Cloud and the Sustainable IT Ecosystem

enabled by supply and demand side management

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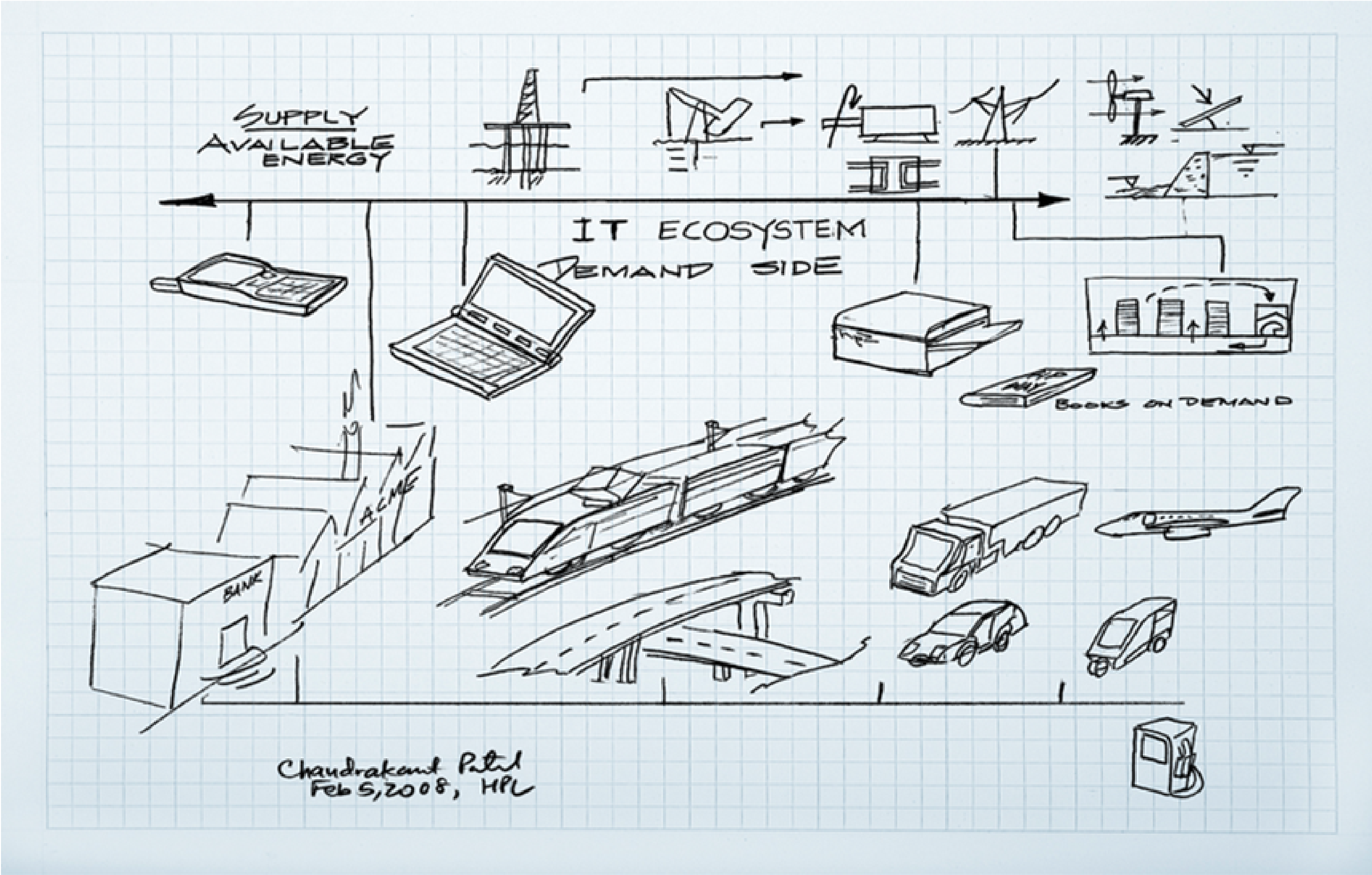
Hewlett Packard Laboratories

Sustainable IT Ecosystem



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Role of the IT Ecosystem

Cloud Services

1. **Cloud services to meet the fundamental needs of the masses**
    - *Advantage of scale when billions utilize IT to address their fundamental needs and improve quality of life*

– Transformation necessitates
  - Reducing the cost of IT for universal accessibility
    – Reducing total cost of ownership necessitates addressing sustainability with an *end to end supply and demand side perspective*

2. **Use the IT ecosystem to enable need based provisioning of resources at community scale**

– **Power, water, transport, waste…..**
  - Transformation necessitates

– pervasive sensing, knowledge discovery, and control

– Supply and demand side management of resources

Key Enablers:
- *Metrics based on fundamentals*
- *Multidisciplinary Curriculum*

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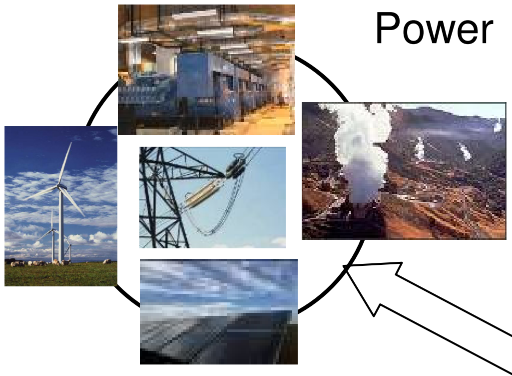
Data Center at the Core

Resource management at community scale

TCO reduction through holistic supply and demand side perspective

Power

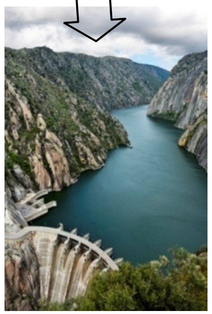


Datacenter

Healthcare

Ecosystem of Clients

Education



Water

Transport

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Approach

Supply and Demand Side Management

Use the IT Ecosystem to enable supply and demand side management based

- **Supply Side**:
  - Lifecycle perspective
    - available energy (exergy) required in extraction, manufacturing, operation and reclamation
    - utilize local resources to minimize destruction of available energy in transmission, construction of transmission infrastructure, etc
- **Demand Side**:
  - Provision resources based on the needs of the user

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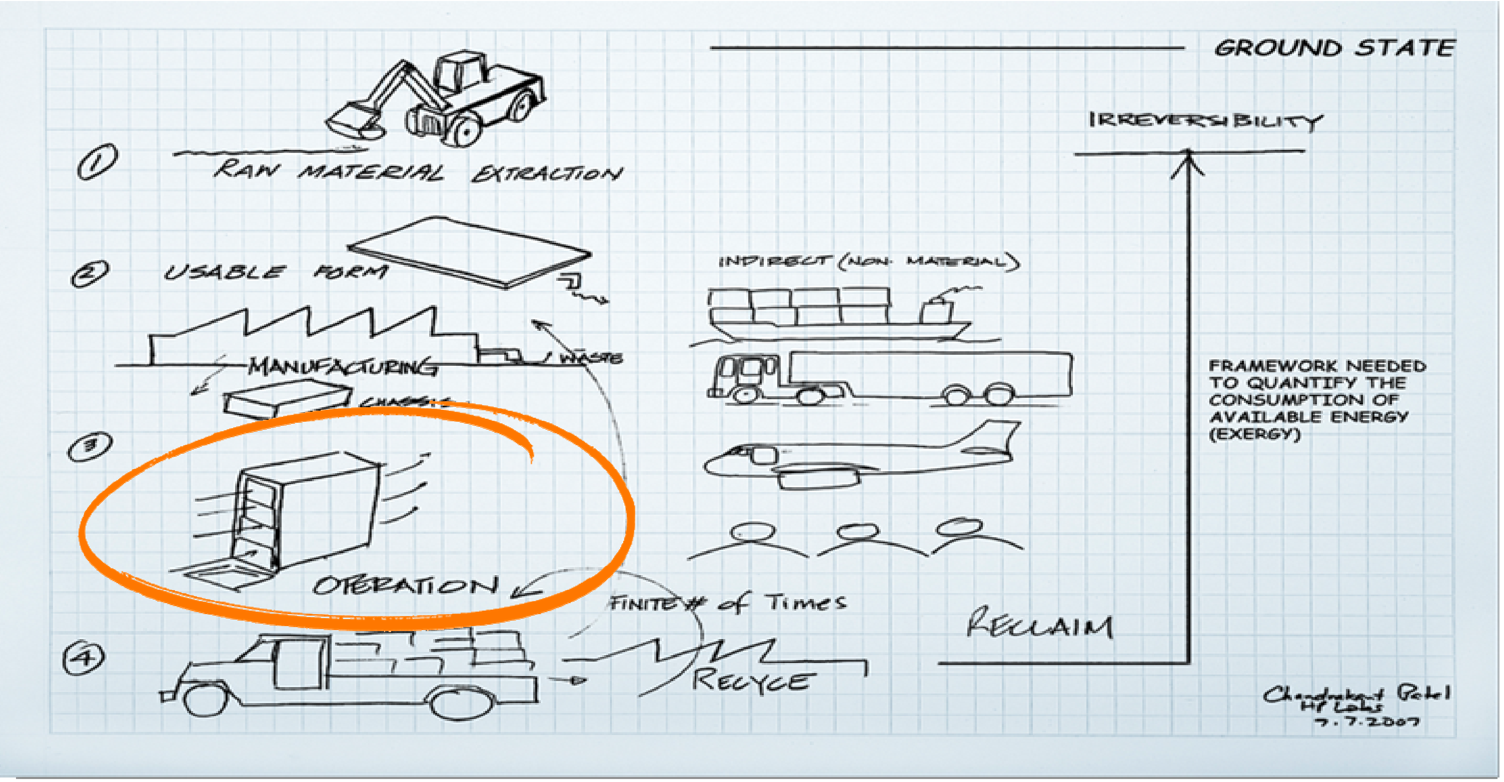
Supply Side

