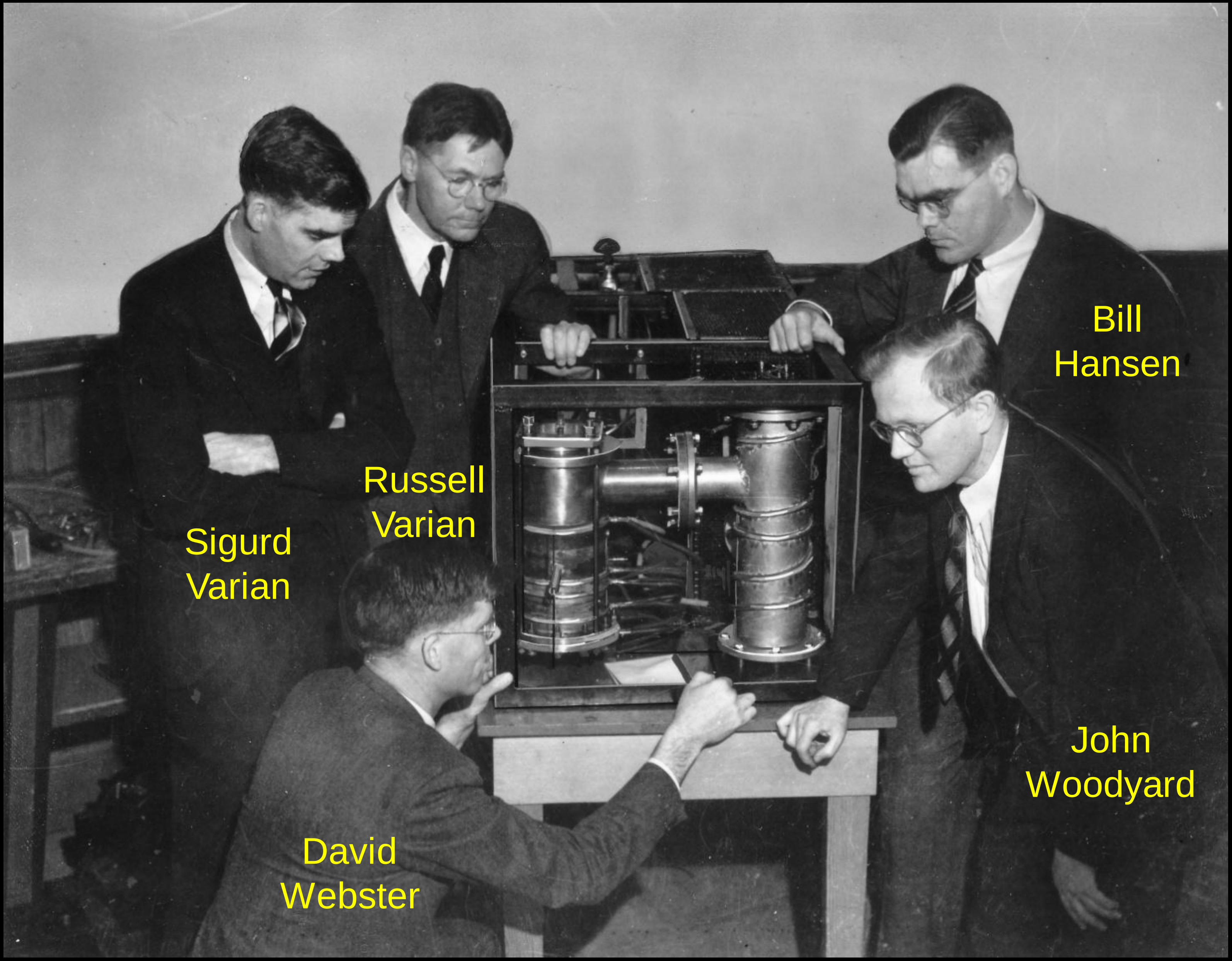
# How technology can change the world

Panofsky Auditorium
SLAC, Stanford University
24 August, 2012

# The Klystron



Steven Chu and Arun Majumdar

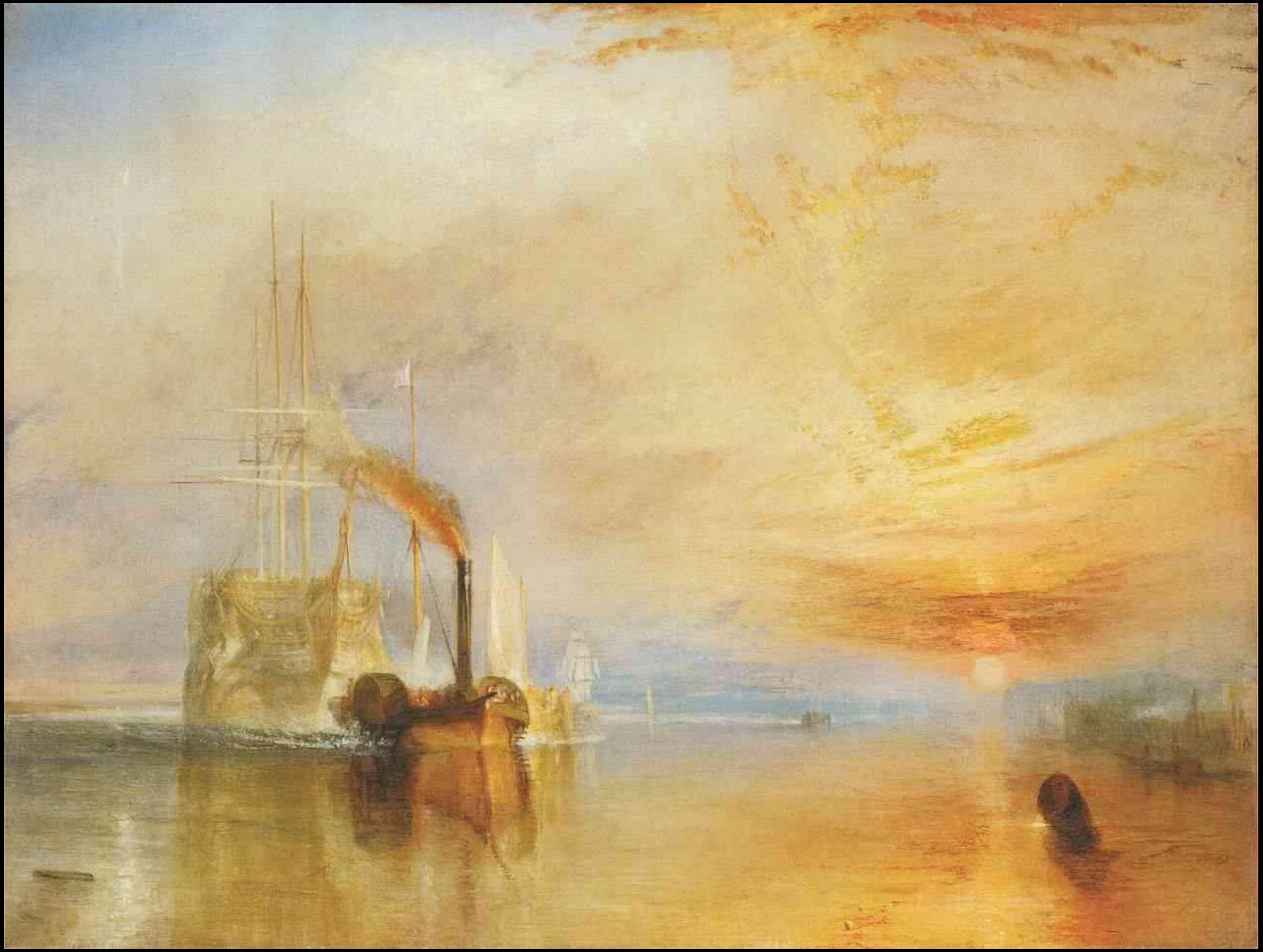
*Nature* **488**, pp. 294 – 303 (2012) August 16 issue.

PERSPECTIVE

doi:10.1038/nature11475

# Opportunities and challenges for a sustainable energy future

# The Industrial Revolution and the transition from horse power to *horsepower* transformed the world



J.M.W. Turner (1839) The H.M.S. Temeraire, distinguished in Battle of Trafalgar, being towed to her last berth to be broken up for scrap.

