The Role of Science and Engineering in Shaping our Energy Future

2008 Hawkins Memorial Lecture in Heat Transfer

October 16, 2008

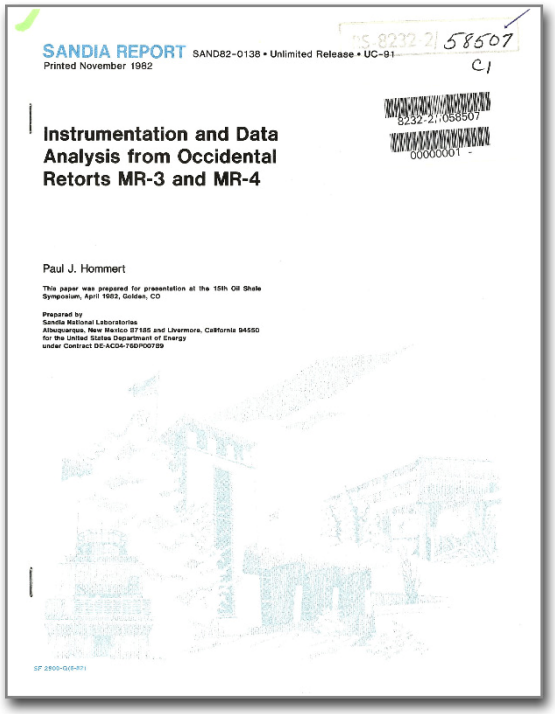
Dr. Paul Hommert
Vice President
Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Have we been here before? I know I have!

1970's and 1980's

- Coal gasification
- Hydrogen pipeline
- Solar thermal
- Shale oil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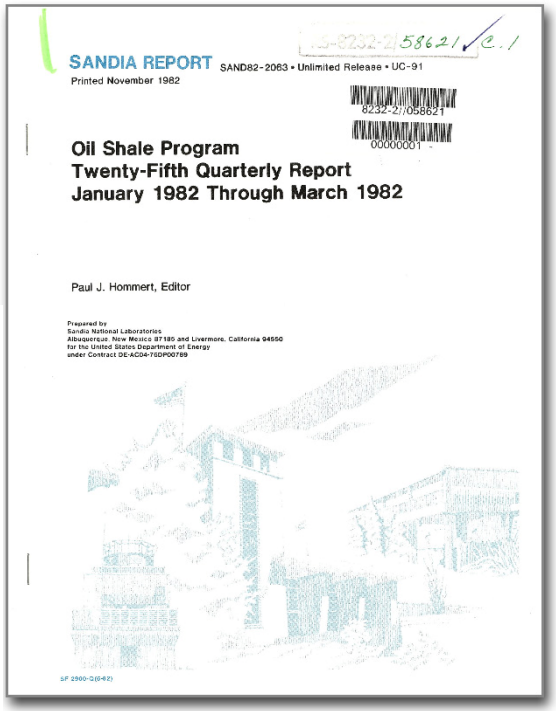
Printed November 1982

Instrumentation and Data Analysis from Occidental Retorts MR-3 and MR-4

Paul J. Hommert

This paper was prepared for presentation at the 15th Oil Shale Symposium, April 1982, Golden, CO

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789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Oil Shale Program
Twenty-Fifth Quarterly Report
January 1982 Through March 1982

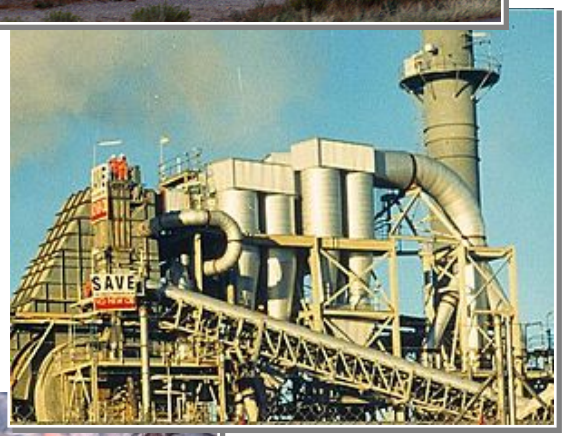
Paul J. Hommert, Editor

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

Middle East turmoil

Rapid increase in energy prices

Energy Independence



Shale oil processing

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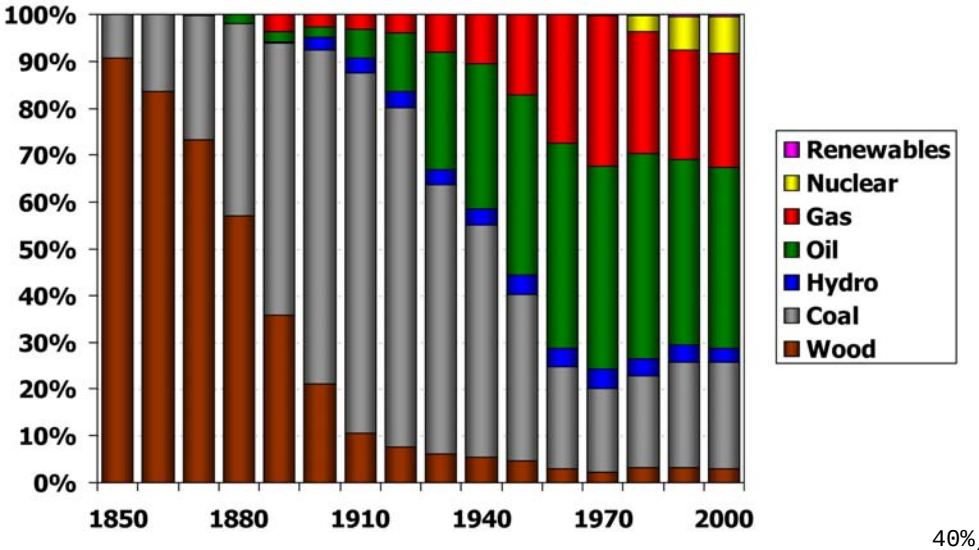
The World has made two major energy transitions. Why hasn't it made a third?

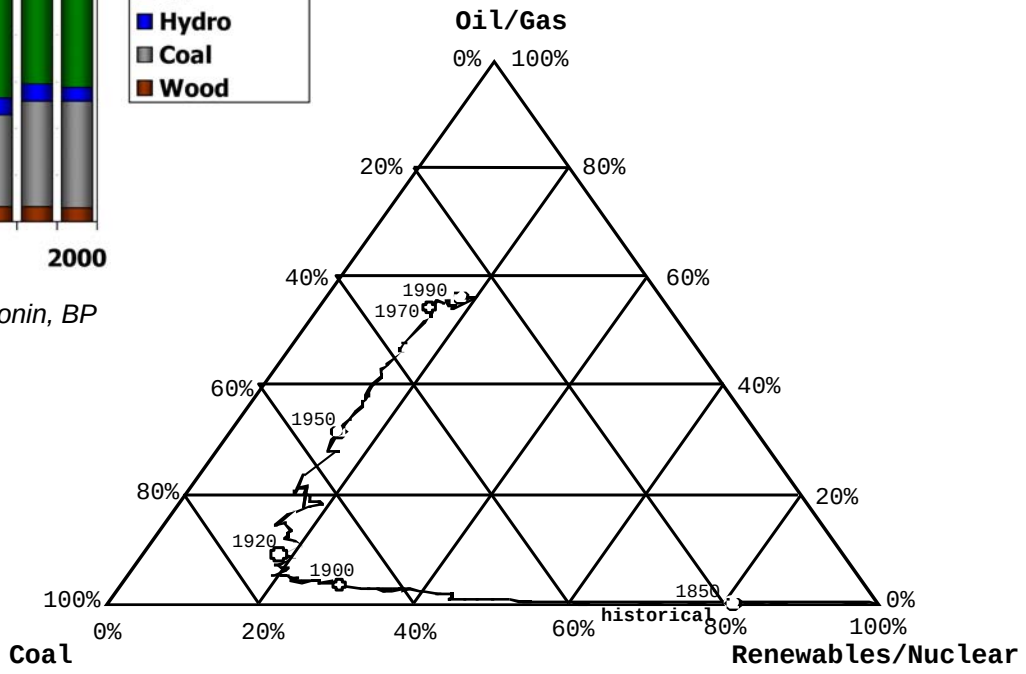


Koonin, BP

1850-1920: wood to coal

1920-1990: coal to oil/gas

1990-2050: oil/gas to ???



Grubler, Yale

Engineering Challenges

Public Perception/Market Forces

Demand/Supply Elasticity

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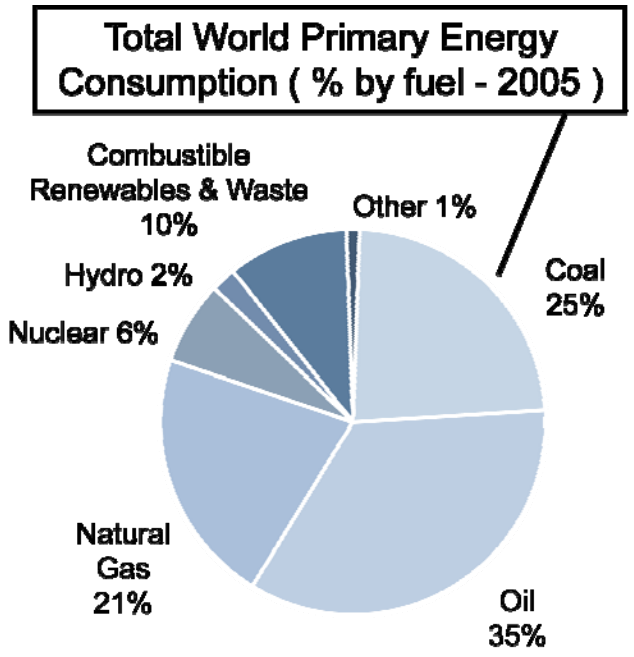
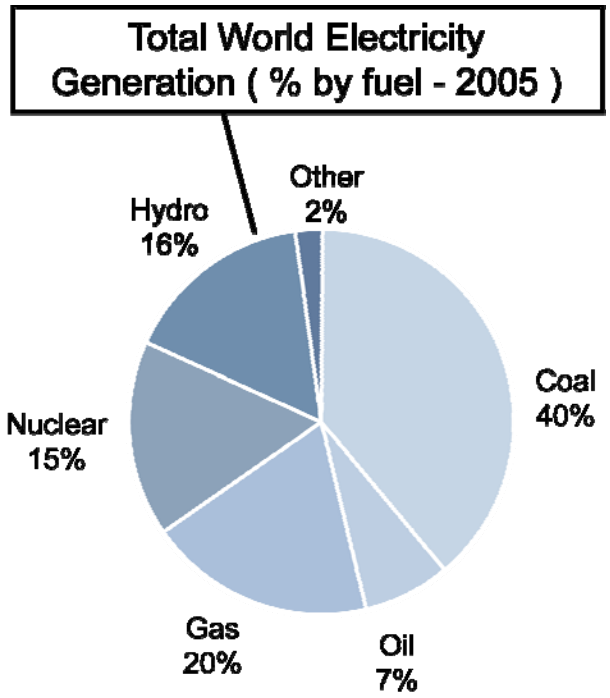
The past 35 years have deepened the world's dependence on hydrocarbons



* Other includes geothermal, solar, wind, heat etc



* Other includes solar, wind, combustible renewables, geothermal & waste

Modern renewable fuels (wind, solar, geothermal) comprise only 1% of world energy supplies. Nuclear supplies 6%.

