LoCal: A Radical Distributed Architecture for Local Energy Generation, Distribution, and Sharing

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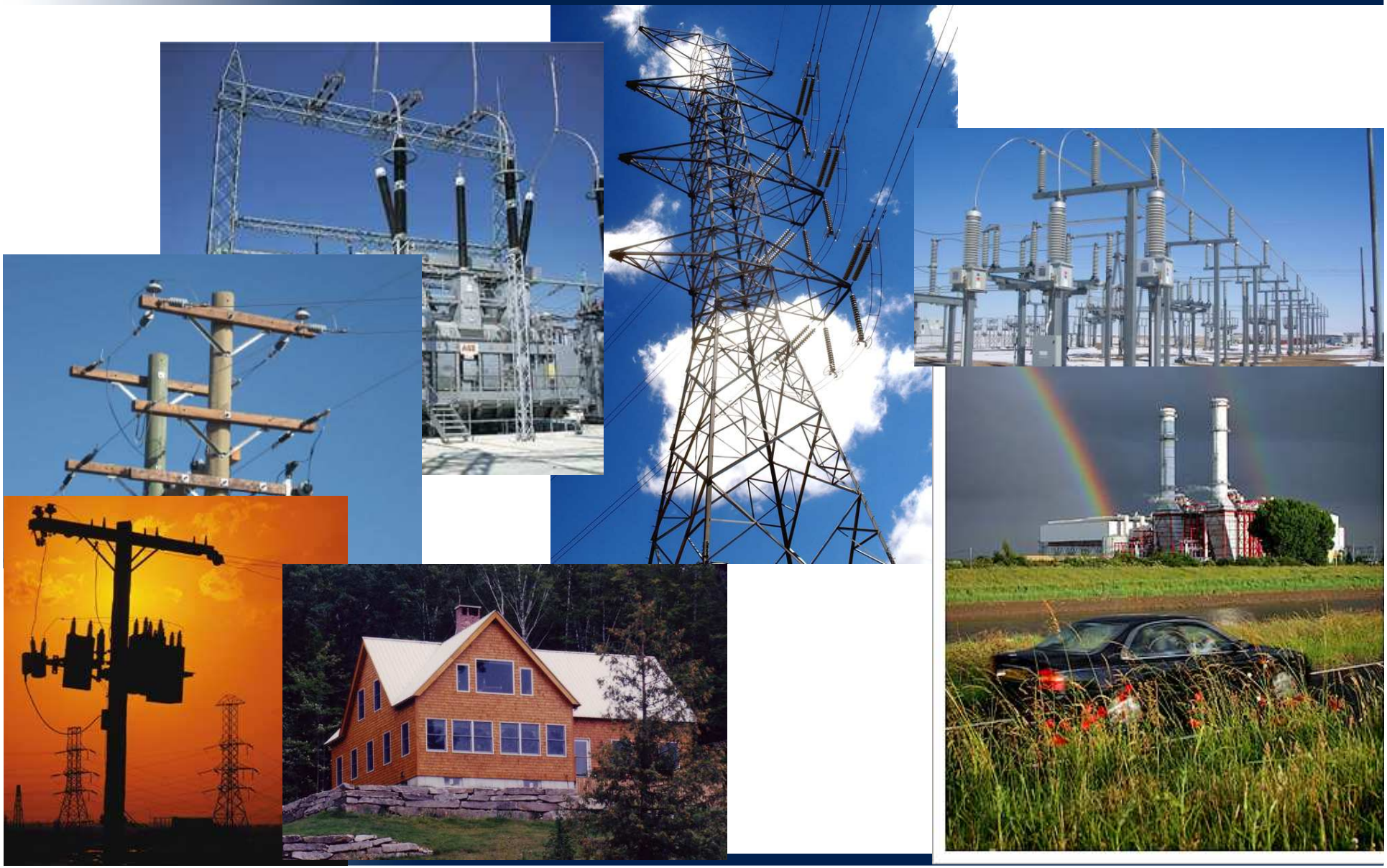
What if the Energy Infrastructure were Designed like the Internet?

- Energy: *the* limited resource of the 21st Century
- Needed: Information Age approach to the Machine Age infrastructure
- Lower cost, more incremental deployment, suitable for developing economies
- Enhanced reliability and resilience to wide-area outages, such as after natural disasters

- *Packetized Energy*: discrete units of energy locally generated, stored, and forwarded to where it is needed; enabling a market for energy exchange

Legacy Energy Infrastructure



Principles for a New Energy Infrastructure

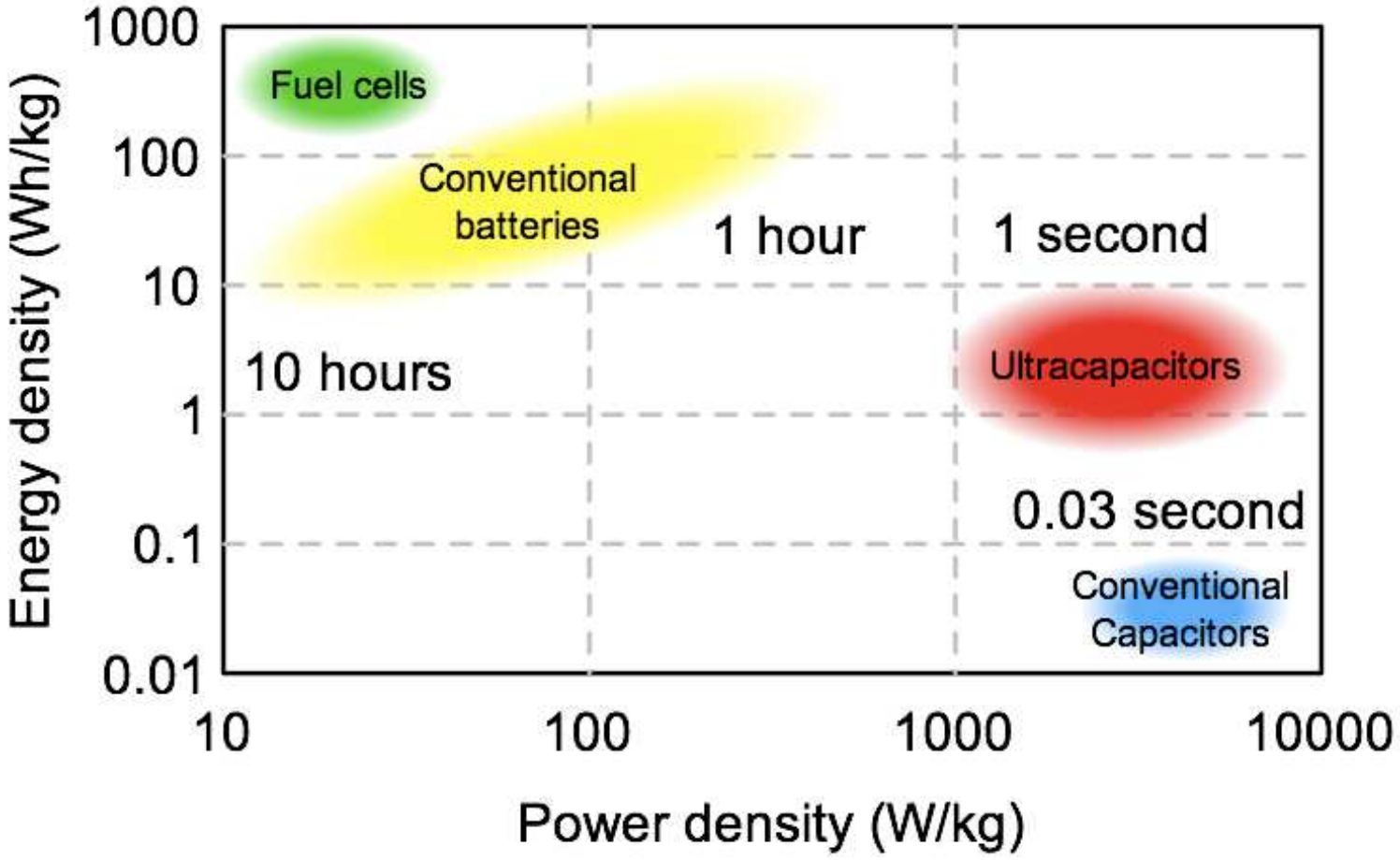
- Lessons from the Internet
  - *End-to-end Principle*: push intelligence to the edges
  - *Narrow Waist Model*: hide diversity of underlying technology
  - Overlay new services on existing infrastructure
  - Incremental deployment to achieve scale
  - "Storage" breaks synchronization between end-points

