Managing Green Datacenters Powered by Hybrid Renewable Energy Systems

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ICAC

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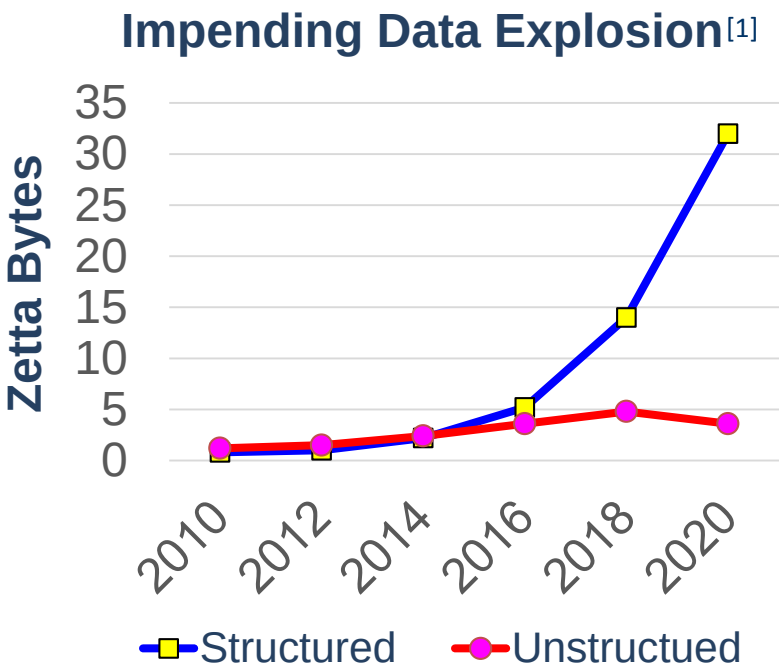
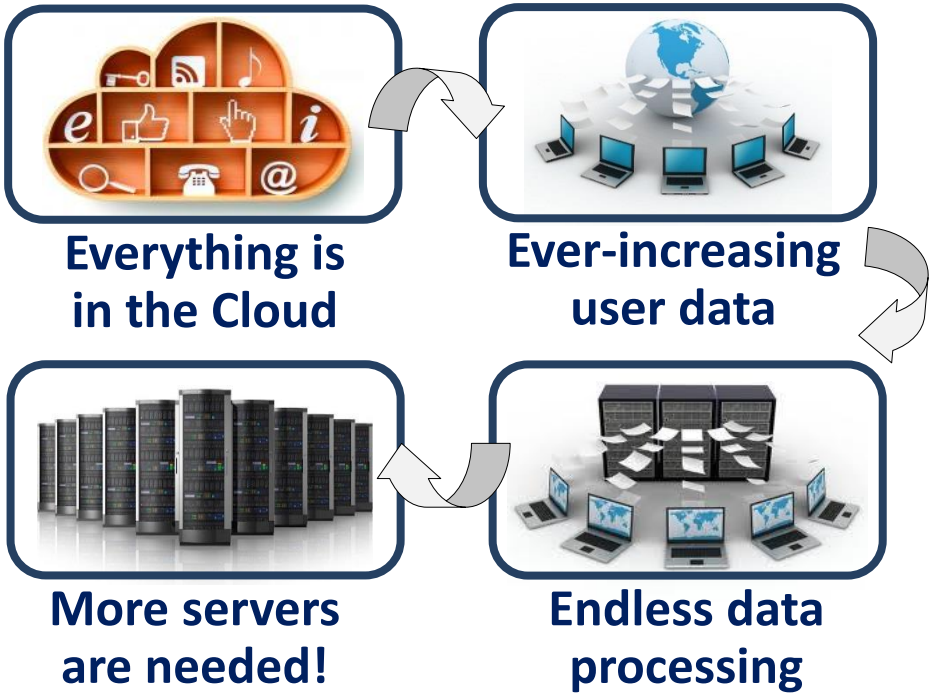
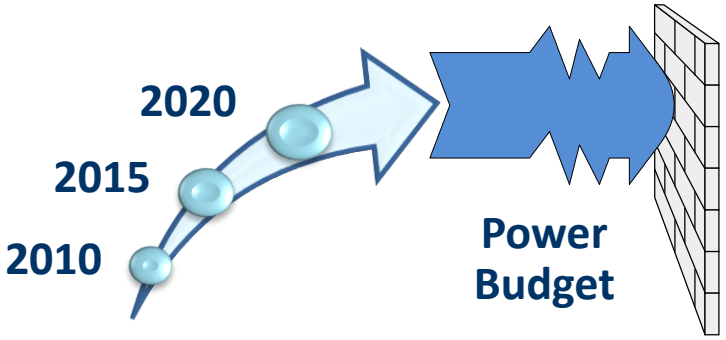
Power is a Big Issue in the Cloud Era





- **Current global server market**
  - 30 GW power demand
  - Doubles every 5 years [2]



[1] http://oraclestorageguy.typepad.com/

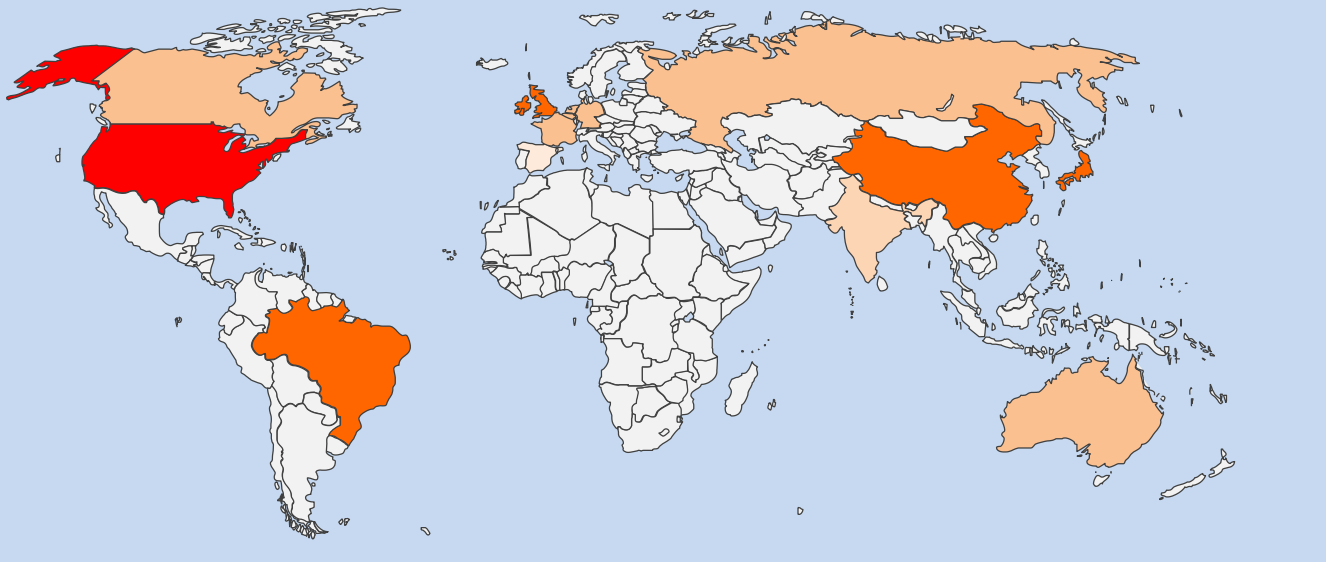
2] Report to Congress on Server and Data Center Energy Efficiency, EPA, 2007


×30

Server Footprint Continues to Expand

8 TWh	USA
3 TWh	China
2 TWh	U.K.
2 TWh	Japan
2 TWh	Brazil
1 TWh	France
1 TWh	Benelux
1 TWh	Canada
1 TWh	Germany
1 TWh	Russia
1 TWh	Australia
1 TWh	India

The increase in server energy demand (2012-2013)[2]



