Evolution to Revolution: The Emerging Smart Grid in America

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Outline of Presentation

- Background & Nomenclature
- What IS Smart Grid?
- Opportunities for Impact in Smart Grid
  - Generation and Transmission
  - Distribution
  - Into the Home
  - Standards
- How/when will our investment pay off?
- UA research contributions to Smart Grid

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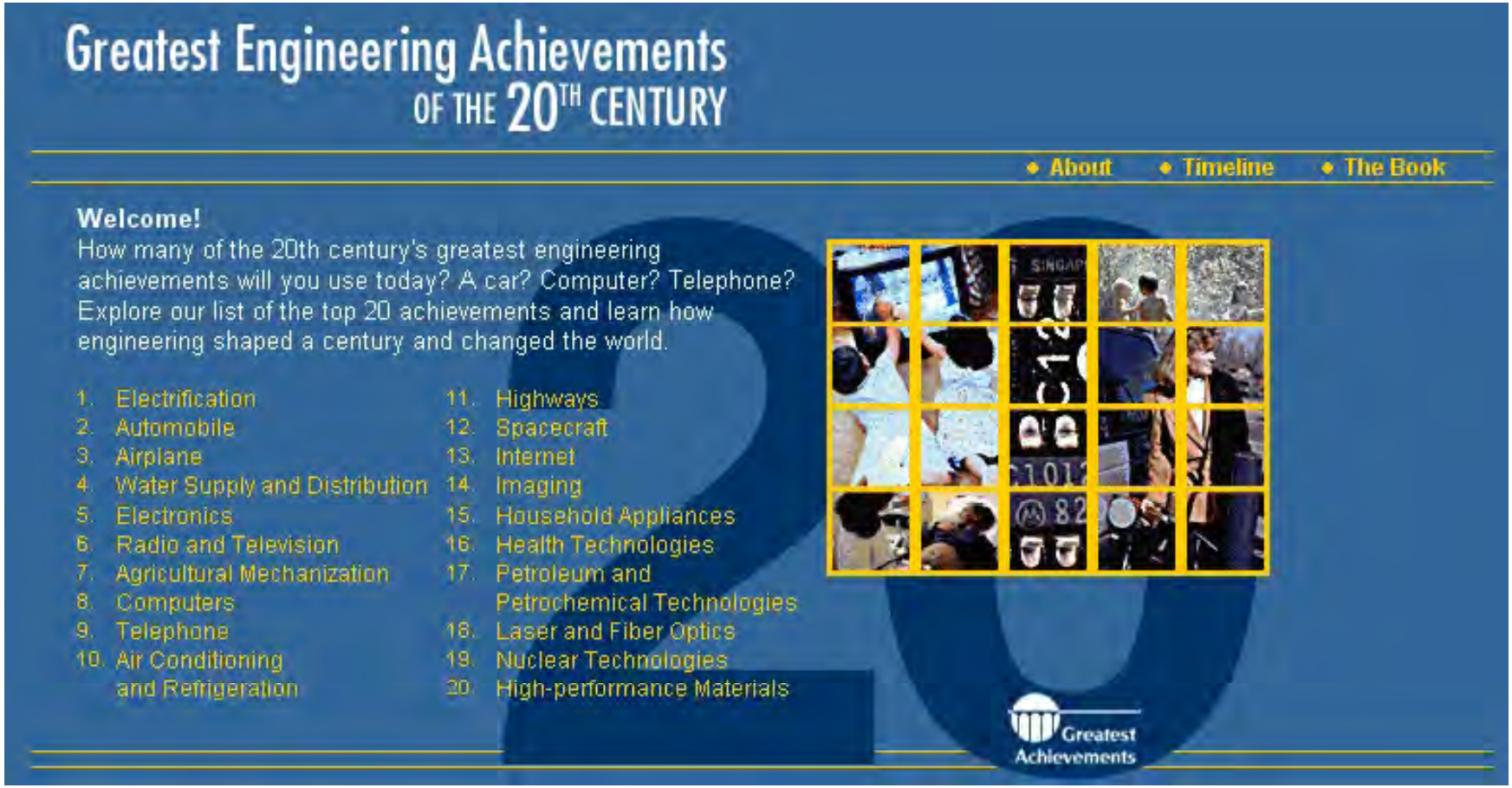
Significance of Electric Power



Source: National Academies

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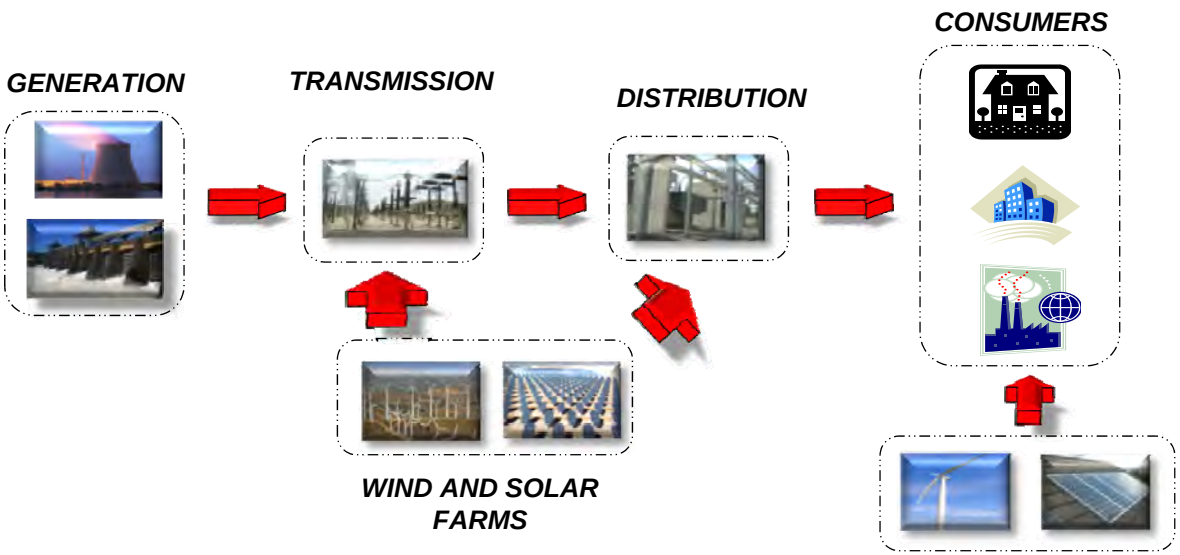
Conventional Power Systems

Conventional power systems have four main components:

- **Generation:** Production of electricity from other forms of energy
- **Transmission:** Transmission of electric power from generators to distribution system; includes power stations and transmission lines
- **Distribution:** Connection of power lines to end users or consumers
- **Consumers:** Use the energy obtained from the previous process



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Nomenclature

This field is packed with jargon and acronyms. Perhaps a guide is useful:

AMI – Automated Metering Infrastructure
CAES – Compressed Air Energy Storage
CES – Community Energy Storage
DER – Distributed Energy Resources
DG – Distributed Generation
DR – Demand Response
PMU – Phasor Measurement Unit
RES – Renewable Energy Sources
SCADA – Supervisory Control And Data Acquisition
SMES – Superconducting Magnetic Energy Storage
SMT – Synchronous Measurement Technology