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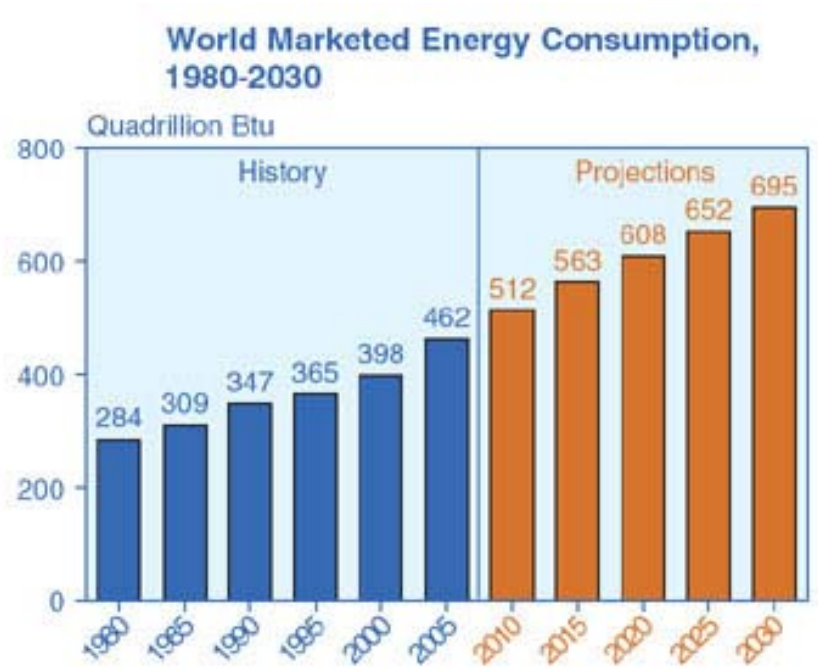
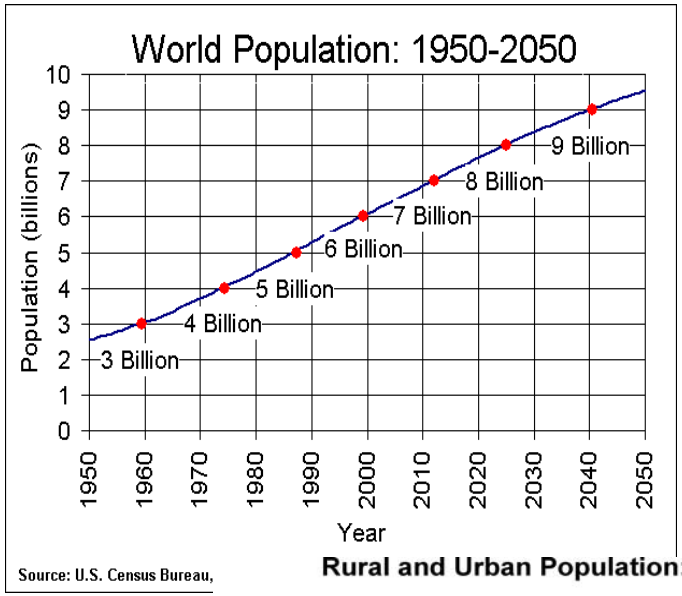
Looking forward, what are the energy drivers: population, urbanization, industrialization

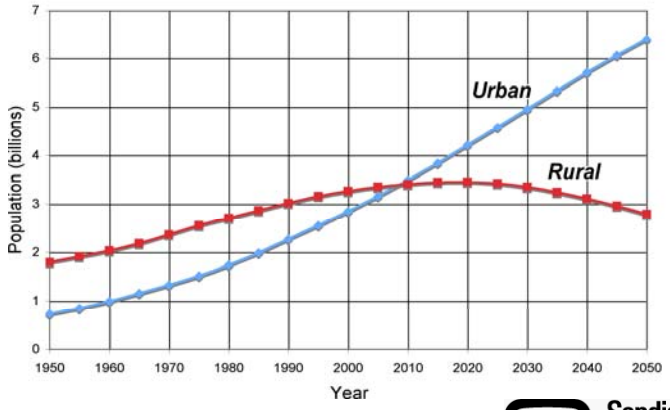


EIA



UN

Rural and Urban Population: 1950-2050



UN

World population will increase another 50% between 2005 and 2030.

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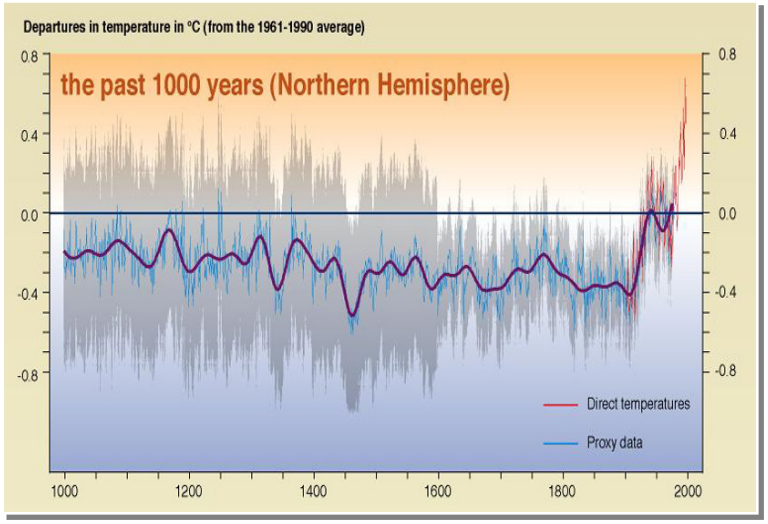
Carbon and climate impose new constraints on the world's energy system



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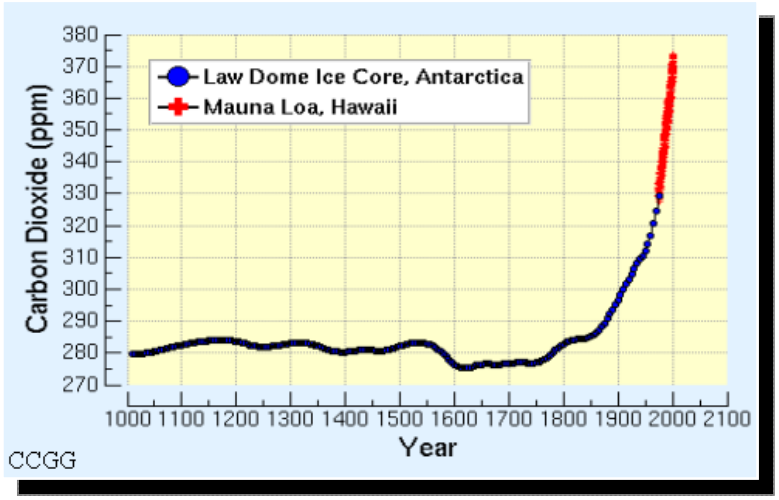

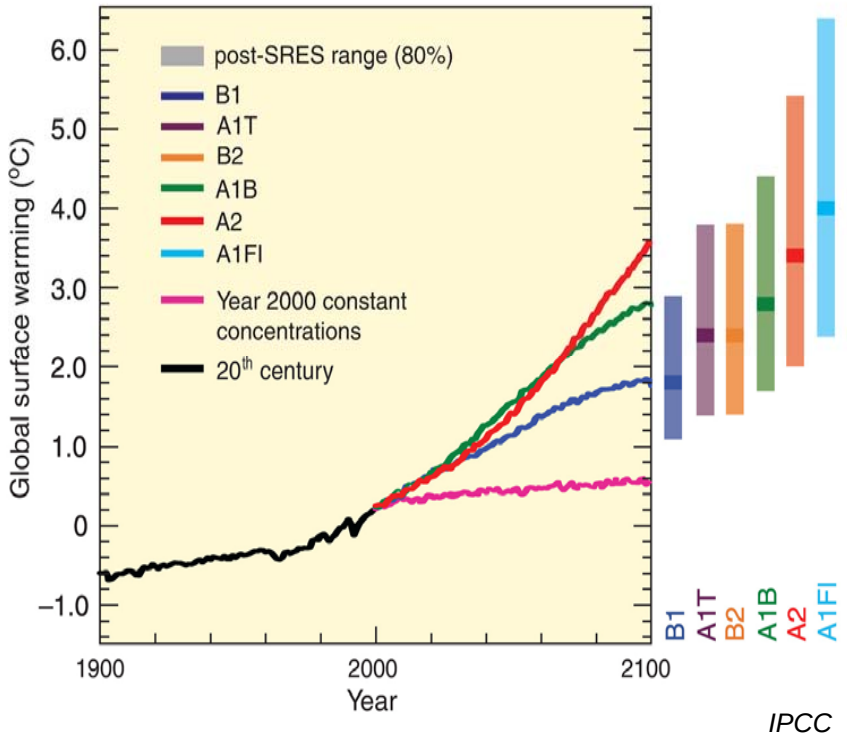

IPCC

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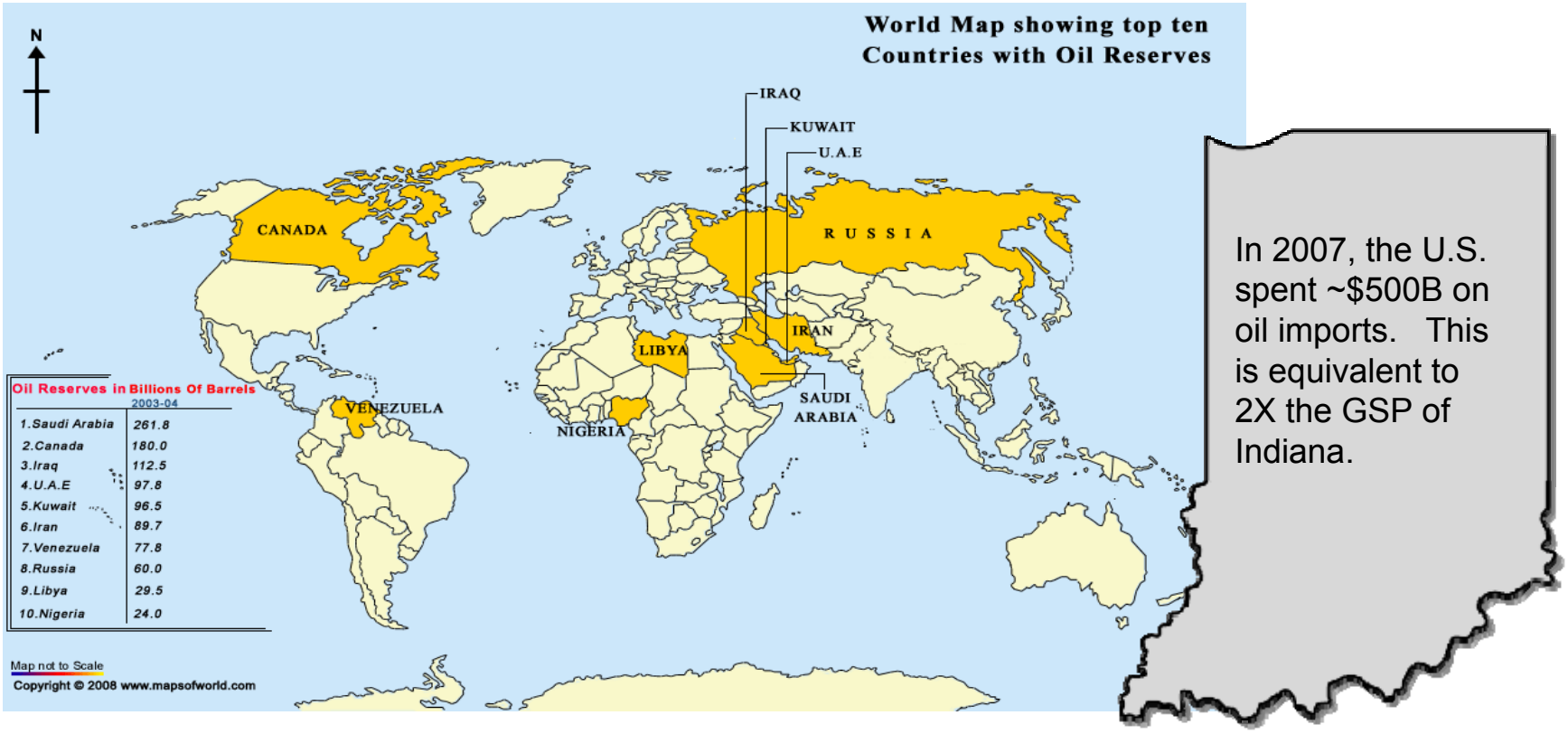
For the United States, energy is core to our national security