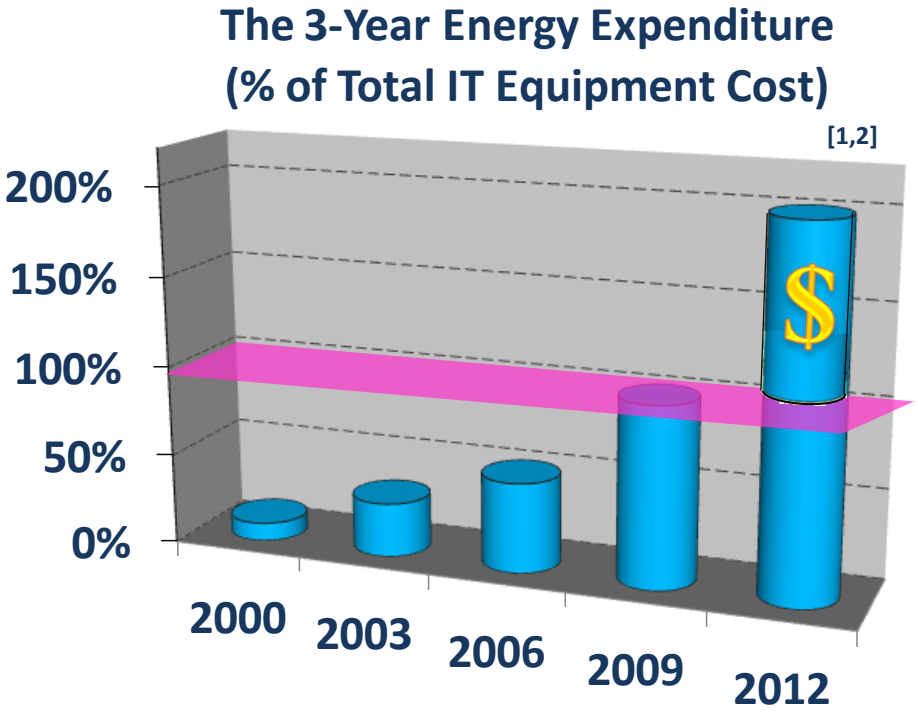
- **The global data center electricity usage in 2012: 300 ~ 400 TWh**
  - 2% of global electricity usage
  - Expected to triple by 2020 [1]

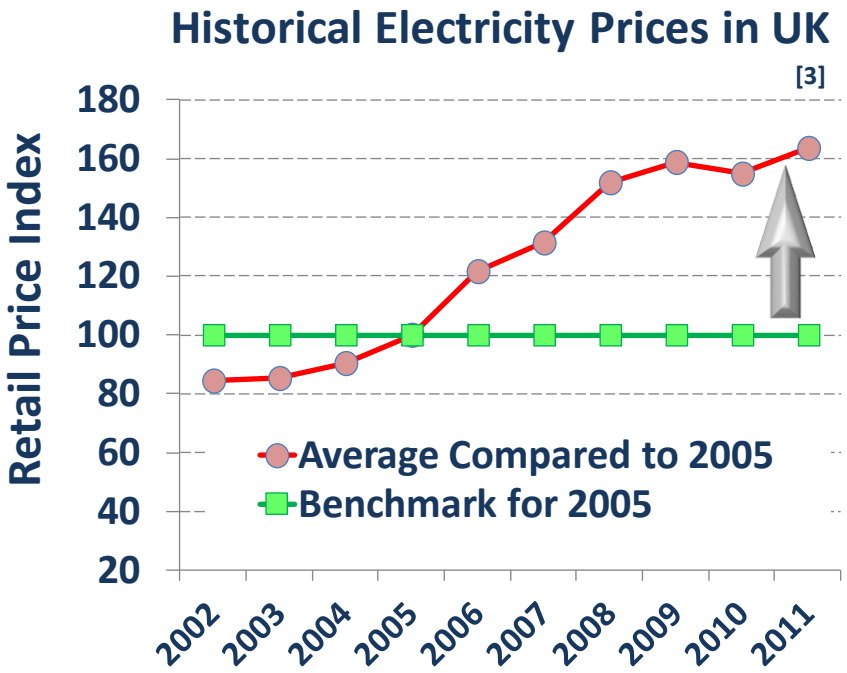


302 TWh
TOTAL ENERGY was consumed in CA in 2012 [1]

[1] C. Belady, Projecting Annual New Datacenter Construction Market Size, Global Foundation Services, 2011
[2] DCD Industry Census 2012: Energy, http://www.dcd-intelligence.com/
[3] http://energyalmanac.ca.gov/electricity/total_system_power.html

The Sustainability Issue: Energy Cost





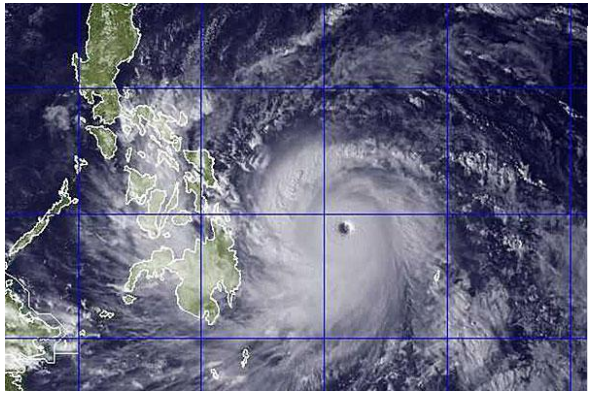
- **Escalating energy consumption drives data center cost up**
  - Need to think alternative power provisioning solutions

[1] Conference report: The Future of the Data Centre, http://www.information-age.com
[2] Ken Brill, The Economic Meltdown of Moore's Law and the Green Data Center
[3] https://www.gov.uk/government/organisations/department-of-energy-climate-change

The Sustainability Issue: CO2 Emission

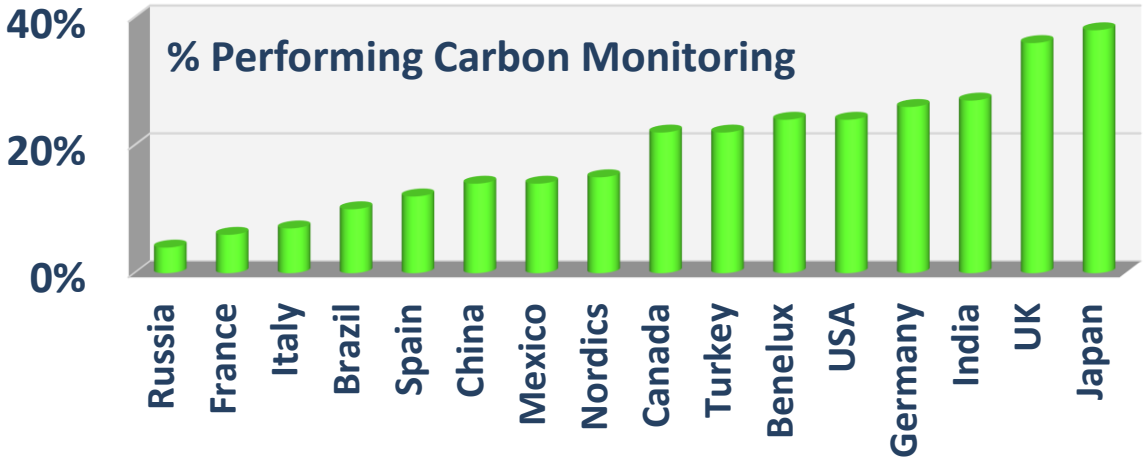


Hurricane Sandy, 2012
(Northeastern US)



Typhoon Haiyan, 2013
(Southeast Asia)

- The greenhouse effect & climate change
- 1MW data center → 10~15 Kt CO_2 yearly
- Data centers are carbon-constrained:
  - They must cap carbon emissions



Major Driving Power of Low-Carbon IT

- **Government regulations and initiatives**



Environmental Protection Agency (http://www.epa.gov/)
EU Emission Trading Scheme (http://ec.europa.eu/clima)
California's SB X 1-2 Law: requiring 33% renewables by 2020

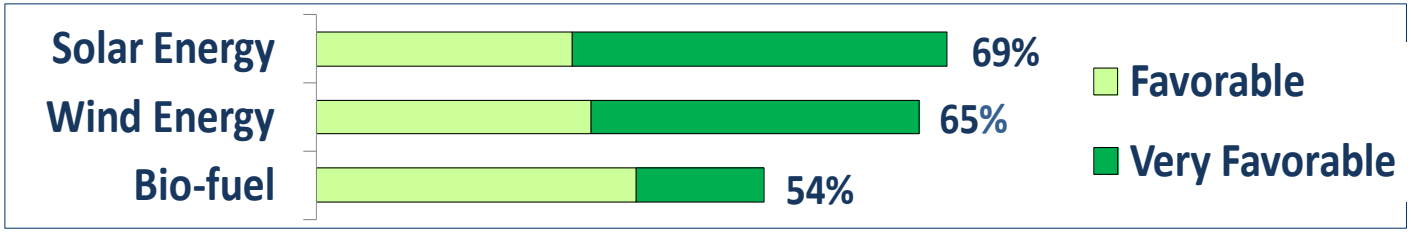
- **Non-profit organizations campaign for sustainability**



