# Sustainable Ecosystems

## supply and demand side management

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# Motivation

Total Cost in light of Sustainability

- **Global population projected to be 9 billion by 2050**
  - Singapore is expected to grow from 4.6 million to 6 million residents by 2032
    - Infrastructure needed to support growing base of citizens
- **Hidden Cost of Growth**:
  - As **social cost** of production and consumption is taken into account, burden of building and operating infrastructure may grow further
- **Cost-effective allocation of infrastructure will be critical**
  - Need an *economically efficient provisioning* of resources based on integrated management of supply and demand



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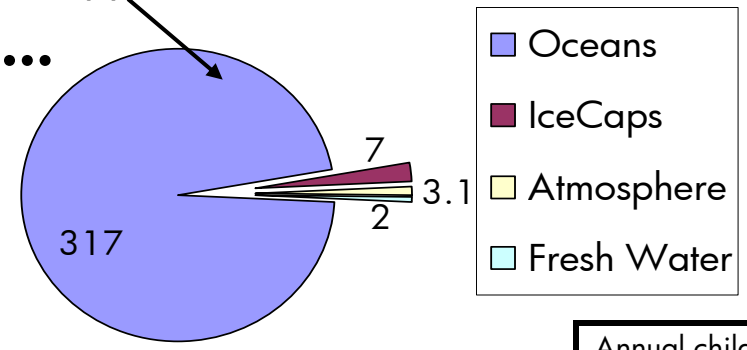
# Impact of Externalities – on Water?

The earth's total water supply is estimated to be 330 million cubic miles, and each cubic mile contains more than one trillion gallons

35000ppm salt concentration

**But …**




In million cubic miles

What will be the impact of externalities – e.g. climate change?

- Effective Conservation
- Effective Management
- Effective Distribution

| | |
|---|---|
| Annual child deaths due to dirty water and poor sanitation and hygiene | 2.2 million |
| Number of people without easy access to safe water | 1.1 billion |
| Number of people without easy access to decent sanitation | 2.4 billion |
| Percent of world's food grown on rain-fed lands | 60-70% |

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# Technical Approach

**Integrated Supply-Demand Management based on Service Level Agreement**

- **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
    - pervasive sensing, communications, knowledge discovery, and policy based control



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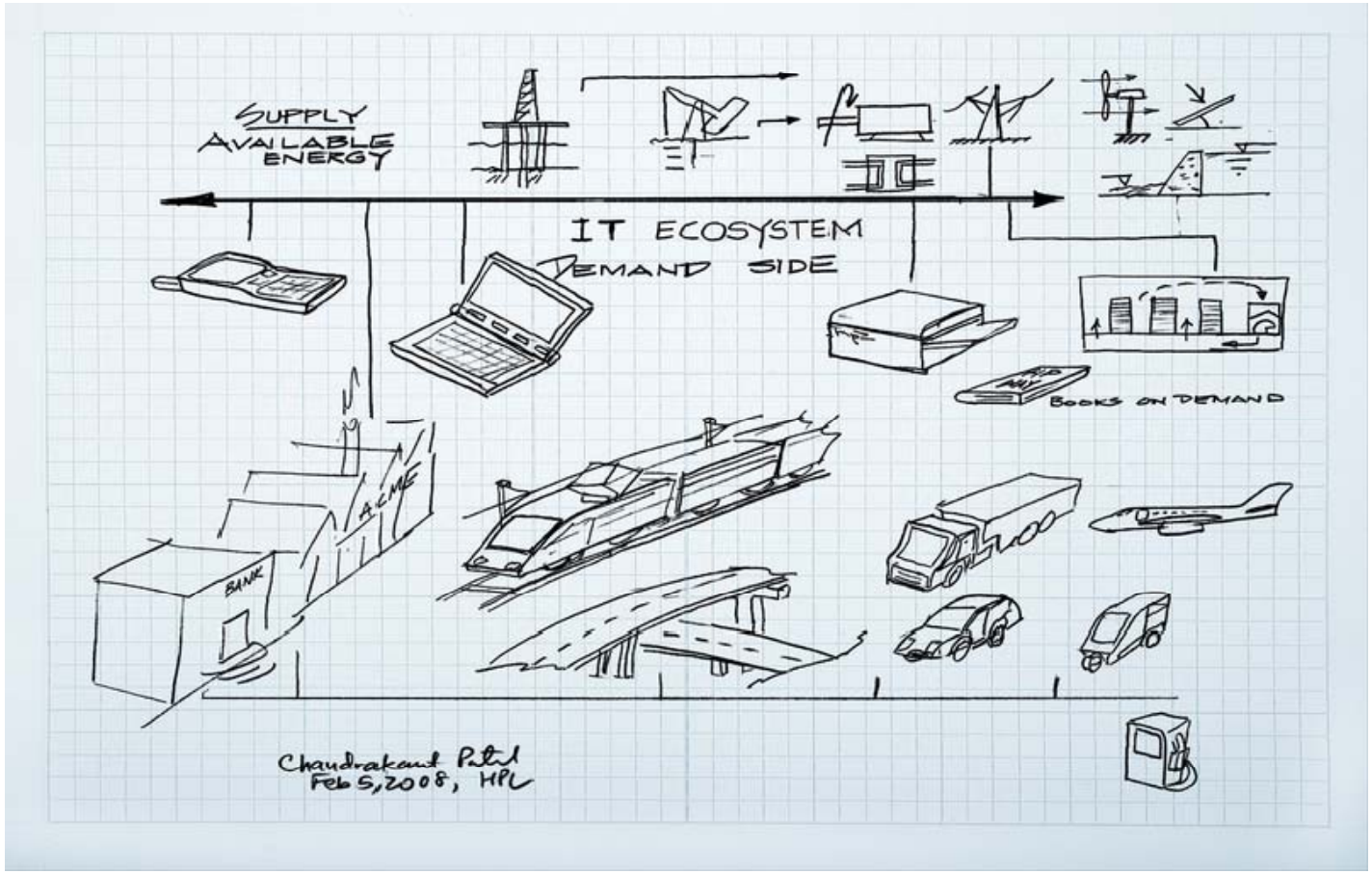
# Role of the IT Ecosystem



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# Role of the IT Ecosystem

## addressing the fundamental needs of society

1. **IT 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*

Micro-businesses

2. **Use the IT ecosystem to enable need based provisioning of resources across all ecosystem**
   - Power, water, transport, waste…..
   - Transformation necessitates
     - *supply and demand side management of resources*


Queue at CNG Filling Station

*Key Enablers:*
- *Unifying Metric, Return to Fundamentals of Engineering & Multidisciplinary Curriculum*




