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Green Storage I - Agenda

- Overview, Motivation, and Definitions
- eWaste Reduction/Recycling: RoHS, WEEE, etc.
- Fundamentals of Energy and Cooling
- Electricity Pricing in the United States
- Datacenter Design and Operation
- Storage Components and Technologies
Overview and Definitions

- ‘Green’ – What does it mean to the IT ‘ecosystem’?
  - Reduction of Total Impact on Environment
    - Systems approach - More than just Energy Use!
  - Defined by Gov’t. (EPA, EU, Kyoto), Orgs, Vendors, etc.

- How does “Green” differ from normal economic considerations, e.g. efficiency, optimization?
  - Rationalize decisions by including “externalities”
  - Widen scope of action across org boundaries, time

- ‘Green’ effects on Storage decisions
The Players in Green IT

- I.T. owners / Data Center operators (“Customers”)
- Energy Utilities and Regulators
- EPA Energy Star programs, Euro “Code of Conduct”
- SNIA – org expertise on enterprise STORAGE
- Green Grid metrics [www.thegreengrid.org](http://www.thegreengrid.org)
  - What amount of Energy (and Cooling) goes to do “useful IT work”? (The rest is “overhead”, from an IT viewpoint)
  - Overall Datacenter (short-term, tactical)
    - PUE (Power Usage Effectiveness) = (Total Facility Power/IT EquipPower)
    - DCiE (Datacenter Infrastructure Efficiency): DCiE = (1/PUE)
- Other interested parties (e.g. Uptime Institute)
Motivators: Why we act as we do

- **“Fear”**: Constraints (Physical limits, Regulations)
  - Physical Laws are not optional!
    - E.g. WAN latency (light-speed), Disk rotation speed, Tape Retrieval
  - Gov. Regulations: Do what you are forced to do

- **“Guilt”**: Competitive and ‘Moral’ aspects
  - Keeping up with industry, responding to non-economics
    - TBL (“Triple Bottom Line”); or “Social, Economic, Environmental”

- **“Greed”**: Profit Maximization / Cost Minimization
  - Strategy ➔ Capital Expenses (CapEx)
  - Tactics ➔ Operational Expenses (OpEx)
  - TCO (Total Cost of Ownership) integrates CapEx and OpEx
**Externalities**

**Problem:** important inputs or outputs (Green-house gases (GHG), ‘Carbon’) have unclear prices or owners

- Some factors are effectively Zero-cost to the decision-maker, but are **not** cost-free to larger group affected
- This leads to non-optimal decisions and behavior
  - ‘Tragedy of the commons’
  - Classic solutions: Government **mandates** (Regulation)
  - Separate accounting system, e.g. for Carbon “Footprint”
  - Unintended Consequences

**Pigouvian taxes:** “Sin Taxes” (modify behavior)

**Cap-and-Trade Carbon** (mod outcomes, e.g. SOx/NOx)

**Coase’s Theorem:** Property Rights, Negotiation
“Green” effects on Storage

“TCO” (Total Cost of Ownership) now combines with Externalities to affect purchase decisions
- In most cases Externalities will evolve to provide clear pricing signals (e.g. RoHS, WEEE, Cap-and-Trade)

Systems viewpoint (bigger picture) is essential!

Expand scope of decision-criteria and constraints to include (at least) entire datacenter (entire supply chain?)
- Servers, Networking, and Storage
- Power, energy, and cooling (CapEx and OpEx)
- People: widen their decision-boundaries, -constraints
  - Include your Facilities managers!

Unintended Consequences: reduced reliability?
Three Stages of Product Life-Cycle

- **Birth:** Product Creation (design for recycle/disposal)
  - Integrated into CapEx *(maybe)* – see WEEE/RoHS
    - Outsourced ‘embedded’ Carbon? – see Carnegie Institute
  - Facilities/Infrastructure (proportional to **POWER**)

- **Useful-Life:** **Energy,** Cooling, and “Other”
  Environmental Impacts during Productive Life
  - Storage: dominated by Energy/Cooling (Electricity)
    - Few consumable supplies, except Tape cartridges
  - Dominated by OpEx (but is this visible to IT?)