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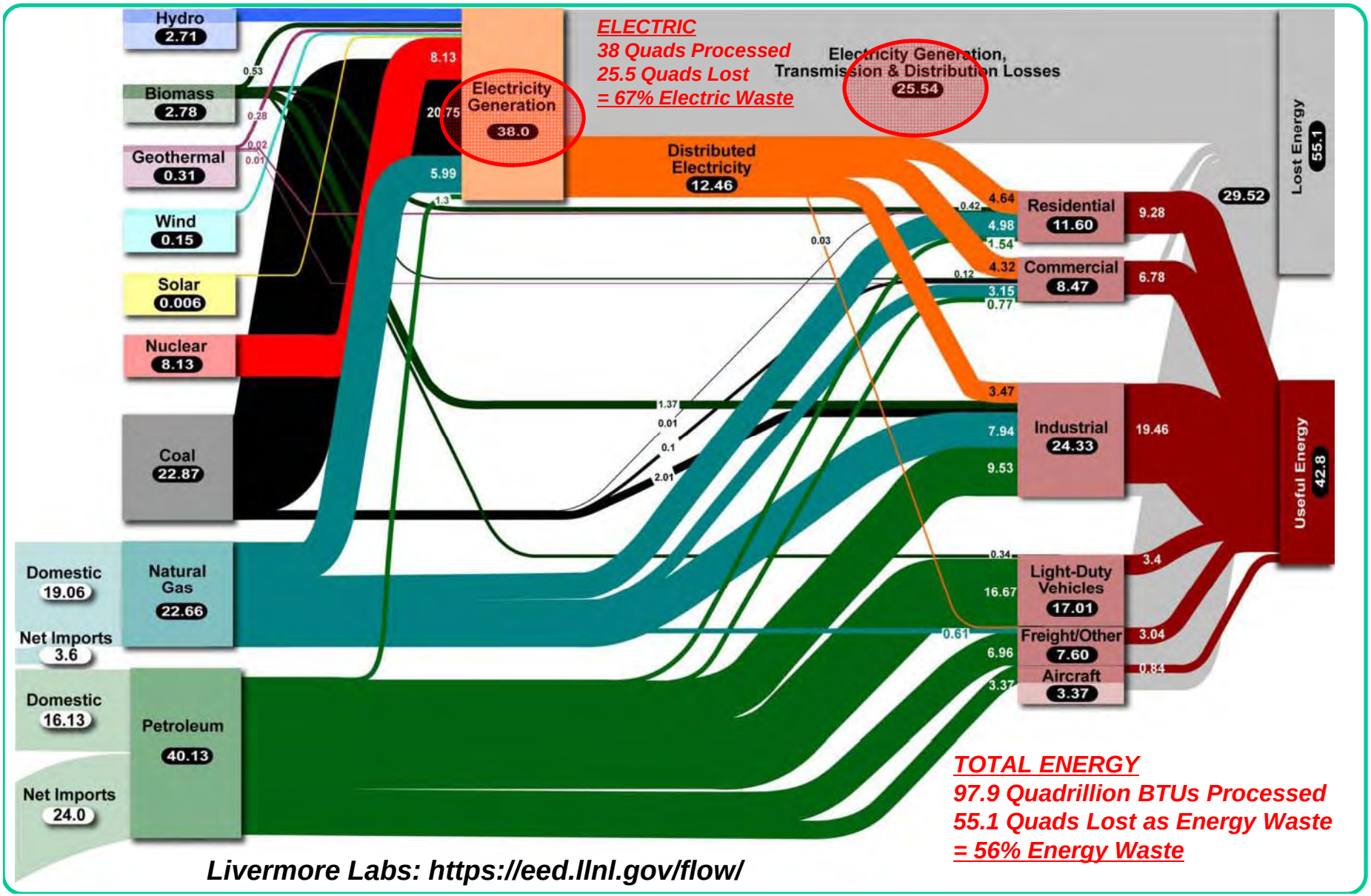
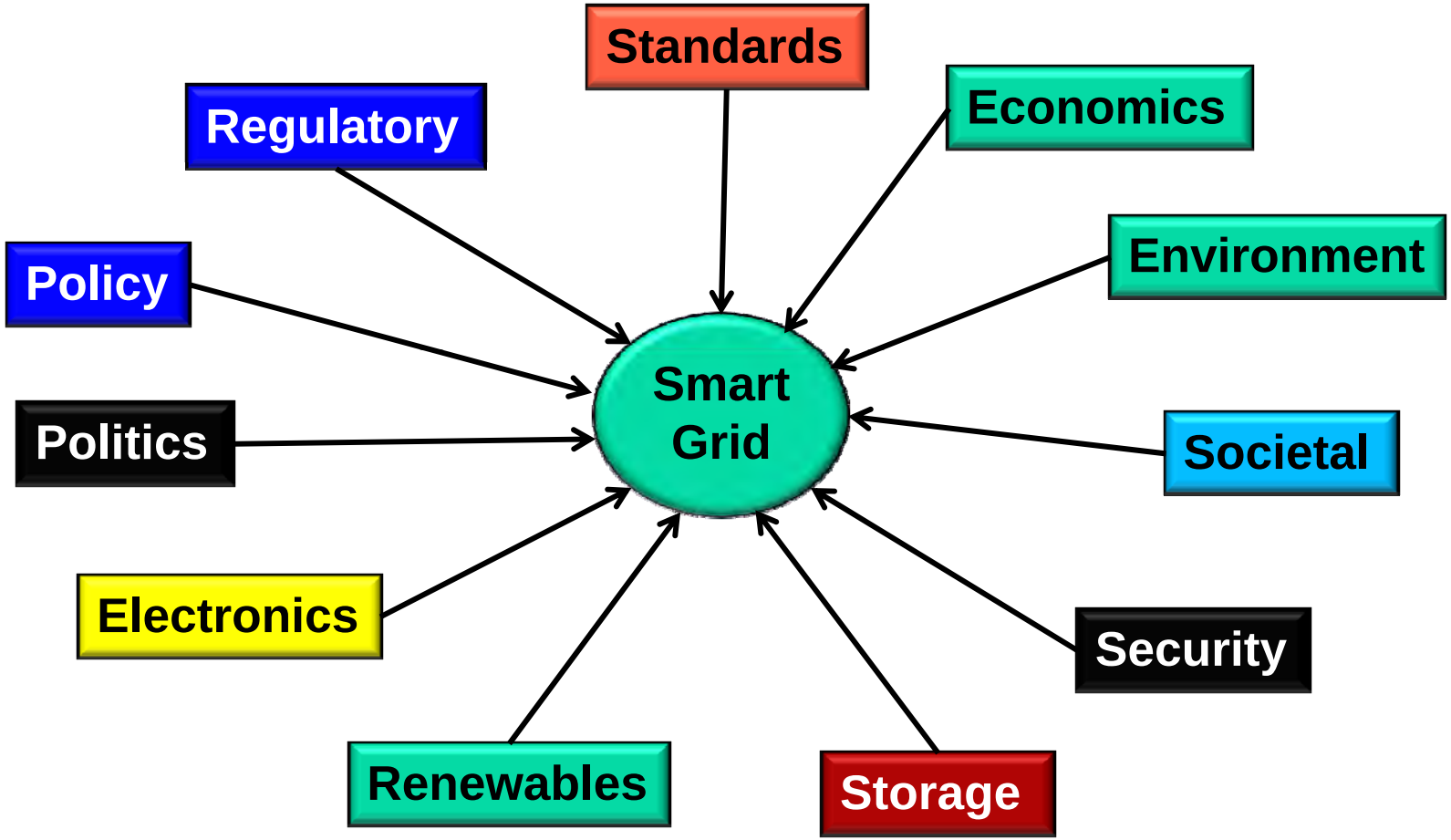
State of the U.S. Energy Industry



Livermore Labs: https://eed.llnl.gov/flow/

Factors Influencing Smart Grid



Electrical energy demand is rising
Fossil fuel costs are rising

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Why Pursue a Smart Grid?

Smart grids appear as a prevalent answer to create more efficient and sustainable energy systems, improve reliability and resiliency, maintain our standard of living, and address environmental concerns.

- Satisfy the growing electricity demand
- Monitor grid status and collect data from the grid
- Optimize and control the produced power
- Modernize and upgrade the transmission and distribution system
- **Enhance resiliency, reliability, sustainability and security of the grid**
- **Minimize grid operation interruptions and blackouts**
- **Integrate renewable sources with the energy market**
- Address environmental issues and respond to new energy policies

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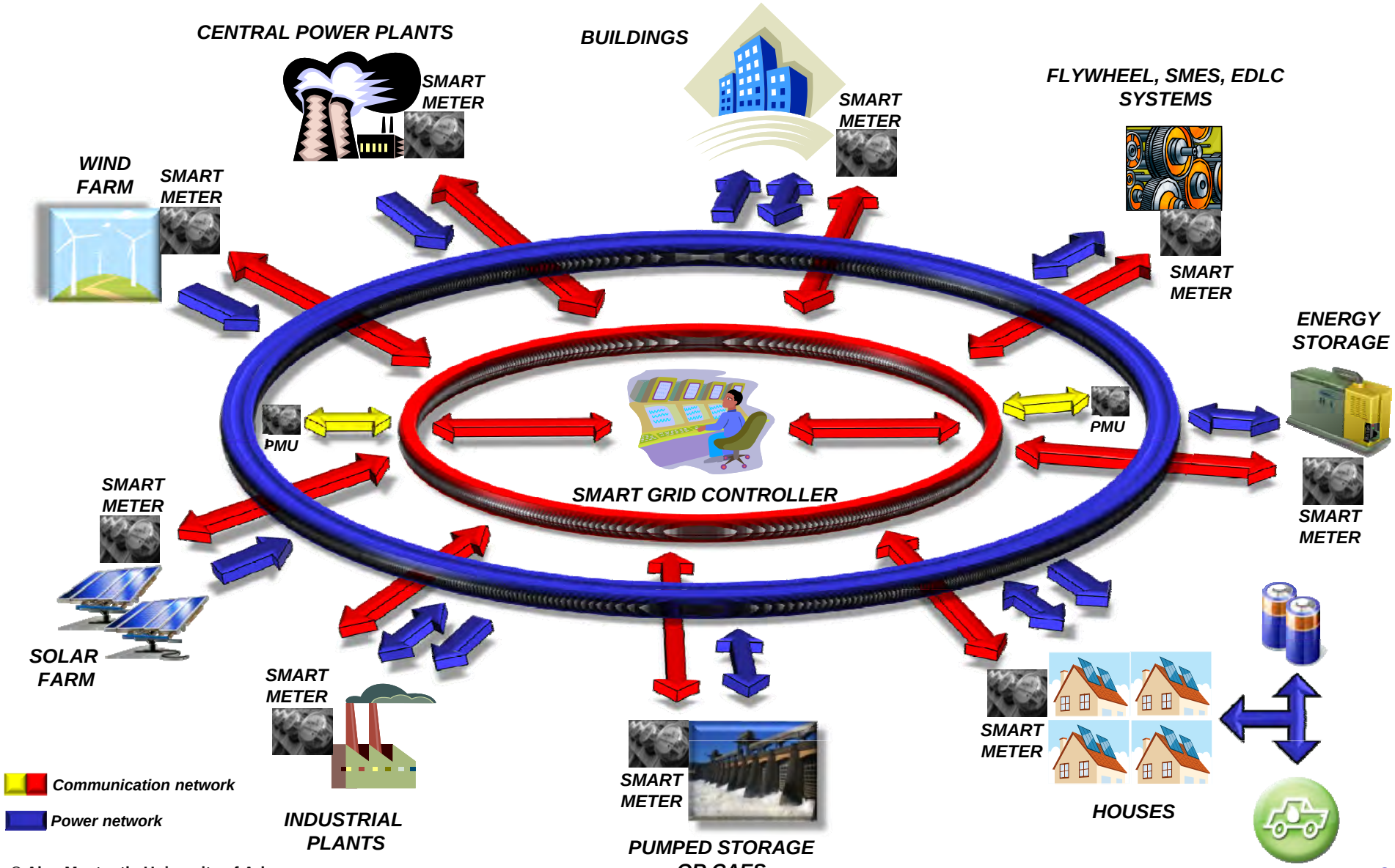
What *Is* the Smart Grid of the Future?



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Perspective / Poll

Is our current grid really that stupid?

Ans. No, not really. Demand-side management and control has existed for well over a decade – even at the residential level.

Is the addition of a communications/IT layer all we need to have a smart grid?

Ans. No, we have to deploy the physical assets while learning how to control, manage, and optimize them.

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Defining Smart Grid

Constitutive elements of a smart grid include:

- DER
- Renewable energy sources
- Storage
- Secure communications
- Measurement units
- Controls and automation
- Time-of-use pricing
- Net and smart metering
- Standards
- Self-healing/resilient
- Reconfigurable/dynamic

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State of the U.S. Energy Industry

- **Greater than 30% of all electricity generated is processed by power electronics and electric motor systems.**

- **Greater than $300 billion in energy is processed by power electronics and electric motor systems.**

- **Average power electronics system is 70-90% efficient**
  (i.e. up to $60 billion in wasted energy annually).