# The gasoline-powered internal combustion engine rapidly replace horse powered vehicles.


**New York, 5th Avenue, ~1890s**

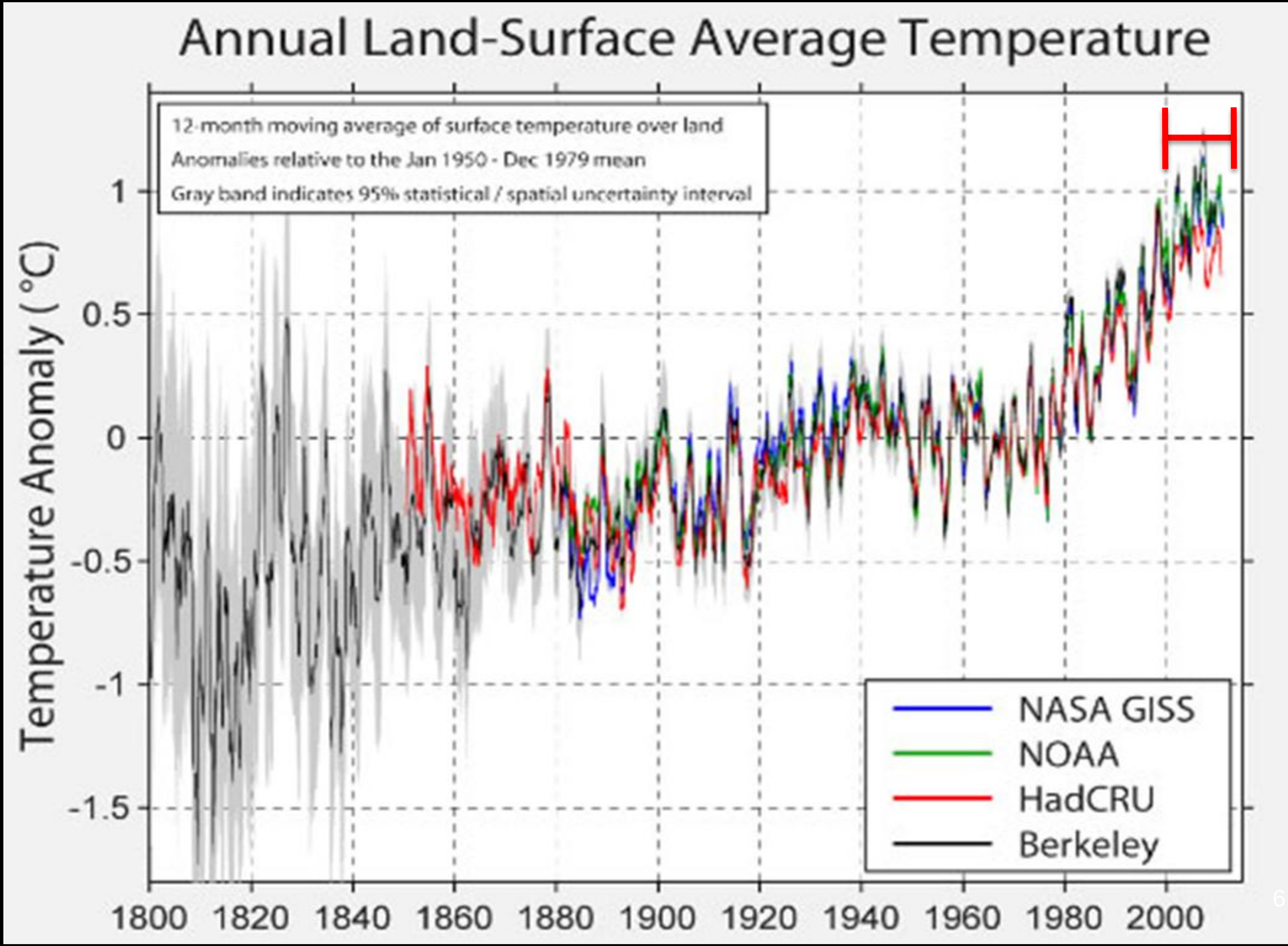

**Detroit, circa 1920**

Automobile technology was superior to horse-drawn vehicles. A serious environmental pollution issue hastened the transition.

The ~160,000 horses in New York and Brooklyn in 1880 were producing 3 - 4 millions pounds of horse manure and 40,000 gallons urine a day.*

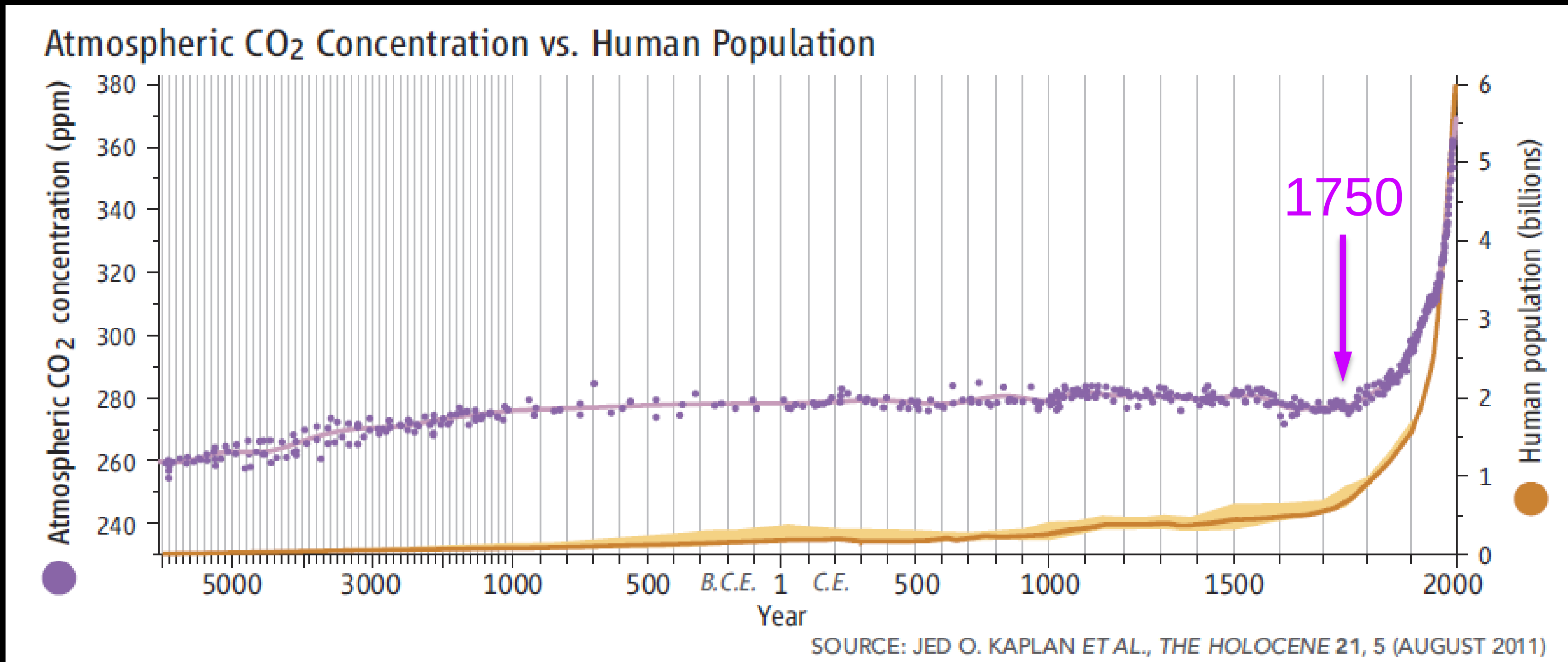
* http://www.uctc.net/access/30/Access%2030%20-%2002%20-%20Horse%20Power.pdf

