An Introduction to Smart Grid

CS 687

University of Kentucky

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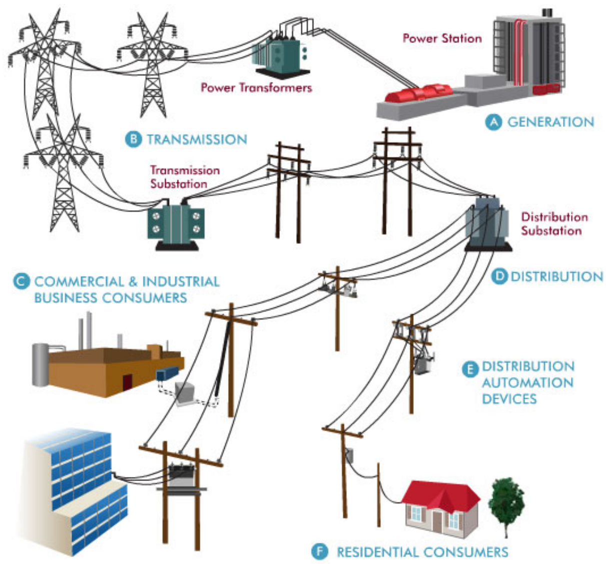
Outline

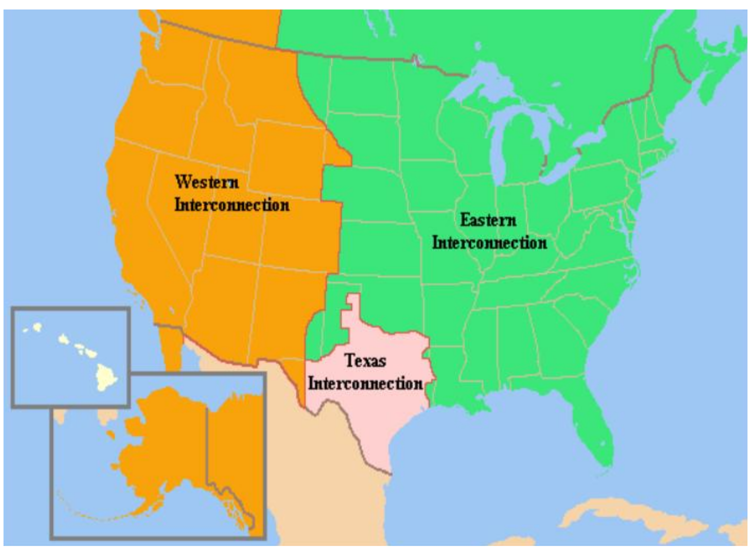
- Why Smart Grid?
- What is Smart Grid?
- Key Technologies of Smart Grid
- NIST Framework
- Examples