Lifecycle engineering and management

extraction	manufacturing	operation	End of Life



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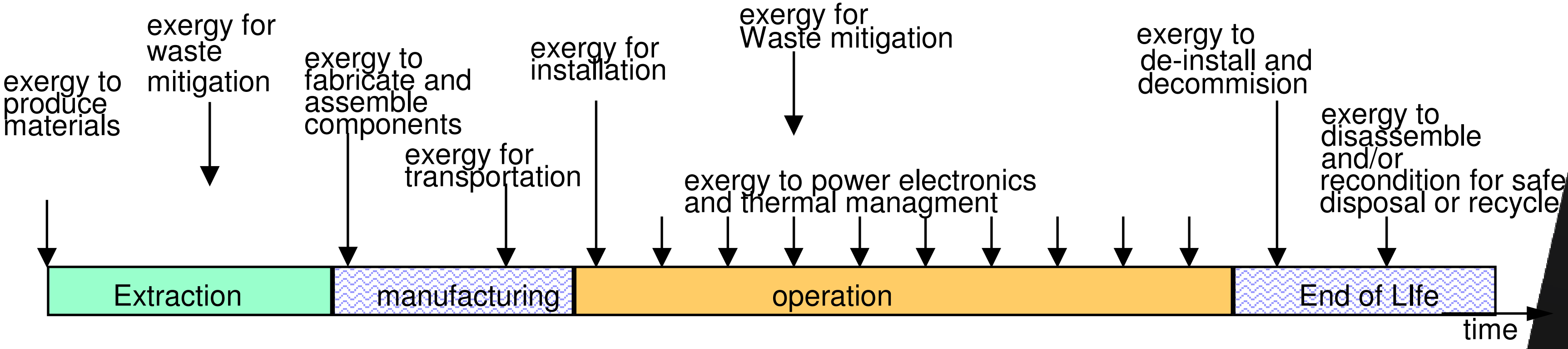
Lifecycle Engineering and Management

Technical Approach

– Can a measure of the total exergy or available energy destroyed across a product's lifetime ("lifetime exergy") be a measure of the environmental sustainability?

– Can we build a "hub" of exergy data to enable lifetime exergy analysis for a given product?

Joules of exergy consumed as a single measure



Hannemann CR, Carey VP, Shah AJ, Patel C., "Lifetime exergy consumption as a sustainability metric for enterprise servers. Proceedings of the ASME Energy Sustainability Conference (ES)", Jacksonville, FL, 2008.

Shah, A.J., Patel, C.D., Carey, V.P., "Exergy Based Metrics for Sustainable Design", 4th International Energy, Exergy and Environment Symposium, Sharjah, UAE, 2009

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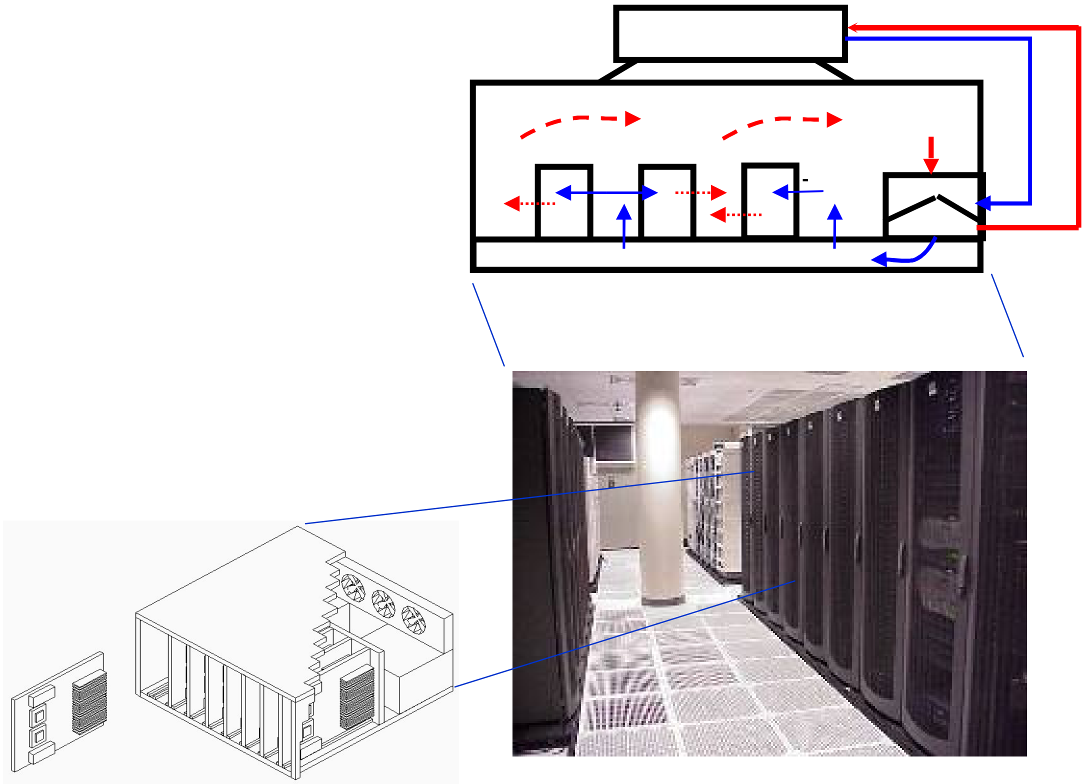
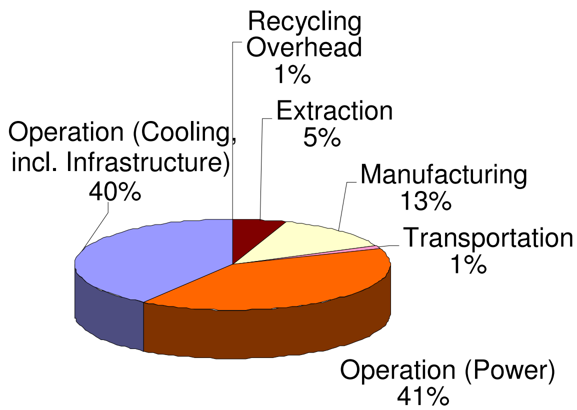
Example: Server in a data center

Lifecycle Footprint





Lifetime Exergy Consumption

Hannemann, C., et. al., “Lifetime Exergy Consumption as a Sustainability Metric for Enterprise Servers”, Proceedings of ASME Energy Sustainability, August 2008

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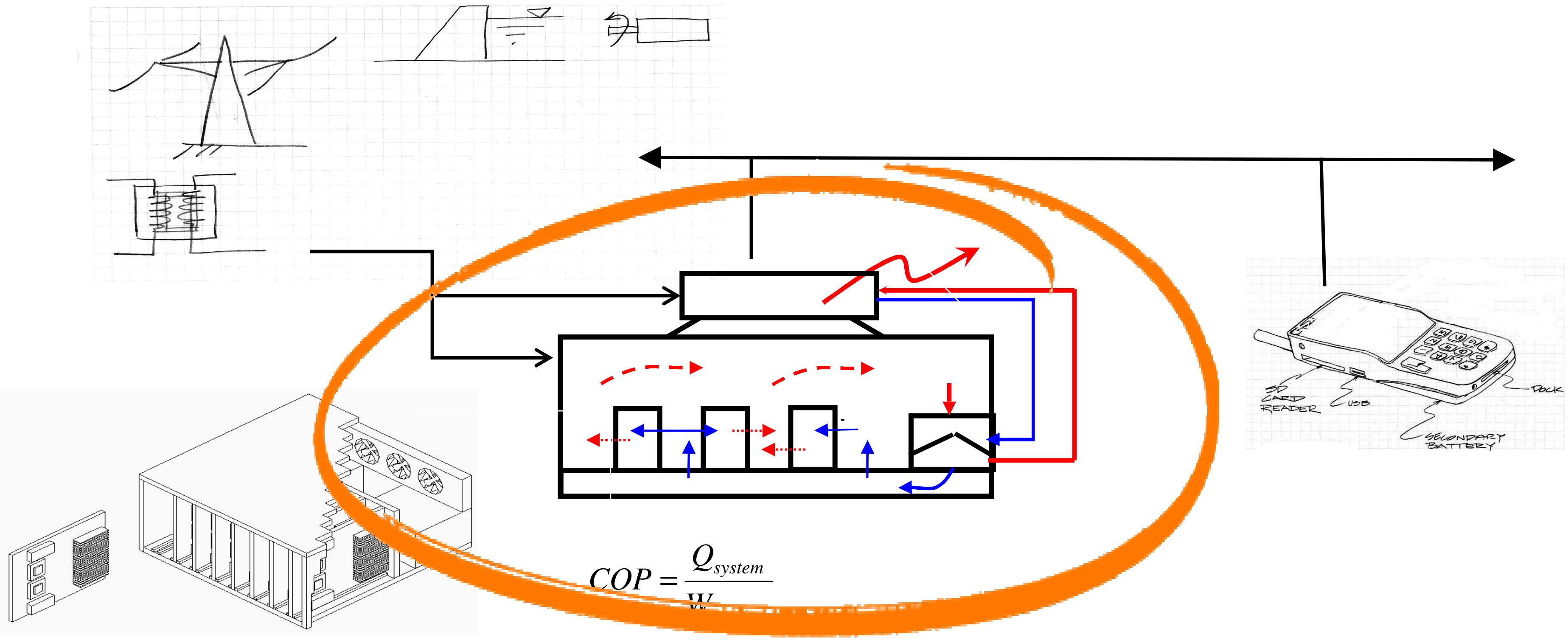
Focus on Data Center