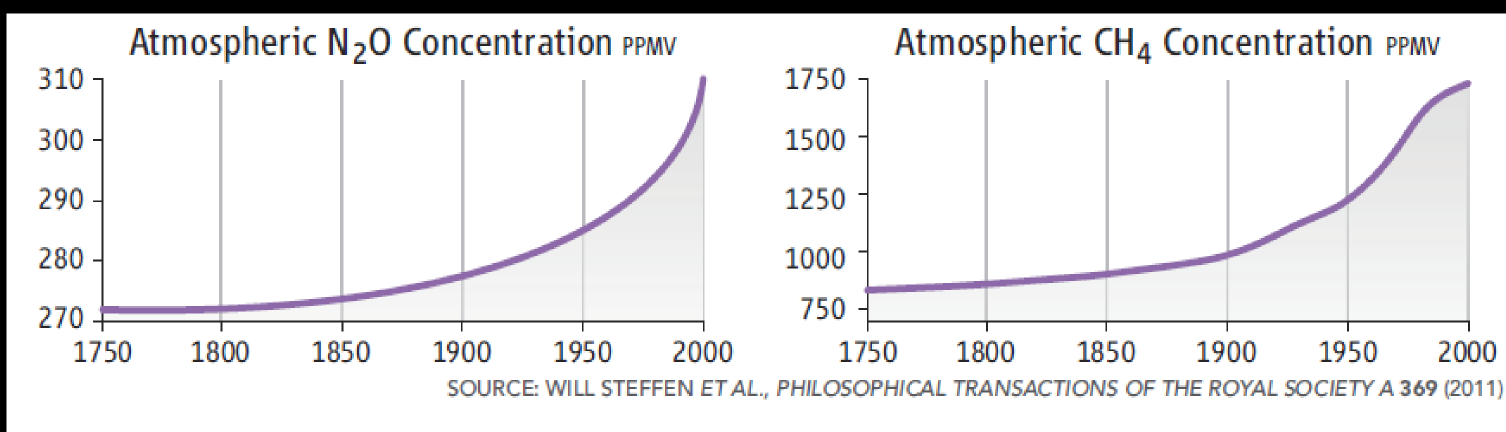
# The temperature record 1800 - 2010



# Greenhouse gases in the atmosphere

*Science* **334**, 34 (2011)

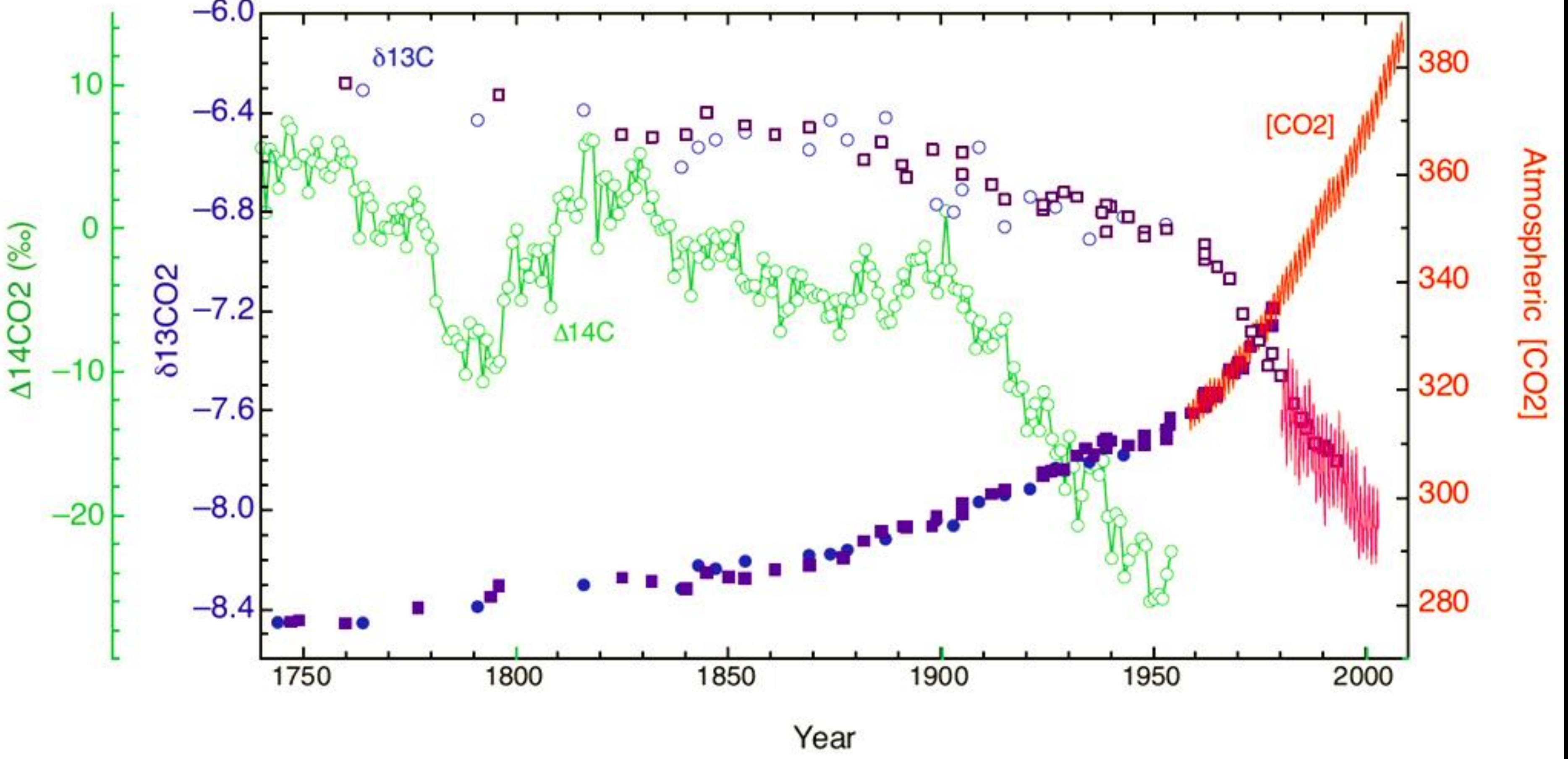


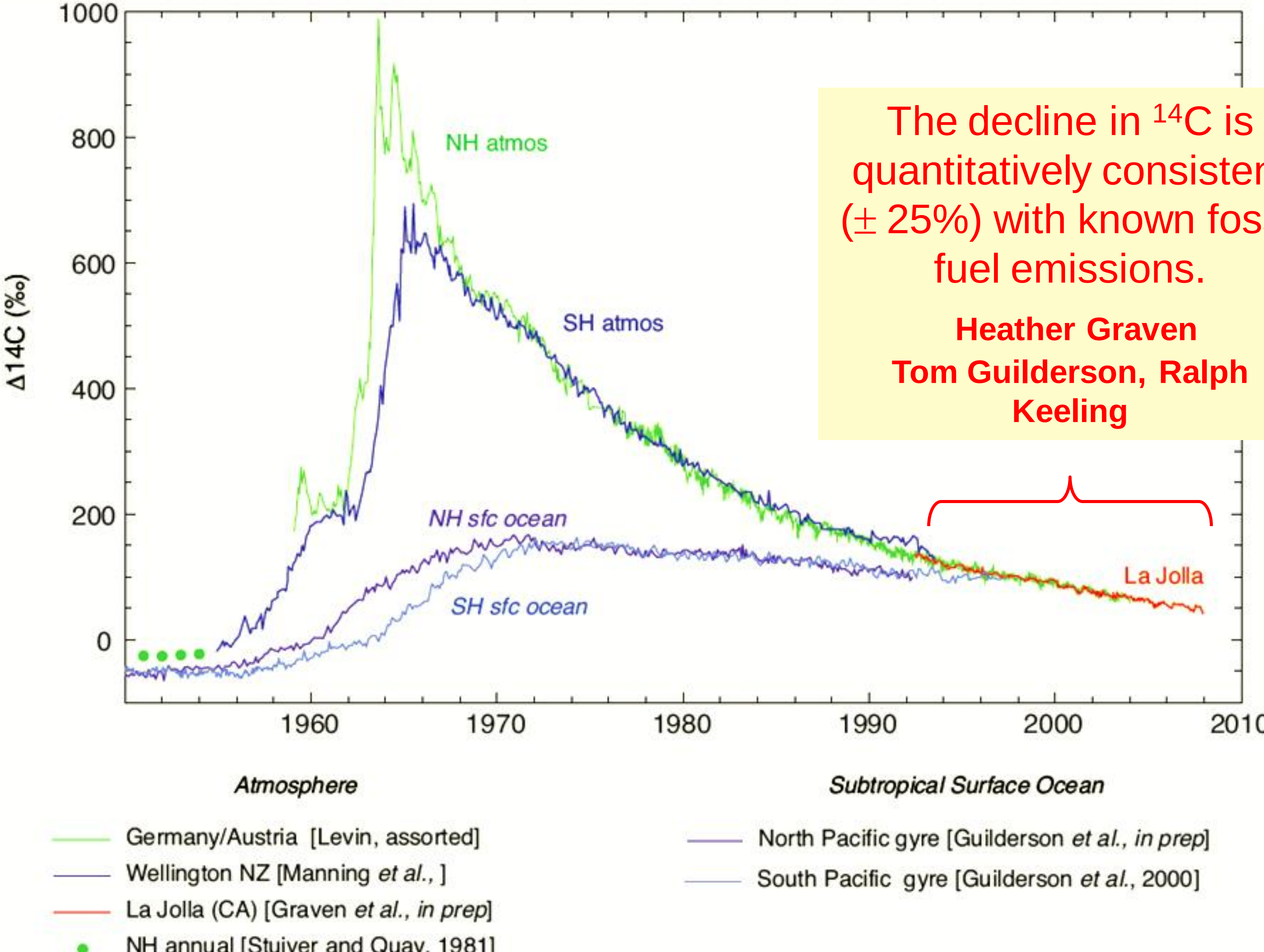
$^{14}C$ is produced through cosmic-ray bombardment. It is incorporated into plants and animals and decays with a 5,730 year half-life.

