Power/Energy & Sustainability: Vision & Future Capability Requirements

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June 16th, 2009

Background

- Energy as combat supply has always been critical

Sustainability of Power as a Combat supply

Harvesting

Power Management

Usability
User Acceptance

Autonomy

Sustainability

Bandwidth

Cost

BATTERIES NOT INCLUDED !!!

Power

Transmission
Distribution

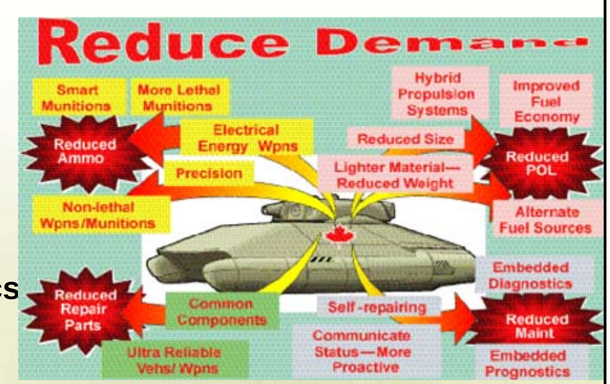
Weight & Size

Environment
Sustainable Development

Time on Station

What is Sustainabilty?

- **AoT definition, what is included:**
- **Energy/Power**
- **Food**
- **Water**
- **Clothing**
- **Ammunition**
- **Medical Support**
- **Load Carriage**
- **Focused Logistics**
- **Etc…**



Power/Energy Scope

- **Power Source**
- **Power Distribution**
  - Connectors,
- **Power Management**
- **Power Consumption**
- **Energy harvesting/scavenging**

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Current Reality

- The CF rifleman's equipment today typically requires the following batteries:
  - **Primary (non-rechargeable) batteries: 13 x AA-size (alkaline), 2 x CR123, (2/3A-size, Li/MnO_2)**
  - **Rechargeable: 1 x BB-521 (nickel-cadmium)**
  - **And the soldier carries twice that number of batteries as a daily resupply. The spare batteries means an extra weight of 0.71 Kg.**
- One Day's Supply

Drivers

- Safety
- Energy Density, Power Density
- Wide Temperature Performance
- Wearability
- Voltage, Rate
- etc..

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One key driver - Affordability

Estimated cost of AA alkaline batteries in the field in Afghanistan is:

$28 / pack of 4 x AA-size

Cost / kWh is $28 / (10 Ah x 1.5V / 1000)

= about $1,860 / kWh (only ~$0.20 in the home)

Every Watt counts:

using 1 Watt continuously costs about:

$45.00 / day

Or

$16,300 / year

This is not the ideal approach for soldier power because 1/3 to 1/2 the energy is usually 'thrown away' prior to a new mission, when a fresh battery is put in equipment.

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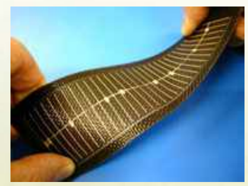
Future Energy Solutions

- Several candidates are possible
  - **Fuel cells**
  - **Batteries**
  - **Thermoelectric generators**
  - **Energy harvesting**
    - Planned
    - Scavenging



Human power

Self Winding Watch: 5 mW

MIT Shoe: 250 mW

SRI Shoe
400 mW

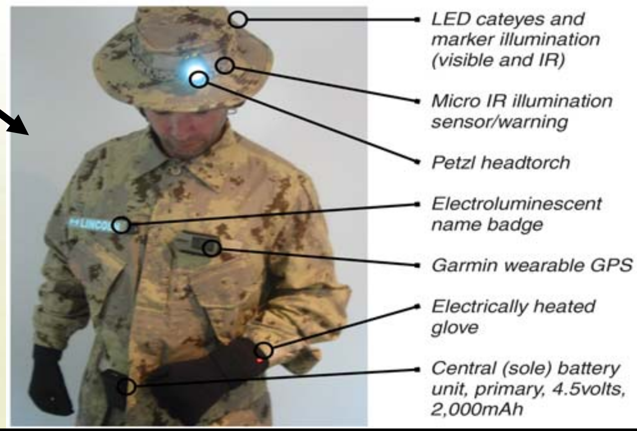
Penn Backpack: 5 W

Requires 38 kg obligatory load

Knee brace
"Bionic Energy Harvester"
Weight: 950 grams
Walking:
5W per device, selectively engaged
10 W per device always engaged

