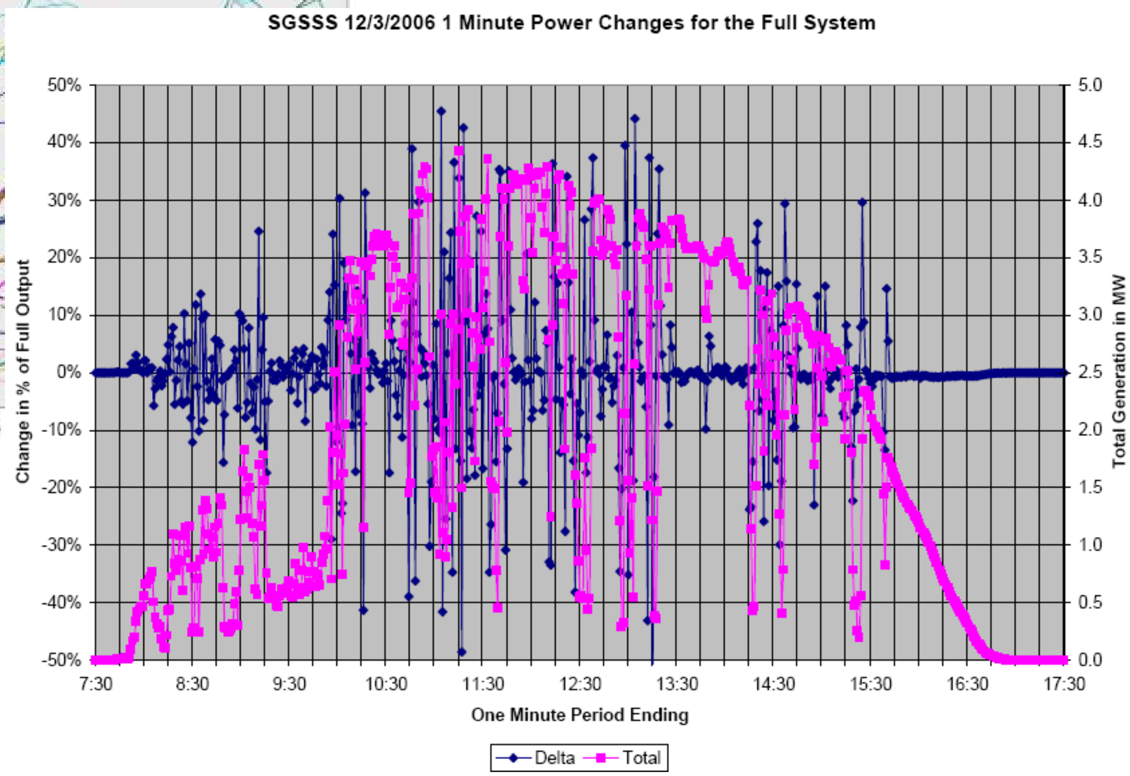
Exhibit 2A

Wind Challenge: Persistent Cycling Intermittency
PV Challenge: Infrequent Intermittency, Local PQ

Wind Production (Tehachapi)



PV Production (Tucson)



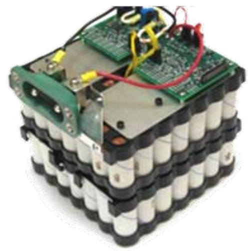
Source: CAISO and TEP

Ideas for Roadmap Development

- Cutting your PCS cost in half and doubling efficiency would be nice, but, wouldn't be a game changer in terms of accelerating significant commercial uptake of advanced-technology grid stabilizing storage; 4,000 MW UK, 10,000 MW US
- Help me map capabilities to grid performance outcomes relevant to grid-access controlling stakeholders.
- Help me characterize of renewable penetration impacts and solutions. Adamant voices want 'business as usual' to 20% penetration. OK, but then what? Stop, or accept higher outage exposure?

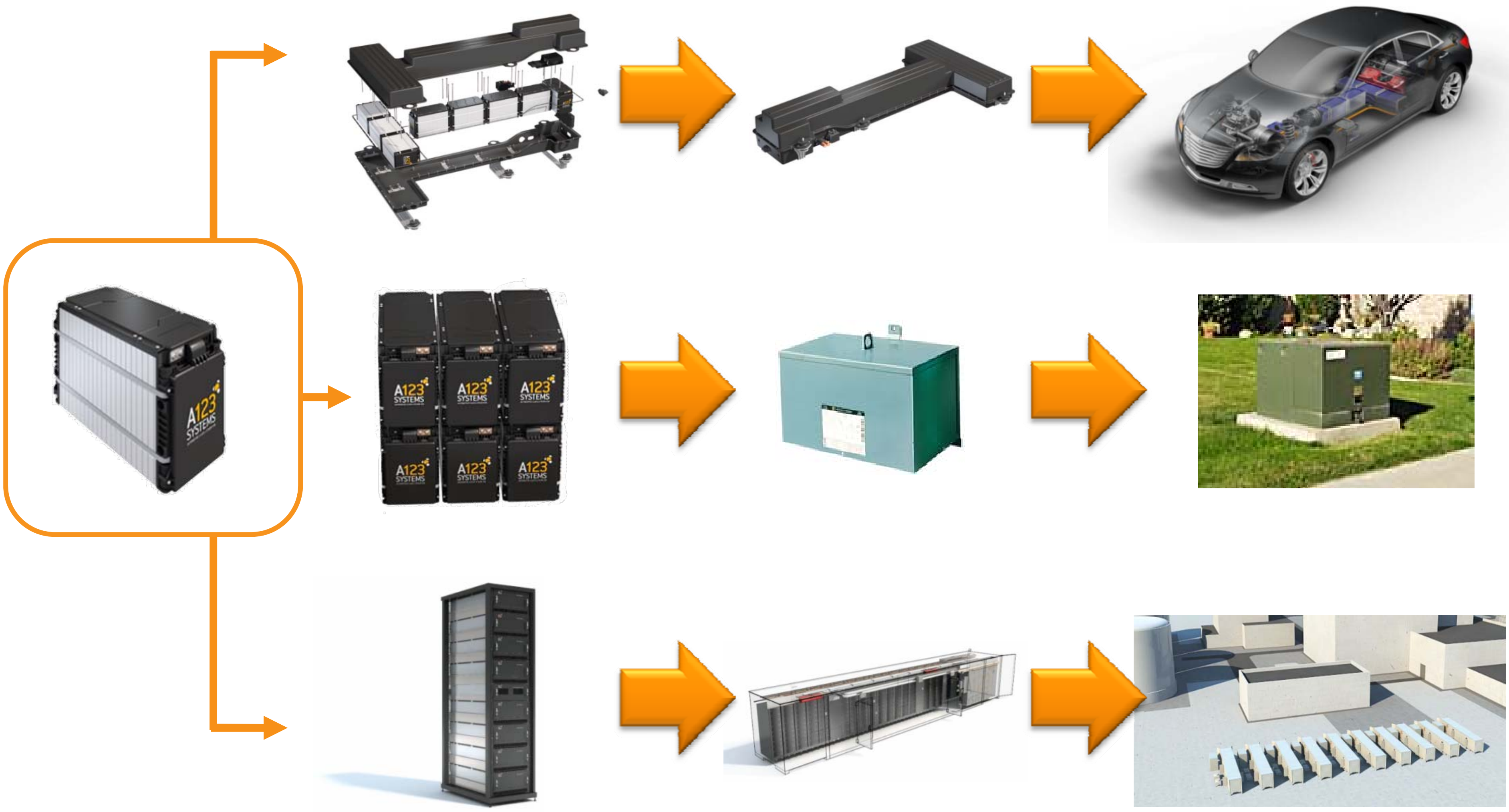
BACKUP SLIDES

A123 Core Competencies



Materials science and development expertise	Battery design capabilities	Battery systems engineering and integration expertise	Vertical integration from battery chemistry to battery system design services	Industry-leading partners in focused markets	High-quality, volume manufacturing facilities and proprietary process technologies

A123 Efficiencies for Maximum Value

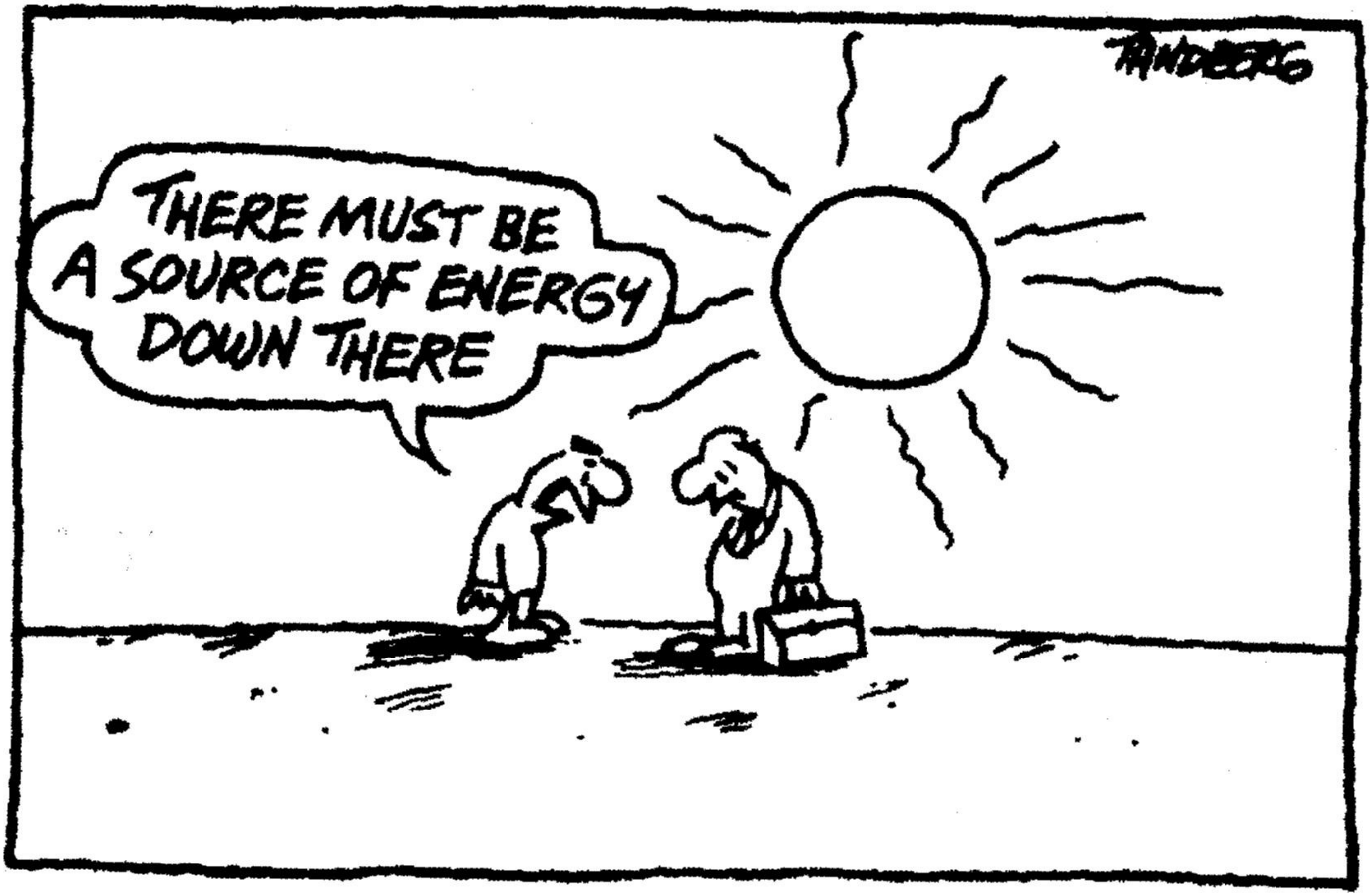


Madhav Manjrekar

Siemens

Circa: sometime in 1800s…the moment when they thought of digging for oil…

SIEMENS

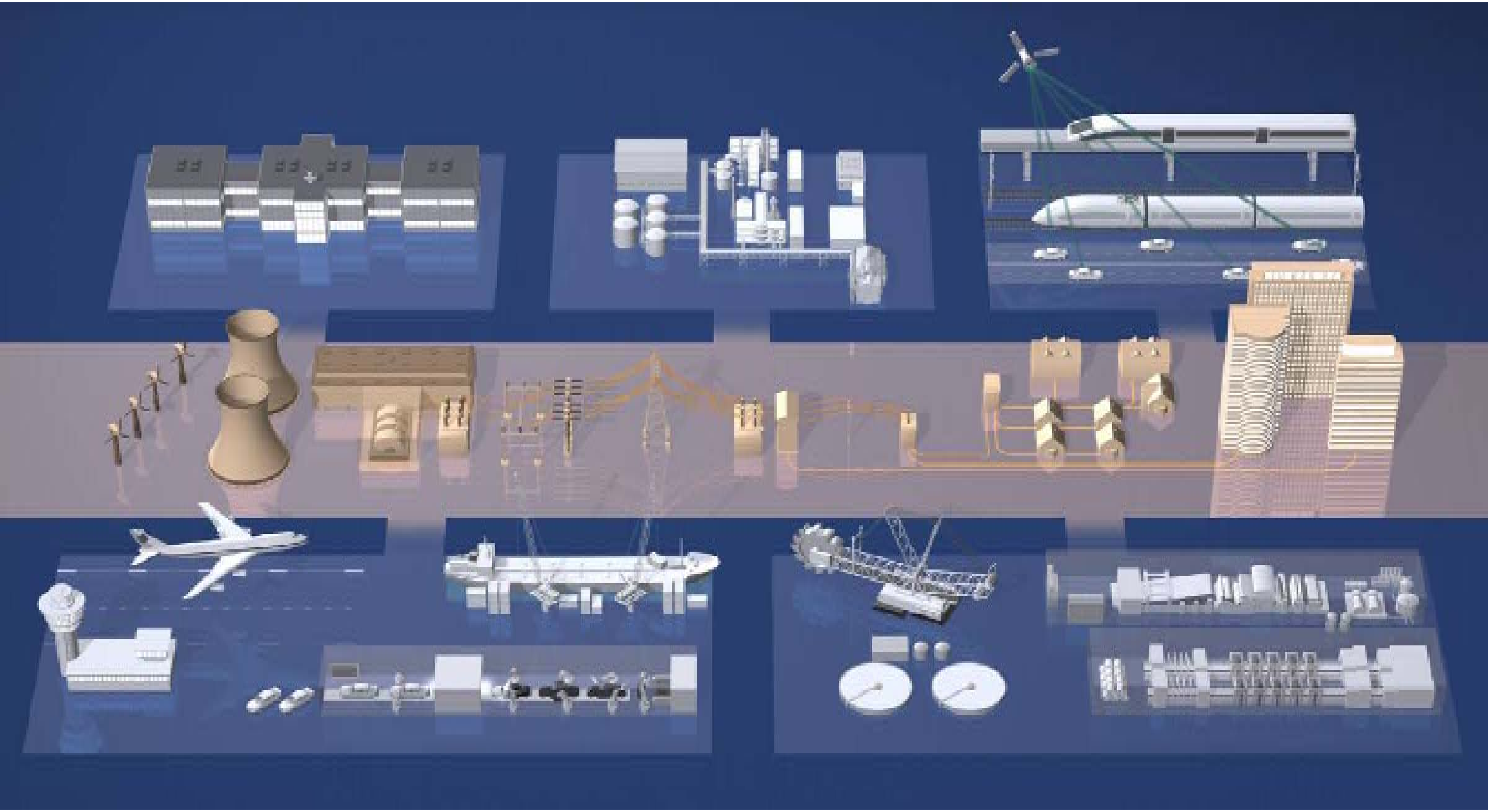


SIEMENS

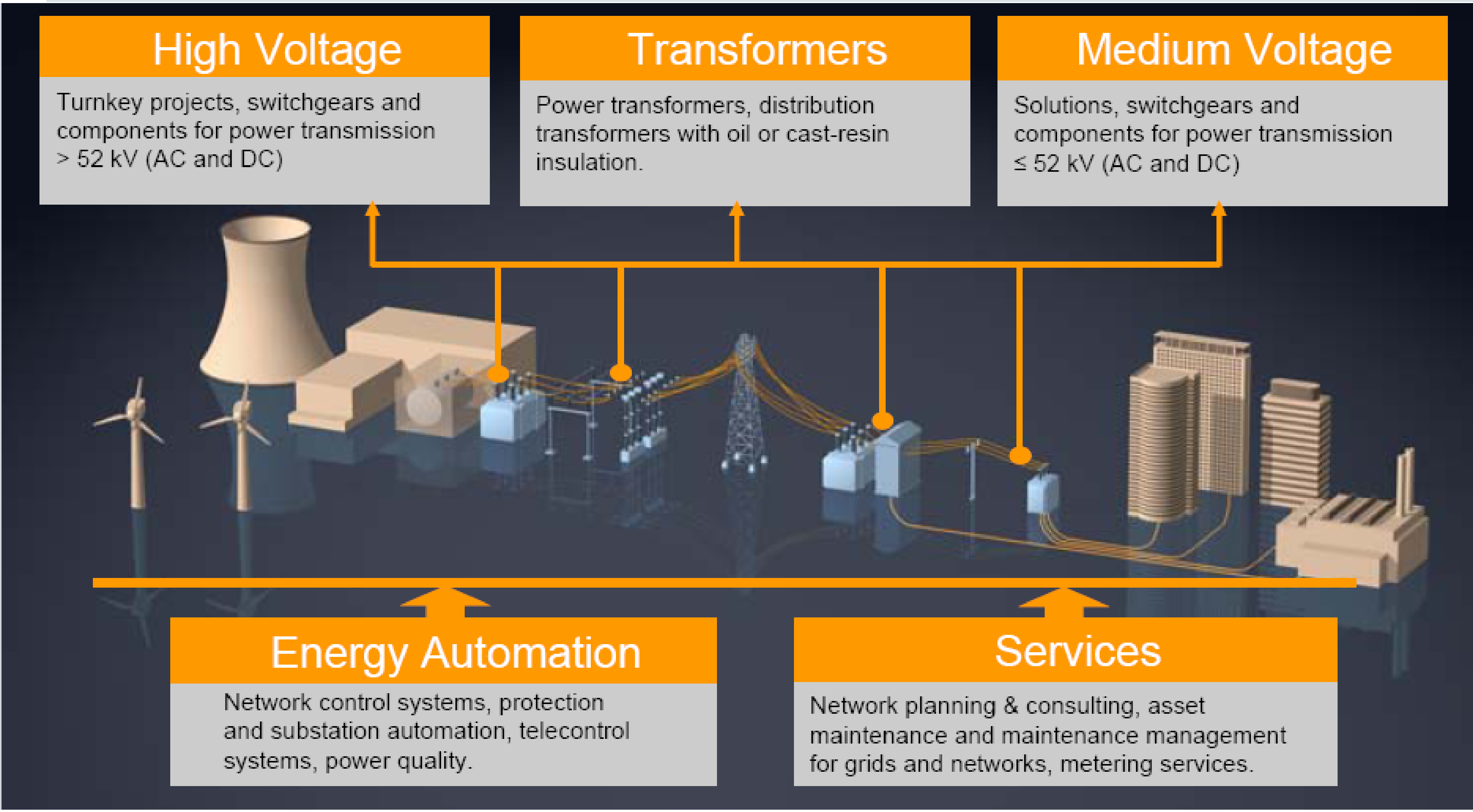
Agenda

- Introduction
- Marketplace Drivers
- Evolution to a Smart Grid
- Smart Grid
- Picture of the Future

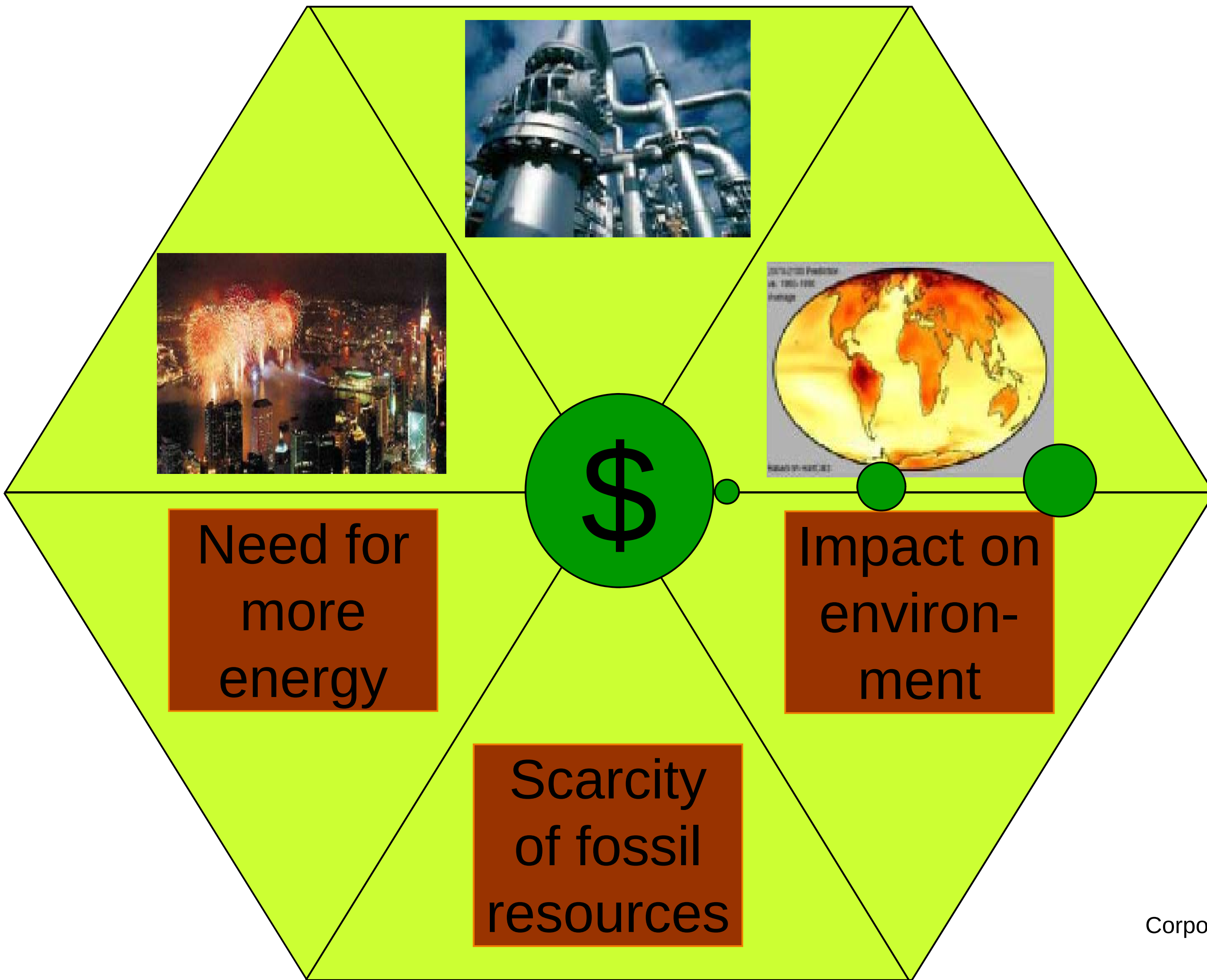
Electrical Energy has been the backbone of our society

