

# Energy Fundamentals and Future:

Importance of Energy Conservation and Renewable and Alternative Energy Resources

An ENERGY Lecture at



Energy Research Institute  
Shanghai Jiao Tong University (SJTU)  
Shanghai, China, January 6, 2008



Prof. M. Kostic  
Mechanical Engineering  
NORTHERN ILLINOIS UNIVERSITY

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Slide 1

# Energy Fundamentals and Applications:

Importance of Energy Conservation and Renewable and Alternative Energy Resources

An ENERGY Lecture at



Institute for Thermal Power Engineering  
State Key Laboratory of Clean Energy Utilization  
Zhejiang University (ZJU), Hangzhou, China, January 8, 2008



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Slide 2

## Earth Energy Balance:

- All energy to Earth surface is **99.98% solar**, 0.02% geothermal, and 0.002% tidal-gravitational.
- About **14 TW world energy consumption rate now (0.008% of solar striking Earth)** is about 6 times smaller than global photosynthesis (all life), the latter is only 0.05% of total solar, and global atmospheric water and wind are about 1% of solar.

The solar constant is  $1.76 \times 10^8$  TW, which is much larger than the 12 TW mean global energy consumption rate from all sources at the present time. Hence, there is ample solar energy potential to provide all of our energy needs from a renewable, carbon-free power supply. From the  $1.2 \times 10^8$  TW of solar energy that strikes the earth's surface, a practical siting-constrained terrestrial solar power potential value is about 600 TW. The numbers range from very conservative estimates of 50 TW to optimistic estimates of 1500 TW, depending on the land fraction devoted to power generation. A good number to use for onshore electricity generation potential is probably 600 TW. Thus, for a 10% efficient solar farm, at least 60 TW of power could be supplied from terrestrial solar energy resources. For calibration, photosynthesis currently supplies 90 TW globally to make the biosphere run, so the amount of power available from the sun is very large.

Source: Basic Research Needs To Assure A Secure Energy Future, ORNL Report, 2003

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Slide 3

## "From the Sovereign Sun ...

...to the deluge of photons out of the astounding compaction and increase of power-density in computer chips ..."



**One hour of solar energy falling on Earth could power the World for a year**

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Slide 4

## What is Energy ?

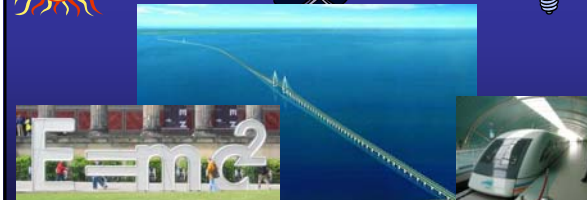
"From the sovereign Sun to the deluge of photons out of the astounding compaction and increase of power-density in computer chips ..."



Energy is more than universal currency. The world view from inside to outside is possible, figuratively and literally, only through the energy prism. From shining stars to rotating planets; to global water, atmospheric, and life cycles; to the evolution, industrialization, and modernization of civilization, energy is the cause and measure of all that there has been, is, and will be.

## What is Energy ?

"From the Sovereign Sun to the deluge of photons out of the astounding compaction and increase of power-density in computer chips ..."



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Slide 6

# What is Energy ?



If one could expel all energy out of a physical system ... then empty, nothing will be left ...

... so **ENERGY is EVERYTHING ...  $E=mc^2$**

# Material system structure and related forces and energies

Table 1 Material system structure and related forces and energies

Particles	Forces	Energies
Atom nucleus	Strong and weak	Nuclear
Electron shell, or electron flow	Electromagnetic	Electrical, magnetic, electromagnetic
Atoms/molecules	Inter-atomic/molecular	Chemical
Molecules	Inertial due to random collision and, potential inter-molecular	Sensible thermal
Molecules	Potential inter-molecular	Latent thermal
Molecules	Potential inter-molecular	Mechanical elastic
System mass	Inertial and gravitational	Mechanical kinetic and gravitational

## ENERGY-Structure/Property (Existence) and ENERGY-Transfer/Exchange (Change/Progress)

- "... Energy is the "building block" and fundamental property of matter and space and, thus, the fundamental property of existence.
- Energy exchanges or transfers are associated with all processes (or changes) and, thus, are indivisible from time."