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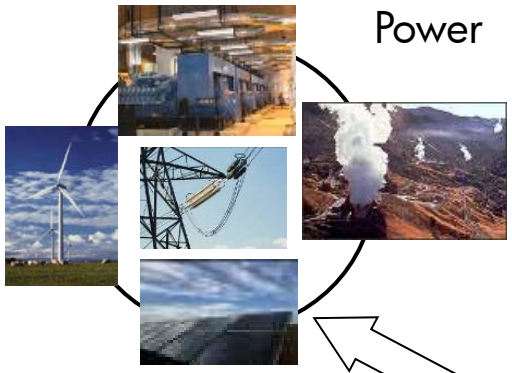
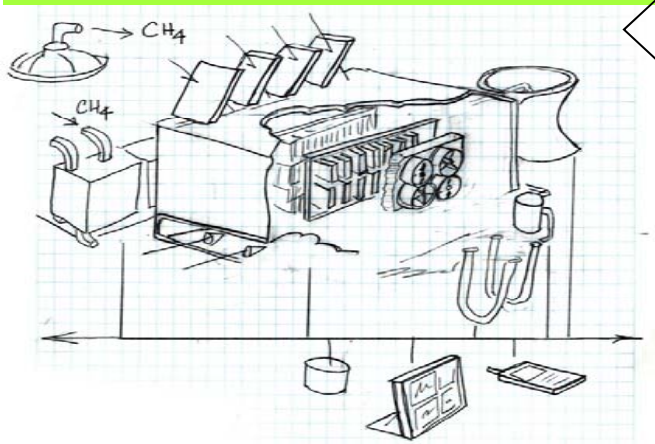
# Data Center at the Core

For Management of Resources at community scale



Power

Sustainable Datacenter




Ecosystem of Clients


Healthcare

Education

Water

Transport

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**Step 1.....**

# Building Sustainable IT

*supply-demand side management*



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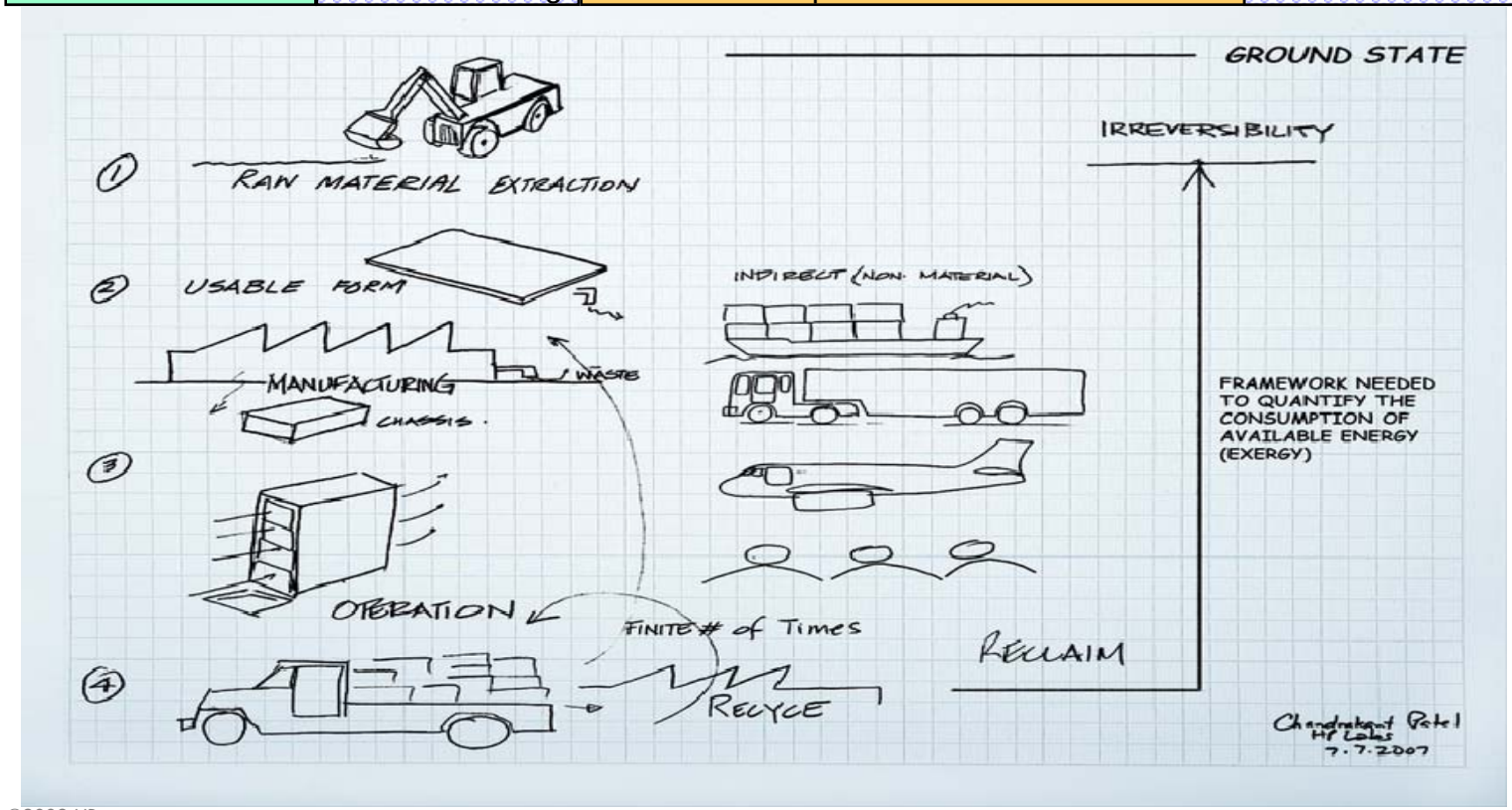
# Supply Side Lifecycle Perspective

Lifecycle engineering and management

| extraction | manufacturing | operation | End of Life |
|---|---|---|---|







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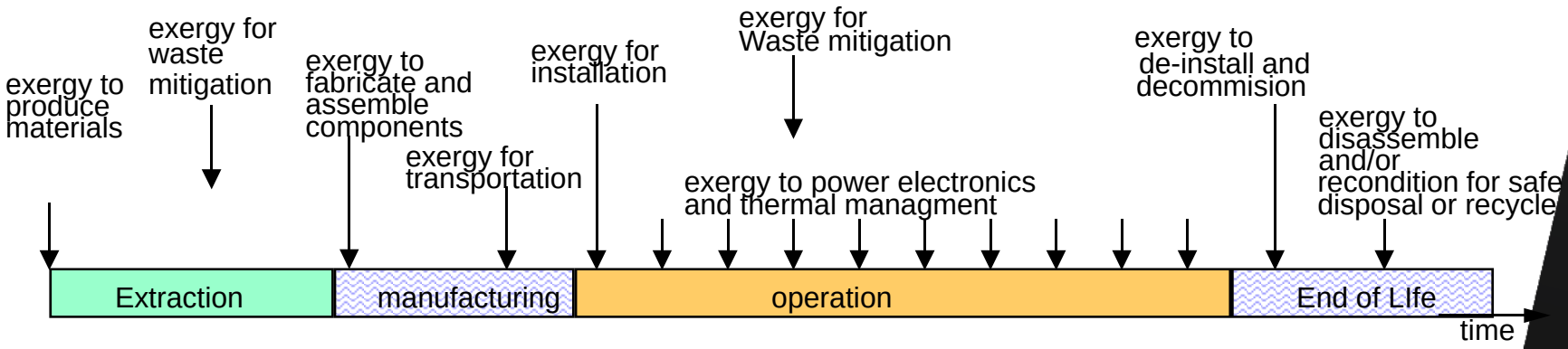
# Lifecycle Engineering and Management