The Traditional Power Grid

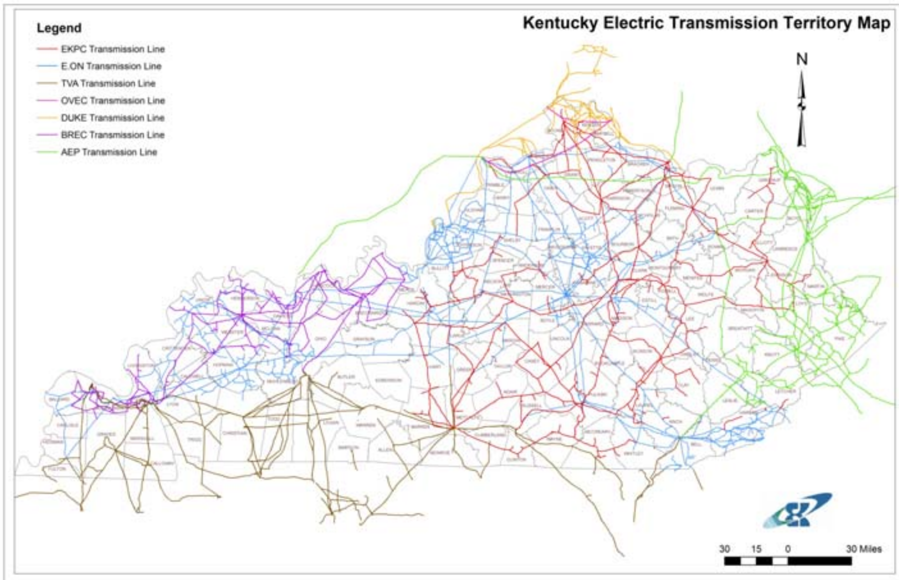


http://oncor.com/images/content/grid.jpg

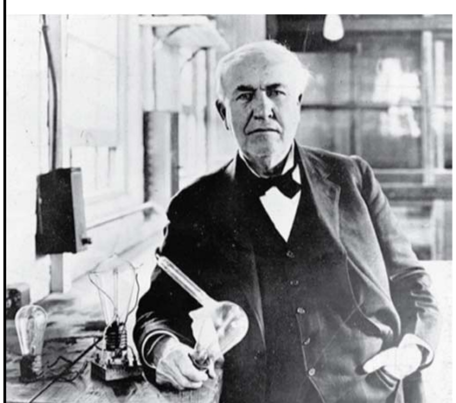
Nationwide Grid

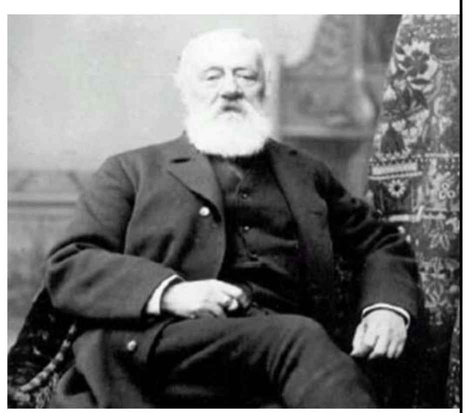


Kentucky Transmission One-Line Diagram



The case for REVITALIZATION





The case for REVITALIZATION

The story goes like this:

- If Alexander Graham Bell were somehow transported to the 21st century, he would not begin to recognize the components of modern telephony – cell phones, texting, cell towers, PDAs, etc.
- while Thomas Edison, one of the grid's key early architects, would be totally familiar with the grid.





Why Smart Grid?

- **RELIABILITY:** There have been five massive blackouts over the past 40 years, three of which have occurred in the past nine years. *Today's electricity system is 99.97 percent reliable, yet still allows for power outages and interruptions that cost Americans at least $150 billion each year.*
- **EFFICIENCY:** If the grid were just 5% more efficient, the energy savings would equate to permanently eliminating the fuel and greenhouse gas emissions from 53 million cars.
- **SECURITY:** The interdependencies of various grid components can bring about a domino effect.

Why Smart Grid? (cont)

- **ENVIRONMENT/CLIMATE CHANGE:** The United States accounts for only 4% of the world's population and produces 25% of its greenhouse gases. Half of our country's electricity is still produced by burning coal.
- **GLOBAL COMPETITIVENESS:** Germany is leading the world in the development and implementation of photo-voltaic solar power. Japan has similarly moved to the forefront of distribution automation through its use of advanced battery storage technology. The European Union has an even more aggressive "Smart Grids" agenda.

What Is Smart Grid? (NIST)

– By integrating an end-to-end, advanced communications infrastructure into the electric power system, a Smart Grid can provide consumers near real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers avoid higher energy bills.

– A Smart Grid uses information and communication technology to make the power grid more efficient, reliable, secure, and resilient while minimizing costly investments in new generation capacity.