Supply and Demand Side Management



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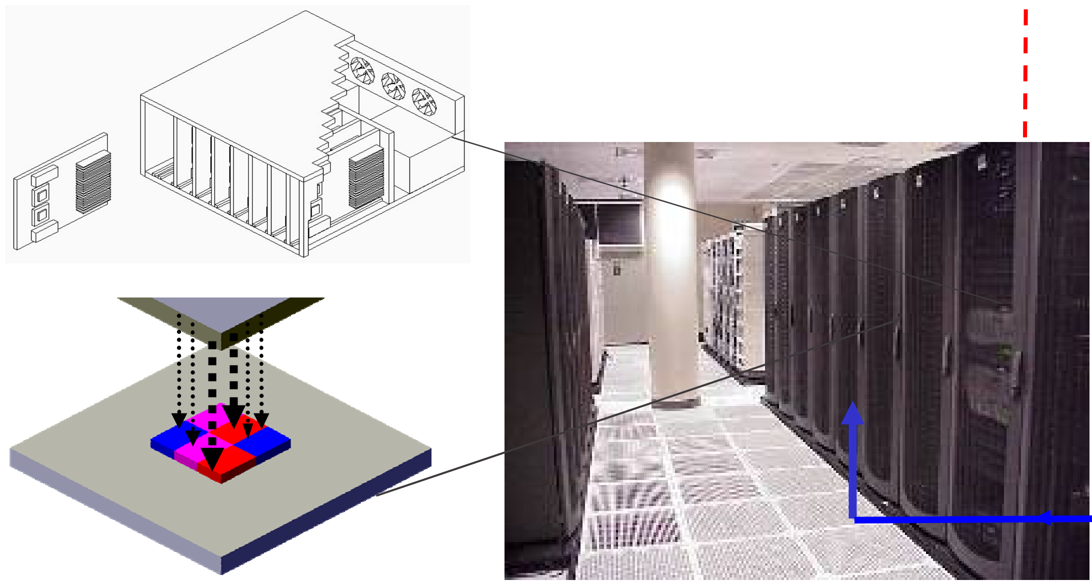
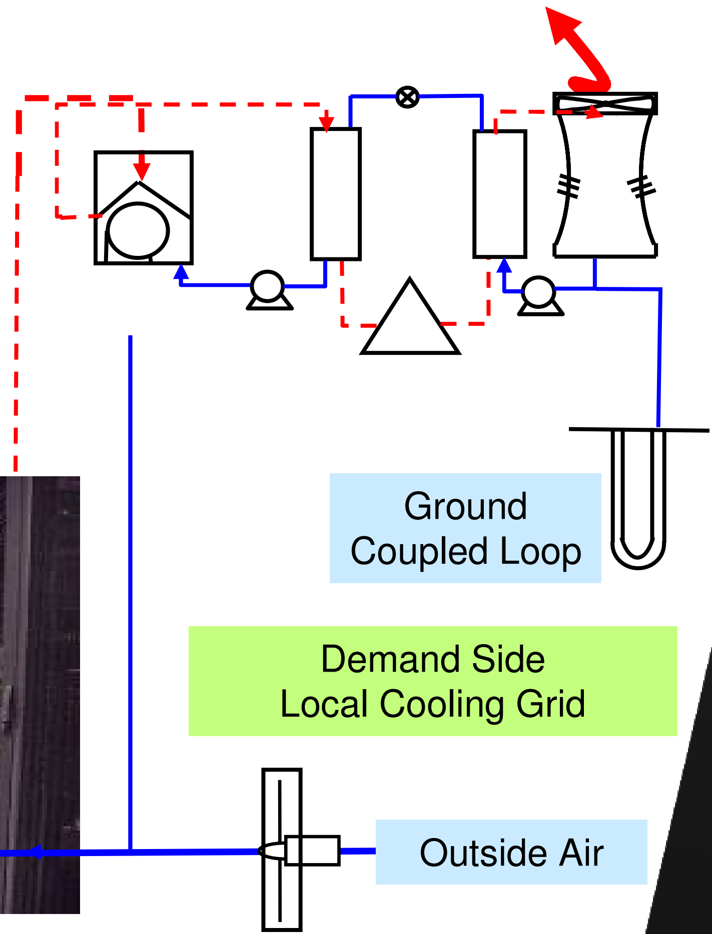
Data Center is the Computer

supply and demand side management

Supply Side using Local Resources
Power Grid





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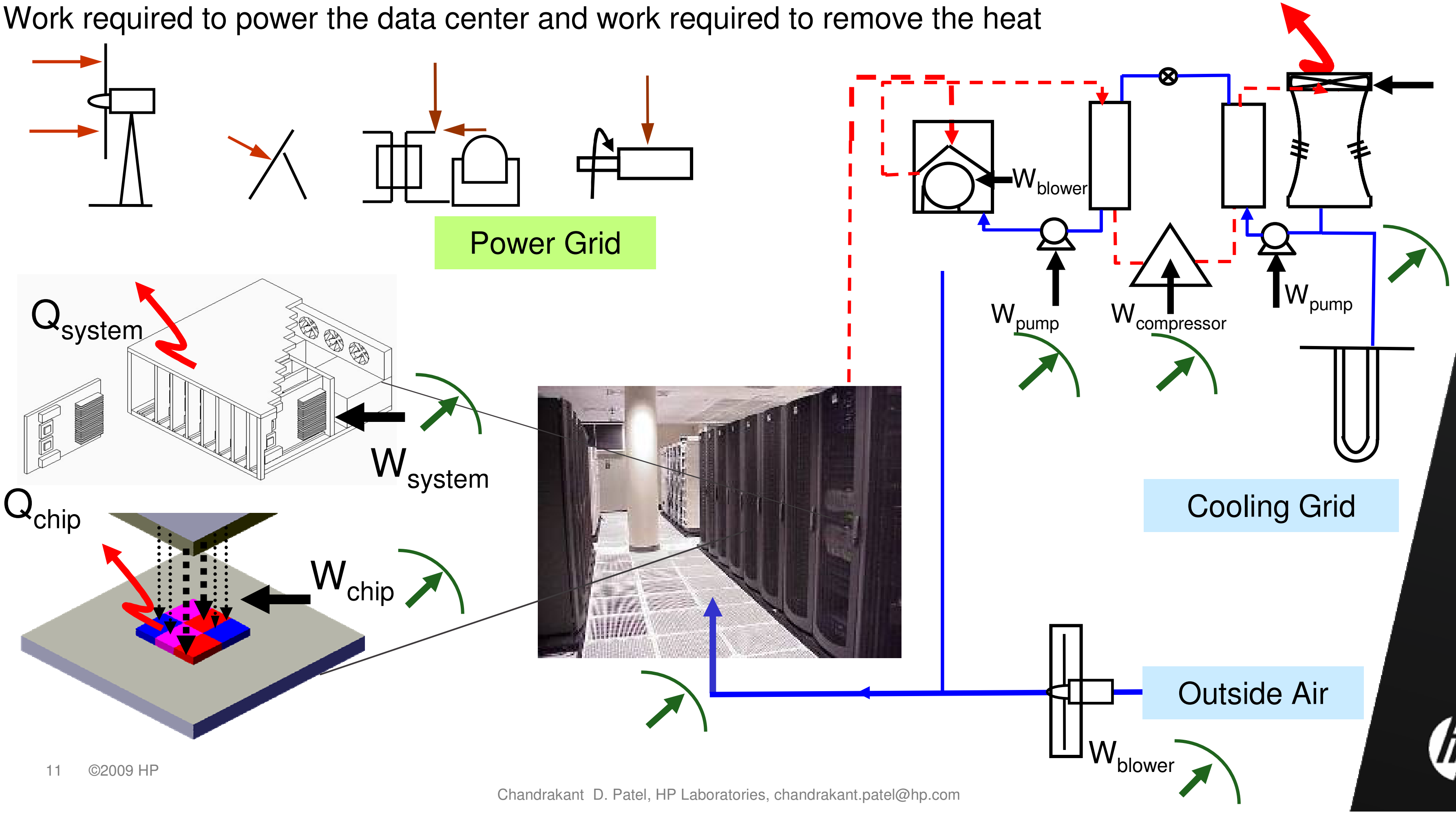
Energy Flow in the IT Stack

