Distributed Computer Systems Engineering

CIS 508: Lecture 13
Computing for Sustainability

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Masdar INSTITUTE CIS

This Course so far …

- *Lectures*
  - Distributed database
  - Cloud computing
  - Embedded systems
  - Mobile networks
  - Peer-to-peer systems, …
- *Labs*
  - Android
  - AWS
  - Arduino
  - Raspberry Pi
- *Broad Applications*
  - Sustainability?

Sustainability?

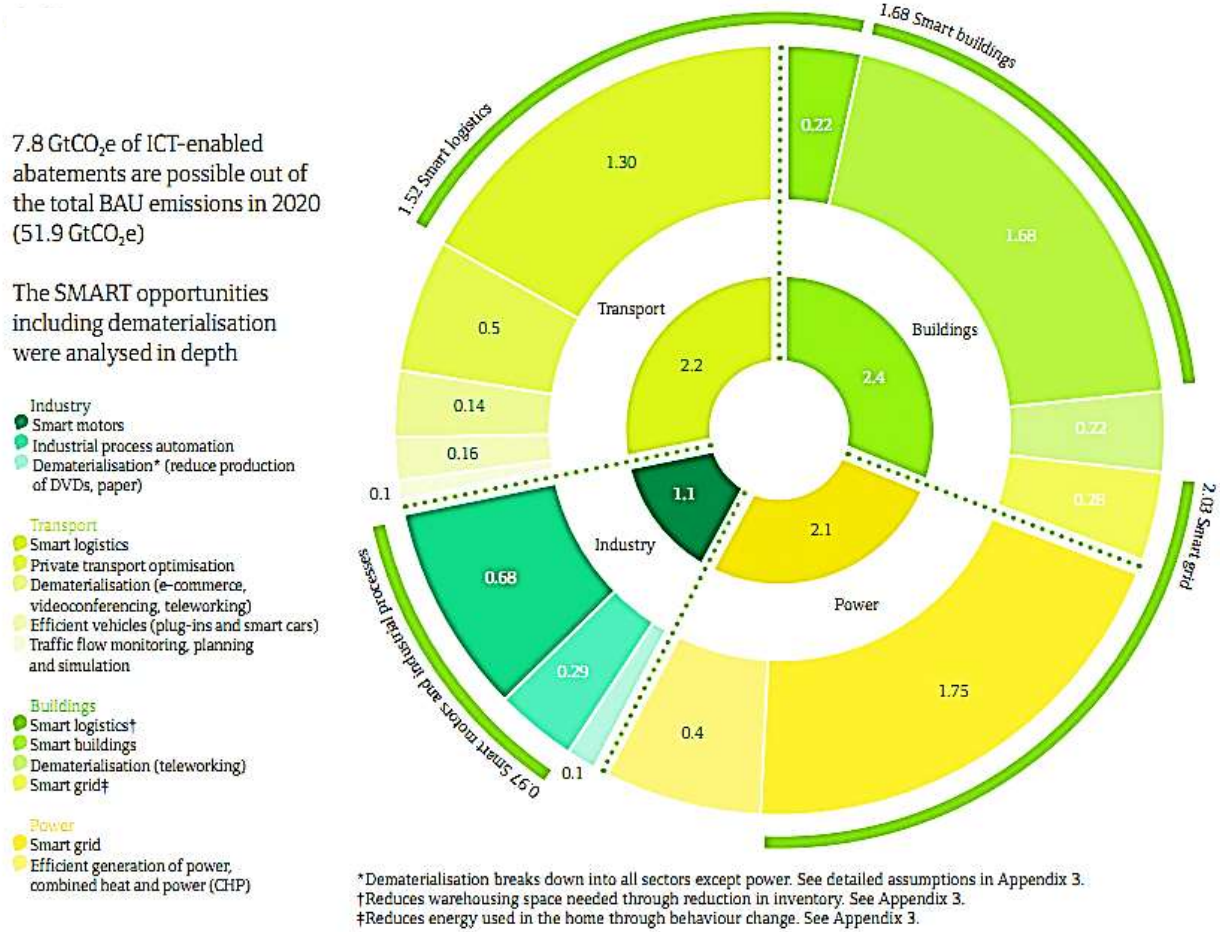
- *What is Sustainability*
  - Dwindling resource, galloping demands, serious impacts of pollutions
  - Balancing and optimizing resources and demands, reducing impacts of pollutions
  - New technology for new harvesting resources and energy efficiency is not sufficient
  - Missing: a new mindset for sustainability
  - New intelligence empowered by computation

What can ICT help

- *Connectivity*
  - Effective communication between supply and demand
- *Optimization*
  - Efficient identification and optimization of resource rapidly and dynamically
- *Prediction*
  - Advanced planning supported by user behavior prediction and data mining/pattern discovery
- *Pervasiveness*
  - Embedding intelligence in smart objects to organize themselves efficiently and automatically

How ICT reduces CO_2 Emissions

- Information & communication technology (ICT) can enable significant CO_2 emissions reductions (7.8 $GtCO_2e$ in 2020)



GeSI
GLOBAL e-SUSTAINABILITY INITIATIVE

How ICT reduces CO_2 Emissions

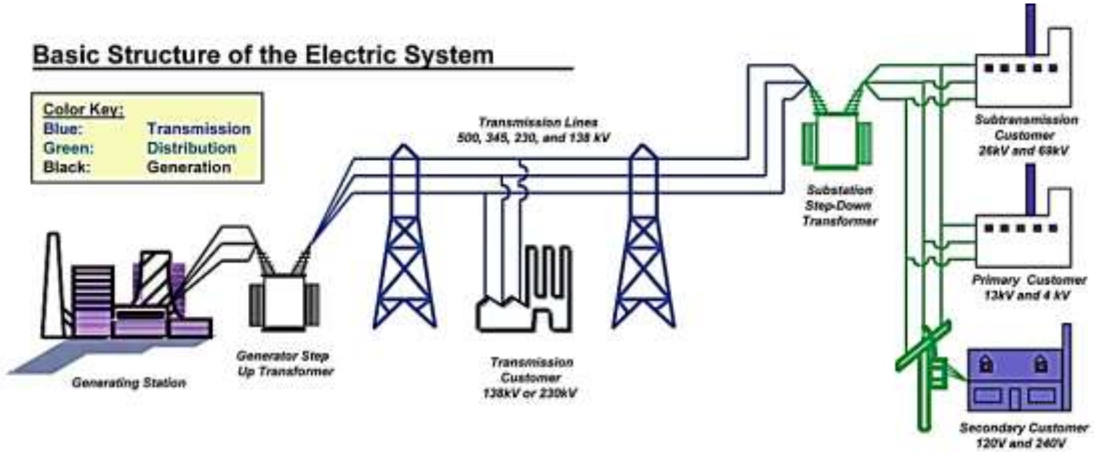
- **Smart Grids**: Improving the efficiency of utility grids (electricity, gas, water)
  - Saving 2 $GtCO_2e$ in 2020
- **Smart Buildings**: Making buildings more energy-efficient
  - Saving 1.7 $GtCO_2e$ in 2020
- **Smart Logistics**: Improving the efficiency of transport and inventory
  - Saving 1.5 $GtCO_2e$ in 2020
- **Smart Motors and Industrial Processes**: Reducing power consumption in industry
  - Saving 1 $GtCO_2e$ in 2020
- **Dematerialisation**: Replacing physical activities by virtual activities
  - Saving 0.5 $GtCO_2e$ in 2020