What Is Smart Grid? (NIST)

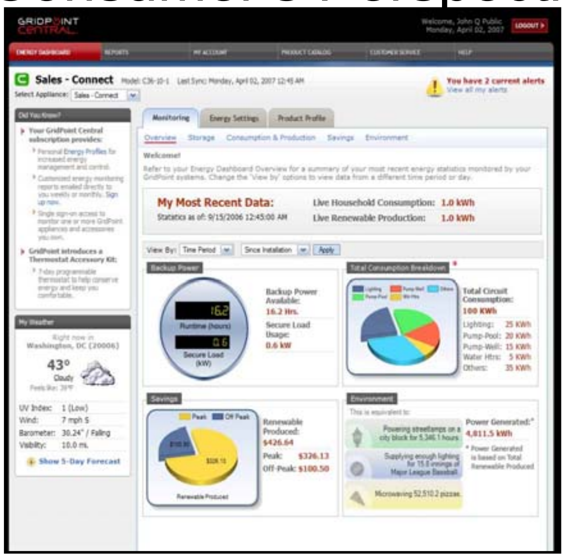
A more intelligent grid can

- support demand response (user participation)
- reduce the duration and frequency of power outages
- lower generation requirements by reducing inefficiencies in energy delivery
- facilitate efficient charging of electric vehicles
- better integrate wind and solar resources
- provide more effective management of distributed generation and storage.

Characteristics of Smart Grid (DoE)

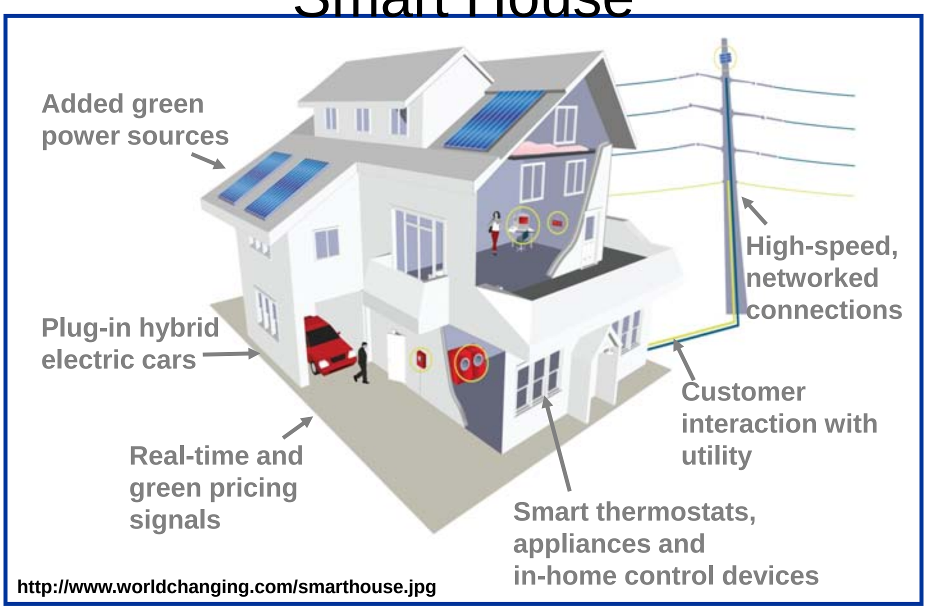
- Enables informed participation by customers
- Accommodates all generation and storage options
- Enables new products, services, and markets
- Provides the power quality for the range of needs
- Optimizes asset utilization and operating efficiently
- Operates resiliently to disturbances, attacks, and natural disasters.

A Consumer’s Perspective



Consumer participation [1]