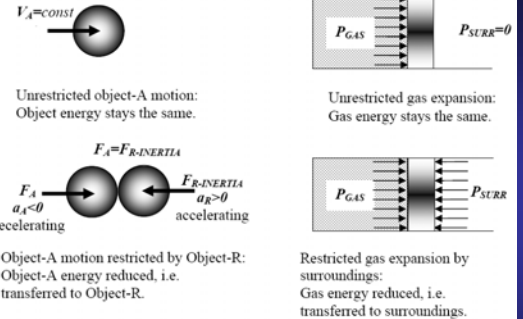
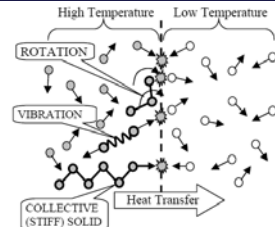
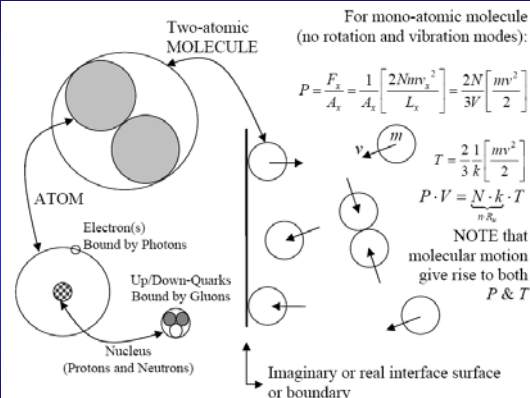


FIG. 7: Energy of an unrestricted particle, object or material system, like gas etc., stays the same (unchanged) and is transferred during forced-displacement-interaction from acting or source system to reacting or sink system and thus conserved within the interacting objects or systems.



Complications: rotation, vibration, and collective (stiff) solid behavior could contribute to the kinetic energy during particle interaction, i.e. temperature.

FIG. 1: Active (energetic) and particulate structure of material system: sub-molecular, sub-atomic and sub-nucleus structures (top-left); gas kinetic structure including simple ideal-gas relations for pressure and temperature (top-right); and random kinetic interactions (collisions) between more and less energetic (high and low temperature) molecules, including complications due to more complex sub-structures (rotations, vibrations, etc.).

# YES! Miracles are possible !

It may look 'perpetuum mobile' but miracles are real too ...

Things and Events are both, MORE but also LESS complex than how they appear and we 'see' them-- it is **natural simplicity in real complexity**

- ... we could not comprehend energy conservation until 1850s: (mechanical energy was escaping without being noticed)
- ... we may not comprehend now new energy conversions and wrongly believe they are not possible: ("cold fusion" seems impossible for now ... ?)
- .....Let us keep our eyes and our minds 'open' .....

# YES! Miracles are possible !

... but there is **NO** ideal 'Things and Events' ...

'Things and Events' are both, MORE but also LESS complex than how they appear and we 'see' them-- it is **natural simplicity in real complexity**

... there are **no ideal things**, no ideal rigid body, no ideal gas, no perfect elasticity, no adiabatic boundary, no frictionless/reversible process, no perfect equilibrium, not even steady-state process ...

... there are **always processes** - energy in transfer or motion, all things/everything ARE energy in motion with unavoidable **process irreversibilities**, however, in limit, an infinitesimally slow process with negligible irreversibility appears as instant reversible equilibrium - thus, **everything is relative** with regard to different space and time scales ...

....Let us keep our eyes and our minds 'open' .....

## Global Energy and Future:

### Importance of Energy Conservation and Renewable and Alternative Energy Resources

Solar 1.37 kW/m<sup>2</sup>, but only 12% over-all average 165 W/m<sup>2</sup>

2000 kcal/day ≈ 100 Watt

World over 6.5 billion 2,200 Watt/e 300 W <sub>el</sub> /e	USA over 0.3 billion 11,500 Watt/e 1,500 W <sub>el</sub> /e
--	---

## Population & Energy:

### Unrestricted Exponential Growth... !?

- About one million years ago our own species, *homo sapiens*, first appeared, **strived most of the history** and boomed with agricultural and industrial revolution. We are **over 6 billion now**.
- Standard of living and energy use **have been growing** almost exponentially due to abundance of resources.
- The **growth will be naturally restricted** with overpopulation and resource depletion as we know it.

*The Growth Curve*

Time in history	Population in millions
Most of BC history	10 due to hardship
AD 1	300
1750	760
1800	1,000
1950	2,500
2000	6,000

## Humanity's Top Ten Problems for next 50 years

### 1. ENERGY (critical for the rest nine)

- Water
- Food
- Environment
- Poverty
- Terrorism & War
- Disease
- Education
- Democracy
- Population

2006: 6.5 Billion People  
2050: 8-10 Billion ( **10<sup>10</sup>** ) People



## What Are We Waiting For?

- (1) An Energy Crisis ?
- (2) A Global Environmental Problem?
- (3) A Technology Boom?
- or **Leadership**

# The biggest single challenge for the next few decades by 2050

- (1) ENERGY for  $10^{10}$  people
- (2) At **MINIMUM** we need additional 10 TeraWatts (150 Mill. BOE/day) from some new clean energy source
- We simply can not do this with current technology!
- We need **Leadership**

# YES! Thermodynamics

an almost forgotten science will provide vision for the future energy solutions  
**FUNDAMENTALS & APPLICATIONS OF ENERGY**