Greenpeace (http://www.greenpeace.org)
Regional Greenhouse Gas Initiative (http://www.rggi.org)
Union of Concerned Scientists (http://ucsusa.org)

- **The green energy concept has mass appeal among consumers** [1]





[1] Energy & Environment Consumer Survey , Pike Research, 2012

Carbon-Conscious Computing System Design

Solar Panels



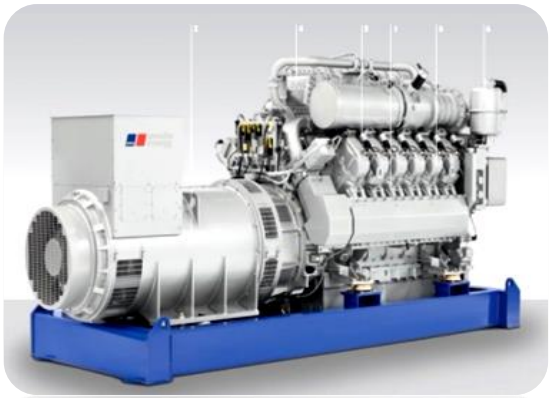
Wind Turbines



Fuel Cells



Bio-mass



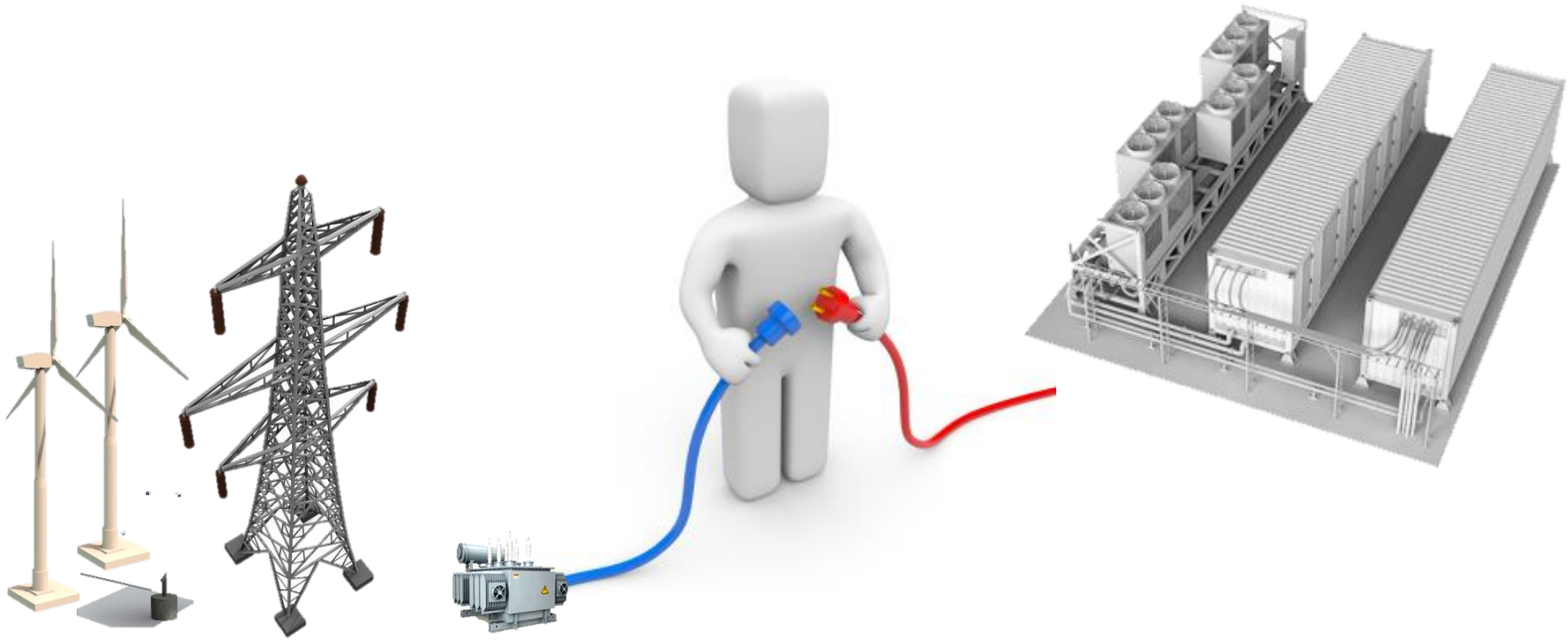
Micro-Turbines



Batteries



Limitations of Prior Work

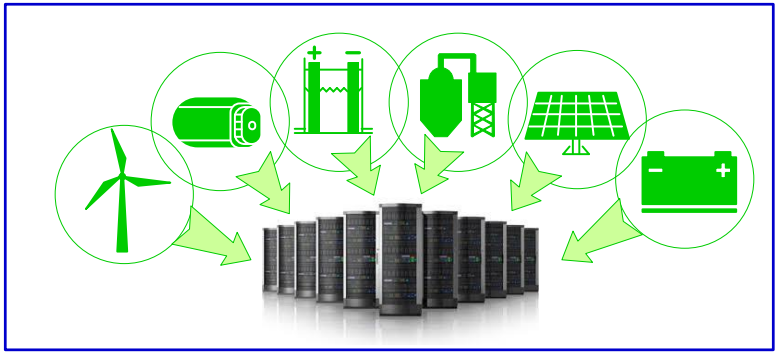


- **Load management and supply management are decoupled**
  - Must combine load management and supply management
- **Only focus on certain specific type of renewable energy**
  - Need to look at hybrid renewable energy systems.

Outline

1. Background: Hybrid Renewable Energy System for Data Centers

2. GreenWorks: A Framework for Multi-Source Powered System



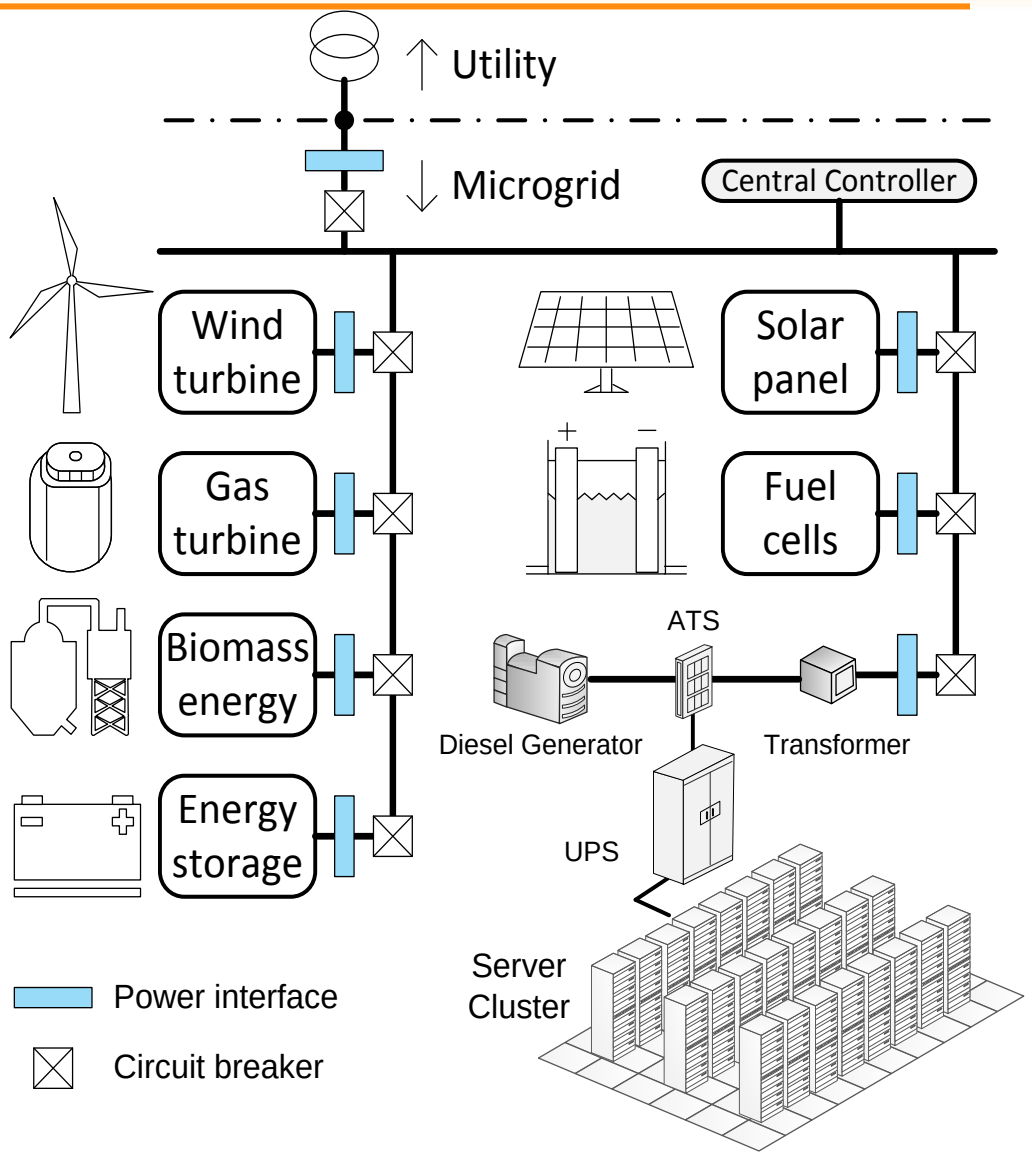
3. Multi-Source Driven Power Management for Data Centers