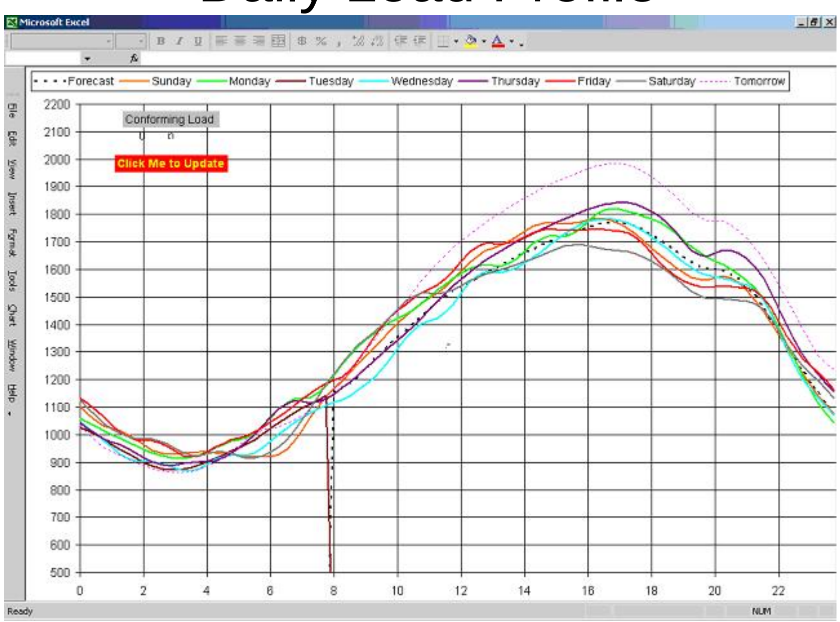
Smart House



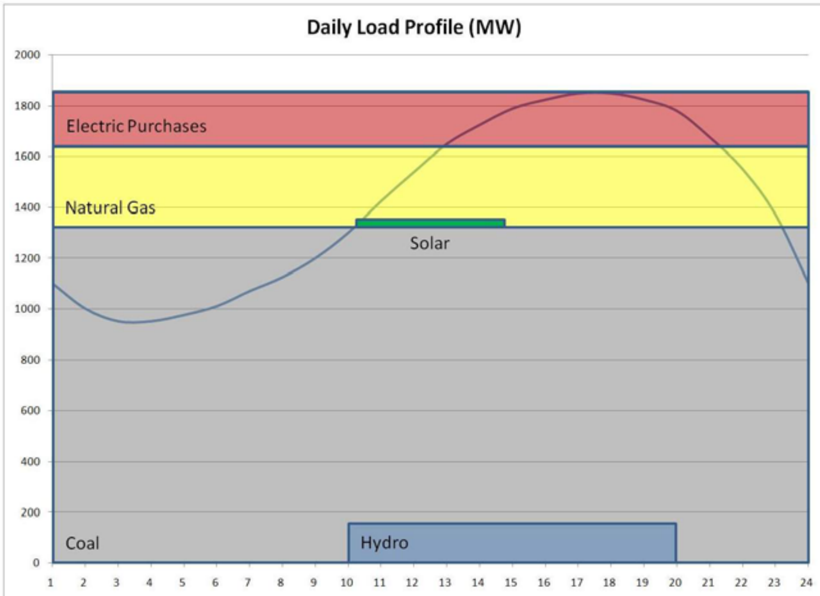
Demand Response

- Keep generation costs as low as possible
- Generation costs differ based on:
  - Construction costs
  - Fuel
    - Renewables
    - Hydro
    - Coal
    - Nuclear
    - Natural Gas
  - Purchases from foreign utilities

Daily Load Profile



Resource Dispatch



Peak Shaving

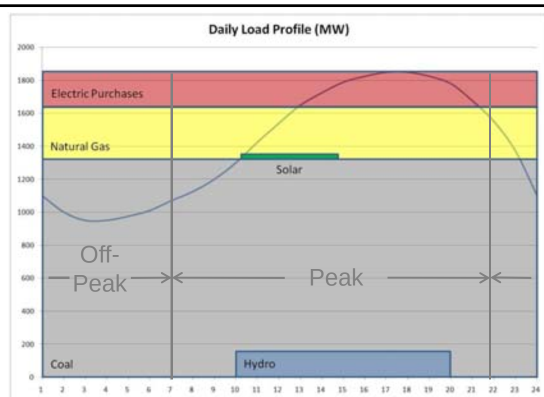
- Demand side management
  - Direct load control
    - Utility control of consumer appliances
- Dynamic pricing of electricity
  - Time of day rates
  - Time of use rates
  - Real time pricing
- Energy Storage
  - Pumped hydro
  - Battery