- **End-stage:** Removal, Recycling, Disposal
  - Integrated into initial CapEx or OpEx surcharges
  - **Alternative:** dump these costs onto everyone else…. 
**Power is NOT the same as Energy!**

<table>
<thead>
<tr>
<th>Item</th>
<th>Power</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>Watts, kW, MW</td>
<td>kiloWatt hours. kWh, MWh</td>
</tr>
<tr>
<td>Measurement</td>
<td>Instantaneous</td>
<td>Integrated over time</td>
</tr>
<tr>
<td>Physical evidence</td>
<td>Infrastructure, Equipment</td>
<td>Usage (Electricity, Cooling)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Examples</strong></td>
</tr>
<tr>
<td></td>
<td>UPS, PDU, CRAC, AHU, plus IT Gear: Servers, Storage, Networking,</td>
<td>Variable usage (‘consumption’) of electricity, water, fuel</td>
</tr>
<tr>
<td>Expense (Cost Accounting)</td>
<td>Capital (CapEx)</td>
<td>Operational (OpEx)</td>
</tr>
<tr>
<td>Internal Cost Recovery</td>
<td>Chargeback (Amortize)</td>
<td>Energy chargeback (variable)</td>
</tr>
<tr>
<td>External Cost Recovery</td>
<td>‘Demand’ Charges or Rent</td>
<td>Facilities chargeback (fixed)</td>
</tr>
<tr>
<td>Billing units</td>
<td>$/kW (peak 15-min. period)</td>
<td>$/kWh x Total usage</td>
</tr>
</tbody>
</table>

**Bottom-line:**
1. Power costs may over-whelm Energy Costs!
2. Big data centers charge-back on Power, Energy, or both.
How much is due to Storage? *(Proportion is increasing!)*
- It depends on Design and Workload (I/O profiles)!
- Published studies range from <10% - >40%
- “Rule-of-Thumb” for energy: 60% servers, 20% networking, and 20% **Storage** (but no consistent definition of ‘Storage’)

**Peak** loads required for design (~Max. Power)
- CapEx: Power (UPS, PDU)/Cooling (Fans, CRAC), Installation
  - Can overwhelm floor-space charges, even Energy Costs
  - Watch for “Demand” charges (e.g. Peak 15-min. of 3 Months!)

**Time-weighted** I/O for Energy/Cooling ~ OpEx

**TCO** = CapEx + OpEx, but which dominates?
Storage gets more (bad) visibility?

DCiE = (IT Energy Demand) / (Total Datacenter Energy Usage)

(DBiE currently ~50%)

Note: Percentages are for illustration only.
(So don’t quote them!)

Facilities Efficiencies will keep improving, so these ‘slices’ get smaller.
(DCiE approaches 80%)

Server percentage also declines, due to Consolidation and Virtualization.
What Affects Storage Energy Use?
Redundancy and RAID Definitions
### Storage Taxonomy Summary