  - *Intelligent Power Switch*: a plug-and-play energy infrastructure building block

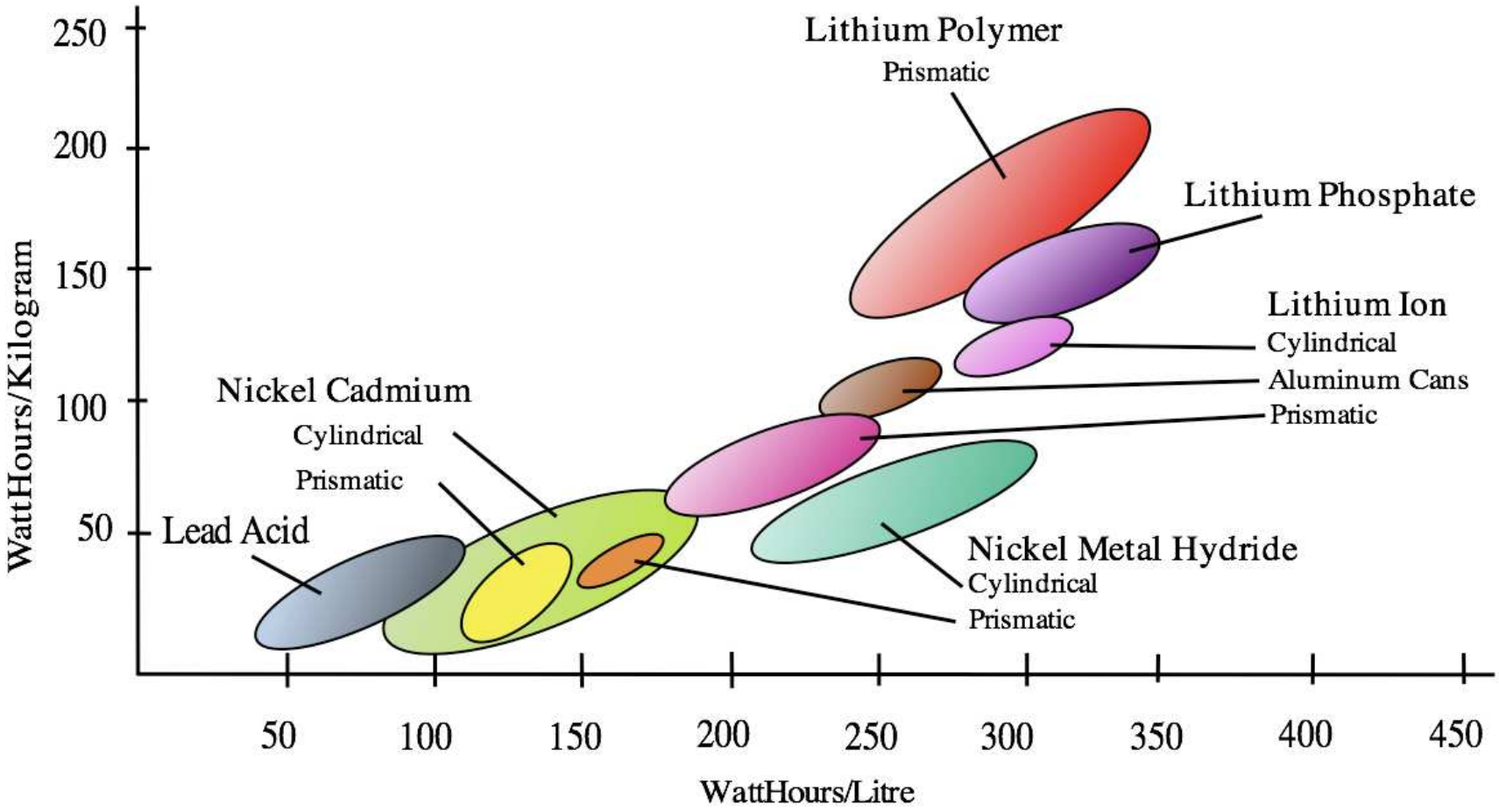
Critical Bet: Energy Storage

- Breaks synchronization of traditional energy generation, transmission, distribution system
- Enables Grid Overlay: independence and resilience
- Compelling economics: pay for average load, not peak