E-textiles

E-textiles are here for Power/Data Transmission

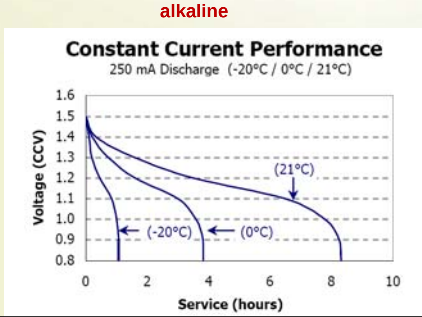


Current Batteries – Variable Performance

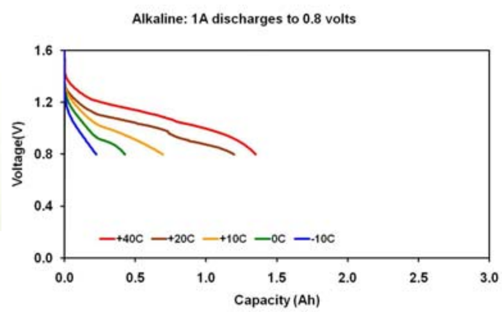
1A discharging to a 0.8V cut-off.

- **Capacity is temperature dependant.**

alkaline



alkaline



Canada's North Efforts: a new challenge for power!

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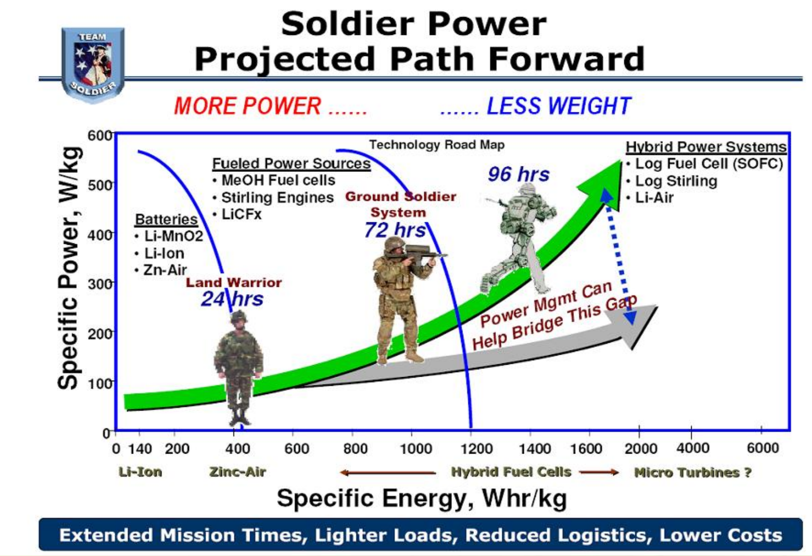
US Forecast Power Expenditure



PEO Soldier US Army, Soldier Technology 2006, London, U.K. June 2006

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Goal

- ENERGY **is Fundamental to the Soldier**
- EVERYTHING A SOLDIER CARRIES has an impact on energy consumption/sustainability of soldier
- ENERGY IS EXPENSIVE and a logistic burden
- POWER DEMAND MUST BE KEPT ACCEPTABLE – Thus each component of the soldier system is a trade-off with energy consumption.

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Energy & Power Challenges

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Worth Remembering

- Energy thus power is needed everywhere
- Soldier Systems are inherently a distributed system,
- Soldier Systems have finite energy storage capability,
- Soldier System are constrained by weight,
- Energy = weight, therefore
  - Waste energy = unnecessary weight,
  - Saving energy = saving weight
- Energy (available) = Operational time
- To conserve energy, we need to limit the consumption (power),
- Energy
  - What you store
- Power
  - What you consume by time unit

- Power = Energy ÷ time (P = E/t)
- Power = Voltage x Current (P = EI)
- Dissipated Power = Current ^{2} X Resistance ($P_d = I^2R$)

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The multidimensionality of Energy & Power

- **User Acceptance**
- **Weight**
  - Energy density
- **Bulk/Volume/Space**
  - Packaging
  - Storage
- **Cost**
- **Logistic**
  - Generation
  - Transport
  - Distribution
- **Operational time**
  - Environmental performances
- **Safety**
  - Human
  - Environmental impact