<table>
<thead>
<tr>
<th>Storage Taxonomy Summary</th>
<th>Online Storage</th>
<th>Near Online Storage</th>
<th>Removable Media Libraries</th>
<th>Virtual Media Libraries</th>
<th>Infrastructure Appliances</th>
<th>Infrastructure Interconnect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Capacity Guidance</strong>&lt;br&gt;Storage which is designed primarily for home (consumer) or small office spaces&lt;br&gt;- Often Direct Connected ( Dort, etc.)&lt;br&gt;- No options for redundancy (with exception of STIF)&lt;br&gt;Group 1) Solo &amp; Consumer</td>
<td>Max Storage Devices</td>
<td>Max Storage Devices</td>
<td>Max Tape Drives</td>
<td>Devices which enable SA/N or other Storage&lt;br&gt;Internal data switching or scaling</td>
<td>Max Storage Devices Supported*</td>
<td>Max Port Count</td>
</tr>
</tbody>
</table>
| **Up to 4 Devices** | Stand Alone Drive (including)
| **More than 4 Devices** | Up to 4 Devices | Up to 4 Devices | Up to 32 |
| **Group 2) Entry / DAS, or JBOD**<br>Storage which is dedicated to one or at most a very limited number of servers. Often will not include any integrated controllers, but rely on a server host for that functionality<br>- Often Direct Connected ( Dort, etc.)<br>- May optionally offer limited number of redundancy features | Up to 100 Devices | More than 20 Devices | More than 4 Devices | More than 24 Devices | More than 100 Devices | Support for more than 20 Devices | Up to 128 |
| **Group 3) Entry / Midrange**<br>SA/N or NAS connected storage which places a higher emphasis on value than scalability and performance. This is often referred to as an 'Entry Level' storage<br>- Usually not connected (NPI, etc.)<br>- Has options for redundancy<br>- Has options for virtualization (i.e. STE) | More than 100 Devices | More than 100 Devices | More than 24 Devices | More than 100 Devices | Support for more than 20 Devices | More than 128 |
| **Group 4) Midrange / Enterprise**<br>SA/N or NAS connected storage which delivers a balance of performance and features. Often higher level of management as well as scalability and reliability capabilities<br>- Usually connected (NPI, etc.)<br>- Has options for virtualization (i.e. STE) | More than 1000 Devices | More than 11 Devices | More than 24 Devices | More than 100 Devices | Support for more than 100 Devices | More than 128 |
| **Group 5) Enterprise / Mainframe**<br>Storage which enables large scalability and extreme performance associated with Mainframe deployments, though not restricted to Mainframe only deployments<br>- Usually connected (NPI, etc.)<br>- Often capable of non-disruptive scalability | More than 1000 Devices | More than 11 Devices | More than 100 Devices | Support for more than 100 Devices | More than 128 |

See: Green Storage Power Measurement Specification for complete details
Need for redundancy

- RAID 10 – protect against multiple disk failures
- DR Mirror – protect against whole-site disasters
- Backups – protect against failures and unintentional deletions/changes
- Compliance archive – protect against heavy fines
- Test/dev copies – protect live data from mutilation by unbaked code
- Over provisioning – protect against volume out of space application crashes
- Snapshots – quicker and more efficient backups
- Energy consumption is roughly linear in the number of naïve (full) copies.
Effect of green technologies

- Green storage technologies use less raw capacity to store and use the same data set
- Energy consumption falls accordingly
What Storage aspects could be affected?

SNIA Shared Storage Model (and don’t forget Tape!)

- Application
- File/record layer
  - Database (dbms)
  - File system (FS)
- Storage domain
  - Block layer
    - Storage devices (disks, ...)
    - Host
    - Network
    - Block aggregation
    - Device

Services
- Discovery, monitoring
- Resource mgmt, configuration
- Security, billing
- Redundancy mgmt (backup, ...)
- High availability (fail-over, ...)
- Capacity planning
Green Storage - Agenda

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Government regulations ("Directives") that may affect storage vendors (and their customers).
- Useful site for US businesses: [www.buyusa.gov/europeanunion/commerce_docs.html](http://www.buyusa.gov/europeanunion/commerce_docs.html)

- WEEE
- RoHS, China-RoHS
- Packaging and Pkg Waste
- Halogens (in plastics)
- Basel Convention/Basel Ban (Transboundary Wastes)
WEEE:
Waste Electrical and Electronic Equipment

- European Community directive 2002/96/EC
  - Conformance from Aug-05
- Increase reuse, recycling, recovery
- Reduce landfill and incineration
- Financed by manufacturers and vendors
  - Users can return WEEE without charge
  - “Take It Back” programs
- Look for the “Wheelie-Bin” logo
  - Recycle, don’t dispose!
RoHS: Restriction of Hazardous Substances