Direct Load Control

- Utility control of consumer appliances
  - Water heaters
  - HVAC / Thermostats
  - Hot tub and pool pumps
  - Commercial refrigerators
  - Compressed air

- Participation incentive
  - Water heaters: $10 annually per unit
  - HVAC - Customer choice:
    - $5 / month from June through September
    - Programmable thermostat

Dynamic Pricing



- Time of day rates
  - More expensive during peak hours (daytime)
  - Less expensive during off-peak hours (night time)
- Time of use rates
  - Bill based on actual costs during time of consumption
- Real time pricing
  - Firm price for energy posted in advance

Distributed Generation

- Most often renewable energy sources
- Includes energy storage systems
- Generation at load centers
  - Integration with utility infrastructure
  - Distribution level voltages
- Reduced system losses
- Defer / delay construction
- Micro-grid concept

Tom Lowery - Winchester, KY
Clark Energy Net Metering Customer

Energy Storage

- Charge during off-peak hours; discharge during on-peak hours
- Store renewable based energy
- Provide backup power
- Respond to and mitigate voltage fluctuations
- Provide uninterruptable power
- Ride through momentary outages
- Defer / delay utility infrastructure construction

Energy Storage
Technologies

- Pumped hydro
  - Two reservoirs at two different elevations
  - Produce hydro power during on-peak hours
  - Pump water back to upper reservoir during off-peak hours
  - Use of nuclear or coal power for pumping
- Compressed air
  - Same principle as pumped hydro
  - Use of underground caverns
- Flywheels
  - Short duration
  - Transportation?
- Utility scale battery systems
- Electric vehicles (cars)?

Pumped Hydro

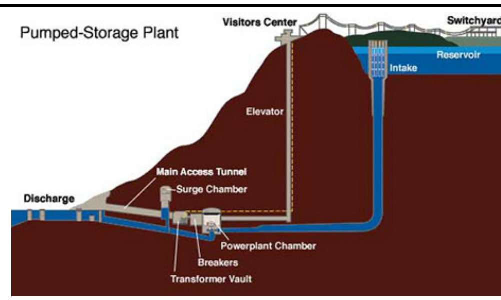


Diagram of TVA Raccoon Mountain

Seawater Pumped Hydro
Okinawa, Japan

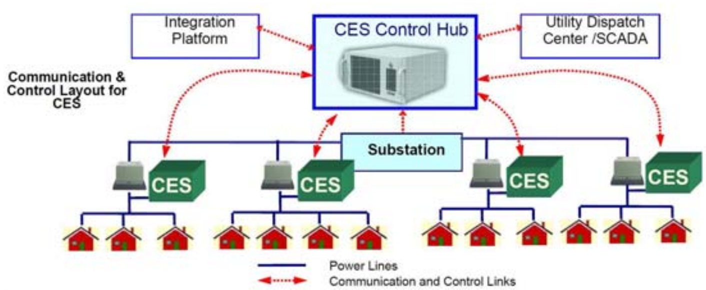
LaMuela, Spain (635 MW)

Utility Scale Battery Systems

- American Electric Power
  - US DOE Sandia National Lab
- 4 MW
  - 80, 50 kW units
  - 4 MW continuous for 8 hours
  - 25 MWh
- NAS sodium sulfur battery system
- Commissioned March 2010
- Gonzales Substation in Texas
- $25M
  - Remember: It doesn't produce power!