- **Generation**
  - Conventional
    - Oil
    - Hydro
    - Coal
    - Natural gas
    - Nuclear
  - Alternate sources
    - Harvesting
      - Solar
      - Wind
      - Hydric
      - Thermal
    - Scavenging (opportunistic)
      - Sound
      - Vibration
      - Movement
      - Heat
  - Storage
    - Solid (e.g. Ceramic)
    - Liquid (e.g. Methanol)
    - Semi Liquid (e.g. Batteries, hyper capacitors)
    - Gas (e.g. Butane)

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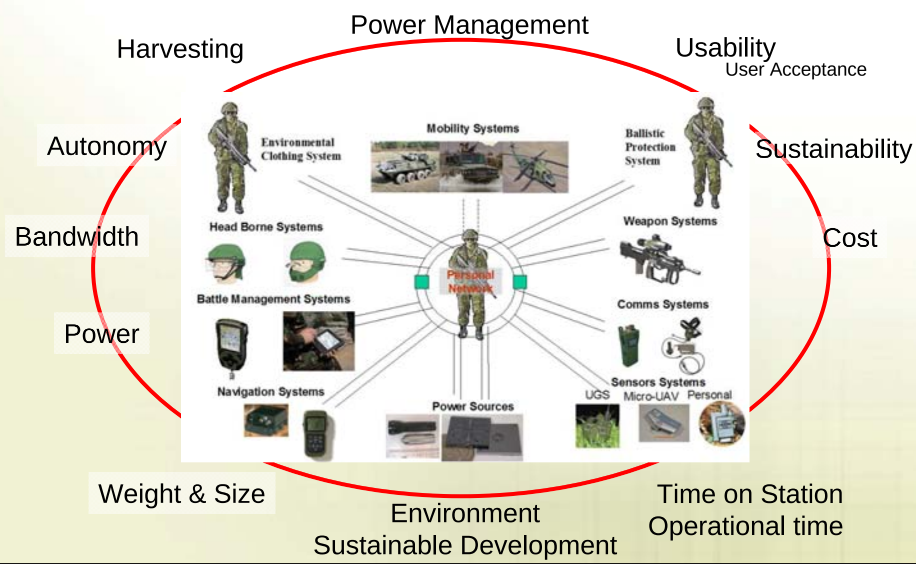
The multidimensionality of Energy & Power



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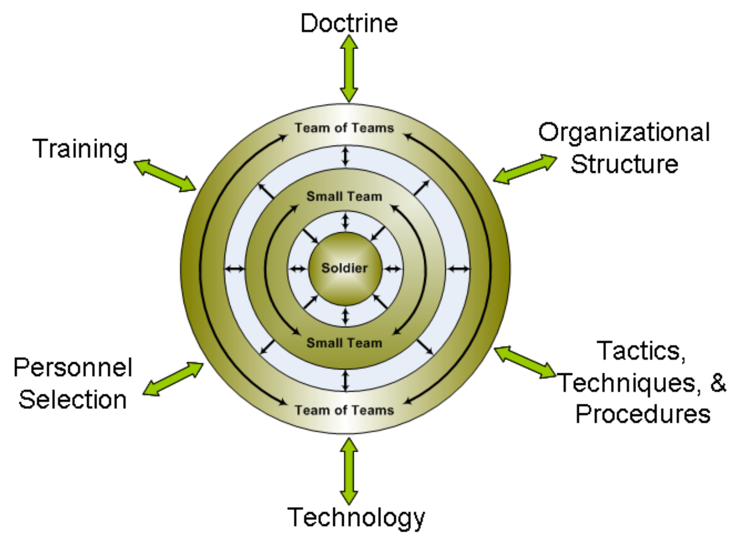
The multidimensionality of Soldier System



