Semiconductors and the Hunt for Sustainable Energy
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Abstract: The ever-giving sun sends the earth nearly 10,000 times the power humans currently use. How we divert and use this power with minimal disturbance to the earth's ecosystem is a complex challenge. Technologies based on semiconductors contribute to solutions in three ways: 1) Convert solar energy to electrical and chemical energy; 2) provide intelligence to use energy efficient technologies; 3) provide guidance to make our journeys coherent thus greatly reducing the loss of usable energy.

Challenges Still Unmet: Sensors and Sources
March 16, 2012

Age of Mindfulness: Technology as Guide and Mentor?
April 6, 2012

The Series will also be available for viewing on YouTube at:
http://www.youtube.com/user/EECSatUM

Engineers/Humanists/Entrepreneurs ... all Welcome!
Semiconductors and the Hunt for Renewable energy

Energy like wealth can allow us to take life journeys ➔
Travel, Make our homes comfortable, Nourish ourselves
…. Make our dreams come true!
Energy: Allows Us To Make a Change And Take Life-Journeys

Like “Breath and Food” energy is needed to live.

Coal  Gas  Bio-fuels  Nuclear  Photovoltaics  Wind
... are all tied intimately to the quality of life.

Mobility

Healthy living

Nourishment
Energy and Quality of Life

- Education opportunities
- Meaningful employment
- Healthcare
- Mobility beyond a few miles
UN Human Development Index

Life expectancy: ~84 years for a high HDI

Education: ~16 years of schooling

Living standard: GNI~$50,000

Is UN-HDI outmoded?
When the next 5 billion join?
Close Connection Between Energy and GDP

USA in 2007:

Energy expense: $1.233 Trillion
GDP: $14.062 Trillion

10 gallons of fuel (equivalent) per person per day
Journeys: Fruit, Fuel and Residue

Every journey needs FUEL: provides us FRUIT but also leaves a RESIDUE.

Maximize the fruit ✔

Minimize the cost of the fuel ✔

Minimize the residue ✔

Residue can be personal, local or global

Fruit!

Fuel

Residue
Finding energy can lead to residues that can be quite expensive to mitigate.
Journeys: Residue and its Removal

Every journey leaves a RESIDUE.

Residue removal can sometimes consume more fuel than the journey itself.

How can one minimize the needed fuel and the residue created?

WHAT IS THE JOURNEY FOR?
Energy is closely coupled with the good life. Energy can allow you to ski in the desert.

Some journeys are more expensive than others! Fruit versus cost is important.
Choosing Journeys: Good Life Layers

✧ Physical Wellness: nutrition/shelter/health

✧ Creativity: New options, beauty, art, technology…

✧ Multi-dimensional role in society; balance in life

✧ Love: Have positive connections to others

✧ Express yourself: Harmony between thought and speech

✧ Self-Reflection and understanding of self

✧ Feeling part of the universe
In 2008 the number of people suffering from diseases related to over-consumption of food exceeded the number suffering from under-consumption of food.

Both under-consumption and over-consumption create poor quality life.
Journeys With Maximum Fruit, Minimal Energy and Residue: A Car Journey as a Metaphor

Select your journey

Joys of the open road, friends and family

Cost of gasoline

Minimize The Residue!
Optimum Journeys: A Car Journey as a Metaphor

踦 Rules of the road: Minimize fines and penalties
踦 Road Infrastructure: Potholes!
踦 Response to stress: Road rage, wrong exits, panic!
踦 Fuel for the journey: Right type of gasoline
踦 Awareness of my strengths: Brakes, transmission, …
踦 Awareness of the road: Other cars, pedestrians, potholes, …
踦 Mindfulness: Map, GPS, speed limits, correct exits
踦 Release the residue of journey: No “road rage”, frustration
Sun’s Gift: Hydrogen to Helium

Nearly 4.2 billion kilograms of mass converted to energy per second!
Sun’s Gift: Lots of power!

