

Department of Electrical & Electronic Engineering
Centre for Electrical Energy Systems

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Smart Grid of the Future



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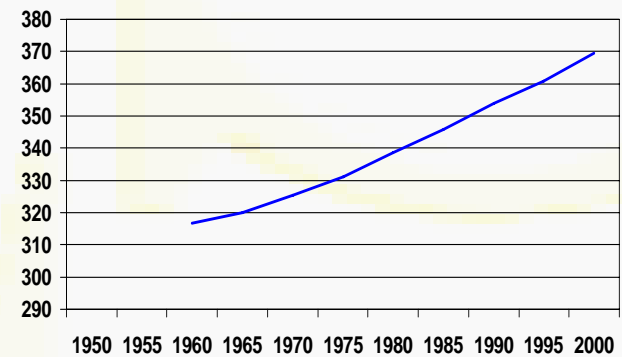
Our Planet



- Global warming
- Greenhouse gases
- CO₂ from fossil fuel energy sources



CO₂ Concentration



Europe Renewable Commitment

**Proportion d'énergies renouvelables
dans le bilan d'énergie des pays de l'UE**

EU Renewable target: 20% by 2020



UK: 10% now

Denmark: 21% now
30% by 2020

Germany: 14% now
27% by 2020

Spain: 20% now
30% by 2010

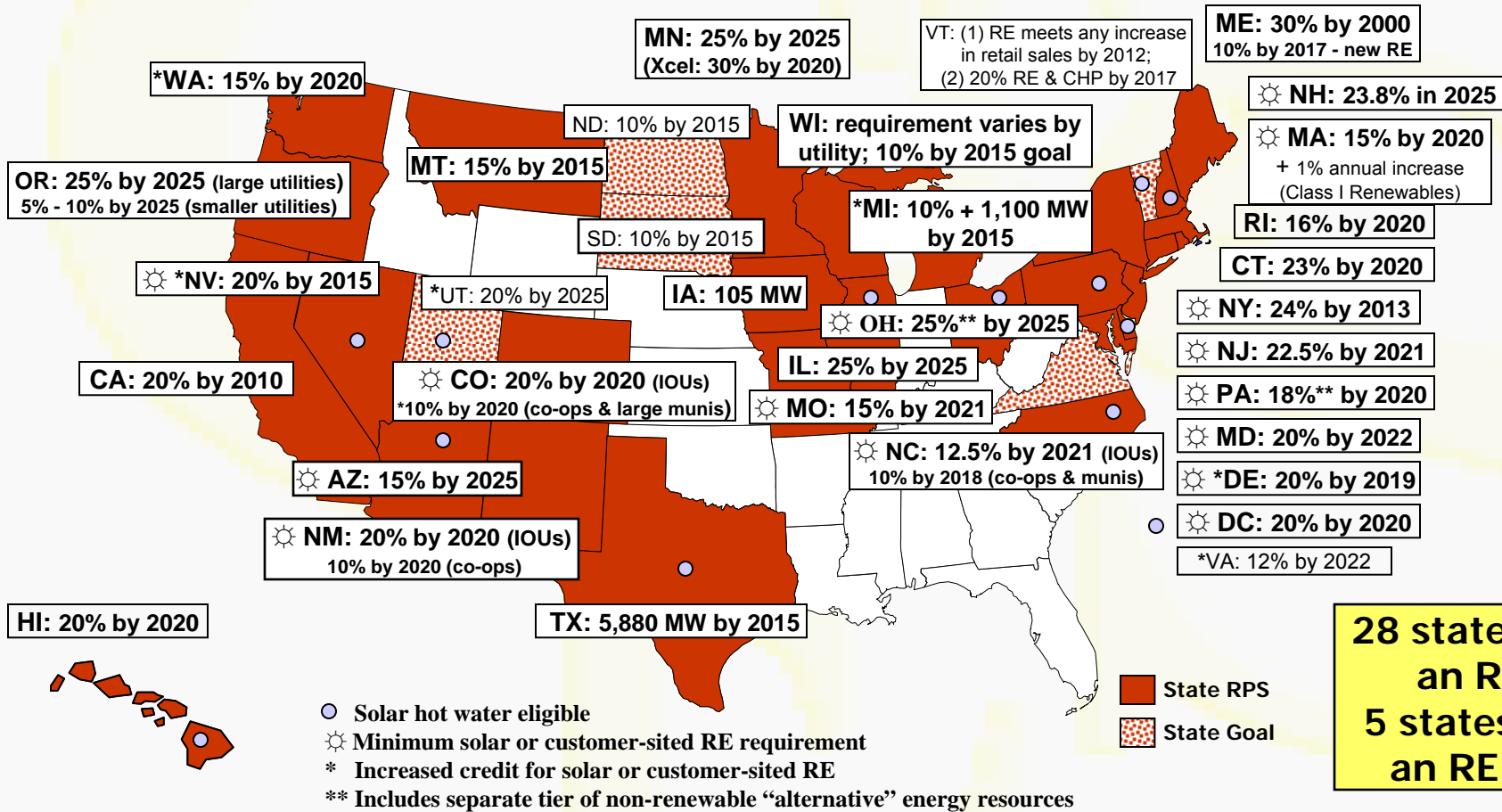
Source:
EMU, 2004

US is Awaken

DSIRE: www.dsireusa.org

March 2009

Renewables Portfolio Standards



Changing Grid

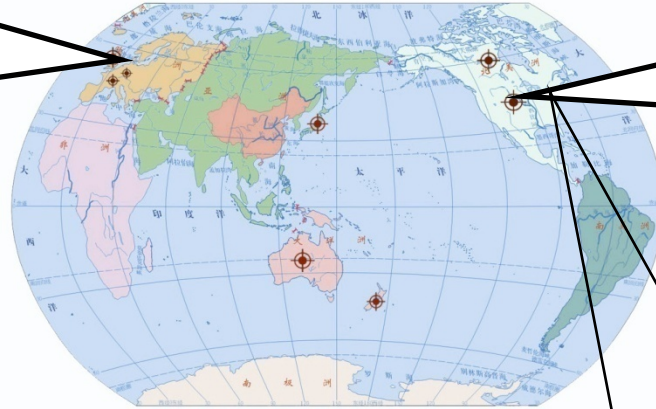
- More smaller generation