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

# On Building Sustainable Data Centers

*supply-demand side management*

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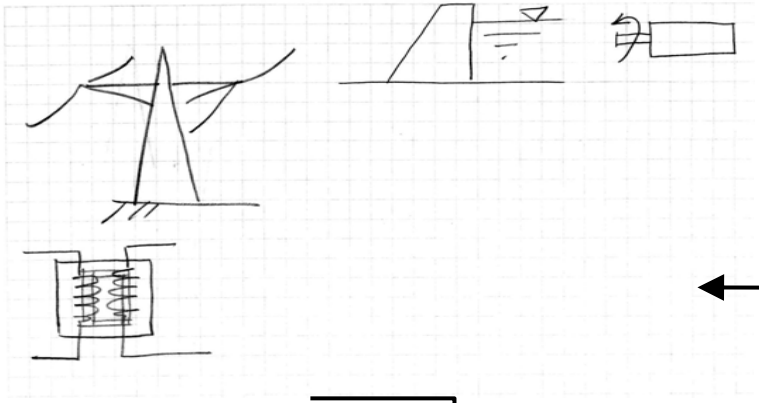
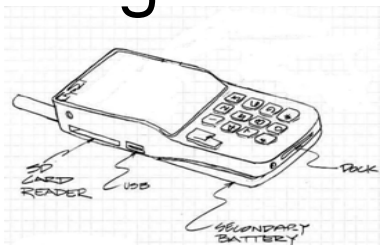
# SLA based Supply-Demand Management

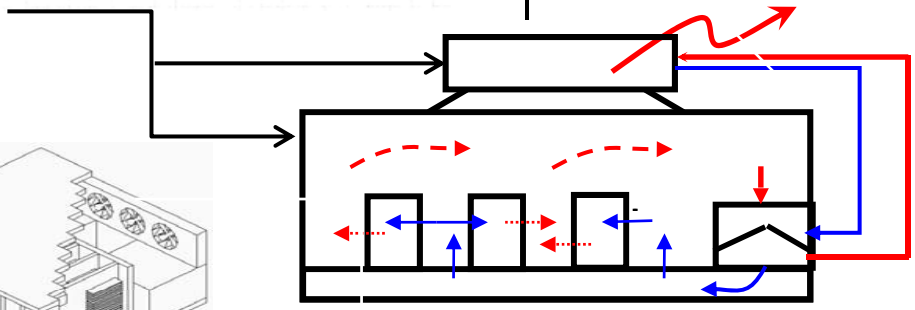
Data Center is the Computer

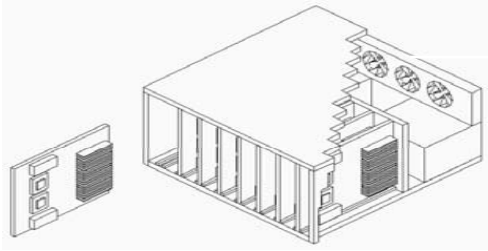





**Service Level Agreement**

$$COP = \frac{Q_{system}}{W_{cooling}}$$





**Supply and Demand Side Management based on the Service Level Agreement**



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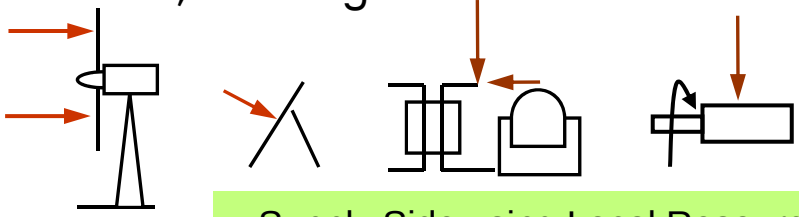
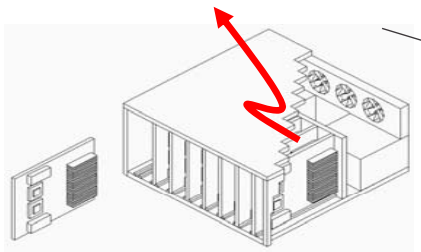
# Supply Side in Data Center Design