Notable Applications

- ***Smart Grids***
  - Smart metering infrastructure
  - Integration of renewable energy
- ***Smart Buildings***
  - Building management systems
- ***Smart Transports***
  - Fuel-efficient telematics and car-sharing optimization
- *Recycling and Waste Management*
  - Classification and redistribution of used components
- *Pollution Sensing*
  - Tracking and tracing pollution sources

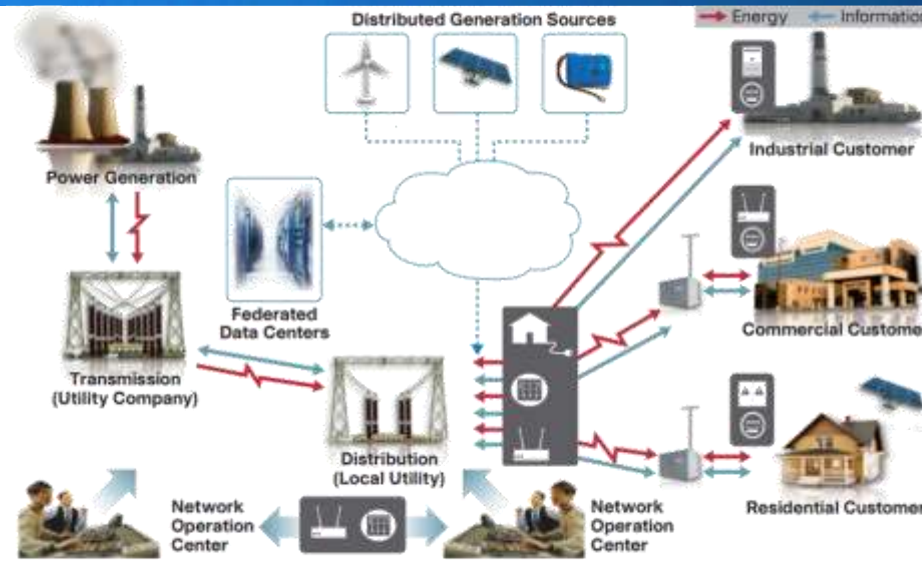
Smart Grids

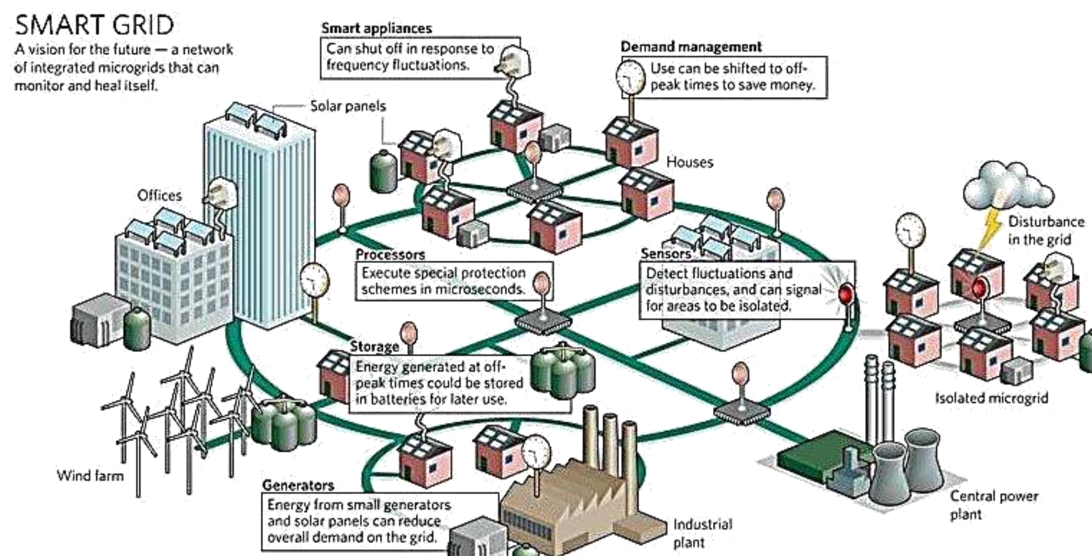
- Power system: A century old system
  - *"If Alexander Graham Bell were transported to the 21st century, he would not begin to recognize the components of modern telephony, while Thomas Edison, one of the grid's key early architects, would be totally familiar with today's grid."*
  - Hierarchical
  - One-way distribution
  - Centralized generation
  - Static topology
  - Limited uncertainty
  - Centralized control



Smart Grids

- Smart Power Grids
  - Information-centric
  - Two-way communication
  - Distributed control
  - Dynamic load balancing and islanding
  - Distributed power generation
  - Disruption withstanding



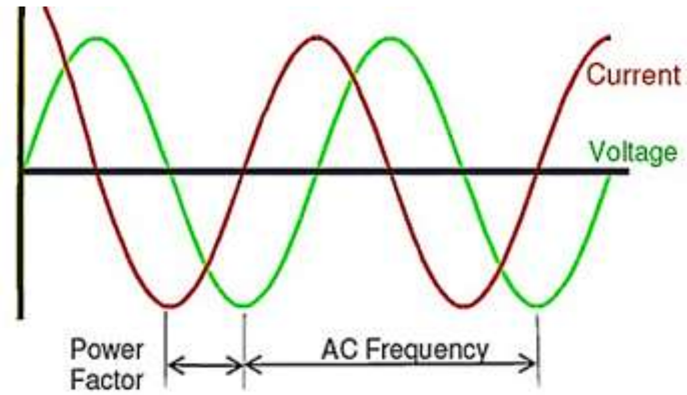


Internet and Grid

- The concepts and technologies pioneered by the Internet can make fundamental contributions to the architecture and operations of the future grid
- The Internet and the grid designed to solve similar problems
  - Matching geographically distributed supplier
- Future grid that features
  - Tens of millions of distributed and variable renewable
  - Energy sources
  - More flexible (elastic) end-devices
  - vastly more storage
  - The use of communication technologies both to allow precise matching of supply to demand and to incentivize appropriate consumer behavior

AC Power 101

- **Alternating Current Power**
  - Circular motion of dynamo generator
    ⇒ Periodic current & voltage
  - Phase between current and voltage
- **Power Stability**
  - Frequency is not always constant
    - Changes according to load and supply
  - If supply from generators cannot match demand
    - Frequency drops, generators overloaded
  - Not always perfect sinusoid-shape
    - Require active monitoring & shaping



Power System Monitoring

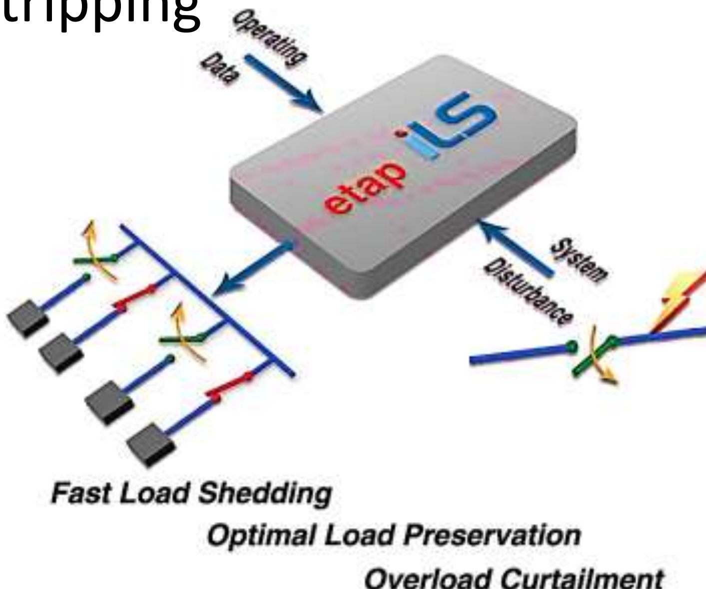
- **State Estimation/Measurement**
  - Measuring bus voltage and line currents at the substations
  - Coordinating power flows to minimize generation and transmission loss
  - Determine available transfer capability
- **PMU (phasor measurement unit)**
  - Instruments to sample bus voltage and line currents at high frequency
  - Synchronized by GPS
  - Estimate power quality and harmonics