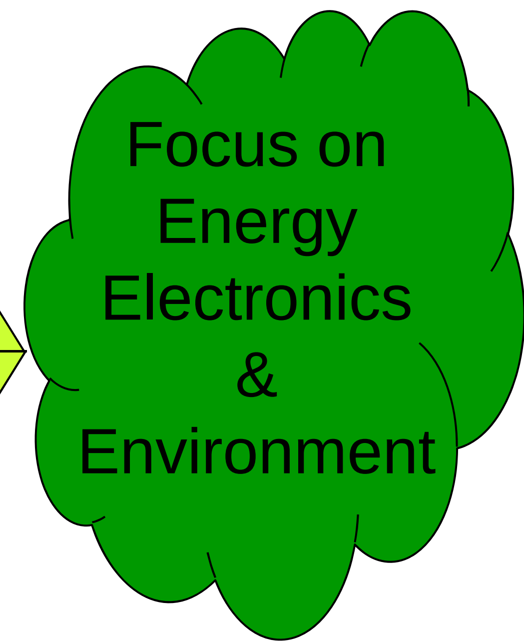


Energy Portfolio



Current Marketplace Drivers



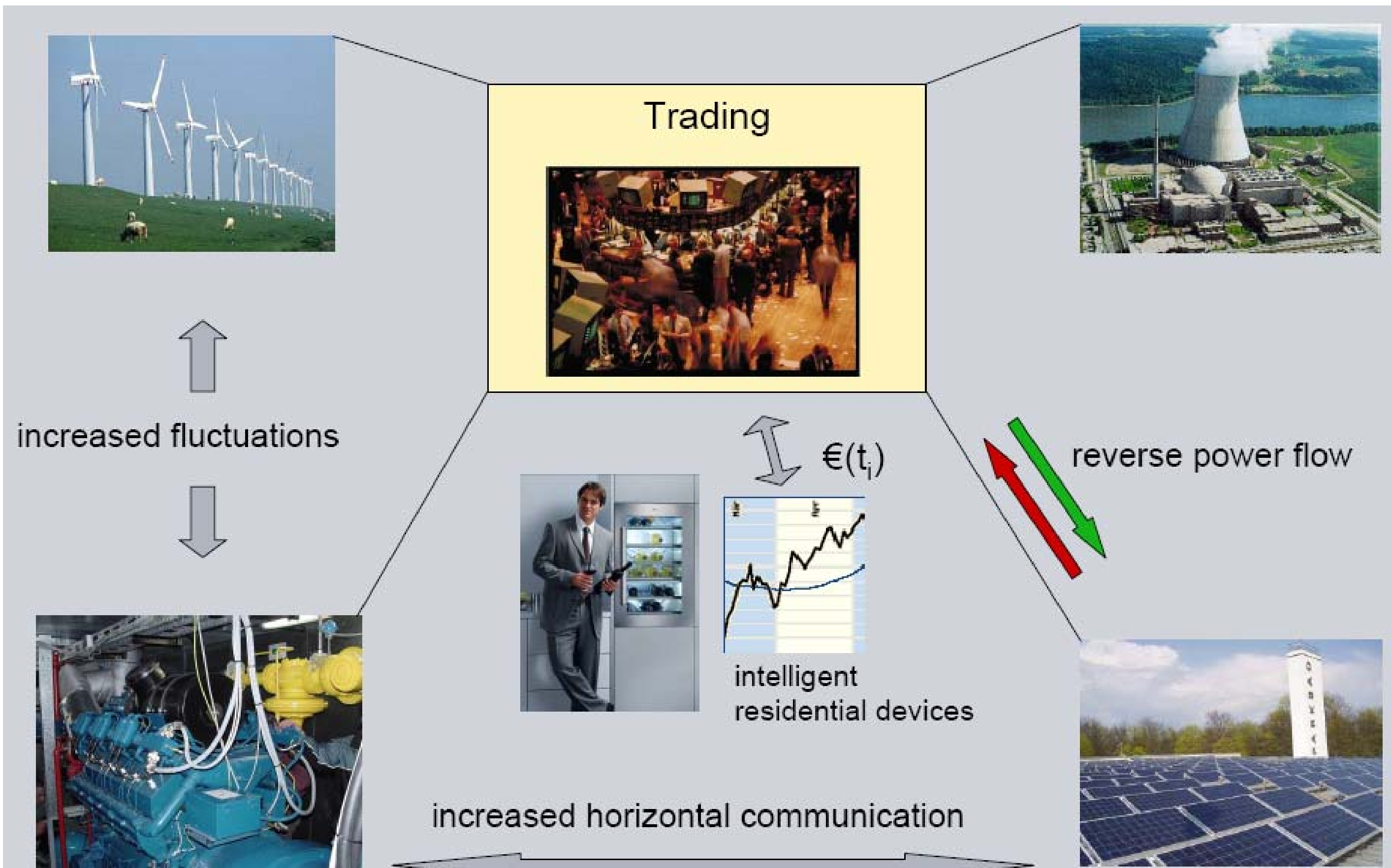


Evolution to a Smart Grid

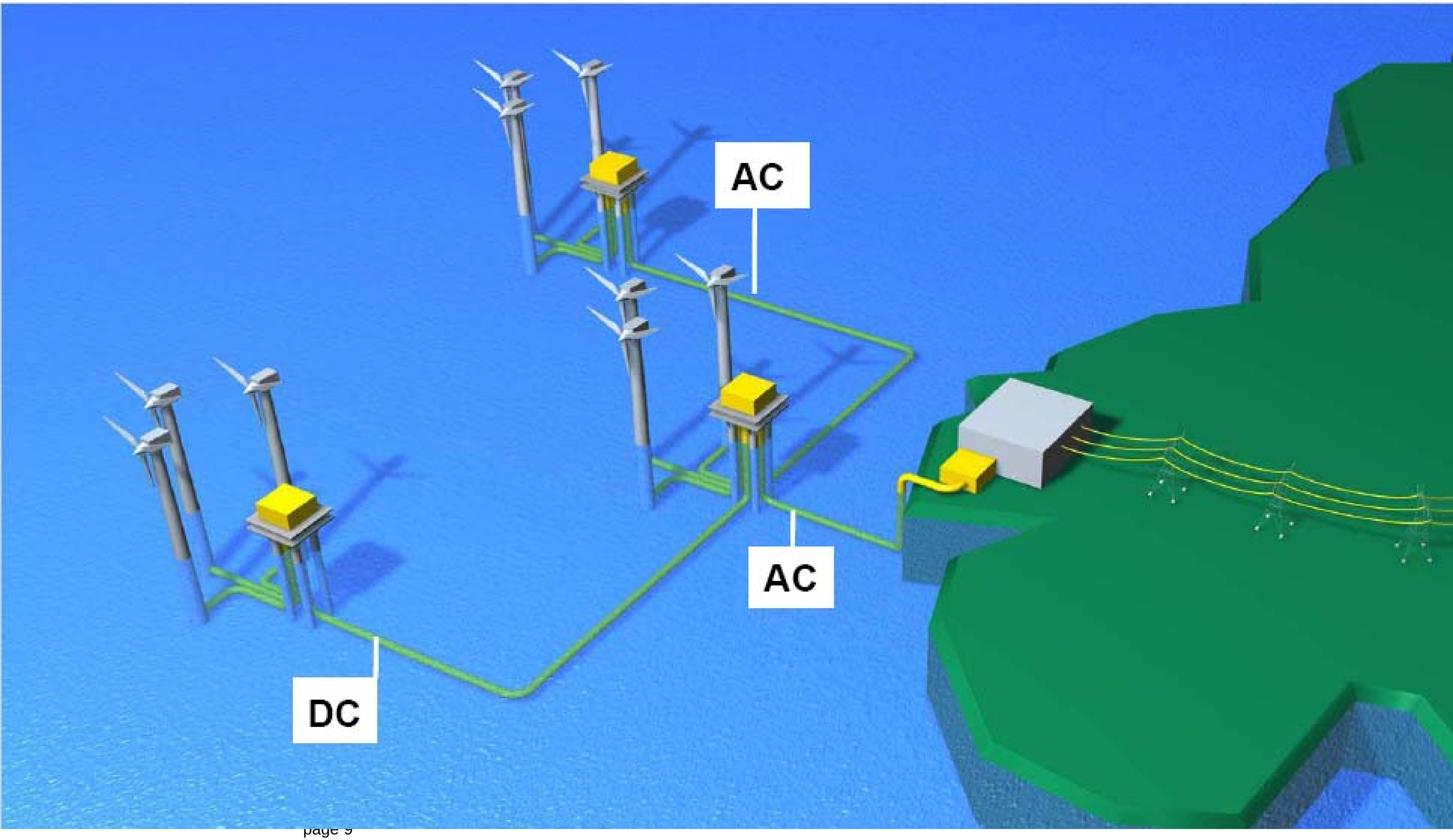
From	To
Central generation and central control	Distributed generation and distributed control
Load flow by Kirchoff's law	Load flow by power electronics
Manual switching, trouble response	Automatic, anticipatory response
Periodic maintenance	Prioritized condition-based predictive maintenance

Evolution to a Smart Grid

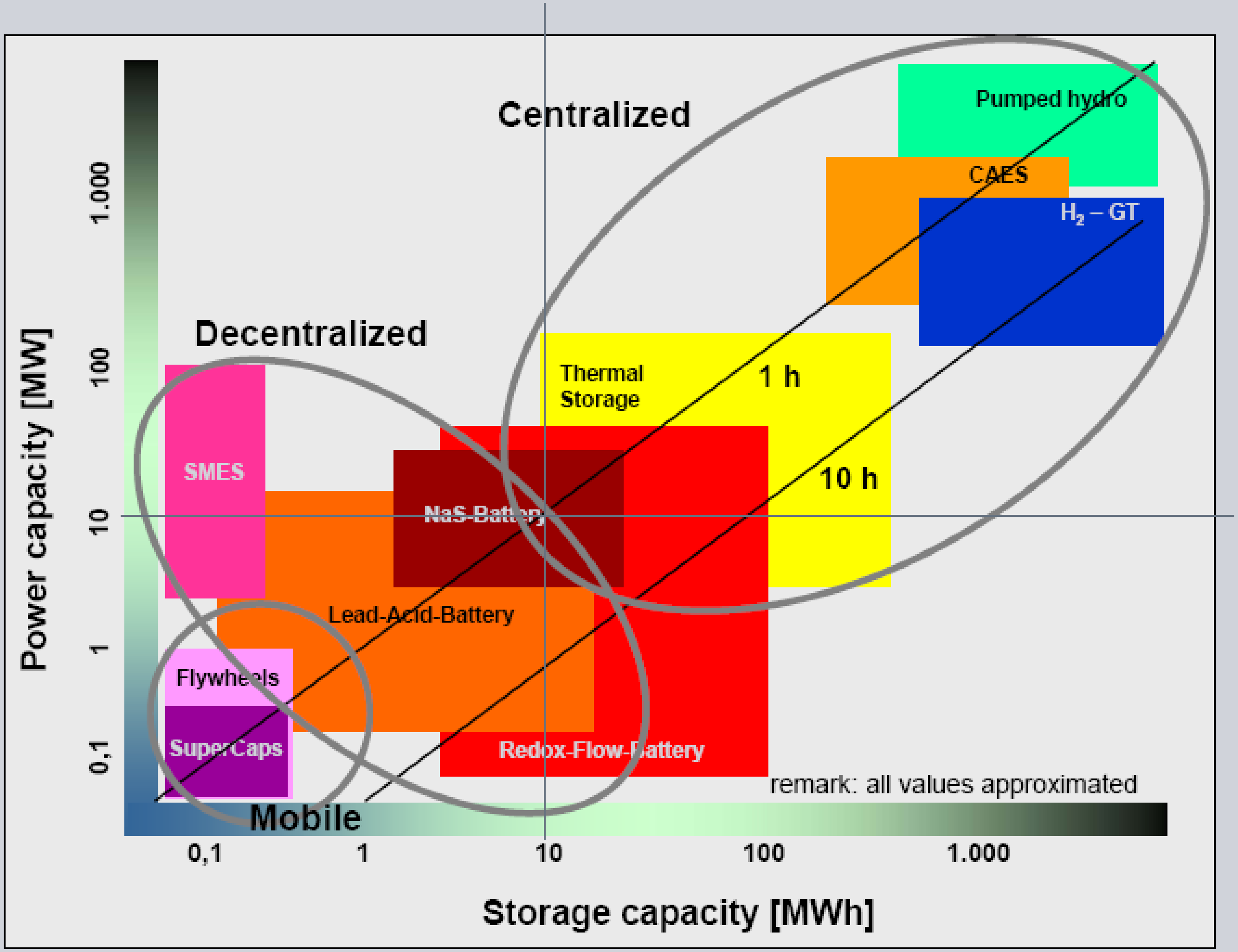
Central generation and central control → Distributed generation and distributed control



Evolution to a Smart Grid – penetration of renewables



Evolution to a Smart Grid – inclusion of energy storage



NaS-Sodium Sulphur

SMES-Super Conductive Magnetic Energy Storage

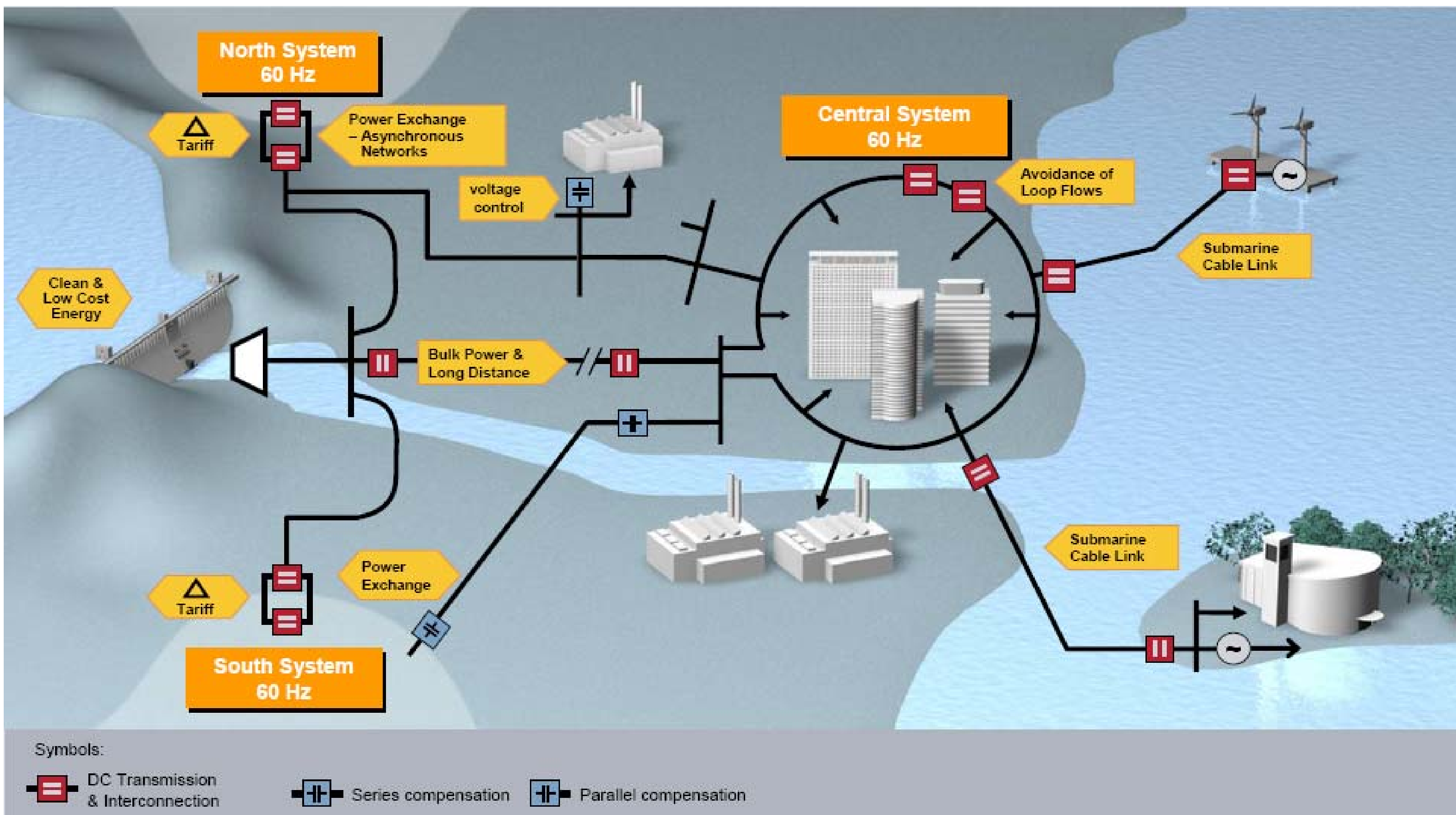
CAES-Compressed Air Energy Storage

SuperCaps-Super Capacitor

Primary Control:
Batteries, Flywheels, SMES

Evolution to a Smart Grid

Load flow by Kirchoff's law → Load flow by power electronics



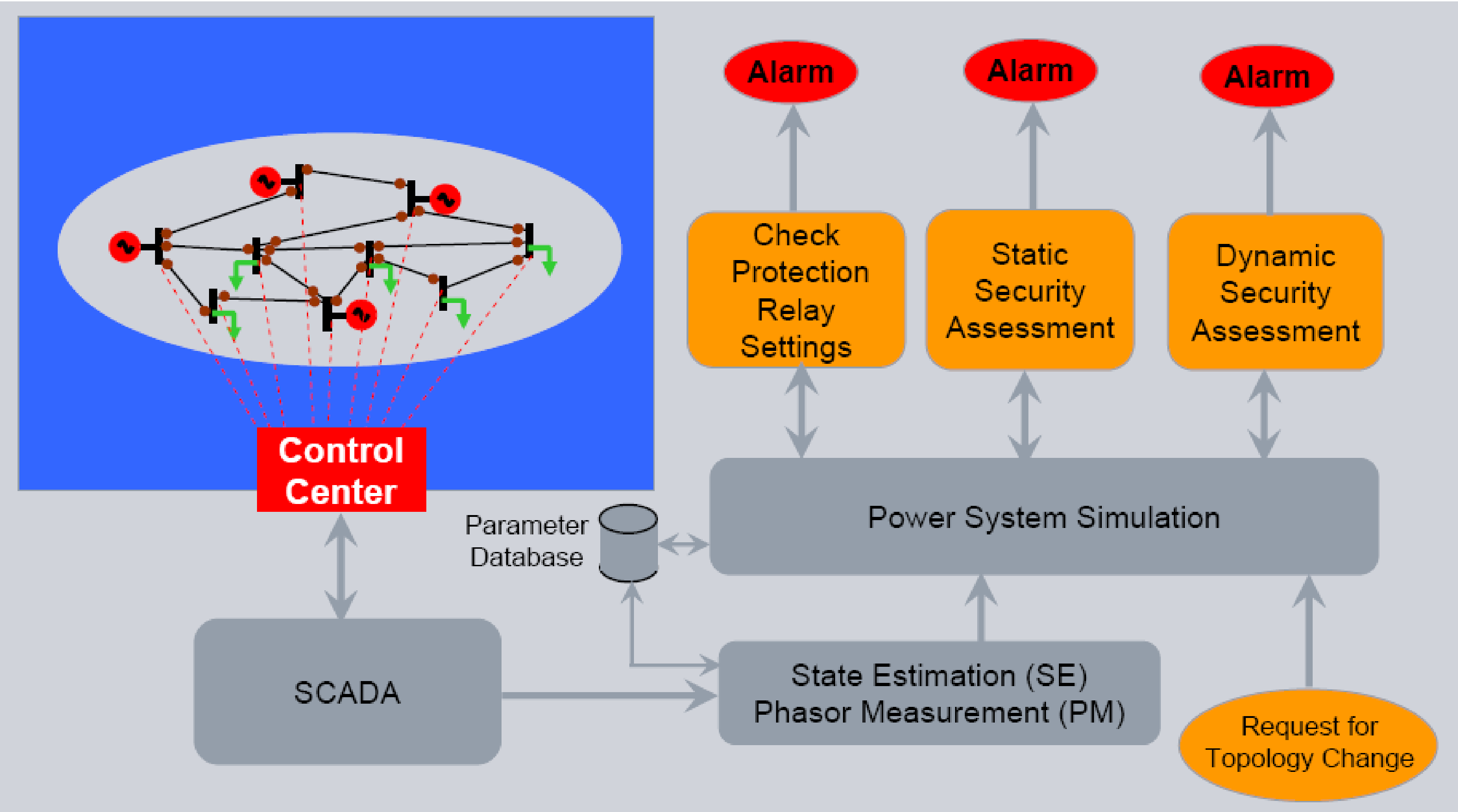
Project Neptune:

with HVDC into load centers

- 82 km sea cable
  23 km earth cable
- 660 MW monopolar
- Completion 07/2007

Evolution to a Smart Grid

Manual switching, trouble response → Automatic, anticipatory response

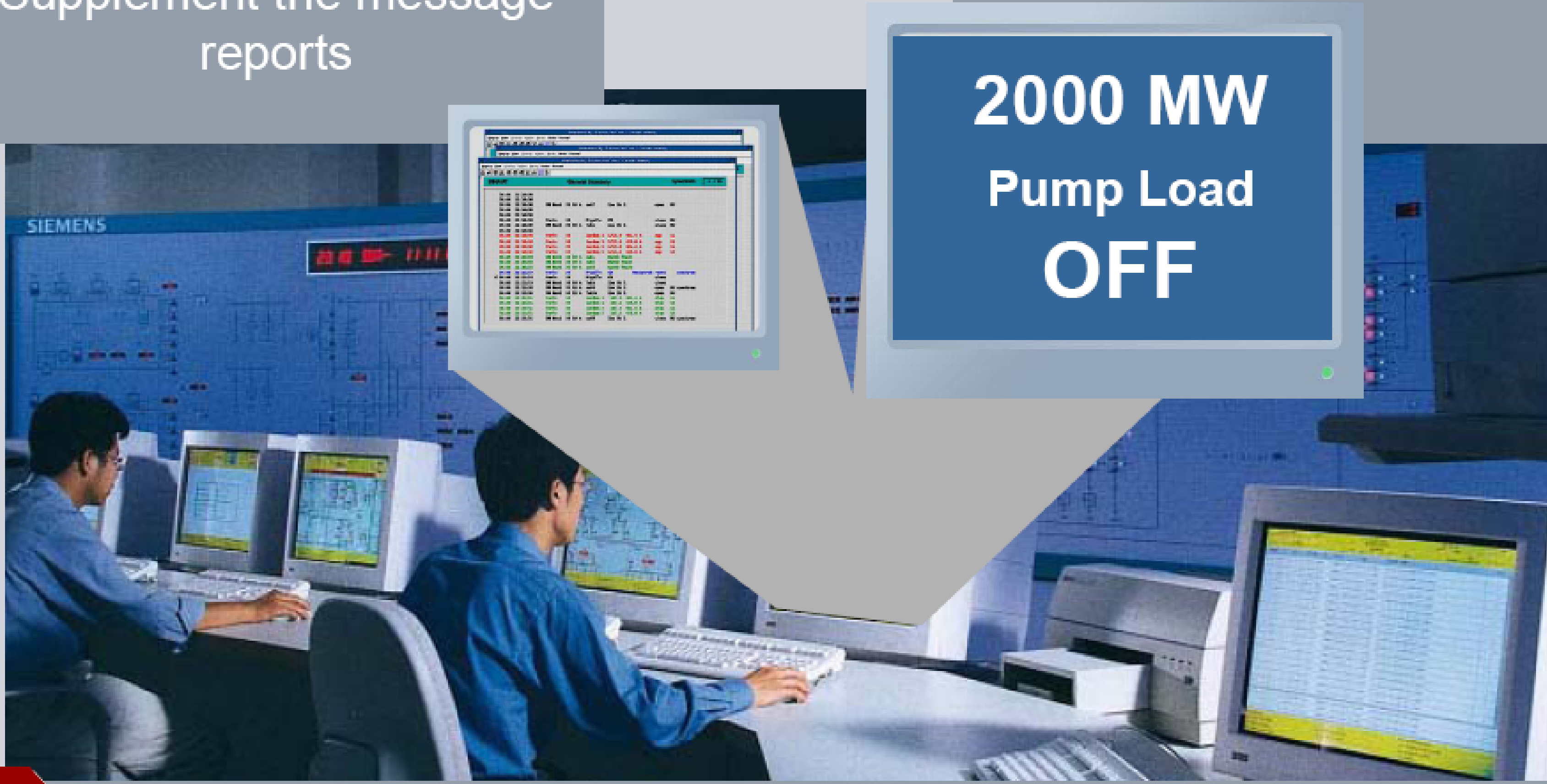


orporation

Evolution to a Smart Grid – built-in intelligence

Supplement the message reports

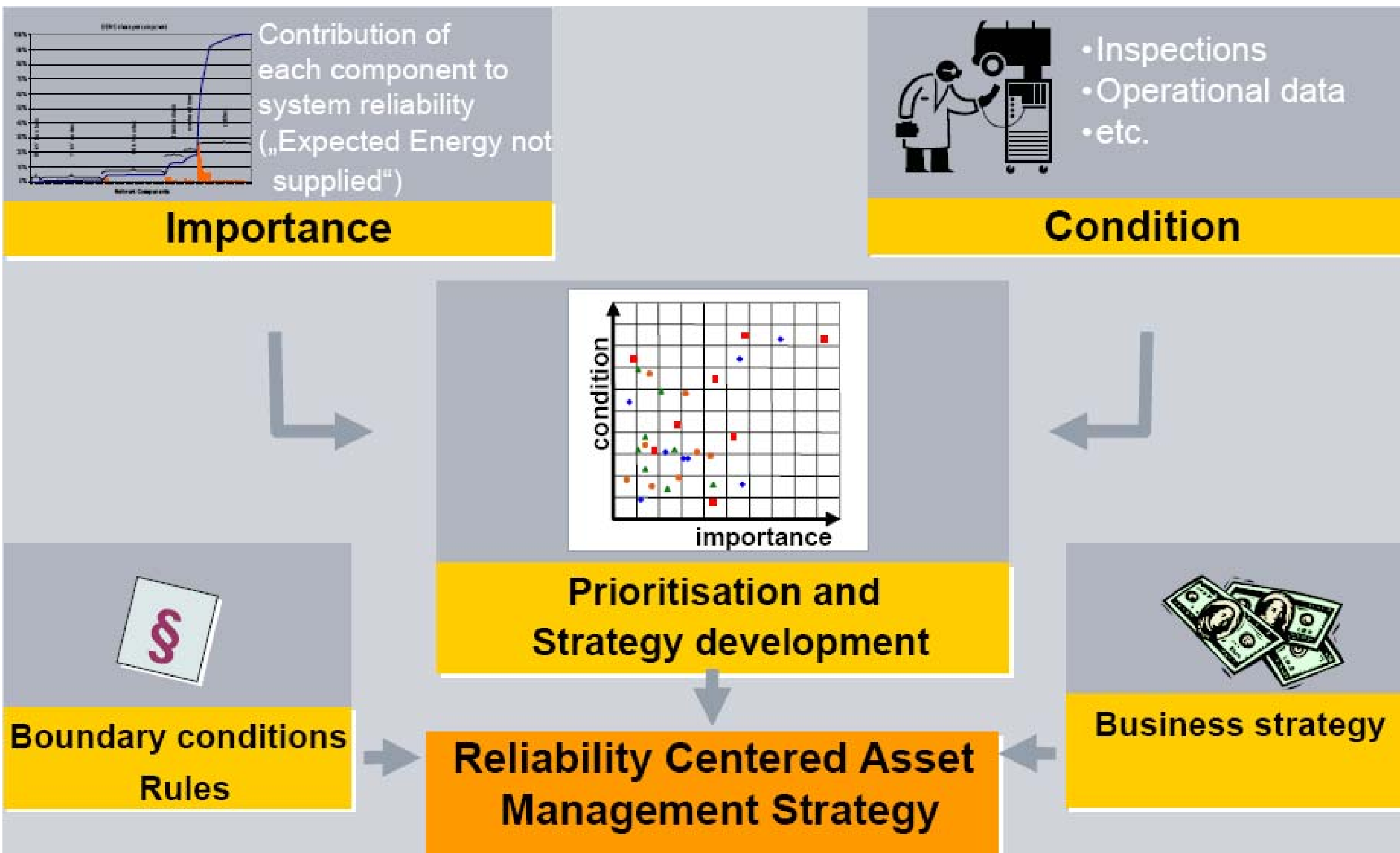
By clear decisions



The grid dispatcher has to decide within seconds….
Incorrect decisions or inactivity may lead to Blackouts.