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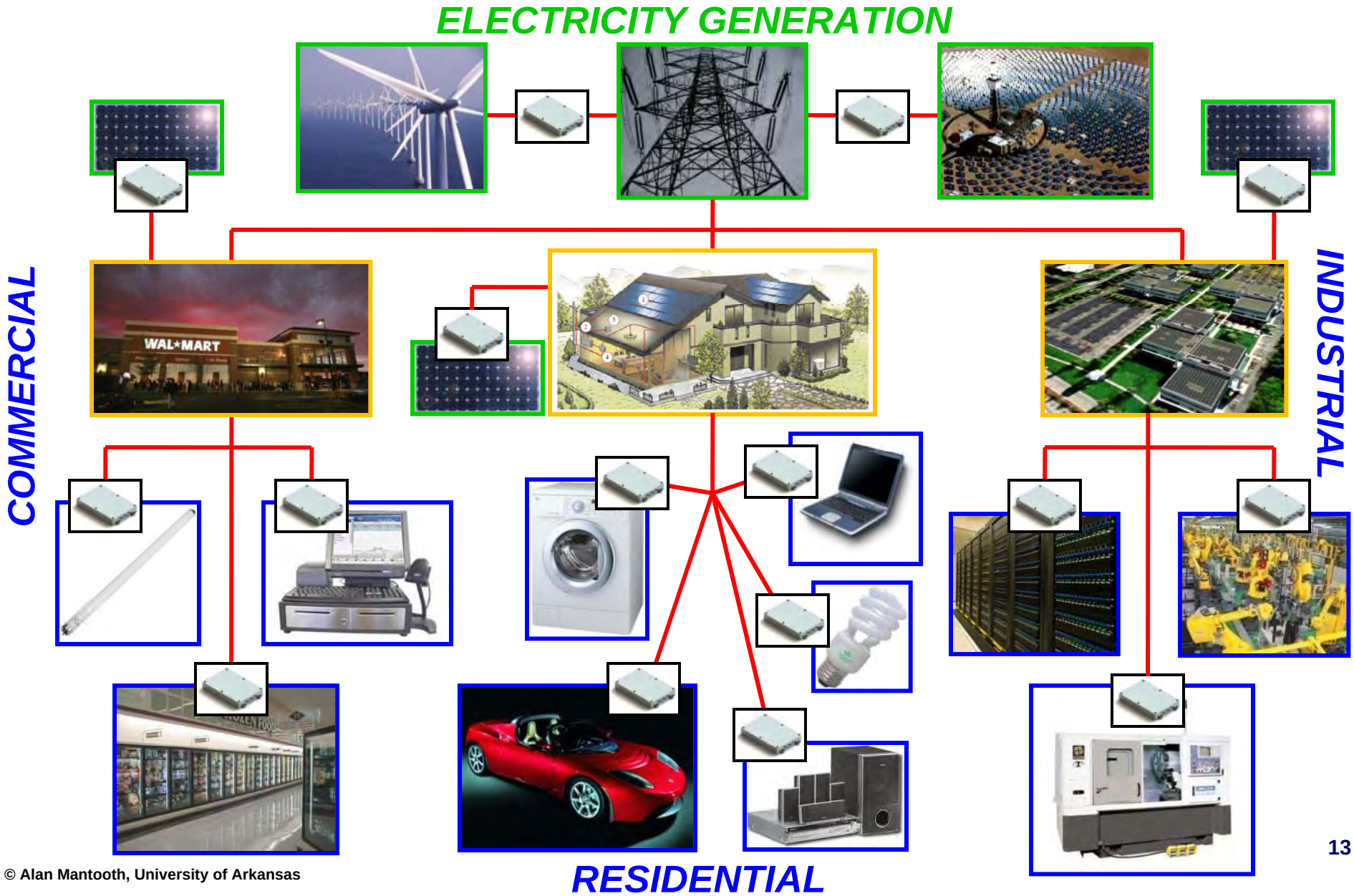
Power Electronic Applications



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Generation and Transmission

- **Renewable Sources**
  - **Wind farms**
  - **Solar farms**
  - **Bulk storage**
- **Dispatch**
- **Role of Power Electronics in RES**
- **Wholesale & time of use pricing**
- **HVDC or not?**

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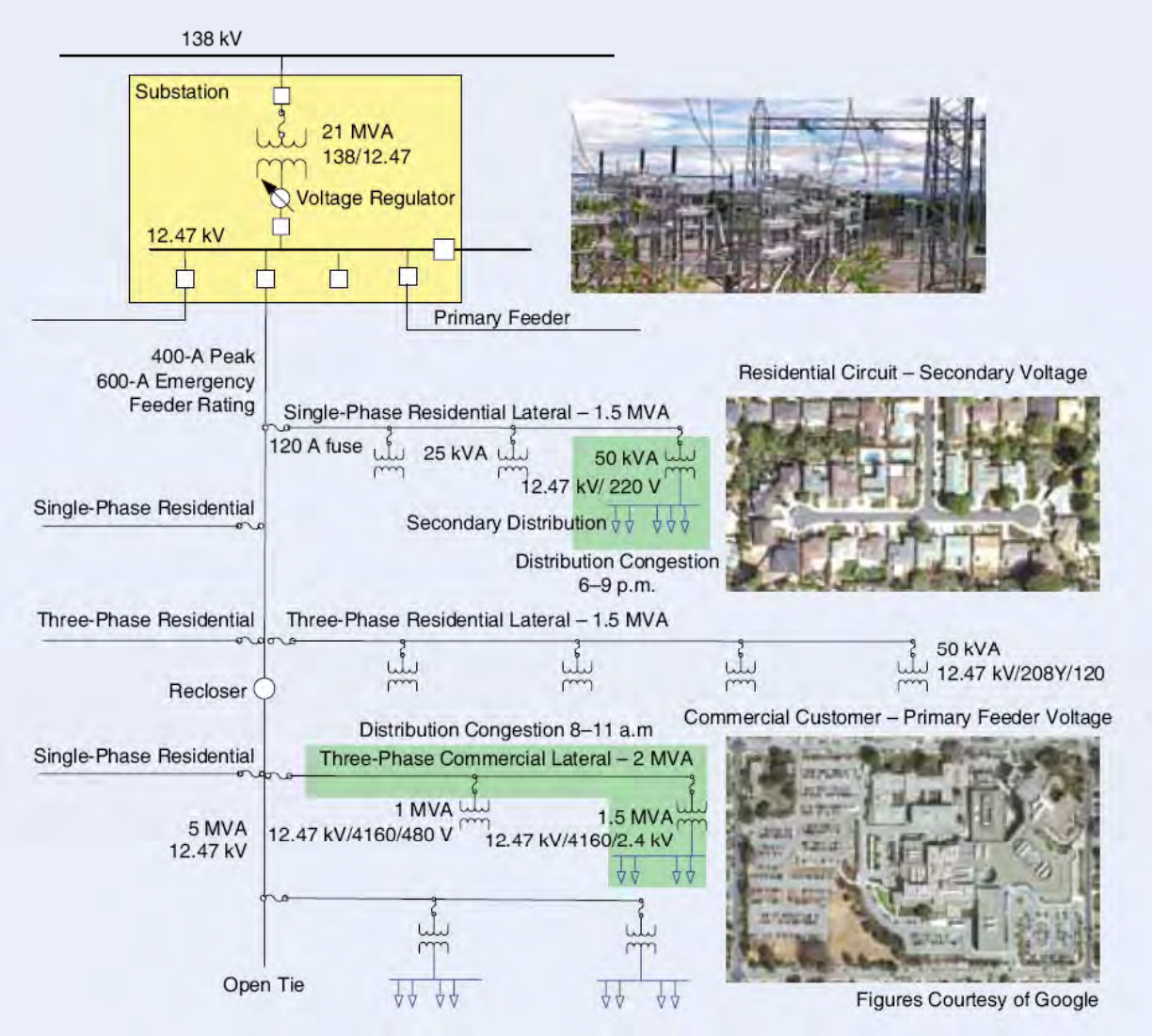
Smart Grid for Distribution

- **Robustness, reliability, resiliency**
- **Energy storage**
- **Smart meters**
- **PHEV, PEV**



Source:
IEEE Power & Energy Magazine, Mar. '09

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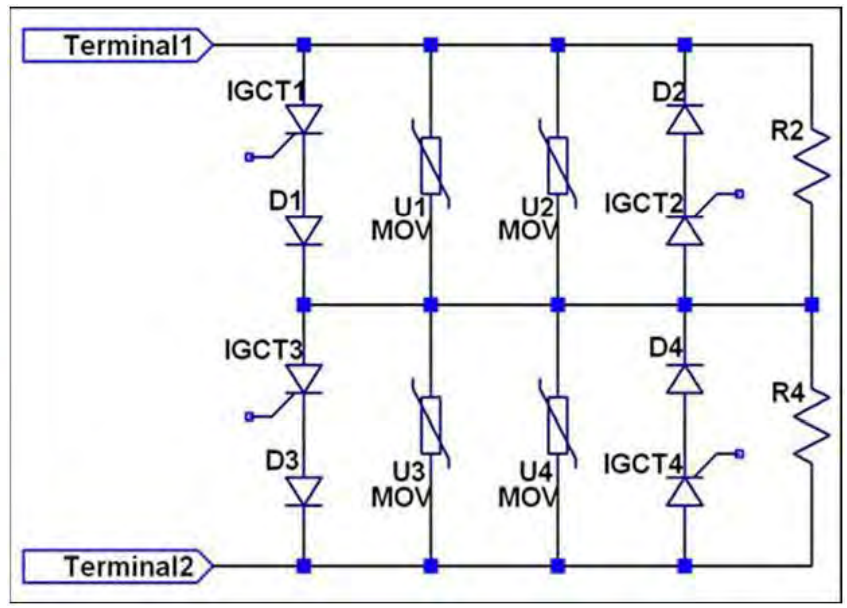
Improving Resiliency / Reliability