- ... a science of **ENERGY**
- ... the **Mother** of all sciences
- ... check-and-balance ENERGY accounting
- ... Energy efficiency enhancement and optimization
- ... provides **VISION** and future **ENERGY** solutions

I am first and foremost a Thermodynamicist

The screenshot shows a web browser displaying the 'ENCYCLOPEDIA OF ENERGY' website. The main article is titled 'Work, Power, and Energy' by M. KOSTIC, Northern Illinois University, DeKalb, Illinois, United States. The article text includes: 'Energy A fundamental property of a system referring to its potential to influence changes to other systems by imparting work (forced directional displacement) or heat (chaotic displacement/motion of system microstructure); energy exists in many forms—electromagnetic, electrical, nuclear, chemical, thermal, and mechanical, where electromechanical energy may be kinetic or potential—and thermal energy represents overall chaotic motion energy of molecules and related microstructure.' The table of contents lists: 1. Basic Concepts, 2. Forms, Classifications, and Classification, 3. Work of Conservative and Non-Conservative Forces, and Work-Energy Principle.

Encyclopedia of Energy Engineering DOI:10.1081/E-EEE-120042341  
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## Energy: Global and Historical Background

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### Physics of Energy

Milivoje M. Kostic

Department of Mechanical Engineering, Northern Illinois University, DeKalb, Illinois, U.S.A.

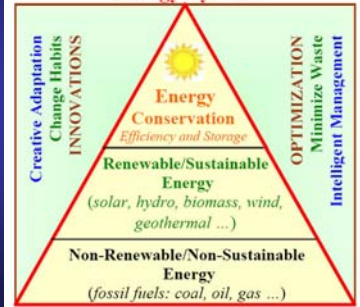
#### Abstract

The concept and definition of energy are elaborated, as well as different forms and classification of energy are presented. Energy is a fundamental concept indivisible from matter and space, and energy exchanges or transfers are associated with all processes (or changes), thus indivisible from time. Actually, energy is "the building block" and fundamental property of matter and space, thus fundamental property of existence. Any and every material system in nature possesses energy. The structure of any matter and field is "energetic," meaning active, i.e., photon waves are traveling in space, electrons are orbiting around an atom nucleus or flowing through a conductor, atoms and molecules are in constant rotation, vibration or random thermal motion, etc. When energy is exchanged or transferred from one system to another it is manifested as work or heat. In addition, the First Law of energy conservation and the Second Law of energy degradation and entropy generation are presented along with relevant concluding remarks. In summary, energy is providing existence, and if exchanged, it has ability to perform change.

# How To "Use" Energy ?

Life May Be Happier After the Fossil-Fuel Era

## Energy Pyramid



# Nanotechnology potentials ...

- **Enabling Nanotech Revolution(s)**  
Nanotech to the rescue ...

- (1) Nano multifunctional
- (2) Nano electronics &
- (3) Nano sensors & a
- (4) Nano devices & ro
- (5) Nano photovoltaic
- (6) Nano super-condu
- (7) Nano energy-stora
- (8) Nano bio-materials

**Some examples:**

Armchair Wire Project: electrical conductivity of copper at 1/6 the weight with negligible eddy currents  
Single Crystal Fullerene Nanotube Arrays ... (Etc.)

Wet-Nanotechnology:  
**nanofluids**  
at NIU  
In collaboration with ANL  
[www.kostic.niu.edu/DRnanofluids](http://www.kostic.niu.edu/DRnanofluids)

# The two things are certain

- (1) the **world population** and their living-standard expectations will **substantially increase** (over 6 billion people now, in 50 years 10-11 billion - energy **may double**)
- (2) **fossil fuels' economical reserves**, particularly oil and natural gas, will **substantially decrease** (oil **may run out** in 30-50 years)

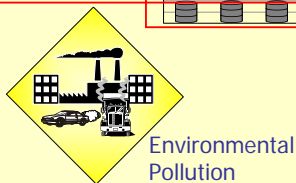
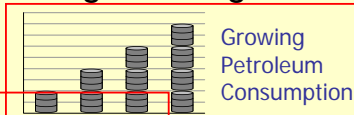
# Some Headlines...:

- It took World 125 years to consume the first trillion barrels of oil – the next trillion will be consumed in 30 years.
- The World consumes two barrels of oil for every barrel discovered.
- Only "Human Power" can deliver **MORE** energy with **LOWER** emission

# More Challenges/Headlines ...

- We need **new ENERGY FUTURE !**  
If it does not exist, we have to **INVENT IT !**
- Saving a lot of energy should not take a lot of energy
- Only "Human Power" can deliver **MORE** energy with **LOWER** emission