Fossilized organic material is depleted of $^{14}C$. Burning fossil fuel will add $^{12}C$ to the atmosphere and lower the $^{14}C/^{12}C$ ratio.

## Suess Effect



# Post 1950 Atmosphere and Surface Ocean $\Delta^{14}C$ History



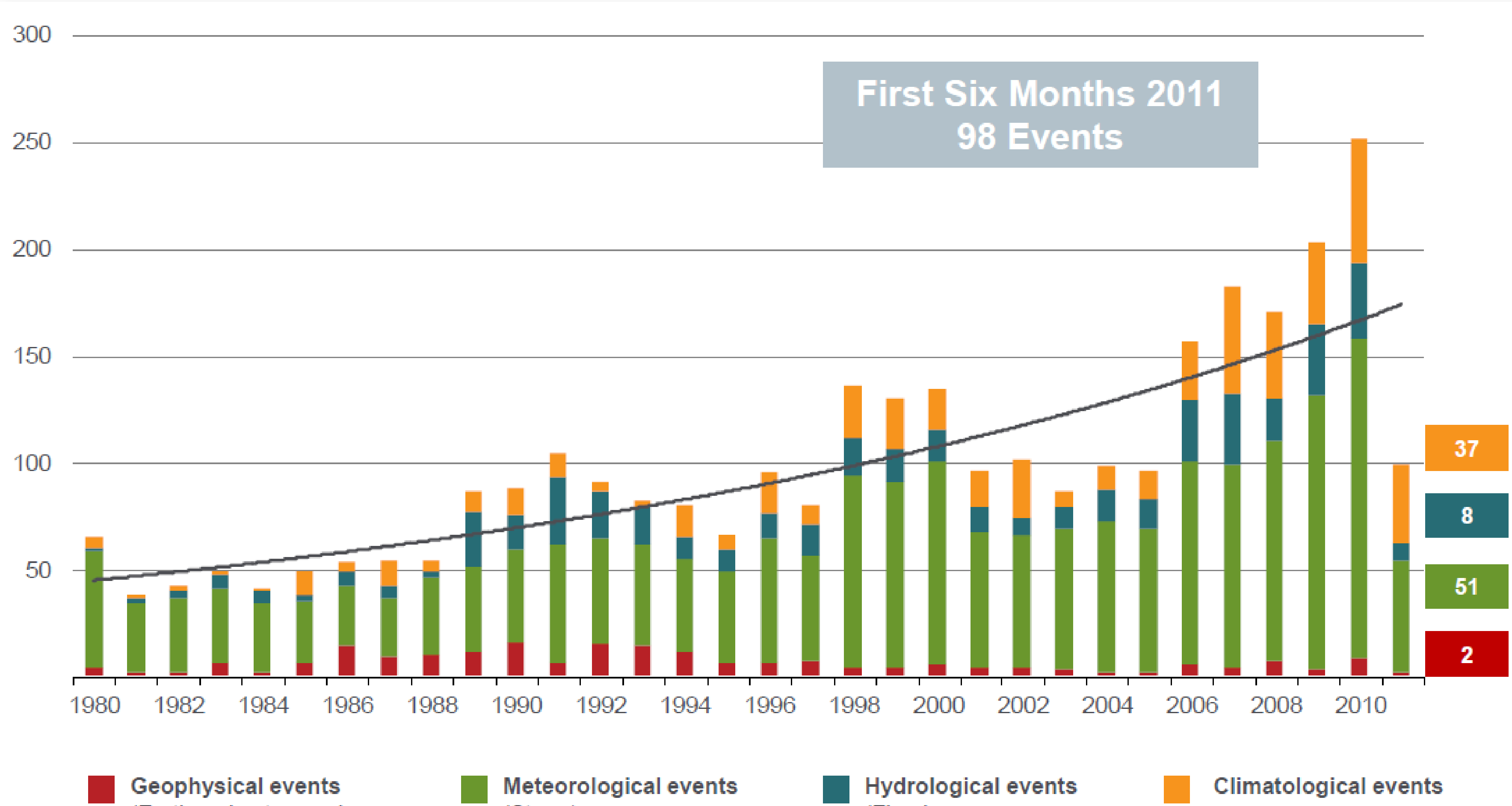

The decline in $^{14}C$ is quantitatively consistent ($\pm$ 25%) with known fossil fuel emissions.

**Heather Graven**
**Tom Guilderson, Ralph Keeling**

# Natural Disasters in the United States, 1980 – 2011

Munich RE

## Number of Events (Annual Totals 1980 – 2010 vs. First Six Months 2011)




**Geological** events (earthquake, etc.)

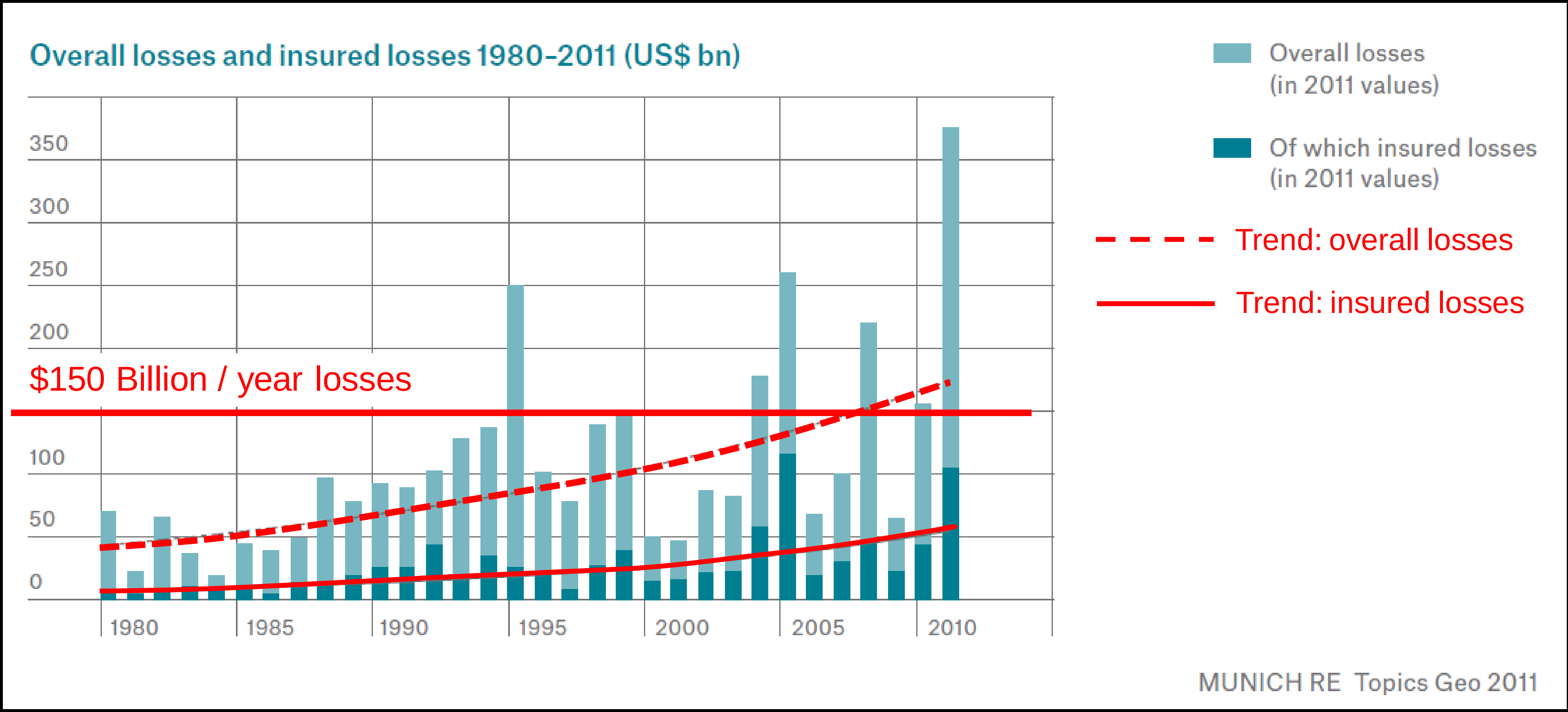
**Meteorological** events (storms)

