NATIONAL ENERGY TECHNOLOGY LABORATORY

Materials Research for Smart Grid Applications

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Materials Challenges in Alternative & Renewable Energy

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Smart Grid Topics

- Drivers & Value Proposition
- Concepts
- Technologies
- Applications
- Relationship to Materials Research
- Metrics & Benefits
- Implementation Challenges
- Deployment and Demonstration Status

Drivers and Value Proposition

Why Modernize the Grid?

- Today's grid is aging and outmoded
- Unreliability is costing consumers billions of dollars
- Today's grid is vulnerable to attack and natural disaster
- An extended loss of today's grid could be catastrophic to our security, economy and quality of life
- Today's grid does not address the 21st century power supply challenges
- Adverse trends associated with the grid
  - Costs, reliability, peak loads, asset underutilization, TLRs, grid divorce
- The benefits of a modernized grid are substantial

Value Proposition

Cost to Modernize

- $338-$476B over 20 years
  - $ 82-90 B for transmission
  - $232-$339 B for distribution
  - $24-46 B for consumer
- $17-24 B per year

  EPRI, 2011

Previous Studies

Benefit to Cost Ratio for West Virginia of 5:1
Benefit to Cost Ratio for San Diego of 6:1
Benefit to Cost Ratio for EPRI (2004) 4:1-5:1
$165 B Cost
$638 - $802 B Benefits

Benefit of Modernization

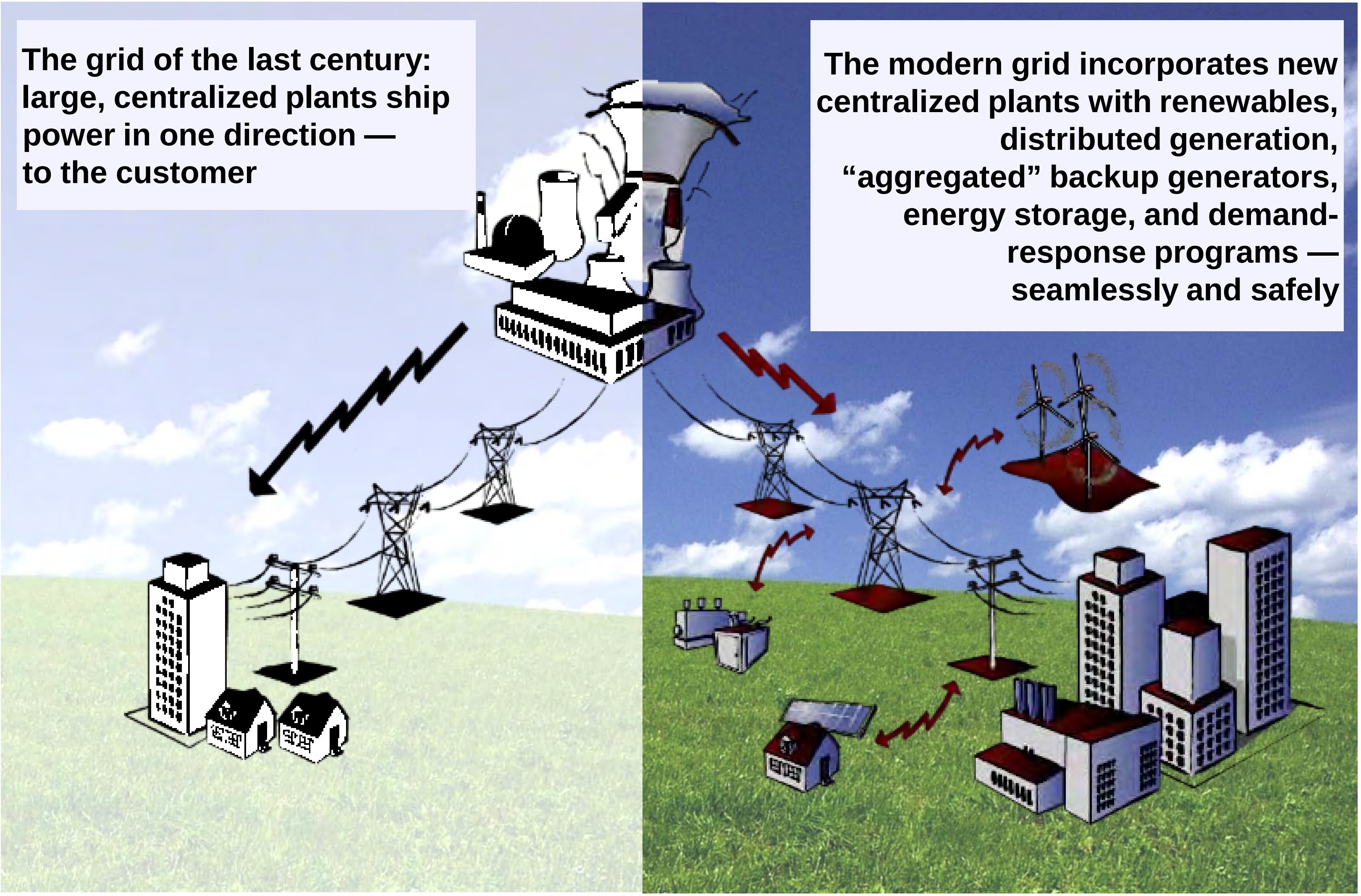
- $1294 – 2028 Billion
- Overall benefit-to-cost ratio of 2.8 to 6.0