Energy Storage: Batteries



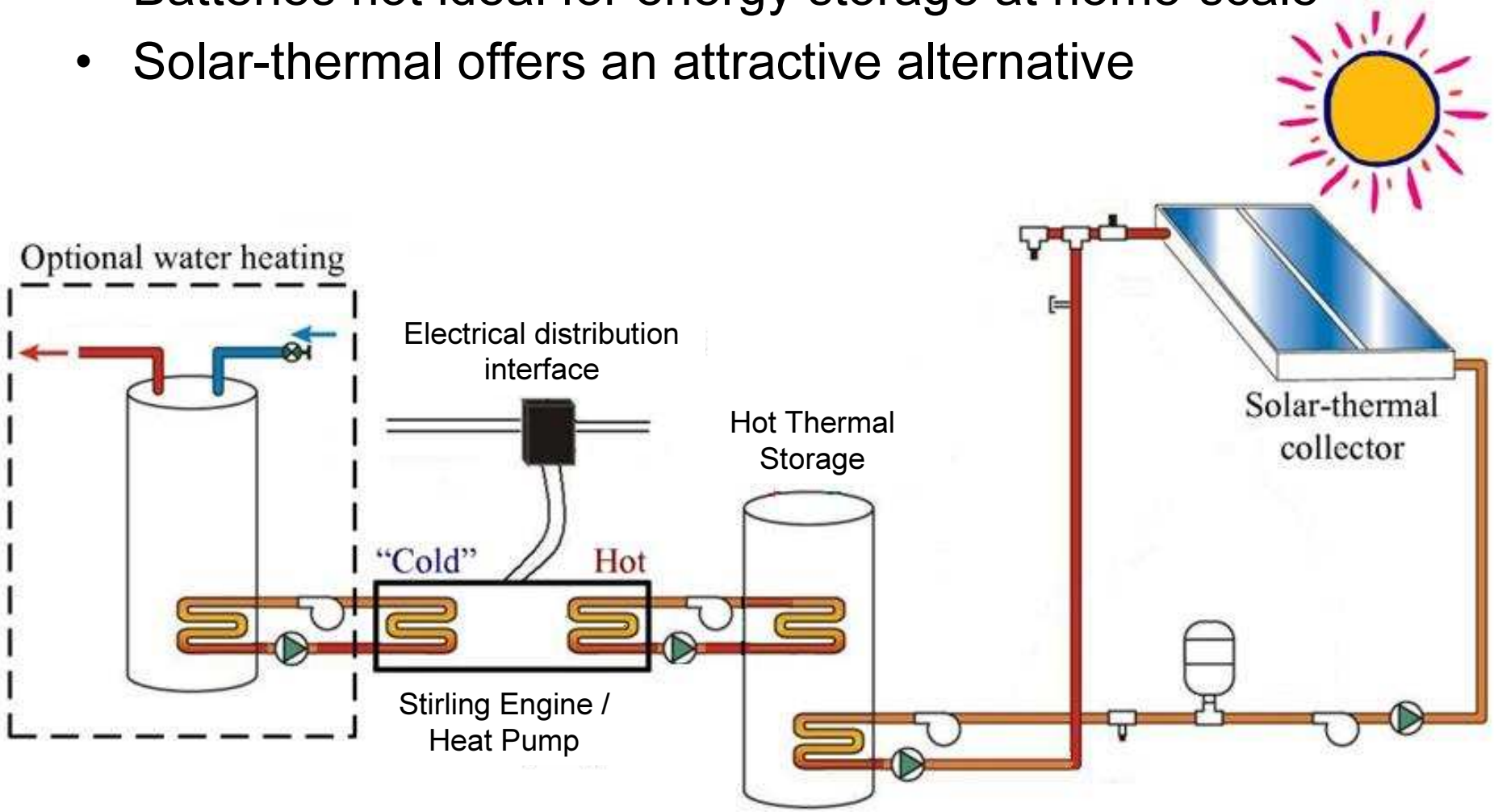
Energy Storage: Batteries



Mike He, Fred Jiang

Energy Storage: Solar-Thermal

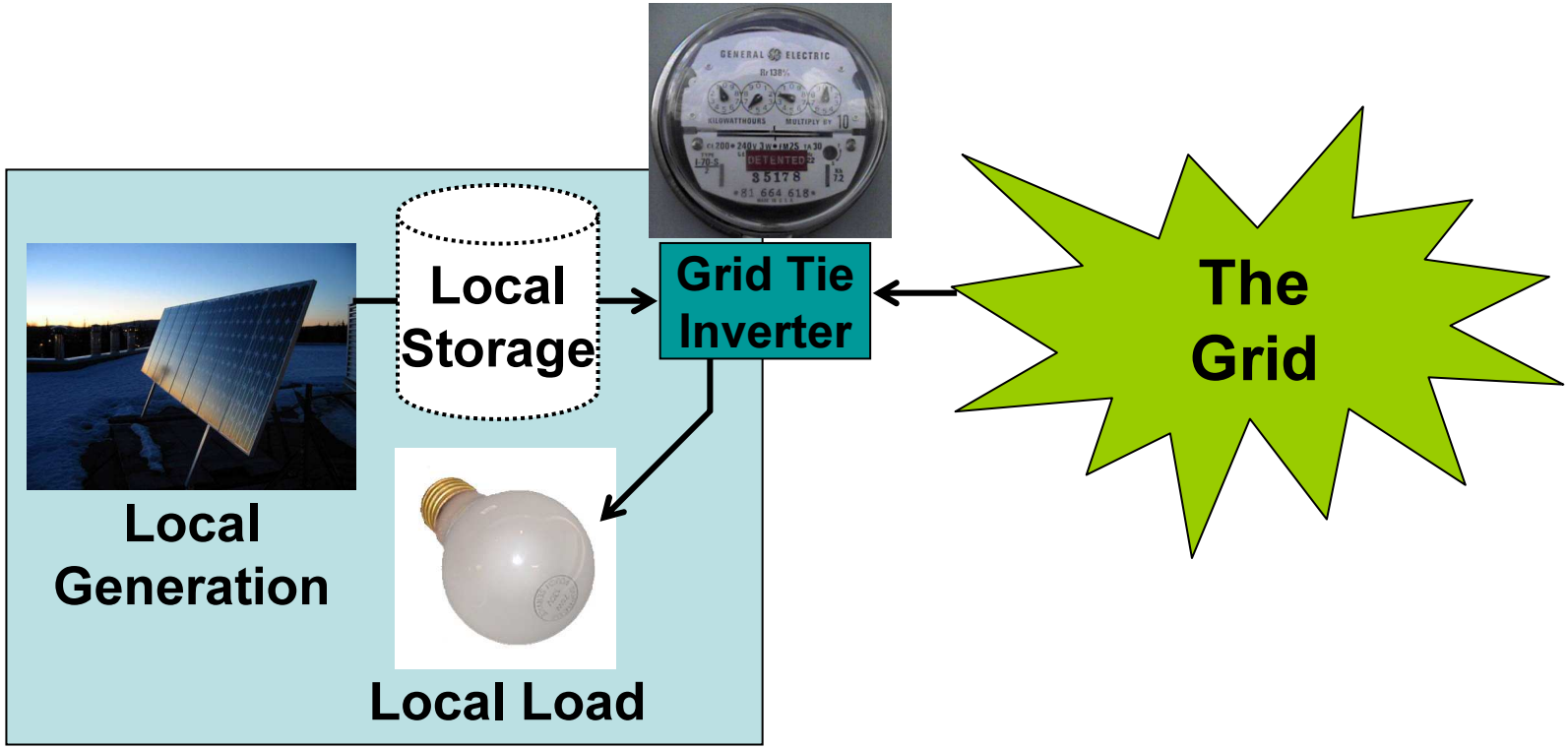
- Batteries not ideal for energy storage at home-scale
- Solar-thermal offers an attractive alternative