Power System Protection

- ***Monitoring of apparent impedances***
  - Transmission parameters should not be static as the assumed system conditions change
  - By PMU measuring apparent impedance crosses threshold, notify changes in power systems
- ***Intelligent load shedding***
  - Using PMU measurements at tie-line flows to evaluate if there is an electric fault
  - Devise anticipatory plans
  - Increase in power inflow, generating load shedding
  - Require fast computations for decision making

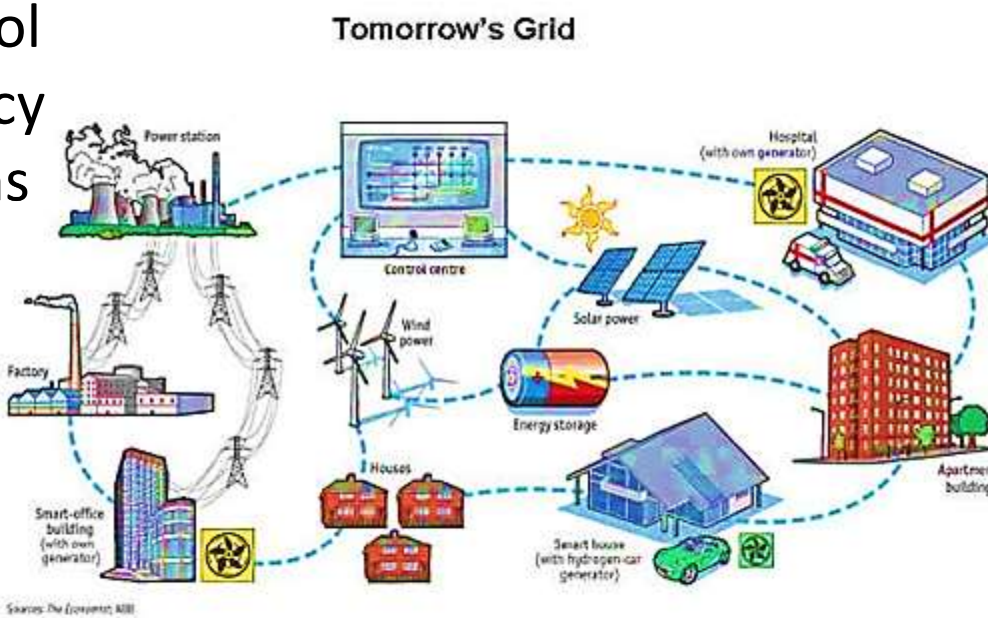
Power System Protection

- ***Intelligent Islanding***
  - Islanding is possible isolation of power grid without connecting to main electricity supply
  - Identify candidate islands which can balance
  - May require Intelligent Load Shedding
  - Should block undesirable out-of-step tripping
  - When out-of-step tripping is desired, use predetermined action plans from simulations
  - Require intelligent control and planning of operations



Smart Grid Communication

- ***Effective Communication to support smart grid operations***
  - Hard end-to-end guarantee for delivery
  - Future-proof design, amortize cost
  - Multicast as normal mode of communication
  - Wide range of QoS (e.g. latency, rate, criticality)
  - Transient stability and control usually need ultra low latency (half/full power cycle 8-16ms for US)
  - Extremely high throughput (720Hz sampling)



SCADA Systems

SCADA (supervisory control and data acquisition)

- *Computer-controlled system that monitors and controls industrial processes (e.g. power plant, oil refinery facilities)*
- Components of a SCADA system:
  - ***Field Data Interface Devices***
    - Remote Terminal Units (RTUs)
      - RTUs convert sensor signals to digital
    - Programmable Logic Controllers (PLCs)
      - PLCs to automate monitoring and control of industrial facilities
  - ***Communications Network***
  - ***Central Host Computer***
  - ***Operator workstations***

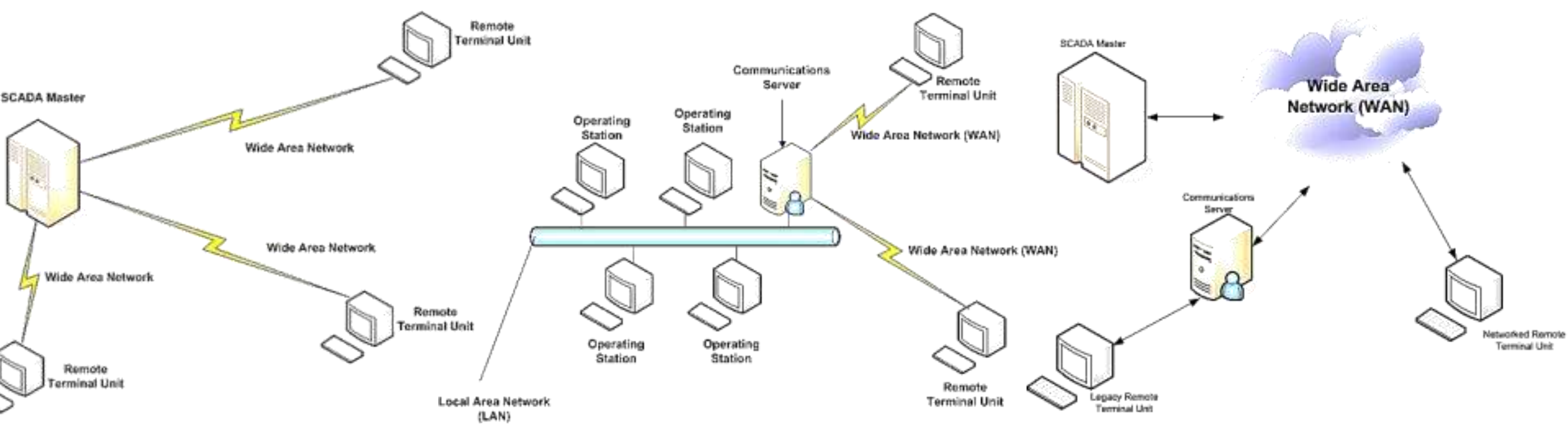
SCADA Systems

Components of SCADA system

- ***Field Data Interface Devices***
- ***Communications Network***
  - Channel between the central host servers and field-based RTUs
  - SCADA LANs could be integrated into existing LAN/WAN networks, instead of a dedicated SCADA network
- ***Central Host Computer***
  - Processes data to/from human operators from RTUs
  - Possible to deploy on servers and easily integrate with existing systems
- ***Operator workstations***
  - Clients that request and send information to the master station
  - Provides an operator interface