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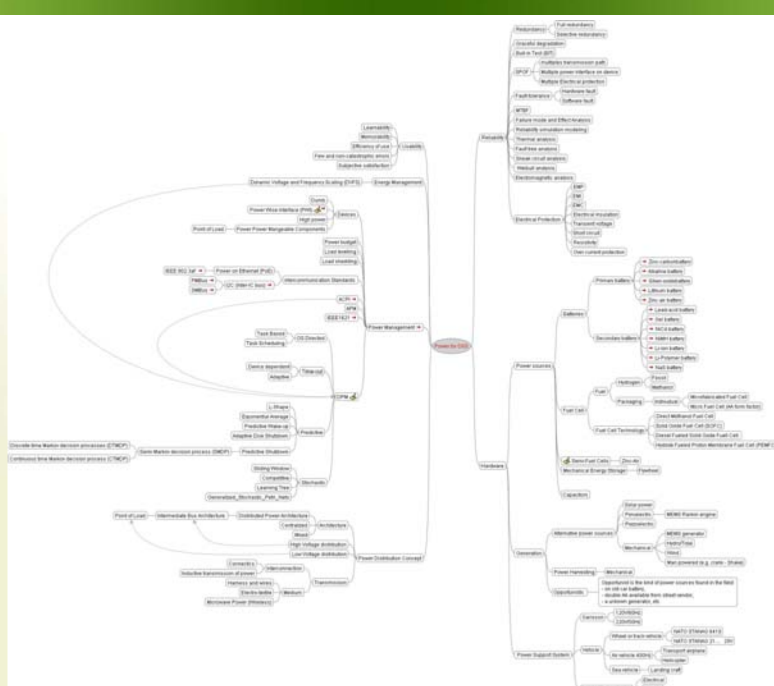

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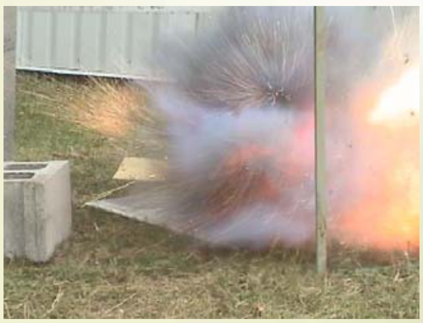
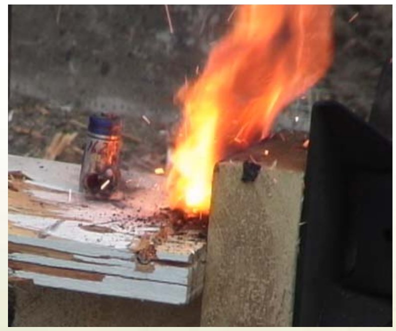
Safety is essential

- The Energy density of batteries is reaching the level of TNT
- Safety of users is a concern



Battery safety testing bullet penetration of AA-size LiFeS2 cells



Can we avoid this danger?
Can it be minimised?

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No Magic bullet

- **The sum of minuscule energy saving:**
  - At the component levels
    - Chips
    - Devices
  - At the Software level (Application, middleware and Operating system)
  - At the storage level (minimum resistance)
  - Harvesting what is available
  - Scavenging what is available
  - Logistics (e.g. transport to site)
- **The sum of minuscule energy generation:**
  - From walking up to thermal energy
- **The whole is bigger then the sum of its parts in the framework of a sub-10 Watts soldier system.**

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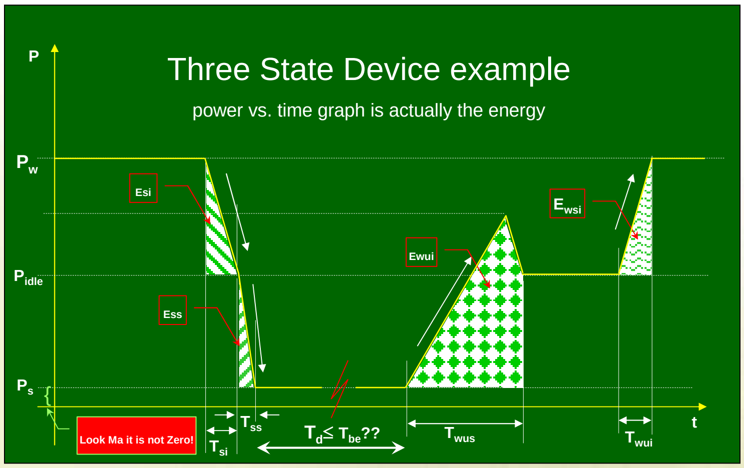
Energy Management

Known energy cost of operation



The sum of minuscule energy saving

- **Known cost of operation:**
  - T_{be}: Break-even Time
  - T_{si}: Idle state delay
  - T_{ss}: Sleep state delay
  - T_{wui}: Wakeup delay from idle state
  - T_{wus}: Wakeup delay from sleep state
  - E_{si}: Energy to idle state (shutdown)
  - E_{ss}: Energy to sleep state (shutdown)
  - E_{wui}: Energy to idle state (wakeup)
  - E_{ws}: Energy to wake up (wakeup)
  - P_{idle}: Power in idle state
  - P_s: Power in sleeping state
  - P_w: Power in working state

The minimum length of an idle period to save energy is called the break-even time (T_{be}).