Work required to power the data center and work required to remove the heat



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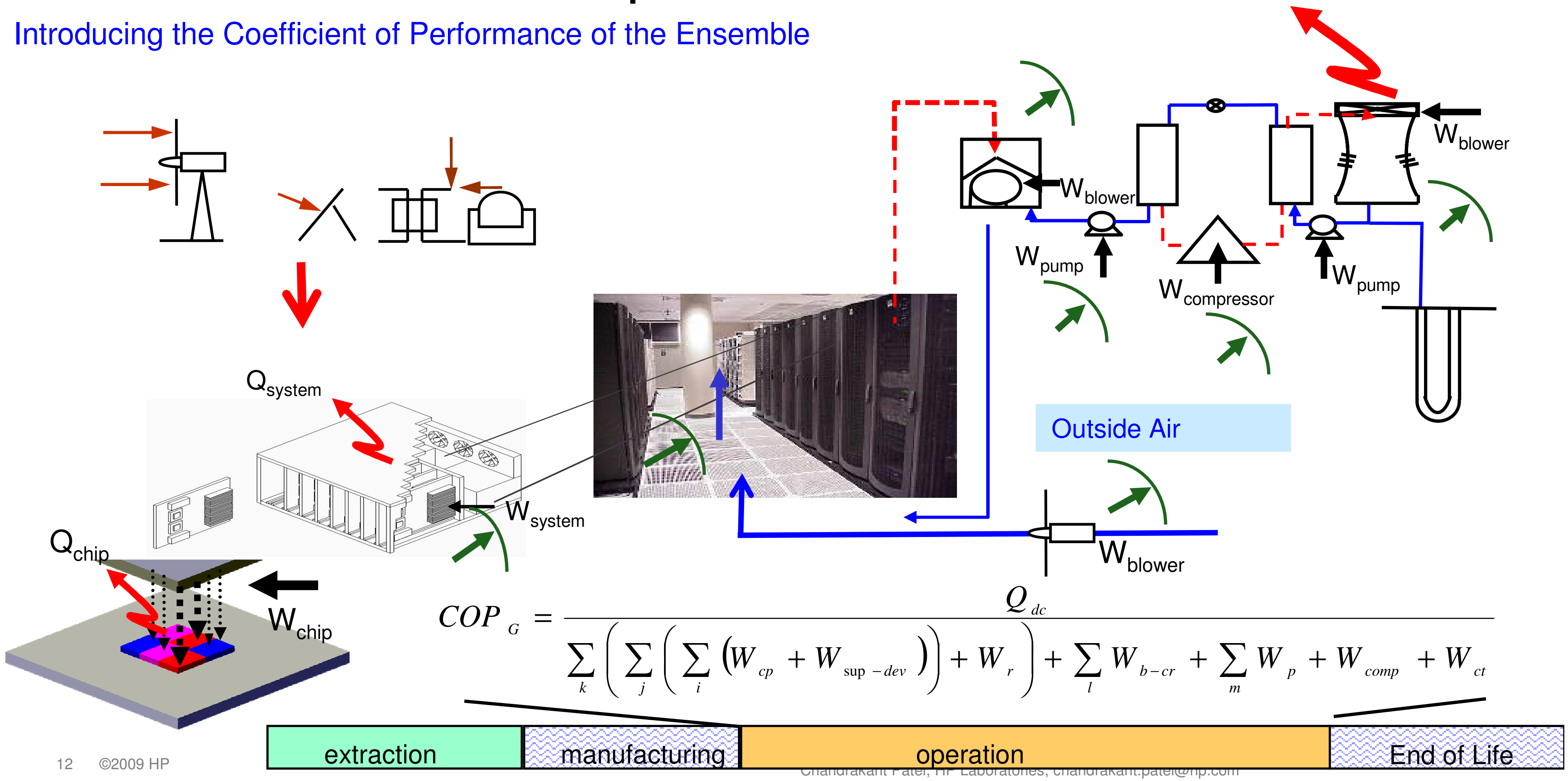
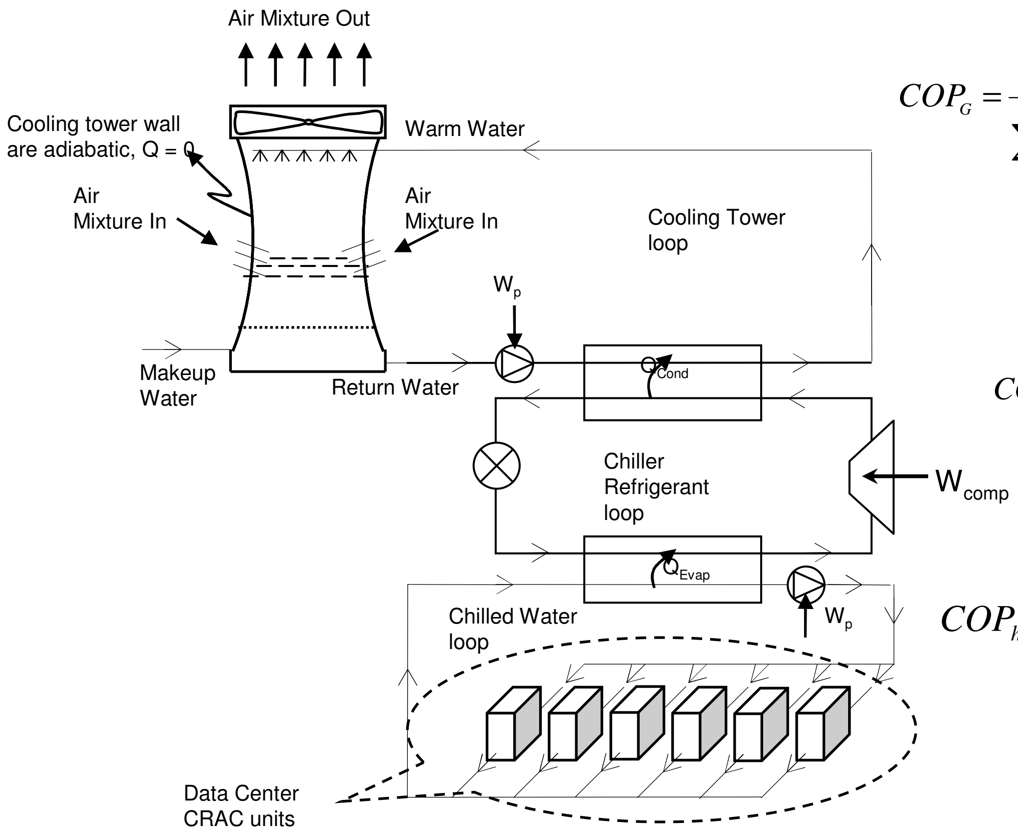
Data Center Metric - Operation

Introducing the Coefficient of Performance of the Ensemble



$$COP_G = \frac{Q_{dc}}{\sum_k \left(\sum_j \left(\sum_i \left(W_{cp} + W_{sup-dev} \right) \right) + W_r \right) + \sum_l W_{b-cr} + \sum_m W_p + W_{comp} + W_{ct}}$$

Coefficient of Performance of the Ensemble



$$COP_G = \frac{Q_{dc}}{\sum_k \left(\sum_j \left(\sum_i \left(W_{cp} + W_{\sup-dev} \right) \right) + W_r \right) + \sum_l W_{b-cr} + \sum_m W_p + W_{comp} + W_{ct}}$$

$$COP_{ch} = \frac{Q_{ch}}{W_{comp}}$$

$$W_{comp} = \frac{\dot{m}_{ref} n P_2 \nu_2}{\eta_p \eta_{motor} (n-1)} \left[\left(\frac{P_3}{P_2} \right)^{(n-1)/n} - 1 \right]$$

$$COP_{hydronics} = Q_{dc} \Big/ \sum \left(W_p \right)_{secondary}$$

Patel, C.D., Sharma, R.K., Bash, C.E., Beitelmal, M, “Energy Flow in the Information Technology Stack: Introducing the Coefficient of Performance of the Ensemble”, ASME International Mechanical Engineering Congress & Exposition, November 5-10, 2006, Chicago, Illinois