In 2007, the U.S. spent ~$500B on oil imports. This is equivalent to 2X the GSP of Indiana.

"While enhancing the military ability to defend themselves from Middle Eastern threats, Americans will have to accept the limits of their power in the area."

"Power, Faith and Fantasy, America in the Middle East 1776 to the Present", Oren, 2008

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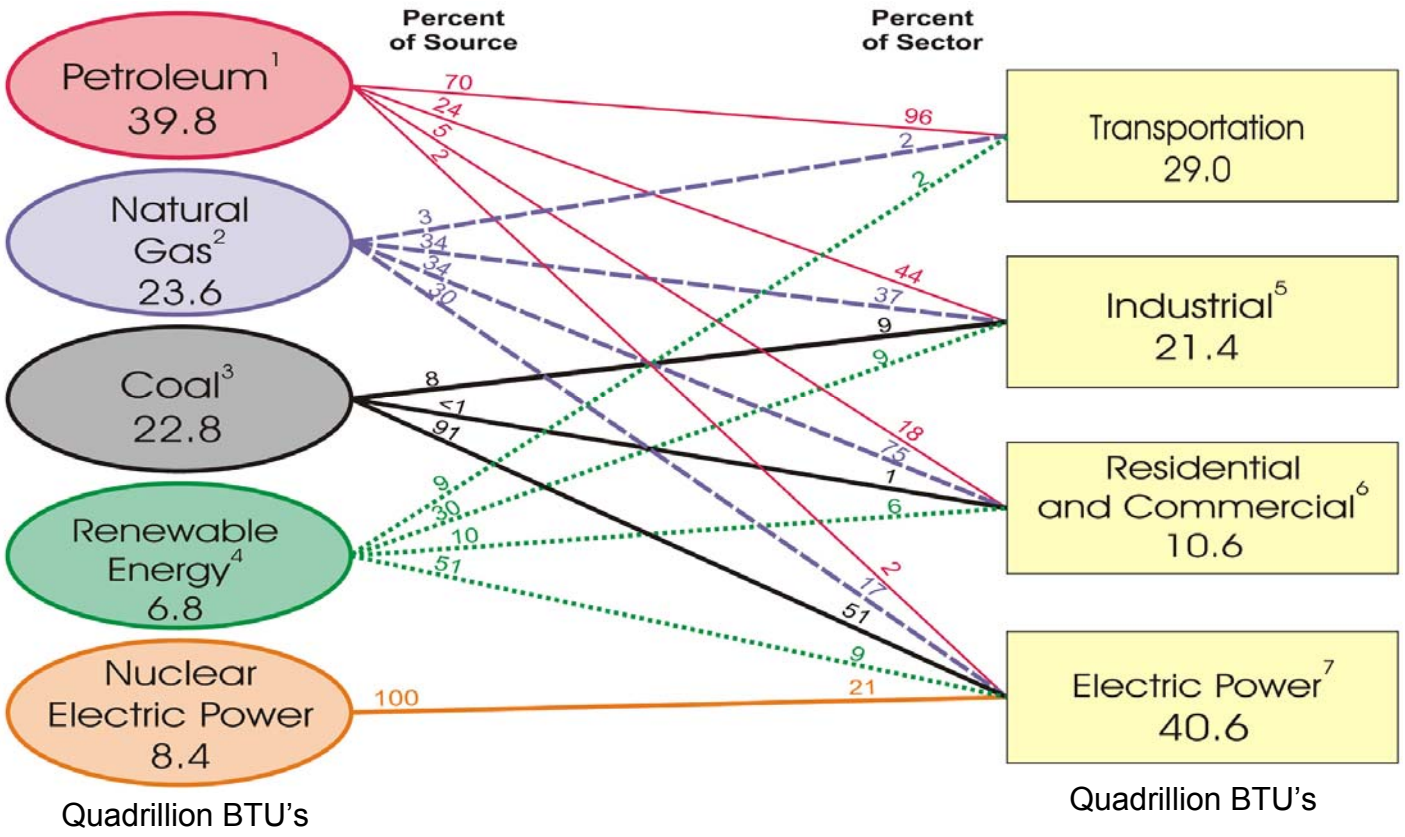
To change where you're going you need to recognize where you are!

United States energy picture



96% of transportation is from petroleum, while 51% of electric power is from coal. New technologies are needed to change this picture.

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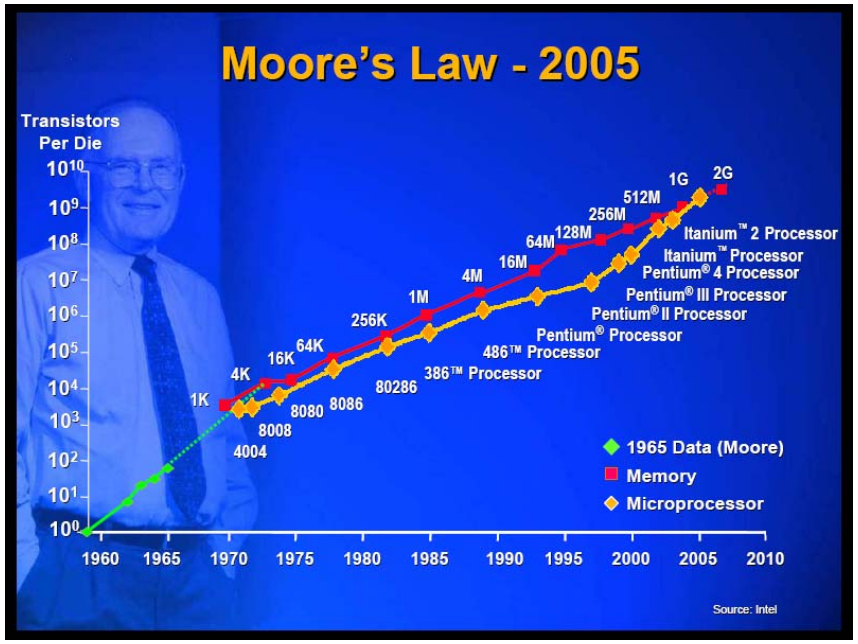
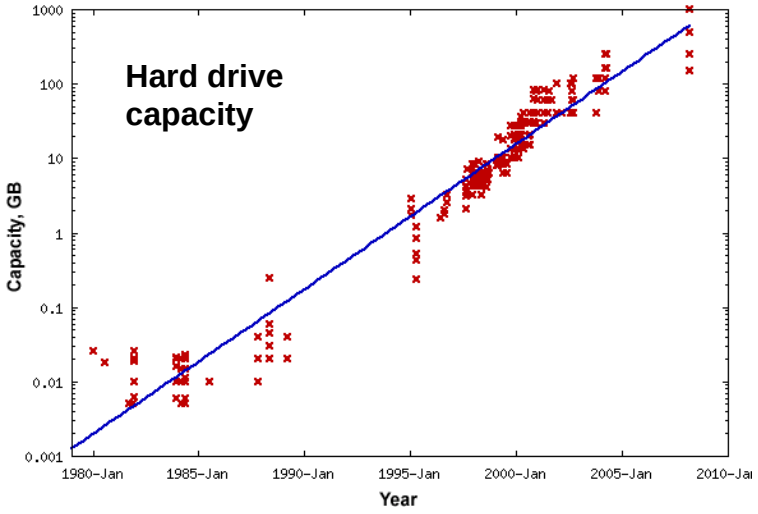
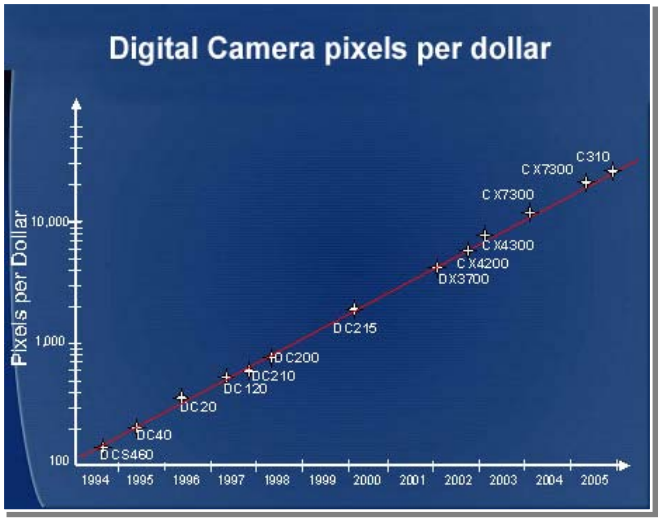
Can we do for energy what microelectronics did for information technology?



Intel





Wikipedia: Moore's Law Images

Atomistic limits?