Intelligent Power Switch

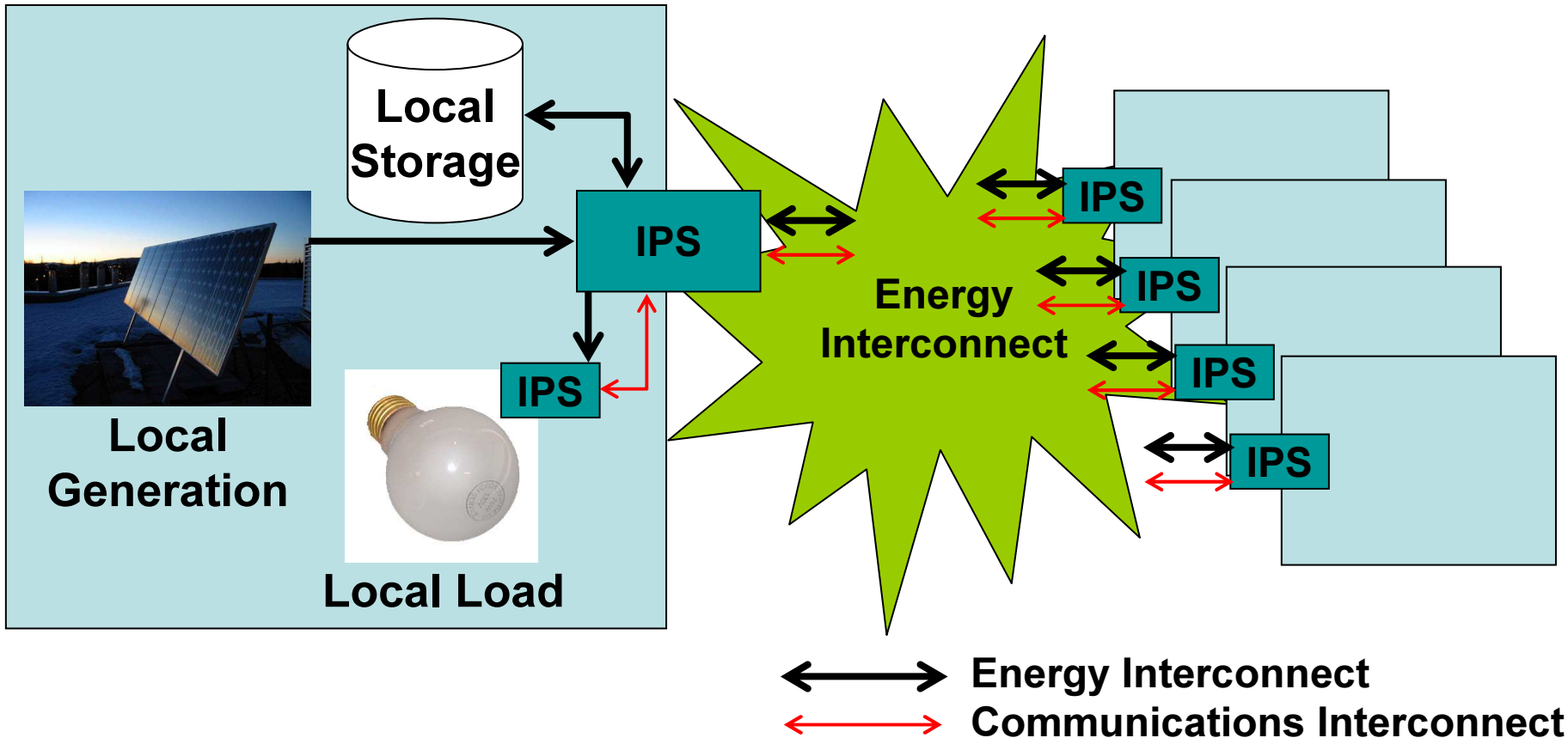
- *Interconnects* load to power sharing infrastructure
- *Bundles* communications with energy interconnection -- PowerComm interface
- Enables *intelligent* energy exchange
- Optionally incorporates energy *generation* and *storage*
  - Scale-down to individual loads, e.g., light bulb, refrigerator
  - Scale-up to neighborhoods, regions, etc.
- Overlay on the existing power grid

Energy Markets



- Typical home solar system configuration
- Run meter backwards
- Optional local storage for off-grid operation

Energy Markets



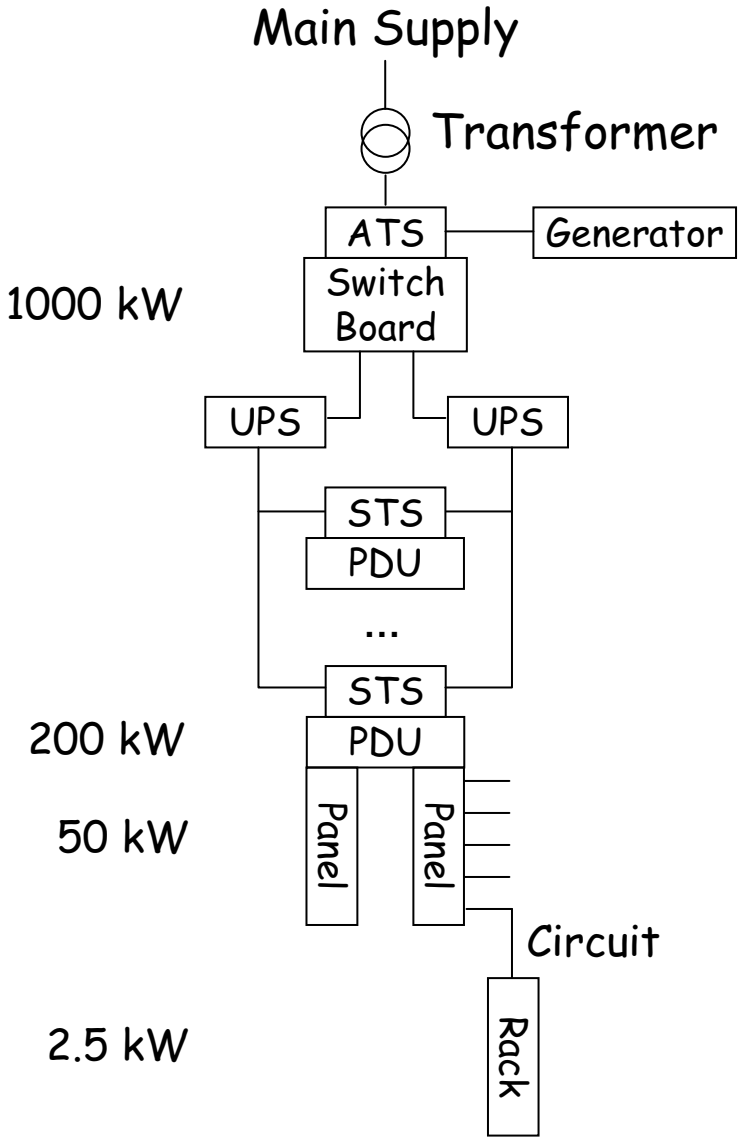
- Hierarchical aggregates of loads and IPSs
- Overlay on existing Energy Grid