4 kV / 4 kA Silicon IGCT Fault Current Limiter

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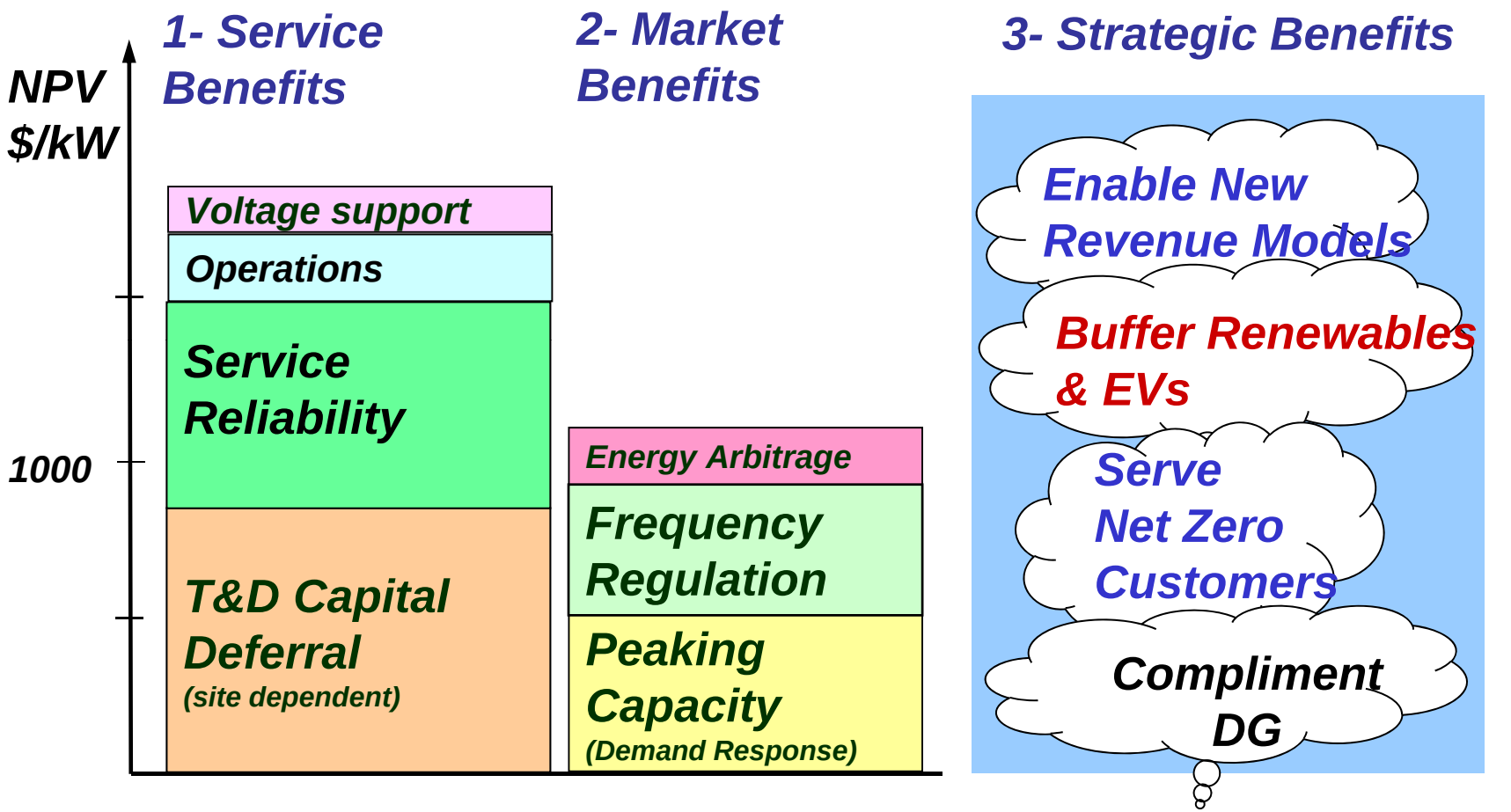
Benefits of Energy Storage



Based on studies for AEP sites with NaS

Based on a Vision of Utility Future

Storage can Benefit both Customers and Utilities

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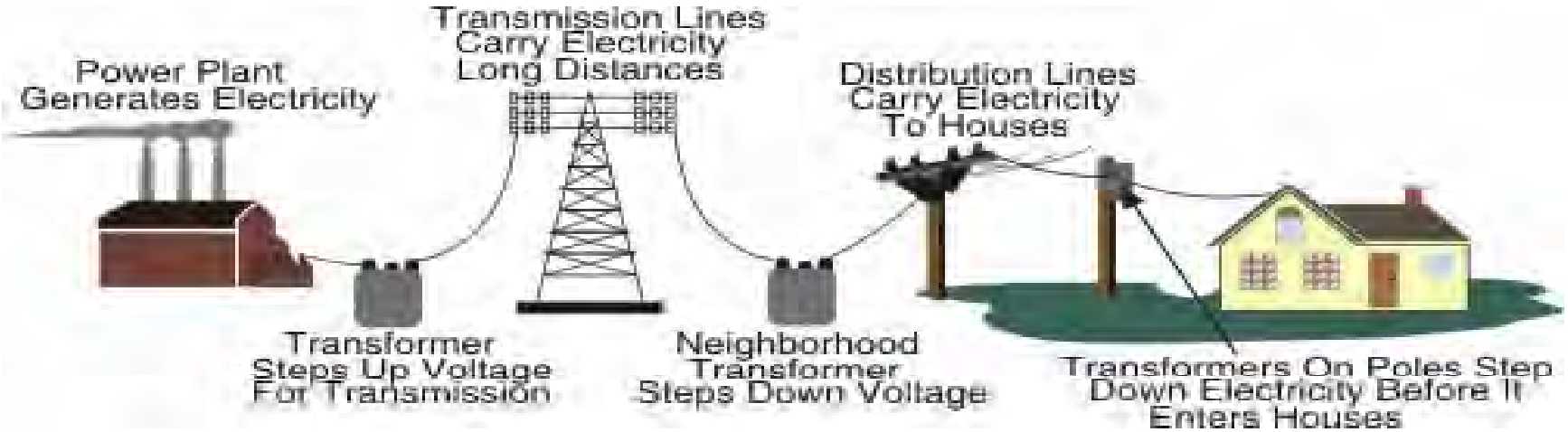
Source: R. Hayes of AEP

Multiple Storage Formats



Bulk Storage

MW x 100's

Substation Batteries

MW's

Grid Edge

KW x 10's x 100's

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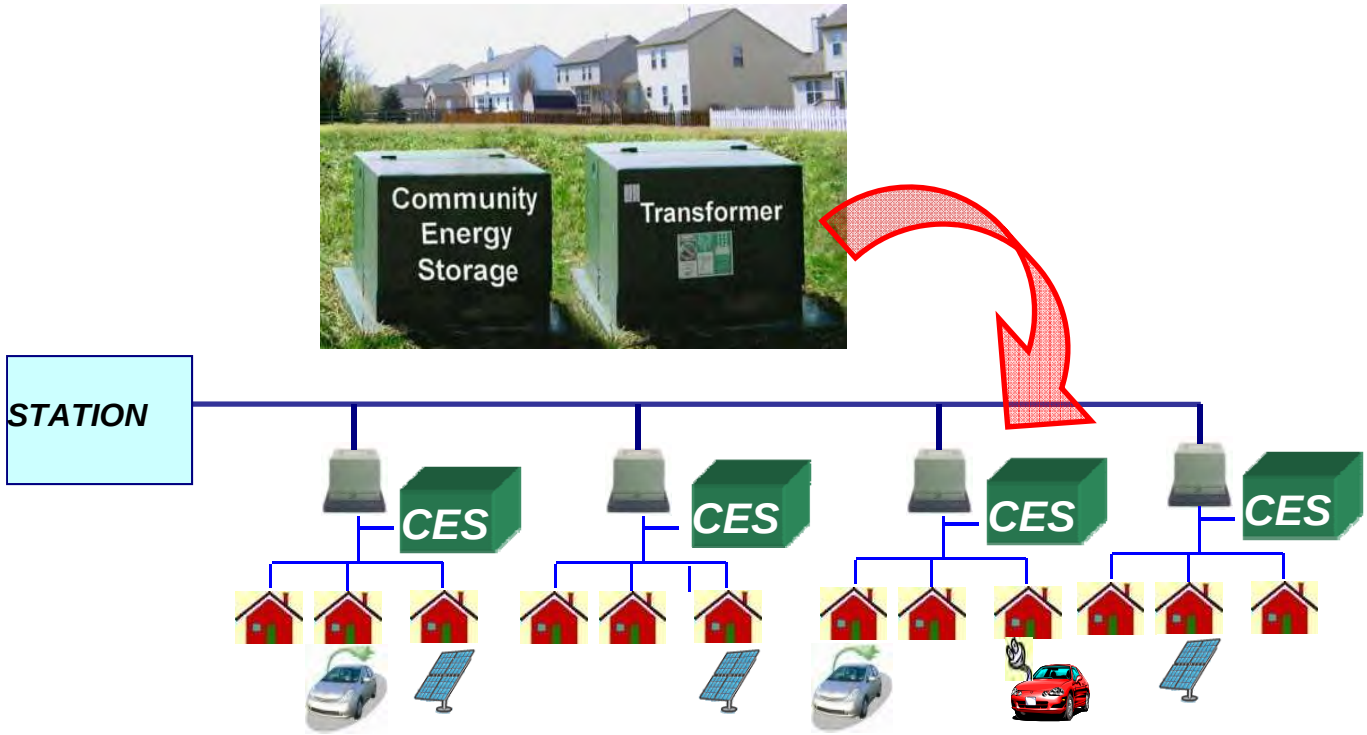
Source: R. Hayes of AEP

Community Energy Storage (CES)

CES is a distributed fleet of small energy storage units connected to the secondary of transformers serving a few houses or small commercial loads.



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Source: R. Hayes of AEP

CES Specifications

Key Parameters	Value
Power (active and reactive)	25 kVA / 25 kW
Energy	75 kWh
Voltage	240 / 120V AC
Battery - PHEV	Li-Ion
Round trip efficiency	> 85%

AEP Specifications for CES are "OPEN SOURCE" for Public Use and Feedback. During 2009 EPRI hosted free, open webcasts to solicit industry wide input.

www.aeptechcenter.com/ces

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Source: R. Hayes of AEP

CES – Virtual Station Scale Storage

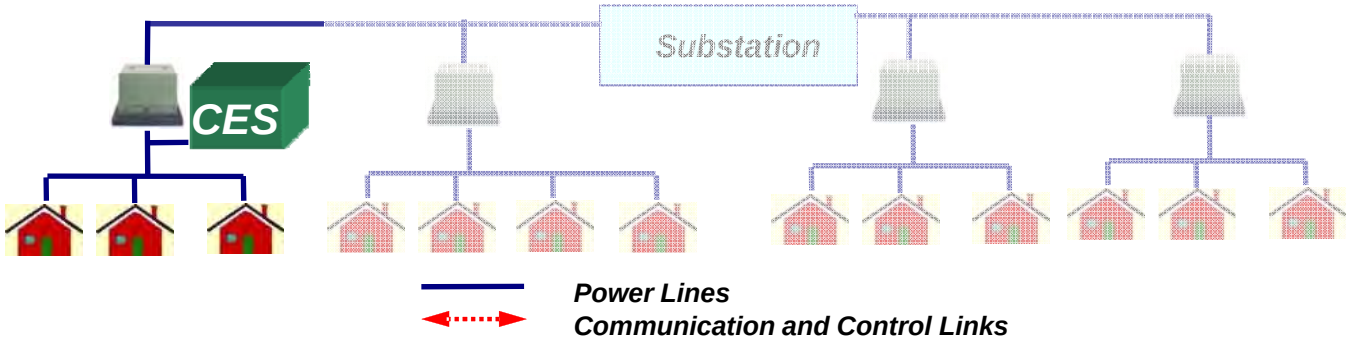
CES is Operated as a Fleet offering a Multi-MW, Multi-hour Storage