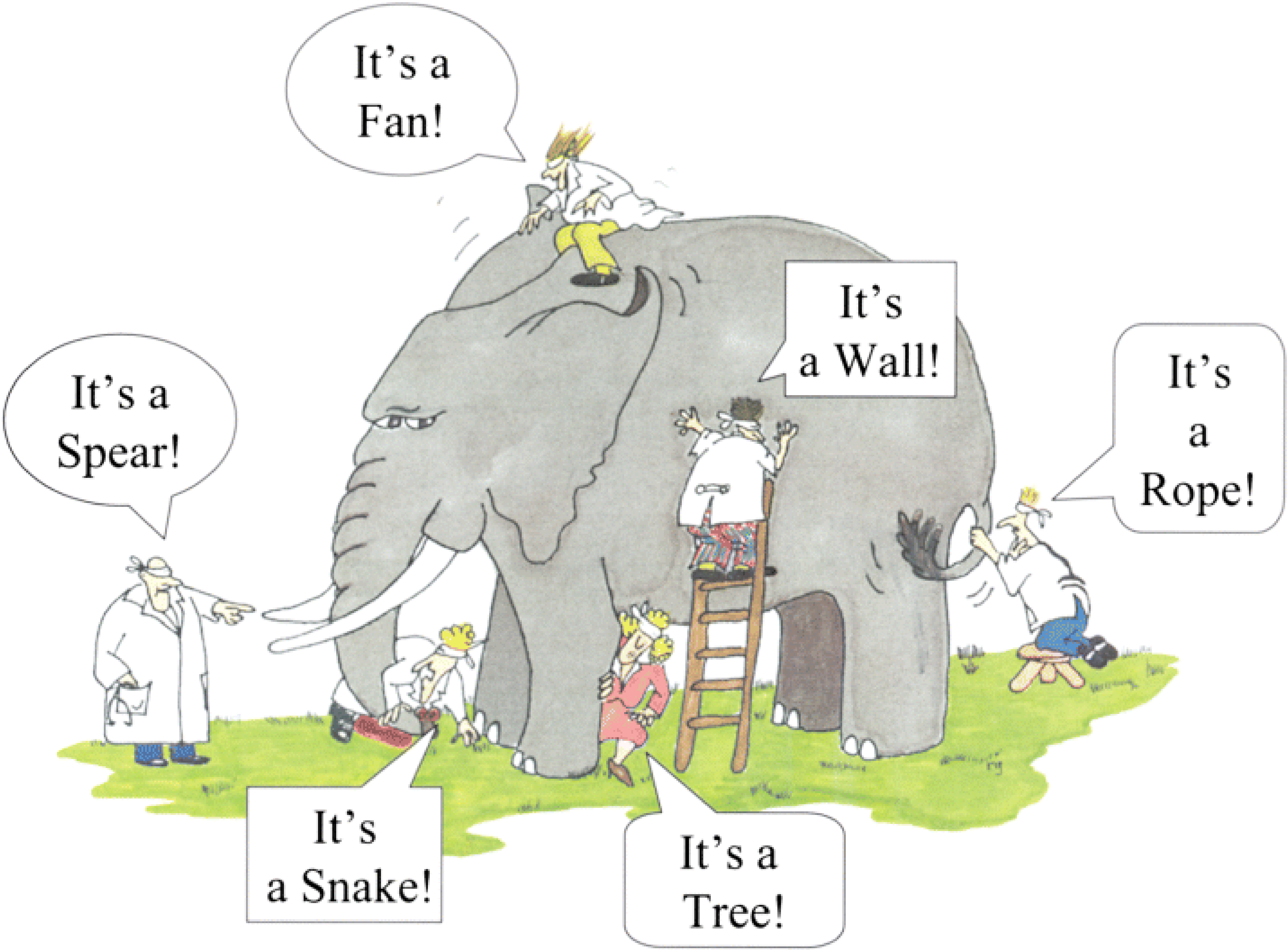
Evolution to a Smart Grid

Periodic maintenance → Prioritized condition-based predictive maintenance

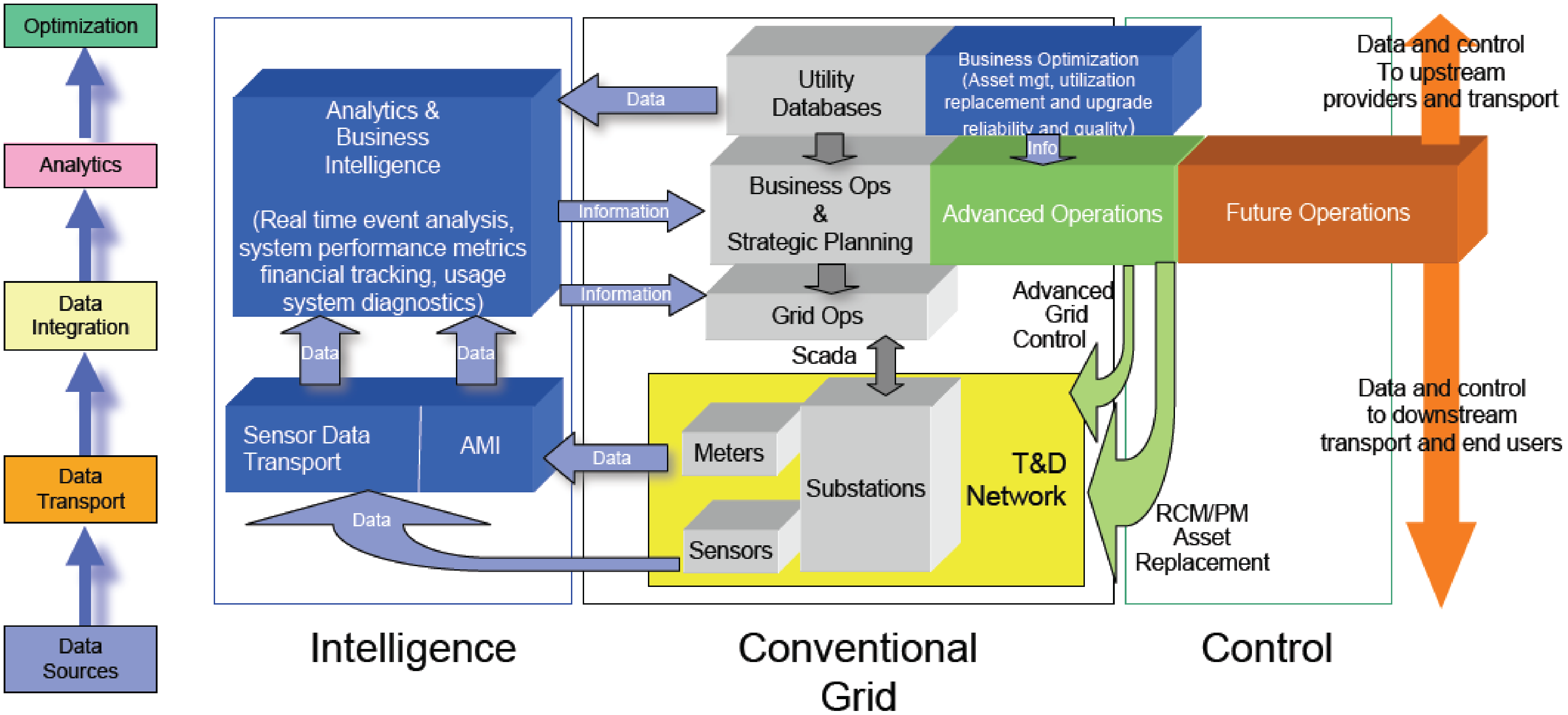


...so what is a Smart Grid???

SIEMENS



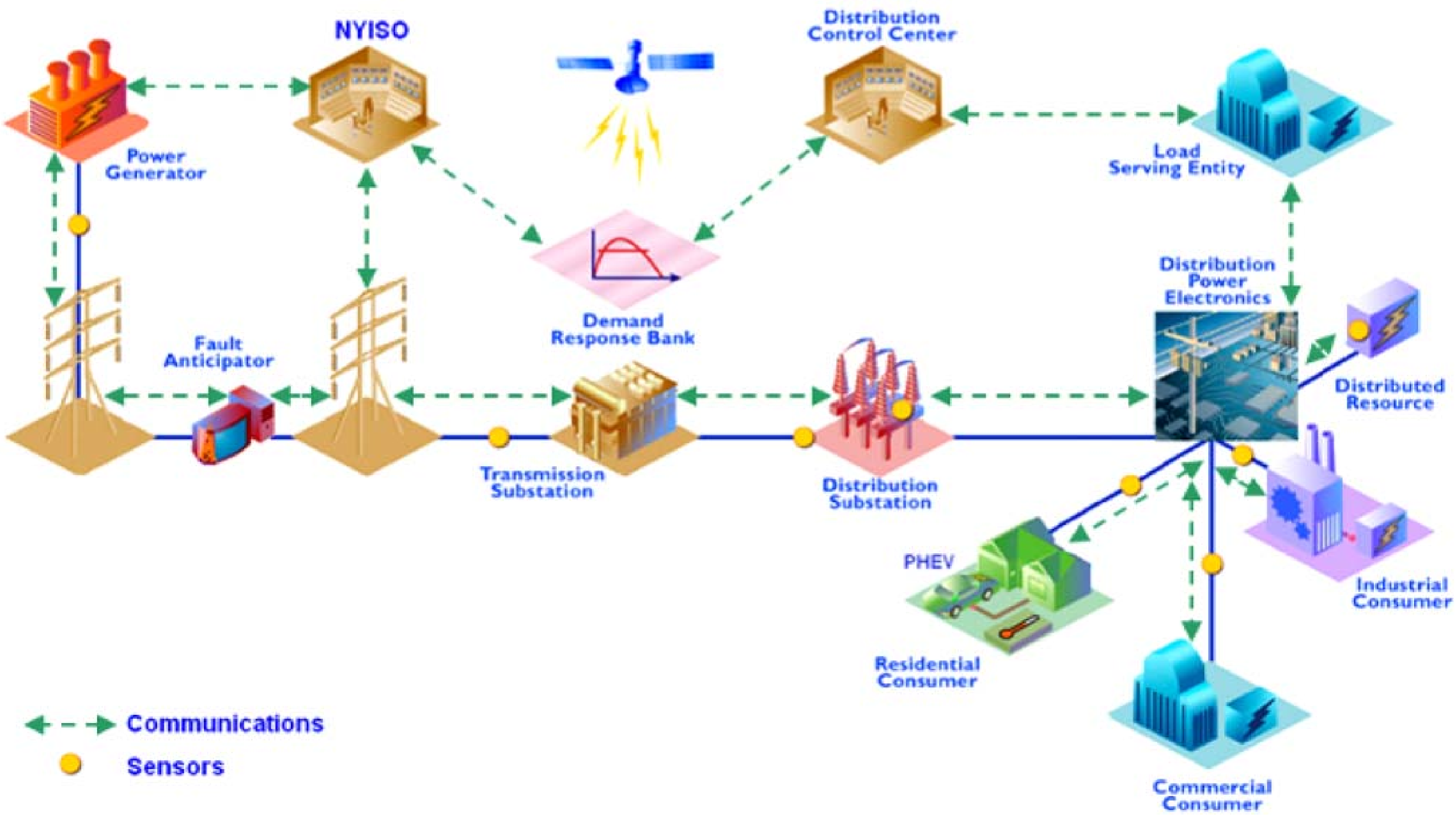
If one asks the SMART Grid - people...e.g. IBM



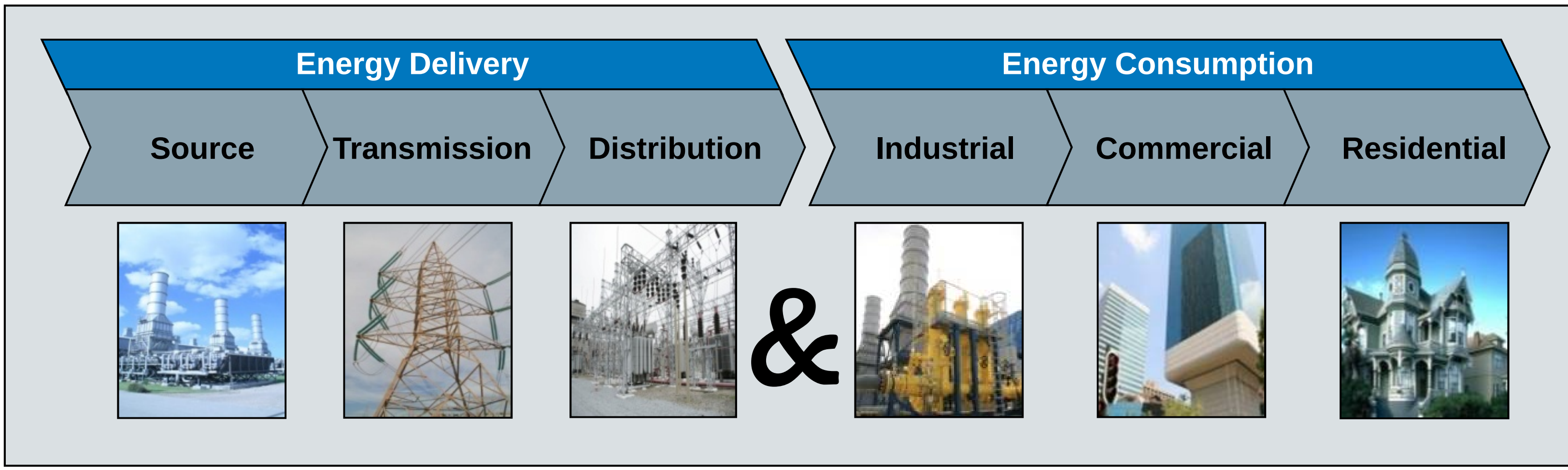
Corporate Research, Siemens Corporation

SIEMENS

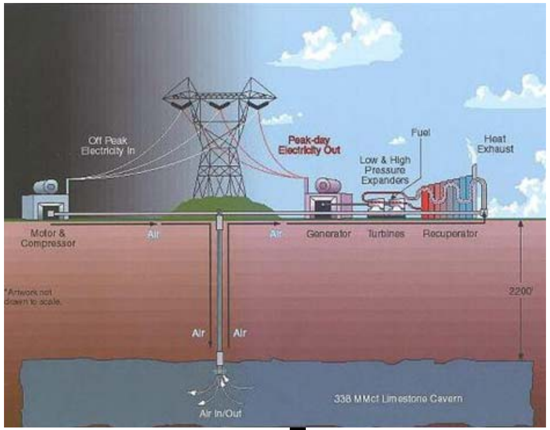
If one asks the Smart GRID - people...e.g. NYISO

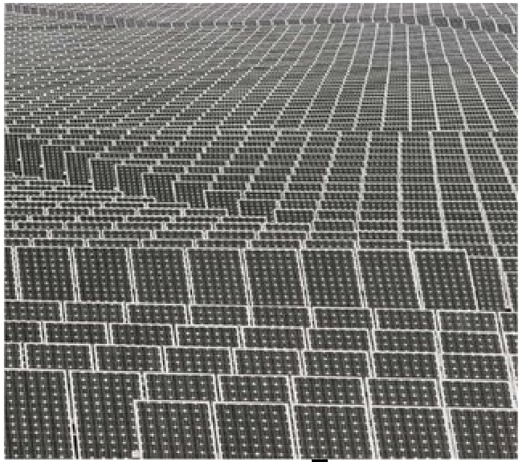


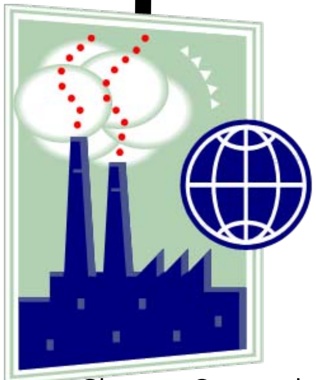
Scope of Smart Grid



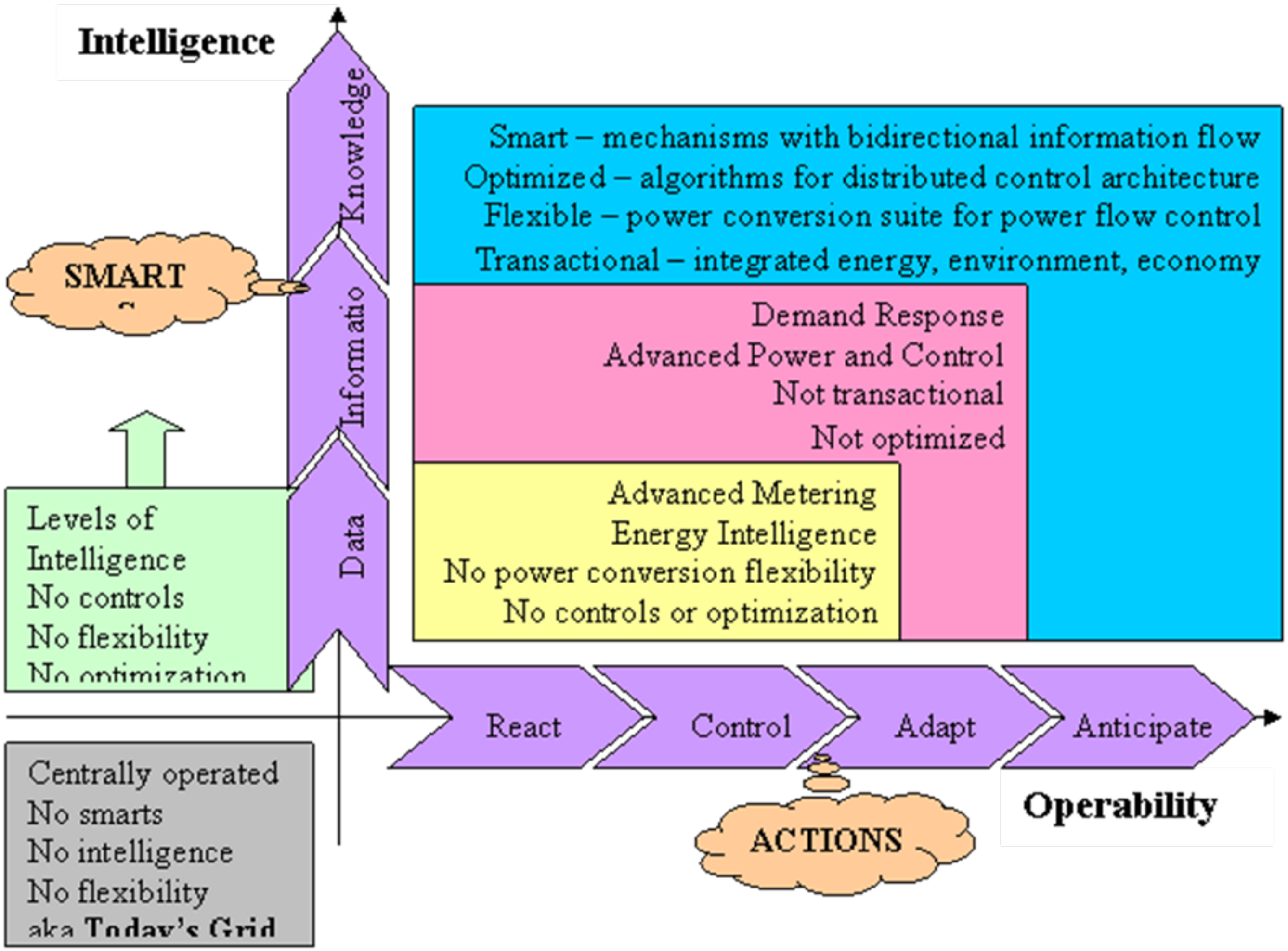
Smart Grid Portfolio



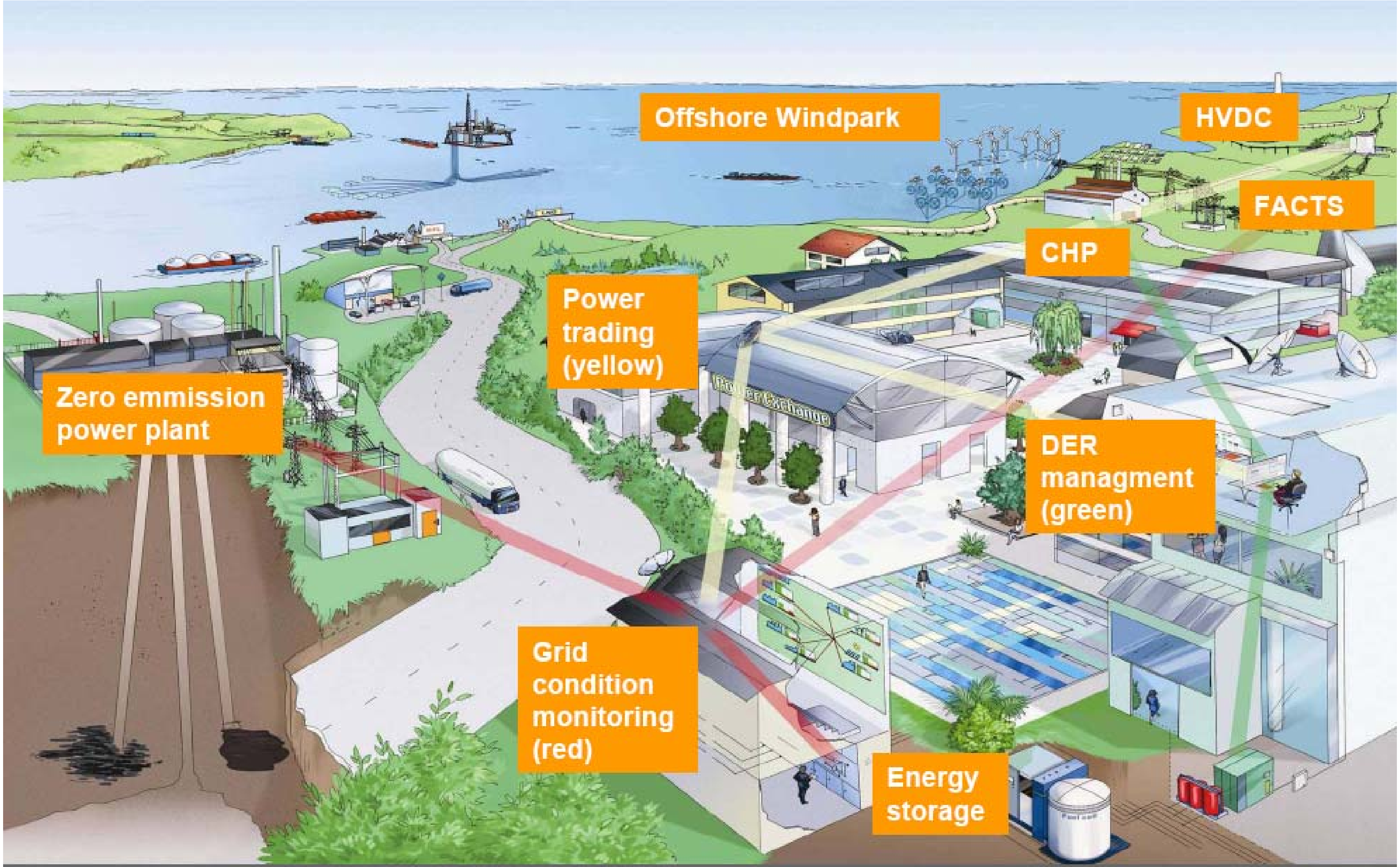




Intelligence v/s Operability



Picture of the Future



Green Energy and Power Systems

Thank you very much!

Name: Dr. Madhav D. Manjrekar

Organization: Corporate Research, Siemens

Address: 755, College Road East

Princeton, NJ 08540, USA

Phone: +1 (609) 734 – 6566

Mail: madhav.manjrekar@siemens.com

Le Tang

ABB

Le Tang, ABB Inc.