Energy Markets

- Centralized vs. decentralized markets
- “Bank” energy surpluses centrally (e.g., in the Grid) or with peers
- As local energy storage is diminished
  - Increase local generation
  - Reduce local load via demand response
  - Spend to “withdraw” energy banked elsewhere
- Pricing incentives
  - As local storage reaches capacity, reduce offered price
  - As approaches zero, increase offered price

Datacenters

Datacenter Power



- Typical structure 1MW Tier-2 datacenter
- Reliable Power
  - Mains + Generator
  - Dual UPS
- Units of Aggregation
  - Rack (10-80 nodes)
  - PDU (20-60 racks)
  - Facility/Datacenter
- EPA, 8/07:
  - 1.5% of total U.S. energy consumption
  - Growing from 60 to 100 Billion kWh in 5 yrs
  - 48% of typical IT budget spent on energy

X. Fan, W-D Weber, L. Barroso, "Power Provisioning for a Warehouse-sized Computer," ISCA'07, San Diego, (June 2007).

Nameplate vs. Actual Peak

Component	Peak Power	Count	Total
CPU	40 W	2	80 W
Memory	9 W	4	36 W
Disk	12 W	1	12 W
PCI Slots	25 W	2	50 W
Mother Board	25 W	1	25 W
Fan	10 W	1	10 W
System Total			213 W

Nameplate peak

Measured Peak 145 W
(Power-intensive workload)

3.5 kWhr/day

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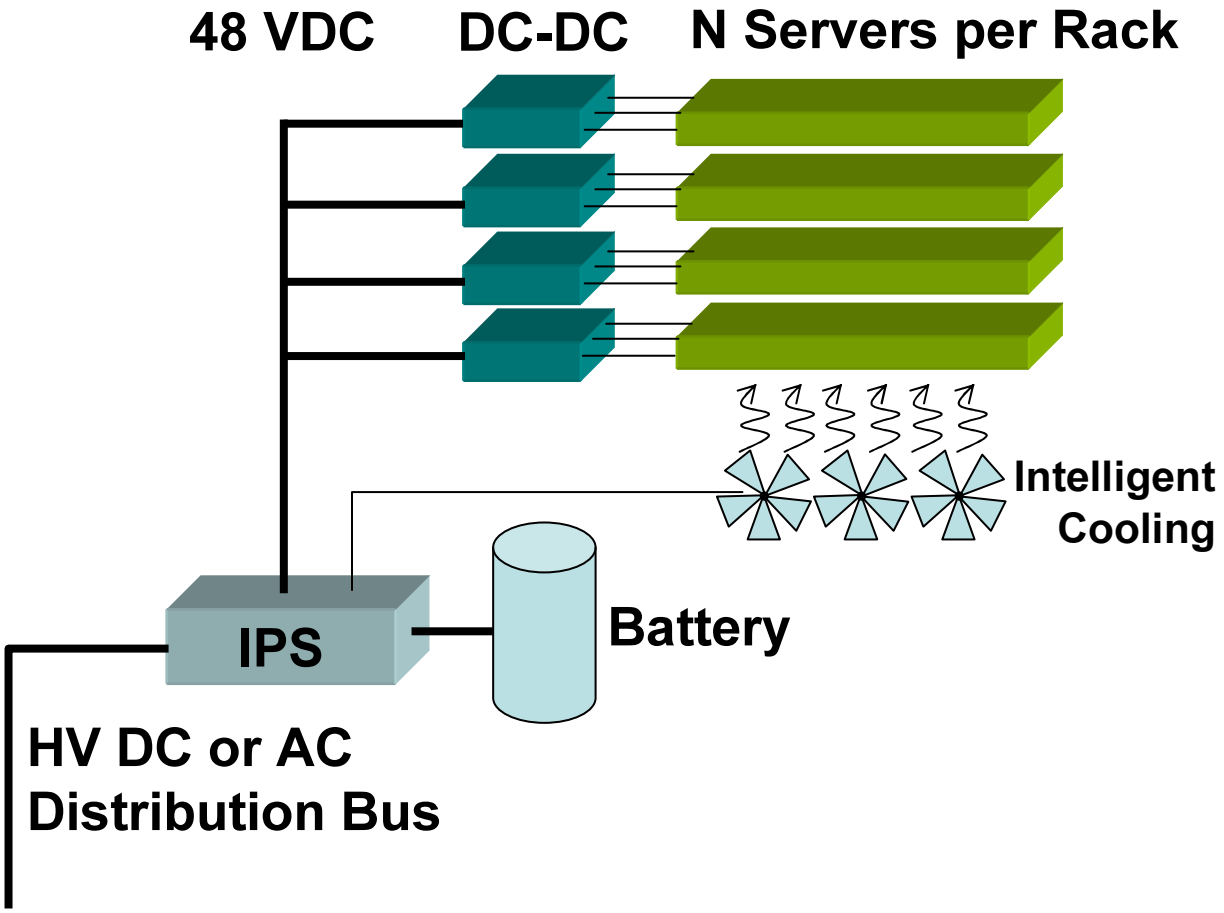
"Doing Nothing Well"

- Systems sized for peak energy
  - Datacenter peak-to-average processing
    - 3-4x for batch processing, 10-20x for web applications
    - Provision for substantially lower average power, energy storage provides margin
    - Factor of 10 power reduction
  - "Always on" assumption for desktops and appliances
    - Typically idle 23 hours a day
    - 3 kWh/day → 1 kWh/week
    - Another factor of 10 power reduction
  - Existing energy management techniques crude
    - 30-40% typically achieved
  - To reach 90-99% power savings
    - Fine-grained idling, aggressive savings requires fast power shutdown/restoration
    - Requires pervasive support in systems and applications, not just hardware

Datacenter Testbed

Rack Unit

- Replace AC power supply in servers with DC-DC converters to generate required voltages
- Battery capacity per rack to simplify design of the DC-DC converter, centralizing the charge controller and energy sharing function in the IPS
- Distributed DC-DC converters provide regulation at the load



Datacenter Testbed

- Key elements:
  - Battery storage in every node
  - Every node connects to a common infrastructure for power and data
  - DC Power Distribution Tier:
    - DC delivered to computing nodes
    - Batteries for peak shaving: power distribution sized for average rather than peak
    - Batteries enable power sharing: Computational nodes can hibernate while battery power is available to the community
  - Centralized energy economy

Summary and Conclusions

- New scalable infrastructure
- Integrated energy generation and storage
- IPS and PowerComm Interface
- Energy marketplace
- Demand response: doing nothing well
- Testbeds: datacenter, village, campground