On building a Sustainable Data Center

through end to end management and design

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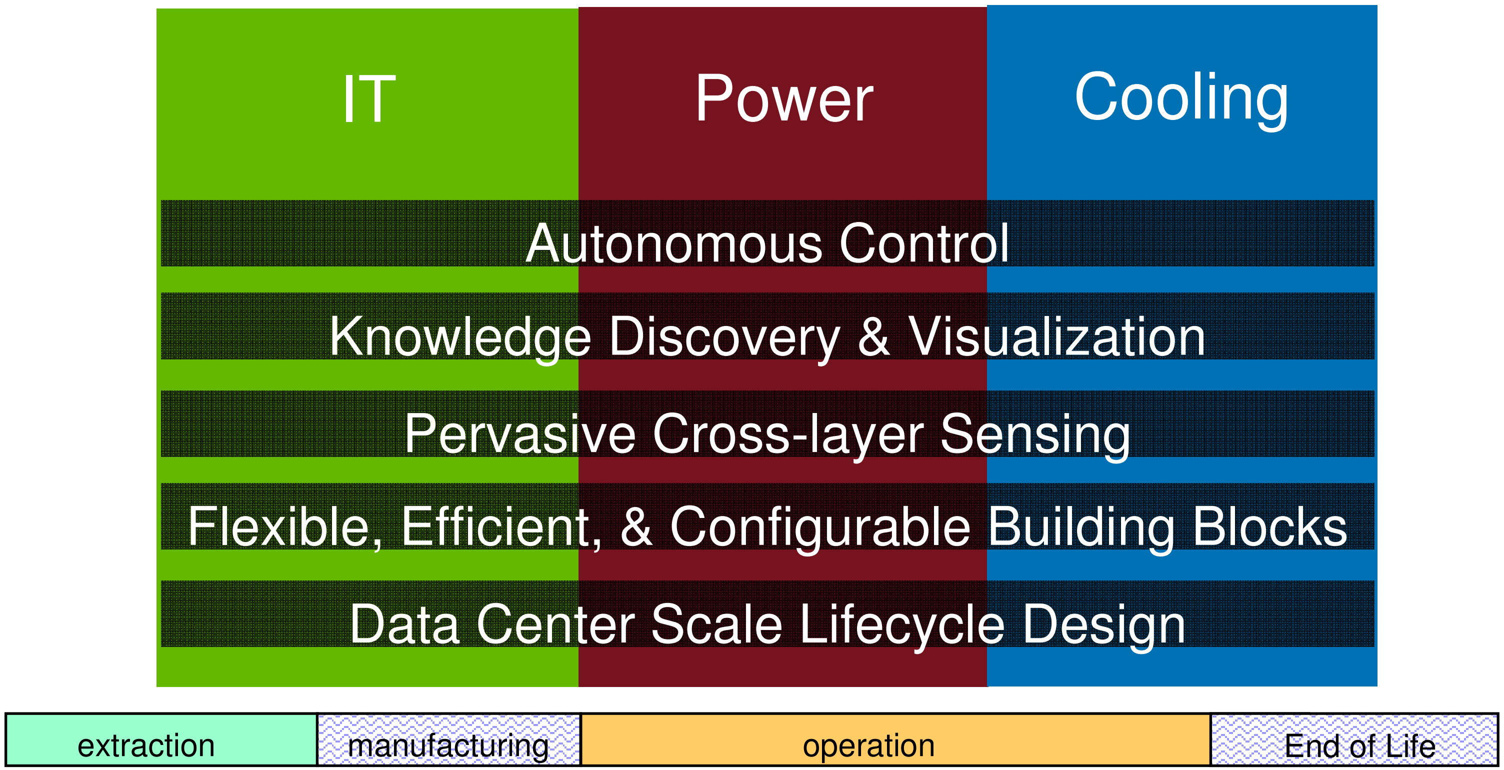
Sustainable Data Center

Key Components and Key Elements



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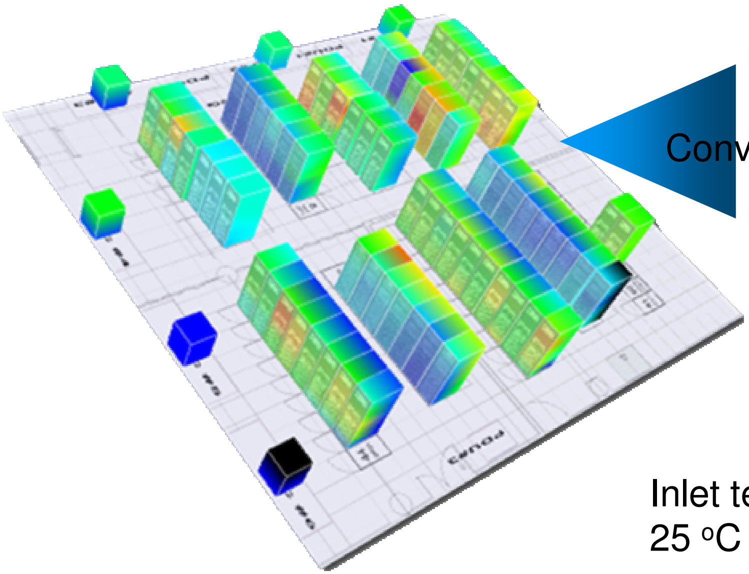
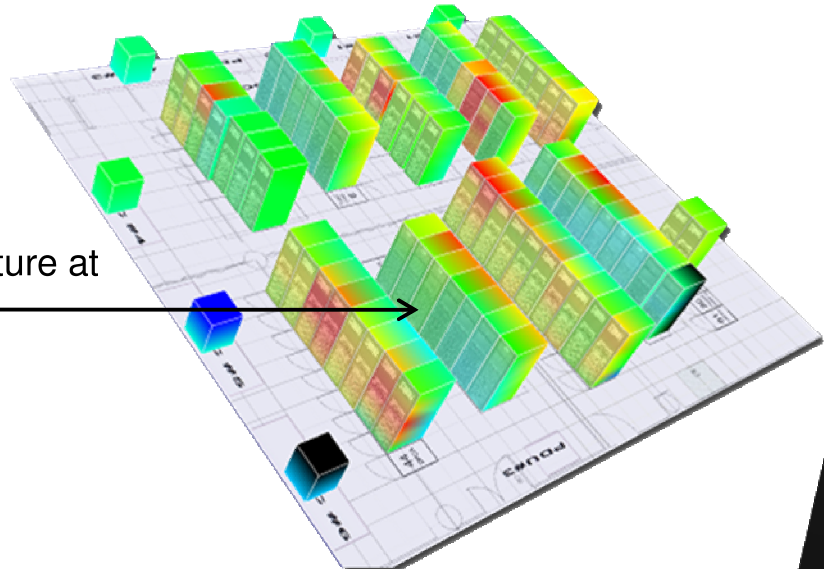
Dynamic Control of Cooling

HP Labs Data Center, Palo Alto, CA

- Minimizing thermodynamic work by operating at higher temperature
- Minimizing flow work by "right" provisioning the fluid flow



Conventional approach



Inlet temperature at 25 ^{o}C

35% Available Energy Savings

Dynamic Control air flow rate and temperature

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application at scale……

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Vindhyas – Asia Pacific Lab Data Center, Bangalore, India

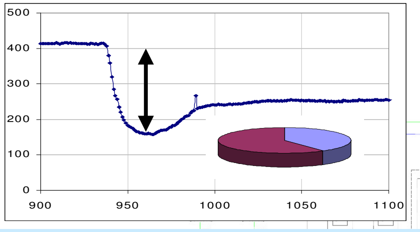
Facility Building Blocks

- **Chillers**
  - 3 air-cooled
  - 2 water-cooled

- **Pumps**
  - 7 Primary
  - 5 Secondary

- **CRAC units**
  - 55 units

- **Diesel Generators**
  - 5 3MW units



40% reduction in AHU power
20% reduction in Infrastructure Power
7,500 tons of CO_2 prevented annually

- Software Operations, Bangalore
- Consolidation of 14 lab data centers

IT Building Blocks

- Servers
  - Non-Stop servers
  - Proliant servers
  - Blade servers
  - Custom Enclosures
- Storage (XP/EVA)
- Multiple Network topologies
- Sensor Network
  - 7500 sensors

5 floors
900kW cooling per floor

- Dynamic cooling control implemented
- Data Analysis, Visualization and Knowledge Discovery to detect anomalies, improve reliability and minimize redundancy

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Dynamic allocation of IT, Power and Cooling

HP Labs Palo Data Center

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Sustainable Data Center

Efficient and light through dynamic allocation of power, compute and cooling resources

Research: Integrated IT-Facility Management

Example: Real-time thermal-aware placement of virtualized IT load

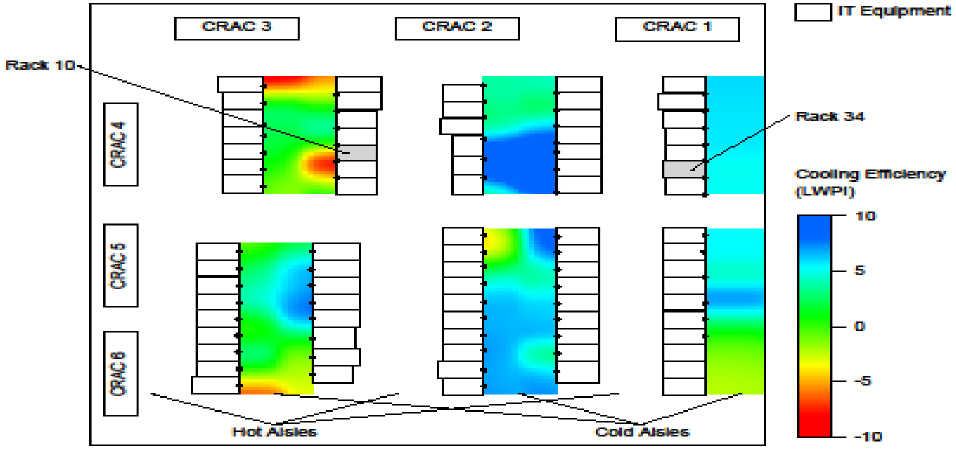
Experiment setup at HPL Palo Alto Demonstrato

20 physical servers
- 9 in Rack 10; 11 in Rack 34

35 Virtual Machines
- 2 interactive 3-tier apps
- 29 computational workloads

10 hour experiment

Integrated controllers
- Application Controller
- Node Controller
- Pod Controller
- DSC Controller