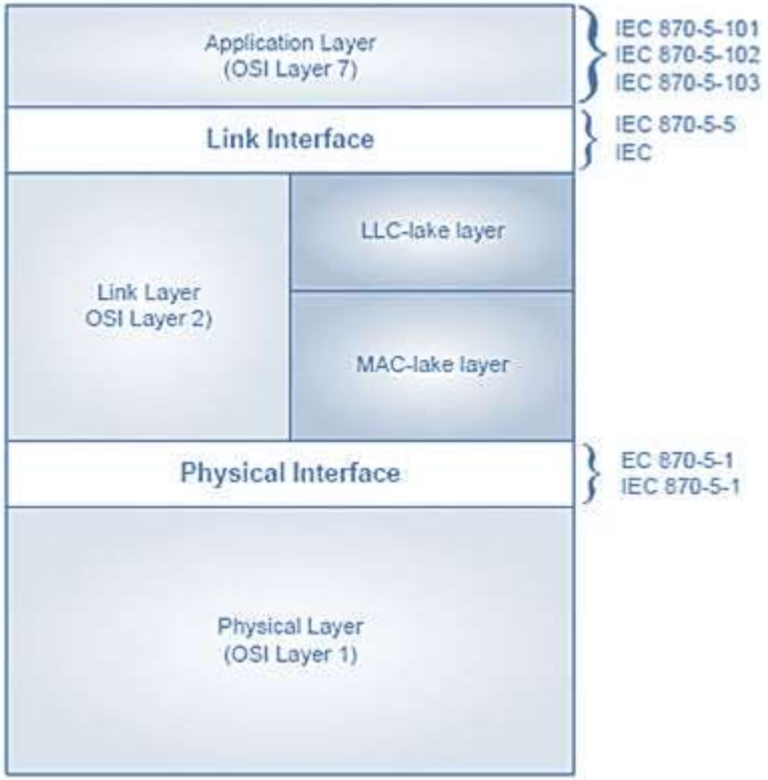
SCADA Architectures

Monolithic	Distributed System	Networked System
• Mainframe system • Propriety protocols, adapters, controllers • Backup mainframe requiring for reliability	• LAN technology allows a distributed master station • LAN (master station), WAN (RTUs) still proprietary • More processing power • Increased reliability	• Current generation Master station functions shared • ‘Open’ system • 3rd-party peripheral devices • IP protocol used for communication • Disaster survivability



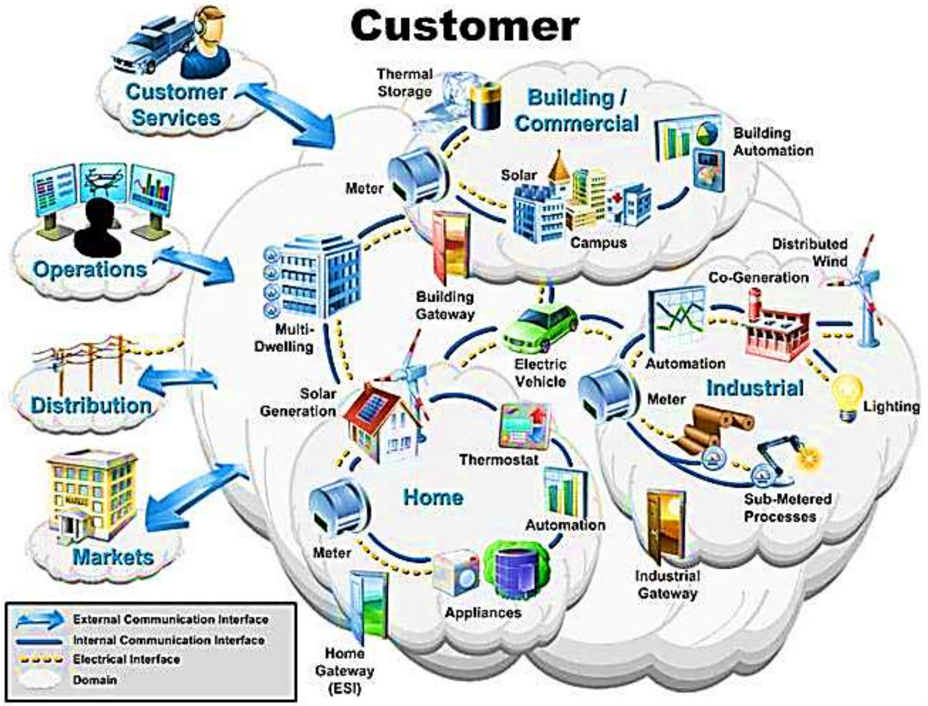
SCADA Protocols

- RTU Addressing Scheme
  - Responsibility of Master Station
- Poll/response format
- Two widely used SCADA protocols:
  - International Electrotechnical Commission (IEC) IEC 60870-5-101
  - Distributed Network Protocol version 3 (DNP3)



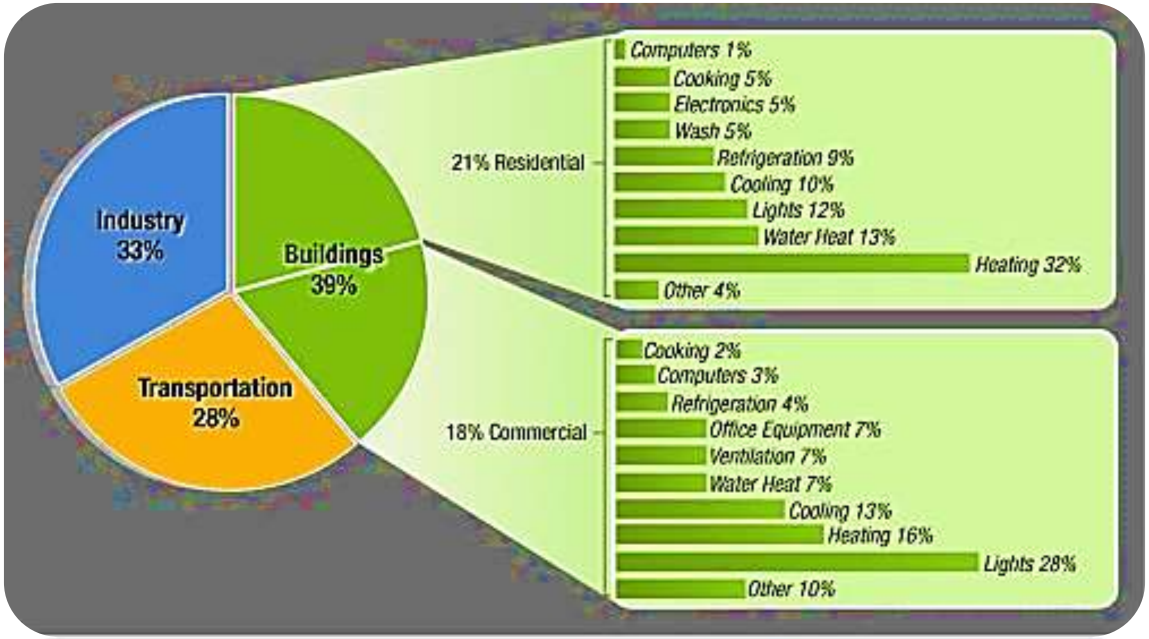
Top 5 Research Topics in Smart Grids

1. Smart Grid Sensing, Control, Decision Systems
2. Application-specific Smart Grid Communication Network
3. Smart Grid Measurement and Analytics
4. Renewable Energy and Energy Storage Management and Optimization
5. Smart Grid Cyber Security