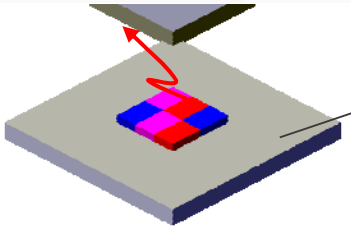
Power Grid, Cooling Grid

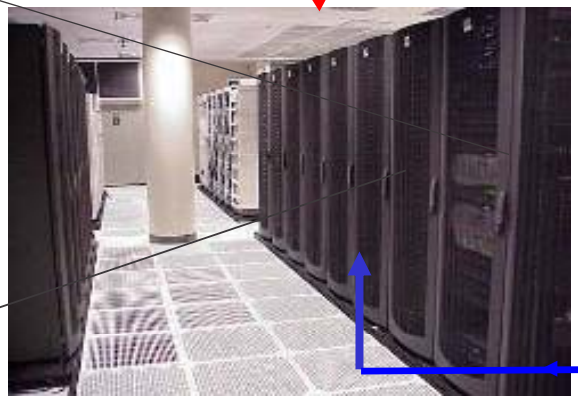


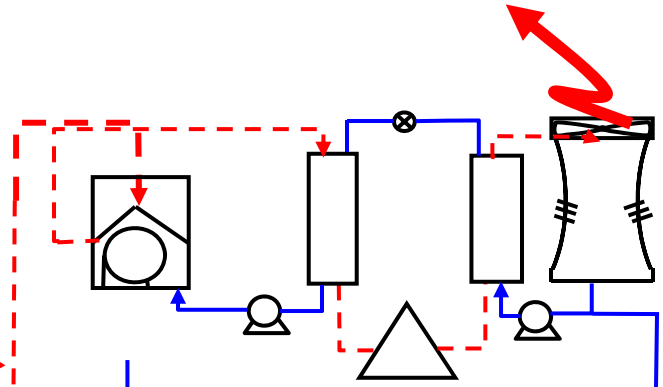
Supply Side using Local Resources

**Power Grid**

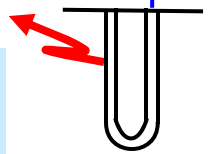






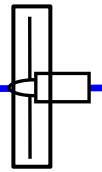


Ground Coupled Loop



Cooling using Local Resources

**Cooling Grid**



Outside Air

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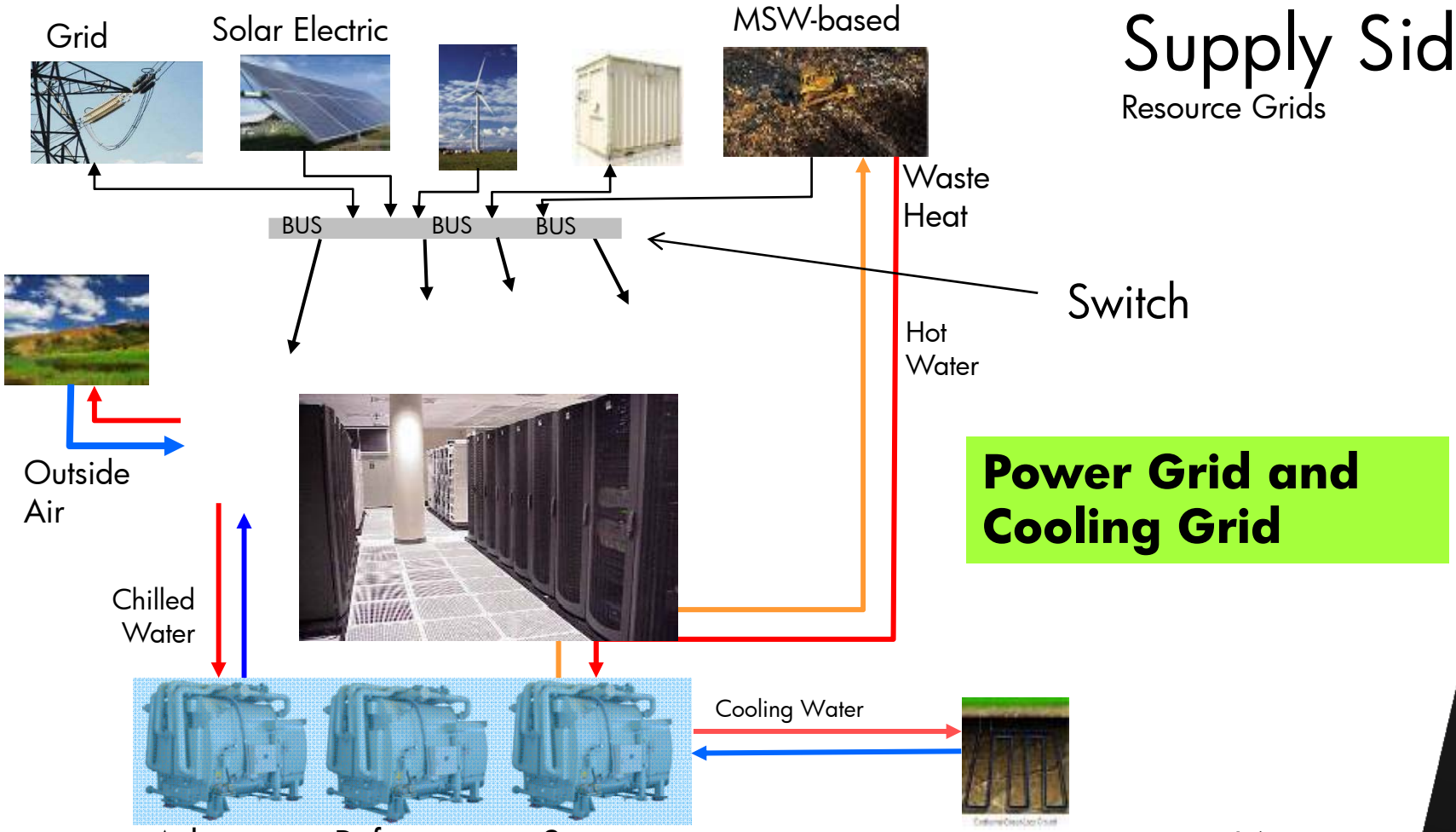
# Supply Side

Resource Grids




**Power Grid and Cooling Grid**

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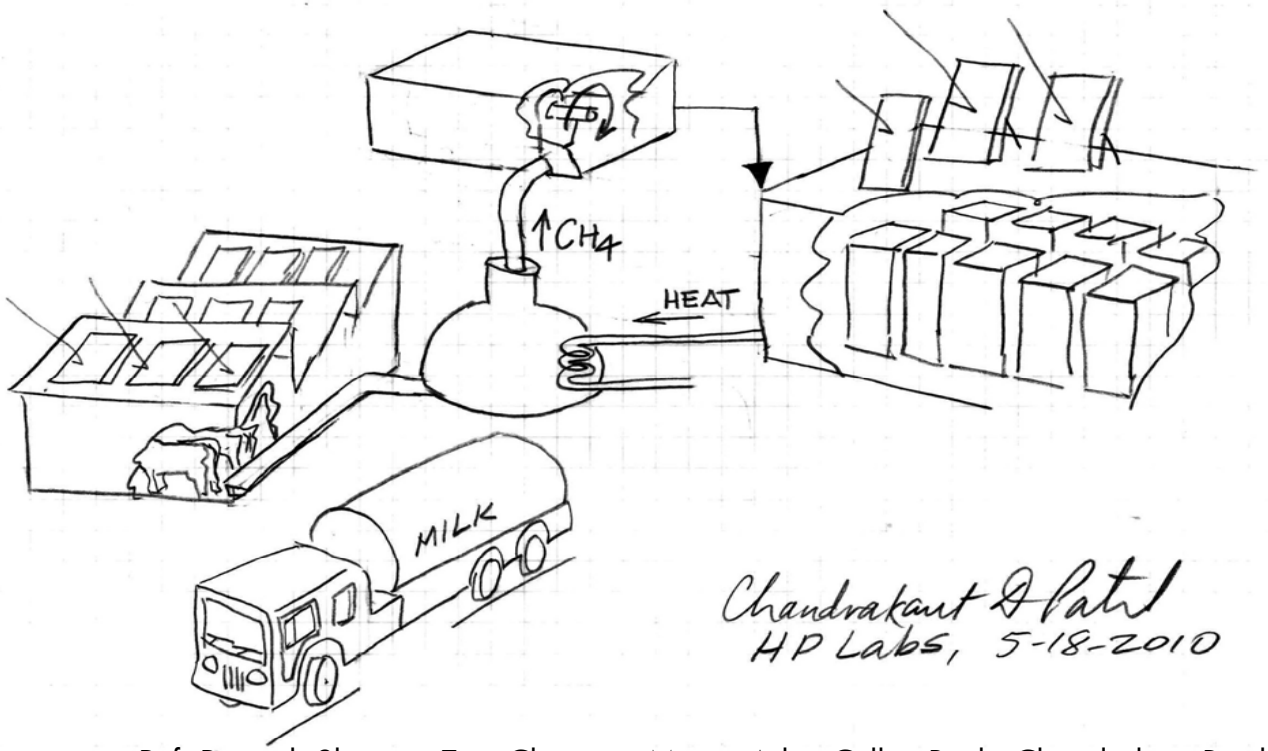
# Server Farm at the Dairy Farm