4. Evaluation and Discussion

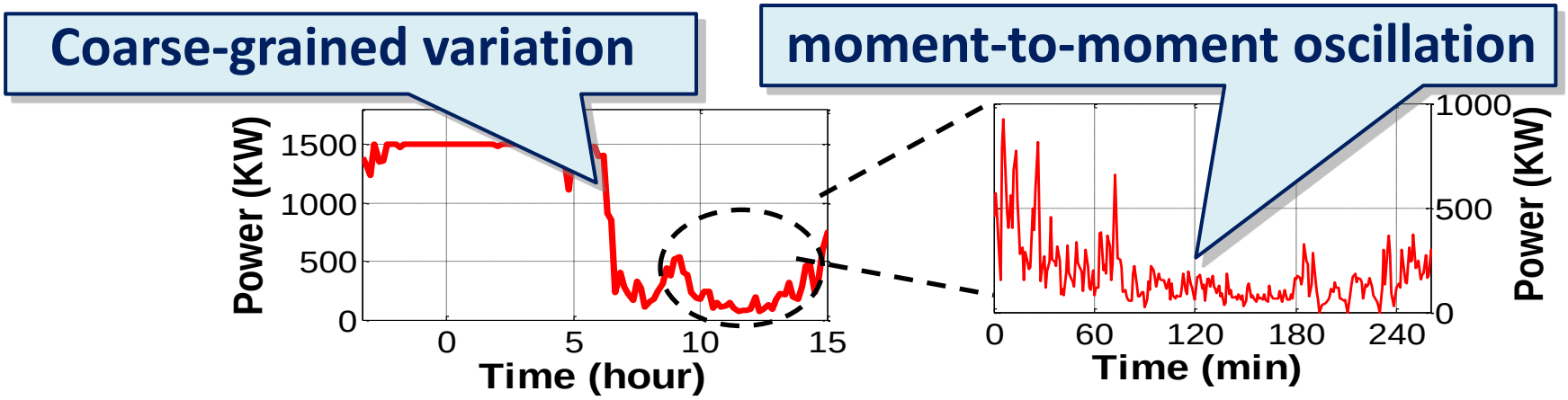
IDEAL RESEARCH

Hybrid Energy Systems

- **Baseload Power Supply**
  - Biomass, gas turbine, etc.
  - Stable and controllable
- **Intermittent Power Supply**
  - Solar, wind, etc.
  - Time-varying output
- **Backup Power Supply**
  - Various batteries
  - Immediate response



Energy Balance Challenge

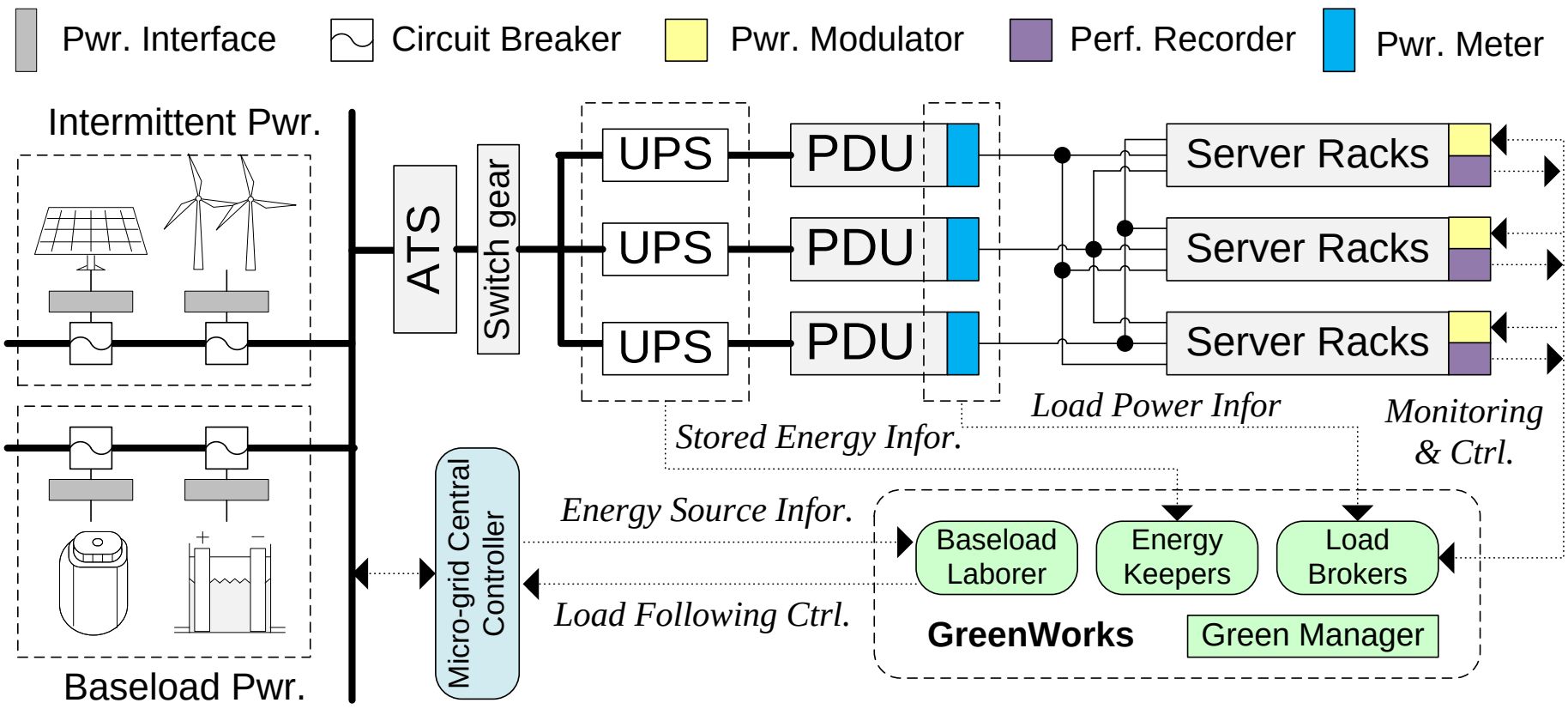


- **Demand/Supply power mismatch problem**
  - Requires fine-grained load and supply management
- **Cannot simply rely on any single type of power supply**
  - Intermittent green power: cannot guarantee power output
  - Baseload power: too slow to follow the fluctuation
  - Battery: limited lifetime and capacity
  - **Over-provisioning power to overcome the above issue?**