High MW Electronics – Industry Roadmap Meeting at NIST, Dec. 11, 2009

Smart Grid and Power Electronics - Why Do We Need High MW Electronics

Smart electricity – efficient power for a sustainable world

A smart grid is the evolved system

that manages the electricity demand

in a

sustainable, reliable and economic manner

built on

advanced infrastructure

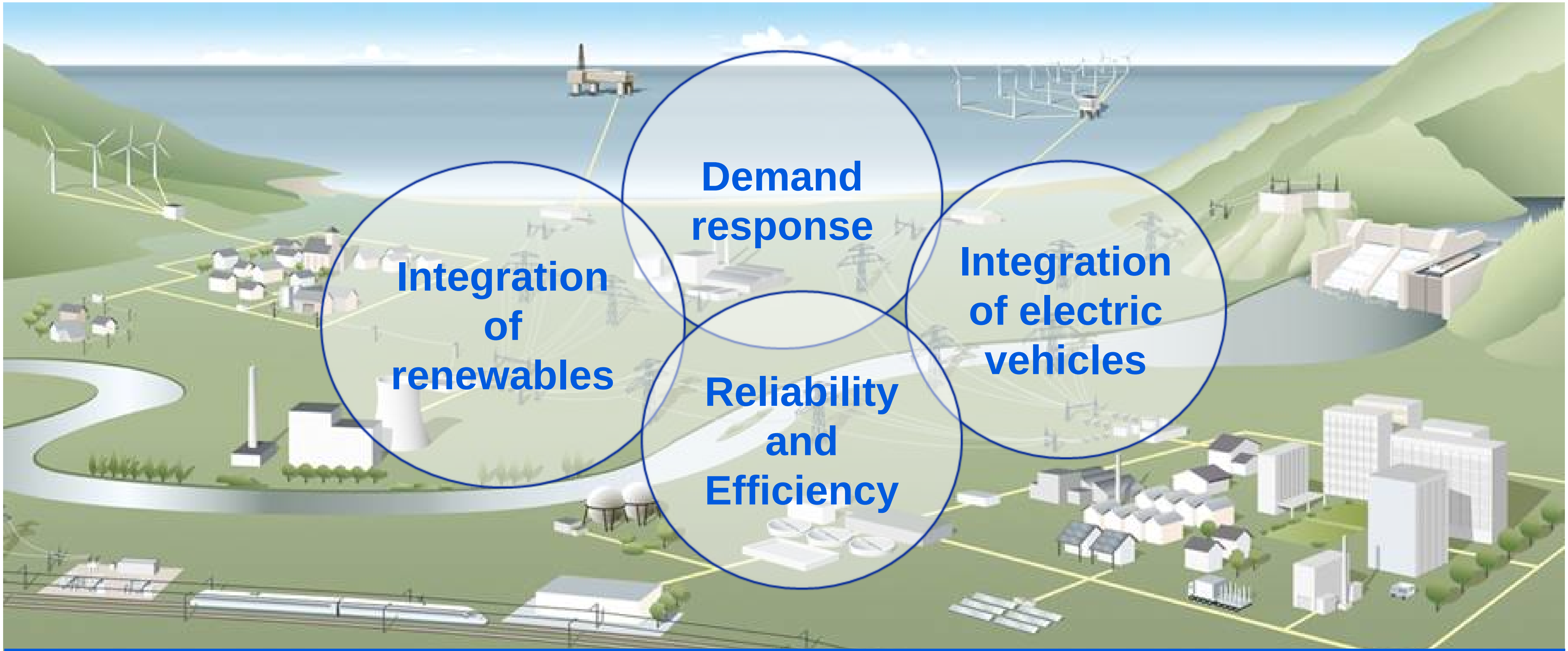
and tuned to facilitate

the integration of behavior of all involved

The visionary smart grid
Summing up the major requirements

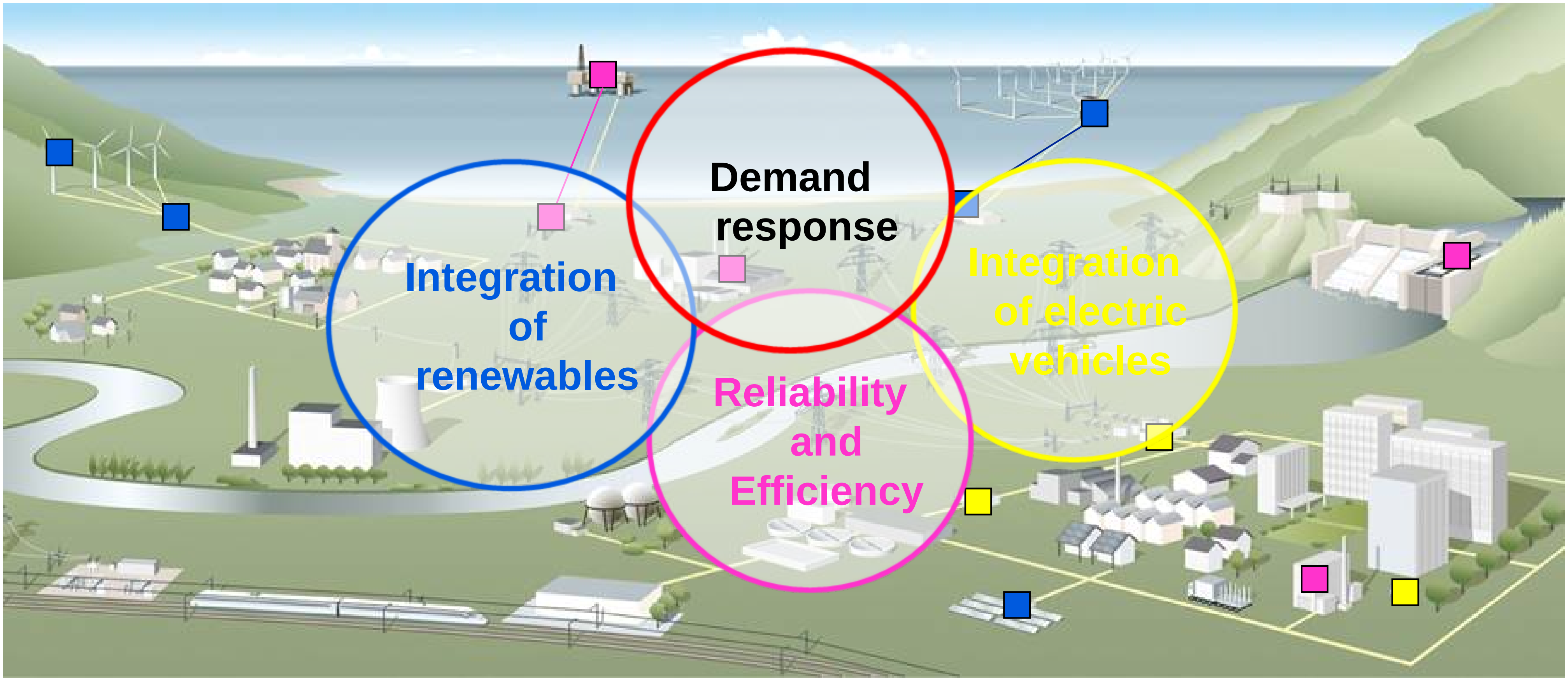
Capacity	Upgrade/install capacity economically Provide additional infrastructure (e-cars)
Reliability	Stabilize the system and avoid outages Provide high quality power all the time
Efficiency	Improve efficiency of power generation Reduce losses in transport and consumption
Sustainability	Connect renewable energy to the grid Manage intermittent generation

Smart Grid Requirements
Integration from supply to demand – 4 pillars



- **Smart Grid is more than only smart meters.**
- **Smart Grid includes both transmission and distribution.**
- **Smart Grid includes both automation/IT and power devices.**

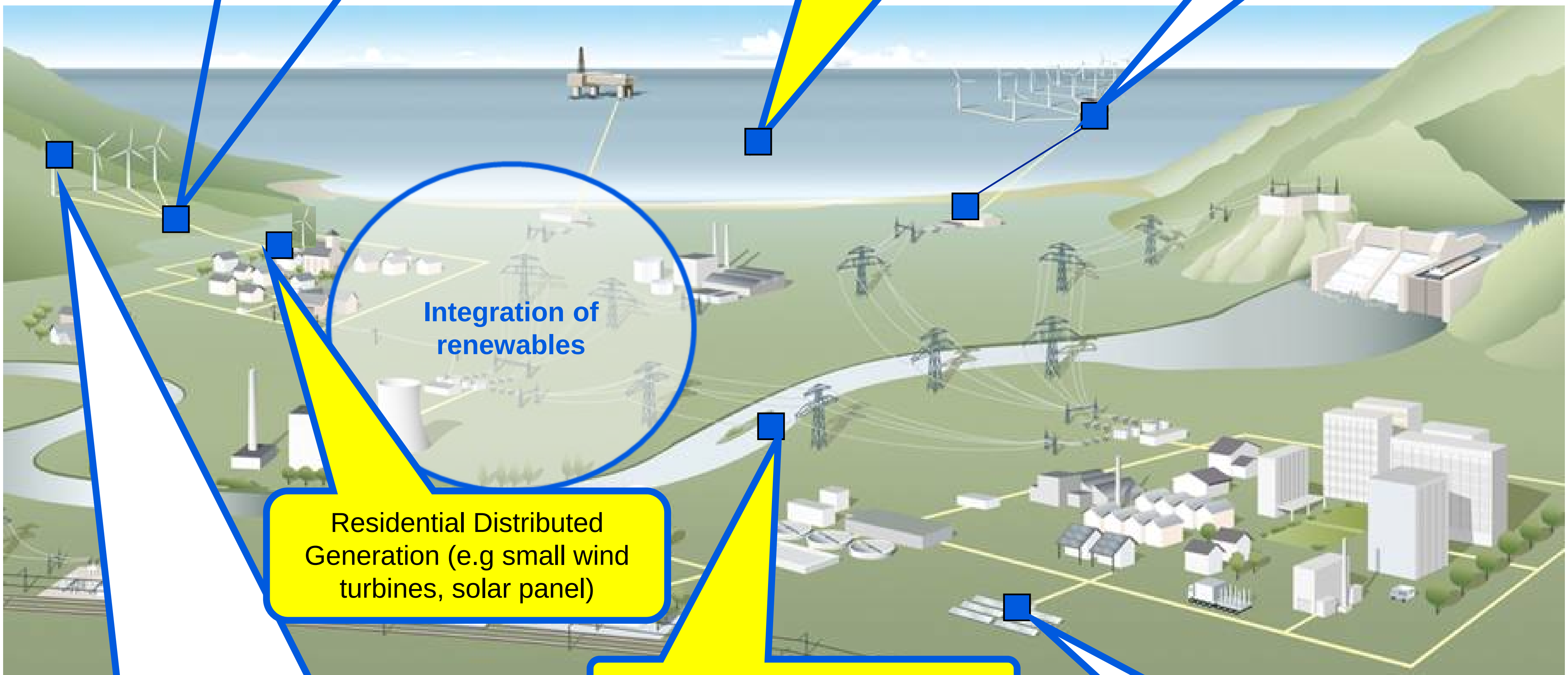
Power Electronics in Smart Grids
A key technology in at least 3 of the 4 pillars



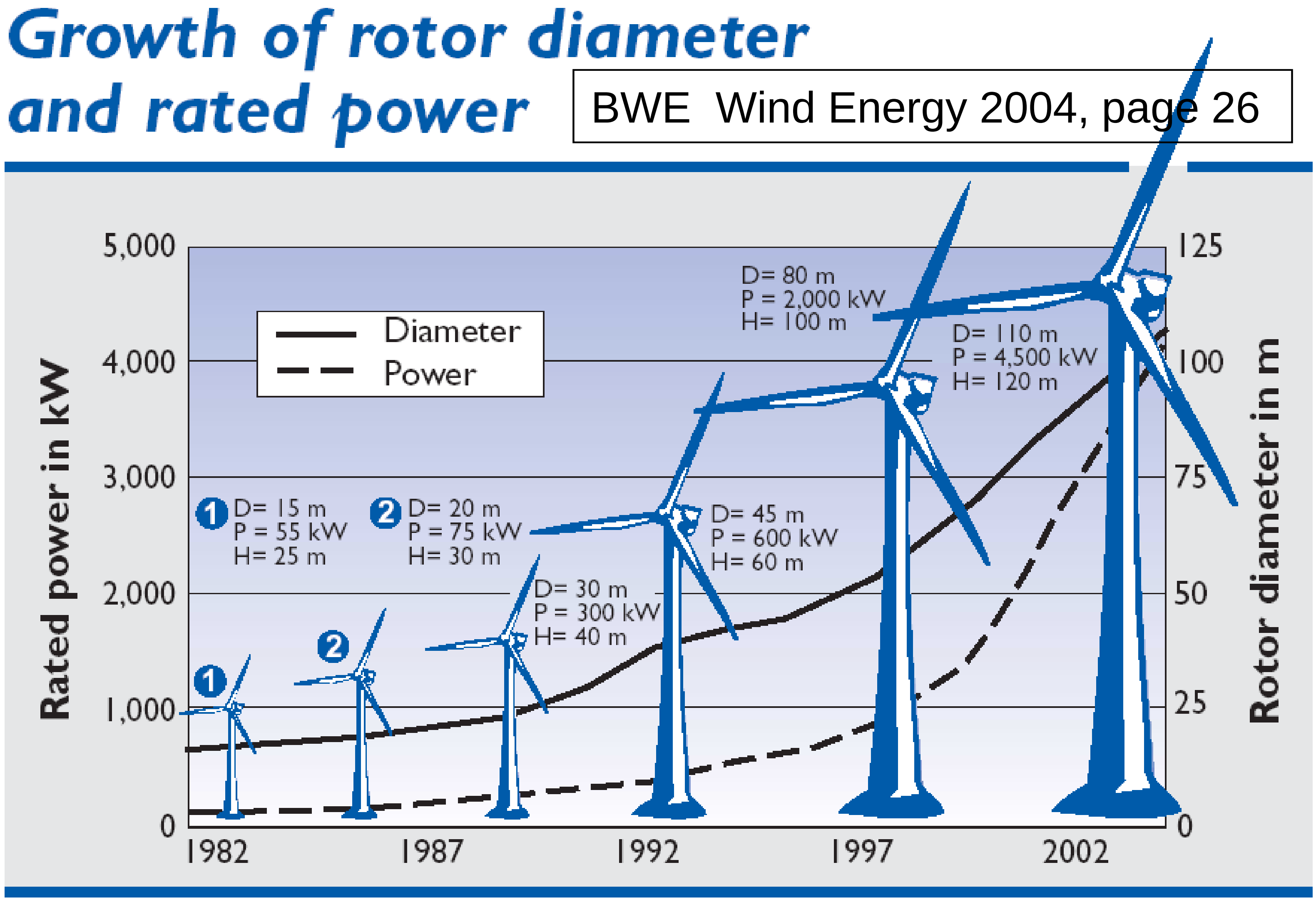
ABB

Power Electronics in Smart Grids

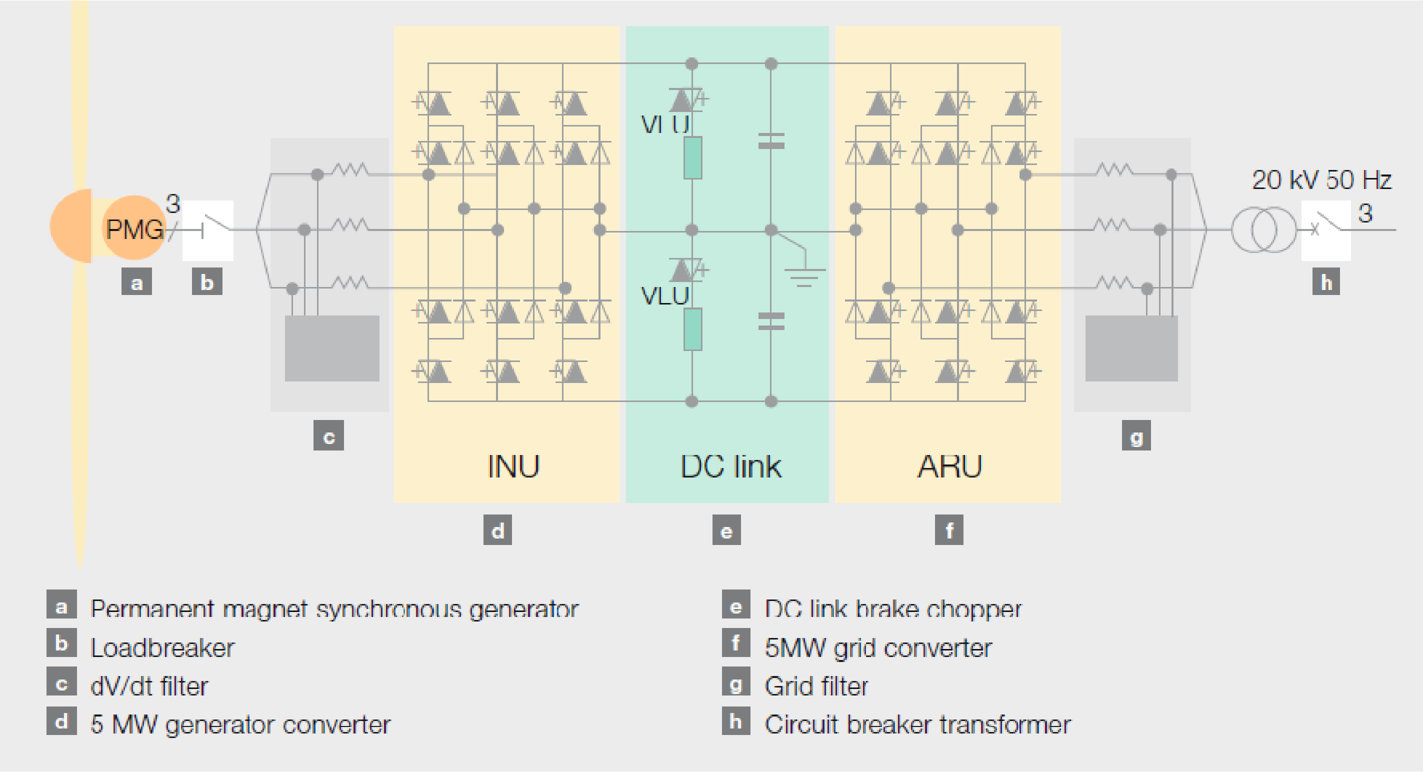
Integration of renewables



Wind turbine trends

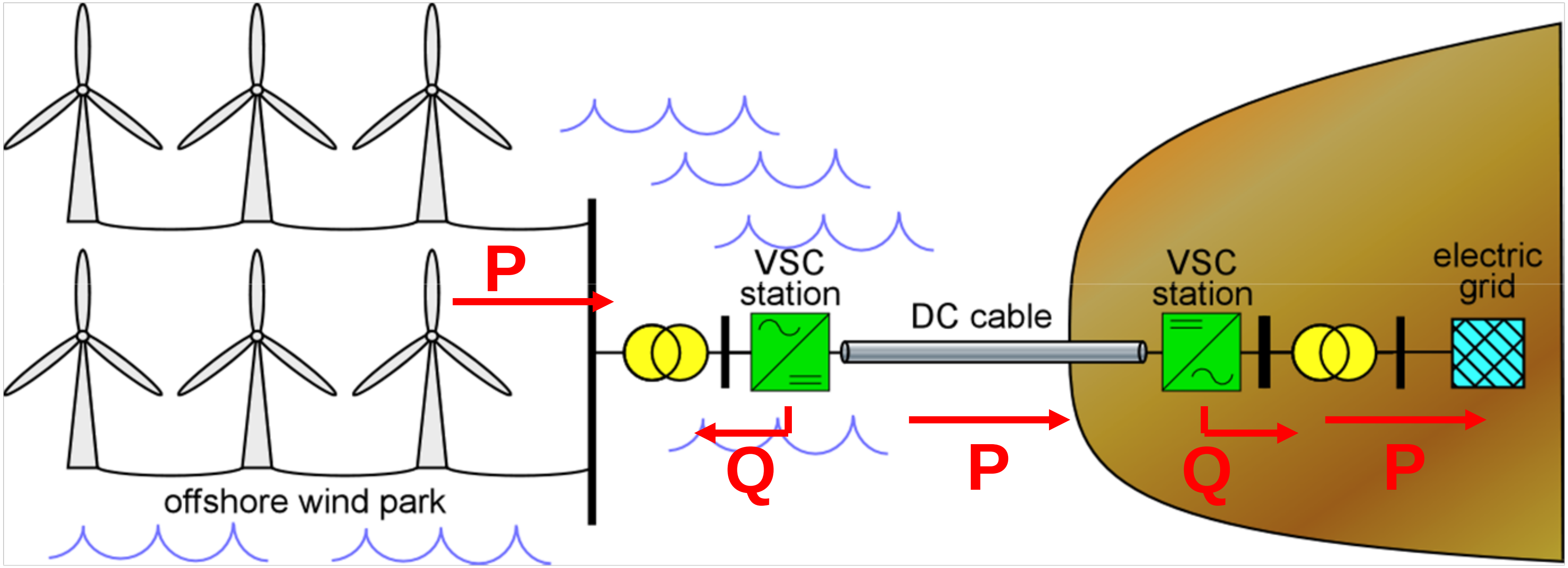


Wind Turbine Converters



- Fit inside the mast of the turbine
- Convert the generated power to the desired frequency and voltage
- Help support weak grid by supplying or absorbing reactive power

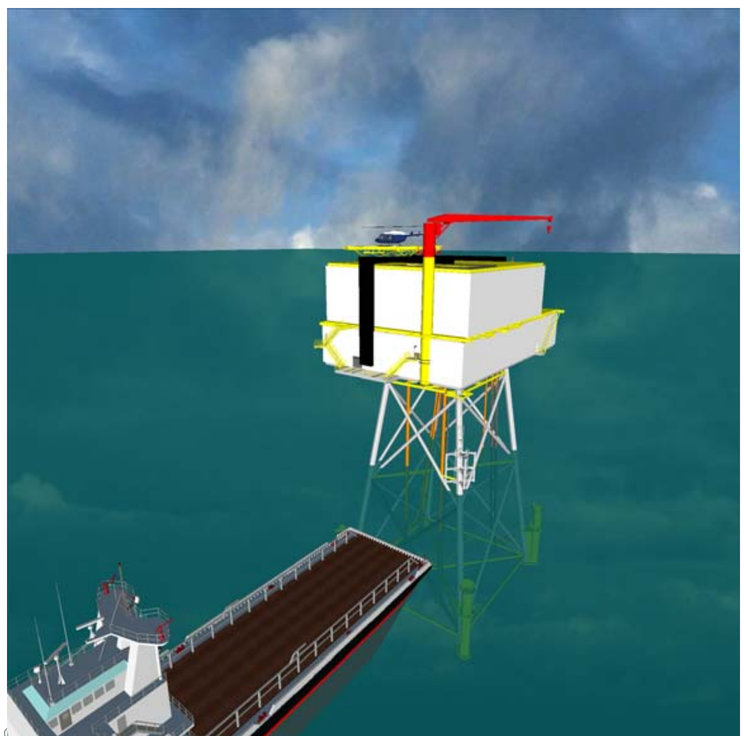
HVDC Light for Offshore Wind Park Connection (1)



- Transistor-based HVDC
- No compensation needed as reactive power is produced by the converter stations
- Can be connected to weak grids

NORD E.ON 1, 400MW off-shore windpark connection

NORD E.ON 1



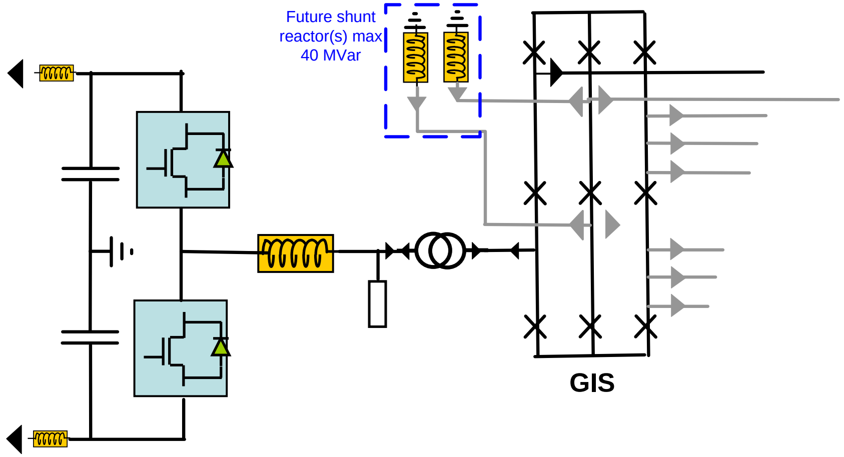
Customer

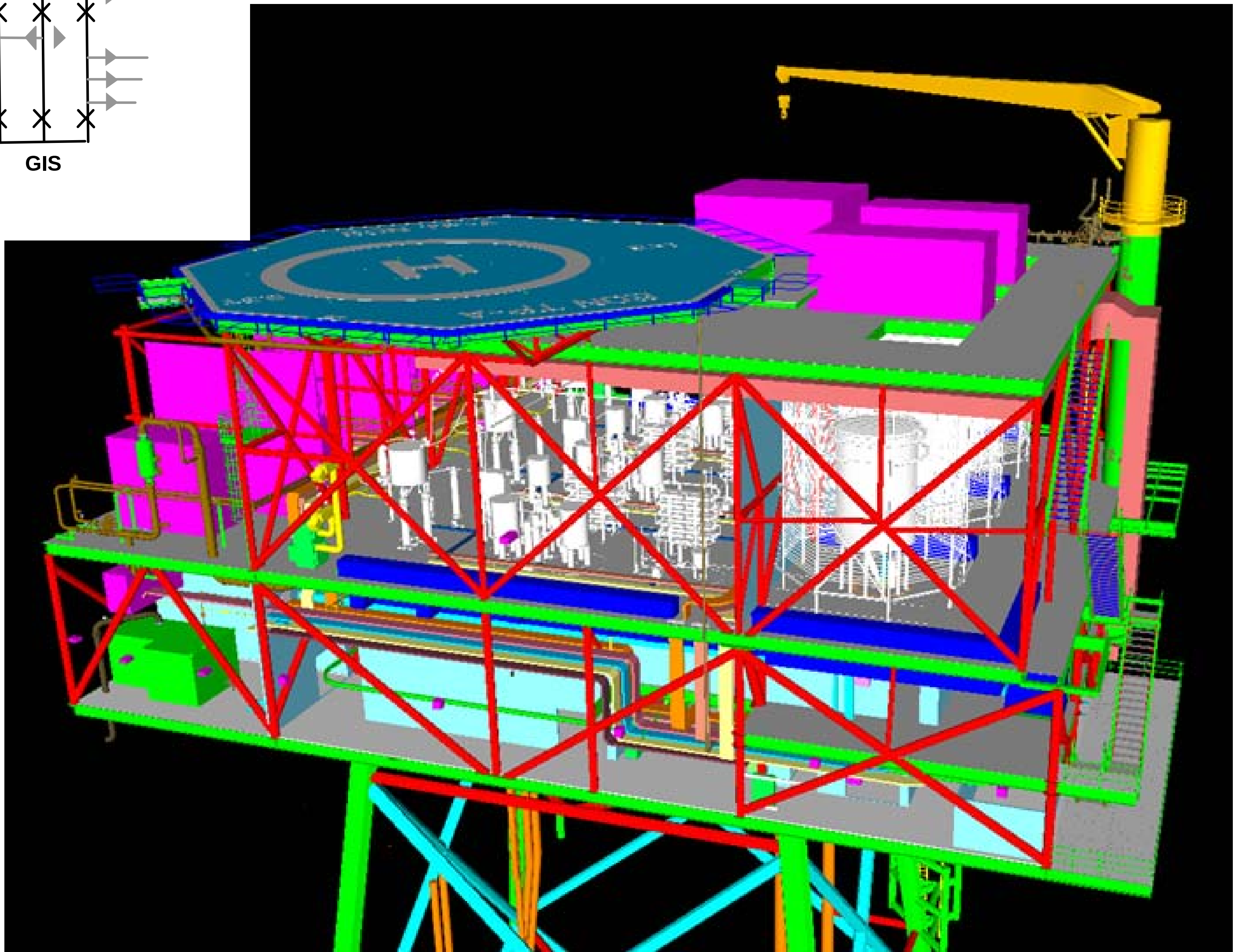
- E.ON Netz GmbH, Germany

Scope

- **400 MW HVDC Light System**
  - Two HVDC Light converter stations
  - DC Cable system
    - DC cable submarine to onshore connection (2x128km)
    - DC cable on land (2x75km)
    - 200 MW Submarine AC cable 170kV (1x1200 m)
    - Fiber optic cable (203 km)
- **170 kV GIS on platform**
- **Offshore platform structure** - jacket and topside
- … **and all Auxiliary Systems** needed to operate and maintain the Offshore station.
  - Sea Water System, HVAC, Dieselgenerators, Fire Protection, etc