**Hydrological events** (floods)

**Climatological events** (extreme temp, drought, forest fire)

Source: MR NatCat*SERVICE*

# The time average trend of insured *and* uninsured losses is exceeding $150 Billion/ year.

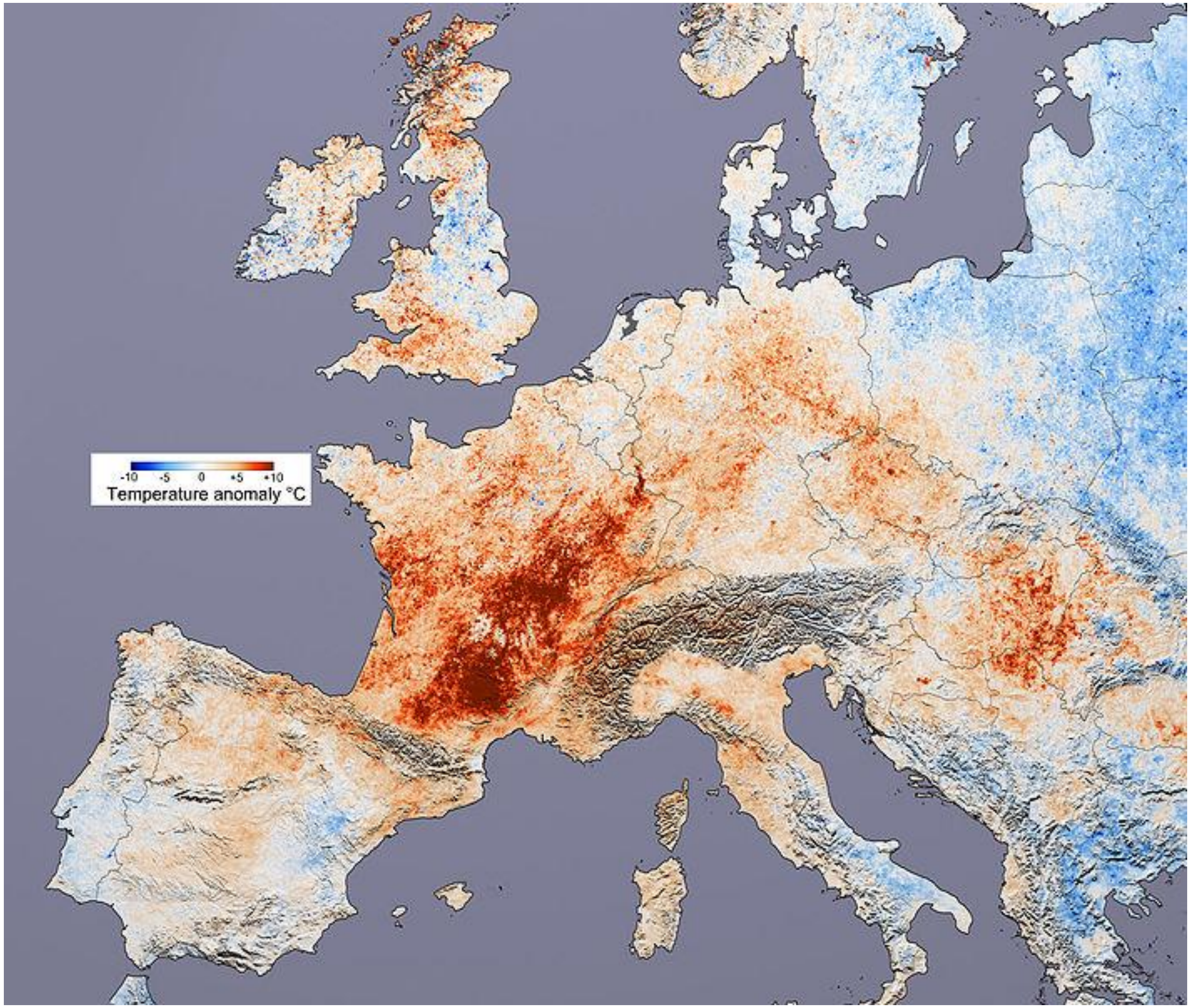



Source: http://www.munichre.com/publications/302-07225_en.pdf

# Aug. 2003: European heat wave

## Temperature anomalies reached 10°C

## 52,000 Europeans died—18,000 Italians (2006 assessment)*



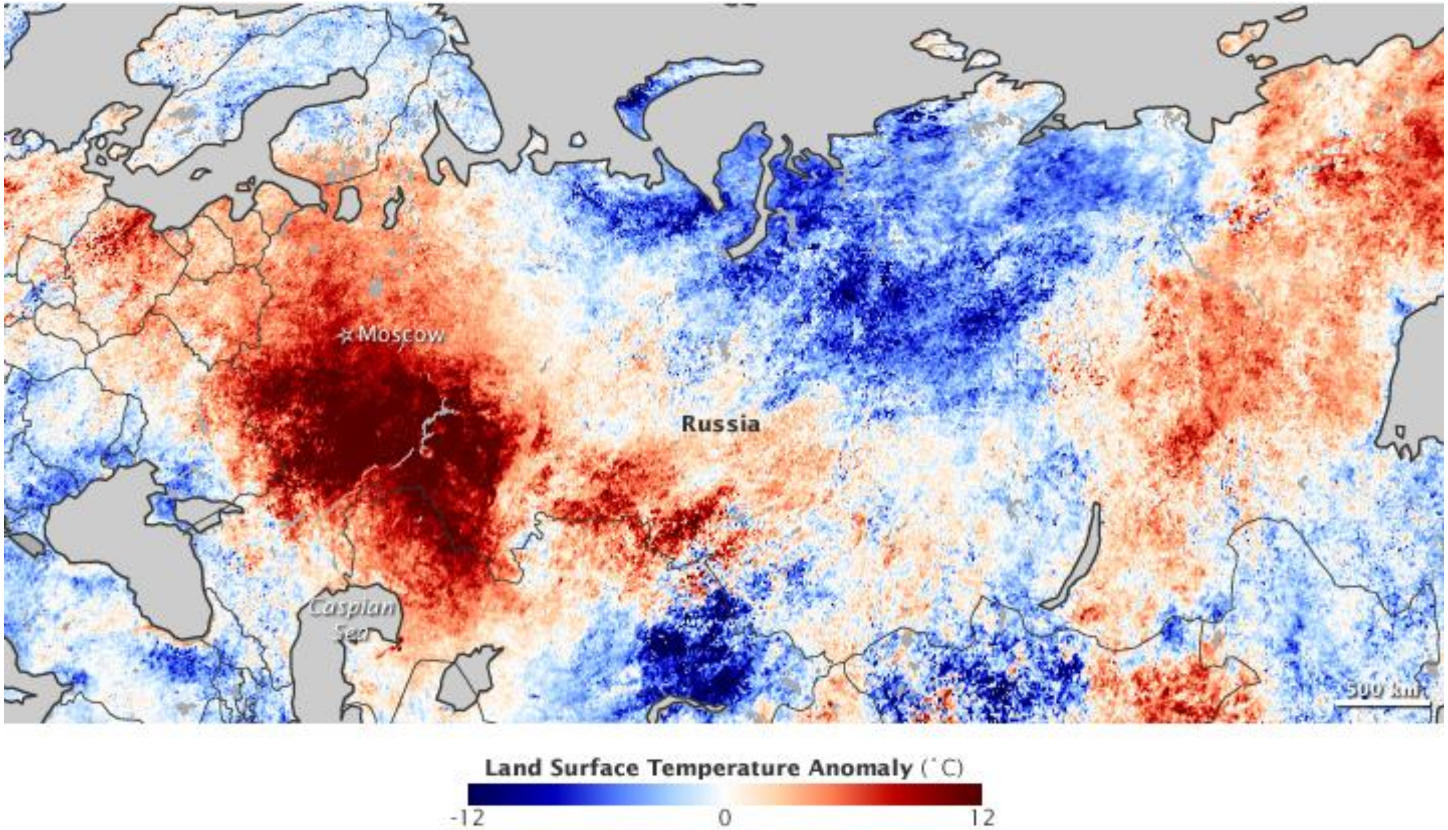

| Country | Fatalities |
|---|---|
| Italy | 18,257 |
| France | 14,802 |
| Germany | 7,000 |
| Spain | 4,130 |
| England & Wales | 2,139 |
| Portugal | 2,099 |
| Smaller countries | 4,025 |
| **Total of above** | **52,452** |