- European Directive 2002/95/EC, effective Aug-06
- RoHS restricts the use of certain hazardous substances in various types of new electronic and electrical equipment. *(Note: at a component level!)*
  - Mercury - Cadmium - PBB
  - Chromium VI - Lead - PBDE

- Unintended Consequences: reduced reliability?
  - EPA report (Aug-05) on lead-free solder!
  - RoHS exemption: lead solder for Servers and Storage?
    - Due to a clear trade-off on reliability and performance
    - This exemption will go away with improved techniques
“China-RoHS”

  - SJ/T 11363-2006 Requirements for Concentration Limits for Certain Hazardous Substances in Electronic Information Products

- Similar restricted substances as RoHS
- Split timetable for labeling and conformance
- Different/Fewer(?) exemptions
- ➔ Ask an expert if you think you are affected!
United States
- Vendors have almost universally adopted RoHS since most do business in Europe
- EPA regulations and recommendations (e.g. Lead-free)
- Proposed federal legislation
- Several States have some regulations
  - California – “Electronic Waste Recycling”
- Many vendors will “take it back” or take trade-ins

Canada/Australia RoHS

Asia (Japan JGPSSI), Korea/Taiwan RoHS
European Commission Code of Conduct on Data Centres Energy Efficiency

EUROPEAN COMMISSION DIRECTORATE-GENERAL JRC JOINT RESEARCH CENTRE Institute for Energy Renewable Energies Unit

- Voluntary initiative
  - education and shared best practices
  - “agreed commitments” for participants
- SNIA-Europe is an Official Endorser.
green Storage - Agenda

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Energy and Cooling: Fundamentals

- Laws of Thermodynamics
- Power vs. Energy: Units of Measurement
- Heat Transfer
  - Conduction, Convection, Radiation
  - Data-center cooling: Air vs. Liquid
- Energy Conversion, Transmission, Storage
  - AC/DC and DC/AC conversion losses
  - Voltage step-down and step-up conversion losses
- Systems of Measurement: SI vs. US
Laws of Thermodynamics

- **First Law**: Energy cannot be created or destroyed, it only changes form.
- **Second Law**: Entropy increases in a closed system. Efficiency of energy conversion is <100%.
- **Alternate Formulations:**
  - You can't win, you can't even break even, and you can't get out of the game....
  - “Nullium Prandium Gratium” (or “TANSTAAFL”)
- **NO**: you cannot power your datacenter using the waste heat to generate electricity to run the site!
  - But you might increase DCiE with “free” cooling
Heat Transfer

Heat (Cooling):
- **Conduction:**
  - thermal glue/grease between CPU and cooling fins
- **Convection**
  - Cooling fluid circulated past hot components
  - Note: “fluid” could be air or liquid, but liquid has a lot more capacity to move heat
- **Radiation**

Phase Change: Solid-Liquid; Liquid-Gas

Newton’s Law of Cooling
- Rate varies with Temperature Difference
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Electricity prices are ~100x variable (at least at the wholesale level)

- **Electricity cannot be stored effectively!**
  - Few exceptions: Pumped Water Storage, Compressed Air
  - Batteries, Flywheels, etc. are short-duration, costly
- **Prices vary with DEMAND (local and regional)**
  - Weather (Hot, Cold, or Both), Supply disruptions
  - Time-dependent: Daily, Weekly, Seasonally
  - Economic conditions – general, regional
- **Prices vary with SUPPLY (local and regional)**
  - CapEx: plant construction (NIMBY), maintenance
  - OpEx: Fuel costs dominate – swings are wild (10^2)
- **Electric Transmission congestion/losses increase cost; hard to build new lines (NIMBY)**
Electric Power Generation