Attribute	Net Present Worth (2010) $B	
	Low	High
Productivity	1	1
Safety	13	13
Environment	102	390
Capacity	299	393
Cost	330	475
Quality	42	86
Quality of Life	74	74
Security	152	152
Reliability	281	444
Total	**1294**	**2028**

EPRI Report: http://www.smartgridinformation.info/pdf/3272_doc_1.pdf

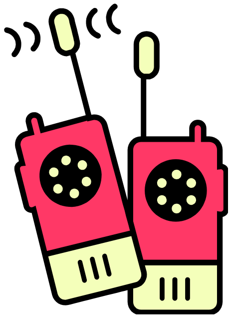
Definitions and Concepts

Smart Grid Supports 21st-Century Demand



What's Different with Smart Grid

- Consumer engagement with resources to solve power issues locally
- Two-way power flow in Distribution
- Two-way communications
- More and smaller and distributed sources of electric power
- Imperative to transform from passive to active control in Distribution
- Dynamic pricing
- New ways for Distribution to become a Transmission resource
- Potential to transform transportation sector



Smart Grid Principal Characteristics

The Smart Grid will:

- Enable active participation by consumers
- Accommodate all generation and storage options
- Enable new products, services and markets
- Provide power quality for the digital economy
- Optimize asset utilization and operate efficiently
- Anticipate & respond to system disturbances
- Operate resiliently to attack and natural disaster

Smart Grid Key Success Factors

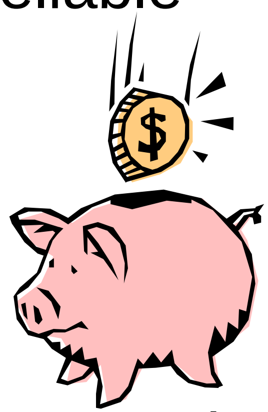
The Smart Grid is MORE:

Reliable

Secure

Efficient

Safe



Economic

Resilient

Environmentally Friendly

Context of Smart Grid

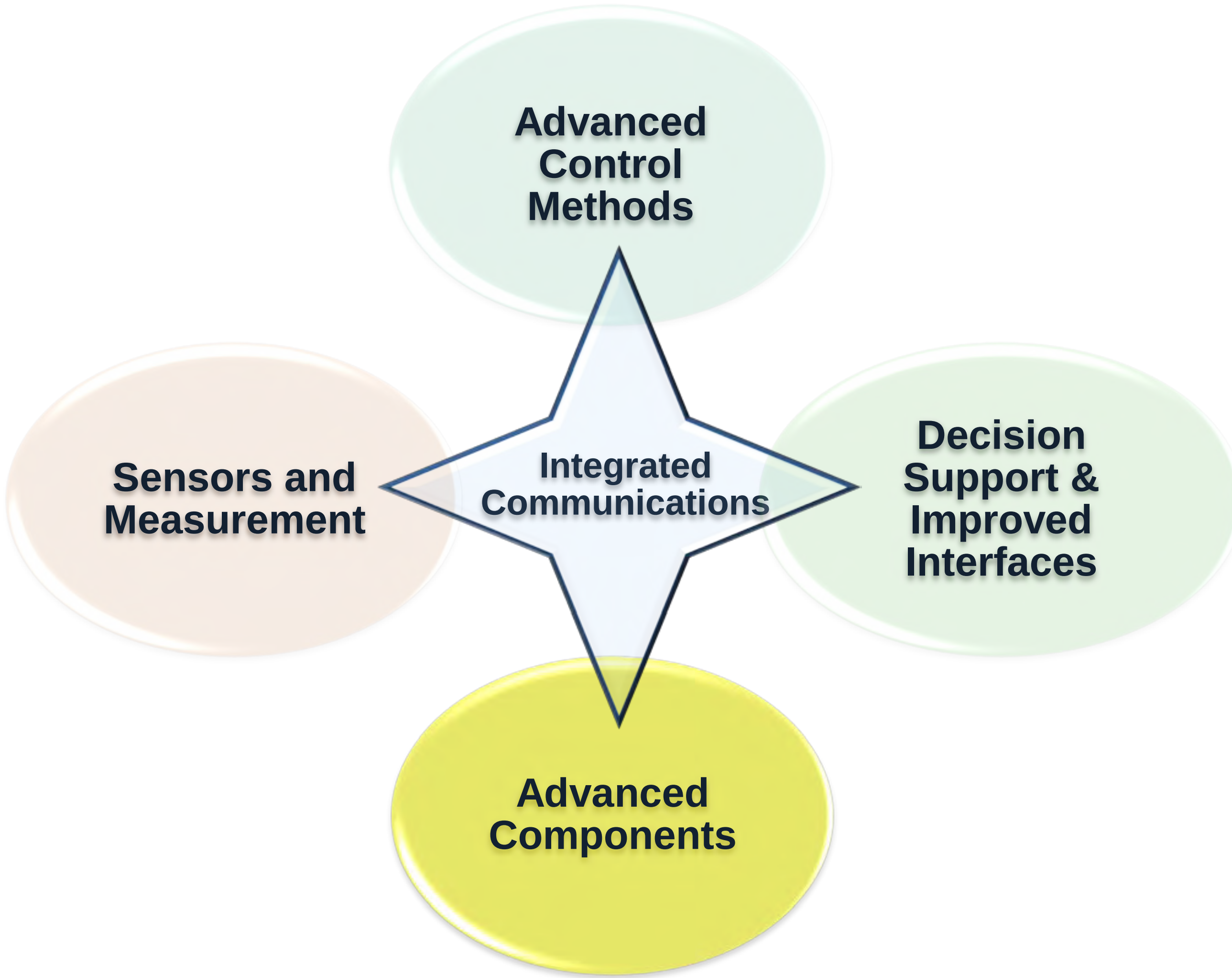
Smart Grid	Enhanced by Smart Grid

Two-way communications
Sensors
Controls
Decision support tools
Components
    Transformers
    Power electronics
    Conductors
	Renewable energy resources
	Electric vehicles
	Energy storage
	Distributed generation
	Grid friendly appliances/devices

Sensing, control, power transformation, and communications	***Generation, storage, and load***

Technologies

Smart Grid Technologies

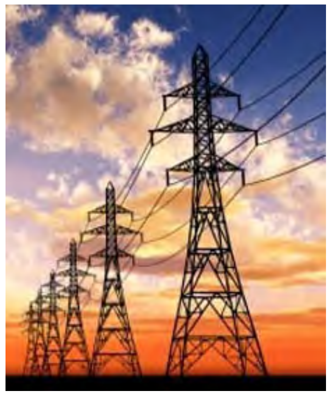


Electric Power System

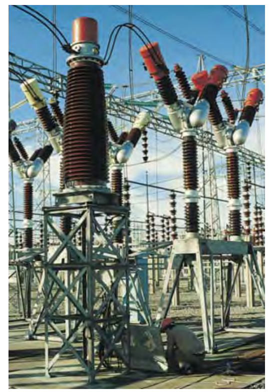
Markets, System Operators and Communications