L. Benini et al., "A Survey of Design Techniques for System-Level Dynamic Power Management," *IEEE Trans. VLSI Systems*, vol. 8, no. 3, June 2000.

Energy generation

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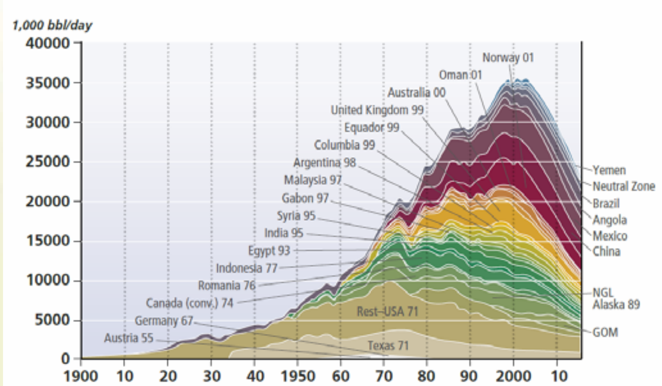
Finite Resource

Figure 3: Hubbert's Curve for Non-OPEC Countries

Source: IHS 2003, BP State Rev 2004; 2004: LBST estimate on Jan–Aug data
Analyses and Forecast LBST



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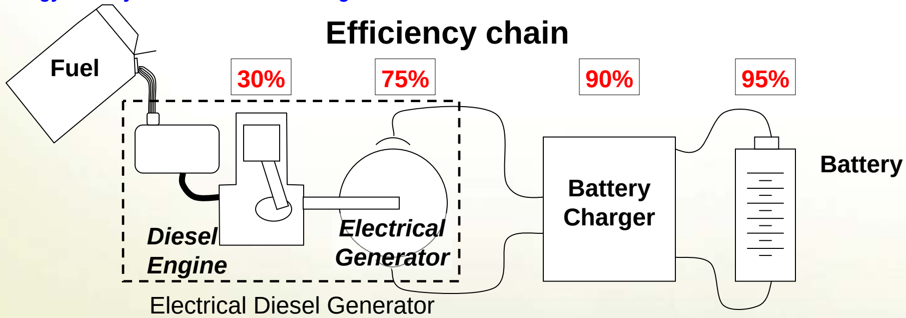
Efficiency is key

Energy Density of Diesel ≈12 700 Wh/kg



From Transportable to Portable

From Chemical →
To Mechanical →
To Electrical →
To Chemical →
To usable Electrical Energy

$\eta tot = \eta bat \times \eta chgr \times \eta gen \times \eta mot$

$\eta tot = 0.95 \times 0.9 \times 0.75 \times 0.3 = 0.192 \approx \underline{20\%}$

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Architecture matters

- **Data need to be generated and transported**
  - Needs Energy
- ***Might as well kill two birds with one stone:***
  - Transport data with energy on the same medium
- **Need to avoid the Christmas tree approach to common in DSS.**
  - The soldier need to have an embedded infrastructure usable and versatile
  - Have an infrastructure that provide for a graceful degradation of performance, using redundancy and common connection points
  - Transport Energy efficiently
    - Remember : $P = E \times I$ versus $P_d = I^2 \times R$

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Architecture matters

- **Which Architecture is best suited?**
  - Entirely distributed (AA conundrum),
  - Centralised,
  - Mixed
- **The most common connector?**
  - The Ethernet connector
- **Typical example: PoE (Power over Ethernet)**
  - 4 or 8 conductors
  - 15 W to 50 W
  - Power and Data at speed up to 1Gb/s

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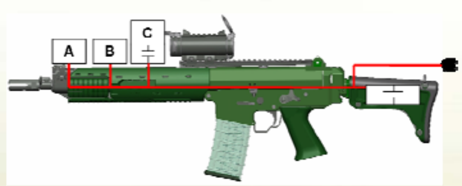
Architecture matters