http://earthobservatory.nasa.gov/IOTD/view.php?id=3714

# 2010: Heat wave centered Southeast of Moscow

Temperature anomalies reached 12°C

10,000-15,000 deaths

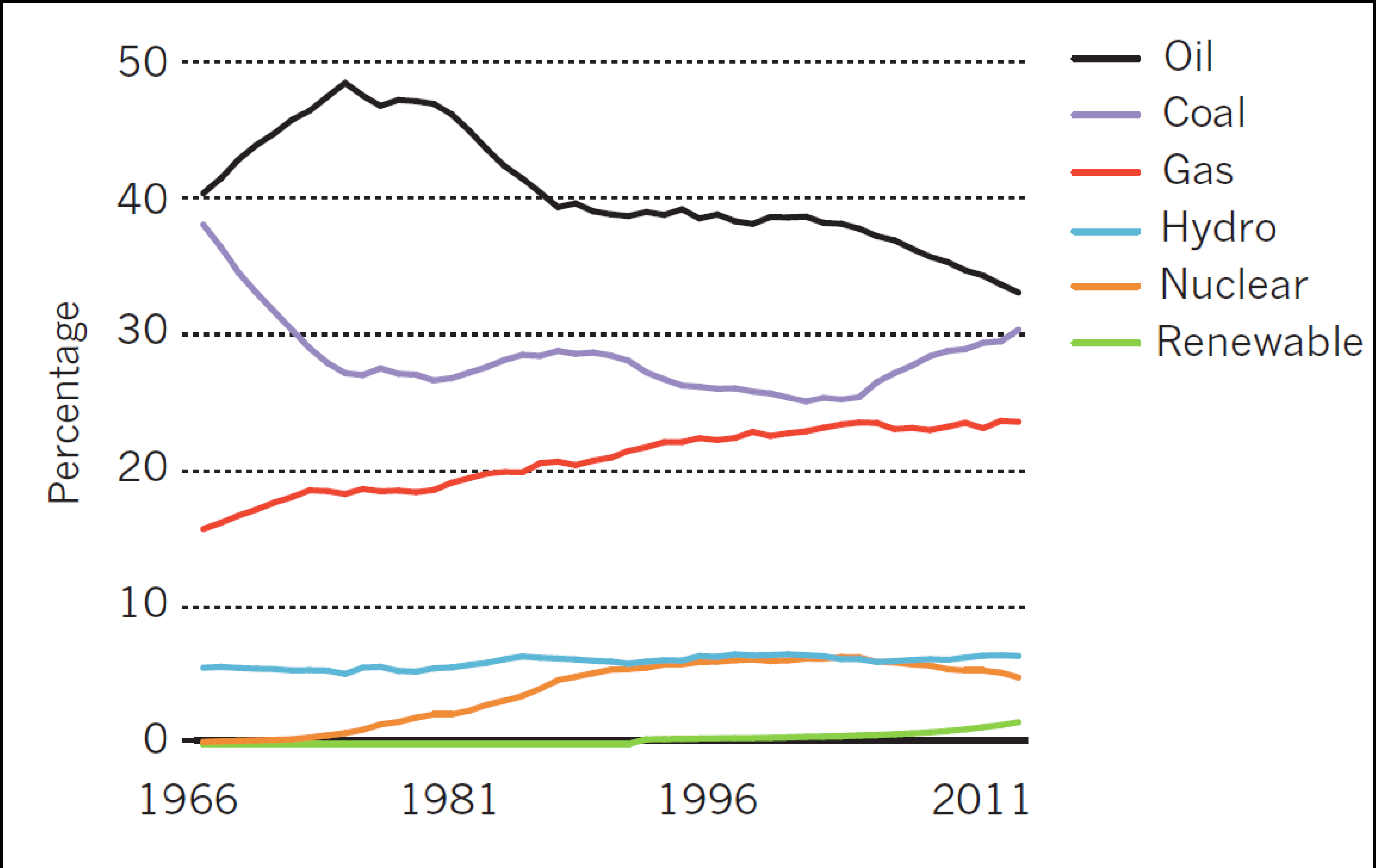



http://takvera.blogspot.com/2011/10/climate-change-fractional-attribution.html

Addressing the energy and climate challenge provides an *opportunity* to promote sustainable growth and secure our future prosperity.

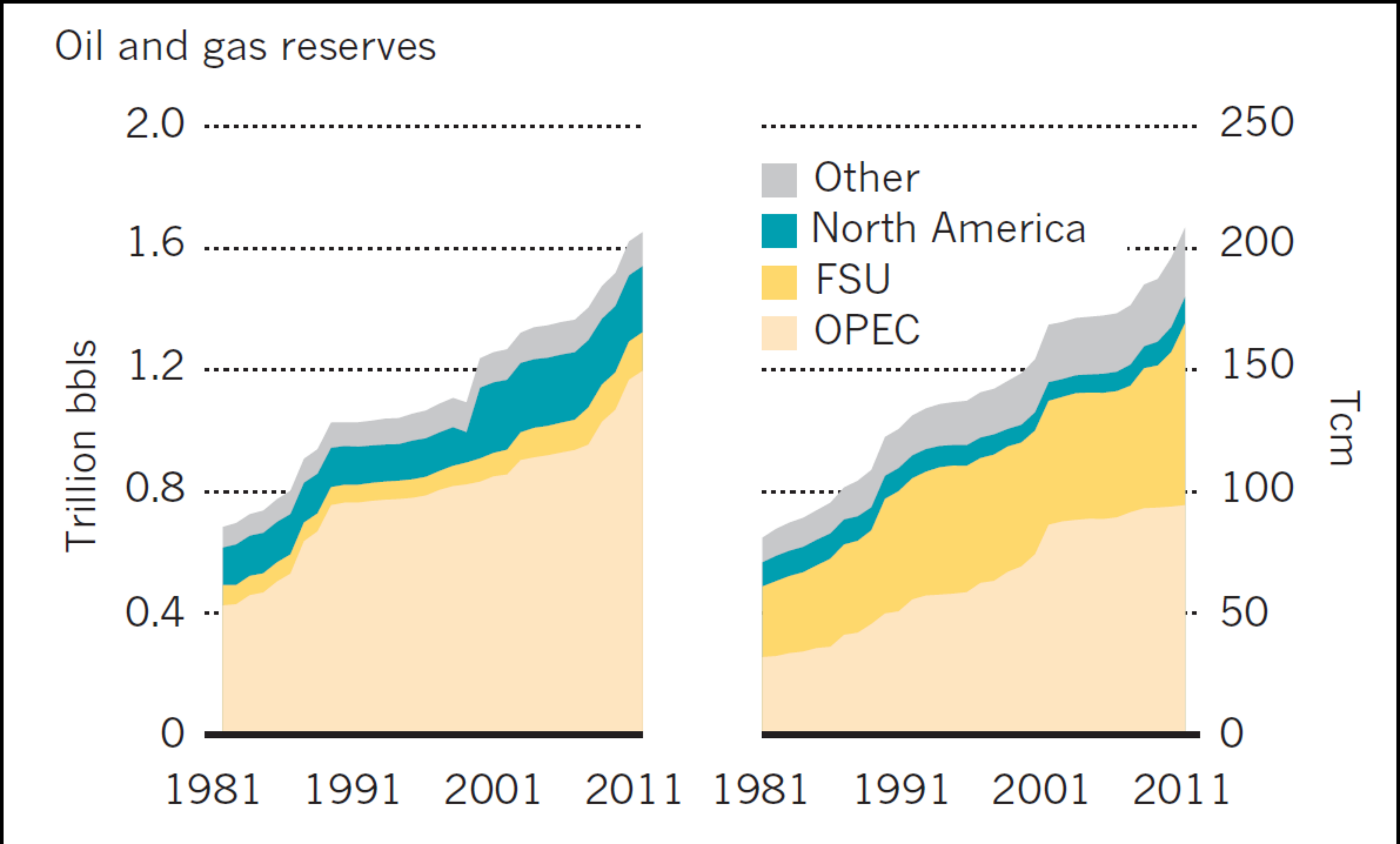
Will the rising price of fossil fuels or the arrival of “peak oil” force us to find alternatives?