Generation

Transmission



Substations



Distribution

Consumers

Coal
Gas
Nuclear
Hydropower
Wind
Solar
Geothermal
Utility-ScaleStorage

SynchroPhasor Tech
Dynamic Line Rating

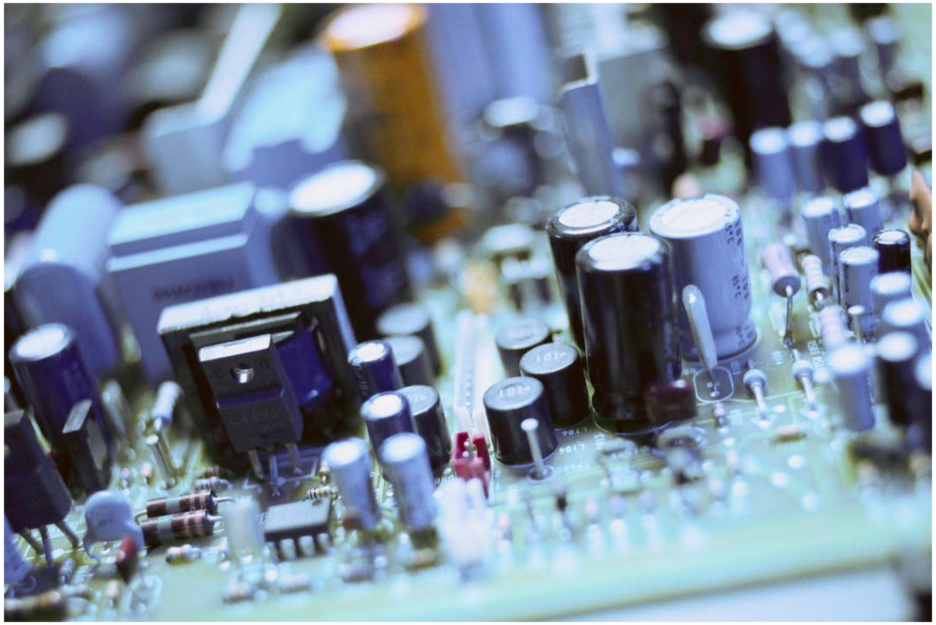
Solid State Transformers
Substation Monitor
Dissolved Gas Analysis
Fault Current Limiters
Smart Relays

Distribution Capacitors
SCADA Systems
Smart Switches/Reclosers
Automated Regulators
Distributed Generation
Energy Storage

Electric Vehicles
Home Area Network
In Home Device
Direct Load Control
Distributed Generation -(Wind, Solar, Combined Heat Power)
Smart Meters
Smart Appliances
Energy Storage

Power Electronics in T&D

- Flexible Alternating Current Transmission System devices (FACTS)
  - Unified power flow controller
  - DVAR/DSTATCOM (insulated gate bipolar transistor)
  - Static voltage regulator
- Static VAR compensator
- Solid state transfer switch
- DC/AC inverter
- Transformers
- Frequency conversion devices
- ***Applications***
  - *Voltage control*
  - *Power quality enhancement*
  - *Reactive power balance*
  - *Correct stability problems particularly long distance transfers*

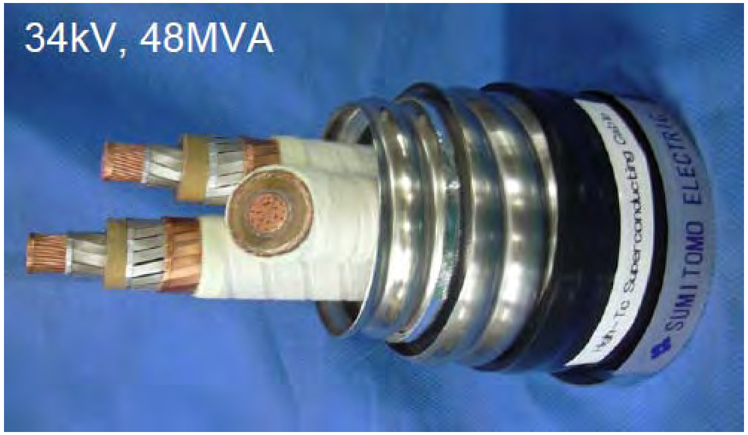


Power Electronics in HVDC

- *Applications*
  - *Coupling of asynchronous systems*
  - *Stability problems with long distanced energy transfer*
  - *Decrease short circuits in meshed systems*

Superconductivity

- First and Second Generation Wire
- HTS Cable



- *Applications*
  - *Magnetic energy storage*
  - *Synchronous condensers*
  - *Fault current limiters*
  - *Efficient motors*
  - *Lossless transmission lines*
  - *Short lines exiting from congested substations*
- *Benefits*
  - *Reactive compensation*
  - *Voltage regulation*
  - *Dynamic power factor correction*
  - *Flicker mitigation*