AEP Battery Storage Systems

Residential Scale Battery Systems



- Residential with or without DG
- Though distributed, aggregated with over-riding control system
- Responds to substation demands
- Both pad mount and pole top units available

AEP Battery Storage Systems

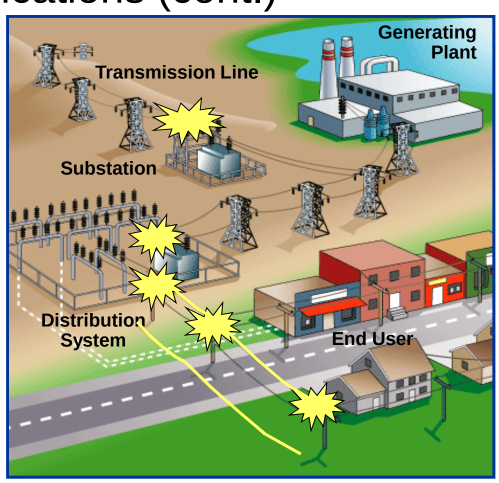
Key Technologies

https://www.sgiclearinghouse.org/Technologies

- Integrated communications
  - Fast and reliable communications for the grid
  - Allowing the grid for real-time control, information and data exchange to optimize system reliability, asset utilization and security
  - Can be wireless, powerline or fiber-optics
  - For wireless
    - Zigbee
    - WiMAX
    - WiFi

Key Technologies

- Integrated communications (cont.)
  - Broadband over Powerlines
    - Provide for two-way communications
  - Monitors and smart relays at substations
  - Monitors at transformers, circuit breakers and reclosers
  - Bi-directional meters with two-way communication



[1]

Key Technologies

- Sensing and measurement
  - Smart meter technology, real time metering of:
    - Congestion and grid stability
    - Equipment health
    - Energy theft
    - Real time thermal rating
    - Electromagnetic signature measurement/analysis
    - Real time pricing
  - Phasor measurement units (PMU)
    - Real time monitor of power quality
    - Use GPS as a reference for precise measurement

Key Technologies

- Advanced components
  - Flexible AC transmission system devices
  - High voltage direct current
  - Superconducting wire
  - High temperature superconducting cable
  - Distributed energy generation and storage devices
  - Composite conductors
  - “Intelligent” appliances

Key Technologies

- Power system automation
  - Rapid diagnosis and precise solutions to specific grid disruptions or outages
  - Distributed intelligent agents
  - Analytical tools involving software algorithms and high-speed computers
  - Substation Automation

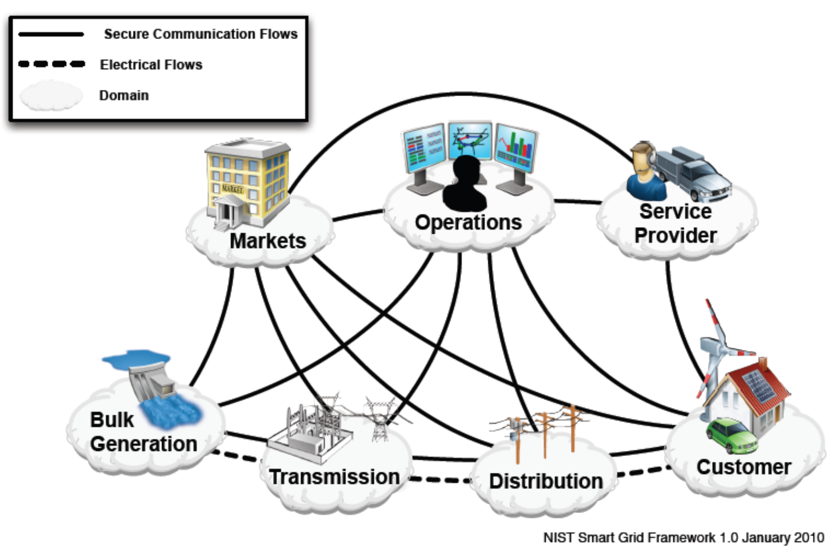
Key Technologies

- Improved Interfaces and Decision Support
  - Consumer gateway and portal
  - Grid friendly appliance controller
  - Power transmission/distribution analysis software
  - Distributed Energy Resources Controller
  - Microgrid control software

IEEE P2030 Task forces

- IEEE P2030 project defined three task forces:
  - TF1: Power Engineering Technology
  - TF2: Information Technology
  - TF3: Communications Technology