symbiotic relationship between IT and manure




## Micro-grid

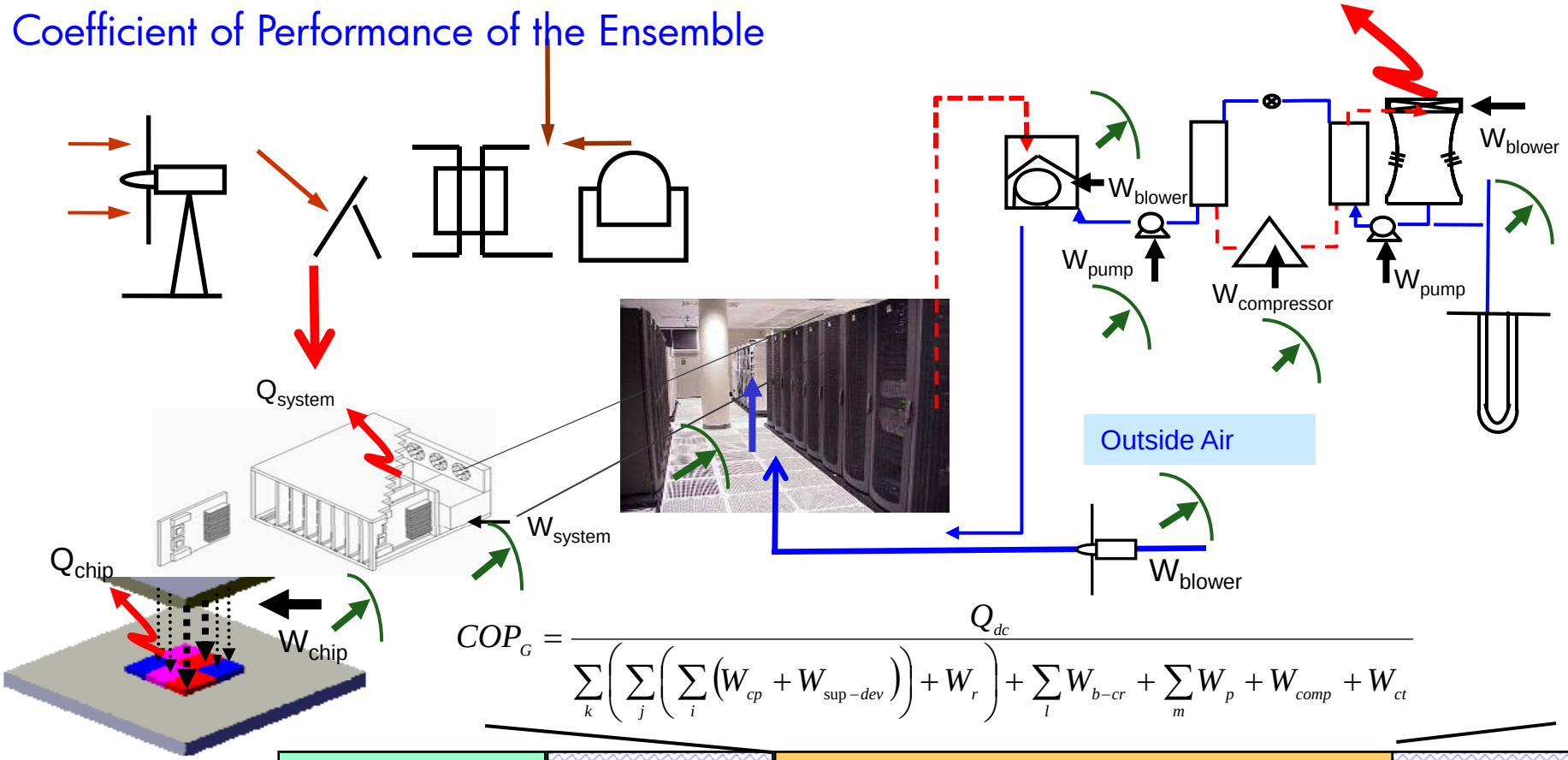
- Exploiting Synergies
  - Exergy in heat energy applied to the "soup" in the digester
  - Exergy in heat energy from the generator used for adsorption refrigeration to cool the data center

Ref: Ratnesh Sharma, Tom Christian, Martin Arlitt, Cullen Bash, Chandrakant Patel, "Design of Farm Waste-Supply Side Infrastructure for Data Centers, ASME 2010-Energy Sustainability, ES 2010-90219

# Demand Side: Energy Flow in the IT Stack

## Coefficient of Performance of the Ensemble




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

| extraction | manufacturing | operation | End of Life |
|---|---|---|---|



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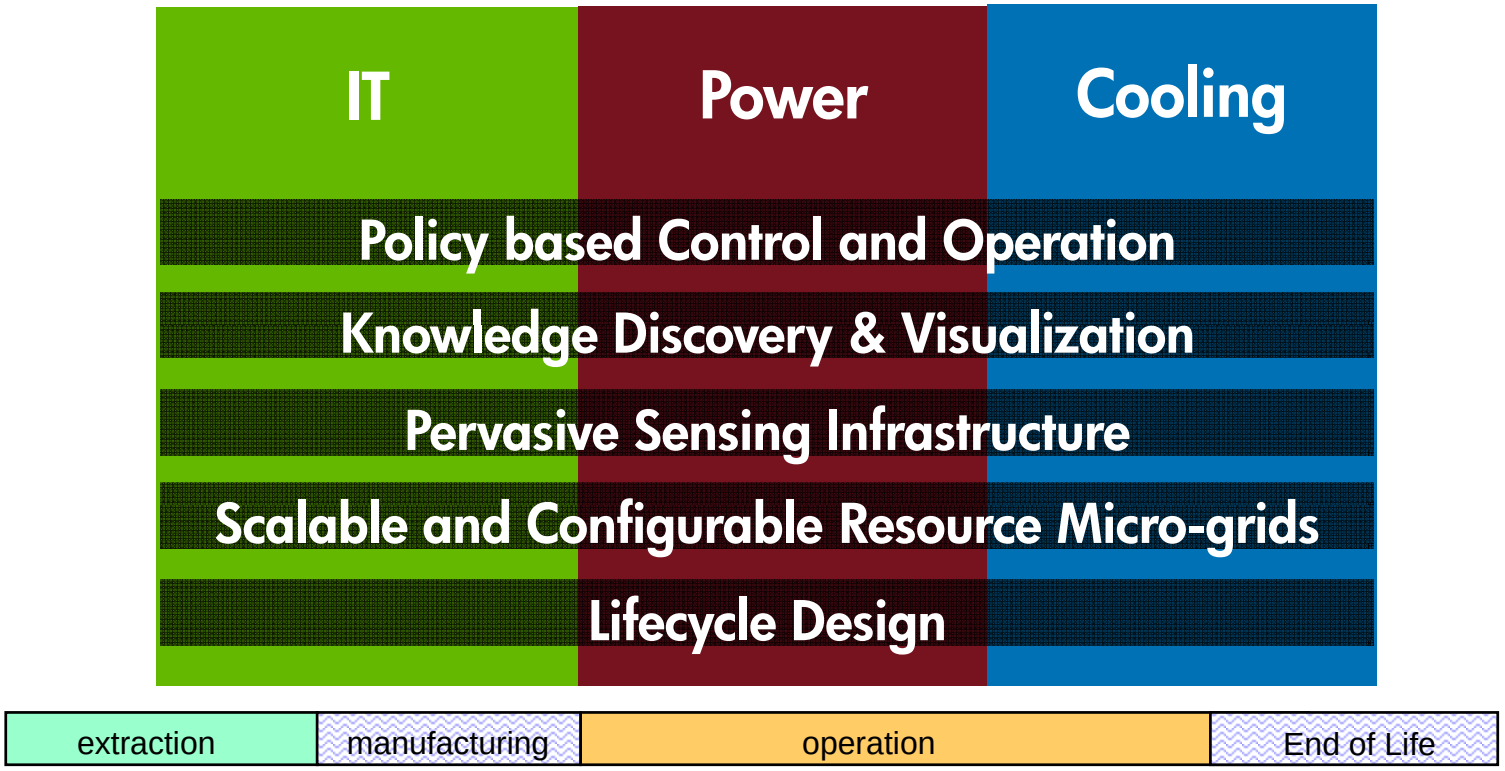
# Integrated Supply-Demand Management