- More variable resources (wind and solar)
- More customer interaction
- Renewables are under-developed and under-utilized
 - » US has 960MW installed capacity, average used capacity is only 440MW



Smart Grid Concept

EU

- Smart grid plan (2005)
 - » ETP



US

- EPRI IntelliGrid
- Standards

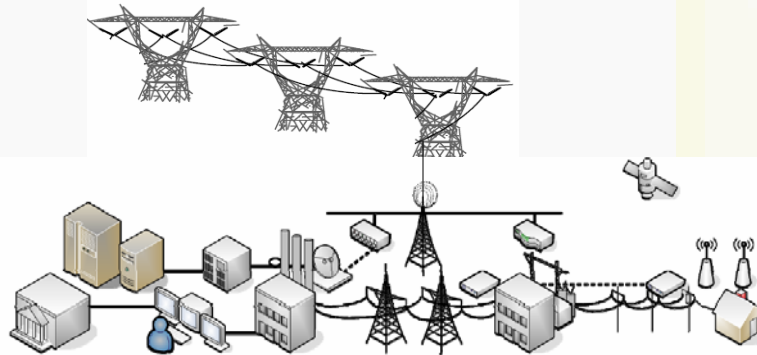
US

- 2007 DOE Modern Grid Strategy
- 2009 Obama stimulus plan

What is a Smart Grid?

Benefit from new
grid function

Superior grid
performance



Smart Grid

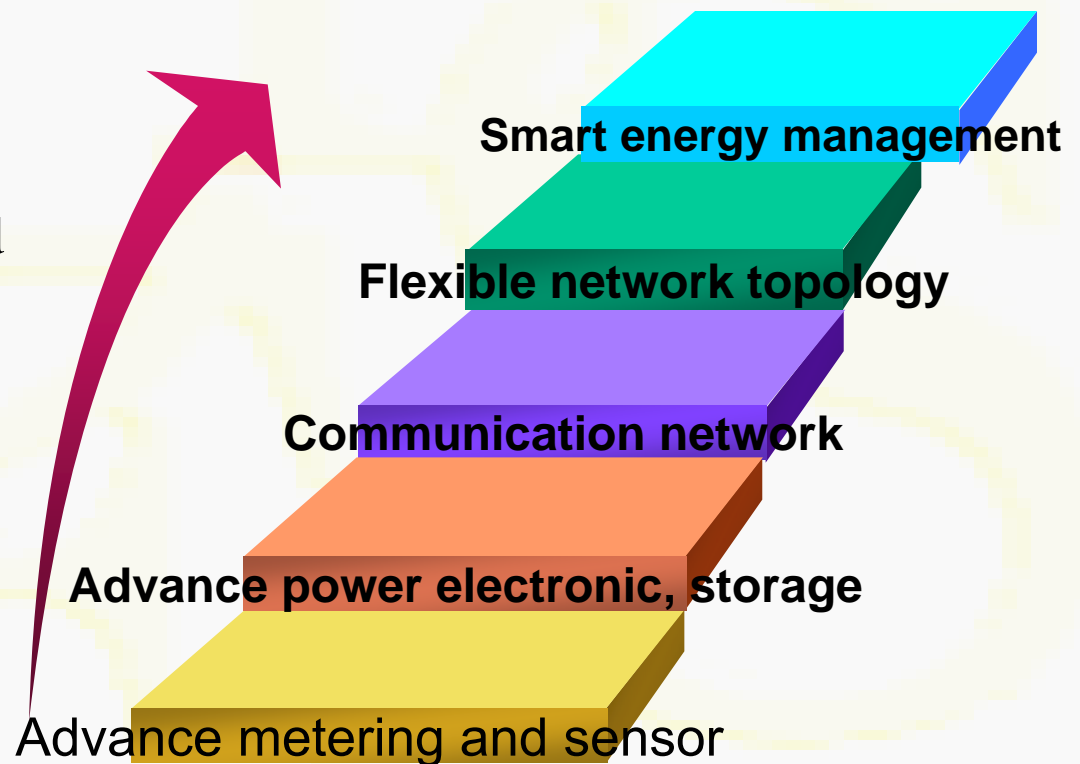
- “Smart Grid” is an aggregate term for a set of related technologies.
- It is a modernized electricity network
- It applies new information and communication technologies to traditional power grid.
- It is a upgrade of the power grid to optimize its operations and to fully accommodate renewable energy resources.