# The challenges facing us...



**BEYOND Oil**  
The View from Hubbert's Peak  
By Kenneth S. Deffeyes

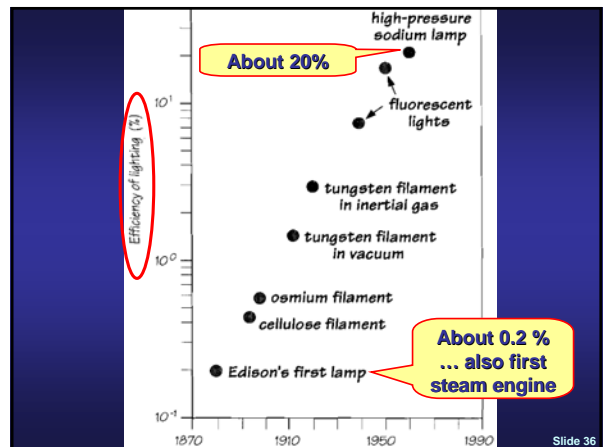
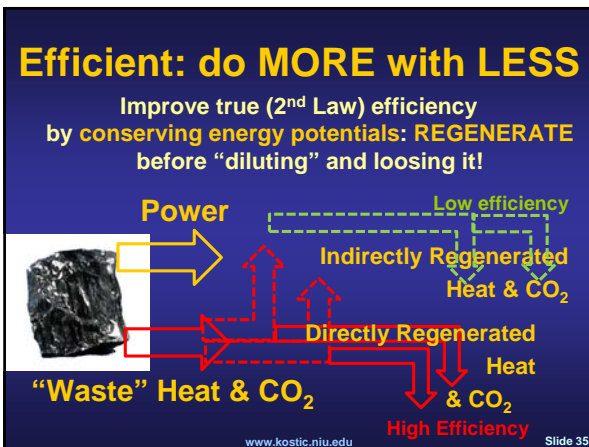
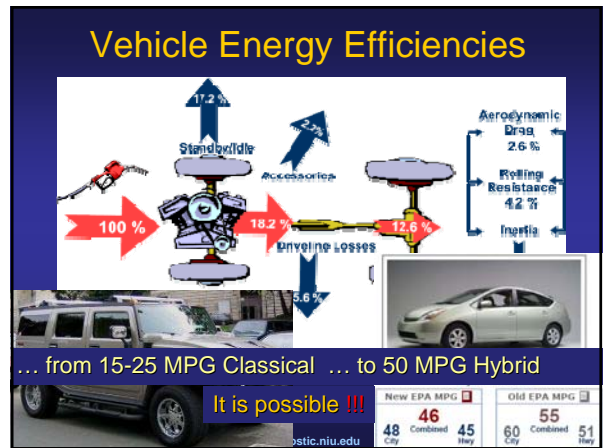
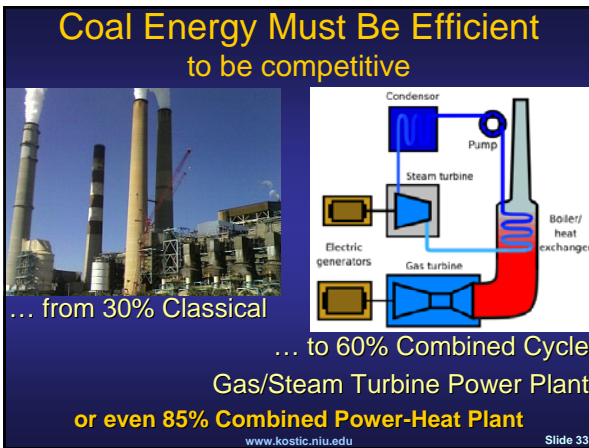
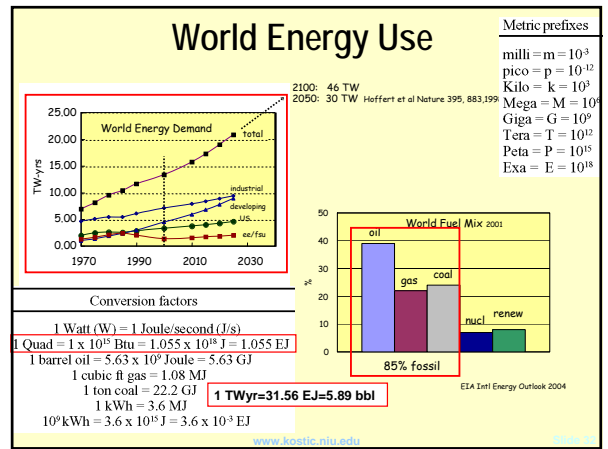
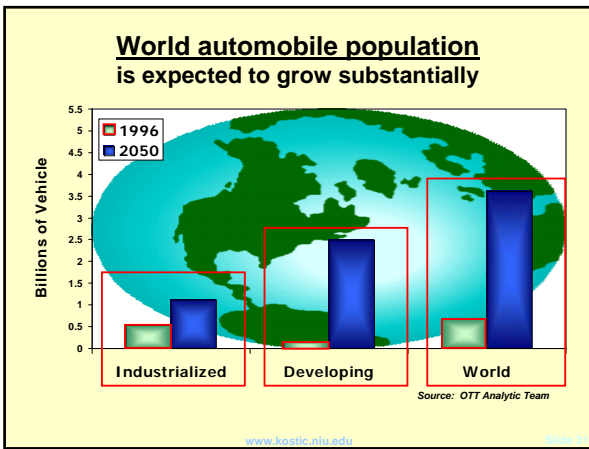
A short history of fossil fuels' abundance and use (a bleep on a human history radar screen).