Total = 4,055 Billion kWh
Electric Utility Plants 63%
Independent Power Producers and Commercial Heat and Power Plants 37%

Data from U.S. Energy Information Administration - 2005
Calif. Generation; Transmission Interconnects

www.energy.ca.gov/maps/
### State Electricity Prices, 2005
(cents/kWh – “Industrial”)

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HI</td>
<td>15.79</td>
</tr>
<tr>
<td>2</td>
<td>DC</td>
<td>14.13</td>
</tr>
<tr>
<td>3</td>
<td>NH</td>
<td>11.48</td>
</tr>
<tr>
<td>4</td>
<td>RI</td>
<td>10.01</td>
</tr>
<tr>
<td>5</td>
<td>NJ</td>
<td>9.76</td>
</tr>
<tr>
<td>6</td>
<td>CA</td>
<td>9.55</td>
</tr>
<tr>
<td>7</td>
<td>CT</td>
<td>9.40</td>
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<td>AK</td>
<td>9.29</td>
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<tr>
<td>9</td>
<td>MA</td>
<td>9.22</td>
</tr>
<tr>
<td>10</td>
<td>NY</td>
<td>8.23</td>
</tr>
</tbody>
</table>

10 Most Expensive States

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>VA</td>
<td>4.46</td>
</tr>
<tr>
<td>43</td>
<td>NE</td>
<td>4.43</td>
</tr>
<tr>
<td>44</td>
<td>IN</td>
<td>4.42</td>
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<tr>
<td>45</td>
<td>ND</td>
<td>4.32</td>
</tr>
<tr>
<td>46</td>
<td>WA</td>
<td>4.27</td>
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<td>47</td>
<td>UT</td>
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<td>48</td>
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<td>ID</td>
<td>3.91</td>
</tr>
<tr>
<td>50</td>
<td>WV</td>
<td>3.85</td>
</tr>
<tr>
<td>51</td>
<td>KY</td>
<td>3.60</td>
</tr>
</tbody>
</table>

10 Least Expensive States

U.S. Average 5.73
Move datacenter to cheap energy?

Energy costs on the Columbia River are about $0.02/kWh for Datacenters.

Ample fiber (WAN) bandwidth is available (www.noanet.net)

The area is also seismically inactive and in a 500-year flood zone.

Result: Construction!
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Datacenter: Design and Operation

- CapEx and OpEx (IT gear: Servers, Storage, Networking, plus Infrastructure, e.g. UPS, PDU, CRAC, Fans)
- Multiplier effects on Power, Cooling, and Energy
- Trends in Conservation and Optimization

Size matters (for Power and Cooling equipment)!

- Undersized infrastructure means less density for IT gear
  - Modern IT gear is increasingly power-dense (>6 kW/rack)
    - May constrain current Storage equipment
  - Chargeback (‘rent’) by power, vs. by rack-space may be required
  - Some datacenters are limited by external Power availability

- Oversized (IT gear plus infrastructure) = excess CapEx
  - Under-utilization = Power inefficiencies (poor OpEx)
Who represents I.T. to the Facilities staff?

- Right now, the conversation is mostly about Servers!
- Try to find “Storage” mentioned in any recent article on power/cooling problems in the datacenter.….
- Try to find “Storage” mentioned in any Utility program.
- Can you show that Storage is significant to the power/cooling load (via modeling or measuring)?

Organizational differences (who owns what?)

- Do you talk with your Facilities managers?
- Do your decisions affect each other? (YES!)
- When will you start planning together?
Datacenter Options:
(Mech, Elec, Plumbing)

- Convert from AC to DC distribution
  - Can be partial conversion (DC arrays available)
- Run at higher voltage (240 or 480 vs. 120)
- Increase Power Supply efficiency (ask vendor)
  - 80 PLUS program ([www.80plus.org/servers.htm](http://www.80plus.org/servers.htm))
- Operate Cooling effectively
  - Leverage sensors, Follow basic rules (hot/cold aisles!)
  - Computational Fluid Dynamics (get some help!)
- Run Generator-testing for Peak-shaving
  - Negotiate with your power supplier for discounts!
Model or Measure: Which is Better?