Local Benefits:

1) Backup power

2) Flicker Mitigation

3) Renewable Integration



Source: R. Hayes of AEP

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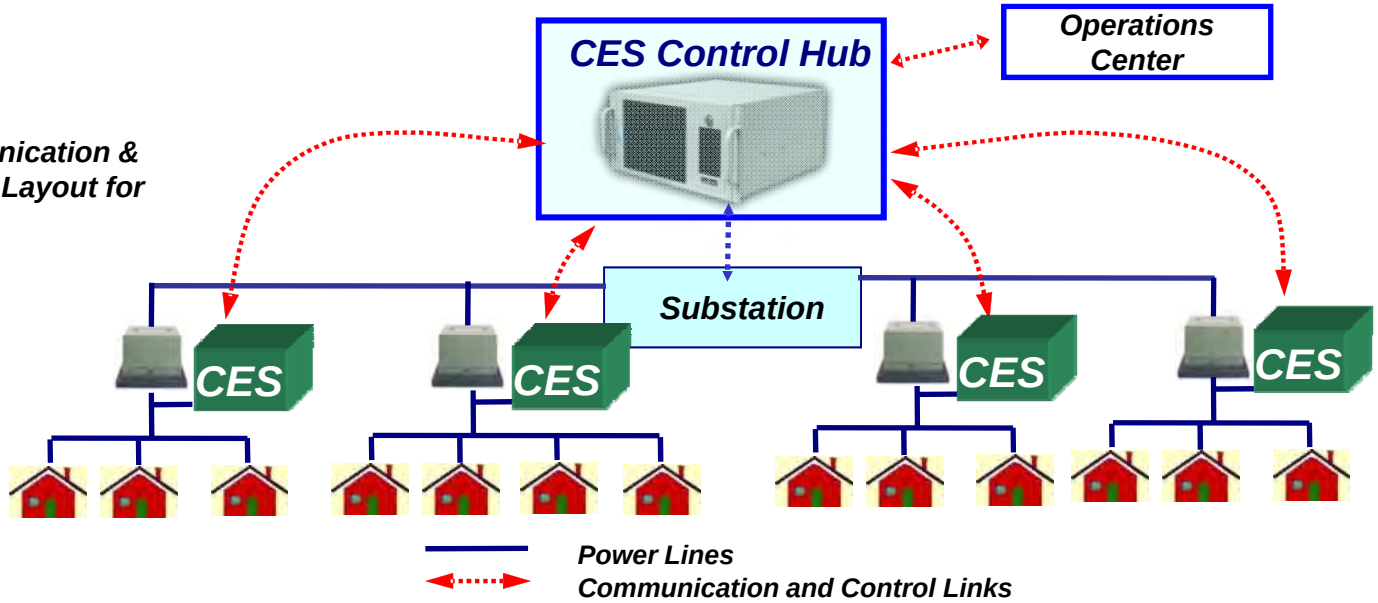
Local Benefits:

1) *Backup power*
2) *Flicker Mitigation*
3) *Renewable Integration*

Grid Benefits:

4) ***Load Leveling at substation***
5) ***Power Factor Correction***
6) ***Ancillary services***

Communication & Control Layout for CES



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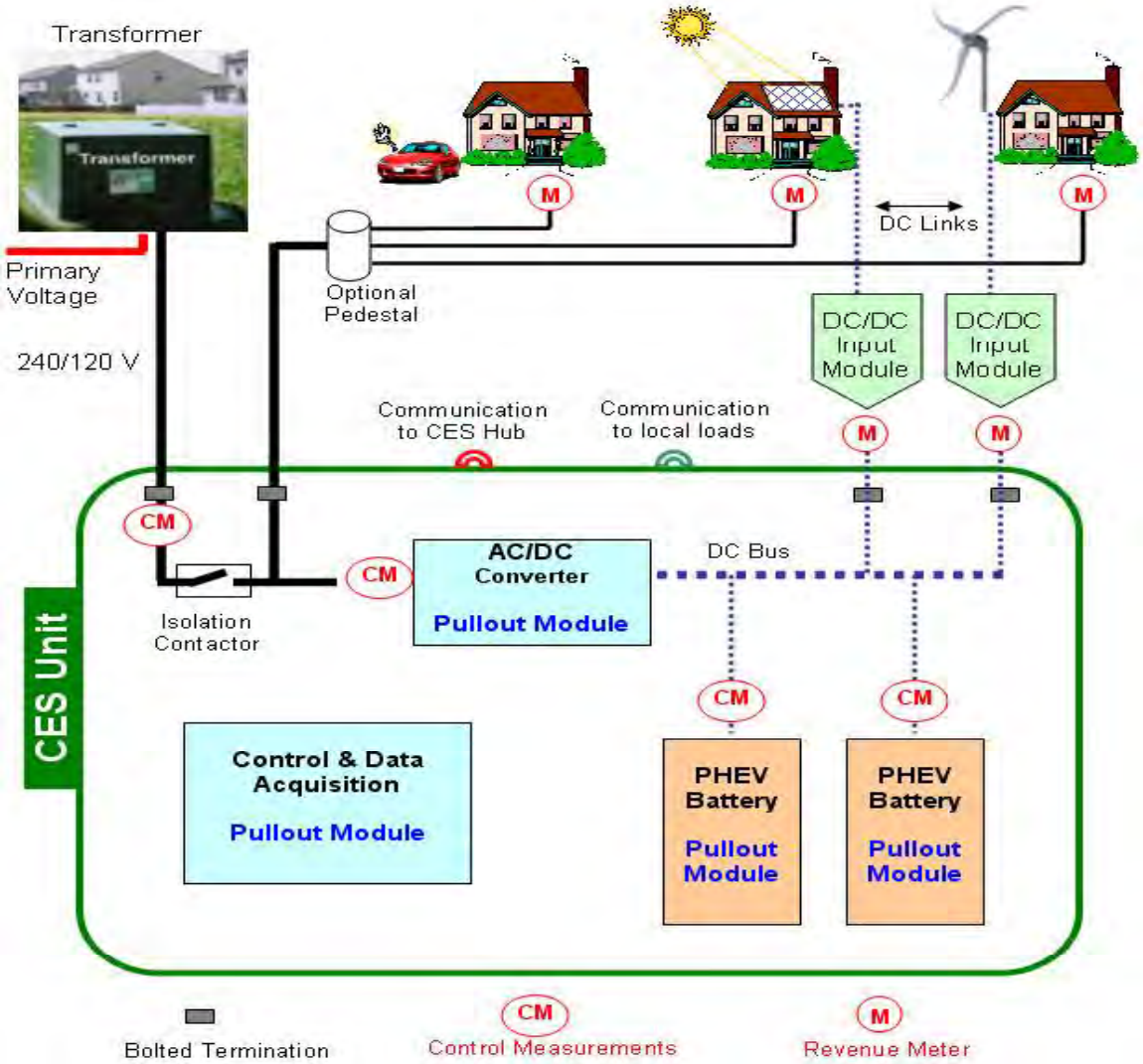
Source: R. Hayes of AEP

CES Components



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Source: R. Hayes of AEP

Benefits of CES

Advantages of CES compared to storage located in Substations:

1. ***More reliable Backup Power to customers (closer)***
2. ***More scalable, flexible implementation (many small units)***
3. ***Distributed, incremental power factor correction***
4. ***More efficient in buffering customer renewable sources***
5. ***Easier installation and maintenance (240 V)***
6. ***Unit outage is less critical to the grid (smaller)***

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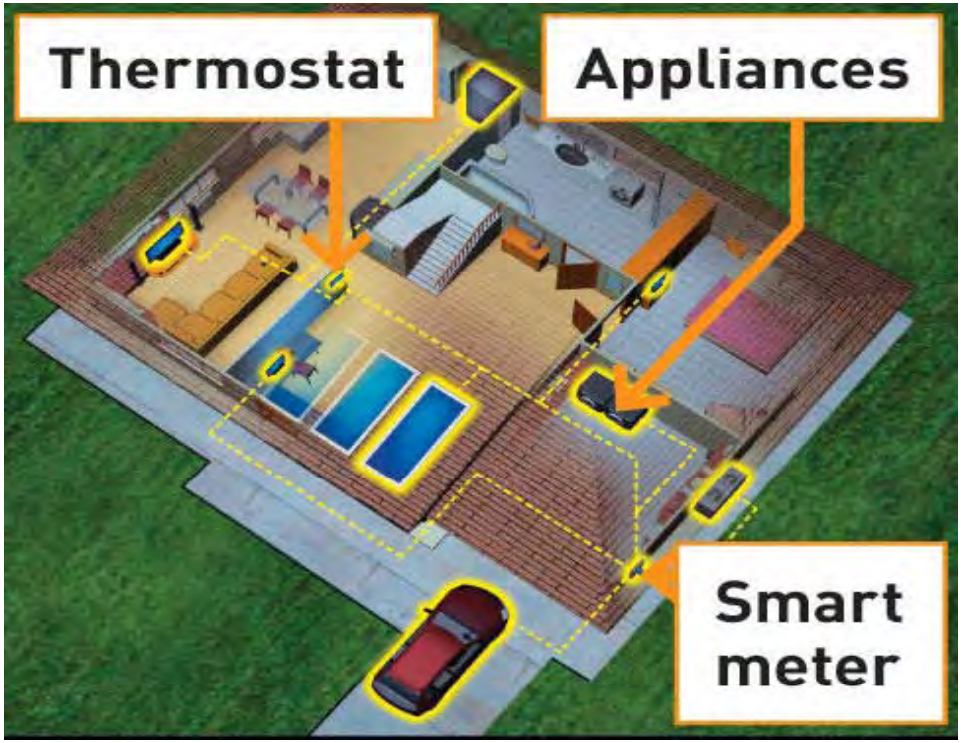
Source: R. Hayes of AEP