# Fraction of world primary energy

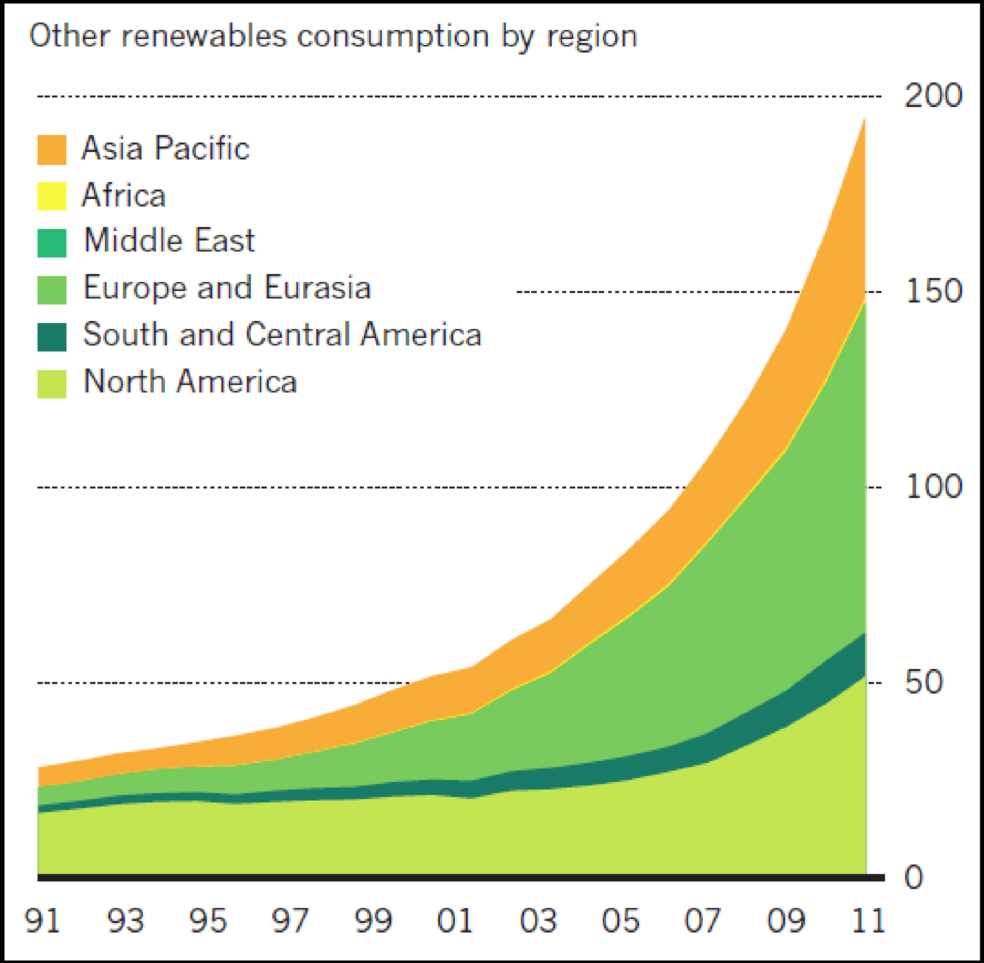



BP Statistical Review of World Energy June 2012 http://bp.com/statisticalreview2012.

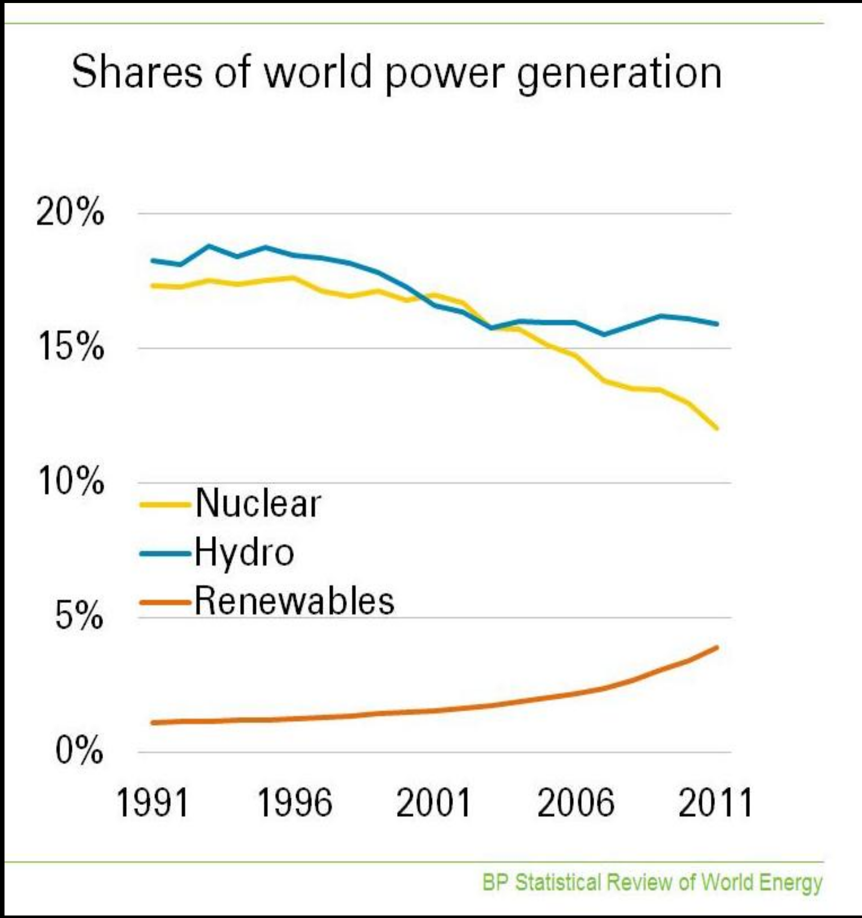
# Oil and Gas reserves have kept pace with rising demand. (Shale gas and shale-oil reserves not yet included)