Layout platform

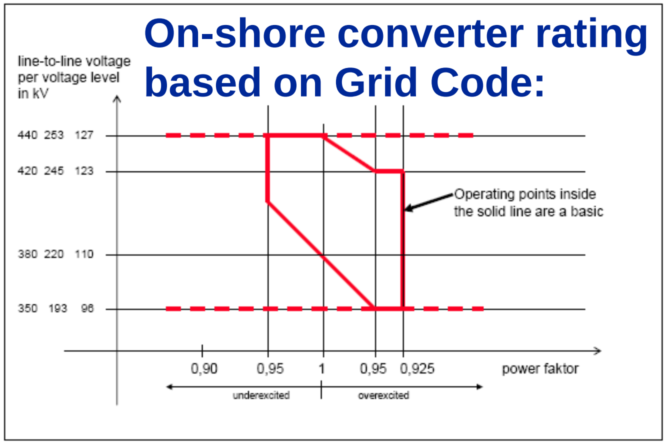




Overview, 400 MW HVDC Light System

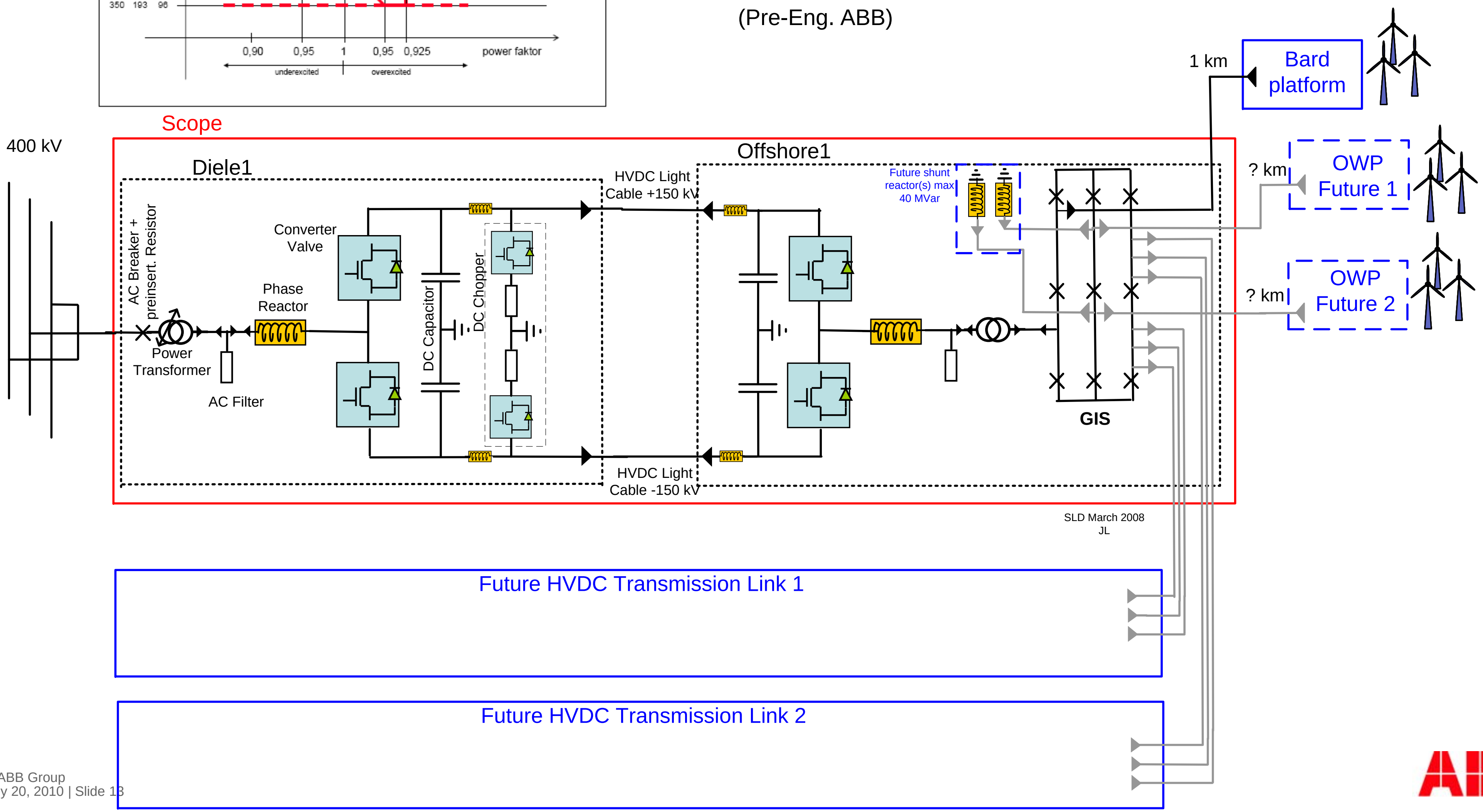
Nord

E.ON 1



Offshore rating conditions

- No tap-changer
- Wind park Q
- Cable grid Q
- Fault ride through
- Future scenarios (Pre-Eng. ABB)



Integrating renewable power
Intermittent power generation

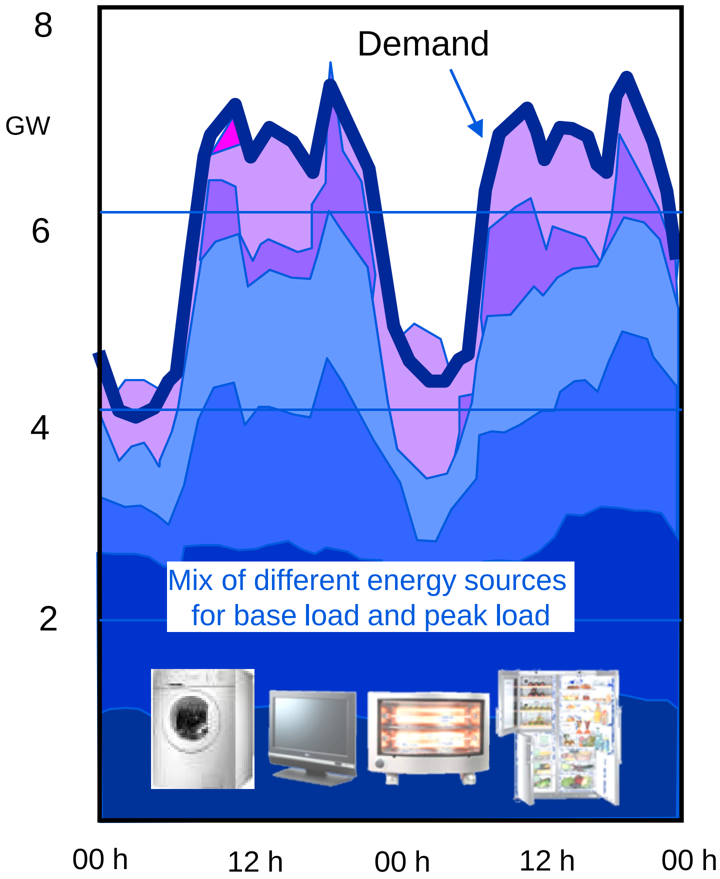
- Capacity
- Reliability
- Efficiency
- **Sustainability**

- Electricity from wind and solar plants is intermittent
- Spinning reserves between 5 and 18 percent of installed wind energy are required[1]
- Plant interconnections and a wide range of storage technologies could reduce the need for reserves

[1] Wind impact on power system, Bremen 2009

The future electrical system must be able to cope with these challenges

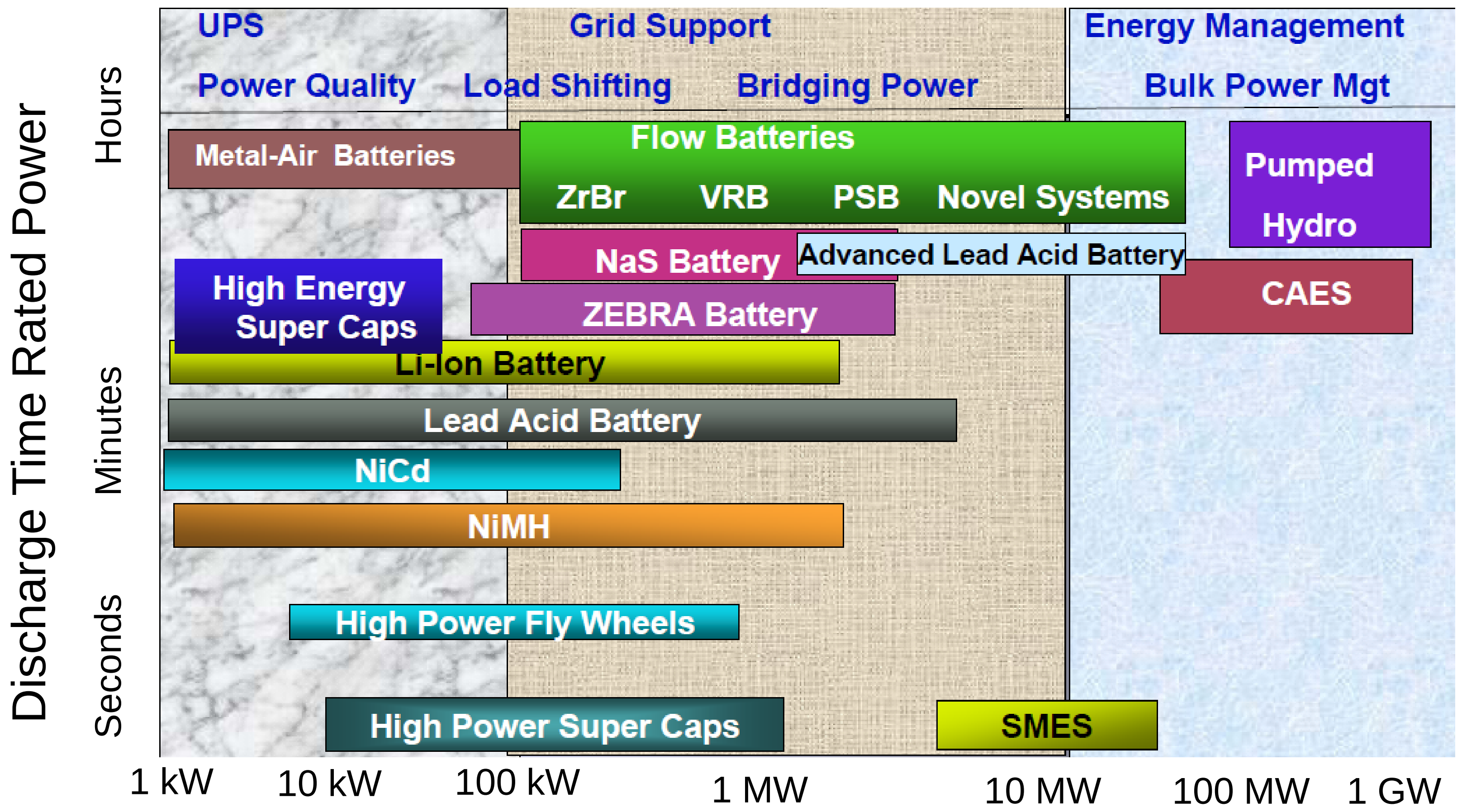
Optimizing supply and demand
Adjusting the energy mix



- Power consumption varies over the year and during the day and night
- To satisfy demand all the time reserve capacity is required. For environmental reasons reserves should be minimal.
- The challenge of reliability grows with more intermittent renewable energy
- A wide range of electrical storage technologies could mitigate the problem

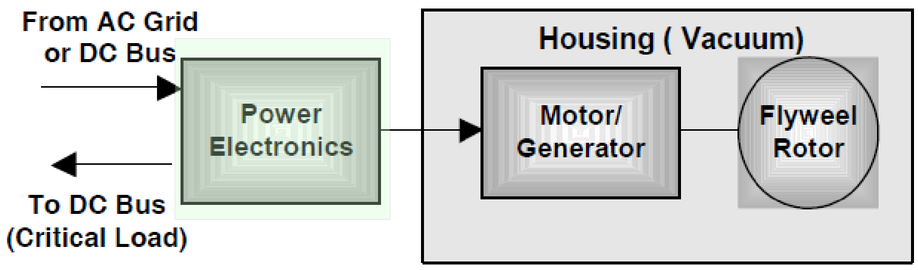
The future electrical system must provide optimal solutions

Energy Storage - Options

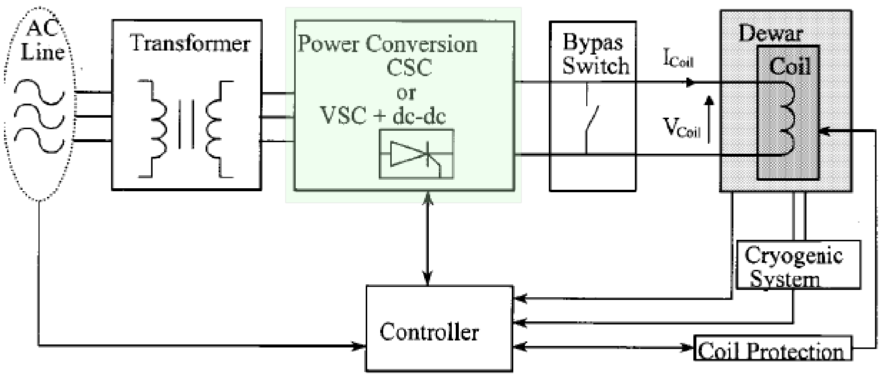


- **Ref.:EPRI, "Overview of Electric Energy Storage Options for the Electric Enterprise**

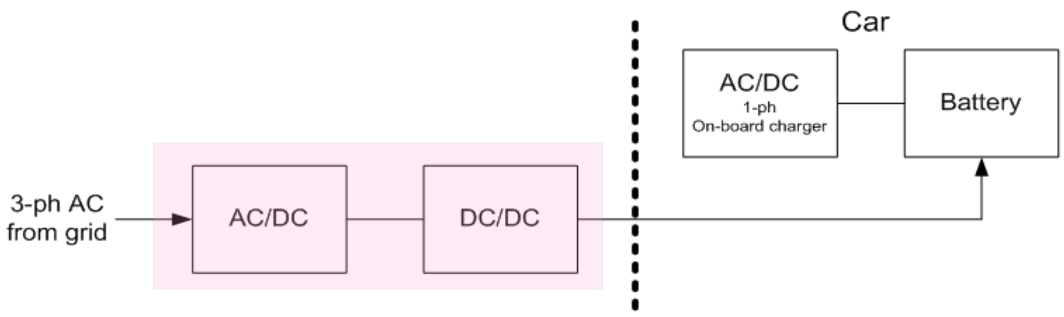
Power Electronics in Energy Storage – Examples



Simplified view of a flywheel energy storage system



Components of a typical SMES system

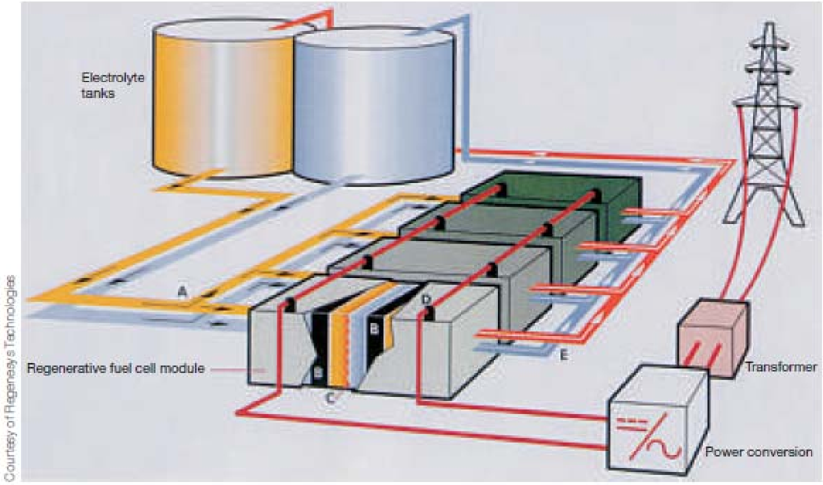


Fast charging system for a car battery

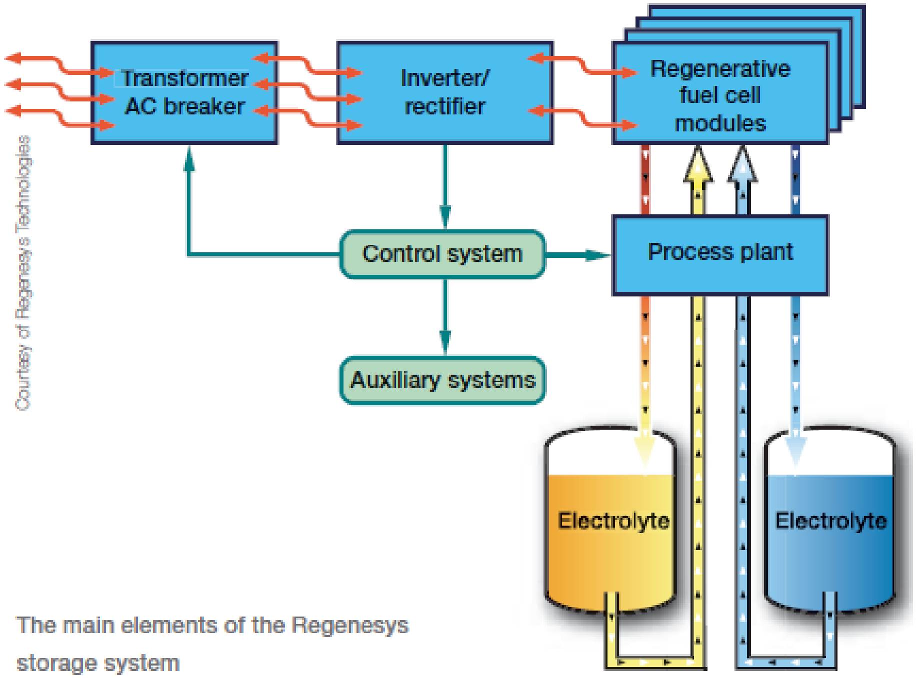
Ref:

- PAULO F. RIBEIRO, BRIAN K. JOHNSON, MARIESA L. CROW, AYSEN ARSOY, “Energy Storage Systems for Advanced Power Applications”
- Edward Furlong, Marco Piemontesi, Prasad P, Sukumar De, “Advances in energy storage techniques for critical power systems”.

Power Electronics in Energy Storage – Regensys Battery Energy Storage System (BESS)



System view of Regensys BESS plant



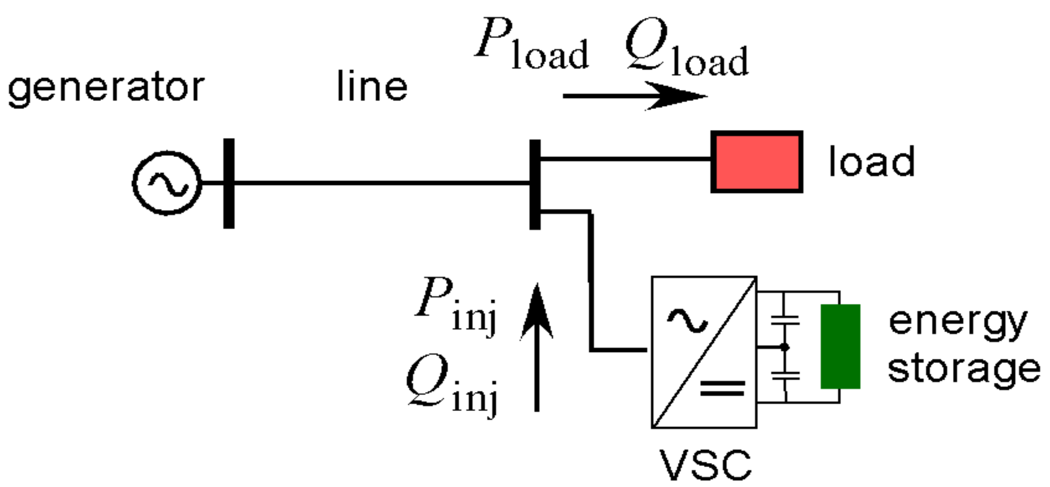
Main elements of the Regenesys system

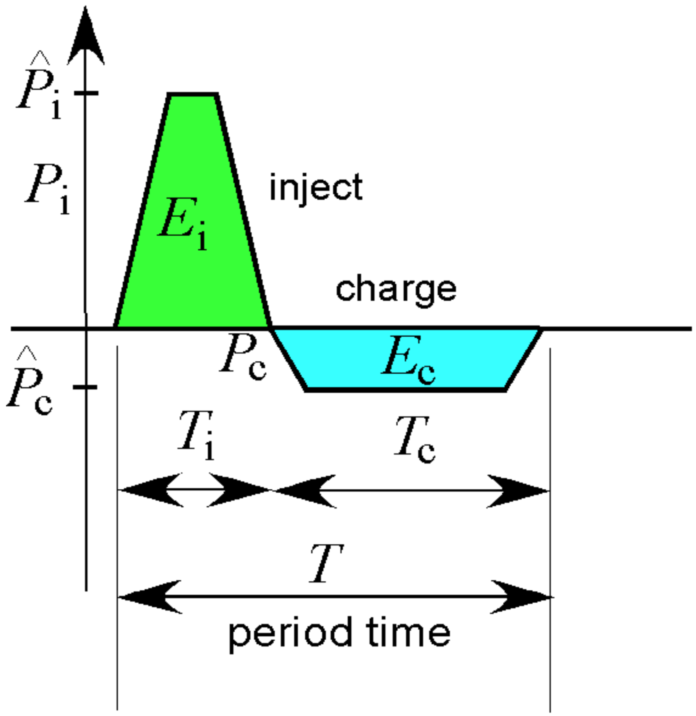
Storage
Project example: Battery Energy Storage for GVEA

Golden Valley Electric Association BESS Project

- **40 MW Rating**
- **10 MWH Battery Capacity**

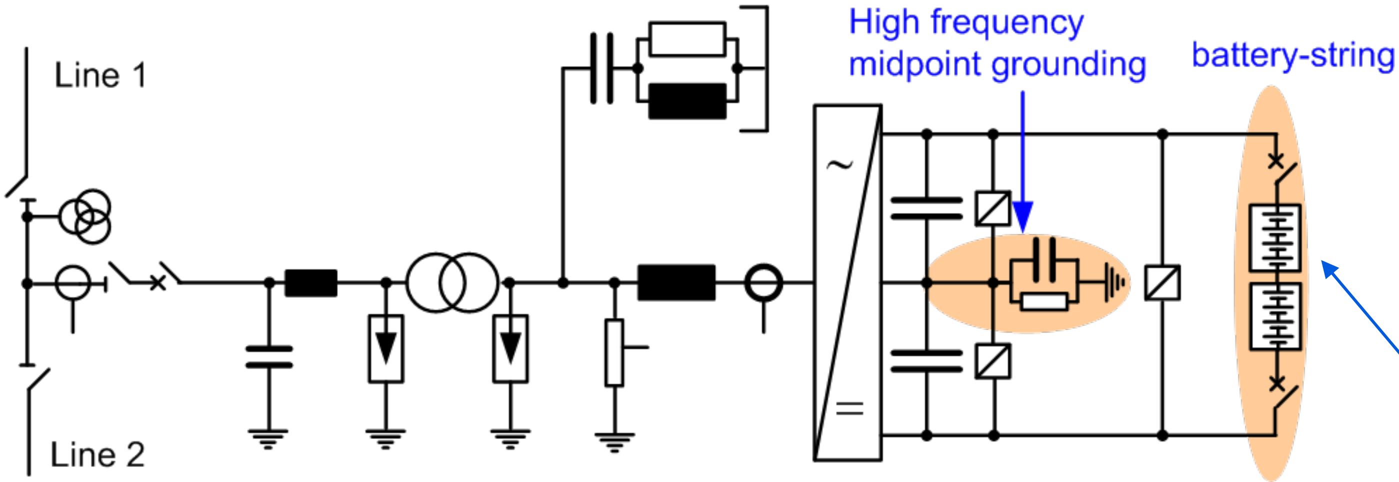
ABB FACTS: Dynamic Energy Storage





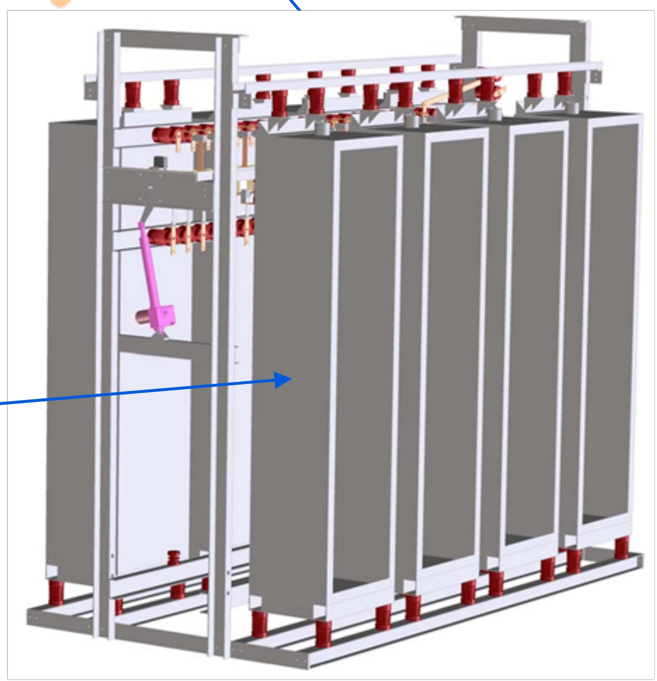
- Energy storage connected on DC-side of converter (SVC Light)
- Size depends on power level and duration
- Charge energy equal to load energy
- Focus on “dynamic”, manages:
  - High number charge and discharge cycles
  - High Power at medium duration
- Chosen high performance battery as energy storage

Storage
FACTS pilot project with active & reactive power comp.