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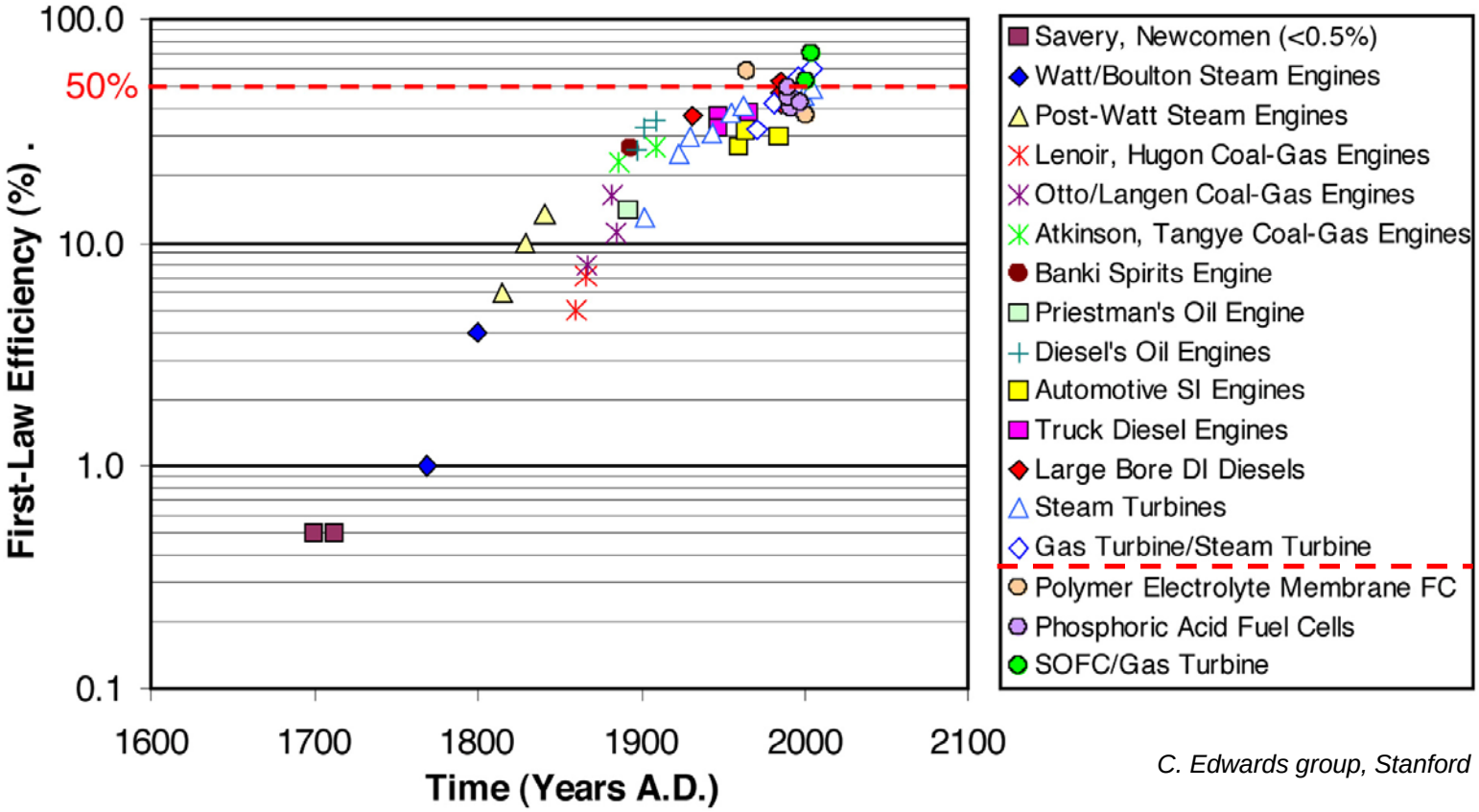
Unfortunately, if you consider a longer time horizon we already have



C. Edwards group, Stanford

For many energy conversion systems, we are at or approaching thermodynamic limits

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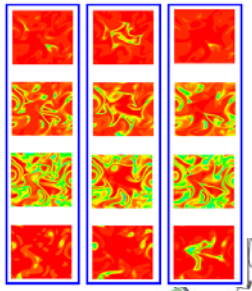
Science and Engineering Excellence and Innovation -- Essential keys to a new energy future

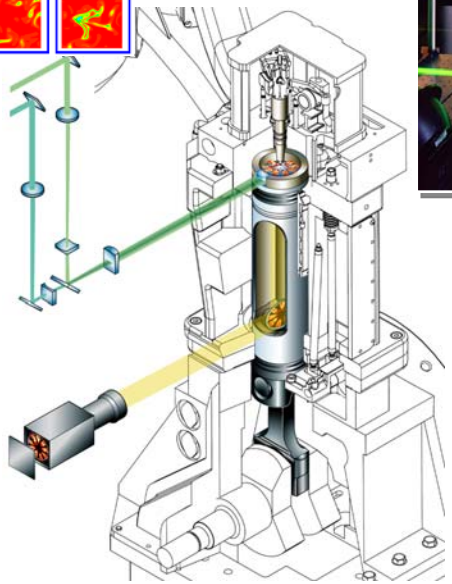
Enabling efficiency and fuel substitution …. three examples

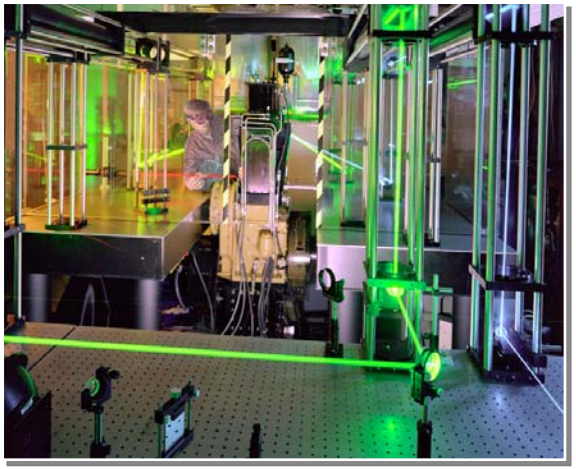
- **Combustion research: transitioning to new fuels while improving efficiency and further reducing pollutants**
- **Solar thermal processing: converting a waste stream, CO_2, to useful products**
- **Biofuels: a systems view and multiple pathways to transportation fuels**

Combustion Research Facility: a 25 year effort to improve the cleanliness and efficiency of auto and truck engines



Theory and experiment





International and university collaborations; Post Doc program

Industrial partnerships

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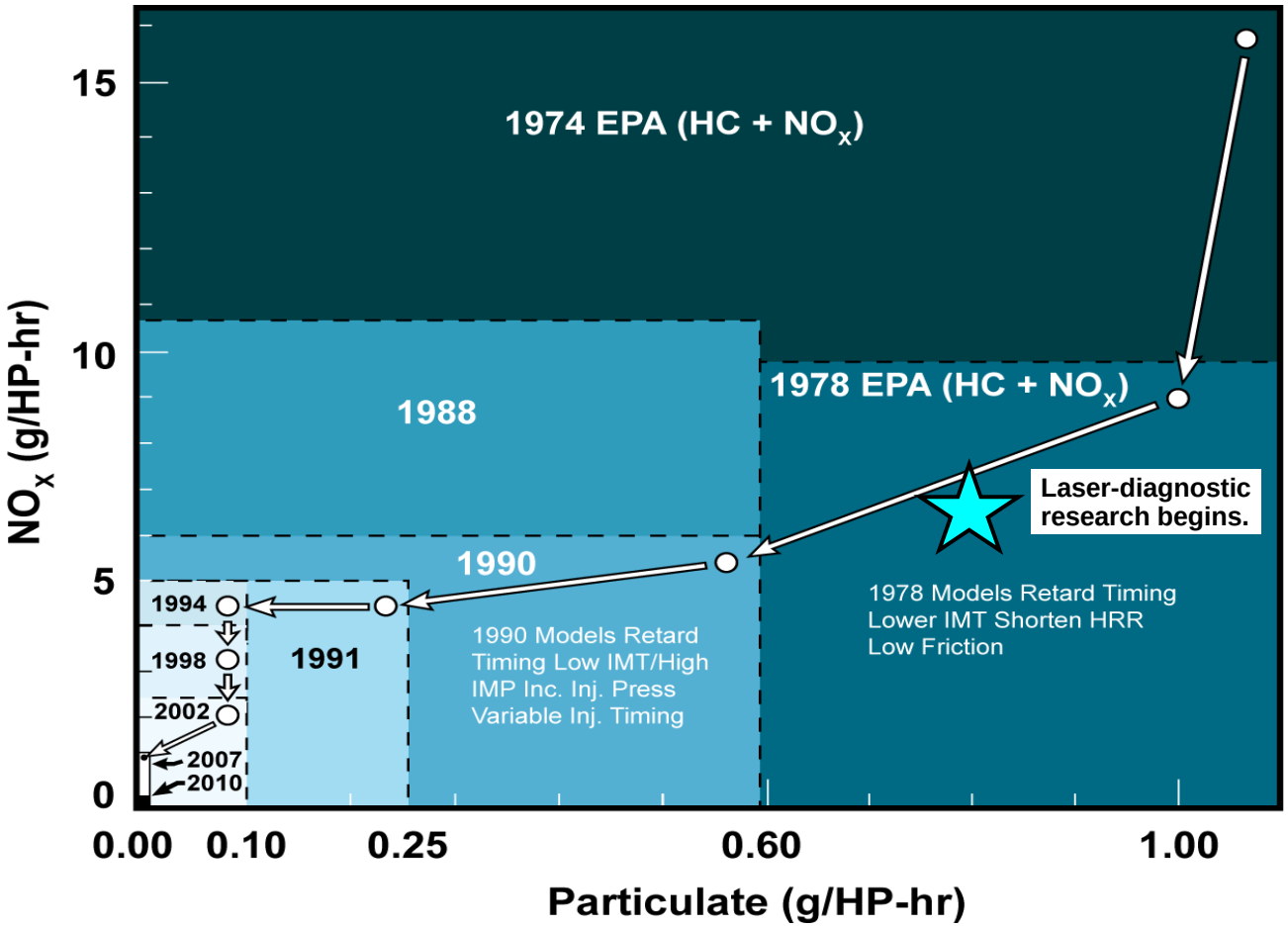
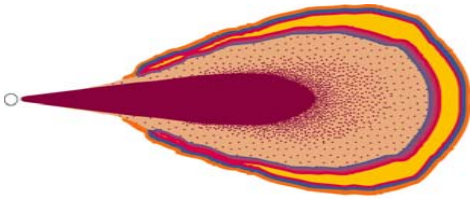
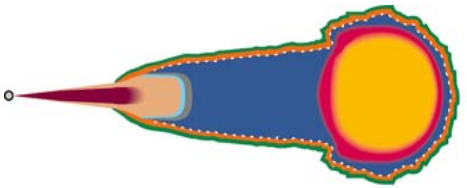
The cleanliness of truck engines has been dramatically improved: NOx and particulates