## Key Components and Key Elements







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**Step 2.....**

# Applying IT for Sustainability

*supply-demand side management at the scale of cities*



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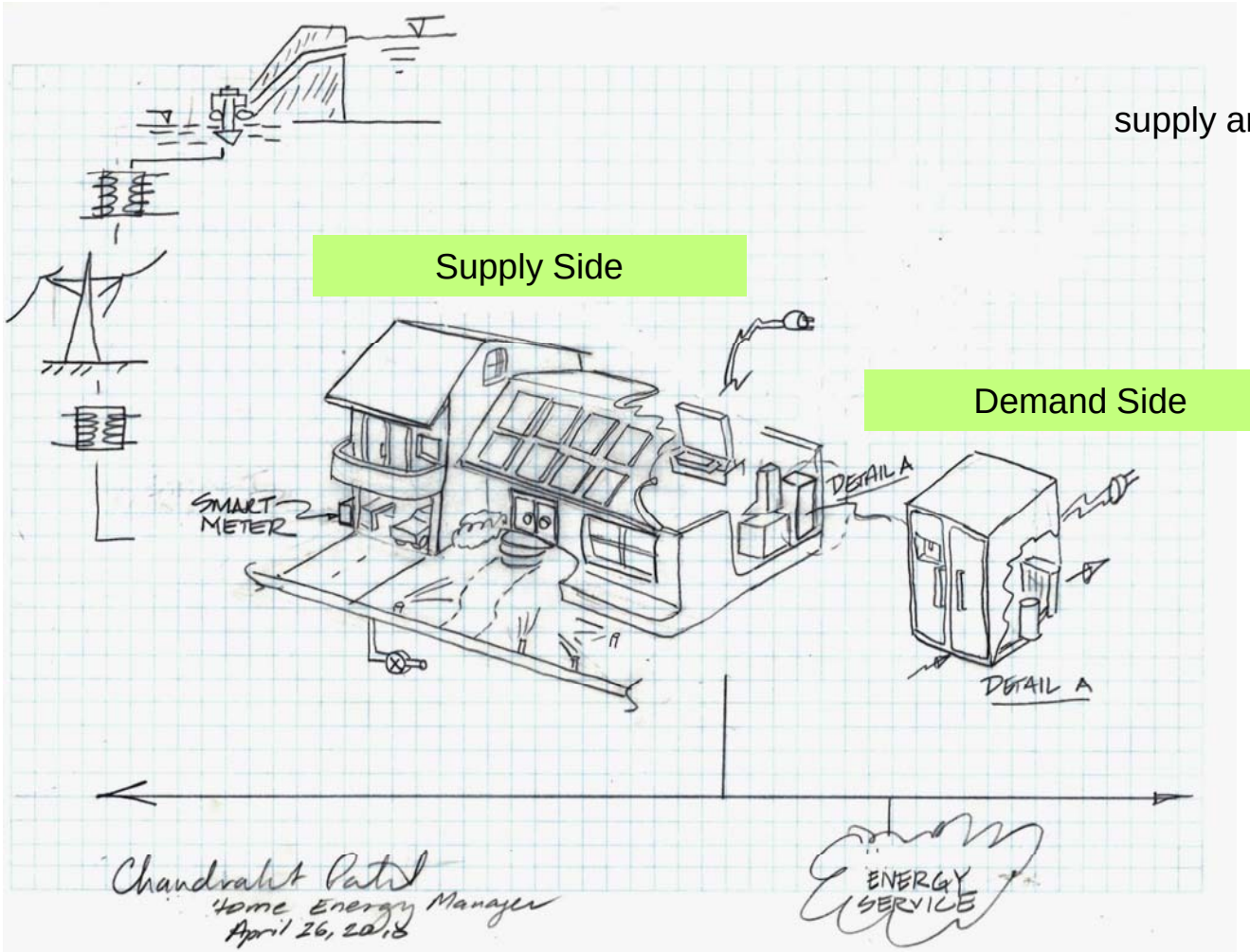
# Home

supply and demand side management







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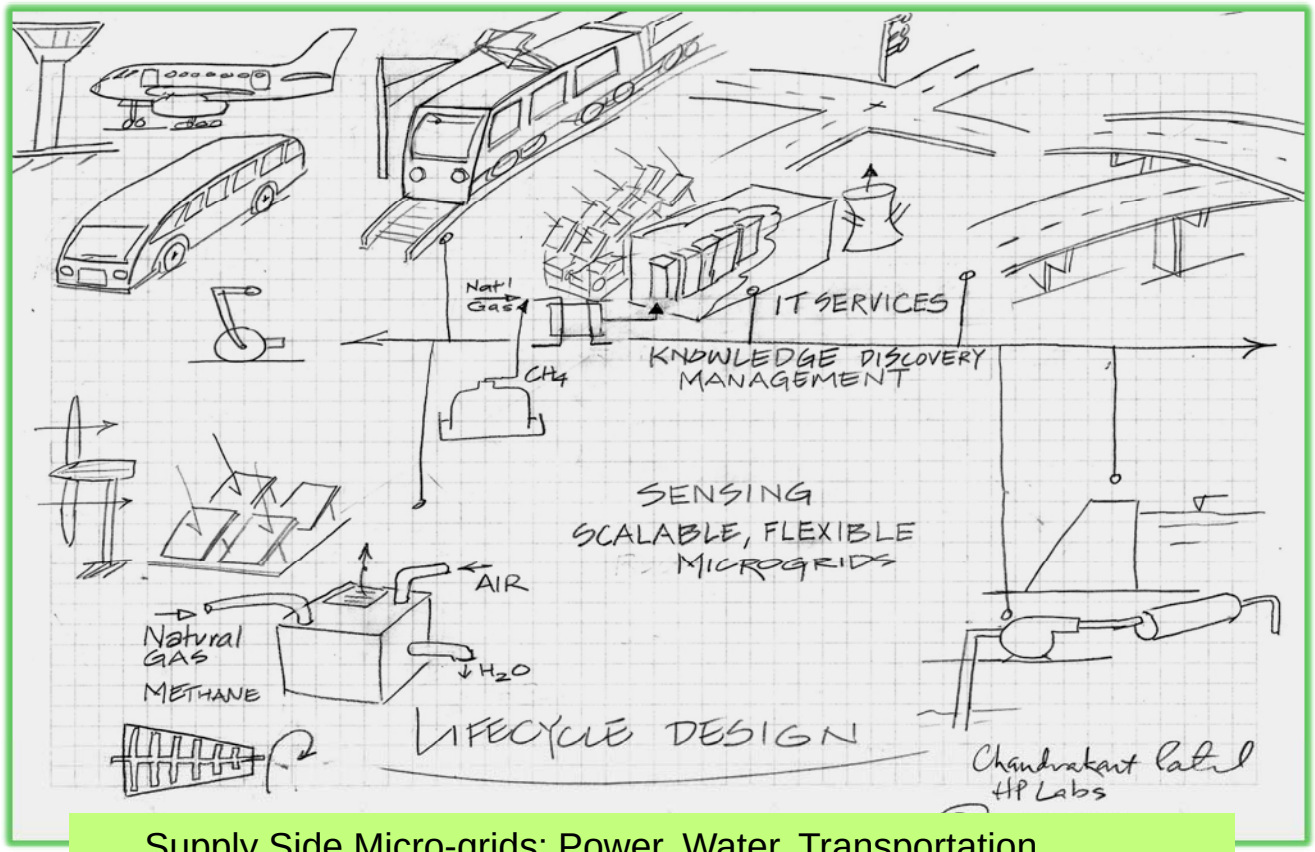
# City