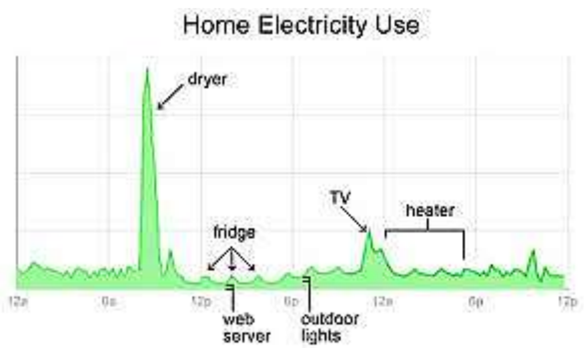


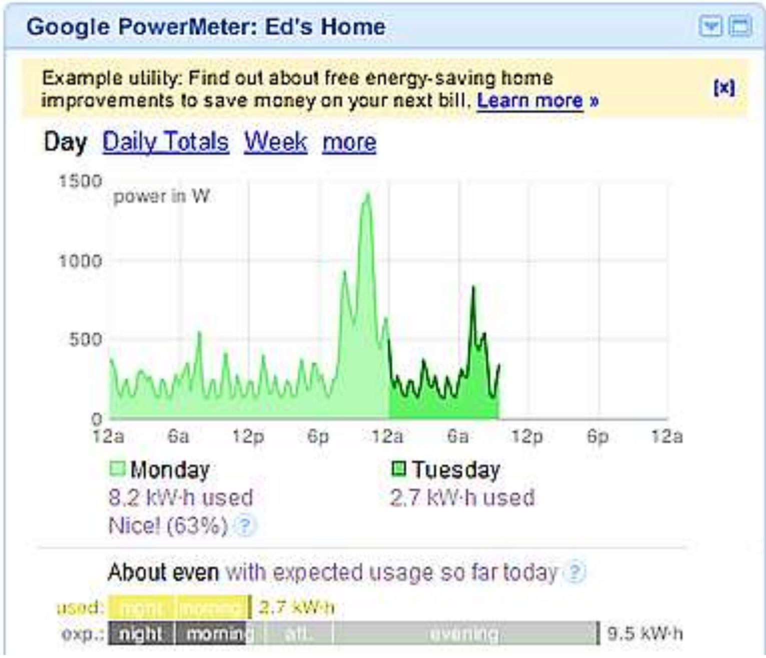
Smart Buildings

- **Buildings** account for about 40 % of total US **energy consumption** (costing $350 billion per year) and greenhouse gas emissions