Smart Meters

- ✓ At a Small Scale: sensors will connect each appliance in homes to a smart meter.
- ✓ The meter will provide both detailed information on how much energy is being used at any given time and what it's costing.
- ✓ Furthermore, it will allow to control energy use remotely by users and provide information to the electric utility to regulate the energy use. This is helpful for reducing power flow during peak demand hours



Source: http://www.popsci.com/environment/article/2009-06/next-grid

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PHEV and PEV Impacts

Type	Driving Range on Batteries (Miles)	Battery Energy kWh	Mile/kWh	Time (Hours) for Full Charge			
				Single-Phase		Three-Phase	
				Level I 120V/15 A 1.4 kW	Level II 120V/30 A 3.3 kW	Level II 208V/32 A 6.6 kW	Level III 208V/80 A 16 kW
Sedan	40	16	5	8	3		
Compact	150	35	4–5	22	8	4	
Roadster	220	53	5–7	33	12	6	3

Source: IEEE Power & Energy Magazine, Mar. '09

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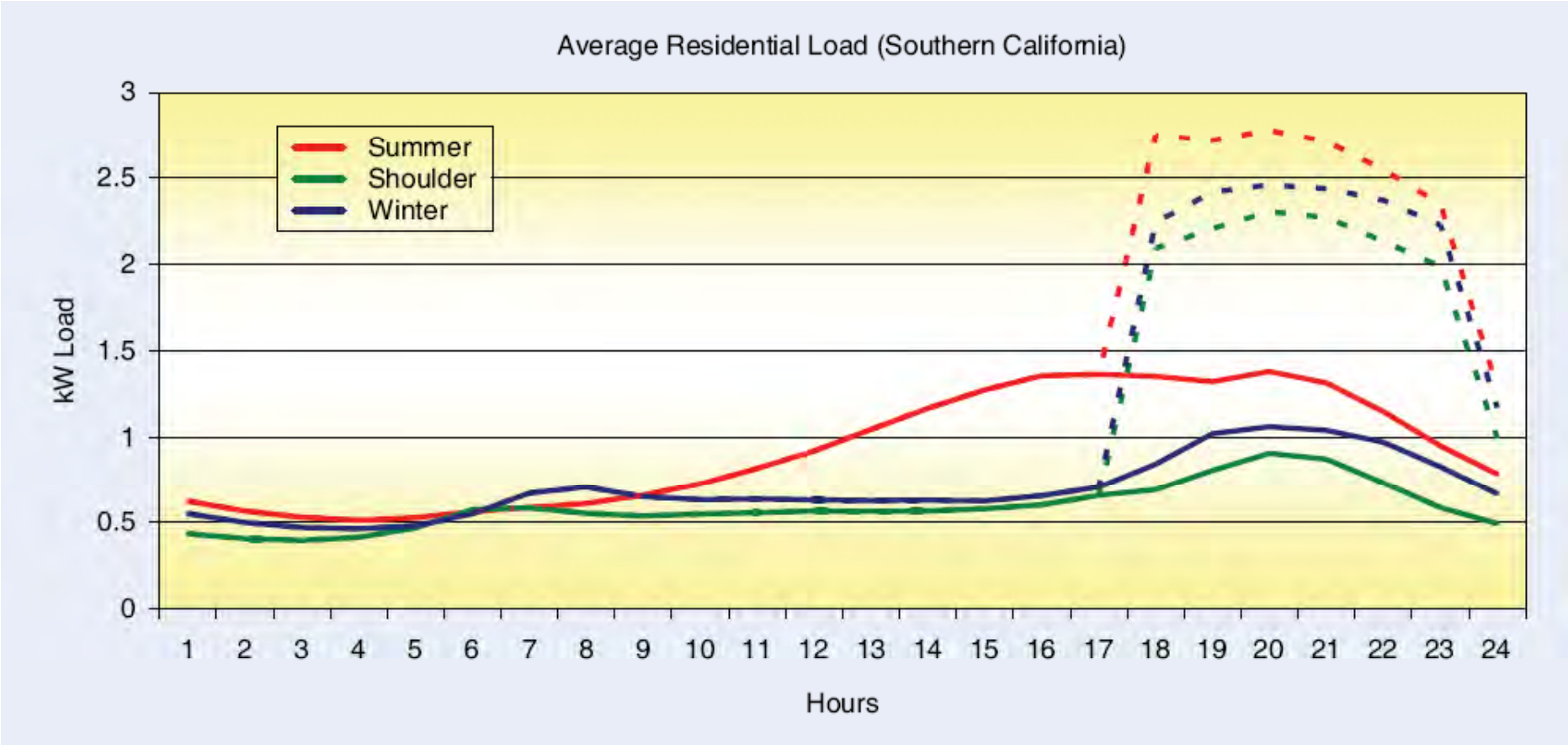
Electric Vehicle Impact



Source: IEEE Power & Energy Magazine, Mar. '09

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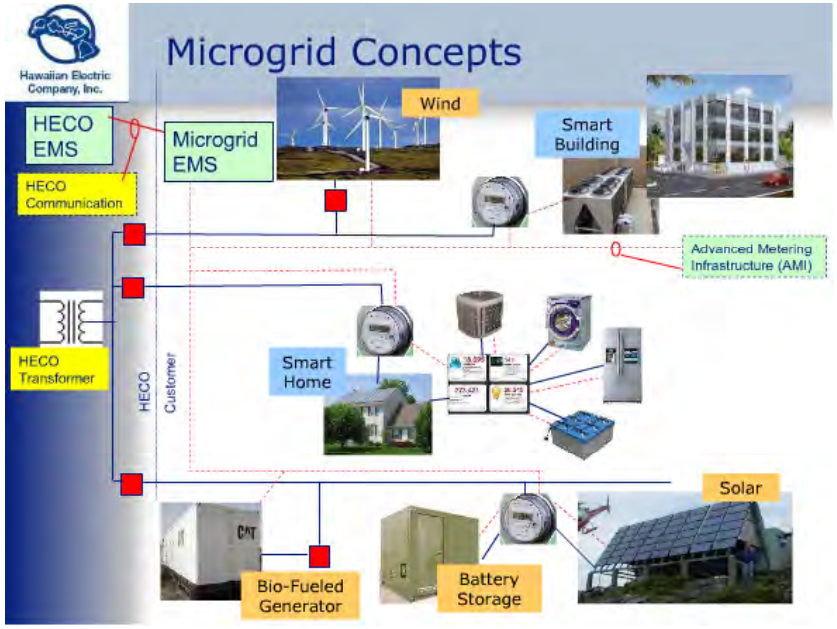
Residential Coming Attractions

- **Smart and efficient new DC standards: *EMerge Alliance***
  - ***Coalition of companies that include Johnson Controls, Philips Electronics, Armstrong World Industries, Nextek Power Systems, and Southern California Edison***
- **DC power Distribution: *Nextek, EMerge Alliance***
  - ***Distributed power generation***
  - ***Energy backup***
  - ***DC power distribution***
  - ***plug-in hybrid vehicles to connect to the building to provide additional power***
- **Microgrid Management & Distributed Generation: *U of Hawaii***
  - ***Distributed power generation***
  - ***Energy backup***
  - ***Plug-in hybrid vehicles***
  - ***Data acquire and transfer***
  - ***Energy Management***



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Competing Products

		Competing Products		
Feature	**Green Power Node**	**Grid-Tied PV**	**Grid-Tied PV with Storage**	**Grid-Tied PV with Monitor**
Cost	**TBD**	**$8,000 to $14,000 for a 2KW system**	**2KW with 13KW battery –$19,000**	**?**
Home Use	✓	✓	✓	
Green Power Source	✓	✓	✓	✓
Energy Storage	✓		✓	✓
Ability to use Solar when Grid is down	✓			✓
Automated Energy Measurement	✓			✓
Enable Power Dispatchability	✓			
Energy Management based on data (weather, price, power usage)	✓			
DC Distribution to improve efficiency	✓			✓
Vendors	GRAPES	Solar Electric Supply INC.	SunWize Technology Inc	Nextek
		Enphase Energy	Xantrex Technology INC	Enphase Energy
		GE		
		Helios Electric		

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Smart Grid Standards

- The electric power system has more standards efforts than any other IEEE field
- Smart grid standardization is no different
- Efforts include:
  - Communications (in-home, smart meter, distribution)
  - Power electronics interconnection
  - Power quality
  - Cyber security
  - Interoperability
  - Many others (NIST has identified 31 initial standards and 46 additional standards for industry comment)
- PELS is involved (contact: Alan Mantooth, PELSC chair)

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Today's Grid vs. Smart Grid

TODAY'S GRID	SMART GRID
Consumers are uninformed and non-participative with power system	Informed, involved, and active consumers; demand response and distributed energy resources
Dominated by central generation; many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug-and-play convenience; focus on renewables
Limited wholesale markets, not well integrated; limited opportunities for consumers	Mature, well-integrated wholesale markets, growth of new electricity markets for consumers
Focus on outages; slow response to power quality issues	Power quality is a priority with a variety of quality/price options; rapid resolution of issues; self-healing
Little integration of operational data with asset management; business-process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Responds to prevent further damage; focus is on protecting assets following fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumer
Vulnerable to malicious acts of terror and natural disasters	Resilient to attack and natural disasters with rapid restoration capabilities

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When? How? How much?

- Grand Challenge
- US investment is in the billions
  - Smart meters
  - Demonstration projects
  - Loans
  - Advanced R&D
    - Security
    - Cabling
    - Power electronics
    - Distribution automation
- Contentious issues
  - Security
  - Higher bills/cost recovery

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Timeline of Outcomes

- Early Adopters -> next 5 years
- Broader adoption in 5-10 years based on early adopter knowledge (one size doesn't fit all in the US)
- Smart power management commonplace in 10 years along with greater resiliency and reliability.
- In 20 years, I believe, if we've stayed the course, we will have a balance of resources to create power, a substantial supply of green energy and automated but over-rideable controls on all aspects of our grid that maintains our standard of living but does so in a more eco-friendly way.