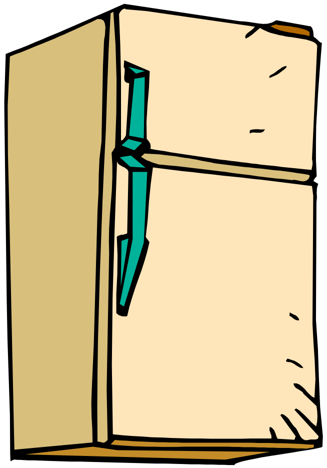
Composite Conductors

- Aluminum conductor composite core cable
- Aluminum conductor composite reinforced cable
- Annealed, aluminum, steel, supported, trapezoid cross-section conductor wire
- ***Benefits***
  - ***Increase power through existing ROW***
  - ***Reduce cable sag***
  - ***Reduce line losses***

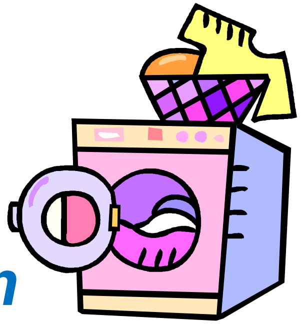
Distributed Energy Resources

- Microturbine
- Fuel Cell
- Photovoltaic (PV): “Solar Panel”
- Wind Turbine
- Energy Storage
  - Batteries (NaS, vanadium redox, ultracapacitor)
  - Compressed air
  - Flywheels
  - Pumped hydro

Grid Friendly Appliances



- Microelectronics
  - Cycle appliances on/off
  - Respond to price signals
  - Sense voltage and frequency



- ***Benefits***
  - ***Reduce peak load***
  - ***Stabilize frequency and voltage of system***

Applications and Functions

Smart Grid Functions

Sensing	Control	Protection
Wide Area Monitoring, Visualization, and Simulation	Power Flow Control	Fault Current LImiting
Diagnosis & Notification of Equipment Condition	Automated Feeder Switching	Dynamic Capability Rating
Real-Time Load Measurement and Management	Automated Islanding and Reconnection	Adaptive Protection
	Automated Voltage and VAR Control	Enhance Fault Protection
	Real-Time Load Transfer	
	Customer Electric Use Optimization	

Energy Storage Applications

Renewable Support	Investment Deferral	Ancillary Services	Load Management
Renewables Energy Time Shift	Electric Supply Capacity Deferral	Area Regulation	Electric Energy Time Shift
Renewables Capacity Firming	T&D Upgrade Deferral	Load Following	Transmission Congestion Relief
Wind Generation Grid Integration, Short Duration	Substation Onsite Power	Electric Supply Reserve Capacity	Time-of-Use Energy Cost Management
Wind Generation Grid Integration, Long Duration	Electric Service Reliability	Voltage Support	Demand Charge Management
		Electric Service Power Quality	
		Transmission Support	

Smart Grid Analysis Focus Areas

Peak Demand and Electricity Consumption
- Advanced Metering Infrastructure
- Pricing Programs and Customer Devices
- Direct Load Control

Operations and Maintenance Savings from Advanced Metering
- Meter Reading
- Service changes
- Outage management

Distribution System Reliability
- Feeder switching
- Monitoring and health sensors

Energy Efficiency in Distribution Systems
- Voltage optimization
- Conservation voltage reduction
- Line losses

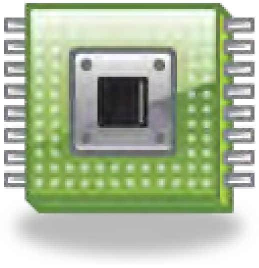
Operations and Maintenance Savings from Distribution Automation
- Automated and remote operations
- Operational Efficiency

Transmission System Operations and Reliability
- Application of synchrophasor technology for wide area monitoring, visualization and control

Materials Research

Materials Research

- High voltage capability
- Higher current
- High frequency tolerance
- Decrease size and weight
- Reduce ancillary equipment
- Reduce cost
- Higher operating temperature without cooling
- Longer life
- Faster sensing and switching speed
- Greater efficiency
- Better protection