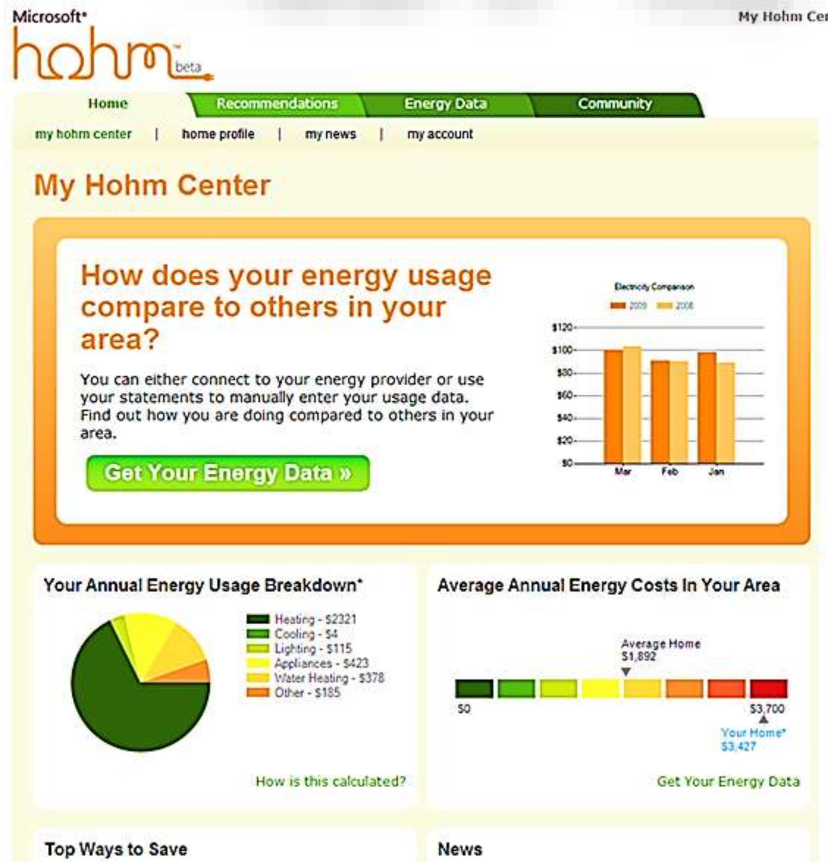


Smart Home

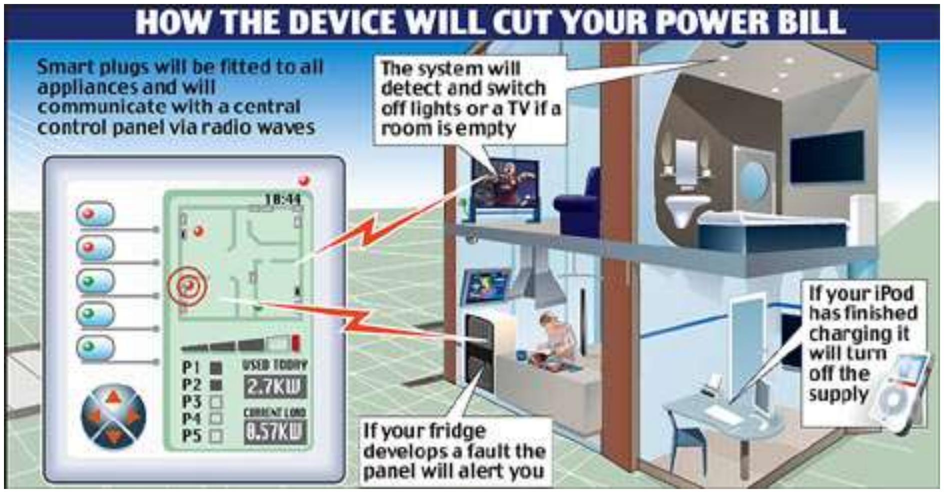




Microsoft hohm beta



Smart Plugs

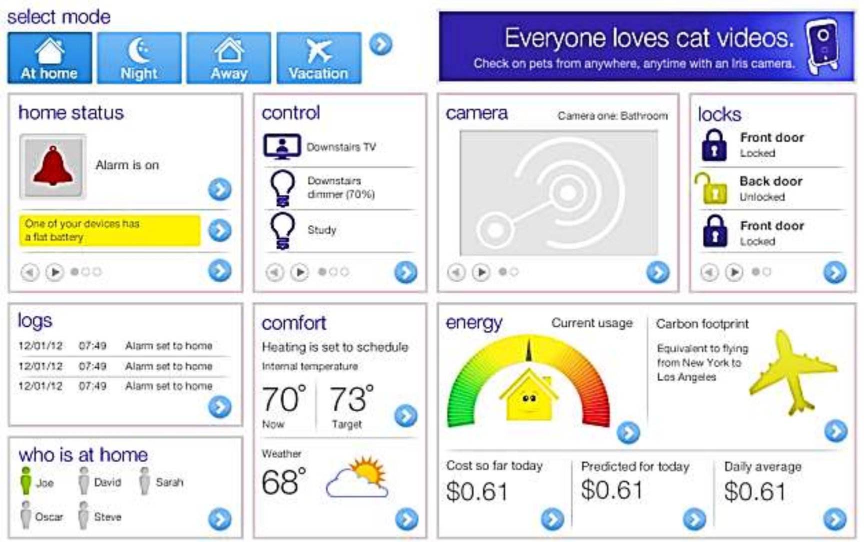


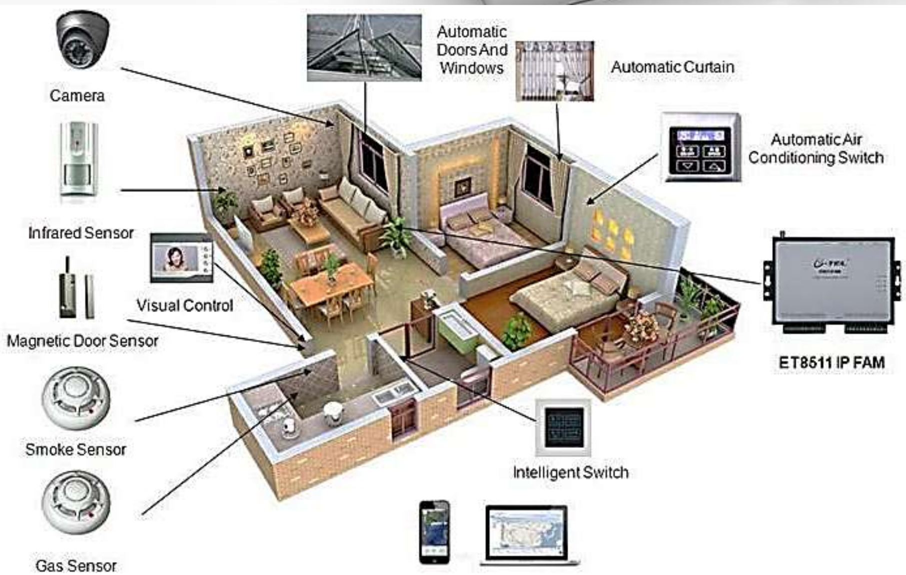
- Wireless connected power outlets
- Track consumption pattern and preference
- Context-based control
- Shut down "sleeper" appliance
- Remote control
- Predict and optimize consumption
- $30-$60

Smart Light Blubs

- Wireless connected light bulbs (Bluetooth)
- Mobile App controllable
- Changing colors
- $50-$80

Smart Home Sensors





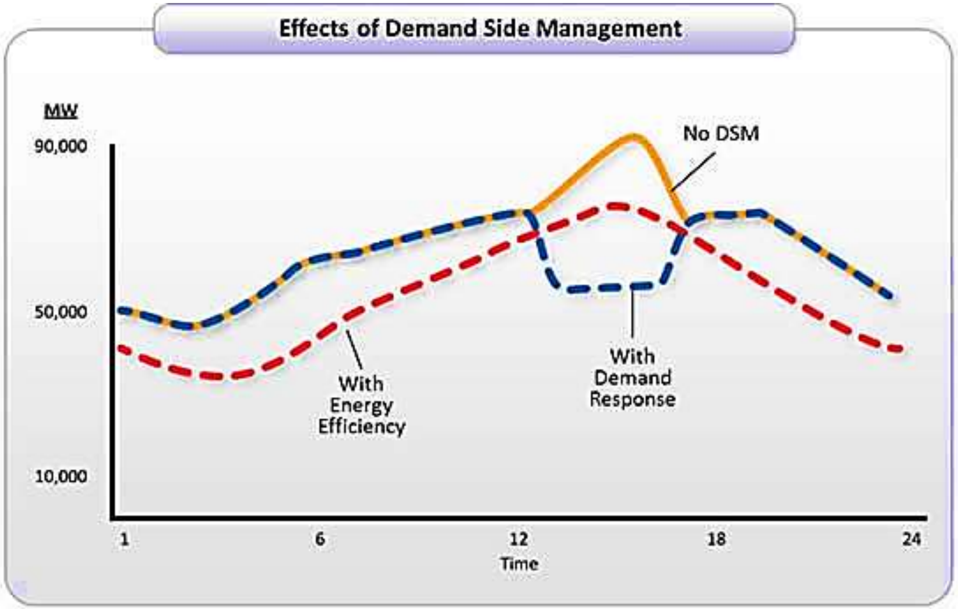
- Suite of wireless connected sensors
- Cameras, security/activity/hazard sensors, RF tags
- Plug-and-play
- Mobile App controllable
- May require subscription
- $50-$300

Smart Thermostats

- Nest: Intelligent thermostat
- Predict user’s demand
- Learn occupant’s preference
- Acquired by Google for $3.2B

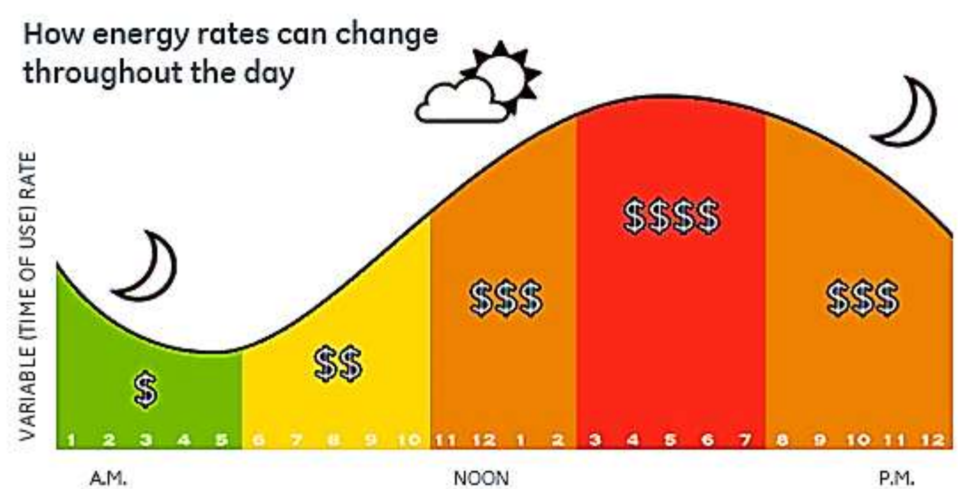
Demand-Side Energy Management

- Techniques to control building's energy footprint
  - Respond to energy availability
    - Manual
    - Automatic
- Components of DSEM
  - Load monitoring
  - Load shedding
  - Load shifting
    - Reduce peak usage
    - Battery



Demand-Side Energy Management

- Benefits of Peak Load Reduction
  - For utilities:
    - Infrastructure savings
    - Lower operating cost
    - Less carbon emissions
    - Transmission & distribution
  - For consumers:
    - Cost savings
    - Reliable grid