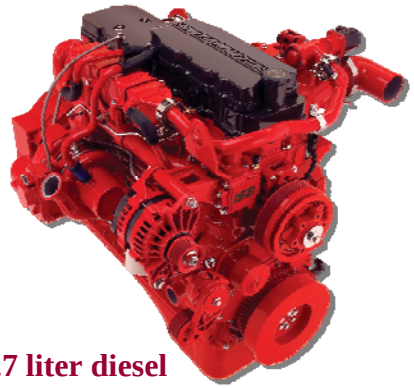




Older diesel theory



Current diesel theory



Cummins 2007 ISB 6.7 liter diesel

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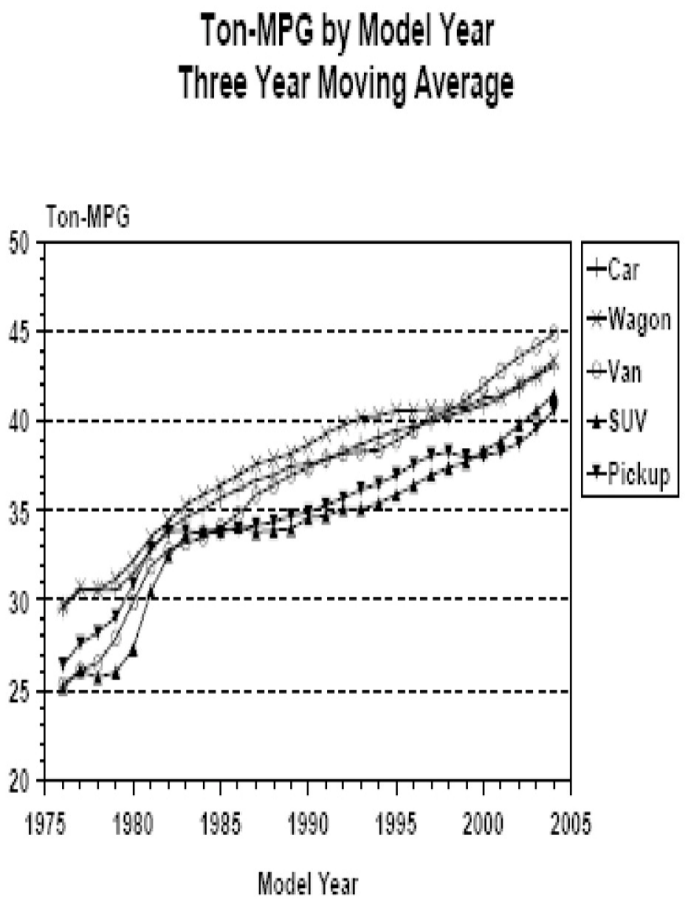
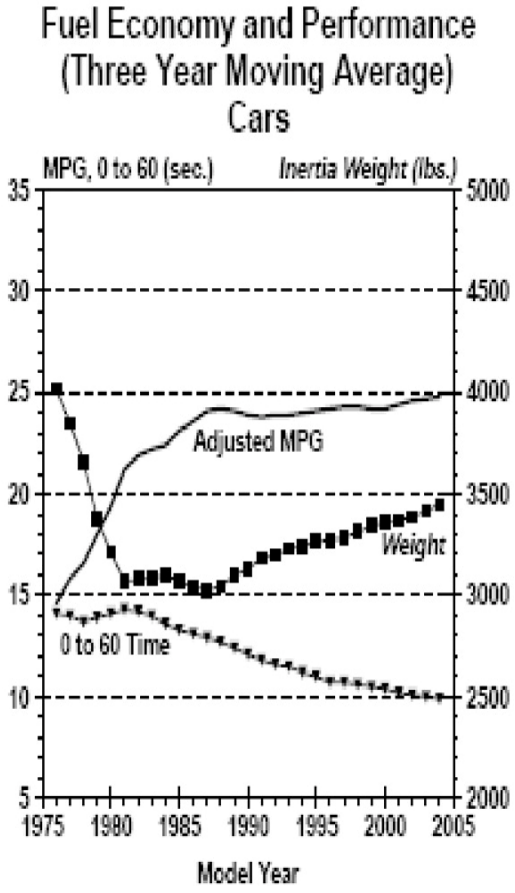
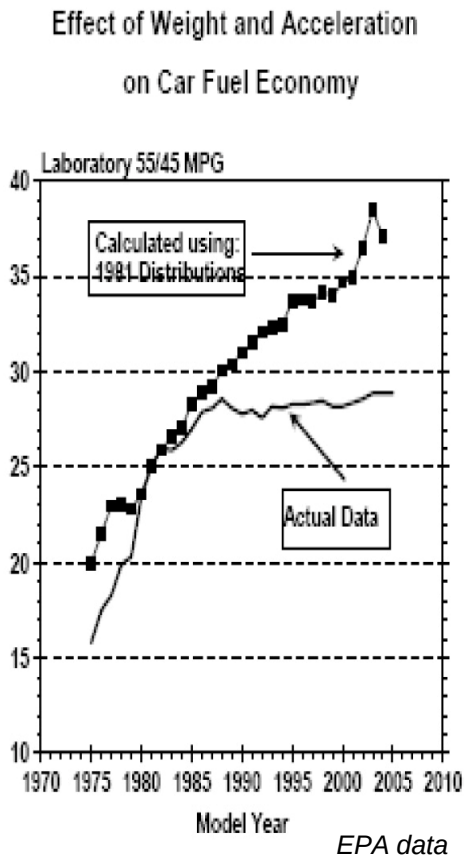
Any energy solution is intertwined with public policy and private choices in the market place







EPA data

Since 1980, U.S. consumers opted for greater weight and acceleration

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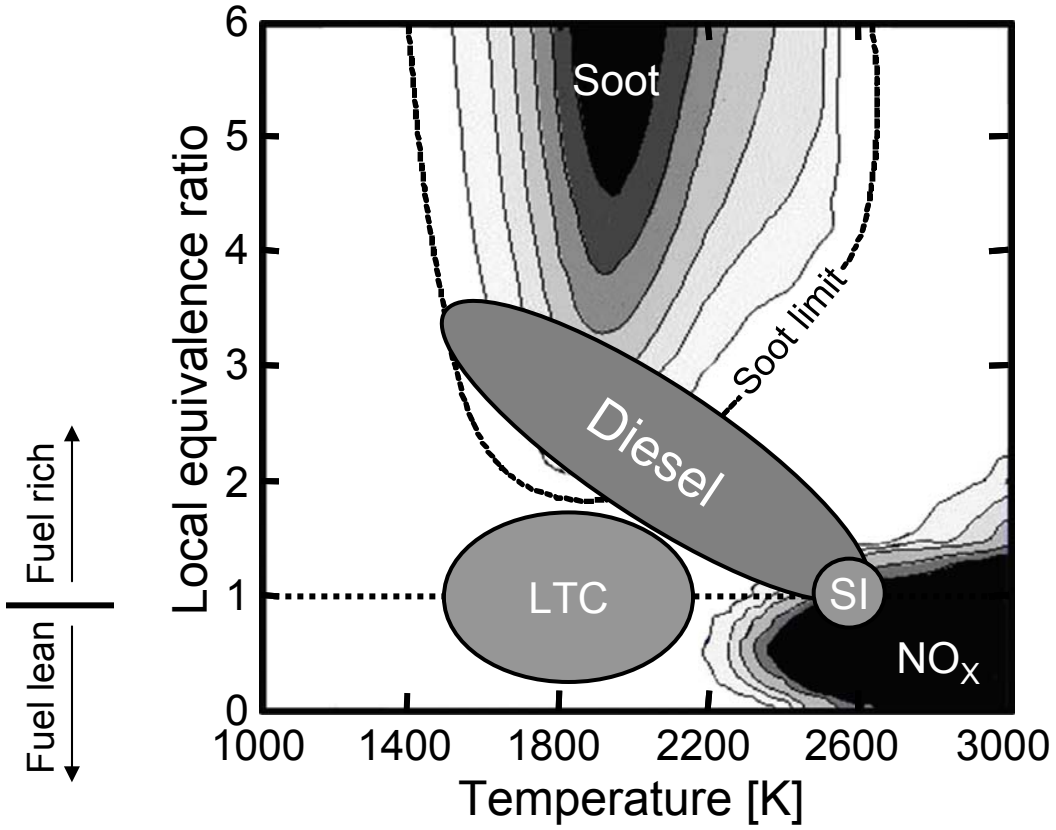
Low-Temperature Combustion (LTC) strategies can both improve efficiency and reduce pollution



Two LTC strategies:

- Homogeneous-Charge Compression-Ignition (Spark Initiated)
- Premixed-Charge Compression-Ignition (Diesel)

LTC challenges:

- Combustion phasing
- Engine load range
- Heat release rate
- New fuels

Using existing tools in new and innovative ways:

Heat transfer at very high temperatures and very large scales

National Solar Thermal Test Facility: a unique laboratory for heat transfer experiments and innovations

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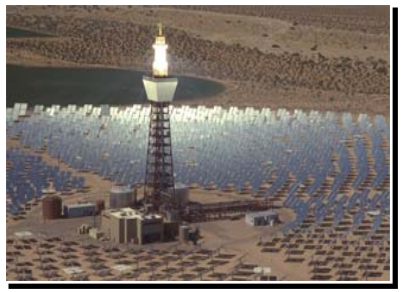
Using solar heat to make syngas from CO_2 and H_2O: *sunlight to fuel without the biology*

Solar Heat

$h\nu$



CO_2

H_2O

Energy Input (Reduction)

CO_2
H_2O

Fuel
O_2

Energy Recovery (Combustion)

O_2

$\underline{CO + H_2}$
Syngas to transportation fuels (gasoline, diesel, jet fuel)

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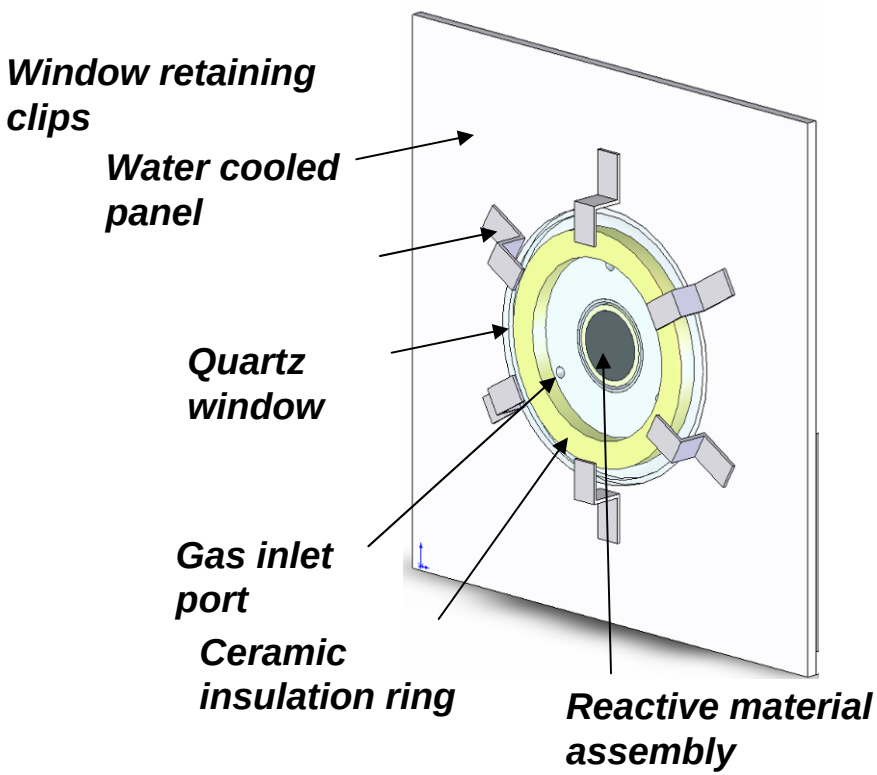
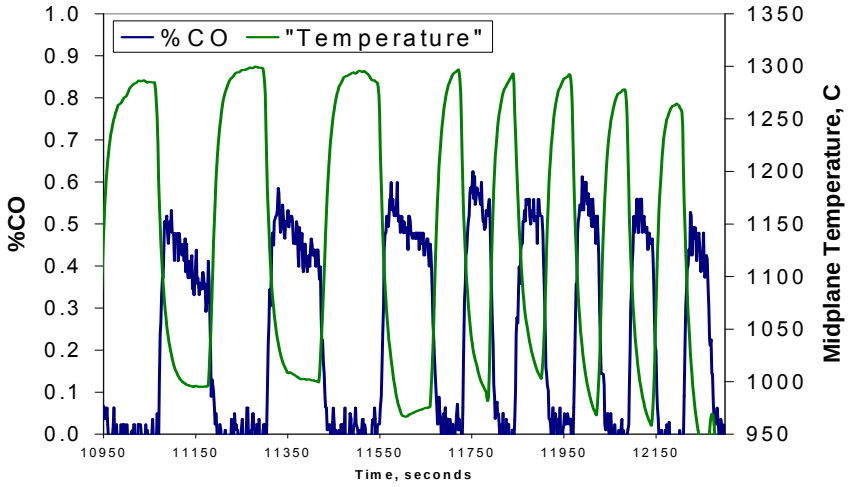
CO_2 and H_2O splitting have been demonstrated: at 1000-1300º C