Metrics and Benefits

Smart Grid Metrics

Reliability

- Outage duration and frequency, momentary disruption, power quality

Security

- Ratio of distributed generation to total generation

Economics

- Electricity prices & bills, transmission congestion costs, cost of outages

Efficient

- T&D electrical losses, peak-to-average load ratio

Environmentally Friendly

- Ratio of renewable generation to total generation, emissions per kwh

Safety

- Injuries and deaths to workers and public

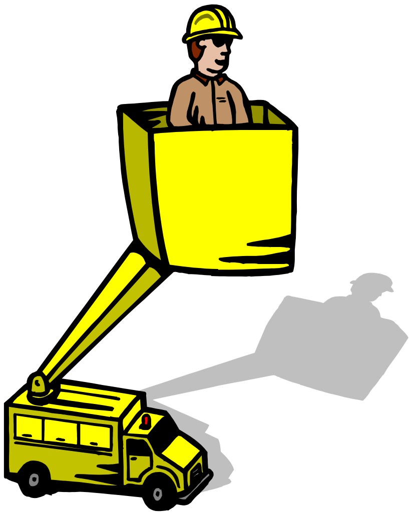
Field Data → Metrics → Benefits → Value

Who are the Beneficiaries?

- Utilities (What's in it for my shareholders?)
- Consumers (What's in it for me?)
- Society (What's in it for us?)

We get what we reward!

Utility Value Proposition



Opportunities

- Rate of return
- Operational Benefits
  - Outage restoration, billing, reduce T&D losses, optimize asset utilization, maintenance, planning
- Improved Customer Satisfaction
- May defer generation and transmission investments

Cost

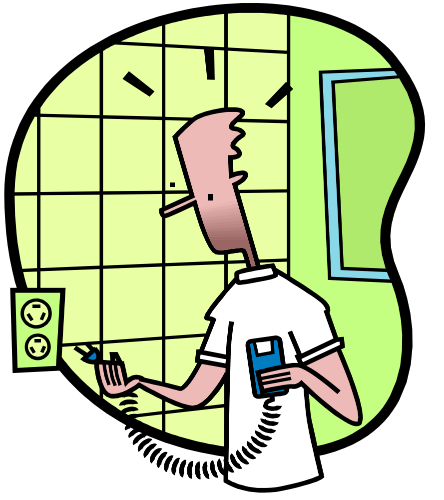
- Risk of cost recovery

Utilities are the engine for investment in Smart Grid

Consumer Value Proposition

Opportunities

- More reliable service
- Reduce business loss
- Energy bill savings
- Transportation cost savings
- Information, control, options
- Sell resources into the market