supply-demand side management of resources




Supply Side Micro-grids: Power, Water, Transportation…….

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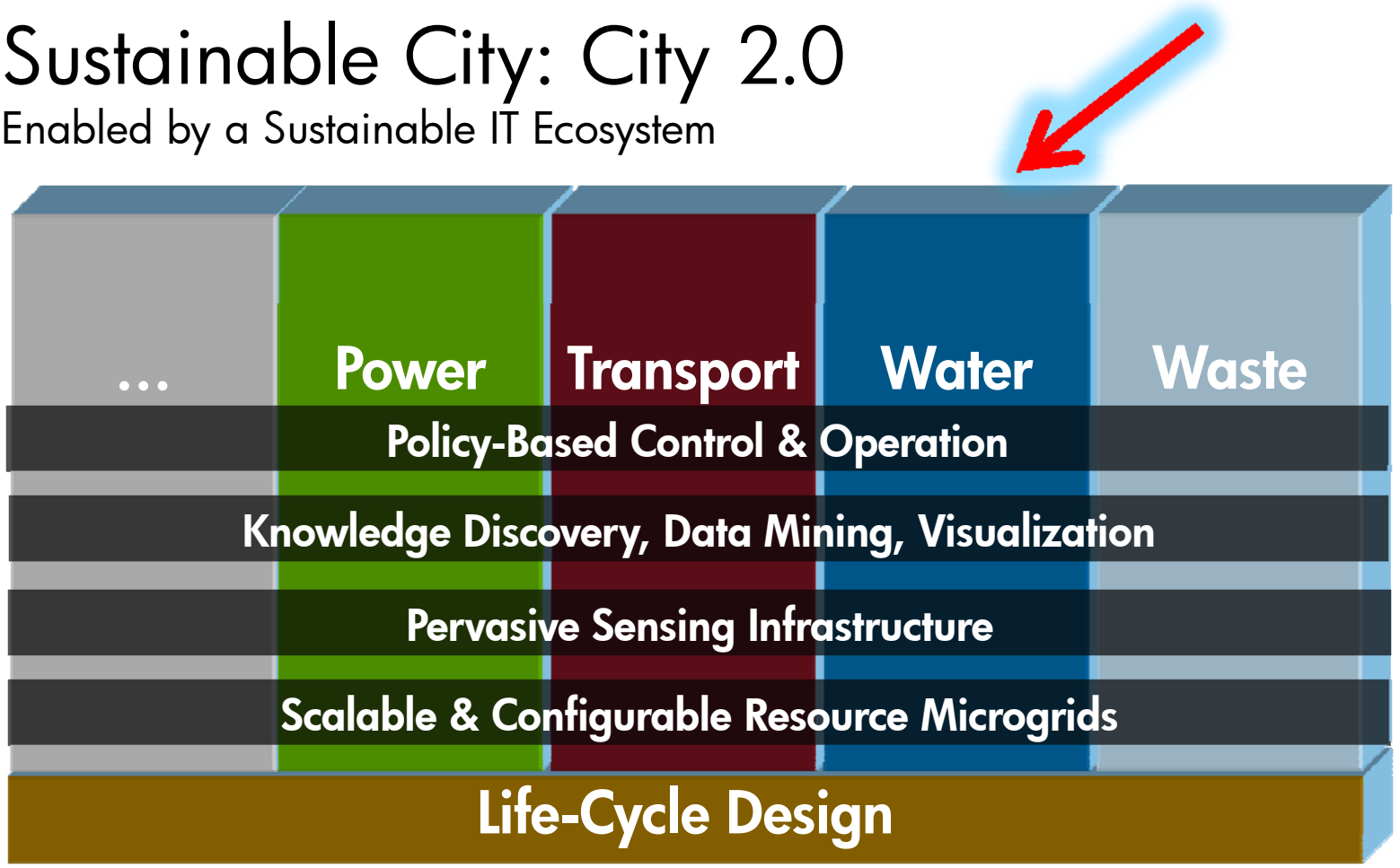
# Sustainable City: City 2.0

## Enabled by a Sustainable IT Ecosystem



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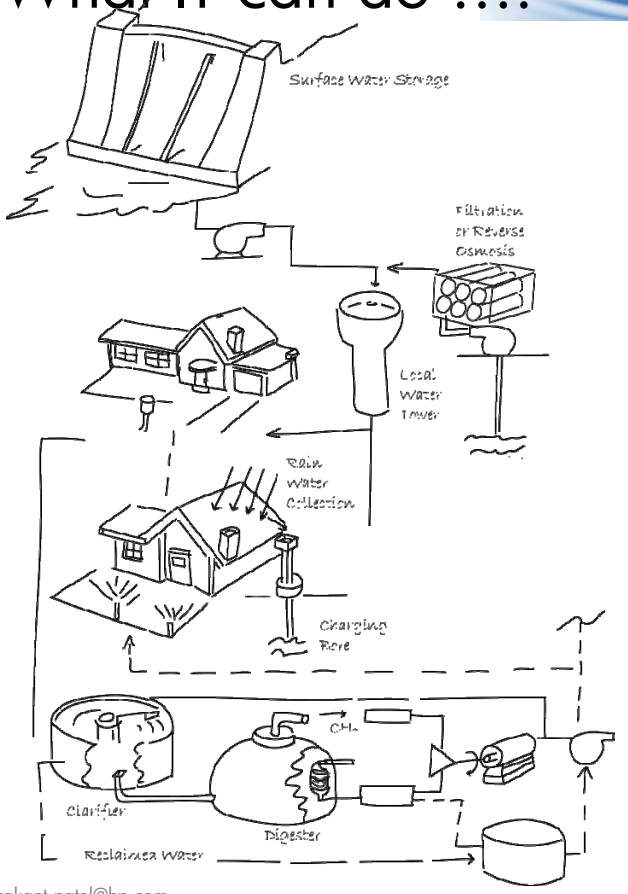
# IT in Water Management