Savings: 26.5% IT power, 16.5% cooling power

EXTRACTION | MANUFACTURING | OPERATION | END OF LIFE

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Knowledge Discovery

Inference from thousands of sensed points

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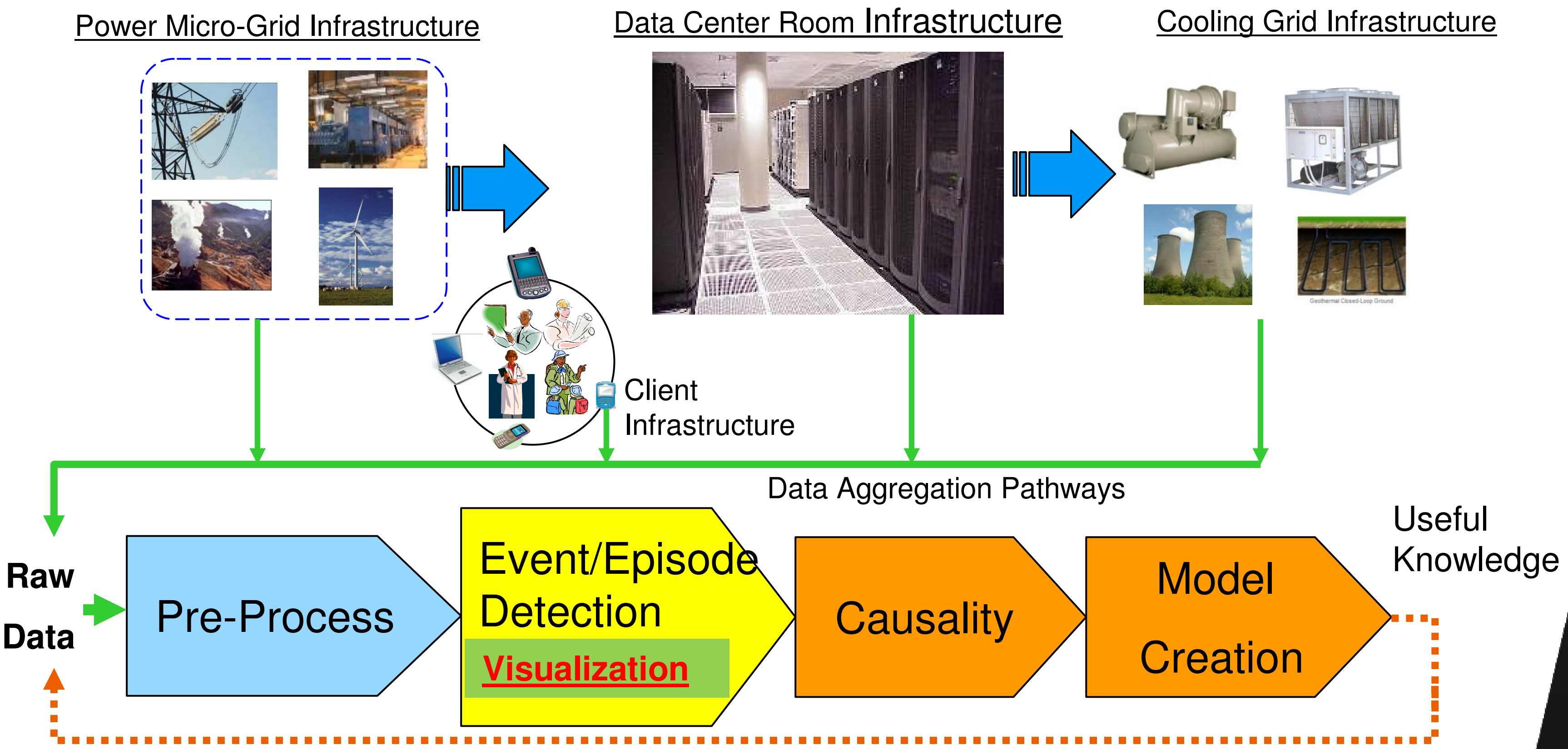
Knowledge Discovery



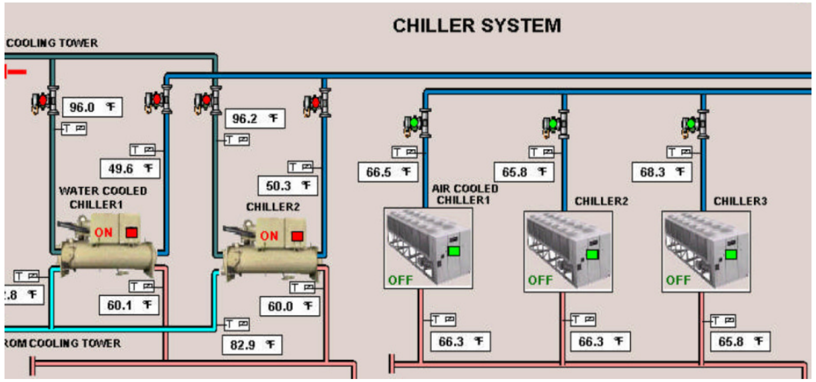
Example of Knowledge Discovery

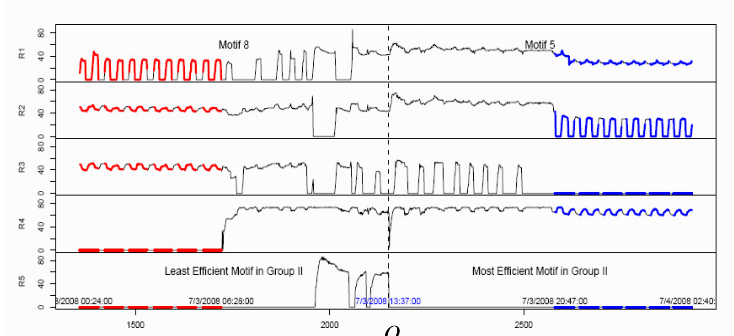
Pattern mining of chiller ensemble in Bangalore data center

Research: Motif mining, Anomaly Detection, Visual Analytics (HP Data Center Mobile Studio)

Focus on: Operational energy, emission, consumption of water and reliability

Example: Motif Mining applied to water and air cooled chiller ensemble





$$COP_G = \frac{Q_{dc}}{\sum_k \left(\sum_j \left(\sum_i \left(W_{cp} + W_{sup-dev} \right) \right) + W_r \right) + \sum_l W_{b-cr} + \sum_m W_p + W_{comp} + W_{ct}}$$

Annual Savings: 359 MWh (~10%); 179,580 G direct water; 287, 328 Kg CO_2

EXTRACTION	MANUFACTURING	OPERATION	END OF LIFE

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Data Center Total Cost of Ownership

extraction	manufacturing	operation	End of Life

$$Cost_{total} = \left(\frac{\$}{ft^2}\right)\left(A_{critical},\ ft^2\right) + \left(1 + K_1 + L_1 + K_2 L_1\right) U_{\$,grid} P_{\substack{consumed \\ hardware}} + R\left(M_{total} S_{avg} + IT_{dep} + \sigma_1\right)$$

Real Estate — **Burdened power consumption** — Personnel, equipment, SW per rack

J_1 : capacity utilization factor, i.e. ratio of maximum design (rated) power consumption to the actual data center power consumption

$K_1 = F(J_1)$: burdened power delivery factor, i.e. ratio of amortization and maintenance costs of the power delivery systems to the cost of grid power

$K_2 = F(J_1)$: burdened cooling cost factor, i.e. ratio of amortization and maintenance costs of the cooling equipment to the cost of grid power

Depreciation factors (applies to K_1 and K_2)

L_1: cooling load factor, i.e. ratio of power consumed by cooling equipment to the power consumed by compute, storage and networking hardware (inverse of $COP_{ensemble}$)

Reference: Patel and Shah, Cost Model for Planning, Development and Operation of a Data Center, HP Labs Tech Report, 2005; http://www.hpl.hp.com/techreports/2005/HPL-2005-107R1.html

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application to other ecosystems……