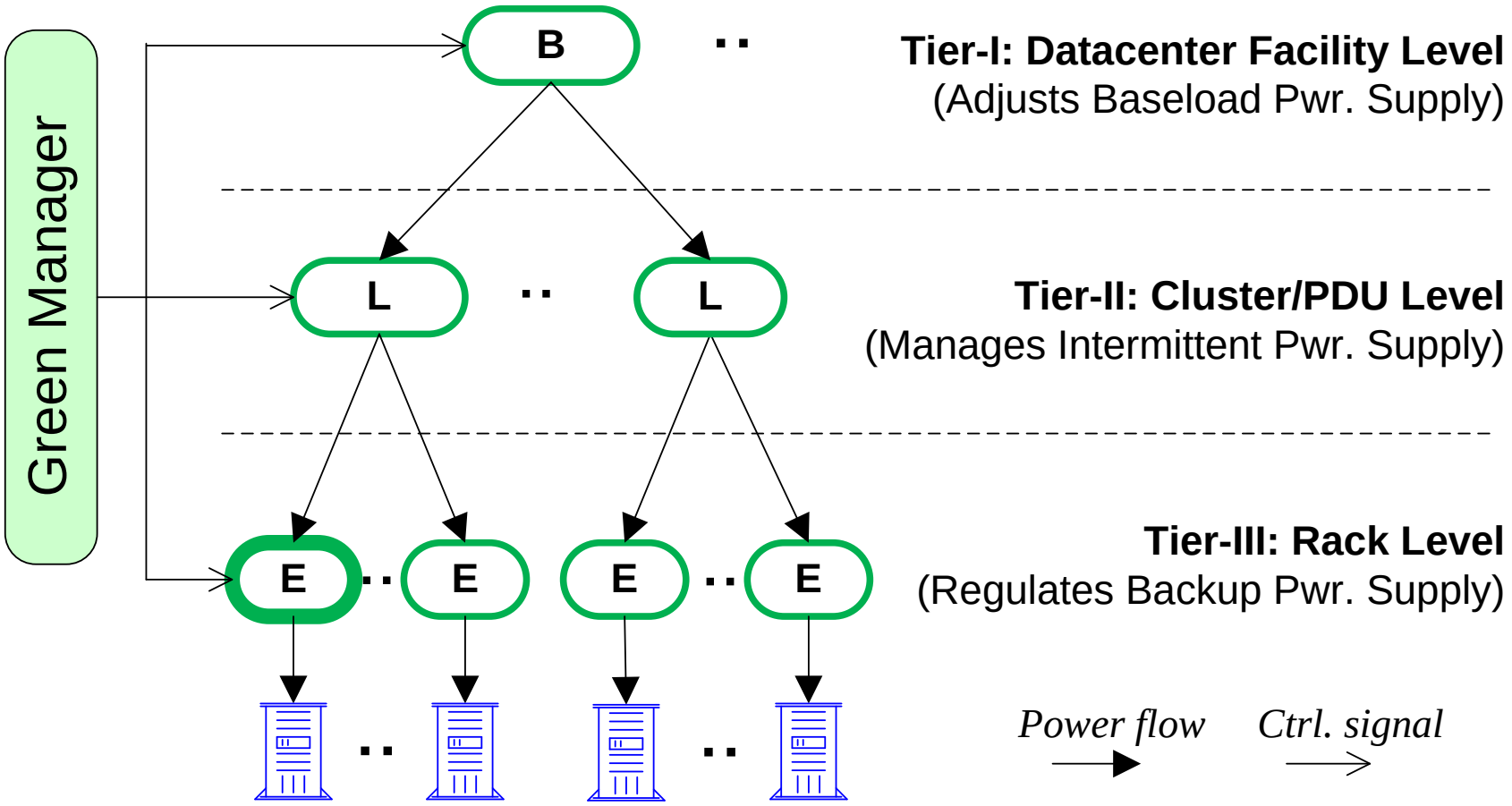
GreenWorks: An Overview

- A synergy of various power supplies, as well as computing loads



Power Management Hierarchy

- **A multi-layer power integration and management strategy**



Outline

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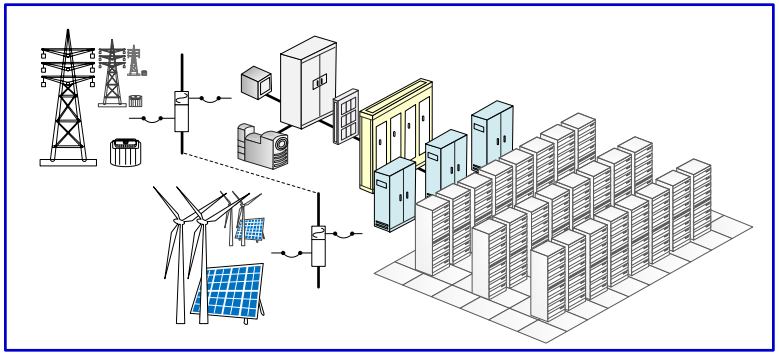
2. GreenWorks: A Framework for Multi-Source Powered System

3. **Multi-Source Driven Data Center Power Management**

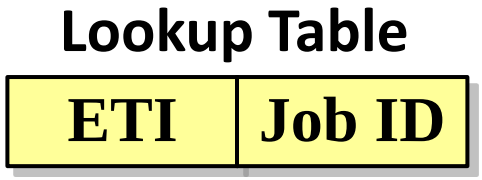


4. Evaluation and Discussion

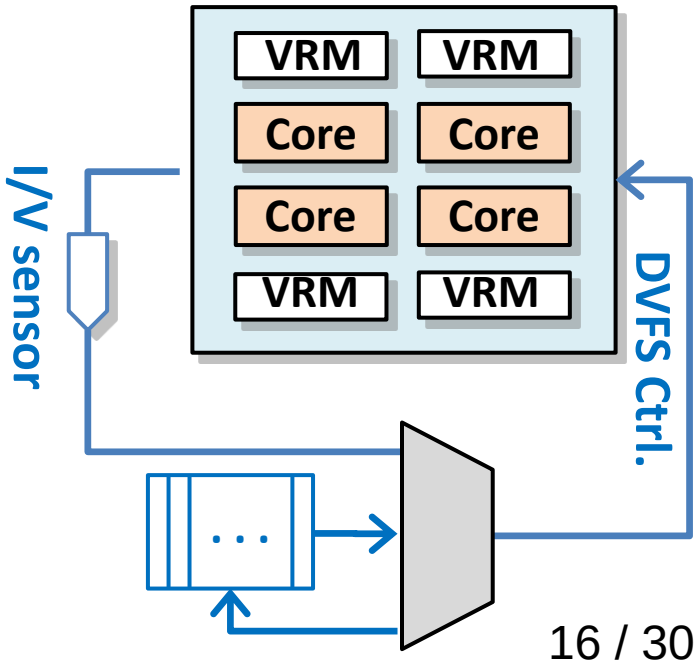
Stage I: Adequate Power Supply Budget

- **Opportunistically Boost System Performance**

- **Maintain a lookup table, which contains**
  - Job ID and job execution progress
  - Calculate anticipated execution time based on the current progress and speed
  - **ETI: Execution Time Increase (%)**

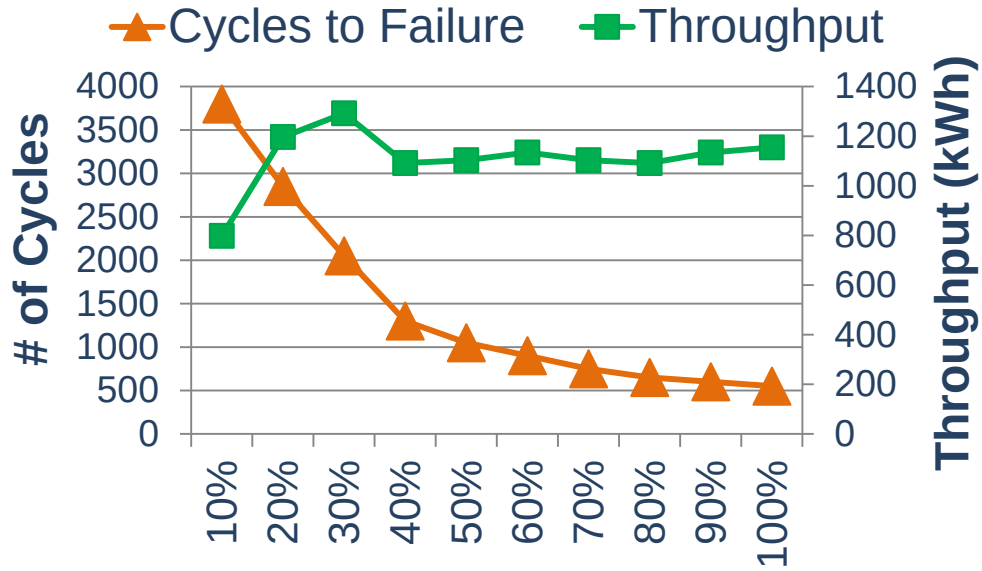


- **Use alternating processing speed**
  - Increase server performance with over-clocking (e.g. Turbo Boost)
  - Give priory to jobs that are have higher anticipated ETI



Stage II: Moderate Power Supply Drop

- **Balancing load shedding and battery discharging**
- **Calculate a discharge budget**
  - The total energy that can be cycled through a battery is fixed



$$D_{aggregated} = \sum_0^t D_{Ah}$$

$$D_{budget} = T / Lifetime \times D_{rated}$$

Manage solar energy usage based on $D_{budget} - D_{aggregated}$

- **Give load shedding priority if the discharge budget is low**
  - Otherwise, use the stored energy to maintain server speed.