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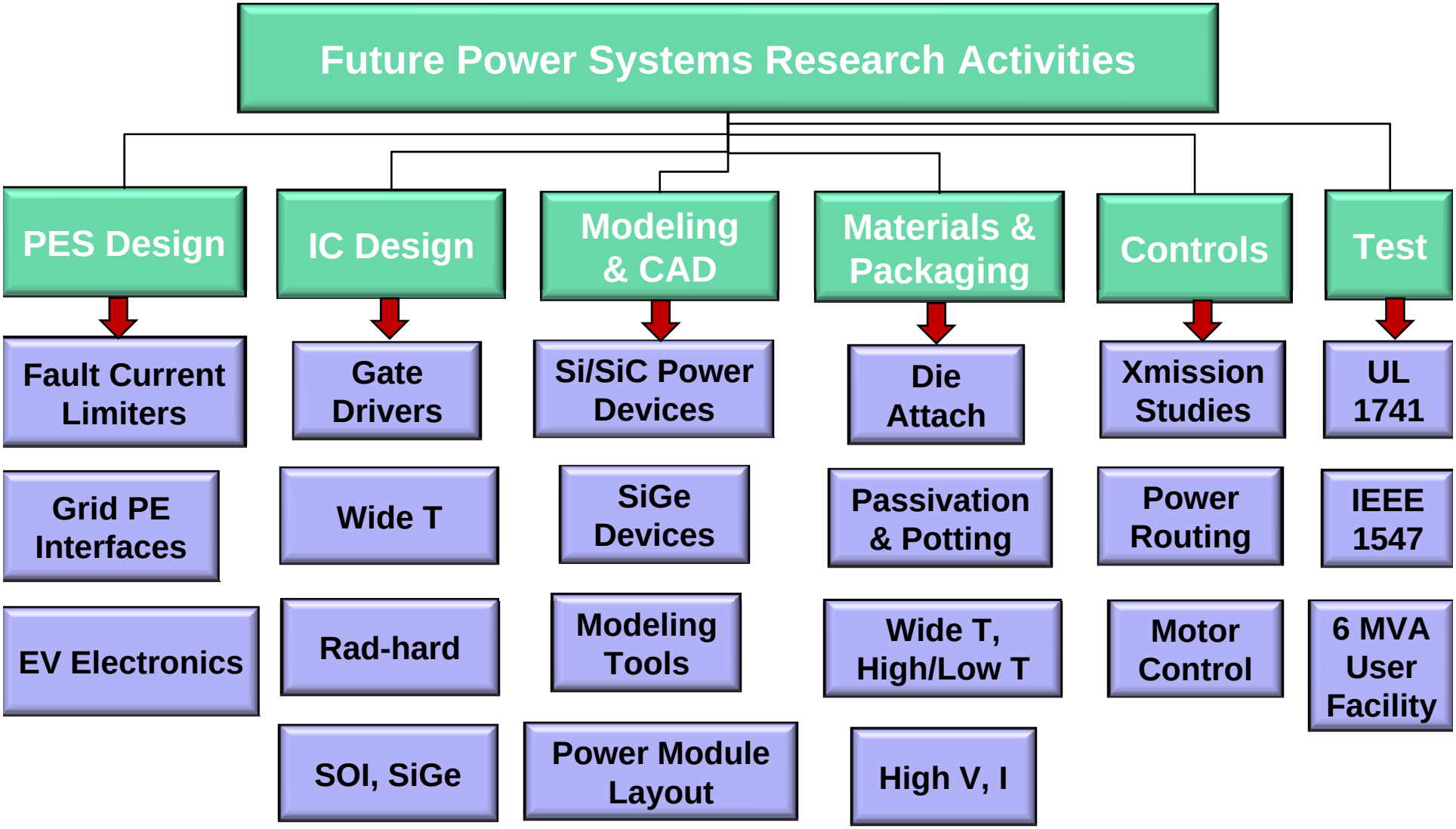
Research Activity at NCREPT



"Materials to the Grid"

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Smart Grid Apps

- Fault current limiter
- Smart power routing
- Interfaces to renewables (wind, solar)
- Interfaces to storage (CES)
- Electric vehicle charging & drive electronics
- Transmission support
- HVDC terminals

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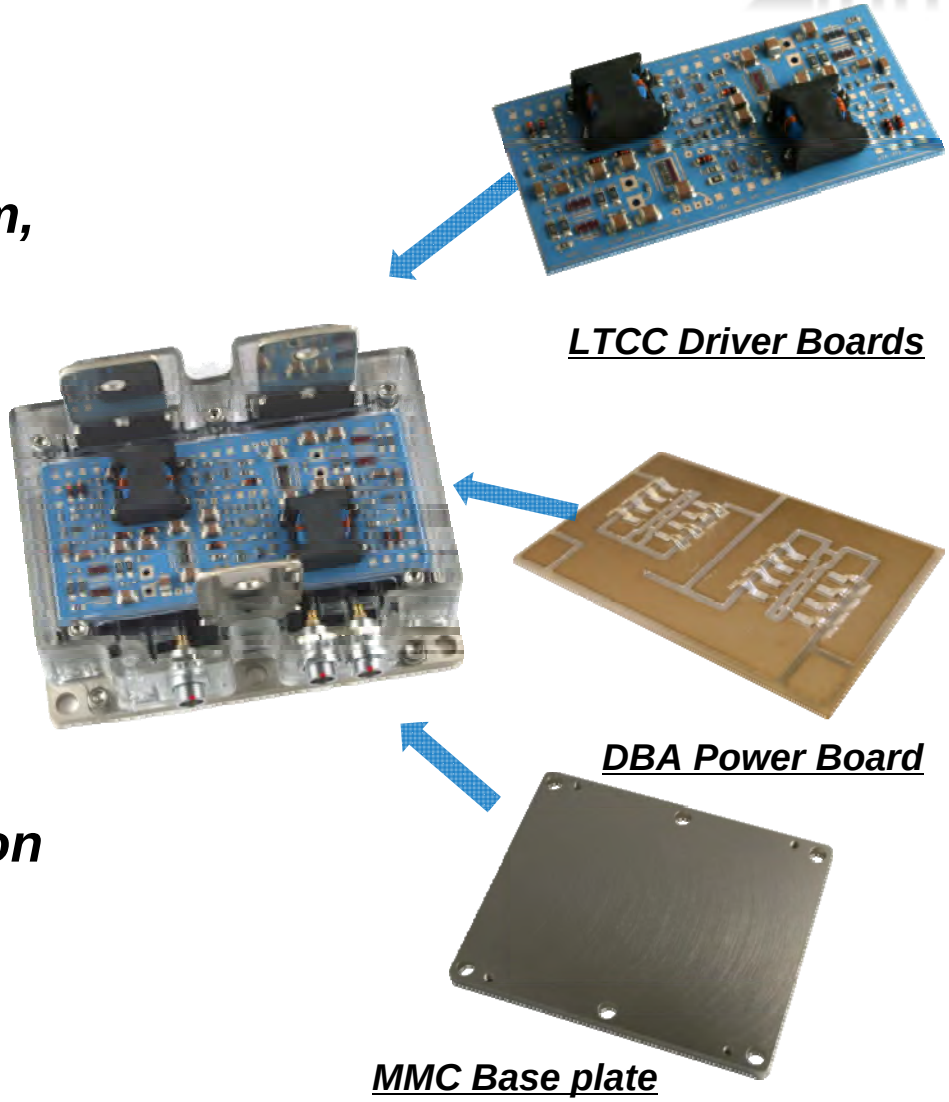
High Temperature Power Modules

SiC Single-phase half-bridge modules

- ***Collaboration with APEI, Rohm, Sandia***
- ***R&D 100 Award Winner (2009)***
- ***UA High temperature TLP attachment technologies for devices and substrate***
- ***6 parallel SiC devices per "switch position"***
- ***1.2kV / 150+ A***
- ***Operational to > 250 °C junction***
- ***Includes miniaturized integrated high temperature gate driver***



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Prototype Test & Evaluation Facility

- 7000 ft^2 building
- $5 million test facility
- One-of-a-kind
- Cost-effective facility for businesses, national labs, and universities
- UL and IEEE Standards testing

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NSF Industry/University Cooperative Research Center

GRid-Connected Advanced Power Electronic Systems (GRAPES)

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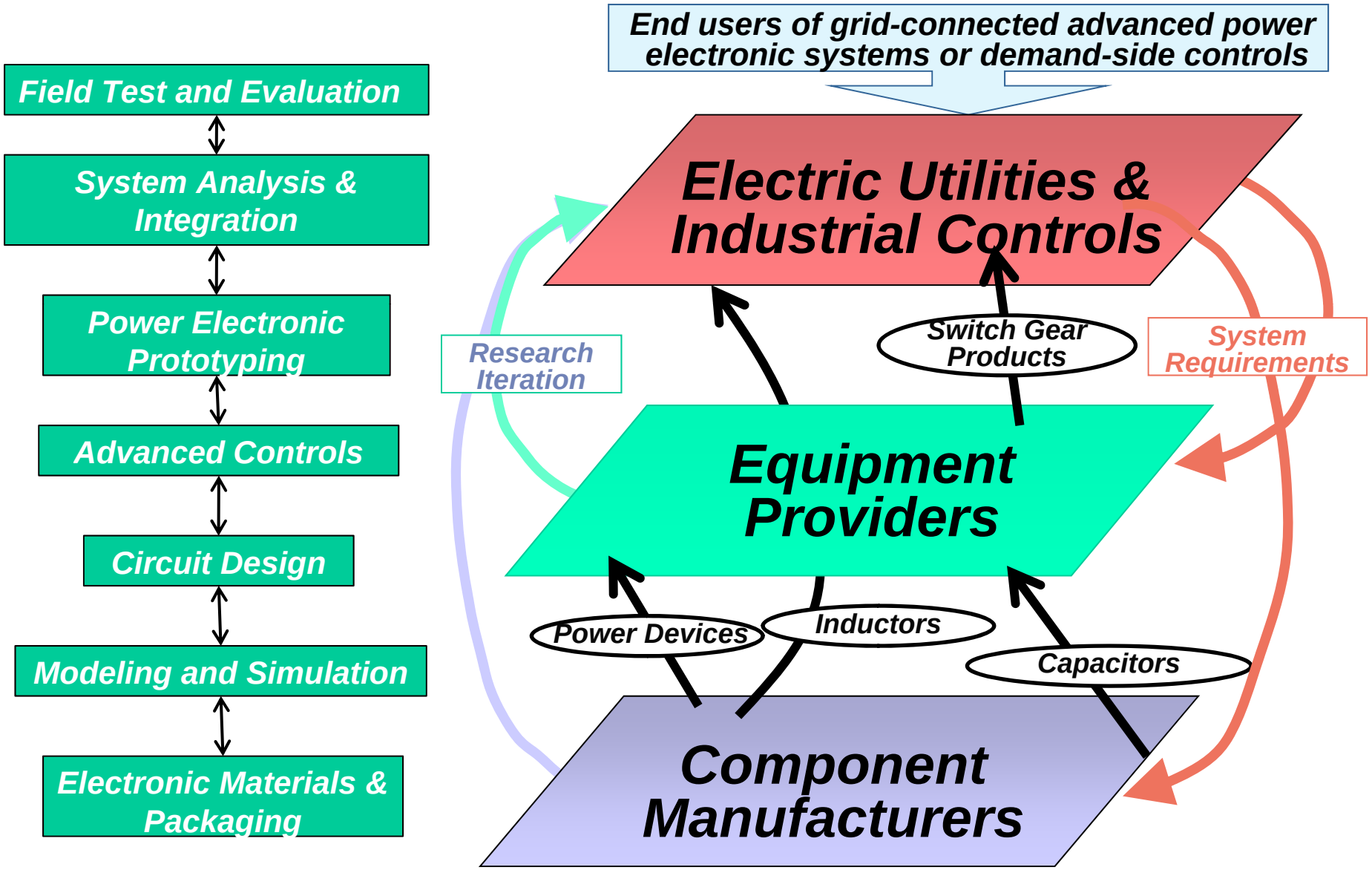
The GRAPES Solution