Battery: Li-Ion (Saft)
- Pilot: 8 stacks x 13 cells
- Customer: EDF UK
- Per stack: 720 V, 400 kg
- Total: 200kW for 1h,
  or 600kW short time
- Factory acceptance
  test: 6/2009
- Target installation: Q4/2009

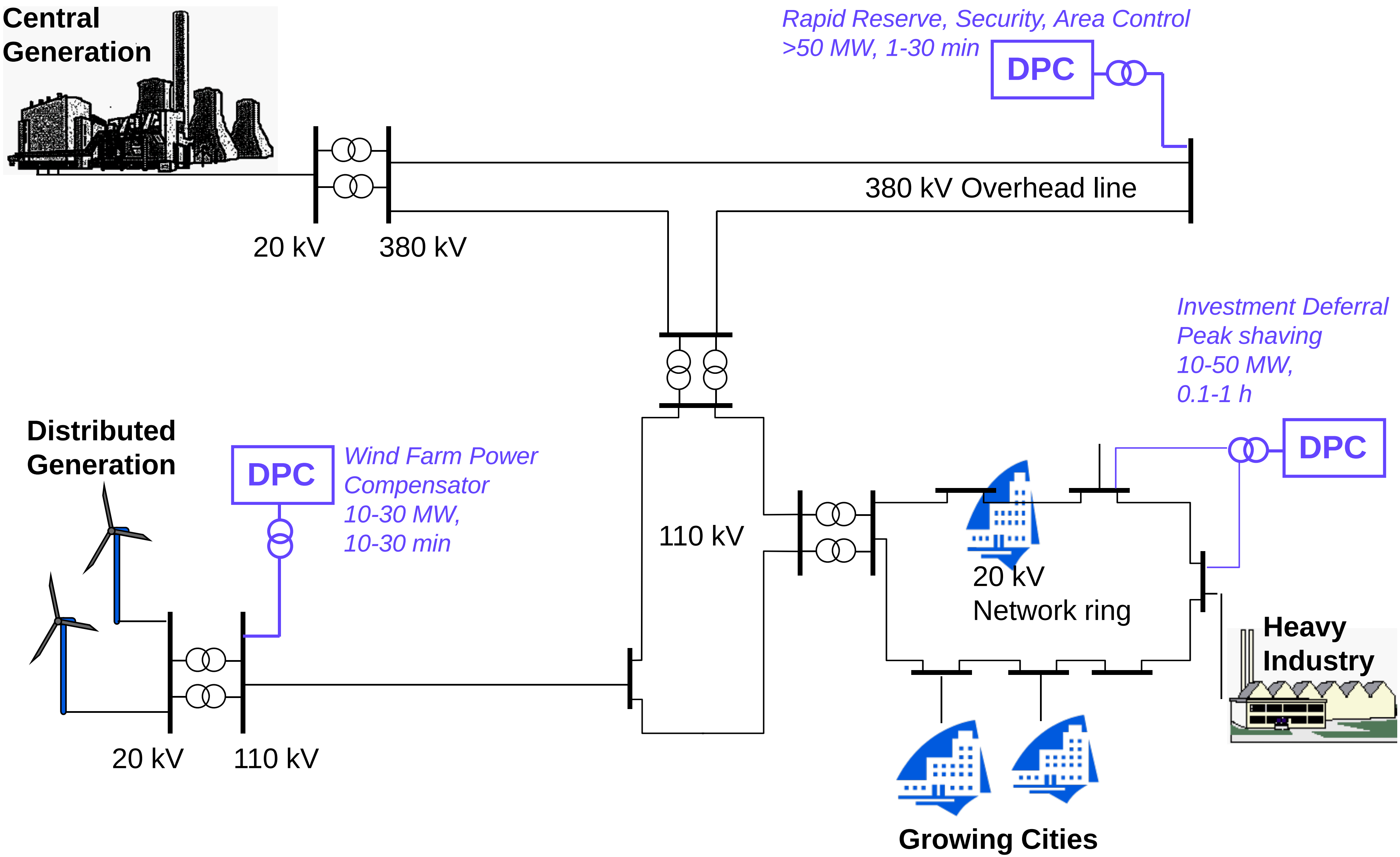
8 x



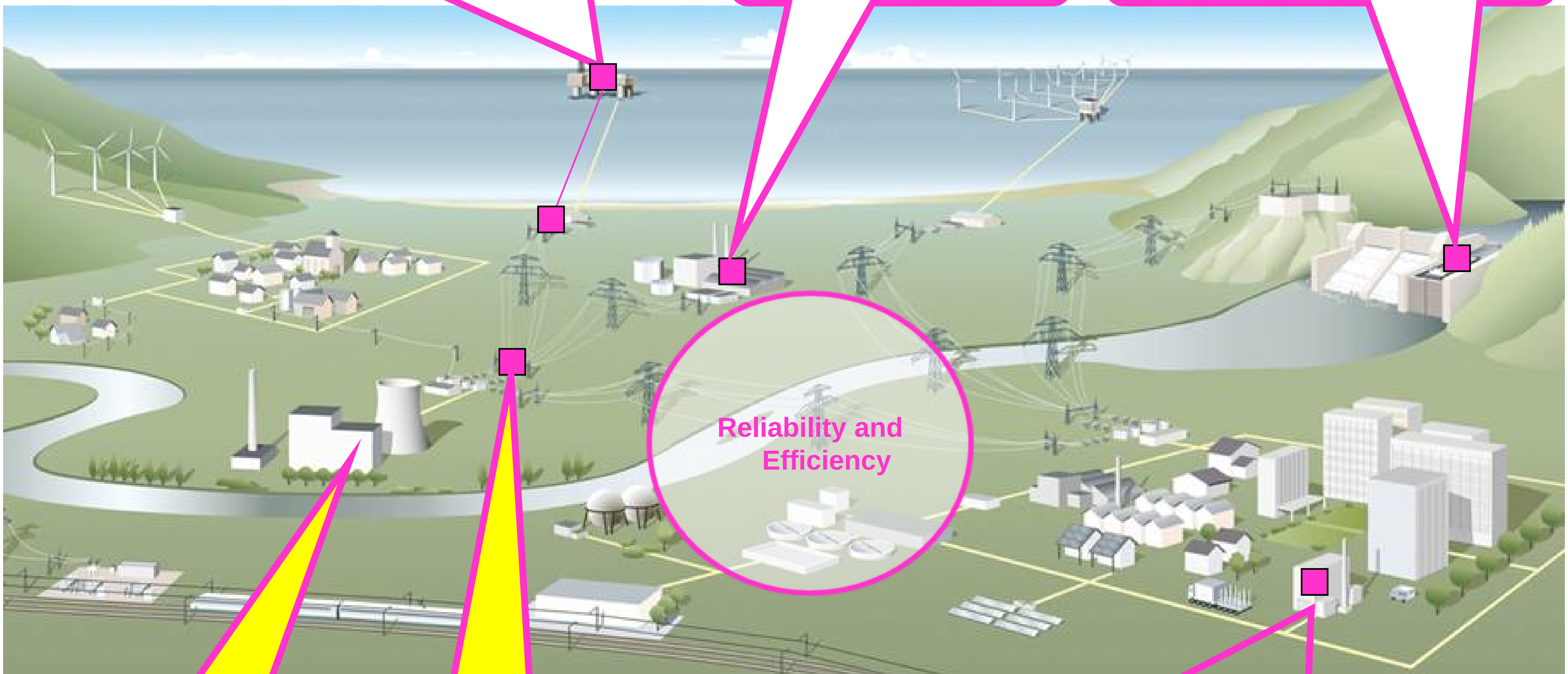
Installation of Field Demonstrator

- ABB UK has a contract on an installation of a field demonstrator installation in distribution network
- Customer is EDF Energy, UK
- 11 kV Energy Storage and Voltage Control
- Data:
  - System Voltage: 11 kV ±6%
  - Reactive Power: 600 kVAr inductive to 600 kVAr capacitive
  - Active Power: 600 kW (short time), 200 kW during 1 hour

Dynamic Power Compensation Markets



Power Electronics in Smart Grids
Reliability and efficiency



Reduced losses with HVDC

- Capacity
- Reliability
- **Efficiency**
- Sustainability

- HVDC is especially beneficial for long distance transmission with low losses
- Lower cost for infrastructure (fewer and smaller pylons, fewer lines) compensate higher investment in converter stations
- ABB will save 30 percent transmission losses by installing an ultra-high voltage direct current (UHVDC) connection more than 2,000 km long in China
- One of the world’s longest and powerful transmission systems from ABB operates at ± 800 kV, transporting 6,400 MW

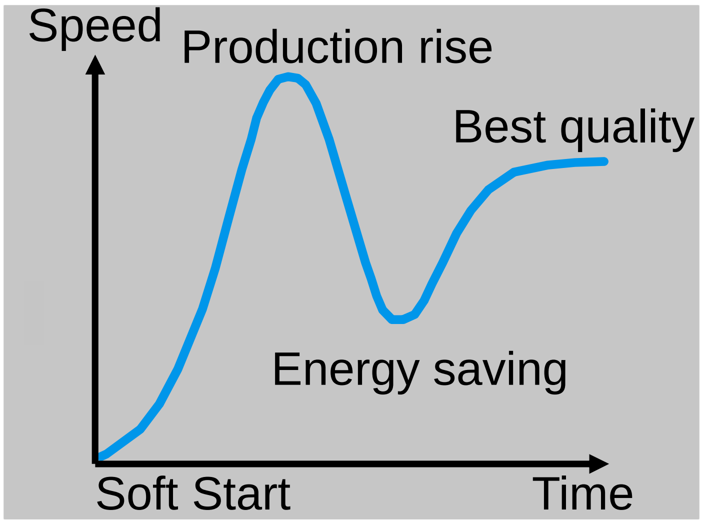
ABB has delivered most of the world’s installed HVDC systems

MV Drives
Why variable speed drives?

- 60 - 65% of industrial electrical energy is consumed by electric motors
- For each 1 USD spent to purchase a motor, 100 USD are spent for energy cost during its lifetime
- Today, only 5% of these motors are controlled by variable speed drives
- 30% of existing motors can be retrofitted with variable speed drives

- The installed base of ABB drives saves more than 120 TWh of energy per year, the equivalent of 15 nuclear power plants
- ABB drives reduce CO_2 emissions by approx. 60 million tons per year

MV Drives
Benefits of variable speed control



- Energy savings
- Improved product quality through better process control
- Reduced process equipment wear and longer lifetime of equipment
- Soft start and stop reduce waste and save raw material
- Noise reduction
- Improved process efficiency

MV Drives
Medium voltage AC drives for…


Cement, Mining & Minerals


Chemical, Oil & Gas


Marine

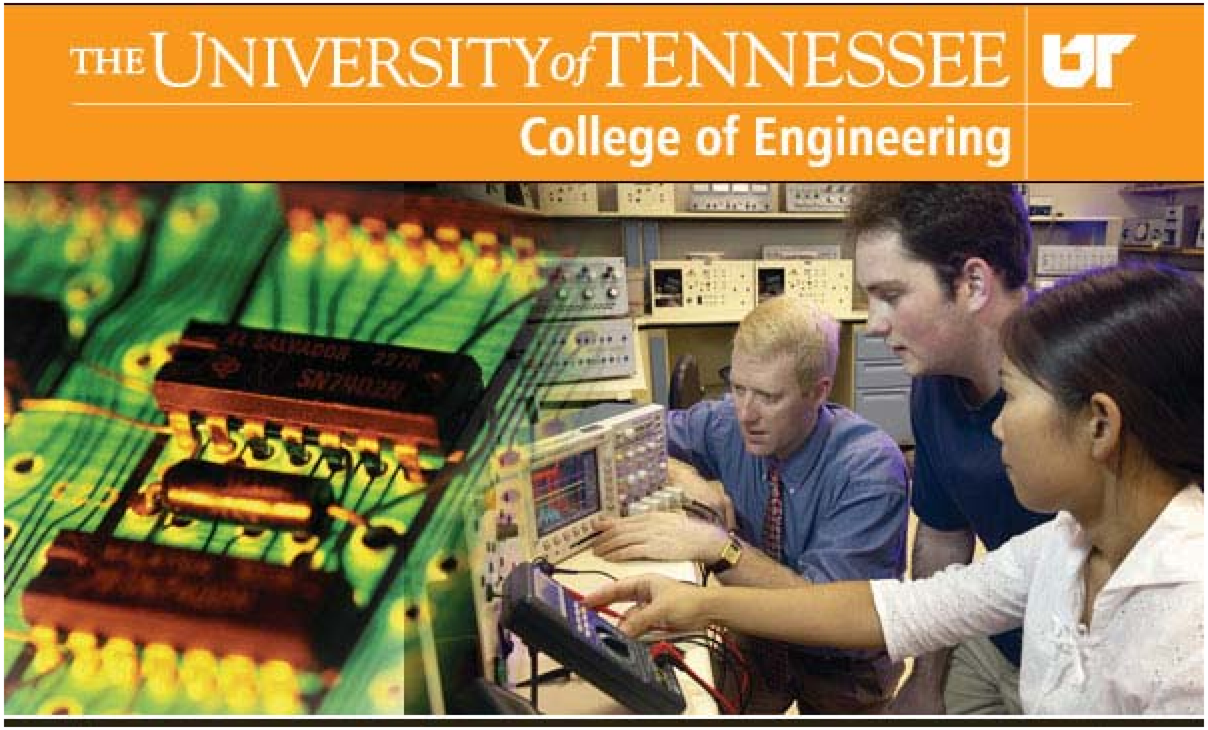

Metals


Power


Pulp & Paper


Water


Special applications, e.g. wind tunnels



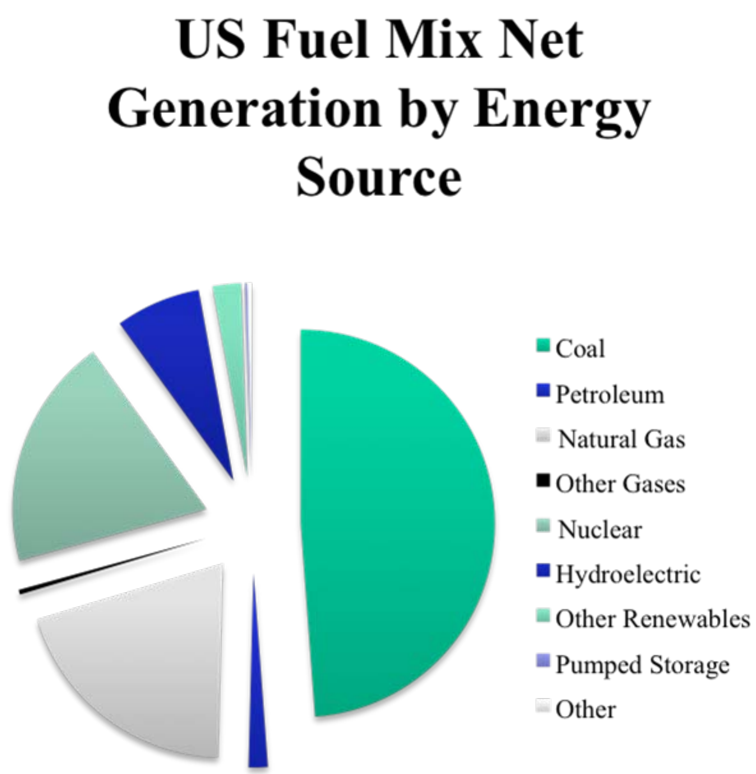
Power System Control Research Issues

Kevin Tomsovic
CTI Professor and Head, Department of EECS

US Fuel Mix for Electricity

By Energy Delivered

- Net Generation, by Energy Source (2006, GWh)
  - Coal (1,990,926)
  - Petroleum (64,364)
  - Natural Gas (813,044)
  - Other Gases (16,060)
    - Blast Furnace gas
    - Propane gas
    - Other manufactured and waste gasses derived from fossil fuels
  - Nuclear (787,219)
  - Hydroelectric (289,246)
  - Other Renewables (96,423)
  - Hydroelectric Pumped Storage (-6,558)
  - Other (13,977)

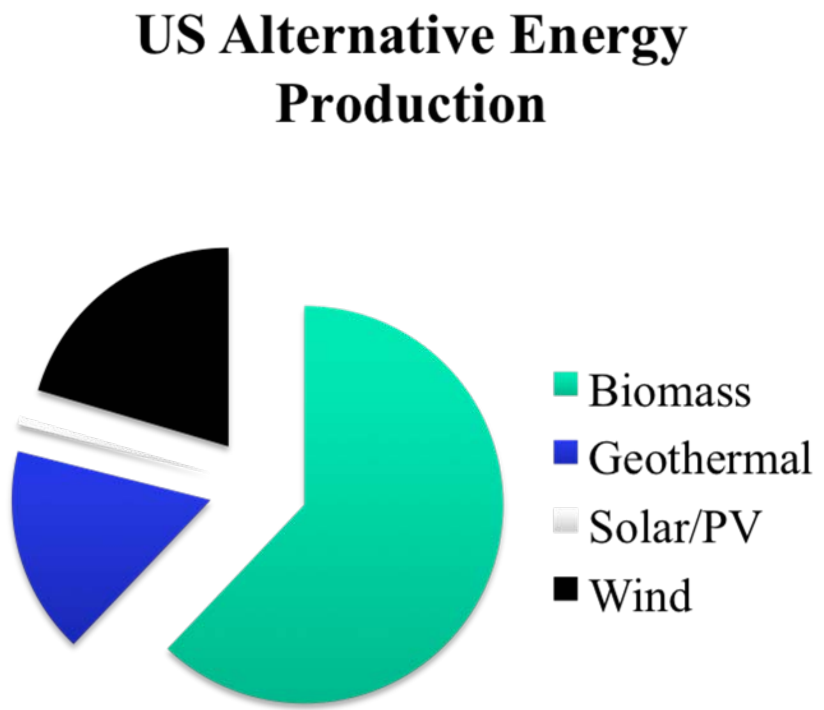


Some First Observations/Opinions

- Biggest contributors to CO_2 emissions are transportation and electricity
- Easiest ways to reduce CO_2 emissions
  - Reduce coal usage in electric power systems where alternatives can be found
  - Shift some transportation load to electric power grid
  - Greater use of electricity waste heat (CHP)
  - Increase use of petroleum alternatives in transportation (ethanol, biodiesel, methane, etc.)

US Alternative Energy Production

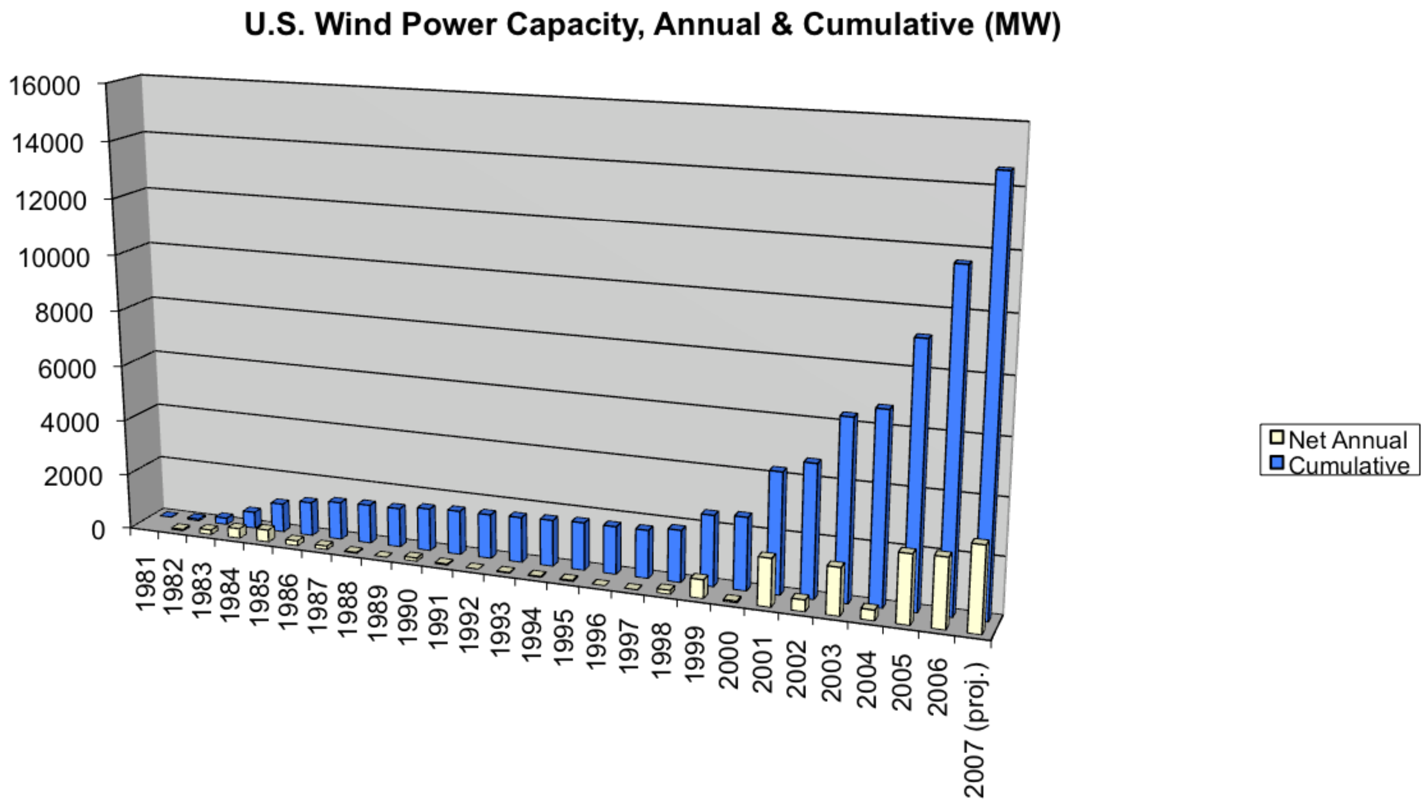
- By Source (2005, GWh)
  - Biomass (54,160)
  - Geothermal (14,691)
  - Solar/PV (550)
  - Wind (17,811)



Some More Observations / Opinions

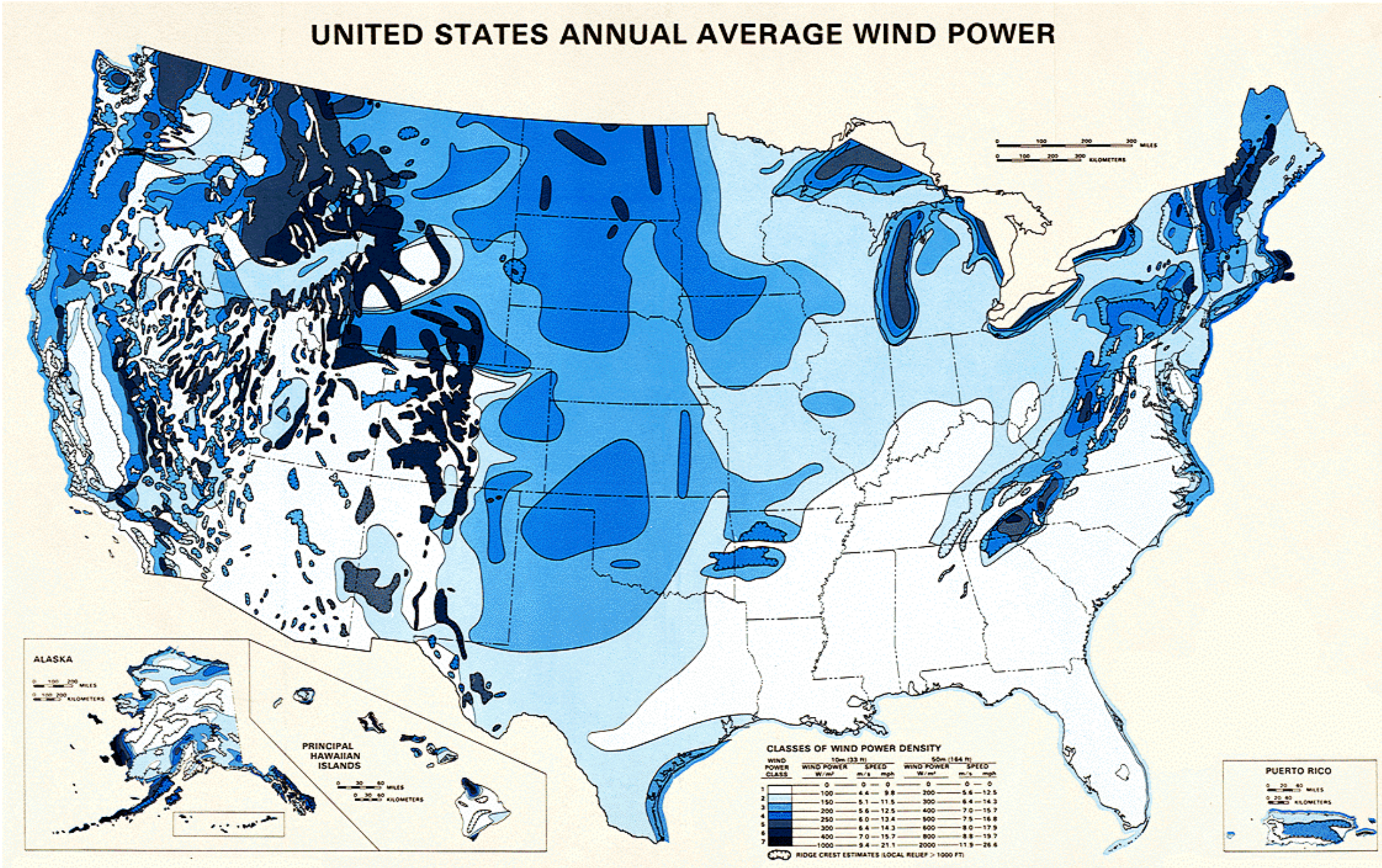
- Considering cost, availability of sites, development of technology, medium term (5-10 years); carbon limited generation will be dominated by
  - Wind – both on-shore and off-shore
  - Solar – to a lesser extent but depends on ability to compete at retail level
- Problems with wind and solar
  - Wind highly stochastic (variable)
  - Seasonal variations
  - Solar diurnal cycle does not match load