Stage III: Significant Power Supply Drop

- **Deadline Driven, Power-Aware Load Shedding**

- **Calculate a time budget, which evaluates:**
  - whether a job could meet its deadline in the future with frequency boosting techniques.

$$Time\ Budget = Remaining\ Runtime \times D \times P \times S$$

$$S = \mu \times (1 - 1 / Frequency\ Speedup)\ ;$$

D: the duty cycle of performing turbo boost

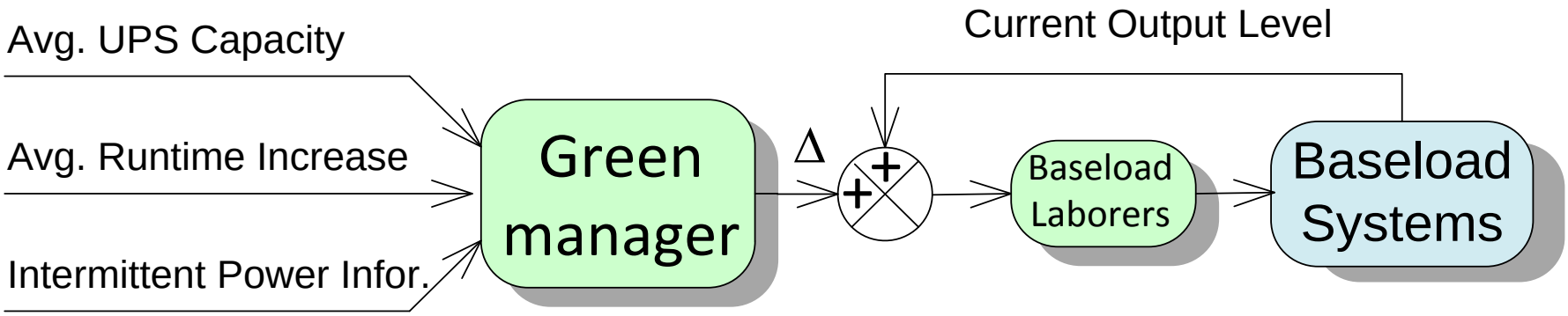
P: likelihood of receiving adequate renewable power

S: the execution time that 1s frequency boost can save

- **Choose load shedding if the time budget is enough**
  - Otherwise, use stored energy to handle the power shortfall.

Managing Baseload at Coarse-Grained Intervals

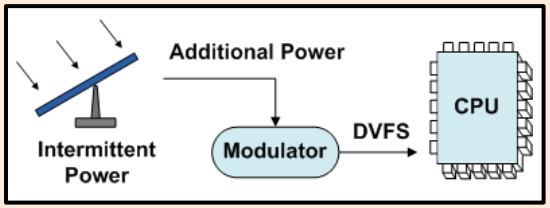
- **Adjust the baseload power output based on**
  - Moving average of the load power demand
  - Current power demand
- **Can also add additional bonus power output**
  - Based on the average battery capacity
  - Average performance of the workload



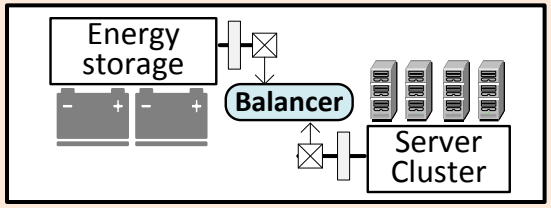
GreenWorks Power Management: A Summary

- Matching power demand to total power supply

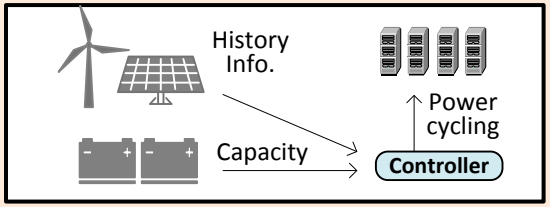
1. Abundant Power: Boost Load



2. Inadequate Power: Maintain Load



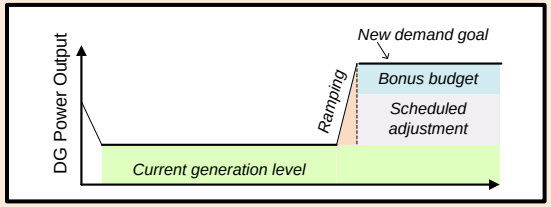
3. Power Emergency: Shed Load



Fine-grained load management

Green Manager

Adjust Baseload Power



Coarse-grained load management

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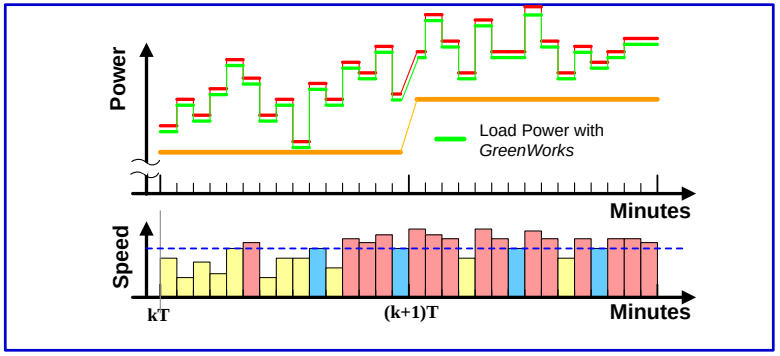
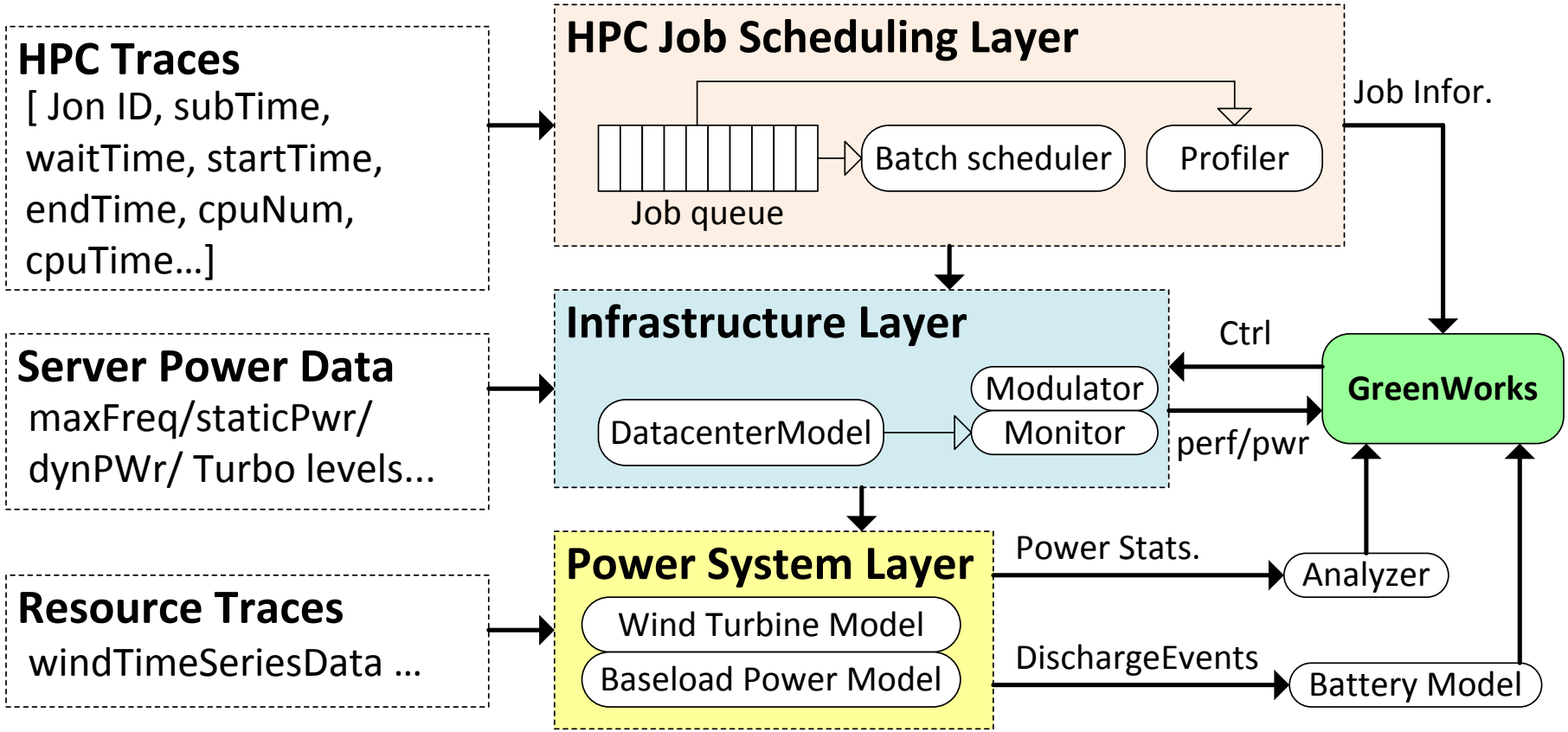
4. **Evaluation and Discussion**