Enabling Technologies

- **Enabling technology**

- » Information and communication technology (ICT)
- » Advanced power system monitoring and control

- **Smart grid applies such technologies to power system operation**



Visions of Smart Grid

- Accommodate all generation (including **renewables**) and **storage**.
- Enable active participation by **consumers**.
- Optimize asset utilization and operational efficiency.
- Provide power quality for the digital age.
- Anticipate & respond to system disturbance (self-healing)
- Operate resiliently against **attack** and natural disaster.
- Enable **new** products, services, and markets.

Real-time Control of Power Systems



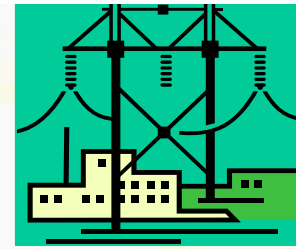
Generation



Transmission



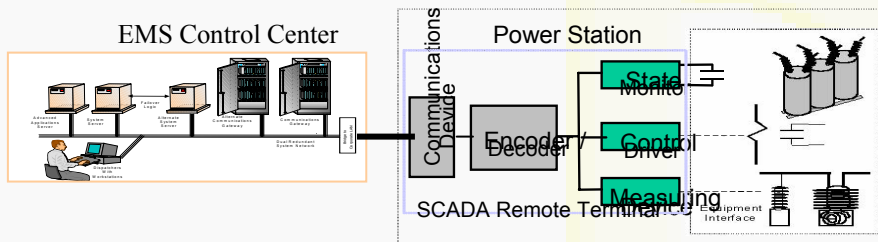
Substation



Distribution




Consumers



Mostly no real-time control and rely instead on manual control

Development of Smart Grid

- Start from Smart Meters, AMI
 - » Demand response
 - Distribution side
 - » Distribution network
 - » Substation
 - Transmission side
 - » Power flow control
 - » Transmission system operation
- 
- Metering
 - Communication
 - Sensors
 - IT, GIS
 - Visualization
 - Computation
 - Advanced control
 - Advanced application software

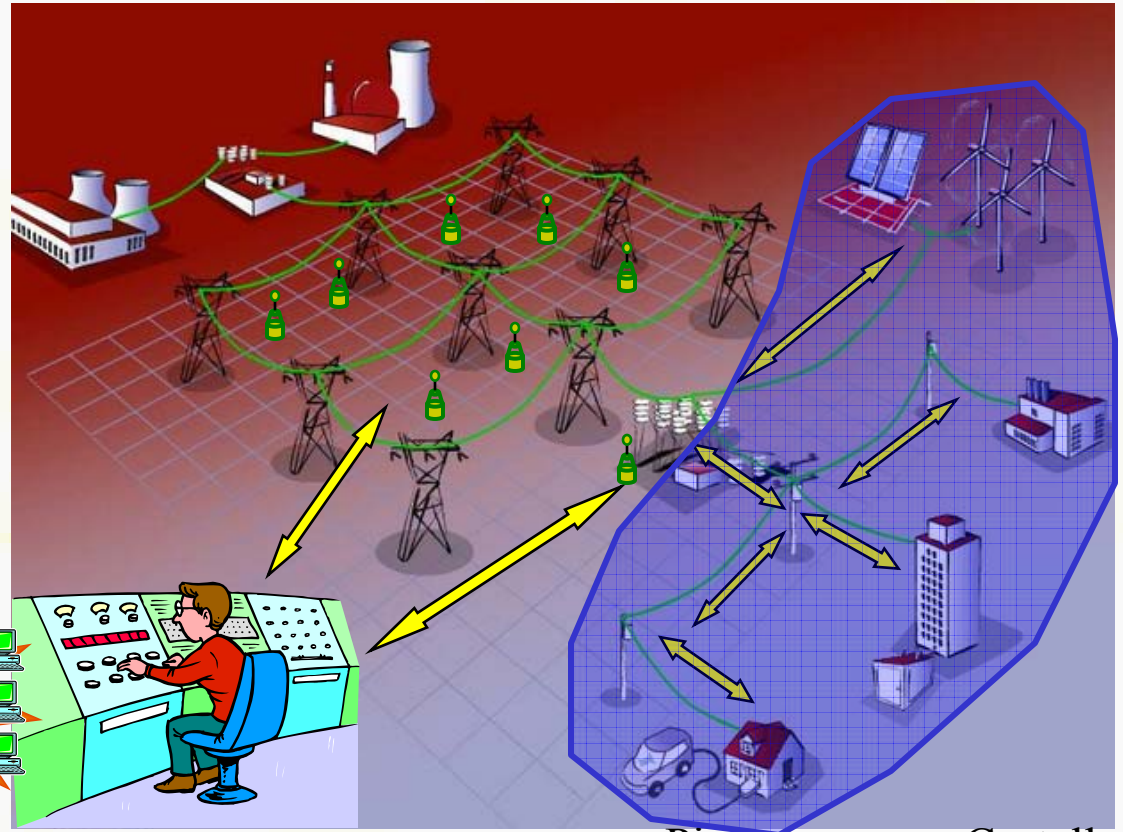
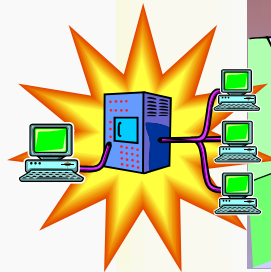
Advanced Metering Infrastructure (AMI)