- **Modeling: some info is required!**
  - Accurate manufacturer data by Component and Product (Frame)
  - Stand-by Power vs. “Idle” vs. Full-load – CRUD analysis
  - Knowledge of I/O workload
    - Well-known benchmark (e.g. SPC, SNIA-IOTTA) – vary replay
    - YOUR unique workload traces (time-weighted and Peak)

- **Measurement issues (Reality validates Modeling)**
  - Actual *in-situ* workloads ("normal" and Peak) – can use traces
  - Actual Energy usage from Power Meter
    - Watts or kWh (what you pay for!), not Amps
    - Must be adequate to fit your Storage device (>30 Amp?)
    - See your Facilities Mgr, or a consultant for help

- **SNIA Green Storage Technical Working Group projects**
REDUCE Performance when possible
- “Underclocking”: reducing performance-state of CPU reduces power/cooling needs for Servers
  - Out-of-band mgmt (BMC) = no OS tuning
  - Management via OS gives more granular control

CONSOLIDATE (Virtualize)

What are the equivalents for Storage?
- TAPE or Optical? (trade-off response time vs. energy usage)
- Solid State Storage: high IOPS, low/no power, expensive???
- Disk drives and RAID arrays
  - Slower/Larger drives where possible (Design choice vs. Dynamic)
  - Power-off or spin-down drives: MAID (Massive Array of Idle Disks)
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Each component of a Storage system has Power and Cooling requirements

- Understand “Idle” (*not* ‘stand-by’) vs. “Loaded” (R/W)
- Label ratings are usually peak power required
  - If you design using this data, your power/cooling equipment may be (grossly) over-built (Bad!), and CapEx will suffer.
  - Operating equipment below its rated temperature offers little (no?) benefits (except for Operators!)
- Some manufacturers offer better data or design info
- If you really want to know, you may have to instrument in order to get real measurements.
- Or, you could wait to see what SNIA comes out with…
Sample Idle Storage System Measure
Group 3 - Online Block Storage
Idle Phase of Idle Test Measurement

System under test is Online Block Storage Group 3
Notes:
- Graph is for a 24 hour measurement time period; graph does not include the pre-conditioning phase
- A profile of a graph for Group 2 Online Storage, e.g. 100% JBOD, would not have the energy related activity spikes for disk & system background diagnostics and data validation. This is one of the major differences between Online Storage Group 2 and 3 Systems - a procurement tradeoff for energy consumption versus system and data reliability.

Increased energy use for disk’s continuous background diagnostics, system housekeeping, and if needed incremental cooling.

Baseline energy use for disks spinning, controllers, power supplies, lowest level temperature management, etc.
Disk-specific Power/Cooling

- Operational envelope
  - No clear effects on MTBF or TCO of variation within design temperature range
  - Can temp bounds be expanded?
- Rotational speed of Disks
  - Buy slower disks, if you don’t mind the latency
  - Variable-speed disks?
- Use appropriate RAID levels
  - Disks may be ‘free’, but power/cooling are NOT!
- Max Disk Utilization (OpEx: per disk, not per GB)
What Affects Storage Energy Use?
RAID Definitions

Standalone
Cluster
Hot swap
RAID 0

RAID 1
RAID 5
RAID 0+1
RAID level vs. Power/Cooling

- RAID (*Redundant Array of Independent Disks*), a family of techniques for managing multiple disks to deliver desirable cost, data availability, and performance characteristics to host environments.
- Despite capacity cost reductions exceeding Moore’s Law, RAID is not ‘free’ – extra disks add CapEx and infrastructure costs.
- **plus OpEx for Energy/Cooling**
- Compare RAID levels against equivalent JBOD (“Just a Bunch of Disks” = Capacity only)
RAID level vs. Power/Cooling