Village/Community Testbed

- Consumer loads (houses) with their own local capabilities for generation, storage, and embedded loads
- Power exchange as either AC or DC
- Large scale IPSs associated with a home
- Small scale IPSs associated with primitive loads within the home, e.g., appliances

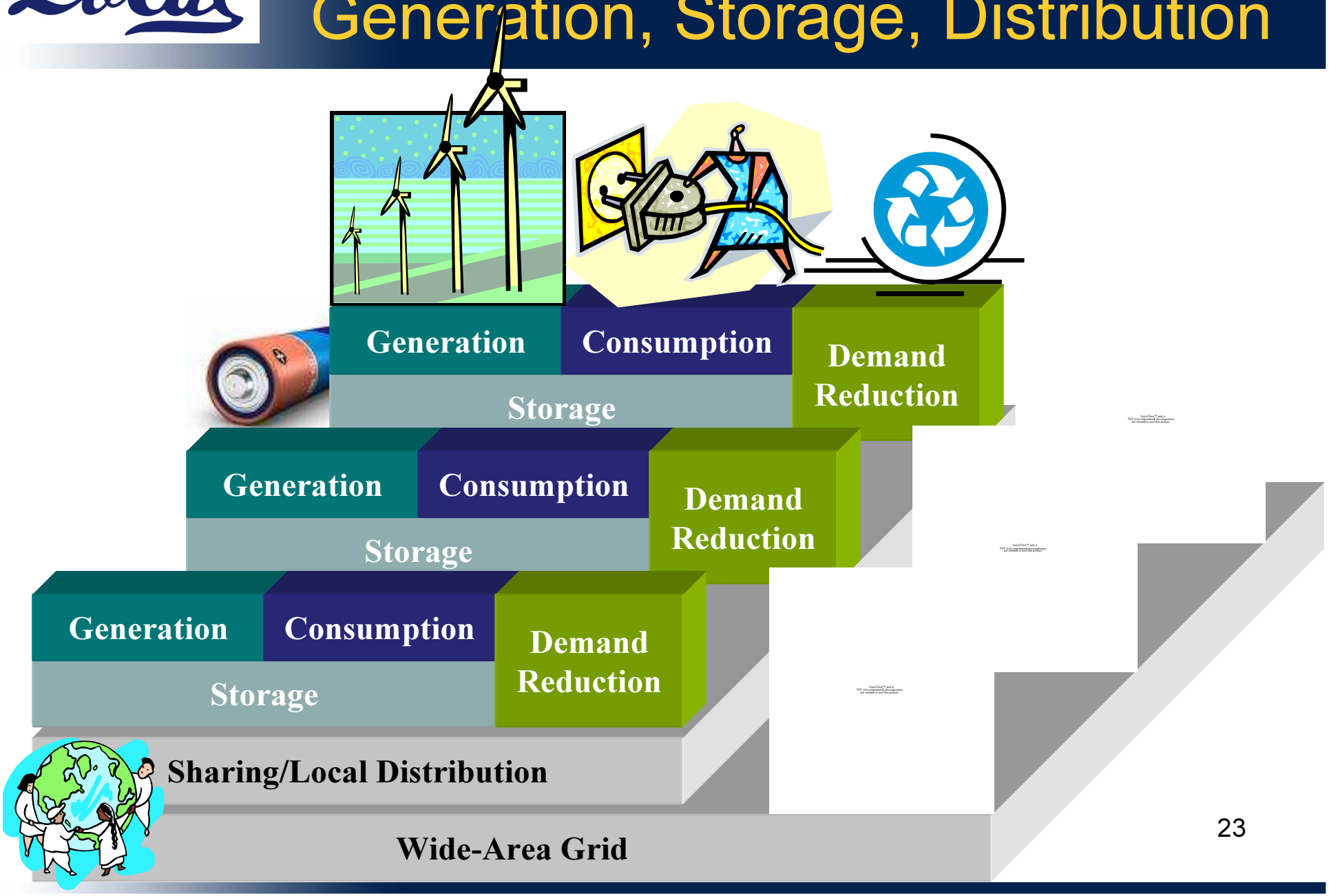
Village/Community Testbed

- Key attributes:
  - High Voltage DC backbone interconnect
  - Village-level connection to AC grid
  - Village encompasses generation, storage, “housing” and grid connection elements
  - Local energy exchange enabled by information flow within village and to backbone
  - Housing units include generation, storage and both DC and AC loads
  - Bidirectional energy flows.