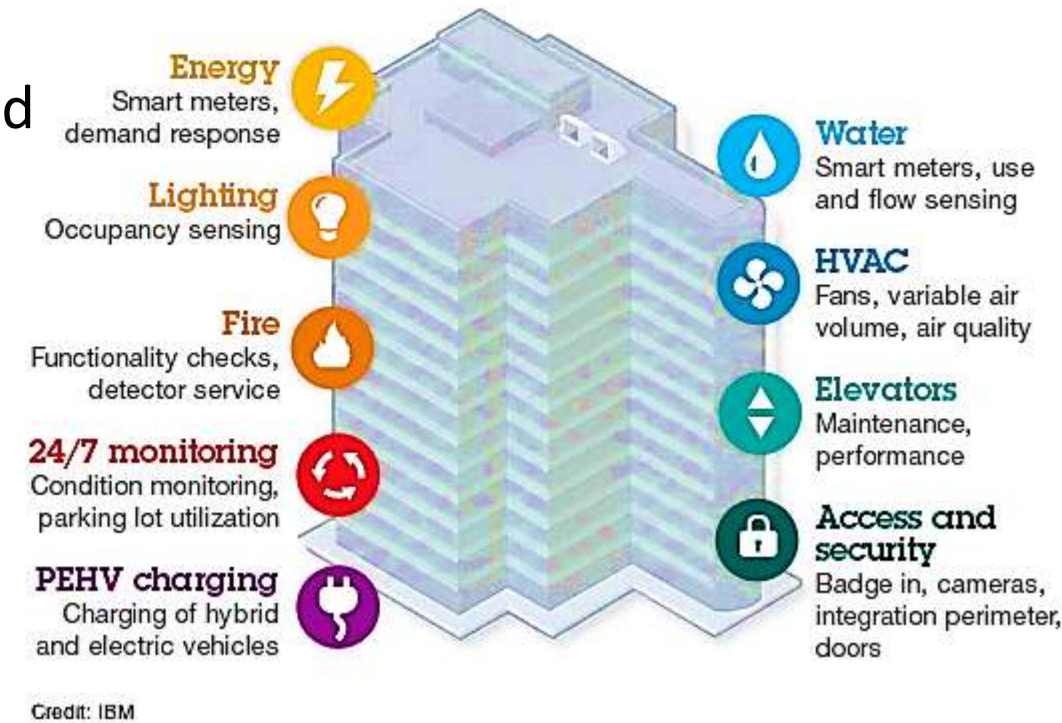


Demand-Side Energy Management

- Measuring energy consumption in buildings
  - Building-level Sensors
    - eGauges
      - Measures aggregate consumption (every second)
    - TED
  - Outlet-level Sensors
    - Insteon meters/switches
      - Polled every 10 seconds
      - AC-power lines and RF communication
    - Z-Wave devices
      - Control appliances wirelessly
      - Use low-power radio waves (900 MHz)
    - Kill-A-Watt

Top 5 Research Topics in Smart Buildings

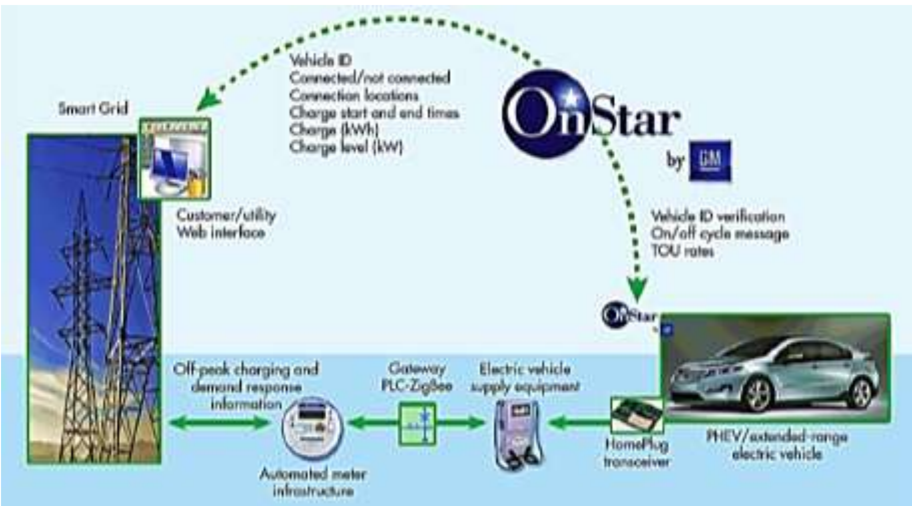
1. Demand-side energy management
2. Intelligent HAVC sensing and control
3. Occupancy and activities prediction and learning
4. Coordination and optimization of Appliances
5. Electric vehicle charging optimization

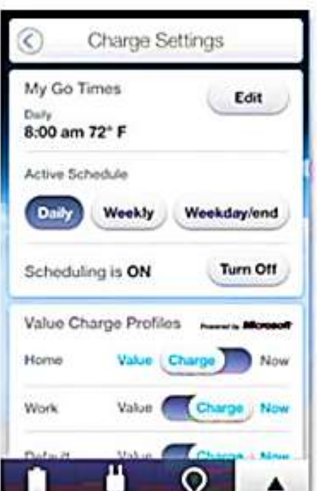


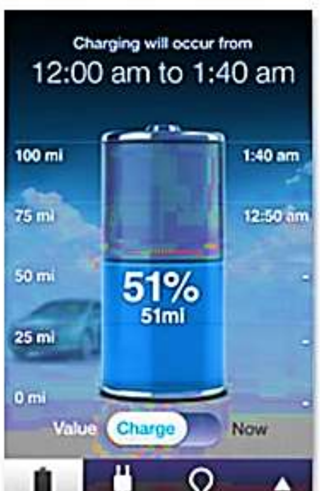
Smart Transports

- Vehicles and transport systems take up 20-25% of energy consumption and CO2 emissions
- Exhaust and greenhouse gas emissions contribute to local air pollution and smog
- Vehicles becoming highly intelligent, computerized and network-enabled systems
- Transportation systems need an overhaul

Electrification

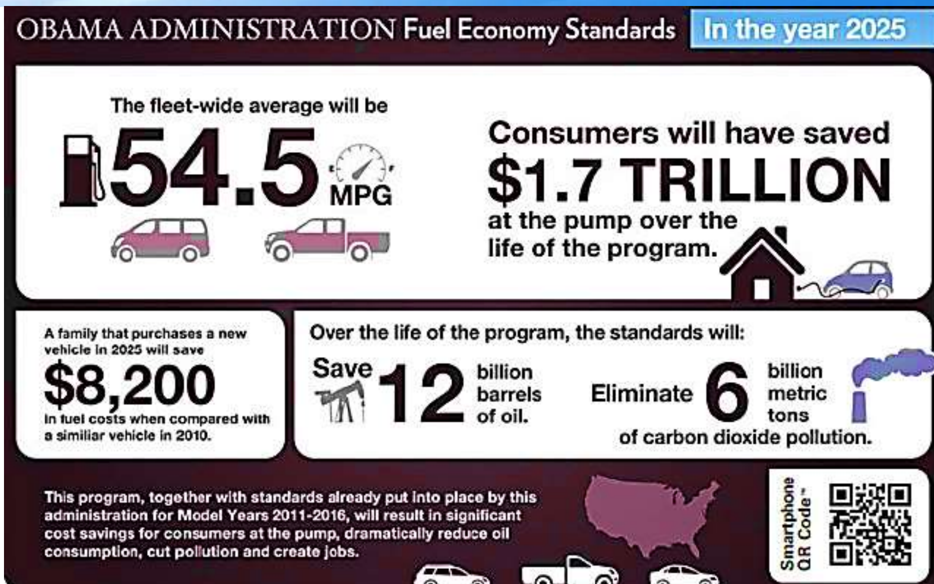






- Major effort to convert fossil fuel powered vehicles to alternative energy powered
  - Electric vehicles, fuel cell
- California's new clean-air regulations: 1 in 7 cars sold in 2025 are plug-ins or full EVs
- Optimize and manage the charging processes of EVs
  - When, how much to charge
  - Demand response management
- Predict EV driving range