NIST Framework



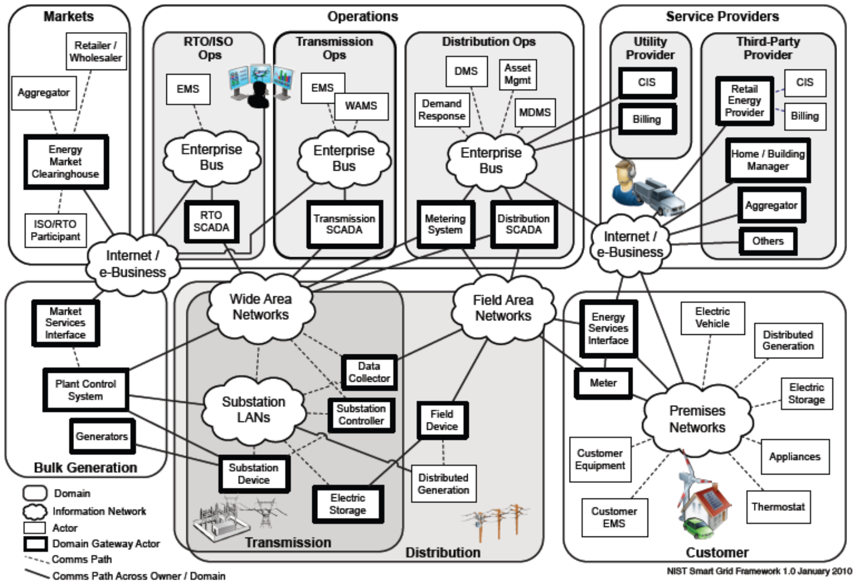
Domains and Actors

- **Customers** -- The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
- **Markets** -- The operators and participants in electricity markets.
- **Service Providers** --The organizations providing services to electrical customers and utilities.

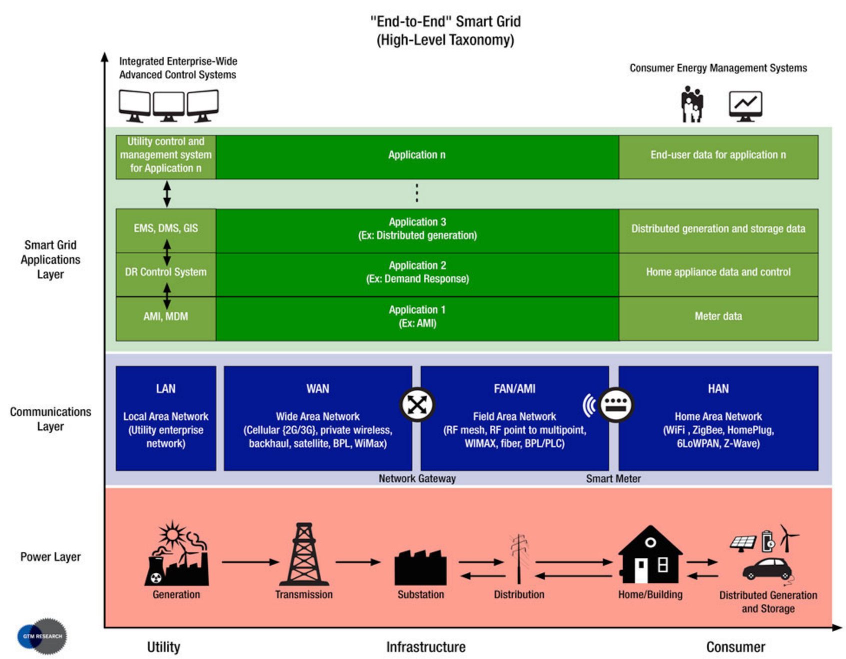
Domains and Actors (cont)

- **Operations** -- The managers of the movement of electricity.
- **Bulk Generation** -- The generators of electricity in bulk quantities. May also store energy for later distribution.
- **Transmission --** The carriers of bulk electricity over long distances. May also store and generate electricity.
- **Distribution** -- The distributors of electricity to and from customers. May also store and generate electricity