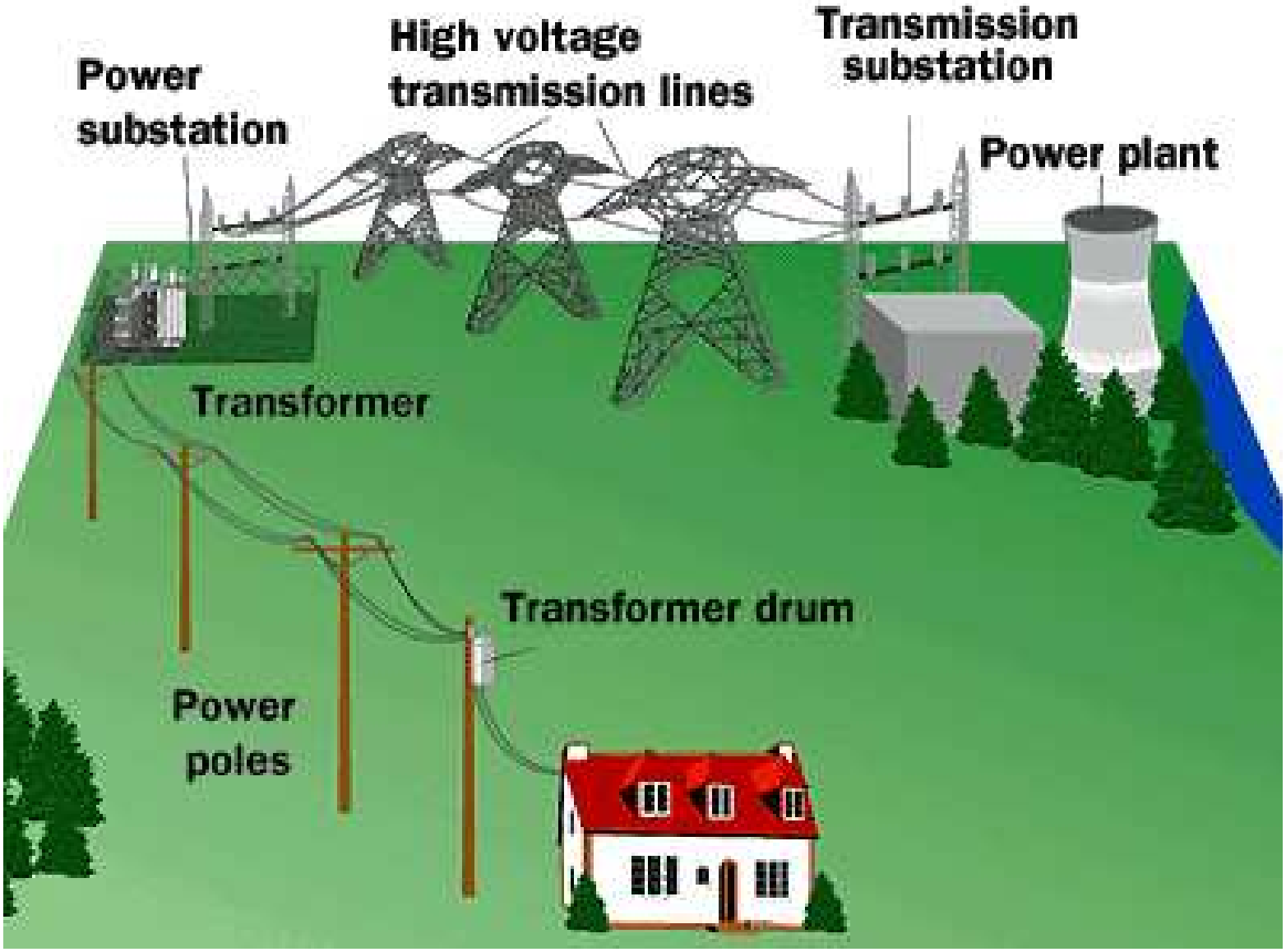
Campground/Rapid Deployment Testbed

- Snap together energy infrastructure completely independent of existing grid
- Key attributes:
  - Autonomous operation independent from a central grid
  - IPS packaging suitable for diverse generation, storage, and loads
  - Size and scale easily transported into the field
  - Peer-to-peer energy economy

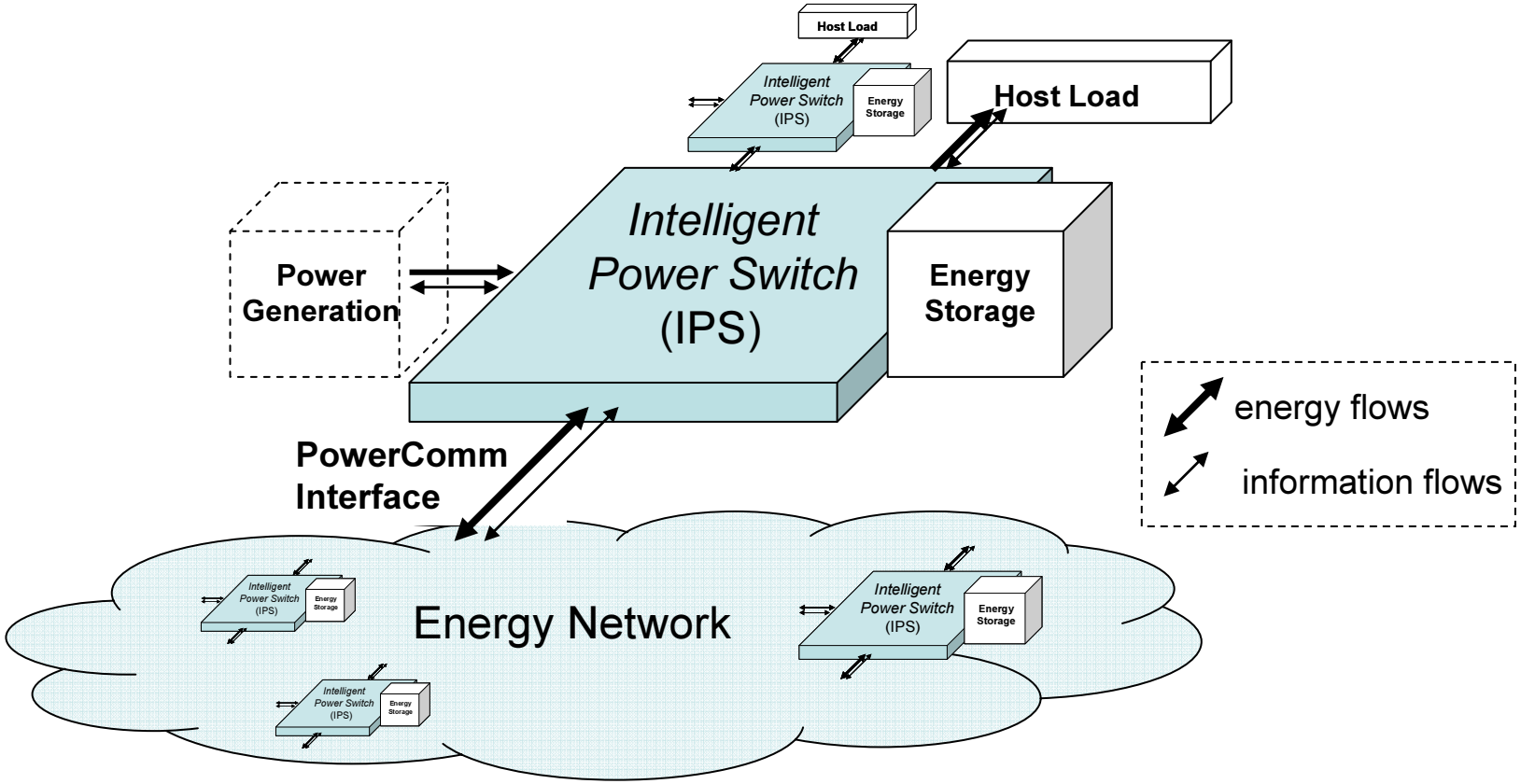
LoCal Architecture: Generation, Storage, Distribution