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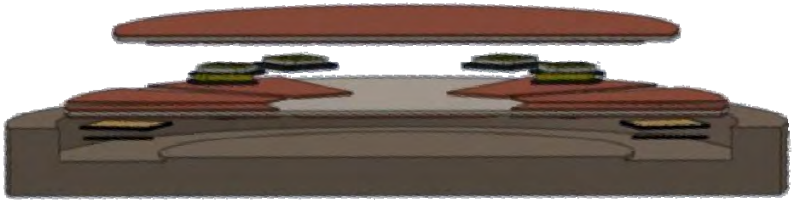
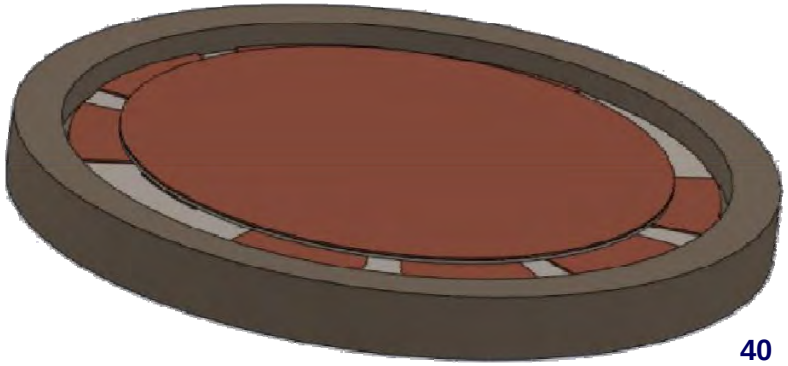
SiC SGTO-based Switching Position for Fault Current Limiters

- **High voltage series connected single device**
  - Switch position for 7.2 kV, 50A
  - Test bed developed for evaluation power devices and drive and control circuitry at lower power level behavior
  - Individually packaged for device level testing prior to integration so packaging not optimized
- **High voltage parallel connected multichip modules**
  - High current/voltage module (8 kV, 500 A)
  - Designed around 8 SiC devices in parallel
  - SiC current sharing resistors embedded
  - DBC Anode/Gate routing direct attachment
  - Modules designed around liquid cooling





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VICTER: Vertically-Integrated Center for Transformative Energy Research

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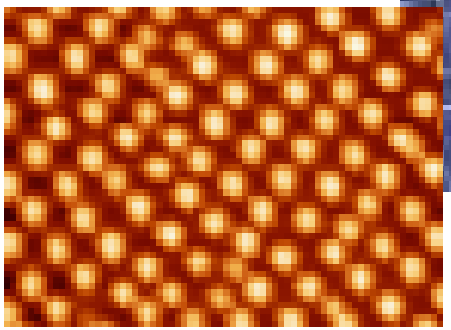
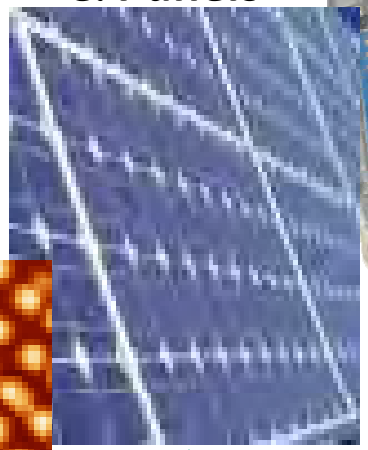
MATERIALS 2 GRID

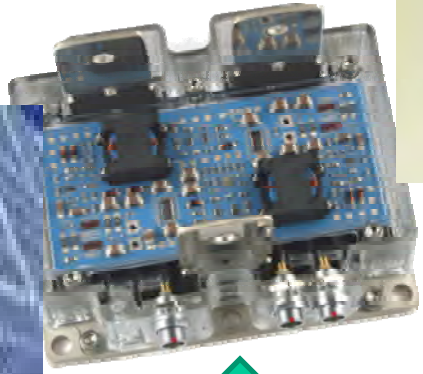
Novel Nano-materials for PV, Thermoelectrics, etc.



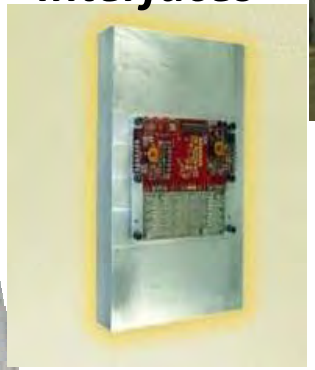
Packaged Solar Cells & Panels



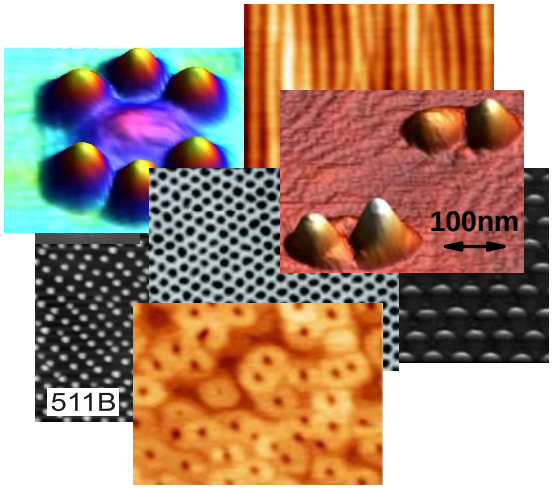
Power Electronic Modules



Packaged Power Electronic Interfaces



Grid Test Facility



Materials form the foundation of VICTER

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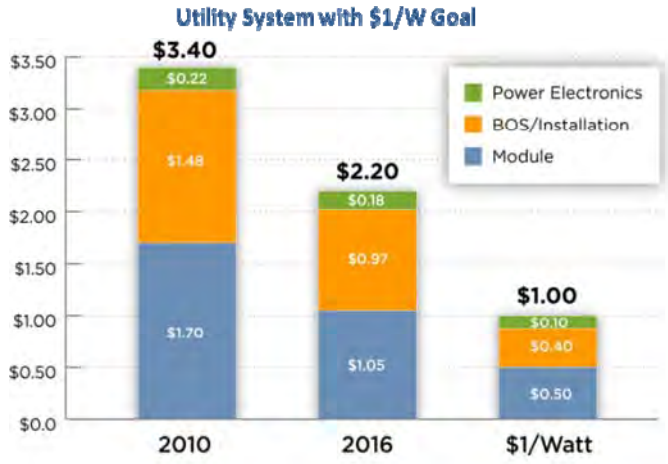
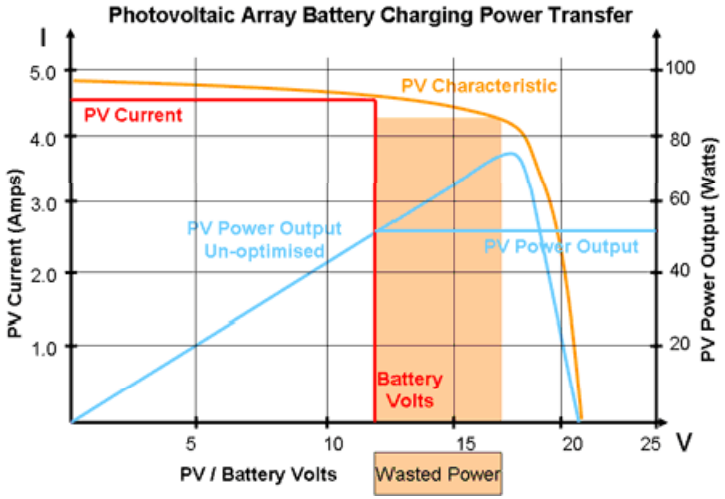
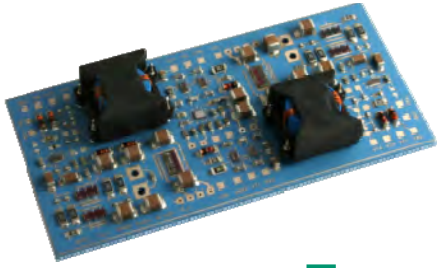
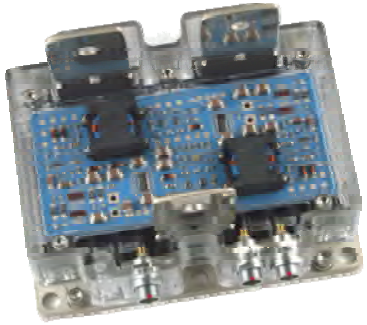
Challenges

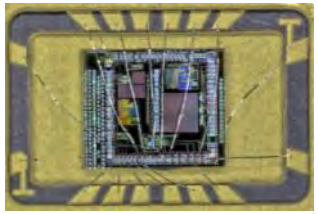
Power Electronics

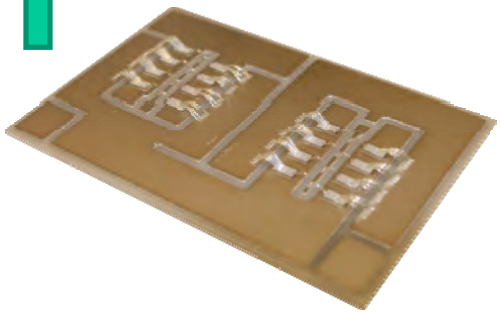












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Question and Answer

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