- **JBOD:** Number of disks scales to data capacity
  - Cost of Power/Cooling = \(N \times \text{single disk cost}\)
- **RAID 0** = data striping, disks required = \(N\)
- **RAID 1** = mirroring, disks required = \(2 \times N\)
  - RAID 0+1 or RAID 1+0, power/cooling = \(2 \times N\)
- **RAID 5** = parity RAID, parity check data is distributed across the RAID array's disks.
  - disks required = \(N+1\)
- **RAID 6** = various methods to tolerate two concurrent disk failures; disks required = \(N+2\)
Key Strategies: Energy/Cooling

- Understand Usage vs. Demand and Other charges!
- Are you sure that Storage is a significant contributor?
- **Increase Utilization** (Storage Resource Mgmt helps)
  - Thin Provisioning, Dynamic LUN Grow/Shrink
- Consolidate (possibly change storage architecture)
- Trade Response Time (Latency+Throughput) for Reduced Power. i.e. Use Lower-tier Disk, VTL, Nearline, MAID, or Off-line Tape of Optical
- **Move**: when energy/cooling costs or availability dominate TCO, you might consider moving to cheap energy/cooling with adequate WAN bandwidth
  - Columbia River, West Texas, Canada datacenters?
Increase ‘effective’ Data Density

- Metric: kW/GB vs. kW/disk – Which is correct?
- Store less stuff; delete when approved: Classify ➔ ILM, HSM
- Location: Tiered Storage (SSD, SAS/FC, SATA. Tape, Optical)
- Increase effective Data Density on Disks (or Tape)
  - File de-duplication (Single-instance)
  - De-duplication (Factoring, Common Blocks)
  - Lossless Compression

- Trade-offs on Reliability, Performance
  - Single-copy of data?! (RPO, RTO)
  - Unpack/Inflate penalty may be incurred
  - Hotspots? – spread data across disks
Are savings multiplicative?

♦ Sometimes yes
  ✦ RAID 6 + writeable clone
    › Assume 1000GB writeable clone = **2000GB** needed for a raw writeable copy on RAID 1 storage
    › 90% writeable clone savings takes us to 200GB
    › 35% RAID 6 savings takes us from there to **130GB**
    › **130GB** needed for a writeable clone on RAID 6

♦ Sometimes no
  ✦ Thin provisioning + resizeable volumes
    › Similar effects, but you only get the savings once

♦ Sometimes maybe
  ✦ Snapshot + deduplication
    › Can’t dedup readonly snapshots
    › Snapshots are a form of deduplication, so there’s less to dedup
    › OTOH, already deduped data can be snapshotted efficiently
## Savings multiply in combinations with checkboxes

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<th>C</th>
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<th>VC</th>
<th>TP</th>
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E.g. Thin provisioning with snapshots, RAID 6, and Dedup – big win!

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Equipment power savings

- **Server virtualization**
  - up to 80% savings
  - much depends on load

- **Power supply efficiencies**
  - 10 – 20%
  - difficult to do anything about this in a vacuum
  - probably okay to just ride industry trends

- **Variable speed fans**
  - up to 80% savings
  - power consumption cubic in rotational speed
  - interesting interaction with data center cold aisle temperatures
Facilities savings

⦿ State of the art data centers
  - PUE* drops from 2.25 to 1.25 = 45% savings
    - 10MW → 5.5MW
    - $6.0M → $3.3M annually
  - Rebates in the $M from utilities on top of savings

* Power Utilization Efficiency – see www.thegreengrid.org/gg_content
Final point - continued monitoring

- Essential to continued success
- Adjust-and-rebalance scenarios
  - E.g. economizer optimization
- Overall system health
  - SLA verification etc.
Please send any questions or comments on this presentation to trackgreenstorage@snia.org

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