Fe and mixed metal oxides have the ability to split both CO_2 and H_2O

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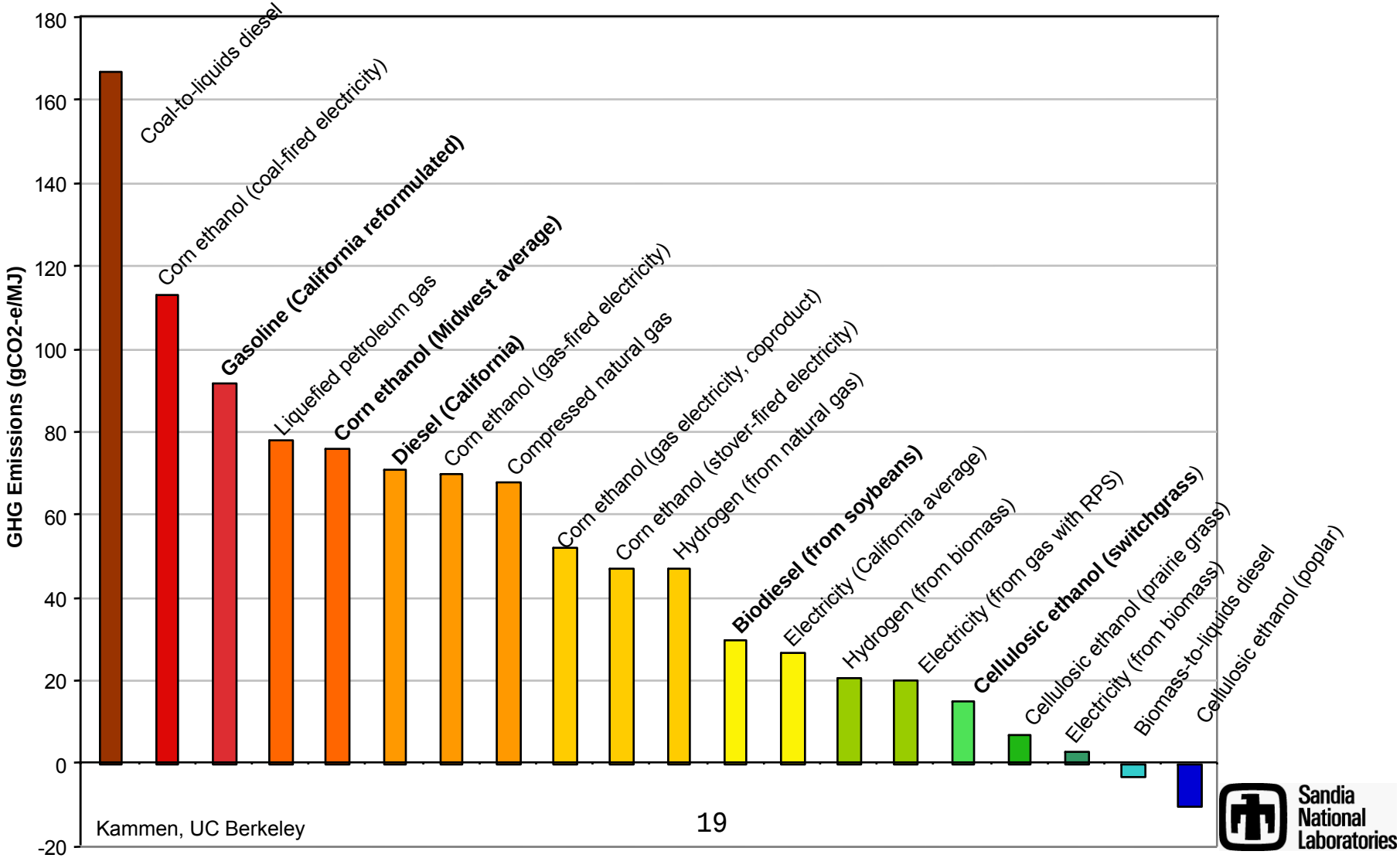
The complexities of carbon management make system level approaches an imperative



Kammen, UC Berkeley

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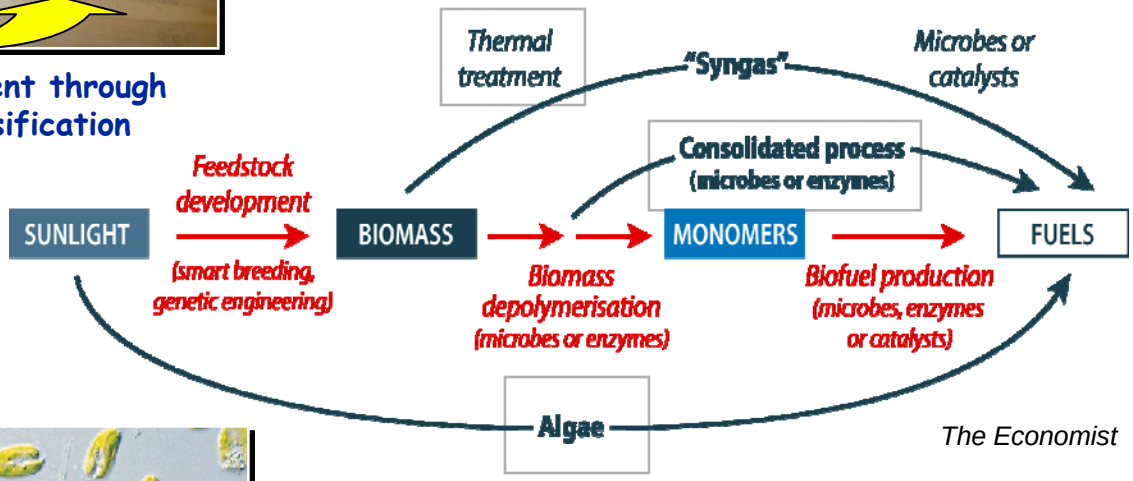
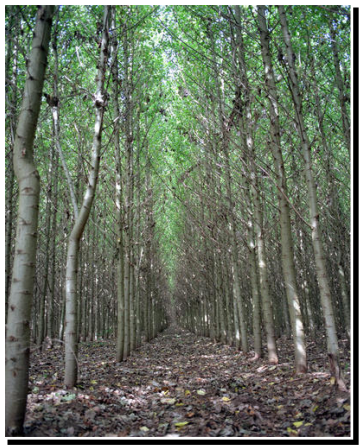
Biofuels using biology: multiple pathways enable process and fuel options

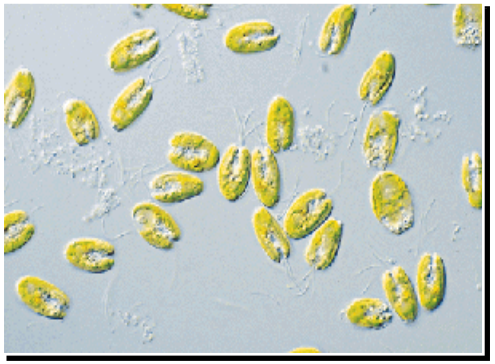
Thermal treatment through pyrolysis and gasification



The Economist



Enzymatic processing of lignocellulose



Bioengineered algae

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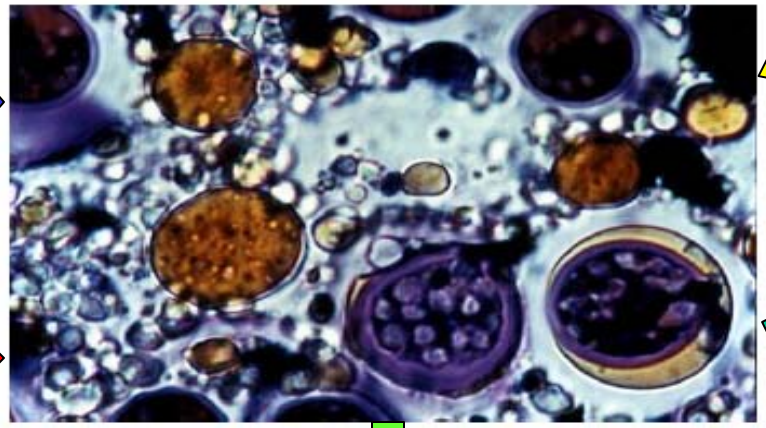
Algae Production Systems: reducing the cost of inputs and improving the value of fuels and co-products requires systems thinking

Impaired Water
- Desalination concentrate
- Ag wastewater
- Industrial wastewater
- Municipal wastewater

CO_2 & Heat
- Electric power generation
- Ag processing
- Industrial processing
- Wastewater treatment
- Desalination

Algae Production Systems



Sunlight

O_2

Biomass harvesting

Processing

Co-products
- feeds
- fertilizers
- biopolymers
- glycerine
- other

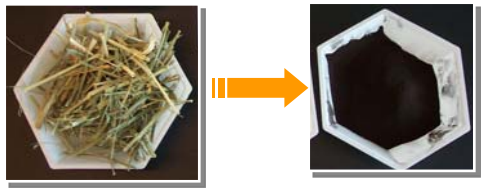
Reclaimed Water
- nutrient removal

Biofuels
- biodiesel
- ethanol
- biogas
- bio-oil

Thermal processing of biomass:
post-processing of cellulose and production of biocrude

Gasification

- **Conversion efficiency and rates: effect of temperature and pressure**
- **Gasifying residual lignin in cellulosic ethanol plants**

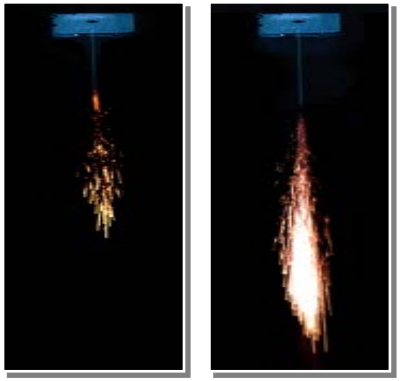


Switchgrass *Lignin*

Lab-scale gasifier

Pyrolysis

- **Effect of pyrolysis severity (temperature and residence time) on the combustion properties of biocrude**