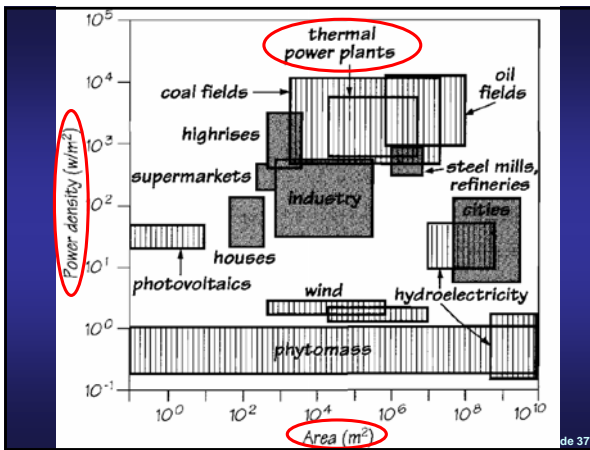
The Peak  
Links  
Current Events  
FRS Cookbook  
About Ken  
Pictures  
Speaking Engagements

Hubbert's Peak in the 21<sup>st</sup> Century

World oil production will start to fall sometime during this decade, never to rise again. In 1956, M. King Hubbert predicted that U.S. oil production would peak in the early 1970's. Although Hubbert was widely criticized by some oil experts and economists, in 1971 Hubbert's prediction came true. The 100 year period when most of the world's oil is being discovered became known as "Hubbert's Peak". The peak stands in contrast to the hundreds of millions of years the oil deposits took to form. Hubbert's methods predict a peak in world oil production less than five years away.

Hubbert's methods predict a peak in world oil production less than five years away.





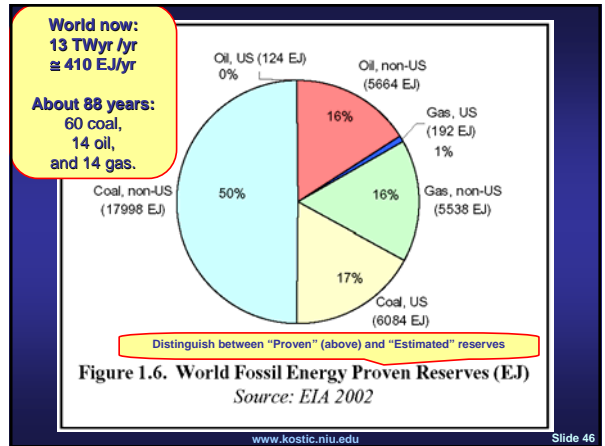
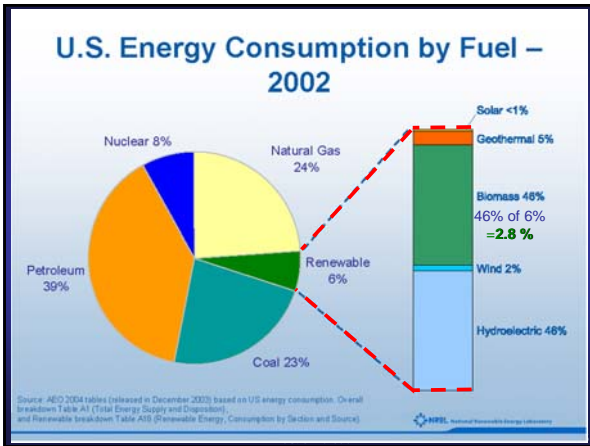
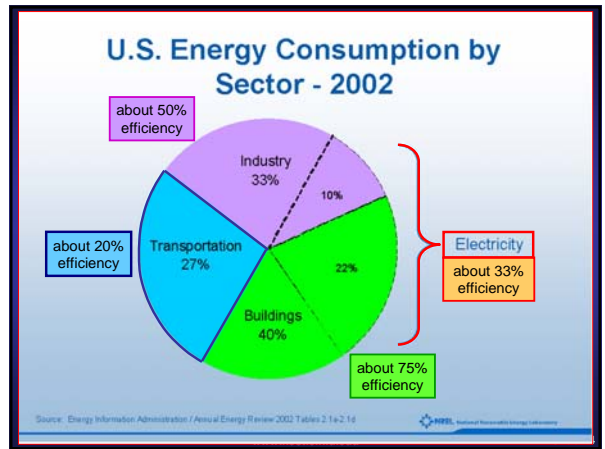
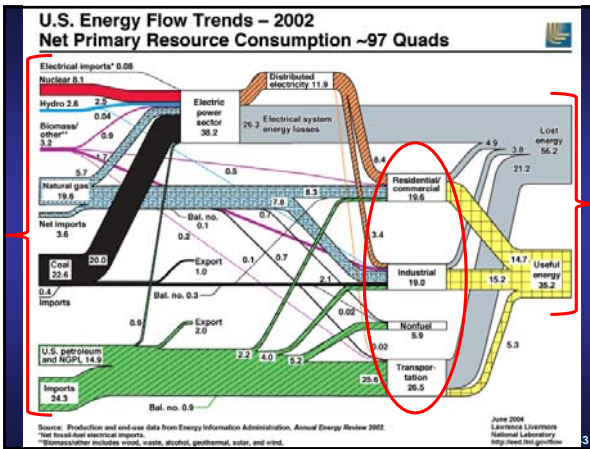
Energy of	Magnitude
Global coal resources	200,000 EJ
Global plant mass	10,000 EJ
Latent heat of a thunderstorm	5 PJ
Coal load in a 100-t hopper car	2 TJ
Barrel of crude oil	6 GJ
Bottle of white table wine	3 MJ
A small chickpea	5 kJ
Fly on a kitchen table	9 mJ
A 2-mm raindrop on a blade of grass	4 $\mu$ J