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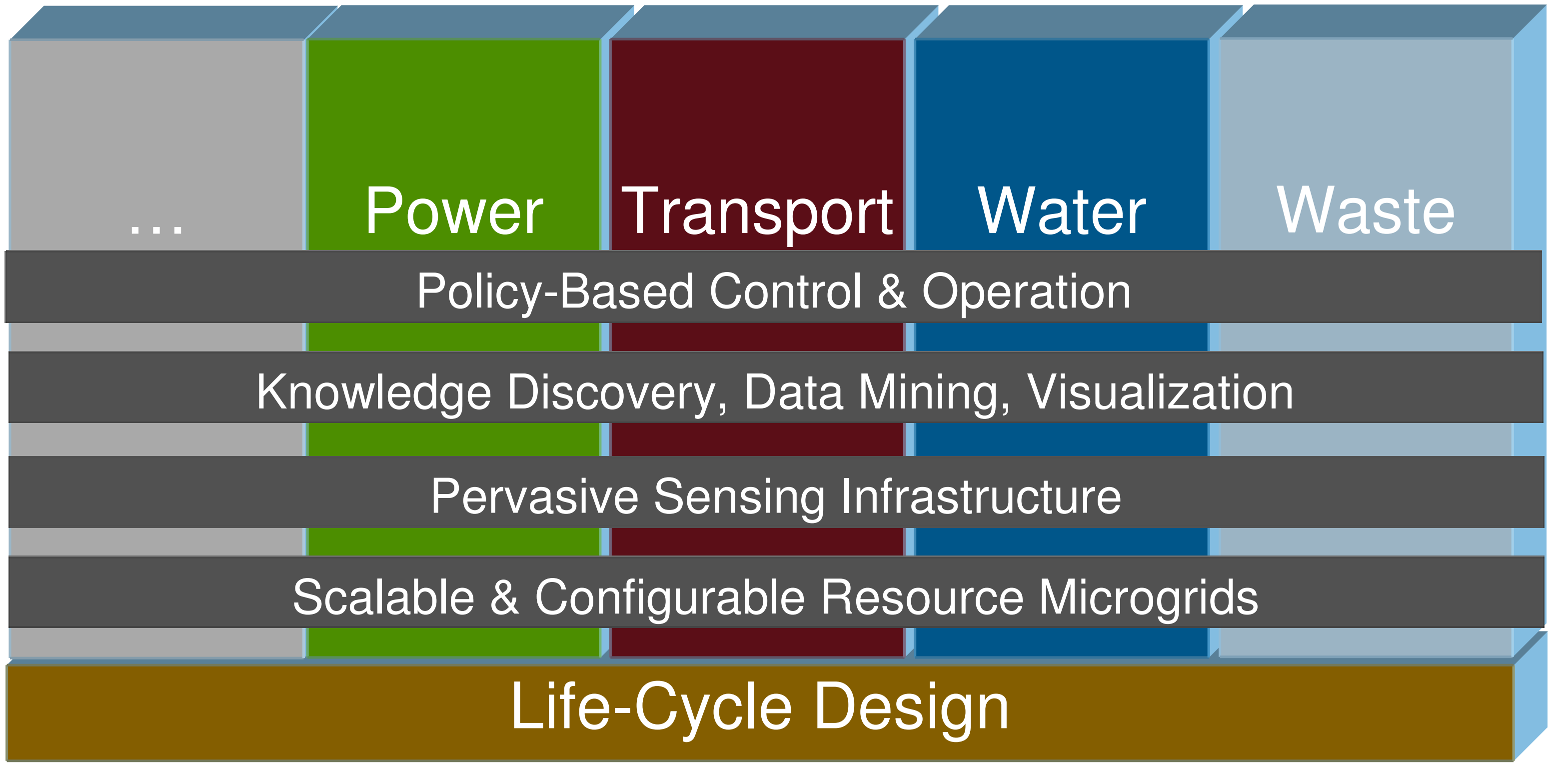
IT for Sustainability: City 2.0

Enabled by measurement, communications and computation



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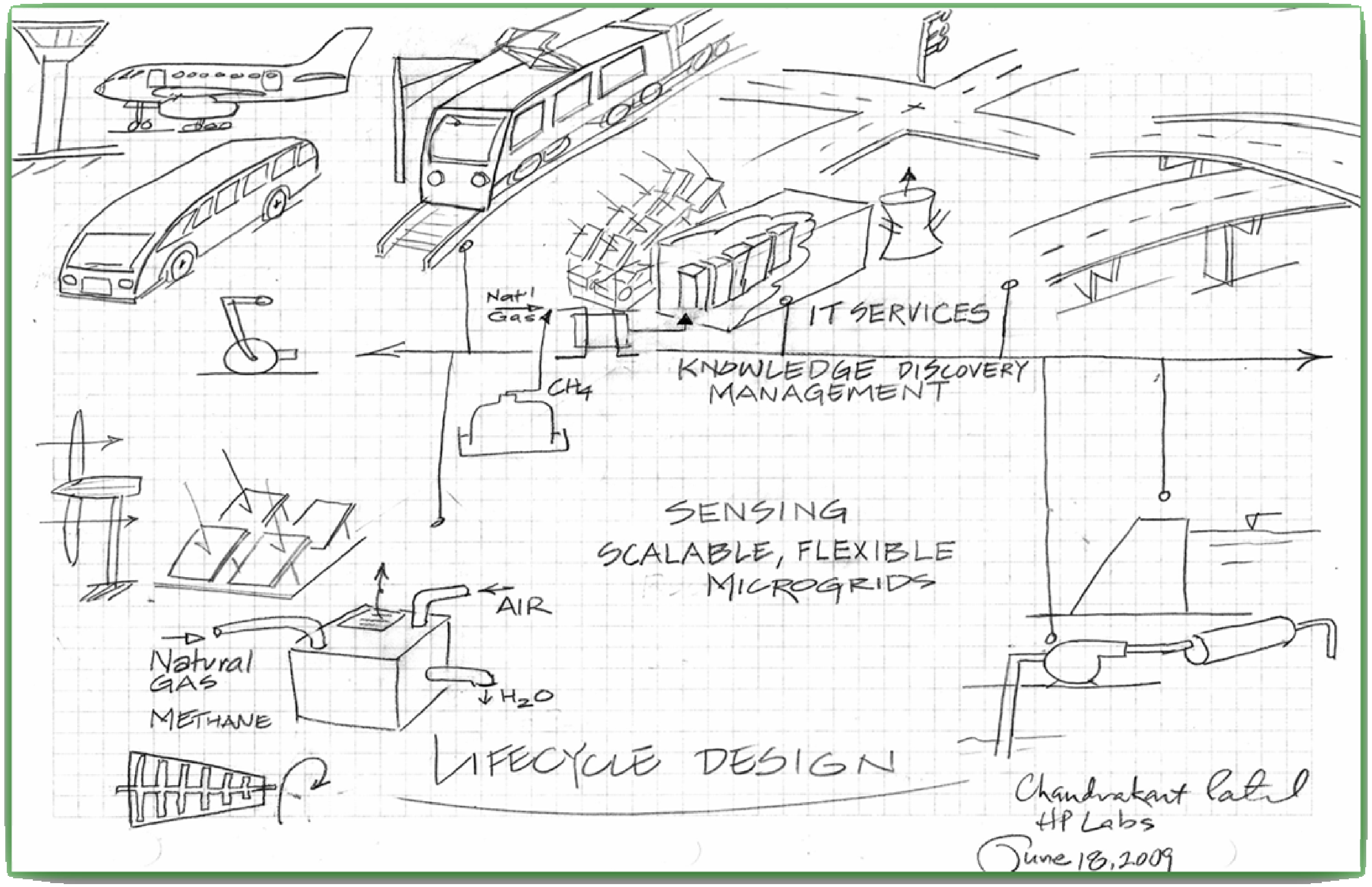

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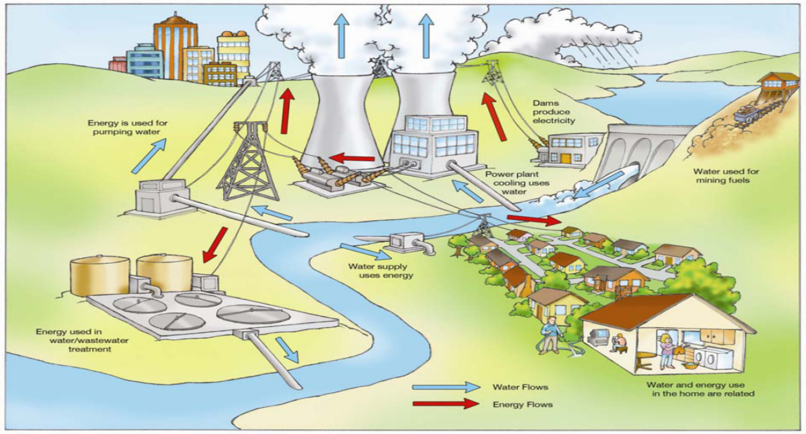
Water: Lifecycle Perspective

exergy



(ref. SANDIA/DOE)

Energy consumption	Average per million gallons
Water Treatment	0.25MWh
Water distribution	1.3 MWh
Waste Water Treatment	2.5 MWh
Desalination	20 MWh

(Ref. California Energy Comission)

Average per capita usage in the USA: 100 gallons per day

Total (excluding desalination)	~ 0.5 GWh to serve a city of a million per day

$$Water_{index} = \frac{(\text{Energy Consumed in Direct water usage and Indirect water usage})}{(\text{Energy Consumed by Process})} \times 10^3$$

Sharma et al., “Water Efficiency Management in Data Centers: Introducing a Water Usage Energy Metric”, International Conference on Water Scarcity, Global Changes and Groundwater Management Responses, Irvine, CA, December, 2008