A convincing example:

- **NATO through a study group has design an architecture for the distribution of Power and Data for small combat weapons**



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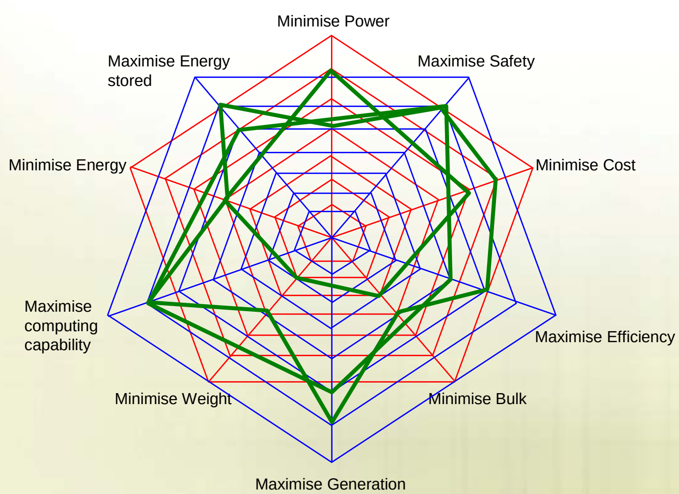
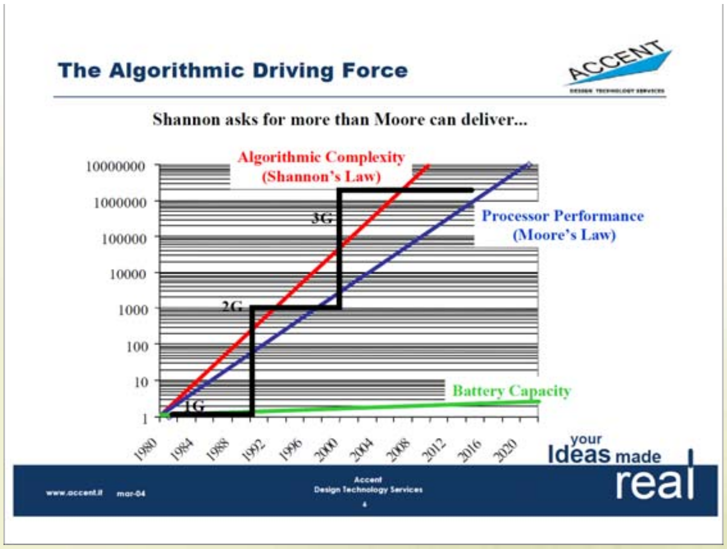
Techniques to minimize Energy demand

- **Power awareness**
  - **Power aware Software**
    - Aware of the power management functions
    - Energy Cost Driven Code Generation that use efficient code to minimize energy usage (power)
  - **Power aware Hardware**
    - Design from the start to minimize energy consumption
      - With know parameters Power aware components are power manageable components in that they support different states (e.g. Run, Idle, Sleep) and are controllable by the OS, the applications (service requester), the user. The number of states depends on the device.
  - **Dynamic Power Management**
    - ON/Sleep/Off
  - **Dynamic Energy Management**
    - Dynamic Voltage and Frequency Scaling (DVFS)

Optimizing is complex



The Growth of complexity



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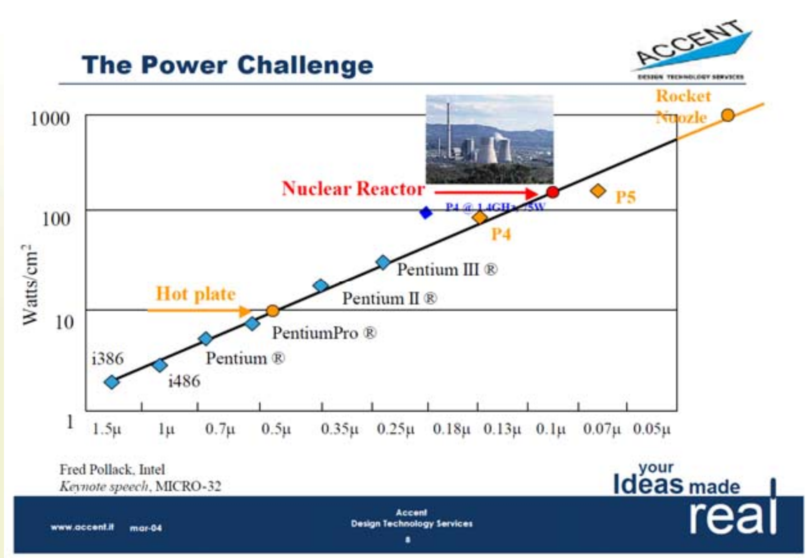
The Growth of Energy Density



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Can it be sustain?