Energy flows	Power
Global intercept of solar radiation	170 PW
Wind-generated waves on the ocean	90 PW
Global gross primary productivity	100 TW
Global Earth heat flow	42 TW
Worldwide fossil fuel combustion	10 TW
Florida Current between Miami and Bimini	20 GW
Large thermal power plant	5GW
Basal metabolism of a 70-kg man	80 W

Energy of	Magnitude
Global coal resources	200,000 EJ
Global plant mass	10,000 EJ
Latent heat of a thunderstorm	5 PJ
Coal load in a 100-t hopper car	2 TJ
Barrel of crude oil	6 GJ
Bottle of white table wine	3 MJ
A small chickpea	5 kJ
Fly on a kitchen table	9 mJ
A 2-mm raindrop on a blade of grass	4 $\mu$ J

Energy of	Magnitude
Solar radiation reaching the Earth	5500000 EJ
Global net photosynthesis	2000 EJ
Global fossil fuel production	300 EJ
Typical Caribbean hurricane	38 EJ
Largest H-bomb tested in 1961	240 PJ
Latent heat of a thunderstorm	5 PJ
Hiroshima bomb of 1945	84 TJ
Basal metabolism of a large horse	100 MJ
Daily adult food intake	10 MJ
Striking a typewriter key	20 mJ
Flea hop	100 nJ

Energy flows	Duration	Power
Richter magnitude 8 earthquake	30 s	1.6 PW
Large volcanic eruption	10 h	100 TW
Thunderstorm's kinetic energy	20 min	100 GW
Large WWII bombing raid	1 h	20 GW
Average U.S. tornado	3 min	1.7 GW
Four engines of Boeing 747	10 h	60 MW
Watt's largest steam engine	10 h	100 kW
Running 100-m dash	10 s	1.3 kW
Machine-washing laundry	20 min	500 W
Playing a CD	60 min	25 W
Candle burning to the end	2 h	5 W
Hummingbird flight	3 min	0.7 W



### Energy Challenges: Local/Regional Pollution

the six principal air pollutants (not including CO<sub>2</sub>)

	origin	secondary effect	hazard
SOx	impurities in fuel	acid rain particulates	health, crops corrosion
NOx	high T combustion in air	particulates ozone, acid rain	health
CO	incomplete combustion		health, reduced O <sub>2</sub> delivery
Particulates	combustion sunlight + NOx/SOx		health
Pb	chemical industry		health
ground ozone	sunlight + NOx + organics		respiratory vegetation

pollution zones near sources  
urban areas, power plants

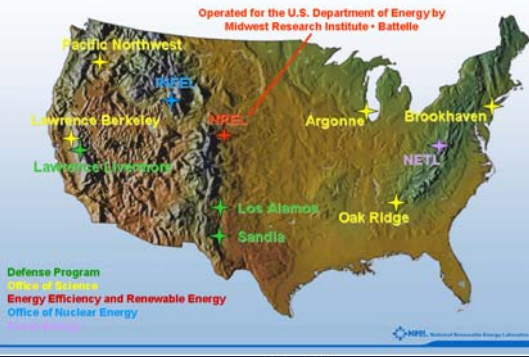
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### So, what are we going to do?