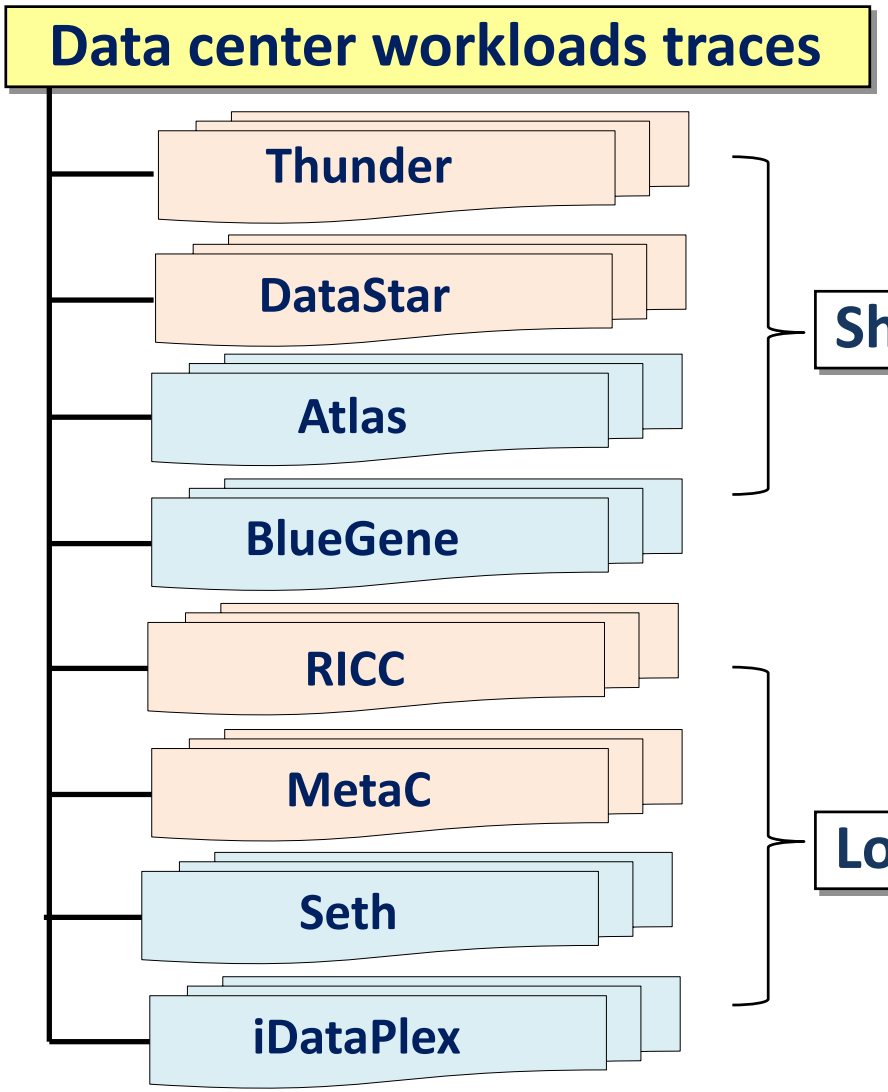


Verification Platform

- **A three-layer simulation framework**
  - Energy systems + Server systems + Job Scheduling



Evaluated HPC Data Center Traces

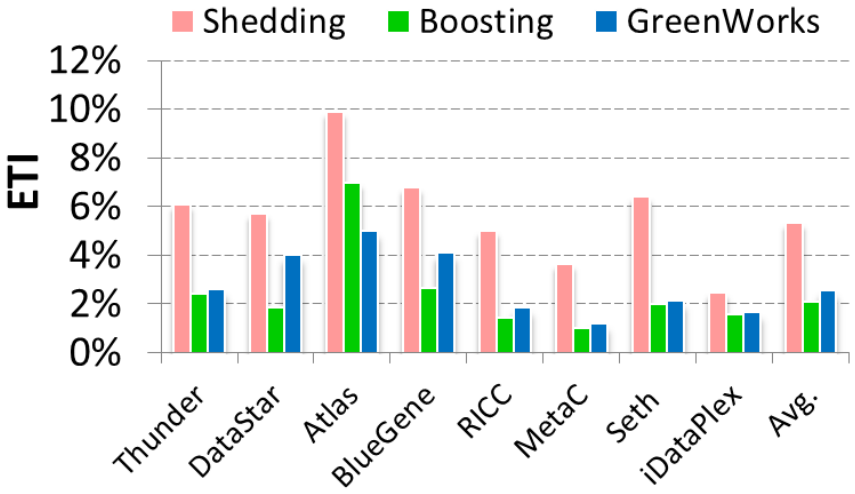


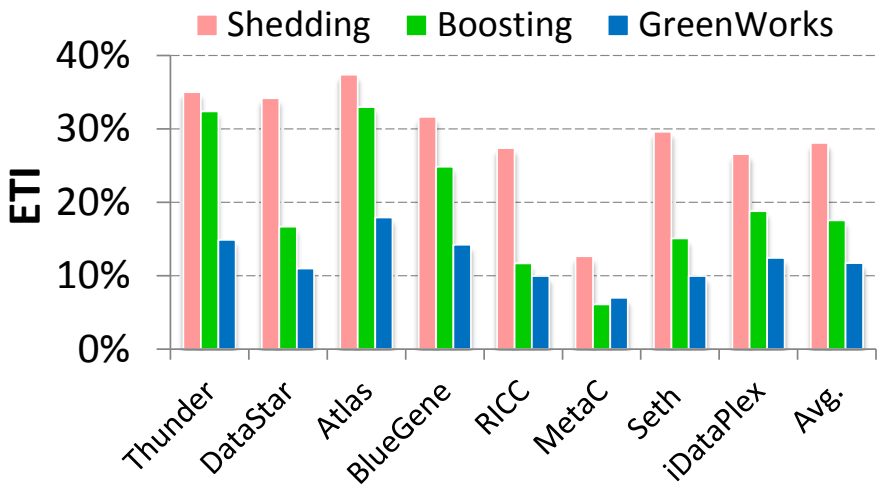
- **Parallel Workload Archive**
  - http://www.cs.huji.ac.il/labs/parallel/workload/