Solar power in all directions $3.8 \times 10^{26}$ Watts

Solar power coming to the earth $10^{17}$ Watts

Solar power received on US $10^{15}$ Watts

Solar power per square meter on earth 1000 Watts
2000 (kilo) calories diet: 100 Watts

US power consumption: $4 \times 10^{12}$ Watts
Newton’s Law: Rate of Change of Momentum is Force

Energy is needed to create the force that moves us and attempts to fulfill our desires.

While Physics ensures that energy is conserved in real life journeys “usable energy” is not conserved.

We know from experience energy is lost. The gas in our car slowly disappears. We eat and get hungry again.

Energy is a scalar; journeys are directional. Nature is UNBIASED ➔ usable energy loss.
Cost of Journeys: Thermodynamic Lessons

Conservation Law: Energy is conserved in all processes …
But the usable energy decreases with time.

Reversible paths: A to B
No “usable” energy lost,
no increase in disorder.

Efficiency: $1 - \frac{T_C}{T_H}$

Nicolas Sadi Carnot
Burning something to get mechanical (motion) energy is very inefficient.

Most of our electricity is created by burning fuels to drive turbines and efficiencies are about 40%.
Cost of Journeys: Forks in the Road

Usable Energy versus Total Energy

Degeneracy in the path: Equivalent paths

Energy “oozes” out to unwanted paths making the usable energy decrease

Some loss is controlled by thermodynamics but a lot is in our control.
Mindfulness and Technologies to minimize undesirable choices

✔✔ Jasprit singh
Estimated U.S. Energy Use in 2009: ~94.6 Quads

Source: LLNL, 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-renewable resources (i.e., hydro, wind, and solar) in MU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL–NI–410527
Energy Consumption in a US Home

Home: 130 gigajoules per year : 4-5 kW
Family transport: 100 gigajoules per year
Energy consumed in food per capita (4000 calories: 6 GJ)
Energy consumed in obtaining the food: (beef 50:1; chicken, grains 4:1): 60 GJ

All energy consumption: per capita per year 300 gigajoules
Energy and Good Life

Opportunities

Renewable sources are only 8.3%

Nearly 60% of energy is lost due to inefficiency in technology or nature of energy source

Residue from energy use is high.
Semiconductors
What do they offer?

- **Energy conversion**: Photons to electrons-holes
  SOLAR CELLS;
  ARTIFICIAL PHOTOSYNTHESIS for fuels

- **Energy efficiency**: Solid state lighting

- **Energy efficiency in delivery**: SMART GRID, EV

- **Energy monitoring systems**: Home, Car, Health,… workplace.

- **Coherent paths**: Minimal dissipation
  GPS, MINDFUL SENSORS

Silicon
GaAs
GaAs
InN
CdS, CdSe …

Jaaprit singh
Semiconductors: Energy Sources

Energy conversion: photons to electrons and holes

✧ Electric power

✧ Oxidation-reduction chemistry for fuels
Semiconductors: Energy Sources

Solar power in all directions
3.8x10^{26} Watts
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Solar power per square meter on earth 1000 Watts

Below bandgap photons: transmitted
Above bandgap photons: Energy above bandgap lost as heat
Semiconductors: Energy Conversion

Energy conversion: Photovoltaics

Status: Challenging environment
Niche applications: off grid
Slowly becoming competitive

Jaspreet Singh
With a 25 year lifespan solar energy is becoming competitive in developed markets. Cost is about 3 cents per kWhr. However, some subsidies and tax breaks are needed. Upfront costs are high. Impact is higher in less developed markets.
Semiconductors: Artificial Photosynthesis

Energy conversion: Photons to electrons-holes to chemical reactions
Semiconductors: Photons Driving Chemical Reactions

Energy conversion: Photons and holes

Oxidation and reduction to cause photosynthesis: CO₂ and water to O₂ and carbohydrates

Challenges: Find reliable catalysts, inexpensive semiconductor particles so voltages of ~1 V can drive chemical reactions
Hydrogen, methane, “gasoline”, …
Lighting: Where is the energy going?