- In the 80's large industrial consumers started the automated meter reading (AMR) system, which was later developed into AMI in late 90's.
- AMI consists of smart meters and a communication network.



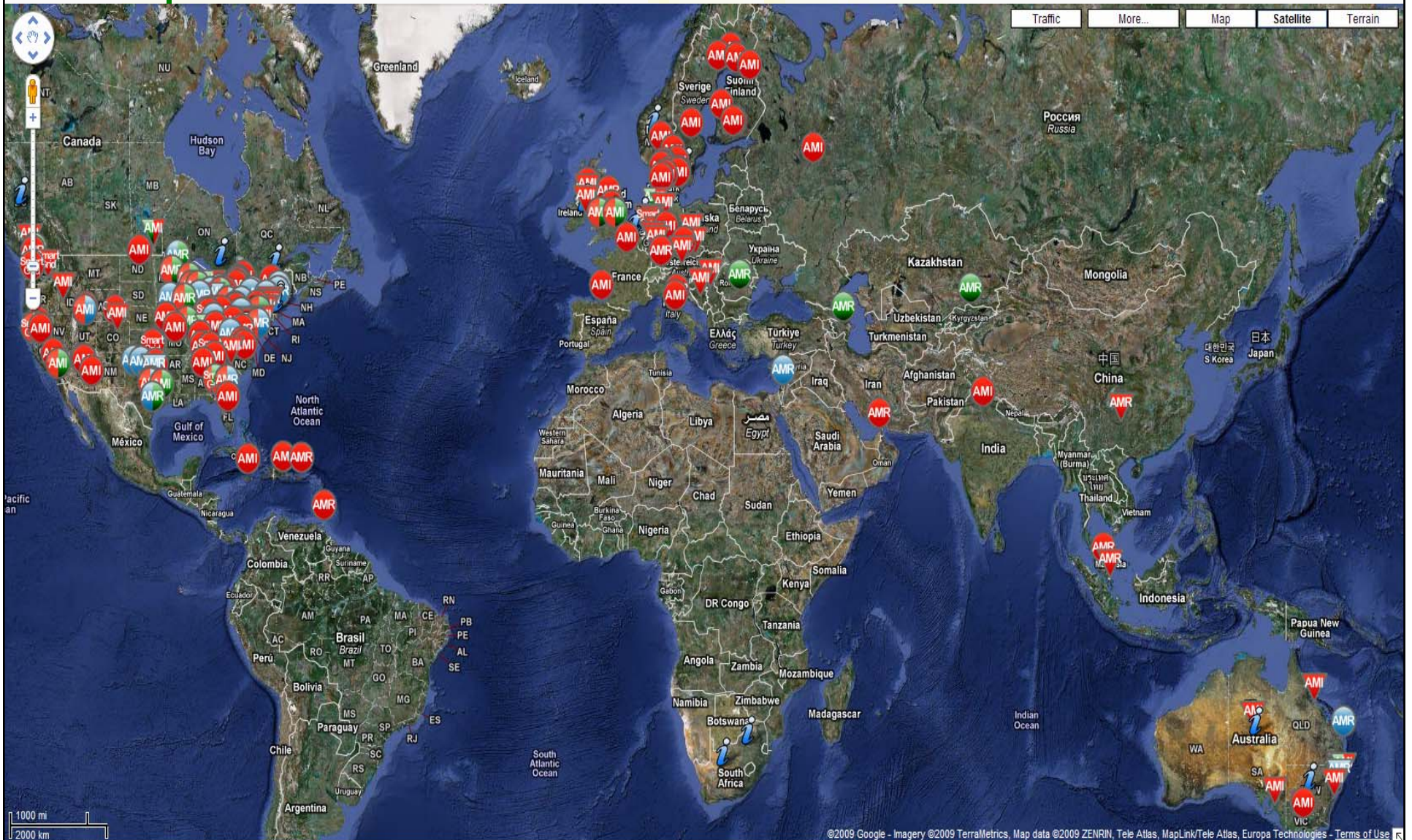
AMI

- Passive load becomes active customer, microgrid
- More info for power grid monitoring
 - » Traditional operation info