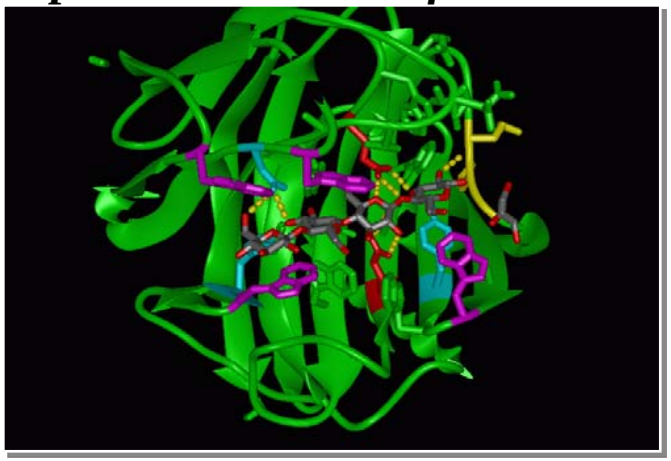


Biocrude combustion

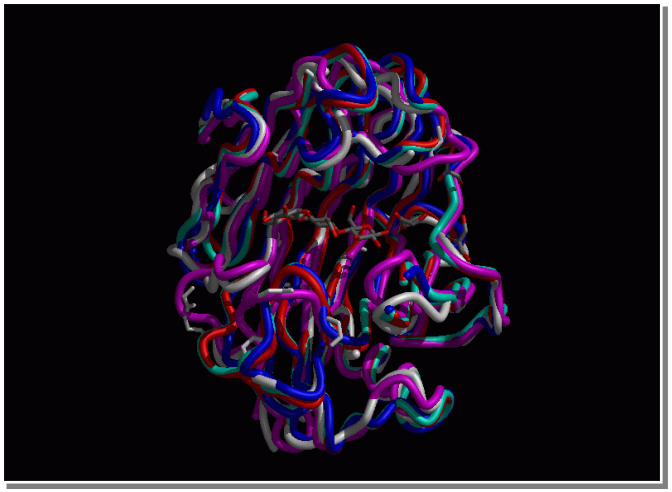
Engineering enzymes for biofuels from cellulose

- **Key challenge: advanced enzymes that hydrolyze cellulose into glucose**
- **Enzymes are one of the most expensive biofuels components**
  - **~$0.50 – 1.00/gallon of fuel**
- **Results to date: new enzymes that work faster and cost less**

Computational Model of Cellulase



Comparative Study of Multiple Enzymes



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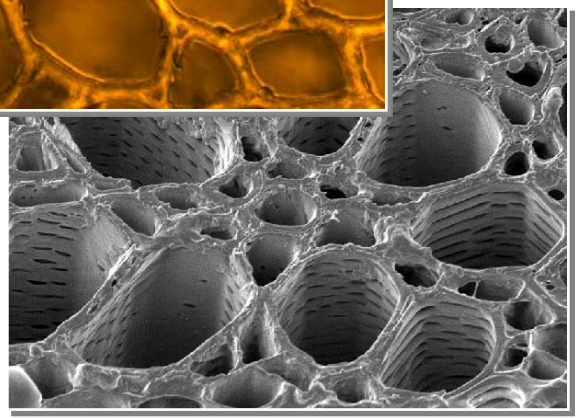
JBEI: a new approach to basic research driven by industry and government

- Joint BioEnergy Institute: five year, $135M
- Transportation bio-fuels R&D
- Laboratory/University consortium: LBNL, SNL, LLNL, UC-Davis, UC-Berkeley, Stanford
- 65,000 sq. ft. at industrial biotech R&D park (Emeryville, CA)
- Industrial advisory committee
- Scale-up is a part of the R&D program design
- Post Doc programs
- Rotational assignments for DOE scientists
- Open innovation: industrial and international partnerships



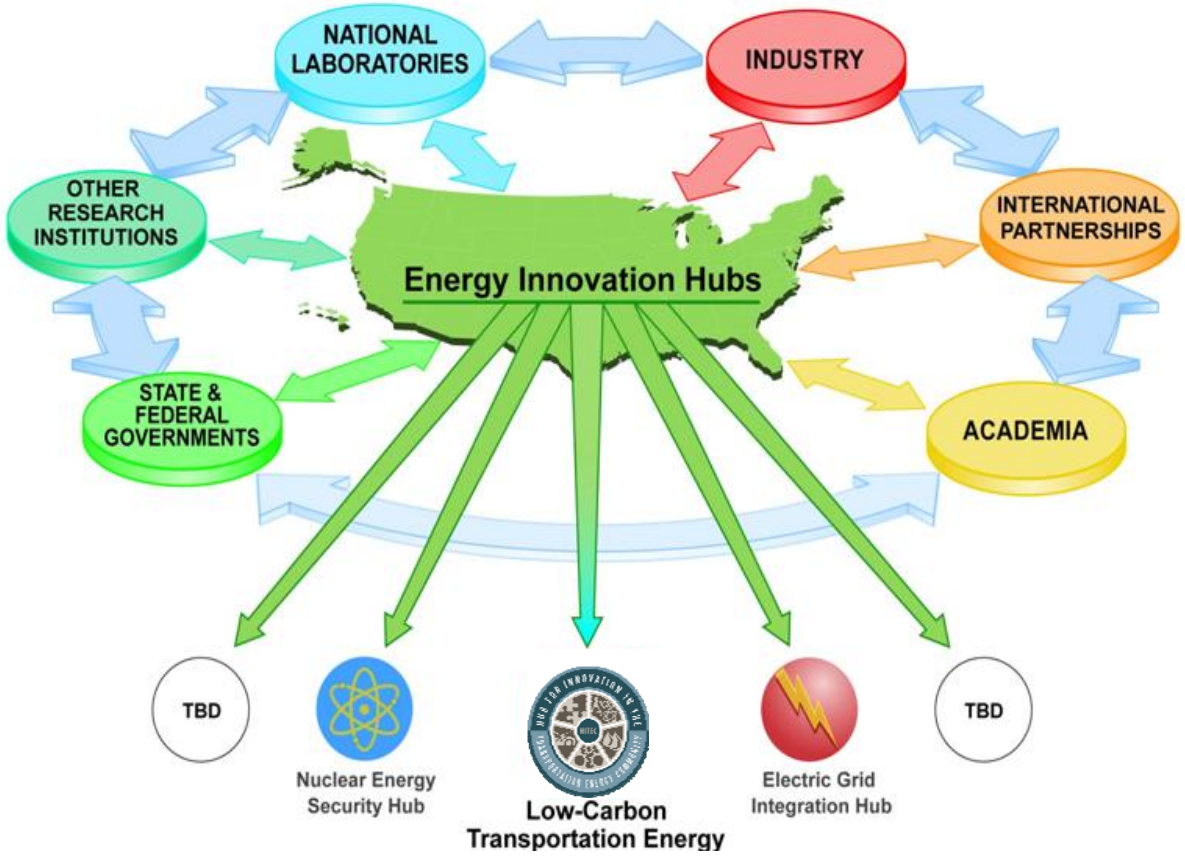
Other DOE Bioenergy Research Centers: at Oak Ridge and at the University of Wisconsin, Madison

Open Innovation and Engineering Networks:
Research hubs organized by outcomes, not technologies

Combustion Research Facility and JBEI-- the eventual goal is

Low-Carbon Transportation Energy

- **Scope: from science to engineering**
- **Scale: broad research base, scale-up of lab innovations**
- **Partners: international science and global industries**



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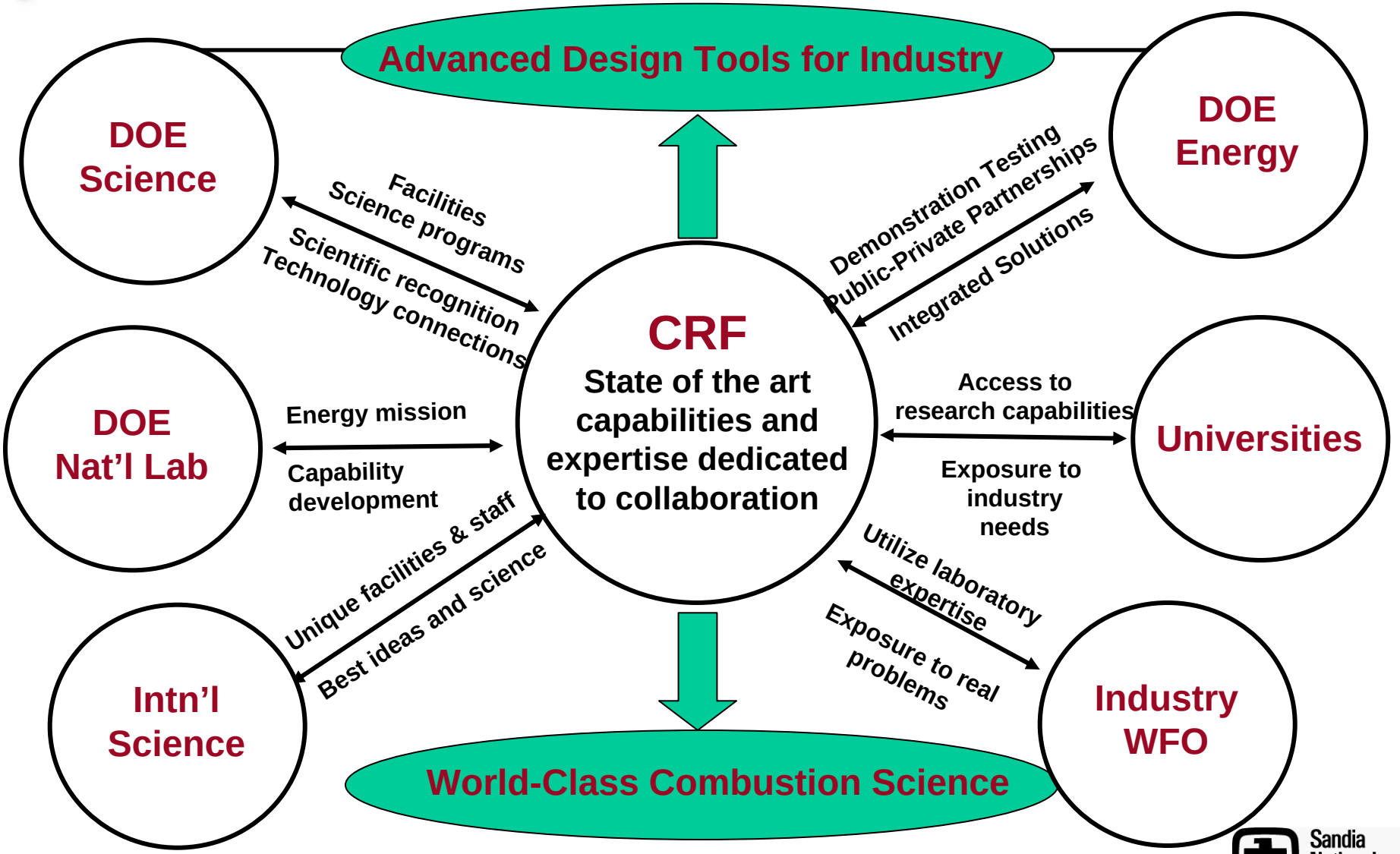
Value Map for CRF