Estimated Power Requirements

Capability	Peak (Watts)	Time Average (Watts)
Physiological Status Monitoring	2	1
Intra-Squad Communication	4	3
Land Warrior Leader 0.6	na	23
Land Warrior Leader 1.0	39	19
Micro Climate Conditioning (Chem/Bio Mission)	>150	>75
Exoskeleton (Load assist, P >> maneuver)	4000	750

Proposed capabilities require large amounts of power

SUMMER STUDY 2001

"THE OBJECTIVE FORCE SOLDIER / SOLDIER TEAM", ARMY SCIENCE BOARD
FY2001 SUMMER STUDY, FINAL REPORT, November 2001, VOLUME II THE SCIENCE AND TECHNOLOGY CHALLENGES
DEPARTMENT OF THE ARMY, ASSISTANT SECRETARY OF THE ARMY, (ACQUISITION, LOGISTICS AND TECHNOLOGY), WASHINGTON, D.C. 20310-0103

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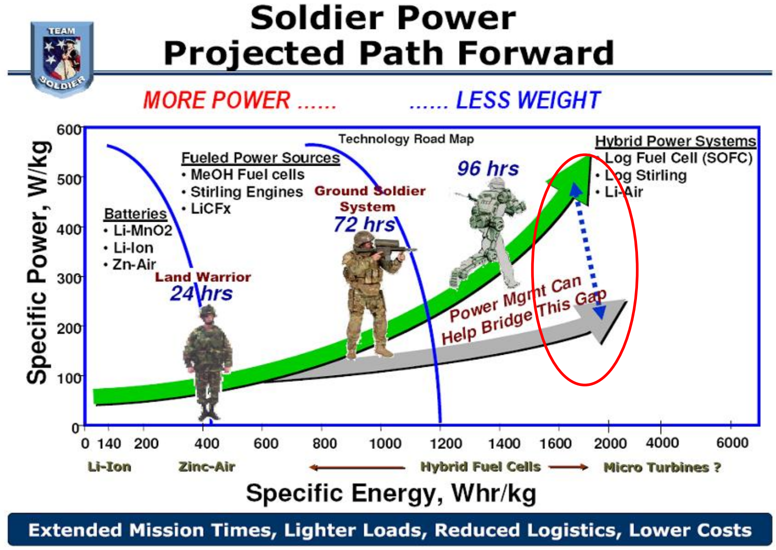
US Forecast Power management



PEO Soldier US Army, Soldier Technology 2006, London, U.K. June 2006

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Key challenges

- **Energy and Power central from the start of design**
- **Minimizing energy demand**
- **Managing peak power**
- **Each part of the system could be as much a frugal consumer or potentially a producer,**
- **Focus Logistics:**
  - Generation,
  - Transport,
  - Distribution.

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Power/Energy & Sustainability Future Workshop

- **Tuesday, September 22nd and Wednesday September 23rd 2009**
- **Vancouver, BC**

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Optimizing is the Key

- **Power-aware design does not necessarily imply minimization of power or energy.**
- **Decreasing average power does not imply decreasing maximum power.**
- **Power and energy efficiency are separate design goals.**
- **Power-constrained applications are distinct from energy-constrained ones.**
- **Energy-constrained systems do not always target energy minimization.**

SOURCE:

System-Level Power-Aware Design Techniques in Real- Time Systems Osman S. Unsal, Member, IEEE, and Israel Koren, Fellow, IEEE

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Efficiency is key

- Out in space the average power density is 1,360 W/m^2
- On average solar energy at the Earth surface 163 W/m^2
- the efficiency of future commercial modules in non-concentrated sunlight remain below ≅ 20%

- 20% of 163 $W/m^2 \cong 33\ W/m^2$

- In $cm^2 \cong$?

http://earthobservatory.nasa.gov/Features/EnergyBalance/page2.php