 - » Market info.
- May incorporate other distribution automation functions



Picture source: Castell

World Map of AMI



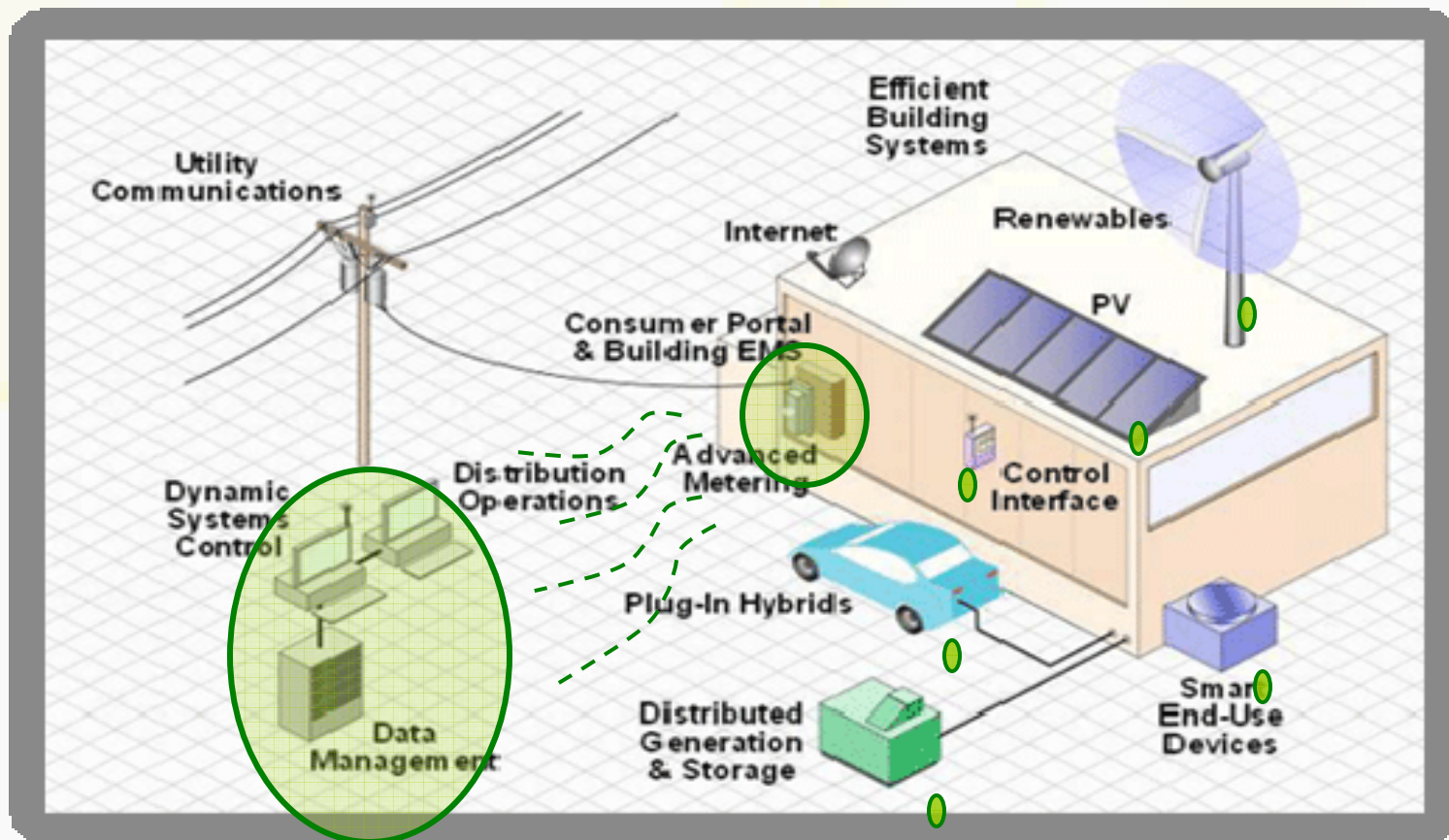
Economic Benefit of AMI

- Depends on demand response, reliability requirement, incorporation of other functions, etc.
- Survey of 38 US power companies
 - » AMI reduces 11% electricity consumption at peak hours.