NIST Framework

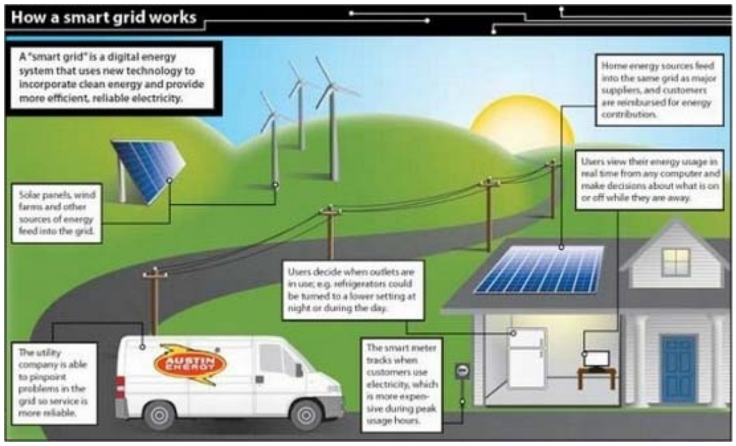


End-to-End Smart Grid (High-Level Taxonomy)



Current Example applications

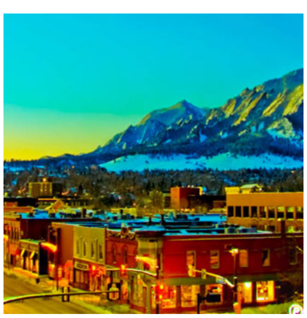
- Austin, Texas, 1st Smart Grid city in US

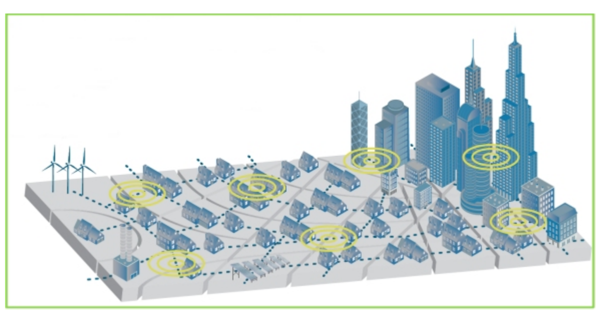


http://www.inhabitat.com/wp-content/uploads/15-grid-537x324.jpg

Current Example applications

- Xcel Smart City in Boulder

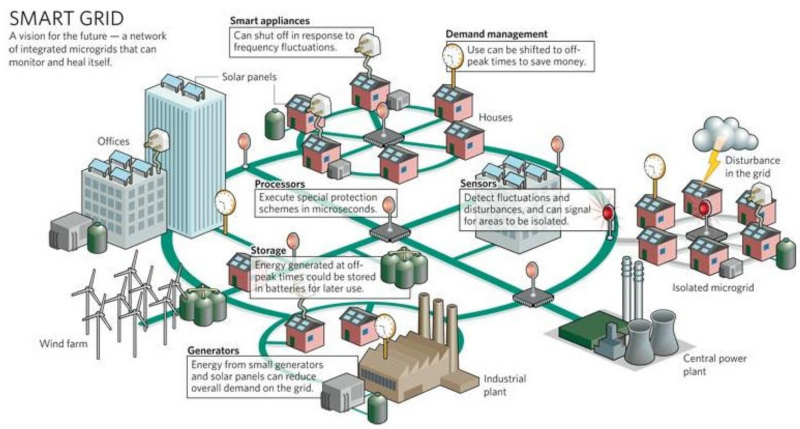




http://smartgridcity.xcelenergy.com

Current Example applications

- Energy Smart Miami



http://tinycomb.com/wp-content/uploads/2009/05/smart-grid.jpg

Current Example applications

- GE “Plug into the Smart Grid”

http://ge.ecomagination.com/smartgrid