"International Center of Excellence"



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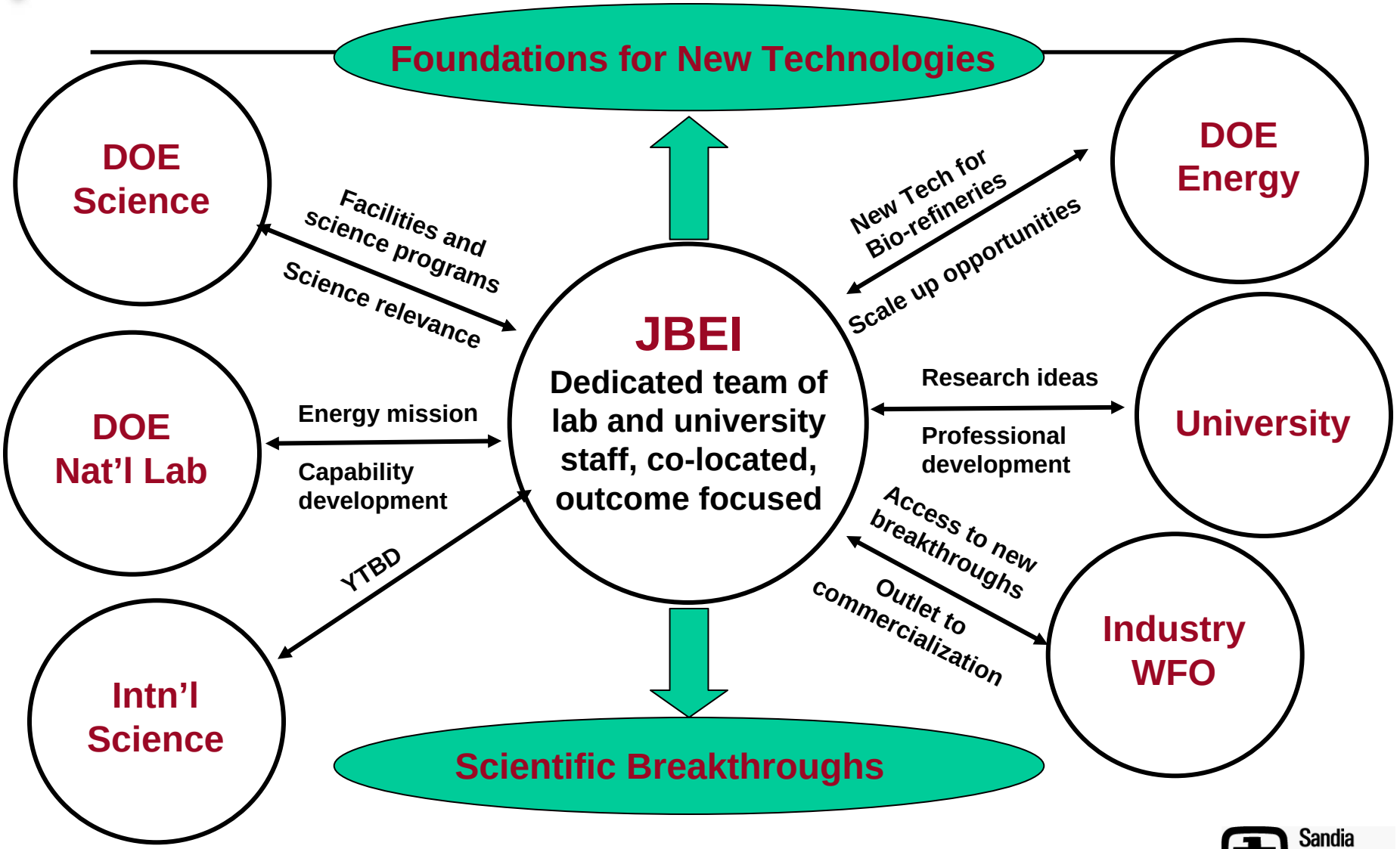
Value Map for JBEI
"Government Start-up"



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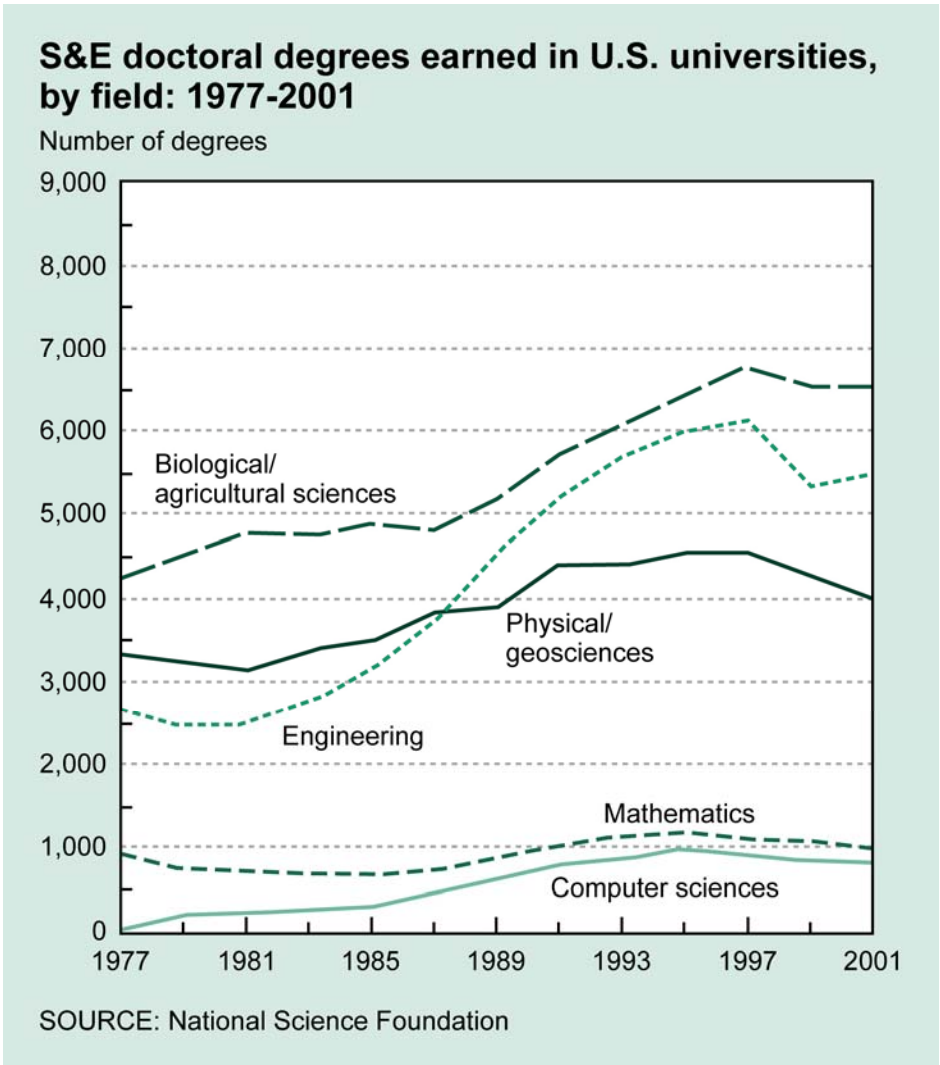
Universities will provide the talent and skills to meet the energy challenge



OTHER RESEARCH OPPORTUNITIES

- **Battery electric storage**
- **Photovoltaic conversion**
- **Hydrogen production and storage**
- **CO_2 capture**
- **Carbon sequestration**
- **Modular safe nuclear reactors**

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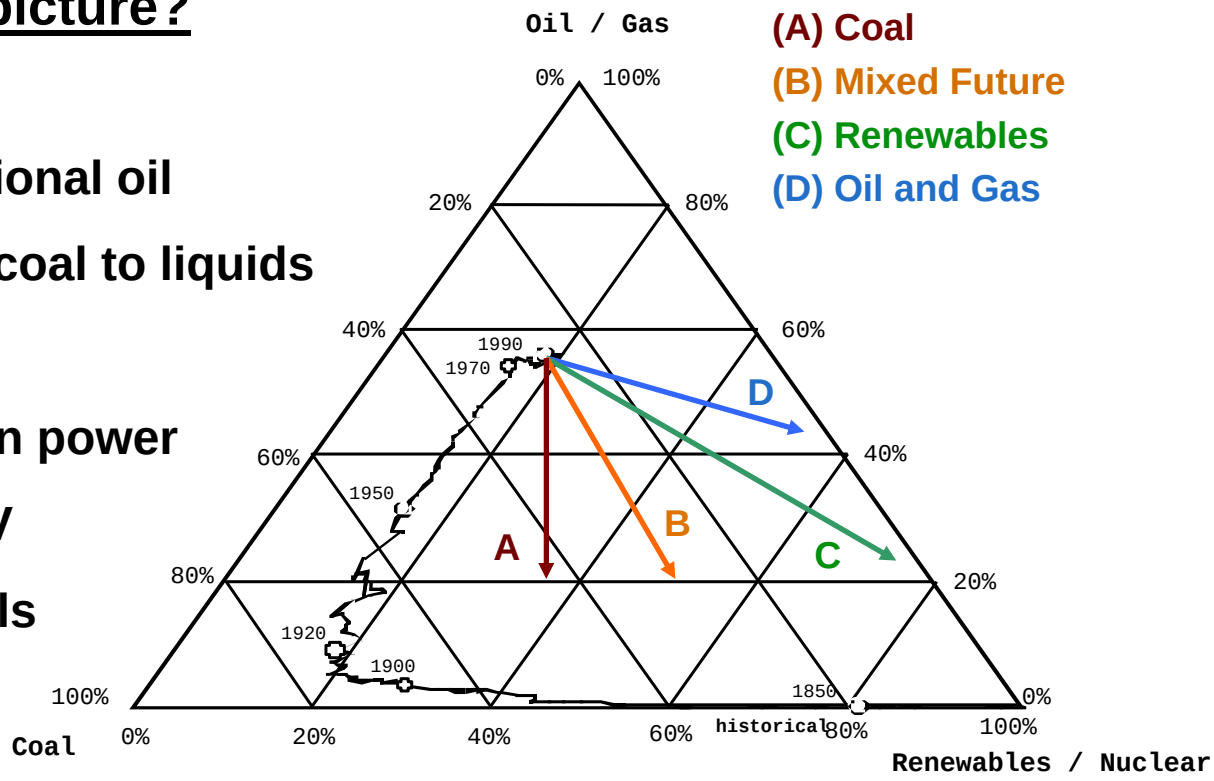
Driving our next energy transition: Our Science/Engineering and Innovation must enable our options

35 years hence, what will characterize our energy picture?

- **Peaking of conventional oil**
- **New sources of unconventional oil**
- **Low carbon conversion of coal to liquids**
- **Methane from shale**
- **Harnessing wave and ocean power**
- **Extremely efficient solar PV**
- **Genetically tailored bio-fuels**



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THANK YOU
PURDUE

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