Smart Home

- Extension to home, smart home, smart appliances.



Smart Substation

- A digitalized platform
- PMU replaces RTU
 - » Time-stamped measurements Local area network
- Self-healing
- Data management and visualization
- Standards



Smart Transmission

- Phase measurement units (PMU) and wide-area measurement systems (WAMS).
- Flexible AC transmission system (FACTS)
- Power line conditioning measuring systems



Smart Grid: Functional View



Smart
Generation

- Wind, solar and other renewables
- Storage



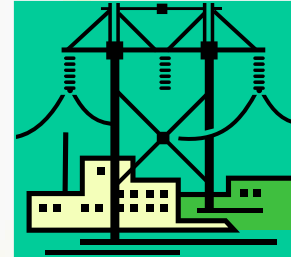
Smart
Transmission

- FACTS
- WAMS
- Line condition monitoring



Smart
Substation

- SCADA
- DMS
- Microgrid



Smart
Distribution

- DA
- AMI
- DER



Smart
Home

- Demand response
- Intelligent appliances

Smart Grid: ICT View

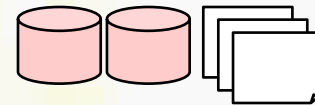
Application



- Risk-limiting dispatch

Information Management

- Data model standardization
- Distributed data service
- Search engine



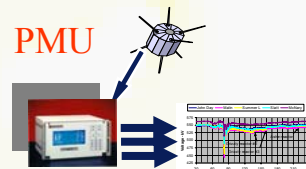
Communication Infrastructure

Communication network



- Optical fiber/ wireless
- Communication network protocols

Monitoring and Control

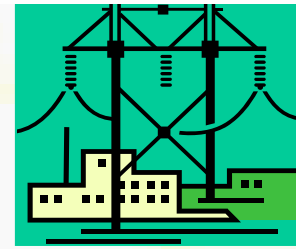


- Embedded intelligent sensors
- Sensor network technology

Power system components



EMS and AMI Integration



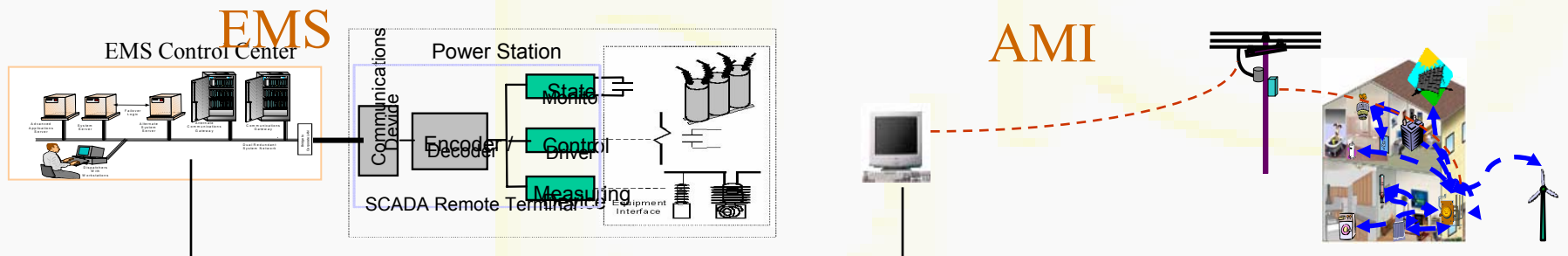
Generation

Transmission

Substation

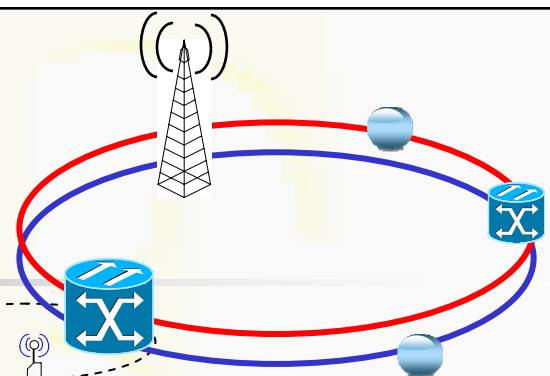
Distribution

Consumers



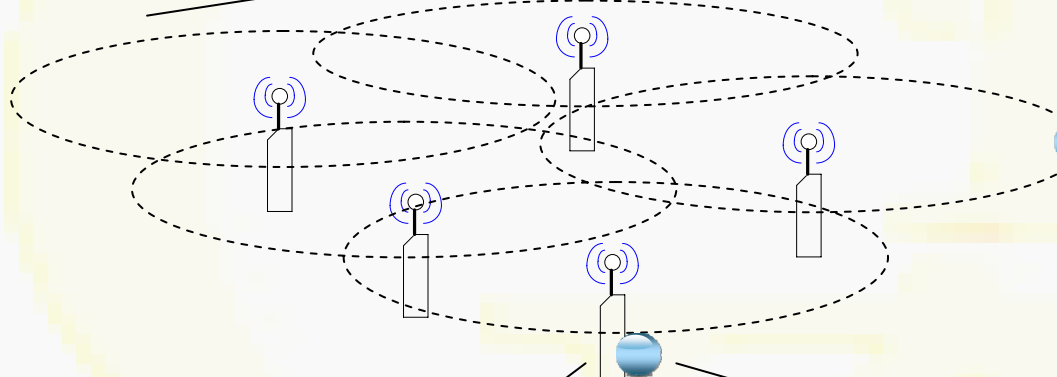
A multi-layer structure communication network is needed