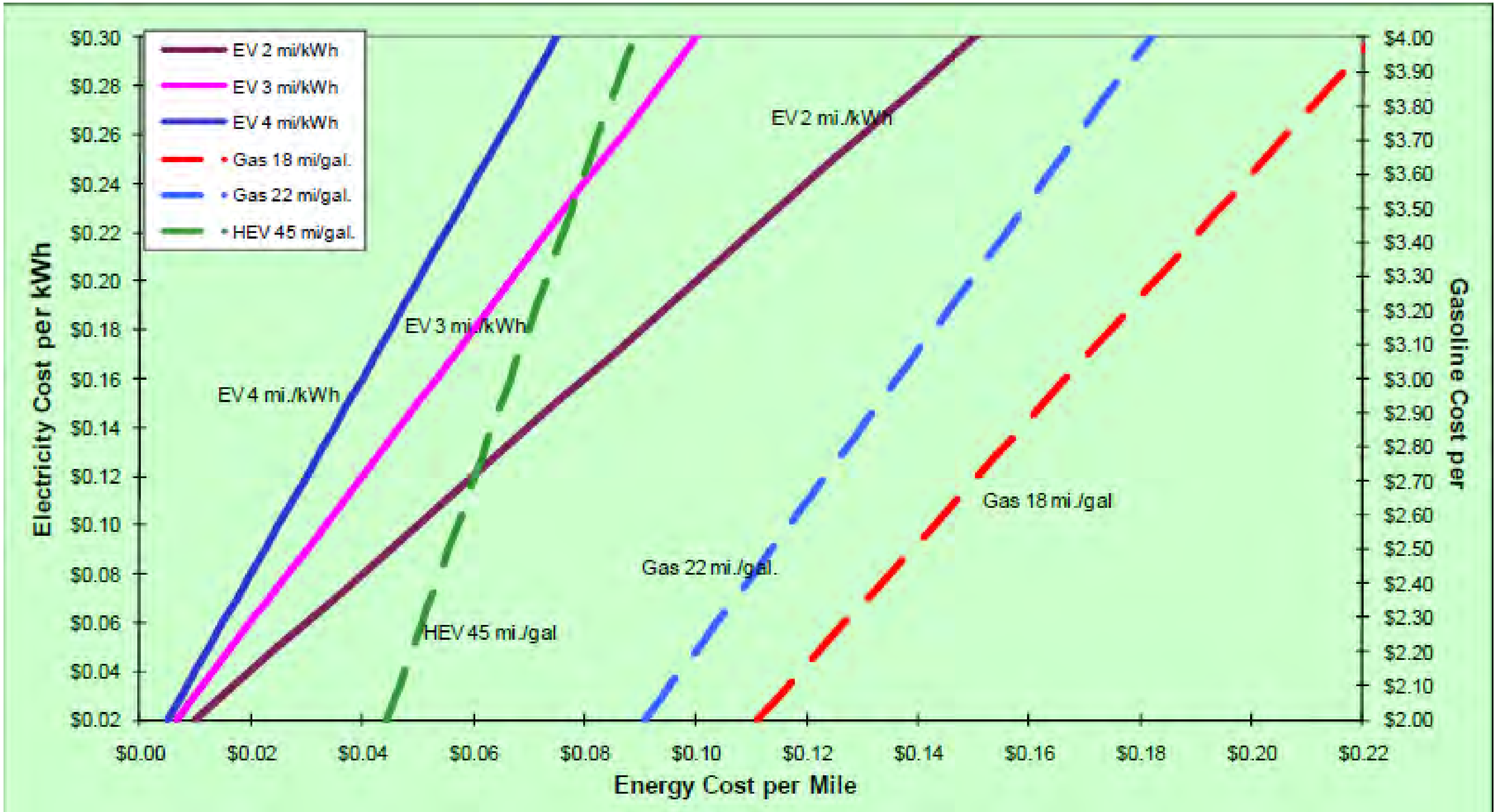


Cost

- "Consumer always pays"

Is this compelling?

"Fuel" Costs Per Mile for Electric Vehicles and Gasoline Vehicles



Idaho National Laboratory

Societal Value Proposition

Opportunities

- Downward pressure on electricity prices
- Improved reliability reducing consumer losses
- Increased grid robustness improving grid security
- Reduced emissions
- New jobs and growth in GDP
- Revolutionize the transportation sector
- Reduce import of foreign oil

Cost

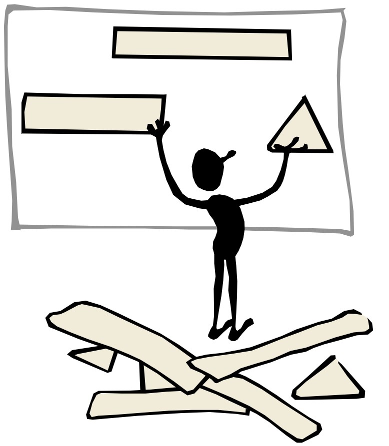
- No incremental cost?

Does the societal value proposition make it compelling?

Challenges

Change Management

A significant change management effort is needed:



- Why do we need to change?
- What is the vision?
- Who’s in charge?
- What is the value proposition?
- Consumer education, alignment, and motivation is critical
- Metrics needed for accountability and to monitor progress
- Active leadership by stakeholder groups needed

Move at the “Speed of Value”

Technical Challenges

- Interoperability and scalability
- Large number of consumers actively involved
- Decentralized operations with 2-way power flow
- Getting the communications right
- “Future proofing” the technologies
- Cyber Security
- Conversion of data to information to action
- Market driven

Where will we find the skilled resources to solve these?