### Do we need CASH for ALCOHOL research?

U.S. DEPARTMENT OF ENERGY  
FEDERAL GOVERNMENT OF THE UNITED STATES OF AMERICA

## Major DOE National Laboratories



## National Renewable Energy Laboratory

- Only national laboratory *dedicated* to renewable energy and energy efficiency R&D
- Research spans fundamental *science* to *technology* solutions
- *Collaboration* with industry and university partners is a hallmark
- Research programs *linked* to market opportunities

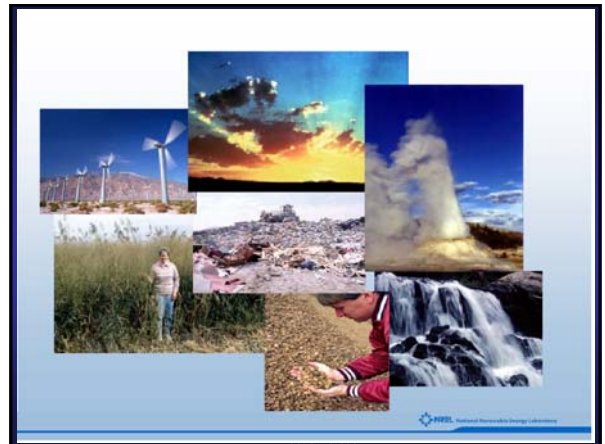


## Major NREL Thrusts

- Wind**
- Solar**
  - Photovoltaics
  - Solar Thermal
- Biomass**
  - Biorefineries
  - Biosciences
- Geothermal**
- Hydrogen**
  - Production
  - Storage
  - Delivery and End Use
  - Systems Integration
- Distributed Energy**
  - Distribution and Interconnection
  - Thermal Systems
  - Superconductivity

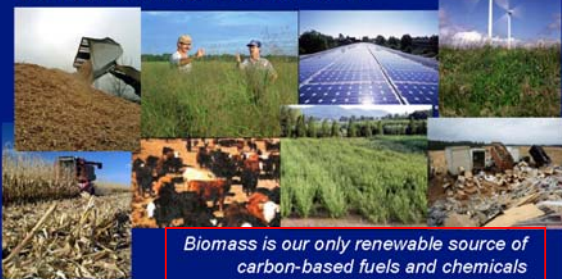


- Vehicle Technologies**
  - Hybrid Vehicles
  - Alternative Fuels Utilization
- Building Technologies**
  - Building Efficiency
  - Zero Energy Buildings
- Federal Energy Management**
- Basic Energy Science**
  - New Materials
  - Chemical and Biological Sciences
- Analytical Studies International**



## The Unique Role of Biomass

While the growing need for sustainable electric power can be met by other renewables...



## The renewable biomass (BM) energy and development of synthetic hydro-carbons ...

- The **renewable biomass energy** (BM) and development of **synthetic hydro-carbons** (SynHC) will be **very important if not critical** for substitution of fossil fuels...
- ... since they are **natural extensions** of fossil fuels, the existing **energy infrastructure** could be **easily adapted**
- global **CO<sub>2</sub> emission** will be **balanced** during renewable biomass production.
- BM&SynHC particularly **promising** for **energy storage** and use in **transportation** to replace fossil fuels,

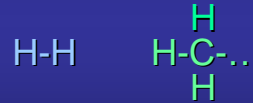
## Hydrogen **versus** Renewable biomass and synthetic hydro-carbons ...

... especially considering the Hydrogen facts:

- (1) **hydrogen does not exist in nature** as primary energy source
- (2) **hydrogen production** (from hydrocarbons or water) is **energy inefficient** (always net-negative, energy storage only)
- (3) **hydrogen storage and distribution** are facing a **host of problems** that cannot be economically resolved with present state of knowledge

## Hydrogen **versus** Renewable biomass and synthetic hydro-carbons (2)

Instead of going '**against**' the nature with hydrogen ...



... we should go '**along**' with nature with biomass energy and development of synthetic hydro-carbons.

## Hydro and Biomass & Waste

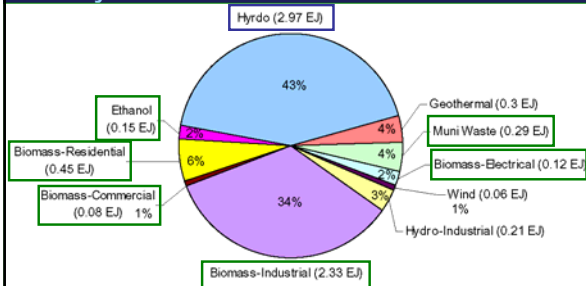
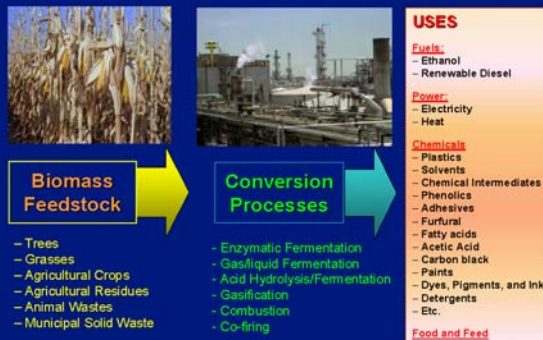