Fuel Economy



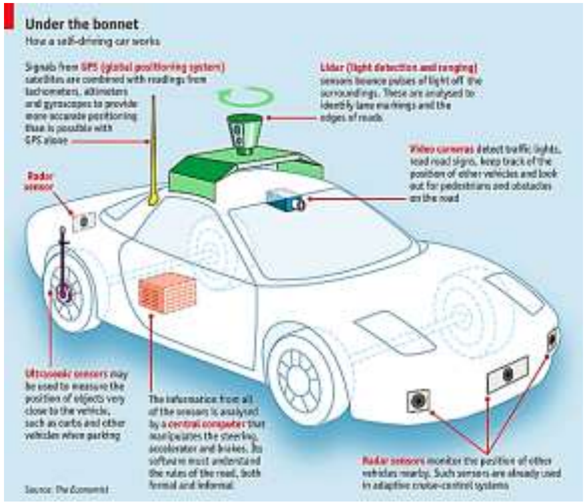
- Improve fuel economy
  - All new vehicles sold in U.S. must have 54.5 mpg in 2025, up from 29.7 now and 35.5 mpg by 2016
- Coach driving behavior for fuel economy
  - Braking, Cornering
  - Useful for accident alert and auto insurance
- Fuel efficiency telematics
  - Avoiding stops

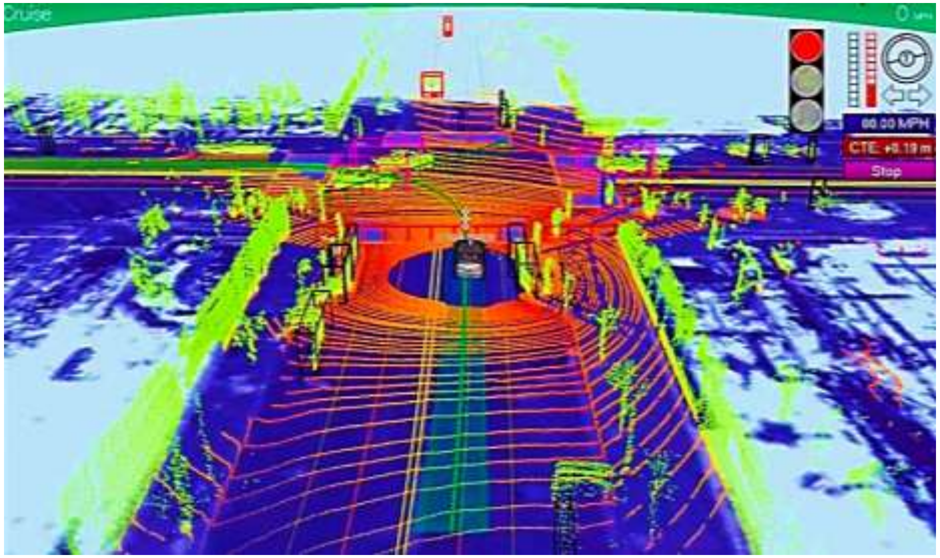
Car/Ride-Sharing

- Demand for private vehicles still strong, especially in China, India
  - Cars outdated faster nowadays
  - Cost of ownership increases
- Car-sharing
  - Flexibly car renting
  - New business model Uber
  - Everyone can taxi-driver
- Rider-sharing, carpooling
  - Matching and cost allocation
  - Economizing and incentivizing drivers and passengers

Top 5 Research Topics in Smart Transports

1. Control and Planning of Autonomous Driving Vehicles
2. Optimization and Management of Electric Vehicles
3. Vehicular Apps
4. Management of Car/Ride-Sharing
5. Driving Behaviour Tracking, Analysis, Coaching

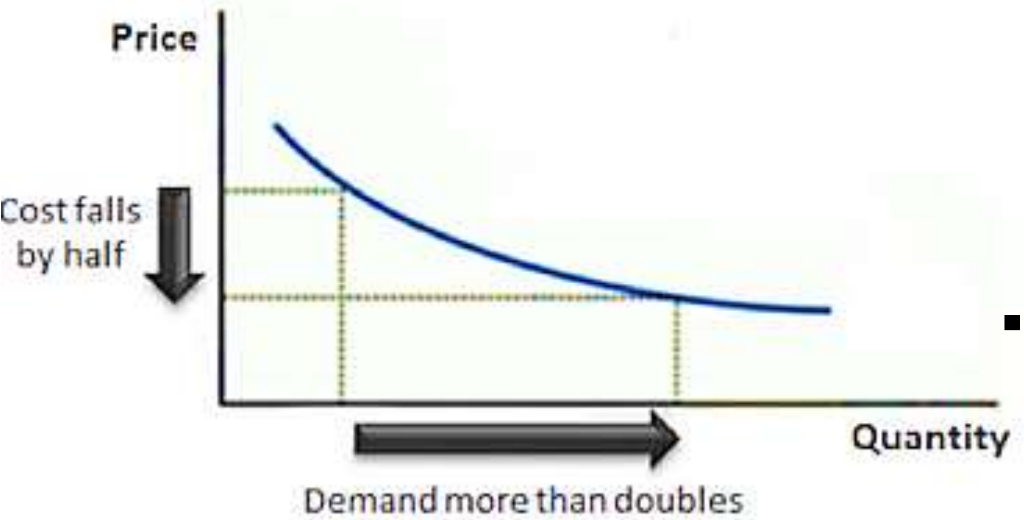




Does Technology improve Sustainability?

- Vision:
  - Energy efficiency reduces consumption and saves resource
- Reality:
  - Energy efficiency may encourage ***more*** consumption
- Why
  1. Increased energy efficiency makes the use of energy relatively cheaper, thus encouraging increased use (the direct rebound effect)
  2. Increased energy efficiency leads to increased economic growth, which pulls up energy use for the whole economy

Jevon's Paradox



- Rebound effects:
  - Increase in the efficiency of a resource (e.g., fuel) causes a decrease in the price of that resource when measured in terms of what can achieve (e.g., work)
  - Thus with a lower price for work, more work will be "purchased" (indirectly, by buying more fuel)
  - This increase in demand may or may not be large enough to offset the original drop in demand from the increased efficiency

Escaping Jevon’s Paradox

- Will increased consumption draw from renewable (free and clean) energy?
- Will improved productivity contribute to innovation of new energy efficient technology?
- Will decreased price be make available to wider population?
- Will the consumers consider the limitation and scarcity of resources?
- Will the policy makers remedy the imbalance of resources (e.g., through taxing and subsidy)?

References

- Courses
  - UMASS Course on Smart Grids
    - http://www-net.cs.umass.edu/cs691_spring_2013
  - Cornell Course on Computational Sustainability
    - http://www.cs.cornell.edu/Courses/cs6702/2011sp/
  - Masdar Institute Course on ***Computing for Sustainability***
    - CIS 618 (To be offered in 2014 Fall)
    - Hands-on techies for sustainability