US Wind Resources



http://www.awea.org/Projects/growth.xls

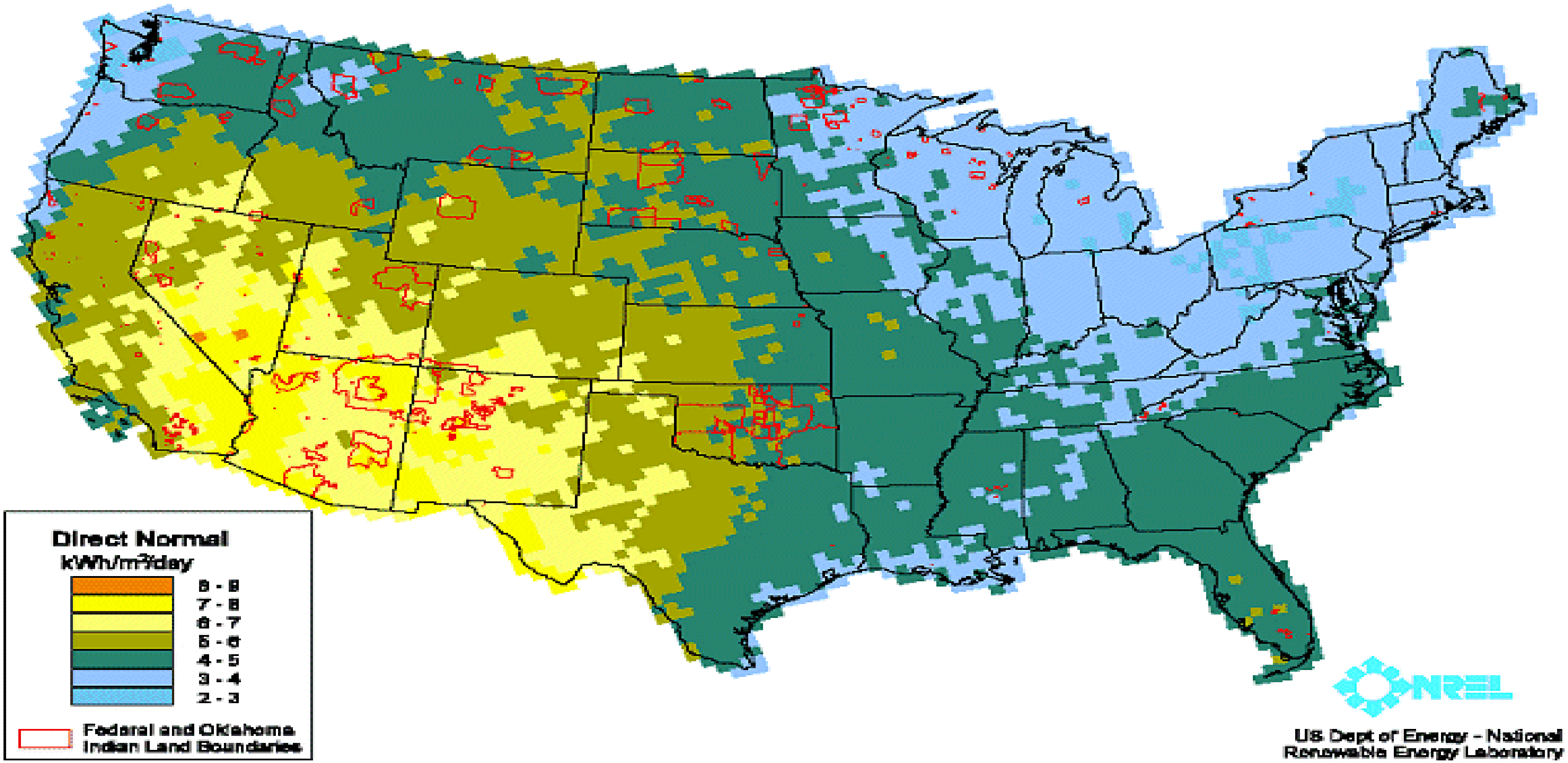
US Wind Resources



http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html

US Solar Resources

Figure 12. Concentrated Solar Power (CSP) Resource Potential



http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig12.html

Challenges

Assume 50% Renewables is Desired Level

Many alternative sources are:

- less predictable than traditional fuel-based power plants;
- tend to be far from load centers so power may have to flow through congested transmission paths;
- do not generally match the daily cycle of load variation;
- suffer from unusual operating constraints, such as, rapid variation or complicated weather dependence;
- need to be tightly coupled to storage, which may be mobile.

Recent Experience with Wind

- Texas – Feb 2008.
  - 1700 MW dropped to 300 MW over several hours. Required drop of non-firm load. Press tended to blame wind but both forecasted load and dispatched generation were in error.
- California
  - California ISO requiring significant new reserves to meet ramp rate constraints brought on by wind units
- Washington State and Spain
  - Both report events of losing up to 1 GW in under a minute
- Major Issue is cost – either new reserves or new transmission

Existing Power System Control

- Connected system built upon rotating machines with high inertia and relies on dependable patterns of consumption
- Very little load is controllable, instead generation tracks daily load curve
- System engineered to meet peak demands
- Numerous centralized controls acting largely independent
- Localized control schemes primarily for protection

➔ Driven by reliability and fuel costs. Current system does have many advantages including high efficiency (from electrical viewpoint) and high reliability.

Overall Control and Communication Structure

- Largely hierarchical and centralized
- Controls separated by time frame and reach (day ahead scheduling, load frequency, voltage, real-time economic dispatch, static security, transient stability, etc.)
- Most communication flows up to control center (little from substation to substation)
- Pricing driven mostly by generation scheduling considerations
- Little customer choice in level of reliability

More Comments on Existing System

- A system solution is mandated mostly by reliability:
  - completely distributed options tend to fail in terms of reliability and affordability,
  - existing system tends to fail in terms of adaptability and sustainability.
- Can existing systems be adjusted incrementally? No, because of scalability
- Existing overall control is a “frozen accident” (a patchwork of controls - transient stability, load frequency, voltage, power quality, protection), largely uncoordinated
- Controlled entities (generators) are assumed to be in the hundreds, not millions

Needed System Changes

- a broader electric grid to include end energy use.
- increased scheduling capability through load management for existing loads and the addition of new load
- new and reconfigurable transmission to improve source diversity
- provide effective storage through a combination of fast start units, PHEVs, low-level UPS, and utility scale storage
- a “flattening” of the control structure that replaces the traditional control strategies with simpler local controls operating within a more global context for the system

Some Potential Research Issues

Control Challenges

- Speed of response
  - Milliseconds (power quality)
  - Seconds (transient stability)
  - 10s of seconds (small signal stability)
  - Minutes (voltage stability and system viability)
  - Days
  - Seasonal
- Amount of response
- Need for new transmission
- Determining transmission limits in real time

Example Control Issues
New Load Controls

With 50% renewables at 40% capacity factor

- Need 600 GW nationwide and can easily have 100 GW of variation to manage (expensive to do with reserve gas units)
- How much load is controllable in the US?
  - Heating/Cooling (35.2 aGW assuming 20% controllable)
  - Lighting (20 aGW assuming up to 50% controllable)
  - Industrial (23 aGW assuming up to 15% controllable)
  - Light electronic load (12.9 aGw assuming up to 15% controllable)

➔ This would be a massive change but probably still doesn't get you far enough if you want to avoid increasing reserves

Possible Solutions

New Controllable Load

- PHEV's
  - Plug in hybrid vehicles
  - Use as storage
  - Use as controllable load – peak shaving, load leveling

Example

- 6kWh load
- Average 5 hour charge time
- 20 million in US
- 24 aGW of controllable load

- Hydrogen production
  - Could couple with wind units

- Potential huge but market for hydrogen probably some time off

Possible Solutions
Flatness as a Control Structure

Our proposed control scheme combines:

- local control for speed and robustness (corrects for uncertainty),
- global (area) control that selects one of finitely many modes for each local controller, e.g., efficiency maximization, cost minimization, stabilization, network recovery. This level compensates for possible myopic actions of uncoordinated local controls.

Divide and Conquer…

Flatness should allow the system operator to systematically generate feasible plans in a relatively simple way by employing a two-degree-of-freedom approach that separates overall scheduling into:

1. Nominal generation plan (performed on a global level),
2. Local (typically fast) tracking and stabilization.

→ Cost is some loss of overall efficiency

Possible Solutions

Transmission System Enhancement with FACTS Controllers

- Conventional methods of transmission planning is linked to large coal/nuclear generation sites – no longer the case with renewables and in restructured power markets.
- Flexible AC Transmission Systems (FACTS) controllers can be strategically located to strengthen flow paths for renewable sources at a much lower cost than new transmission lines. Voltage-sourced converter based controllers are versatile and reconfigurable – for example, the Marcy Convertible Static Compensator (CSC).
- Local (flat) control and coordination of FACTS controllers for active flow control and voltage support need to be investigated – new dispatch and coordination schemes for steady-state and transient operations.
- Use of high-sampling rate synchrophasor data can further improve the response of FACTS controllers to counteract disturbances.
- Need for computer simulation tools and test systems to other researchers in renewable energy community.

Conclusions

- Wide area interconnected electricity grid central to solving energy problems
- Wind has perhaps the greatest potential – problems of variability may have been overstated by media BUT a new control structure is needed to address greater demand side response and new storage
- Need for storage has been overstated
- Shifting of greater load to grid has benefits both for reduced emissions and for ease of control
- Need for new transmission flexibility and reconfigurability
- Must get the economic incentives right

Discussion

MV Drives
Products

ACS 1000, ACS 1000i

- Cooling: air / water
- Power range: 315 kW – 5 MW
- Output voltage: 2.3 – 4.16 kV
- Air-cooled ACS 1000 available with integrated input transformer and input contactor (ACS 1000i)

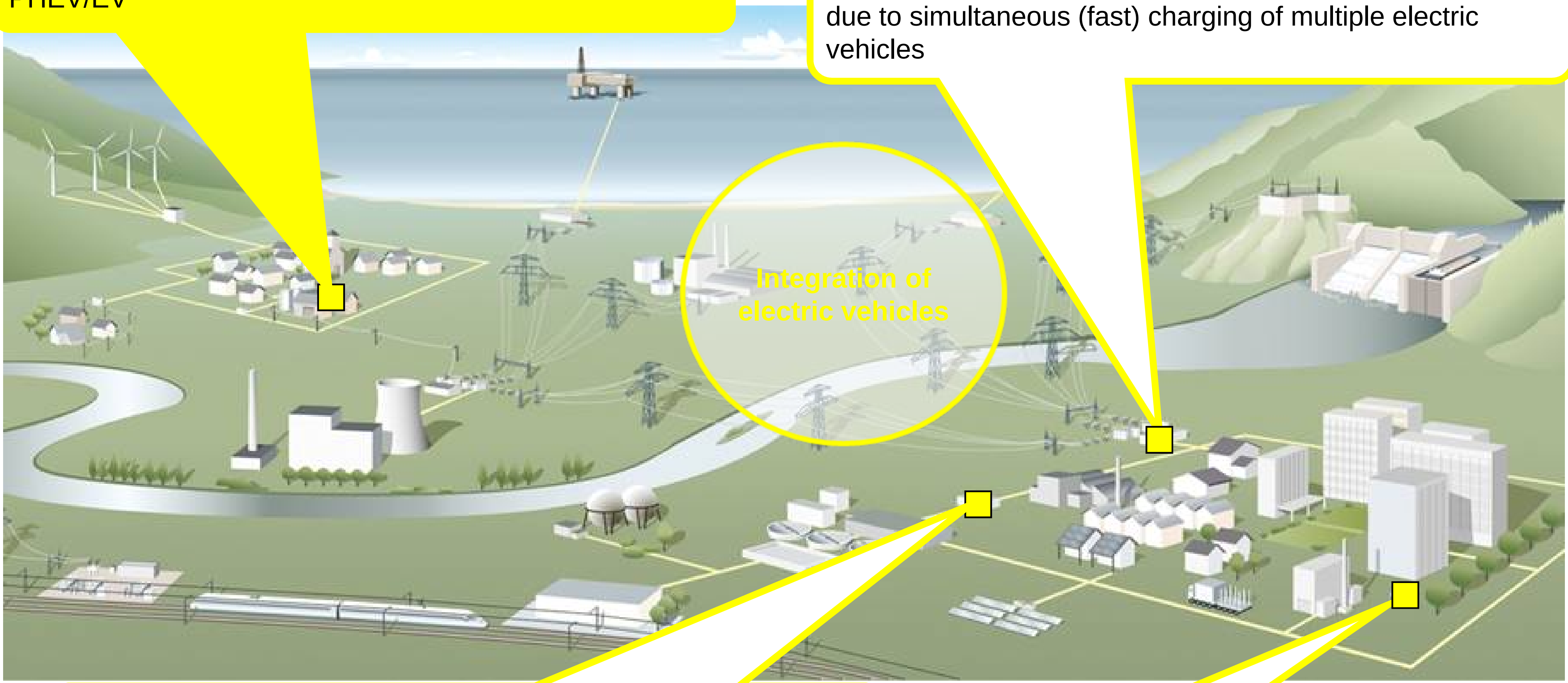
ACS 5000

- Cooling: air / water
- Power range: 2 – 22 MW
- Output voltage: 6.0 – 6.9 kV
- Air-cooled ACS 5000 available with integrated input transformer

Power Electronics in Smart Grids
Integration of electric vehicles

Residential inverters for energy storage, renewables, and PHEV/EV

Centralized energy storage (Dynapow) to absorbe peaks due to simultaneous (fast) charging of multiple electric vehicles



Stations for fast charging of electric vehicles

Traction drives for (hybrid) electric vehicles

Power Electronics for Battery Fast Charging Station

- **<u>What is 'Battery charging station'?</u>**
  A battery charging station is a place supplying electricity for the recharging of electric vehicles including plug-in hybrid electric vehicles. Charging stations can be found on the road (fast), in parking lots (slow), and in garages at home (slow).

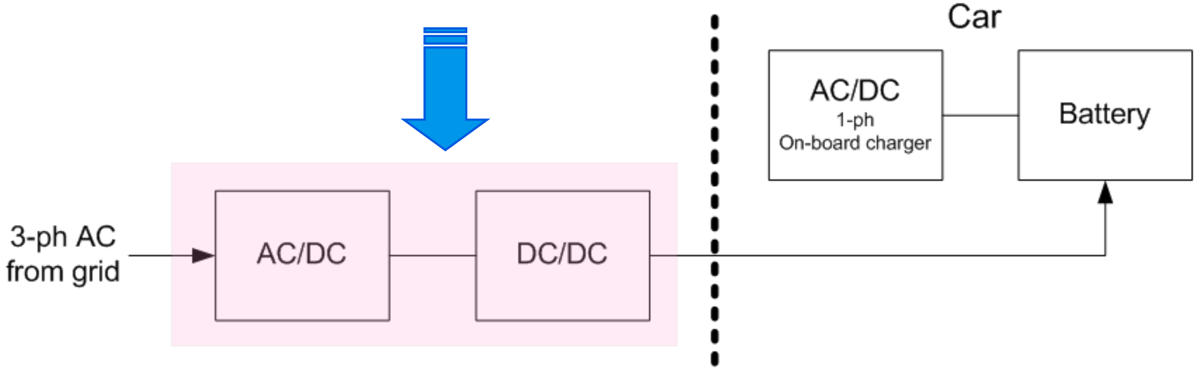
- **<u>What is 'Fast charging'?</u>**

  Fast charging is expected to charge batteries within 10 minutes or less for complete replenishment, which is equivalent to existing 'Fuel Stop'.

- **<u>Why is 'Charging station and Fast charging' needed?</u>**
  - All major automobile manufacturers are actively developing alternative fuel vehicles.
  - All major automobile manufacturers have PHEV & BEV on their short-mid term planning horizon.
  - Substantial EV market growth worldwide by 2030.
  - PHEV/BEV/EV require charging infrastructure, especially fast charging station equivalent to existing 'gas station'.

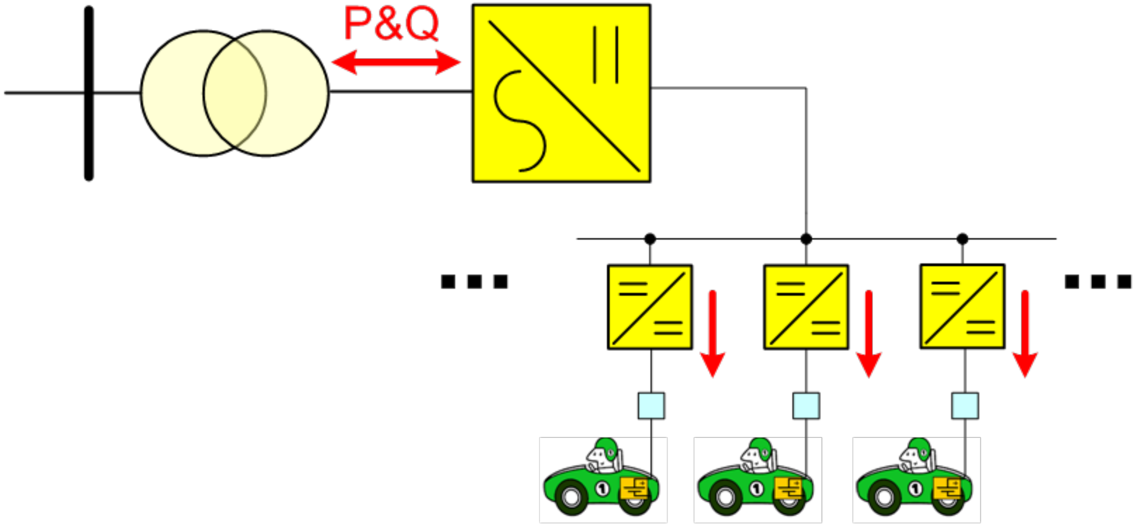
- **<u>Power Electronics for Fast Charging</u>**

  Fast charging requires dedicated AC/DC & DC/DC power conversion



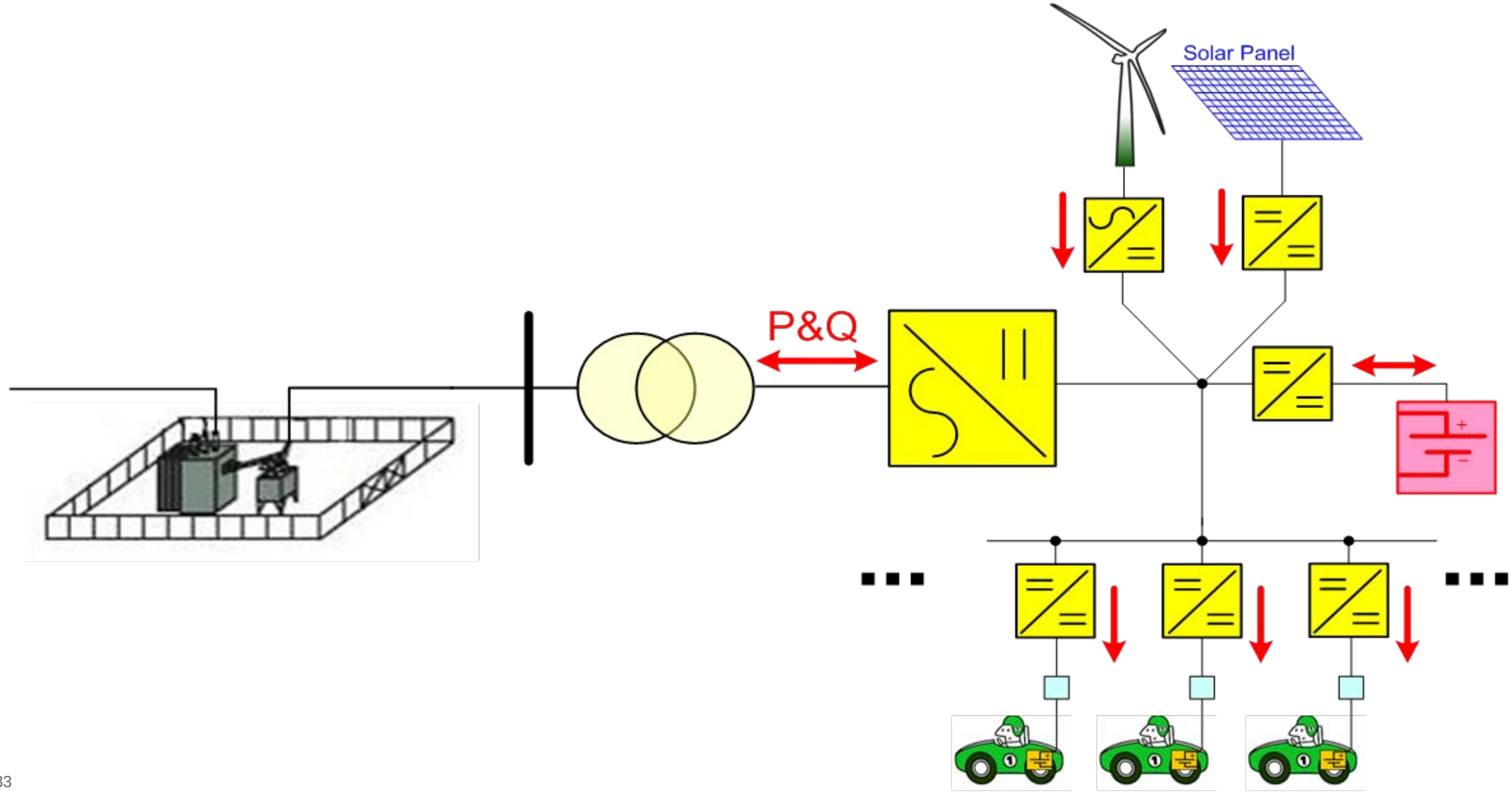
Infrastructure of Battery Fast Charging Station

- Assumption:
  - A fleet of all electric vehicles with battery packs in the range of 25-50kWh (driving range of 100 – 200km)
- Scenario:
  - A ten-minute quick charge from 10% to 90% capacity for 25kWh battery pack would require a power draw of about 120kW from the grid.
  - If average charging station is capable of serving 10 cars simultaneously, a ten-minute quick charge for all 10 vehicles refers to 1.2MW load. Charging station load would continuously fluctuate in the range of 0-1.2MW.
  - If there are 20 fast charging stations in a city, there will be continuous load fluctuation in the range of 0-24MW from a grid perspective.



Opportunities for Power Electronics in Charging Station

- High efficient 3-ph DC-AC and DC-DC converters
- Grid side active rectifier for large fast charging station
- Integration of renewable energy source into fast charging station with bulk electrical energy storage.
- Island mode of fast charging station with electrical energy storage + renewable energy source
- Protection from various situations such as lightening.