## What IT can do ….

- Management of distribution system
  - Pressure management
  - Leak management
  - Flow management
- Management of energy/emission footprint
  - Energy consumption (Gas/Electric)
  - Emissions
- Management of supply reserves
  - Ground water monitoring
  - Reservoir level monitoring
  - Recharge and import/export
- Management of quality
  - Potable water
  - Industrial water
  - Reclaimed water



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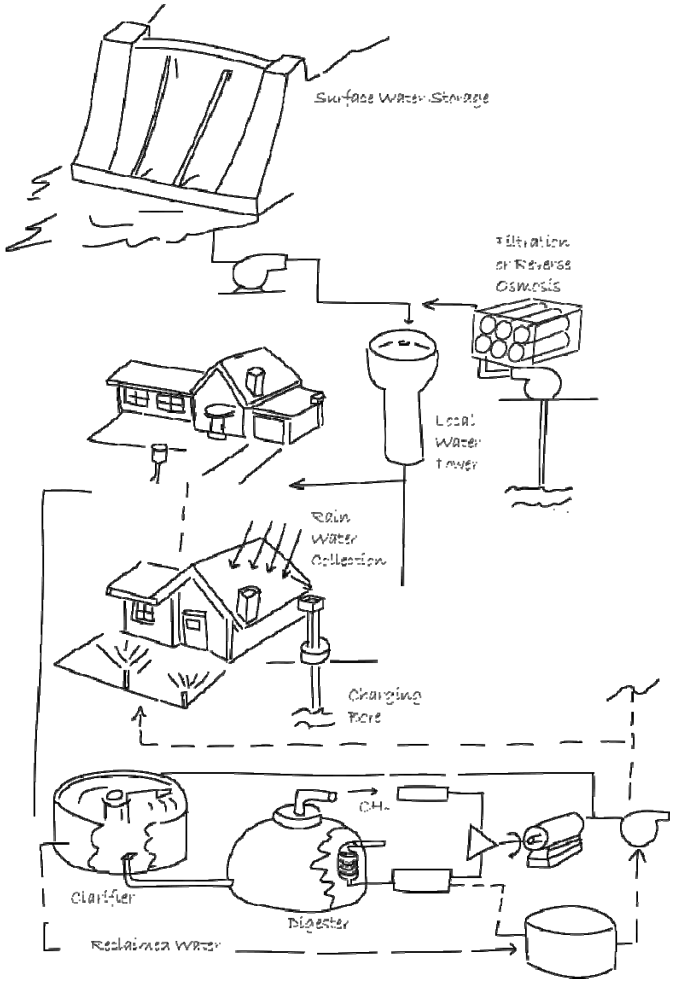


**Sensing**

## Policy Based Control

- Operating the at peak ensemble level performance to reduce energy consumption
- Coupled operation with waste water treatment plants

## 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




**Microgrid of Water**

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# Call to Action at World Engineering Education Forum 2010

To instantiate the Supply-Demand Framework for Sustainability

**Need to build the Human Capital**:

- Leverage the past, and return to "old school" core engineering, to build the foundational elements of the supply-demand architecture using lifecycle design and supply side design principles.
- Innovate a multi-disciplinary curriculum composed of various fields of engineering, e.g., fusion of computer science and mechanical engineering to scale the supply-demand side management of power, etc.
  - The curriculum also requires social and economic tracks as sustainability in its broadest definition is defined by economic, social and environmental spheres—the triple bottom line—and requires us to operate at the intersection of these spheres.



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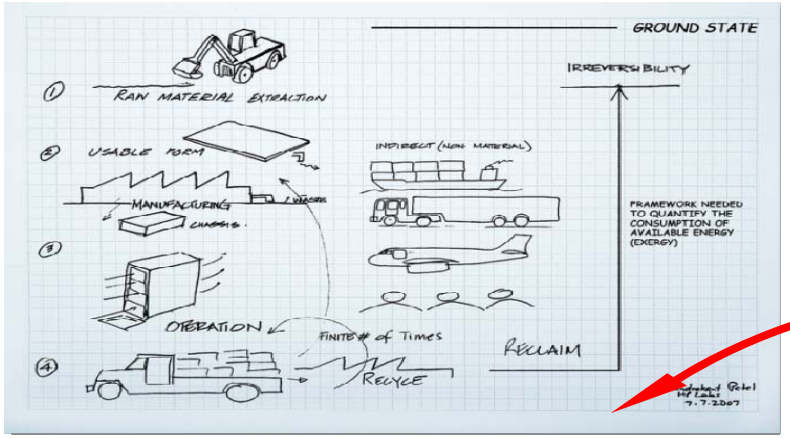
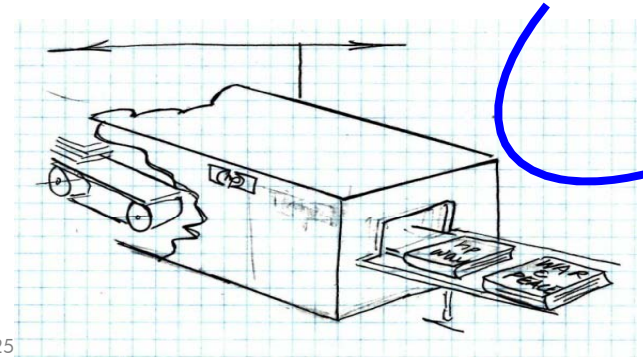
# Joules: Currency of the flat world

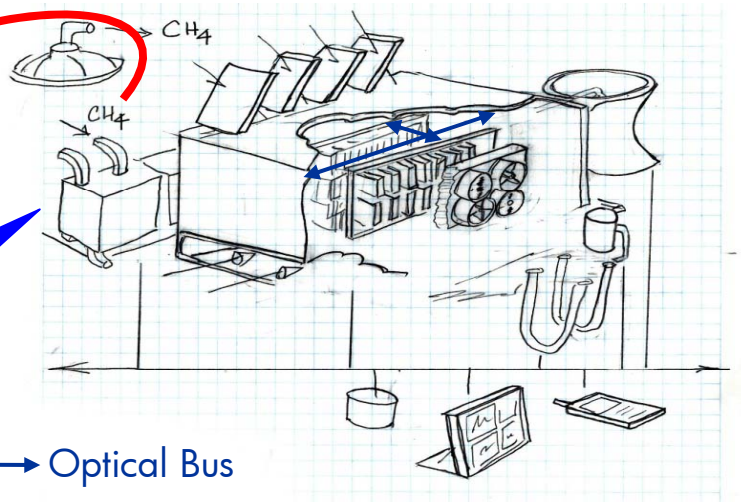
**Enabled by a Sustainable IT Ecosystem**

**in the cloud...**

**Joules of exergy destroyed per transaction?**






Optical Bus



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