Optic Fiber Backhaul

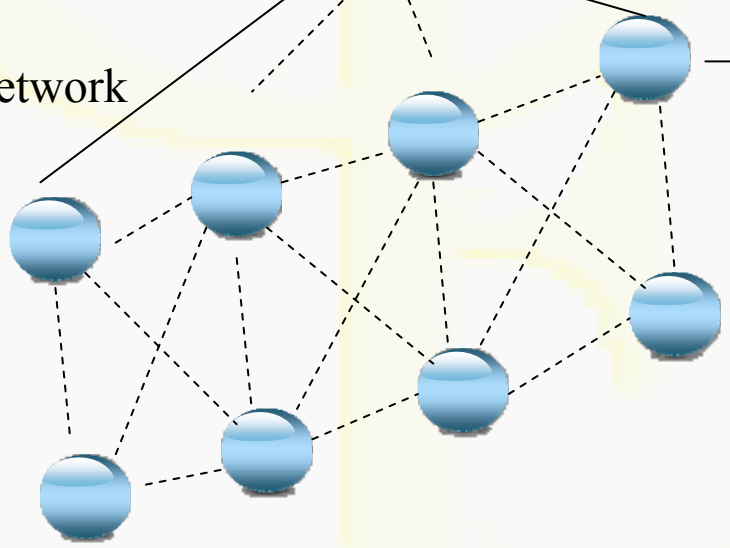


Microwave Backhaul

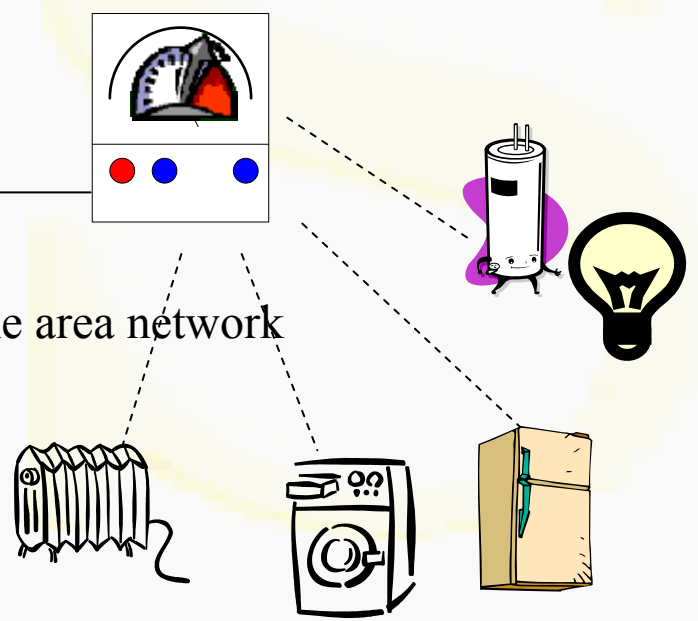
Wide area network



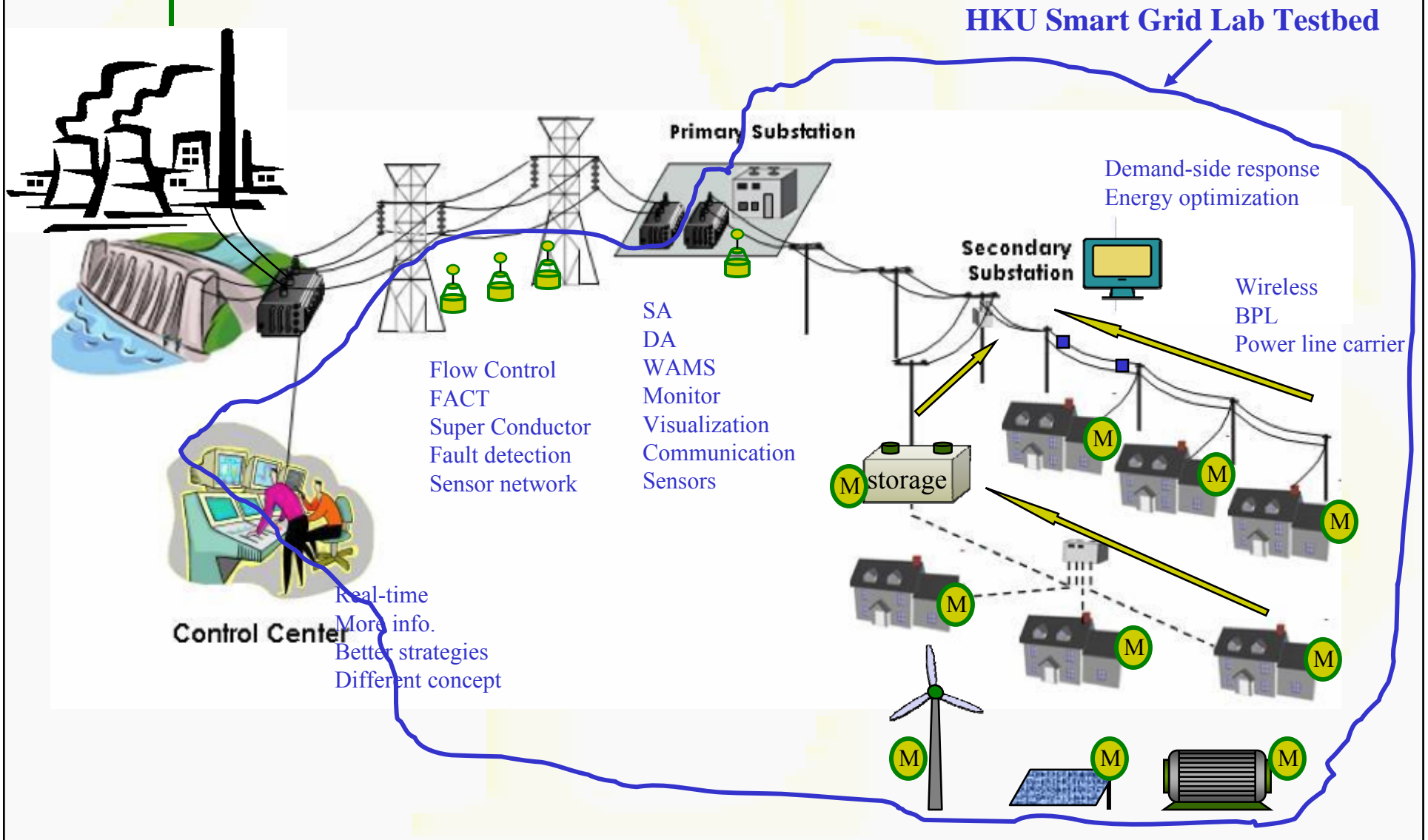
Local area network



Home area network



Smart Grid Challenges



Will Smart Grid Make a Difference?

Without a smart grid

- <13% renewable penetration
- 5% demand response
- <1% consumer generation used on the grid
- 47% generation asset utilization
- 50% transmission asset utilization
- 30% distribution asset utilization

With a smart grid

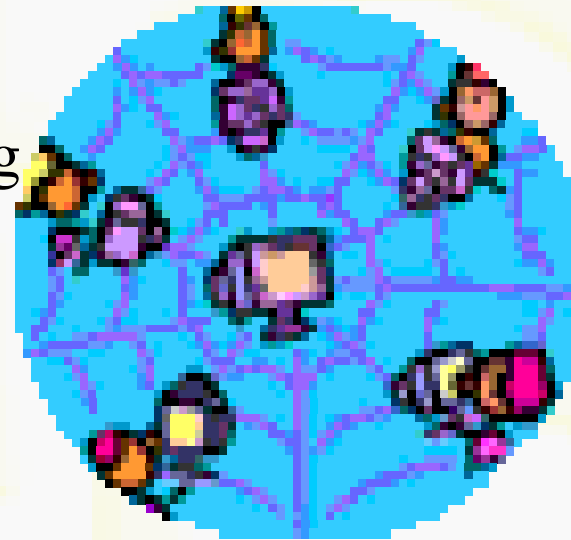
- >30% renewable penetration
- 15% demand response
- 10% consumer generation used on the grid
- 90% generation asset utilization
- 80% transmission asset utilization
- 80% distribution asset utilization

Summary

- Smart grid promises
 - » Integrate and fully utilize renewable resources and demand participation
 - » Optimal operation and resiliency against attack
- Enabling technologies
 - » Information and communication technology
 - » Power electronics
- Unleashing innovation for
 - » New sensors, smart appliances, new devices, new products,

Thank You

F. F. Wu, P. Varaiya, J. Bialek, J. Zhong
“Smart Operation of Smart Grid,”
(Invited paper)
Proceedings of the IEEE,
2010.



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<http://www.eee.hku.hk/~cees>