Legacy Energy Infrastructure

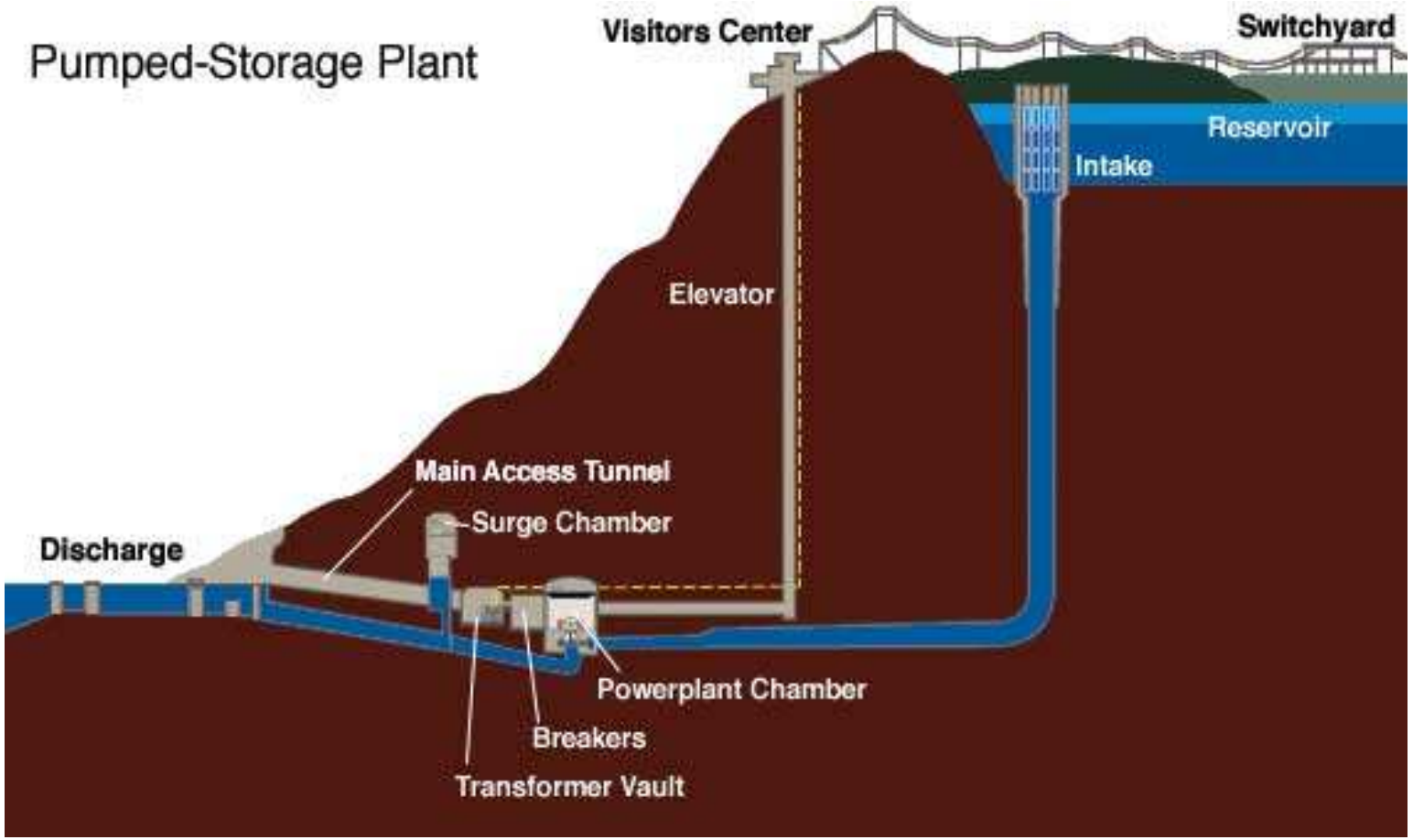


Intelligent Power Switch



- PowerComm Interface: Network + Power connector
- Scale Down, Scale Out

Pumped Storage



Compressed Air

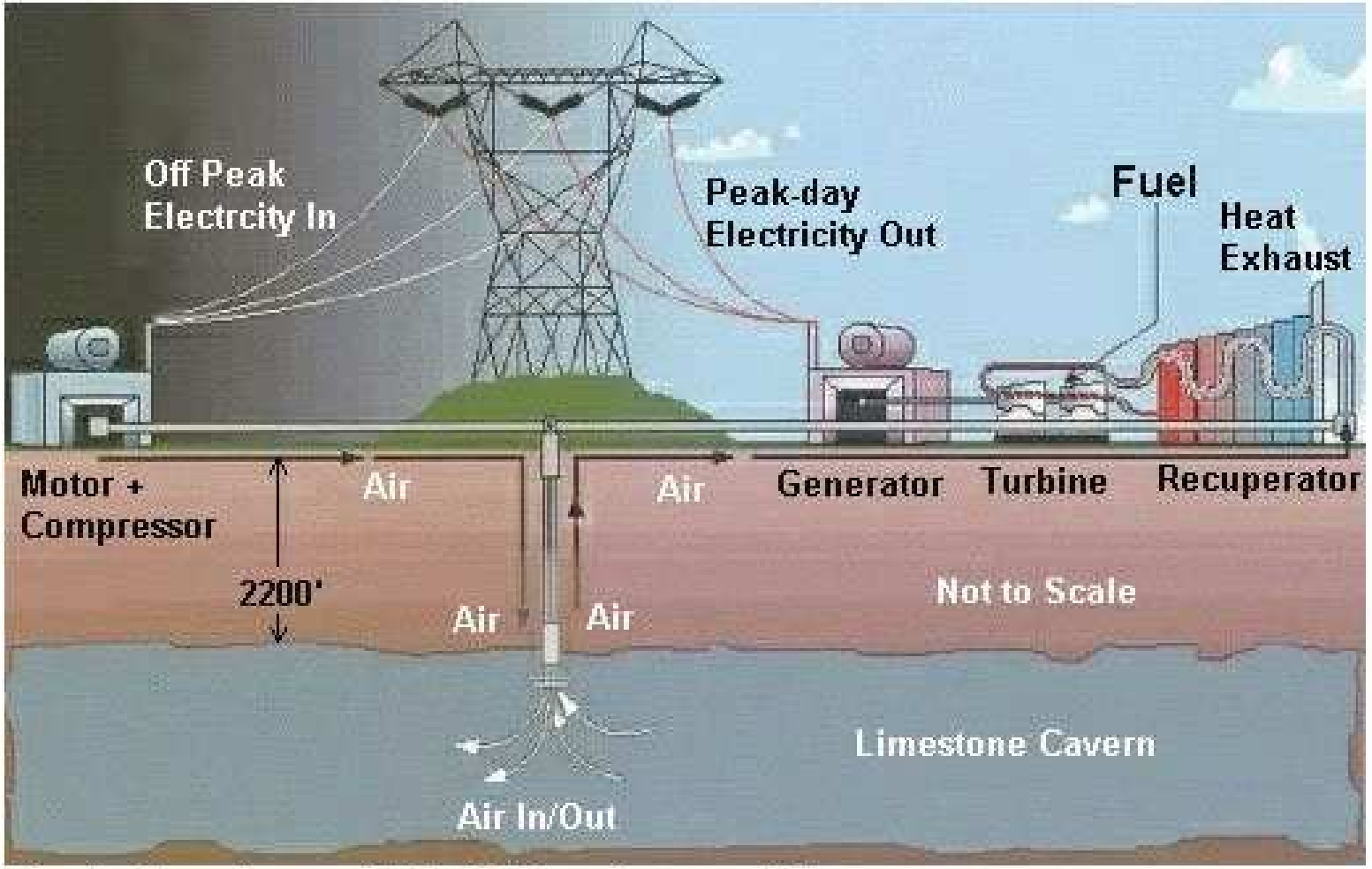


Photo Courtesy of CAES Development Company

Thermal Energy Storage