Energy Efficiency of Incandescent and Fluorescent Lamps

Generating Plant | Distribution Grid | Light Source
--- | --- | ---
Prime Energy Input | Light Energy Output | 60 Watts
188 Joules | 1.35 Joules | (900 Lumens)

Conversion Loss | Resistive Losses | Waste Heat
122 Joules | 6 Joules (10%) | 58.65 Joules

65% | 35% | Light Energy Output

Prime Energy Input | 15 Watts | 1.35 Joules | (900 Lumens)
47 Joules | Resistive Losses | Waste Heat
30.5 Joules | 1.5 Joules (10%) | 13.65 Joules

Jaspreet Singh
Large bandgaps in the InN-GaN-AlN System allow for blue and green light emission and very high power devices.

1.0 Watt ~ 680 lumens
Nitrides and Lighting

Global market share 10yr forecast for lighting

- SSL devices
- Incand/Other
- FL

Graph showing market share from 2003 to 2016.
High Voltage Devices: Electricity Delivery and Electric Vehicles

~ 5 micron Nitride devices can handle more than 1 kV voltage levels

Jaasprit Singh
In societies with less developed energy infrastructure solar cells, solid state lighting provide unique opportunities for enhancing lifestyle: Health, education, job training, …
Technology and Energy Efficiency

Connect  Educate  Remote Healthcare
Coherent Consumption and Sustainability
One plus One is what...?

If one person consumes one barrel of oil (or another energy unit) to live well, how many barrels will 9 billion consume?

9 billion?
Half a billion?
100 billion?

The answer depends on whether the consumption is coherent or incoherent.
Do-Undo, Random and Coherent Journeys

Do-Undo Journeys: Each action nullifies the previous action; Consumes all of our resources and produces no fruit—wars, civil wars, also PERSONAL MIND-BODY WARS...

Random or Incoherent Journeys: Each action is unrelated to the previous action

Coherent Journeys: Each action enhances the previous action

1+1+1 is zero

1+1+1+1... is N

1+1+1+1... is N²
Coherent Journeys: Each action enhances the previous action

Personal level: Eat, rest, exercise, work, relationships, …all in coherence

Society: Ability to enjoy other’s success and be willing to share,…good citizenship

Global level; Recognize our interconnectedness

1+1+1+1+… \rightarrow N^2

Kilowatt lasers can cut through steel!

Anna Switzer
Coherence to mindfully face the “Forks in the Road”

Some energy losses are controlled by Nature i.e. thermodynamics: coal to electricity is only 40% efficient. “Usable Energy” lost is about 60%!
Nature is impartial!

Many of our personal consumption losses are controllable through mindfulness:
Nearly all car crashes, home fires, workplace accidents, most illnesses

Preventable lifestyle costs are nearly Half of our economy.

A mindful brain can select!
Mindful technologies to minimize undesirable choices

Jasprit Singh
Coherent Paths: Technology can enhance coherence . . . . also destroy it!

GPS: Minimize extra time/energy

Backup camera: Avoid catastrophes

Why waste?
Thanks!

Profs. Eusik Yoon, Wei Lu
Rose Anderson, Catharine June

Photovoltaic band profile
http://www.dur.ac.uk/cmp/research/groups/aim/themes/solarcellsprinciple/
Bandgap and efficiency
http://solarcellcentral.com/limits_page.html


http://www.nobelprize.org/educational/physics/energy/fusion_2.html
Home heating and cooling chart http://www.denergyaverobx.com/heating-cooling.html

Electricity conversion efficiency: http://www.mpoweruk.com/energy_efficiency.htm

Clean air:

Fruits and flowers: http://www.sendflowerstomumbai.com/fresh-fruits-india.htm
Thanks!


Solar energy cost studies: http://solarcellcentral.com/cost_page.html


Diabetes: http://www.bioelf.org/types-of-diabetes/

Car backup camera: http://marketplayground.com/2012/02/21/auto-backup-camera-sales-to-nearly-double/
Thanks!

Deep water horizon: http://www.climateshifts.org/?p=5256


Clear cutting: http://www.unitedmountainaindefense.org/mtr.html


Solar cells in Africa: http://www.afronline.org/?p=20269