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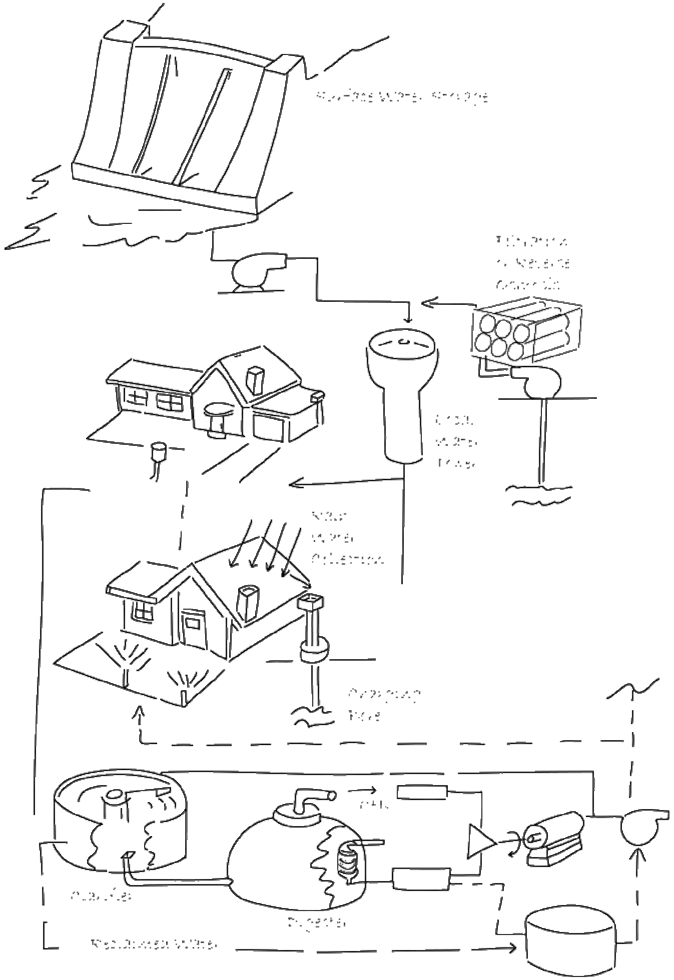

Water Microgrid

Sensing

Active Management and Control

- Operating the at peak ensemble level performance to reduce energy consumption
  - Operating sequence for upstream reservoir level pumps and downstream pumps e.g. supply side considerations in filling reservoirs, and maintaining pressure with downstream pumps based on real time end user consideration
- Coupled operation with waste water treatment plants
  - drive efficient operation of waste water treatment plants based on supply side end user consumption information
  - use of non potable water for irrigation

Knowledge Discovery

- Monitoring of water quality, storage levels in the ensemble of reservoirs, water consumption, evaporative loss, and biological processes
- Inferred monitoring of aggregated parameters: public health indicators
- Analytics:
  - historical trends and prediction for future consumption, recognition of consumption patterns leading to improved distribution
  - Diagnose and suggest remedial methods for faults in delivery systems, pump houses and treatment plants
  - Detection of pipeline leaks, pump malfunction, pump degradation (monitoring wire to water efficiency), valve failure and corrosion related failures

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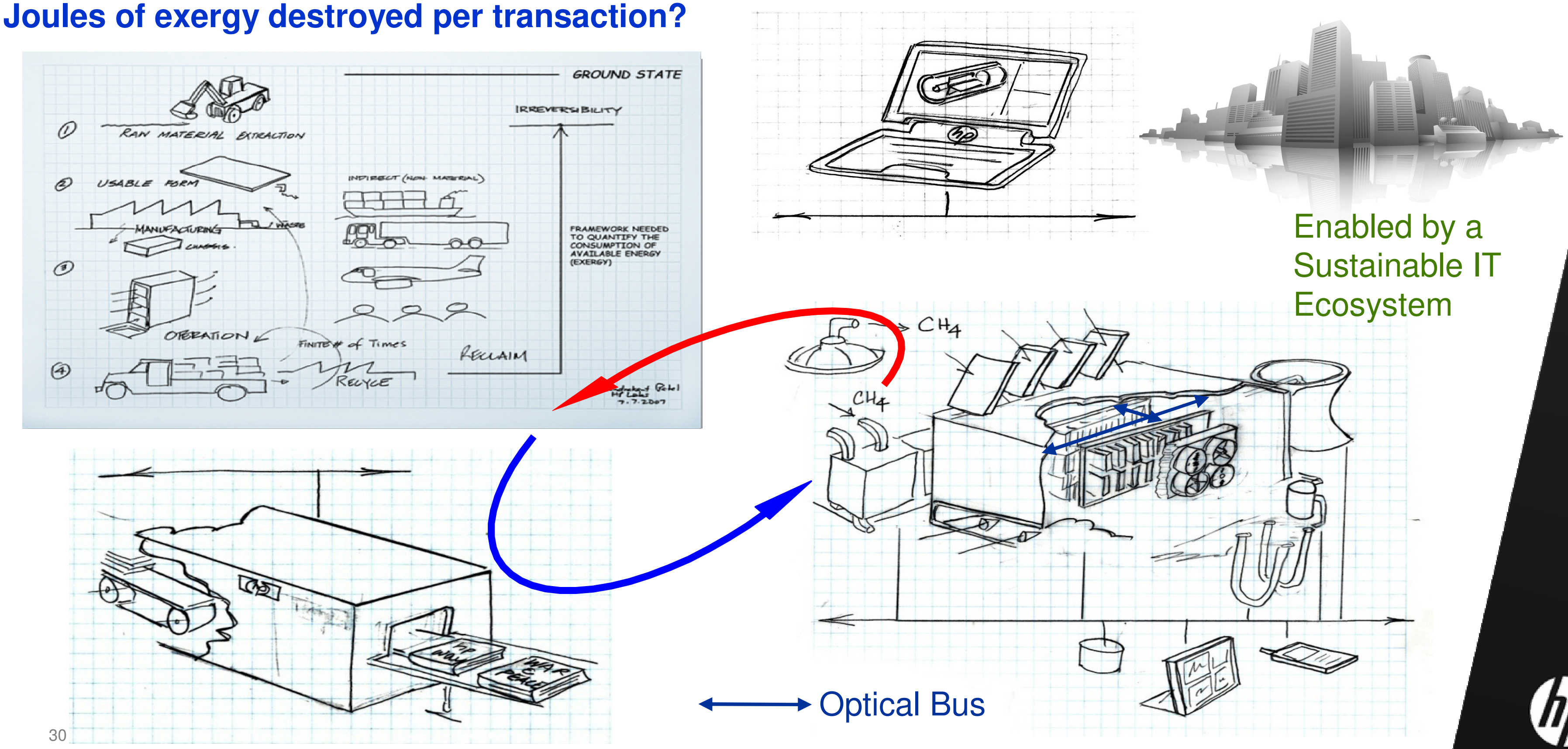
Joules: Currency of the flat world

Measure for building the Cloud

Joules of exergy destroyed per transaction?



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THANK YOU

– I thank you for your time

– I thank:

- Dr. Arutyun Avetisyan and the management of the Institute for System Programming of the Russian Academy of Sciences
- and my HP colleagues

for inviting and hosting me

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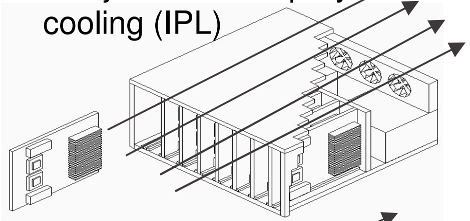
History of Work at HP Laboratories

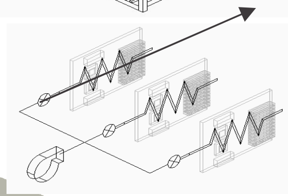
Thermal Management, Systems Design, Data Center Design and Management, Sustainable IT Ecosystem

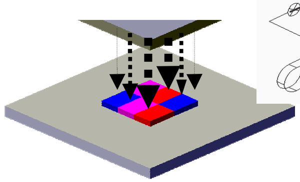
1991 **Chips & Systems** 1998 **Data Center** 2007 **Sustainable IT Ecosystem**

Efficient Management of Heat

- Thermo-mechanical design
  - K-class (1995) to C-class
- Highest heat transfer in the world at chip level
  - inkjet assisted spray cooling (IPL)

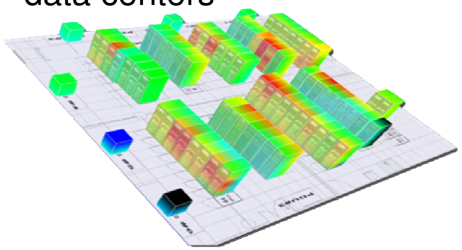


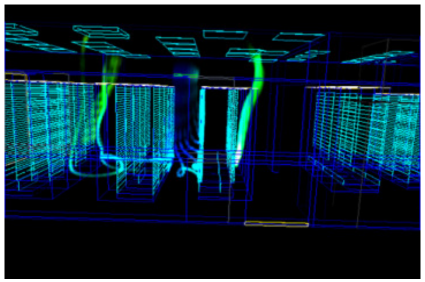




Demand side management

- Static and dynamic provisioning of power and cooling in servers and data centers

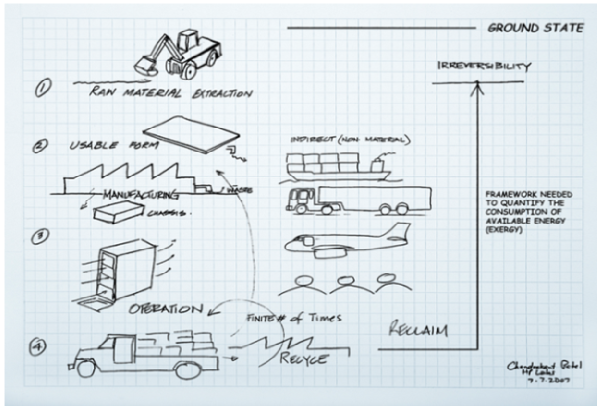




HP Thermal Assessment Service

Supply and Demand side management

- Cradle to Cradle Assessment Toolkit
  - *From component to corporation*
- Ecosystem level resource management over the lifecycle



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