Short job Inter-arrival time

Long job Inter-arrival time

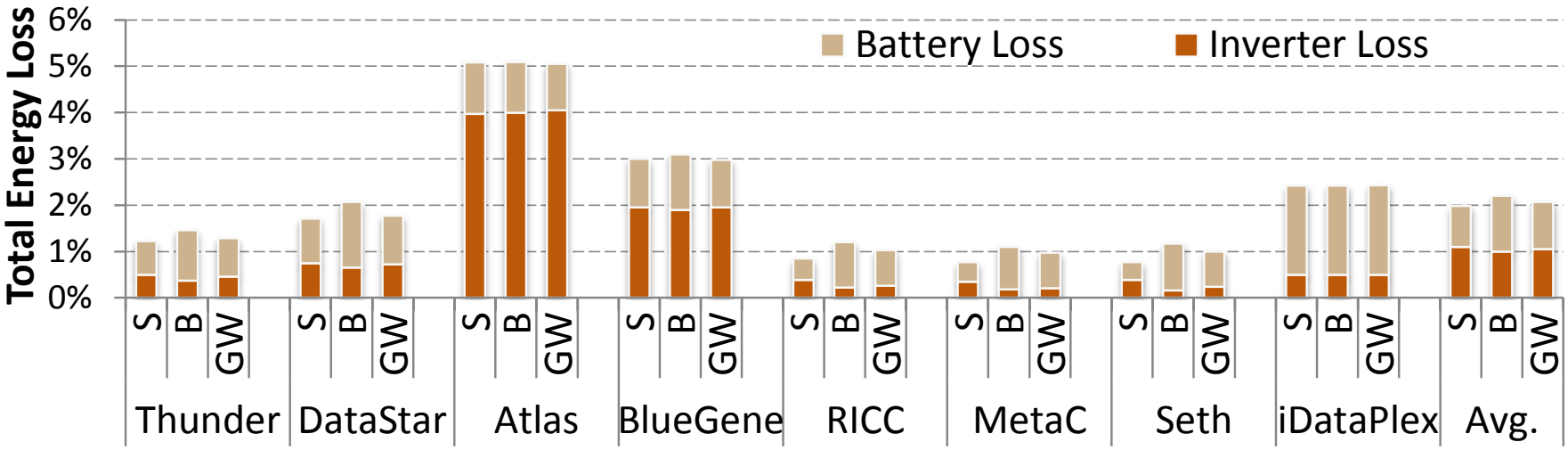
Performance Comparison





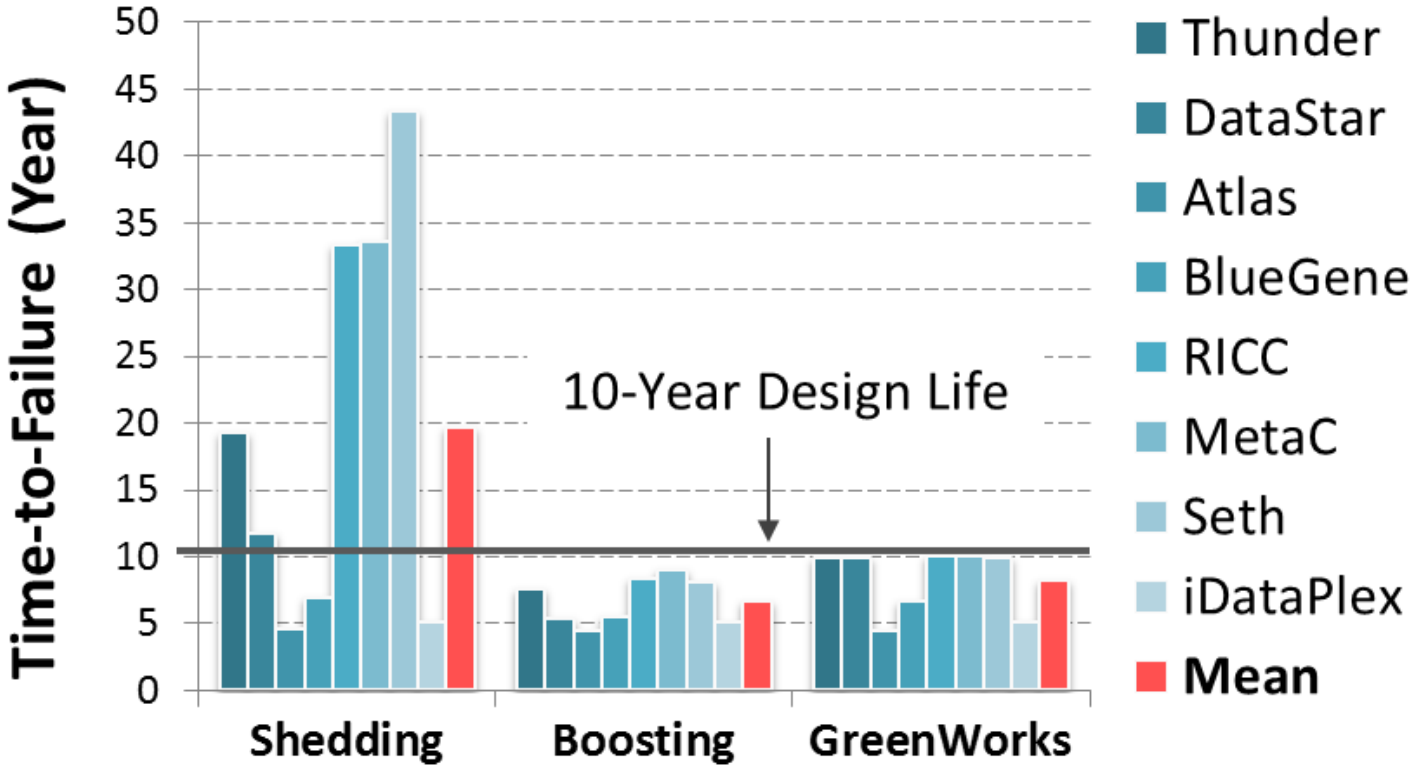
- **Less then 3% performance degradation, on average**
  - Very close to an ideal battery based design (2.1%)
- **About 12% performance degradation, for the 5% worst cases**
  - Bettery than a our baseline, *Boosting*

Energy Efficiency



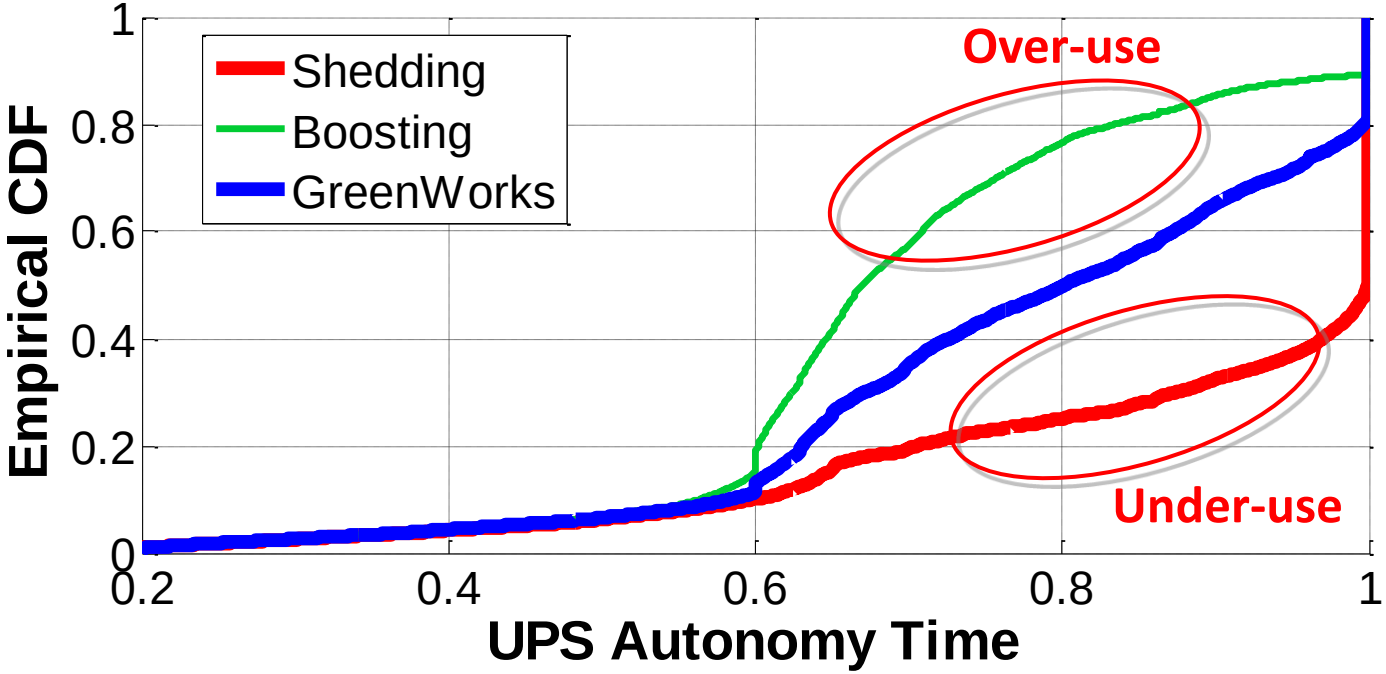
- **Factors that affect energy utilization**
  - Inverter energy loss and battery round-trip energy loss
  - GreenWorks maintains almost the same energy utilization

Battery Lifetime



- **Provides better battery utilization**
  - The lifetime of GreenWorks battery is very close to its designated lifetime.

UPS Autonomy Time (Backup Time)



- **On average, the stored energy level is 78% of rated capacity**
  - Boosting: 70%. Shedding: 88%.
- **Ensures a rated backup time for 20% of the time.**
  - Better than Boosting but worse than Shedding.

Conclusions

- Renewable energy powered computing system design should not ignore the attributes of power supply
- Be very careful when boosting (e.g., over-clocking), maintaining (e.g., use batteries), or shedding (e.g., shutdown servers) the loads in data centers powered by hybrid renewable energy systems.
- A cross-layer and cross-component data center power management scheme could provide us much better design tradeoffs.

Thanks For Your Attention







Green Computing