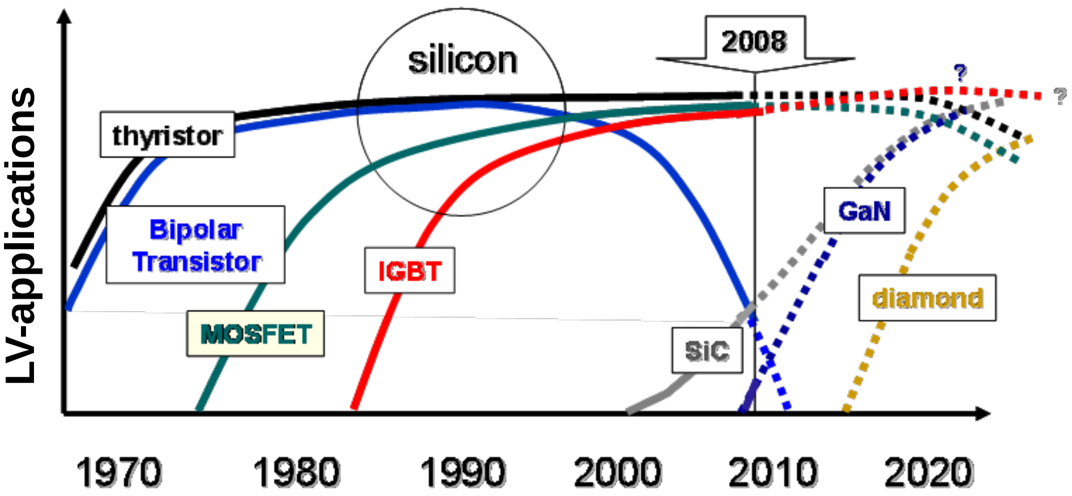


Conclusion: Smart Grid Needs High MW Electronics

- Current switching
- Current interrupting
- Current limiting
- Transformer

→ **Solid-state substation**

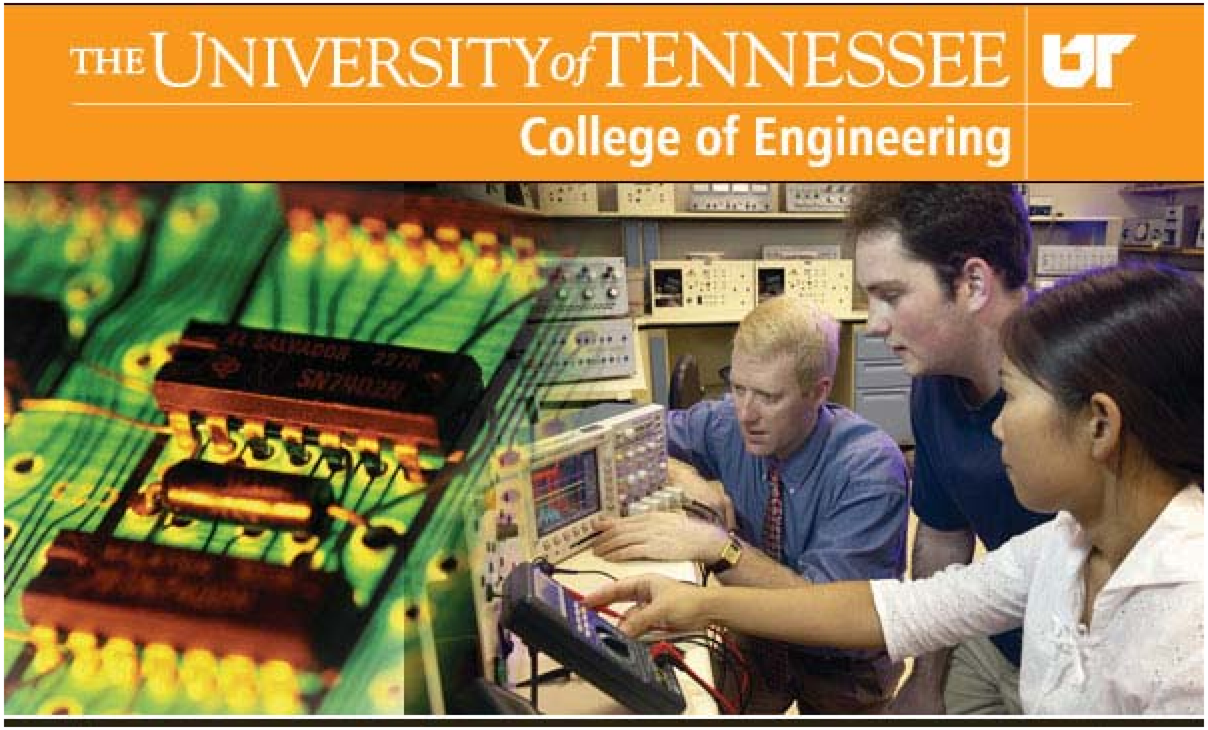
- **Main Challenges:**
  - High reliability
  - Low losses
  - Thermal Management/Cooling
  - High switching frequency
  - High blocking voltage for direct MV connection
  - High power density/Footprint
  - Low cost



Power and productivity
for a better world™

Kevin Tomsovic

Univ of Tennessee



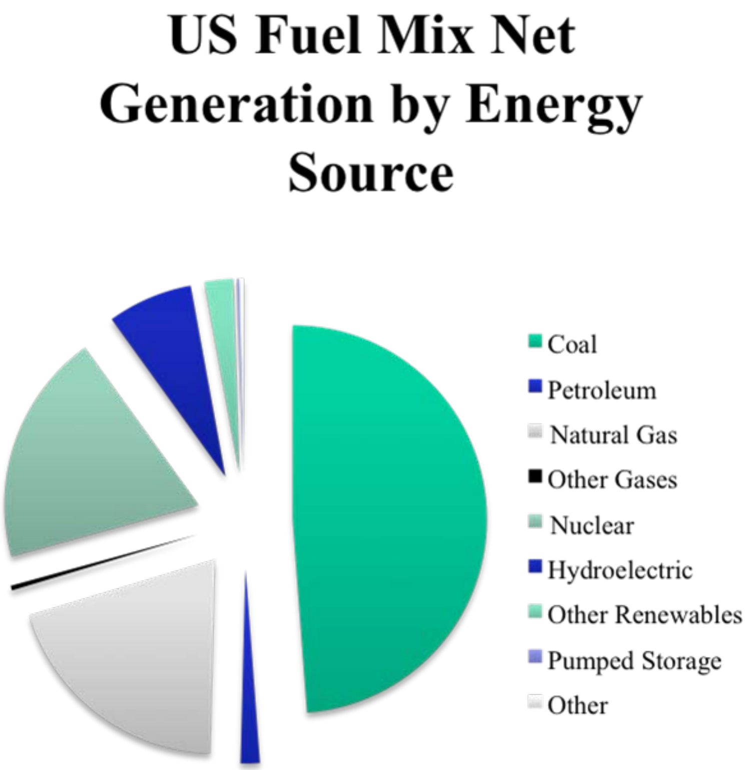
Power System Control Research Issues

Kevin Tomsovic
CTI Professor and Head, Department of EECS

US Fuel Mix for Electricity

By Energy Delivered

- Net Generation, by Energy Source (2006, GWh)
  - Coal (1,990,926)
  - Petroleum (64,364)
  - Natural Gas (813,044)
  - Other Gases (16,060)
    - Blast Furnace gas
    - Propane gas
    - Other manufactured and waste gasses derived from fossil fuels
  - Nuclear (787,219)
  - Hydroelectric (289,246)
  - Other Renewables (96,423)
  - Hydroelectric Pumped Storage (-6,558)
  - Other (13,977)

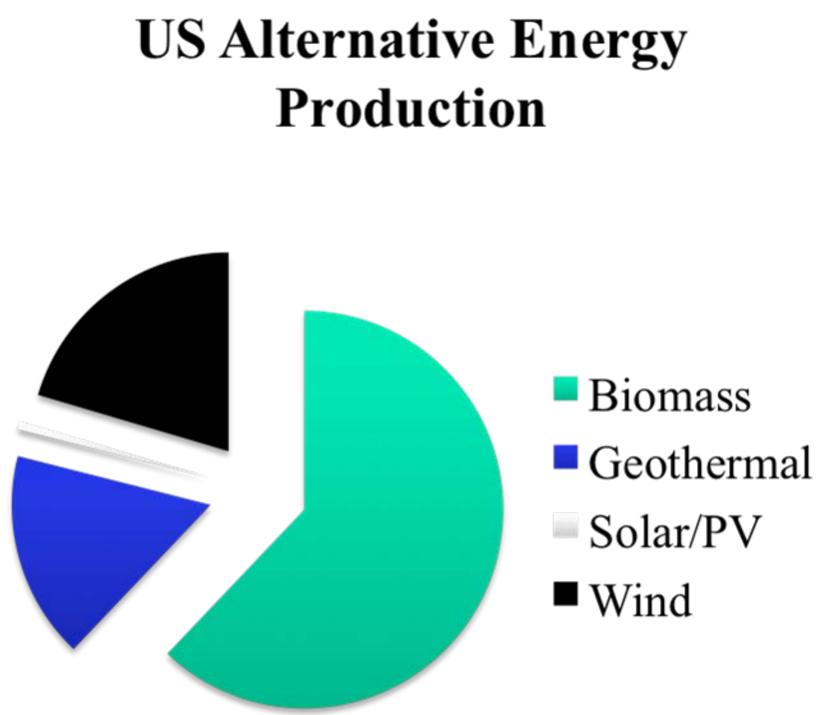


Some First Observations/Opinions

- Biggest contributors to CO_2 emissions are transportation and electricity
- Easiest ways to reduce CO_2 emissions
  - Reduce coal usage in electric power systems where alternatives can be found
  - Shift some transportation load to electric power grid
  - Greater use of electricity waste heat (CHP)
  - Increase use of petroleum alternatives in transportation (ethanol, biodiesel, methane, etc.)

US Alternative Energy Production

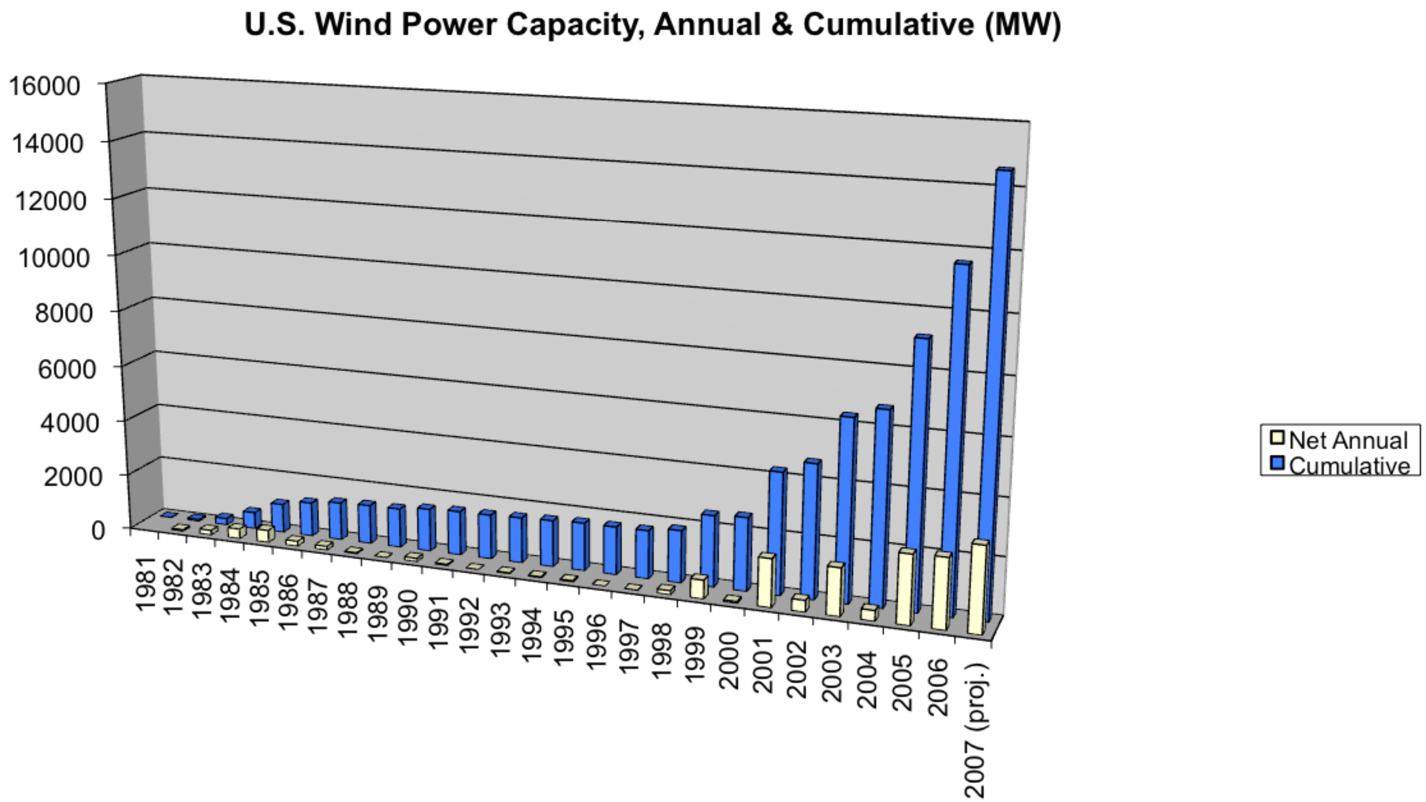
- By Source (2005, GWh)
  - Biomass (54,160)
  - Geothermal (14,691)
  - Solar/PV (550)
  - Wind (17,811)



Some More Observations / Opinions

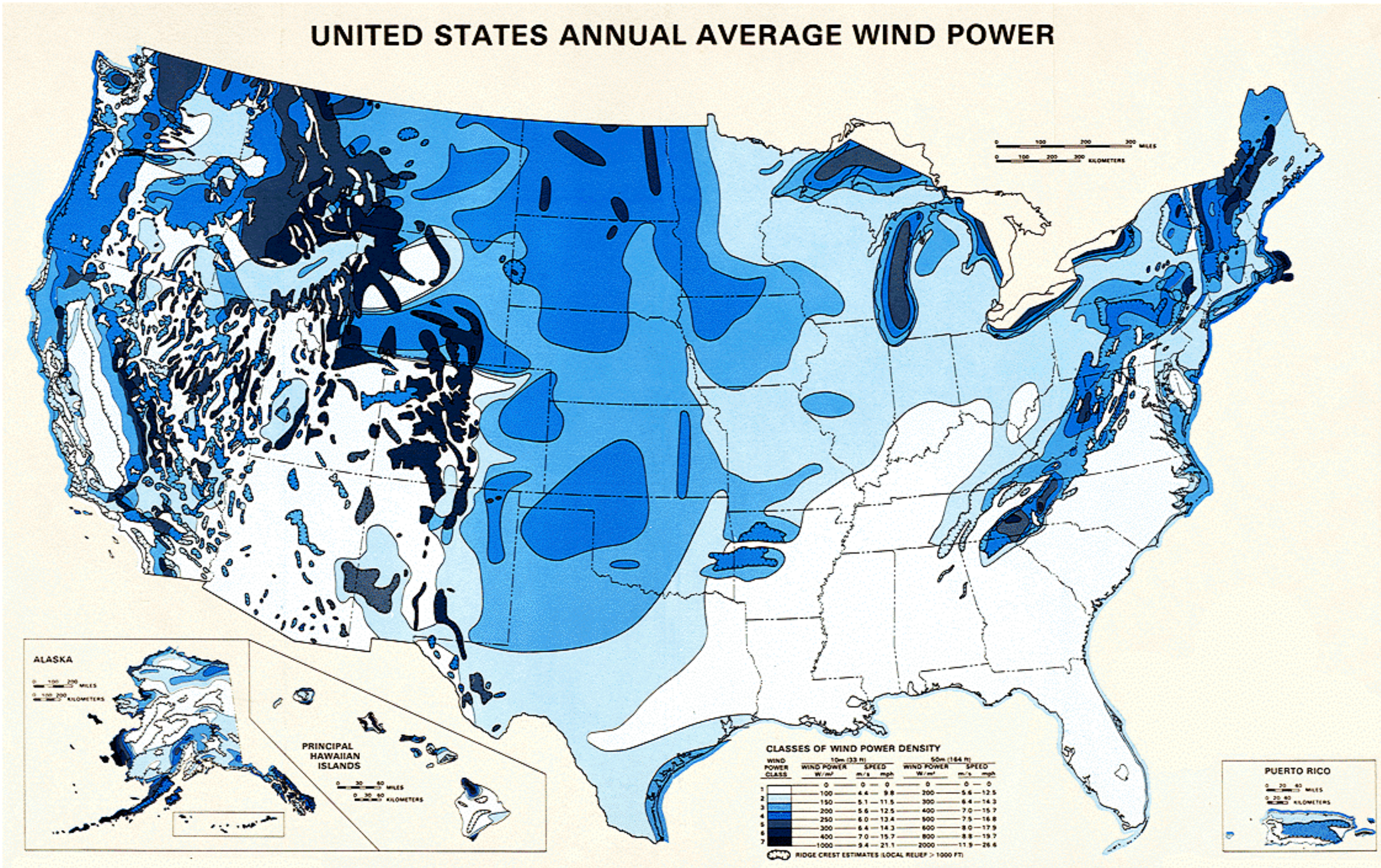
- Considering cost, availability of sites, development of technology, medium term (5-10 years); carbon limited generation will be dominated by
  - Wind – both on-shore and off-shore
  - Solar – to a lesser extent but depends on ability to compete at retail level
- Problems with wind and solar
  - Wind highly stochastic (variable)
  - Seasonal variations
  - Solar diurnal cycle does not match load

US Wind Resources



http://www.awea.org/Projects/growth.xls

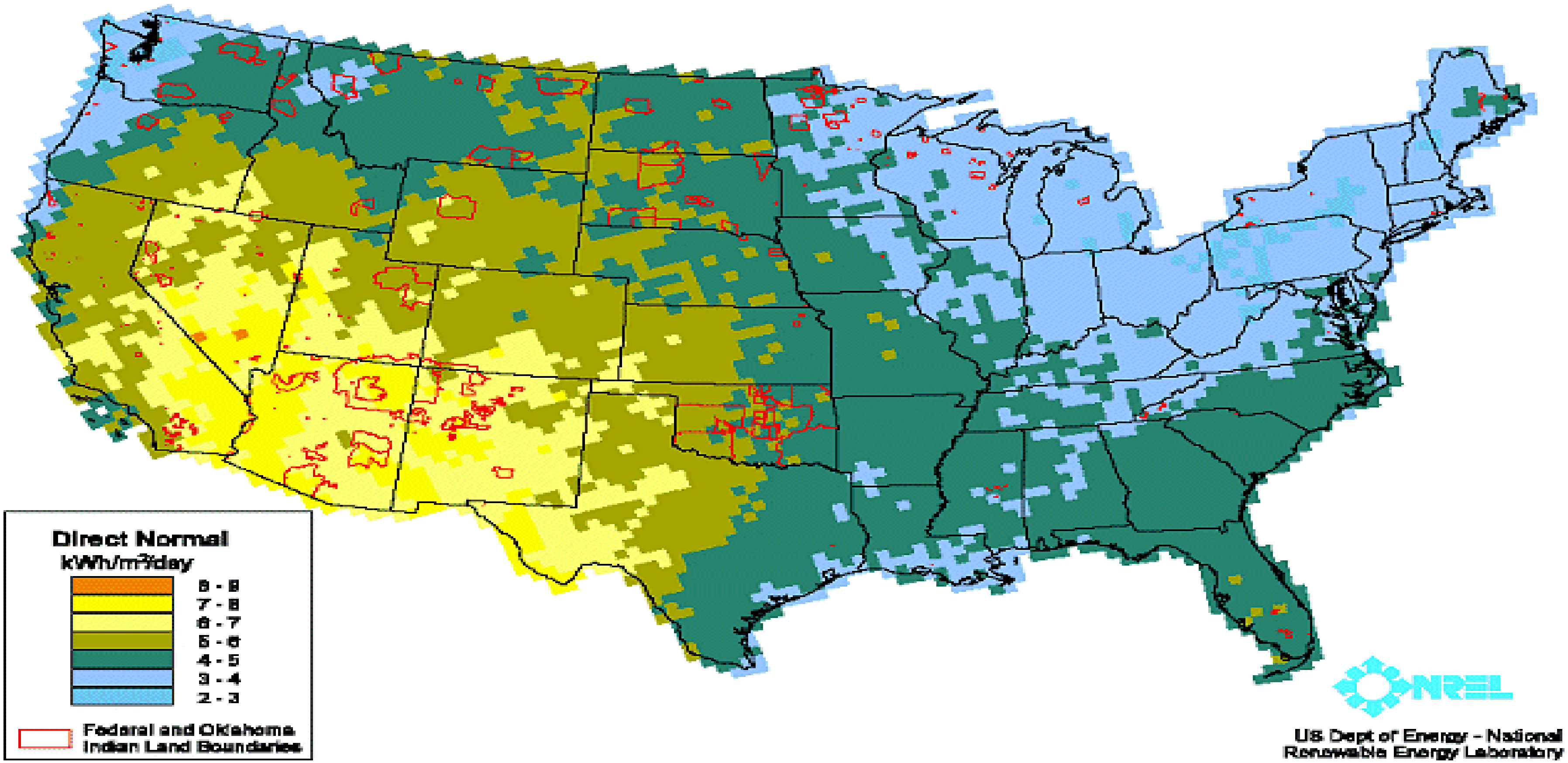
US Wind Resources



http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html

US Solar Resources

Figure 12. Concentrated Solar Power (CSP) Resource Potential



http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig12.html

Challenges

Assume 50% Renewables is Desired Level

Many alternative sources are:

- less predictable than traditional fuel-based power plants;
- tend to be far from load centers so power may have to flow through congested transmission paths;
- do not generally match the daily cycle of load variation;
- suffer from unusual operating constraints, such as, rapid variation or complicated weather dependence;
- need to be tightly coupled to storage, which may be mobile.

Recent Experience with Wind

- Texas – Feb 2008.
  - •1700 MW dropped to 300 MW over several hours. Required drop of non-firm load. Press tended to blame wind but both forecasted load and dispatched generation were in error.
- California
  - •California ISO requiring significant new reserves to meet ramp rate constraints brought on by wind units
- Washington State and Spain
  - • Both report events of losing up to 1 GW in under a minute
- Major Issue is cost – either new reserves or new transmission

Existing Power System Control

- Connected system built upon rotating machines with high inertia and relies on dependable patterns of consumption
- Very little load is controllable, instead generation tracks daily load curve
- System engineered to meet peak demands
- Numerous centralized controls acting largely independent
- Localized control schemes primarily for protection

➔ Driven by reliability and fuel costs. Current system does have many advantages including high efficiency (from electrical viewpoint) and high reliability.

Overall Control and Communication Structure

- Largely hierarchical and centralized
- Controls separated by time frame and reach (day ahead scheduling, load frequency, voltage, real-time economic dispatch, static security, transient stability, etc.)
- Most communication flows up to control center (little from substation to substation)
- Pricing driven mostly by generation scheduling considerations
- Little customer choice in level of reliability

More Comments on Existing System

- A system solution is mandated mostly by reliability:
  - completely distributed options tend to fail in terms of reliability and affordability,
  - existing system tends to fail in terms of adaptability and sustainability.
- Can existing systems be adjusted incrementally? No, because of scalability
- Existing overall control is a “frozen accident” (a patchwork of controls - transient stability, load frequency, voltage, power quality, protection), largely uncoordinated
- Controlled entities (generators) are assumed to be in the hundreds, not millions

Needed System Changes

- a broader electric grid to include end energy use.
- increased scheduling capability through load management for existing loads and the addition of new load
- new and reconfigurable transmission to improve source diversity
- provide effective storage through a combination of fast start units, PHEVs, low-level UPS, and utility scale storage
- a “flattening” of the control structure that replaces the traditional control strategies with simpler local controls operating within a more global context for the system

Some Potential Research Issues

Control Challenges

- Speed of response
  - Milliseconds (power quality)
  - Seconds (transient stability)
  - 10s of seconds (small signal stability)
  - Minutes (voltage stability and system viability)
  - Days
  - Seasonal
- Amount of response
- Need for new transmission
- Determining transmission limits in real time

Example Control Issues
New Load Controls

With 50% renewables at 40% capacity factor

- Need 600 GW nationwide and can easily have 100 GW of variation to manage (expensive to do with reserve gas units)
- How much load is controllable in the US?
  - Heating/Cooling (35.2 aGW assuming 20% controllable)
  - Lighting (20 aGW assuming up to 50% controllable)
  - Industrial (23 aGW assuming up to 15% controllable)
  - Light electronic load (12.9 aGw assuming up to 15% controllable)

➔ This would be a massive change but probably still doesn't get you far enough if you want to avoid increasing reserves

Possible Solutions
New Controllable Load

- PHEV's
  - Plug in hybrid vehicles
  - Use as storage
  - Use as controllable load – peak shaving, load leveling

Example

- 6kWh load
- Average 5 hour charge time
- 20 million in US
- 24 aGW of controllable load

- Hydrogen production
  - Could couple with wind units

- Potential huge but market for hydrogen probably some time off

Possible Solutions
Flatness as a Control Structure

Our proposed control scheme combines:

- local control for speed and robustness (corrects for uncertainty),
- global (area) control that selects one of finitely many modes for each local controller, e.g., efficiency maximization, cost minimization, stabilization, network recovery. This level compensates for possible myopic actions of uncoordinated local controls.

Divide and Conquer…

Flatness should allow the system operator to systematically generate feasible plans in a relatively simple way by employing a two-degree-of-freedom approach that separates overall scheduling into:

1. Nominal generation plan (performed on a global level),
2. Local (typically fast) tracking and stabilization.

➔ Cost is some loss of overall efficiency

Possible Solutions

Transmission System Enhancement with FACTS Controllers

- Conventional methods of transmission planning is linked to large coal/nuclear generation sites – no longer the case with renewables and in restructured power markets.
- Flexible AC Transmission Systems (FACTS) controllers can be strategically located to strengthen flow paths for renewable sources at a much lower cost than new transmission lines. Voltage-sourced converter based controllers are versatile and reconfigurable – for example, the Marcy Convertible Static Compensator (CSC).
- Local (flat) control and coordination of FACTS controllers for active flow control and voltage support need to be investigated – new dispatch and coordination schemes for steady-state and transient operations.
- Use of high-sampling rate synchrophasor data can further improve the response of FACTS controllers to counteract disturbances.
- Need for computer simulation tools and test systems to other researchers in renewable energy community.

Conclusions

- Wide area interconnected electricity grid central to solving energy problems
- Wind has perhaps the greatest potential – problems of variability may have been overstated by media BUT a new control structure is needed to address greater demand side response and new storage
- Need for storage has been overstated
- Shifting of greater load to grid has benefits both for reduced emissions and for ease of control
- Need for new transmission flexibility and reconfigurability
- Must get the economic incentives right

Discussion

Acknowledgements

The organizers would like to thank the following people for their contributions to the workshop and proceedings:

Colleen Hood, Terri Kroft, Tam Duong, Jose Ortiz, Madelaine Hernandez, Brian Grummel, Nanying Yang, Dean Smith, and Sarah Bell.