Figure 1.4. Relative Contribution of Various Renewable Energy Sources in Year 2000 (EJ)  
Source: EIA 2002

## Biomass Resources and Key Issues

<p><b>Wood Residues</b> Sawdust Wood waste Pulp mill wastes</p>	<ul style="list-style-type: none"> <li>• <b>Quality</b> <ul style="list-style-type: none"> <li>- Composition</li> <li>- Ease of Conversion</li> </ul> </li> <li>• <b>Cost</b> <ul style="list-style-type: none"> <li>- Production</li> <li>- Collection and Transportation</li> <li>- Quantity Available</li> </ul> </li> <li>• <b>Sustainability</b> <ul style="list-style-type: none"> <li>- Land, Air and Water Resources</li> </ul> </li> </ul>
<p><b>Agricultural Residues</b> Corn stover Rice hulls Sugarcane bagasse Animal waste</p>	
<p><b>Energy Crops</b> Switchgrass Hybrid poplar Willow</p>	

## NREL's Role: Support the Development of New Industrial Biorefinery Concepts



## Biomass and Biorefinery Summary:

- Biomass is the **only sustainable source** of hydrocarbon-based fuels, petrochemicals, and plastics
- **Large** national and world-wide biomass **resource base**
- **Reduction of greenhouse gas** emissions.
- Will diversify and reinvigorate **rural economy**
- **Bio-refineries utilize residue** from existing industry

## The energy “difficulties” ...

- (1) will be **more challenging** than what we anticipate now
- (2) **NO traditional solutions**
- (3) **New** knowledge, new technology, and **new living habits and expectations** will be needed

## Energy Future Outlook:

...a probable scenario ... in the wake of a short history of fossil fuels' abundance and use (a bleep on a human history radar screen), the following energy future outlook is possible...

### 1. Creative adaptation and innovations, with change of societal and human habits and expectations (life could be happier after fossil fuels' era)

2. Intelligent hi-tech, local and global energy management in wide sense (to reduce waste, improve efficiency and quality of environment and life)
3. Energy conservation and regeneration have unforeseen (higher order of magnitude) and large potentials, particularly in industry (also in transportation, commercial and residential sectors)
4. Nuclear energy and re-electrification for most of stationary energy needs
5. Cogeneration and integration of power generation and new industry at global scale (to close the cycles at sources thus protecting environment and increasing efficiency)
6. Renewable biomass and synthetic hydro-carbons for fossil fuel replacement (mobile energy, transportation, and chemicals)
7. Advanced energy storage (synthetic fuels, advanced batteries, hydrogen,...)
8. Redistributed solar-related and other renewable energies (to fill in the gap...)

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### 3. Energy conservation and regeneration have unforeseen (higher order of magnitude) and large potentials, particularly in industry (also in transportation, commercial and residential sectors)

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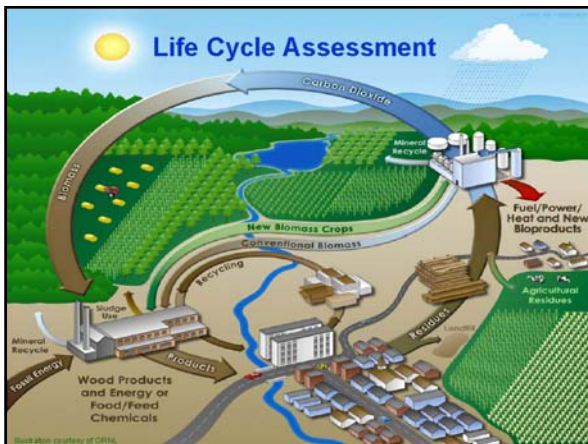
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*Energy in World History* by V. Smil (Westview Press, Inc., 1994)

More information at:  
[www.kostic.niu.edu/energy](http://www.kostic.niu.edu/energy)

Solar 1.37 kW/m<sup>2</sup>, but only 12% over-all average 165 W/m<sup>2</sup>

## Work, Power, and Energy



M. KOSTIC  
Northern Illinois University  
DeKalb, Illinois, United States

1. Basic Concepts
2. Forms, Classifications, and
3. Work of Conservative and  
Work-Energy Principle

Therefore, the outlook for future energy needs is encouraging. There are many diverse and abundant energy sources with promising future potentials, so that humankind should be able to enhance its activities, standard of living, and quality of living by diversifying energy sources and by improving energy conversion and utilization efficiencies while at the same time increasing safety and reducing environmental pollution.