Regulatory Challenges

- Time-based rates
- Clear cost recovery policies
- Policy changes that remove disincentives to utilities
- Societal benefits included in business case
- Increased utility commission workload
- Coordination among state utility commissions
- Future proofing vs. stranded assets
- Consumer privacy concerns
- Least cost
- Used and useful
- New operating and market models

Deployment and Demonstration Status

Smart Grid Activities

American Recovery and Reinvestment Act

- Smart Grid Investment Grants (99 projects)
  - $3.4 billion Federal; $4.7 billion private sector
  - 877 PMUs covering almost 100% of transmission
  - 200,000 smart transformers
  - 700 automated substations
  - 40 million smart meters
  - 1 million in-home displays
- Smart Grid Demonstration Projects (32 projects)
  - $620 million Federal; $1 billion private sector
  - 16 storage projects
  - 16 regional demonstrations

Smart Grid Activities (continued)

- **Additional ARRA Smart Grid Activities**
  - Interoperability Framework by NIST ($10M)
  - Transmission Analysis and Planning ($80M)
  - State Electricity Regulator Assistance ($50M)
  - State Planning for Smart Grid Resiliency ($55M)
  - Workforce Development ($100M)

- DOE Renewable & Distributed Systems Integration (9)
- EPRI Smart Grid Demonstrations (14 projects)

- Smart Grid System Report to Congress
  - http://www.smartgrid.gov/resources

Contact Information

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Smart Grid Implementation Strategy

www.netl.doe.gov/smartgrid/index.html

Federal Smart Grid Website

www.smartgrid.gov

Smart Grid Clearinghouse

www.sgiclearinghouse.org/

Office of Electricity Delivery and Energy Reliability

A Vision for the Smart Grid

Plugging America Into the Future of Power

A Vision for the Smart Grid

What is the Smart Grid?

Introduction

Many people are asking, "What is the Smart Grid?" Many more are trying to define it with short "sound bite" descriptions. These short statements cannot adequately convey the level of detail needed to provide a clear understanding. The Smart Grid isn't a "thing" but rather a "vision" and to be complete, that vision must be expressed from various perspectives - its values, its characteristics, and the milestones for achieving it.

Smart Grid Values

The transformation to the Smart Grid will require new investment and commitment by its many stakeholders. These stakeholders expect significant value in return. Understanding how this value will be created is an important step in defining the vision. Expectations for the Smart Grid are great and will be realized through advances in each of the six value areas described below:

It must be more reliable. A reliable grid provides power, when and where its users need it and of the quality they value.

It must be more secure. A secure grid withstands physical and cyber attacks without suffering massive blackouts or exorbitant recovery costs. It is also less vulnerable to natural disasters and recovers quickly.

It must be more economic. An economic grid operates under the basic laws of supply and demand, resulting in fair prices and adequate supplies.

It must be more efficient. An efficient grid employs strategies that lead to cost control, minimal transmission and distribution losses, efficient power production, and optimal asset utilization while providing consumers options for managing their energy usage.

It must be more environmentally friendly. An environmentally friendly grid reduces environmental impacts through improvements in efficiency and by enabling the integration of a larger percentage of intermittent resources than could otherwise be reliably supported.

It must be safer. A safe grid does no harm to the public or to grid workers and is sensitive to users who depend on it as a medical necessity.

Smart Grid Principal Characteristics

The Smart Grid can be considered a "transactive" agent. That is, it will enable financial, informational, as well as "electrical" transactions among consumers, grid assets, and other authorized users. Its functionality is defined by the following seven principal characteristics:

First, it will enable active participation by consumers. The smart grid will give consumers information, control, and options that enable them to engage in new "electricity markets." Grid operators will treat willing consumers as resources in the day-to-day operation of the grid. Well-informed consumers will modify consumption based on the balancing of their demands and resources with the electric system's capability to meet those demands.

Second, it will accommodate all generation and storage options. It will seamlessly integrate all types and sizes of electrical generation and storage systems using simplified interconnection processes and universal interoperability standards to support a "plug-and-play" level of convenience. Large central power plants including environmentally friendly sources, such as wind and solar farms and advanced nuclear plants, will continue to play a major role even as large numbers of smaller distributed resources, including Plug-in Electric Vehicles, are deployed.

Third, it will enable new products, services, and markets. The Smart Grid will link buyers and sellers together – from the consumer to the Regional Transmission Organization. It will support the creation of new electricity markets from the home energy management system at the consumer's premise to technologies that allow consumers and third parties to bid their energy resources into the electricity market. The Smart Grid will support consistent market operation across regions.

http://www.oe.energy.gov/

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Office of Electricity Delivery and Energy Reliability, OE-1

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