## Renewable Energy grew more than 5x from 1991 – 2011.

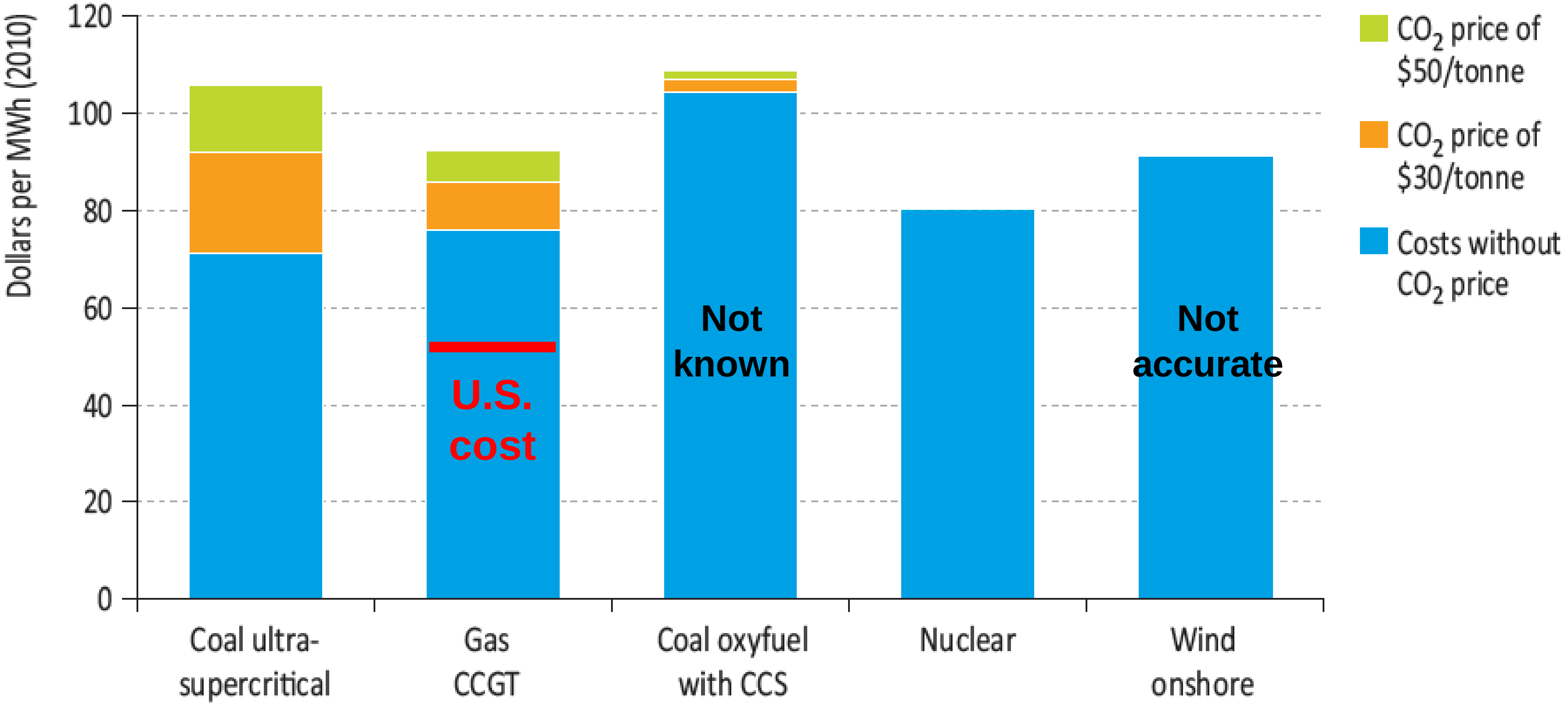



## Nuclear and hydro-power declined, so the fraction of carbon-free primary energy remained roughly constant.



# IEA projection of LCOE of energy

**Figure 5.3** • Typical levelised cost by plant type and carbon price* in the OECD in the New Policies Scenario, 2020




*Levelised cost is cost per unit of electricity generation, taking into account all the costs over the lifetime of the asset, including construction, operation and maintenance, fuel inputs and the cost of capital. In the New Policies Scenario, $CO_2$ prices range from zero to $30/tonne.

Andy Grove
co-founder and former CEO of Intel

Author of *“Only the Paranoid Survive: How to exploit the crisis points that challenge every company”*

# Crisis

Danger 危机 Opportunity

*wei* *ji*

In every Crisis lies
the seed of Opportunity

# Opportunities for improved technologies

Energy efficiency

Clean energy sources

# Opportunities for improved technologies

Energy efficiency

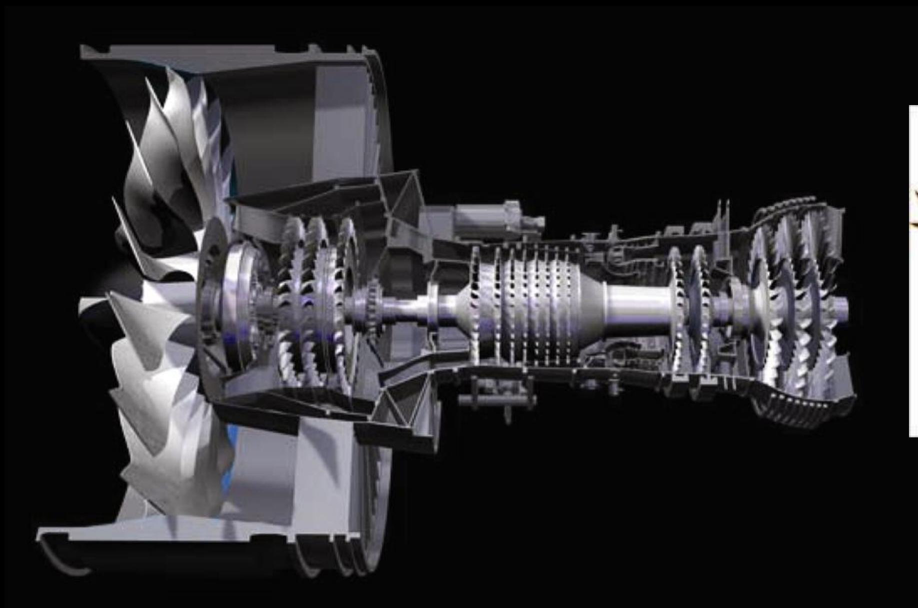
Clean energy sources

# Airplanes have become much more energy efficient.


The Boeing 787 uses only 30% of the fuel as the 707.

Improved aerodynamics, engines and materials (carbon composites)

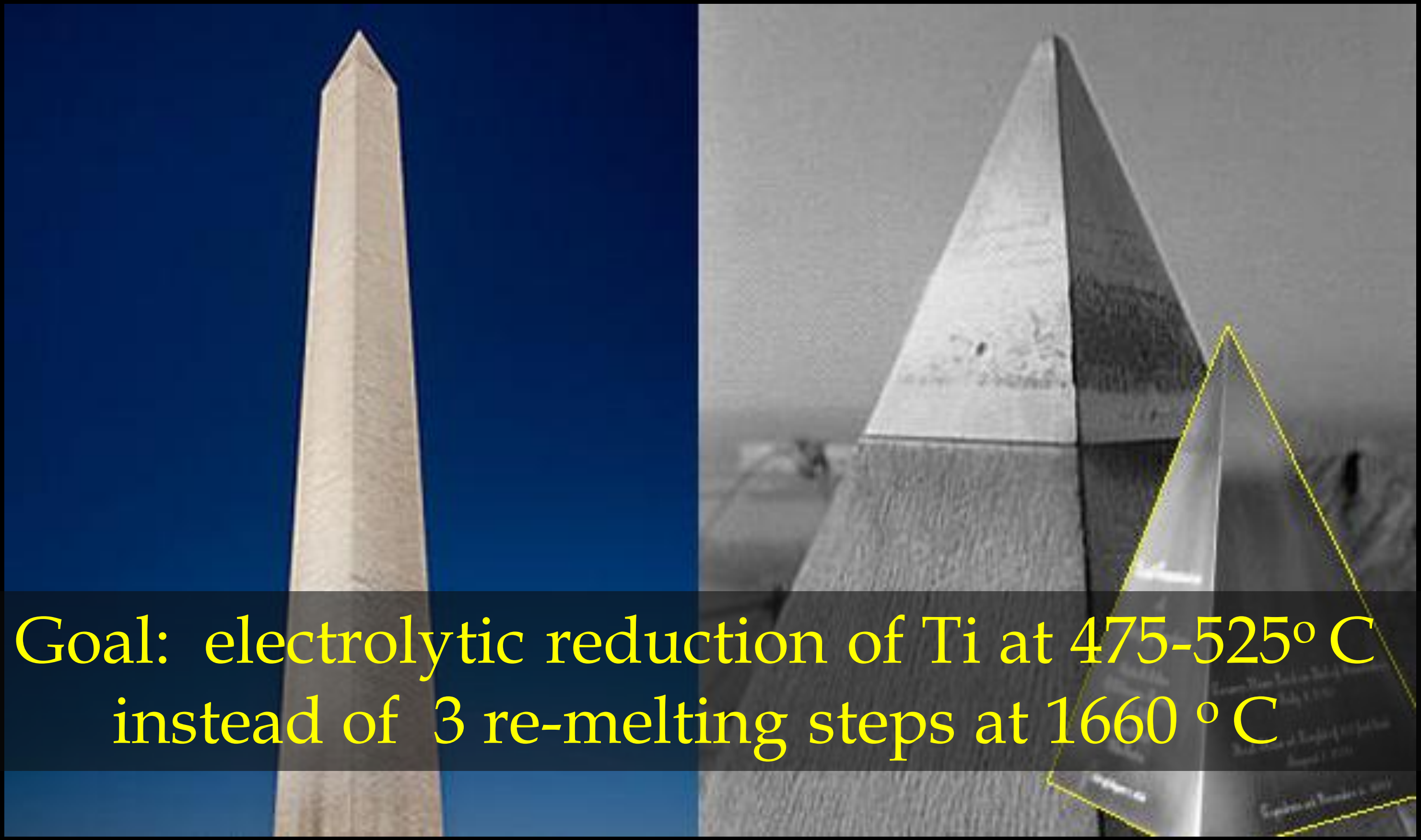
Jet engines have become 50% more efficient since the 1970s. The current engines being designed will have ~12 – 15% higher efficiency



Computer simulations using Argonne National Lab computer resources enabled virtual testing of a turbofan drive gear system.

- 3,000 tons less carbon
- $1.5M savings/airplane/year
- 50% quieter

# New materials and manufacturing methods can change the landscape of energy solutions



Goal: electrolytic reduction of Ti at 475-525$^{o}$ C instead of 3 re-melting steps at 1660 $^{o}$ C

In 1884, the price of aluminum was \$1/oz and the price of gold was \$20/oz.

Today's prices: Al = 6¢/ oz Au ~ \$1776/oz.

# Out-of-the-Autoclave Composites

**Autoclave (conventional)**

**Out-of-the-Autoclave**

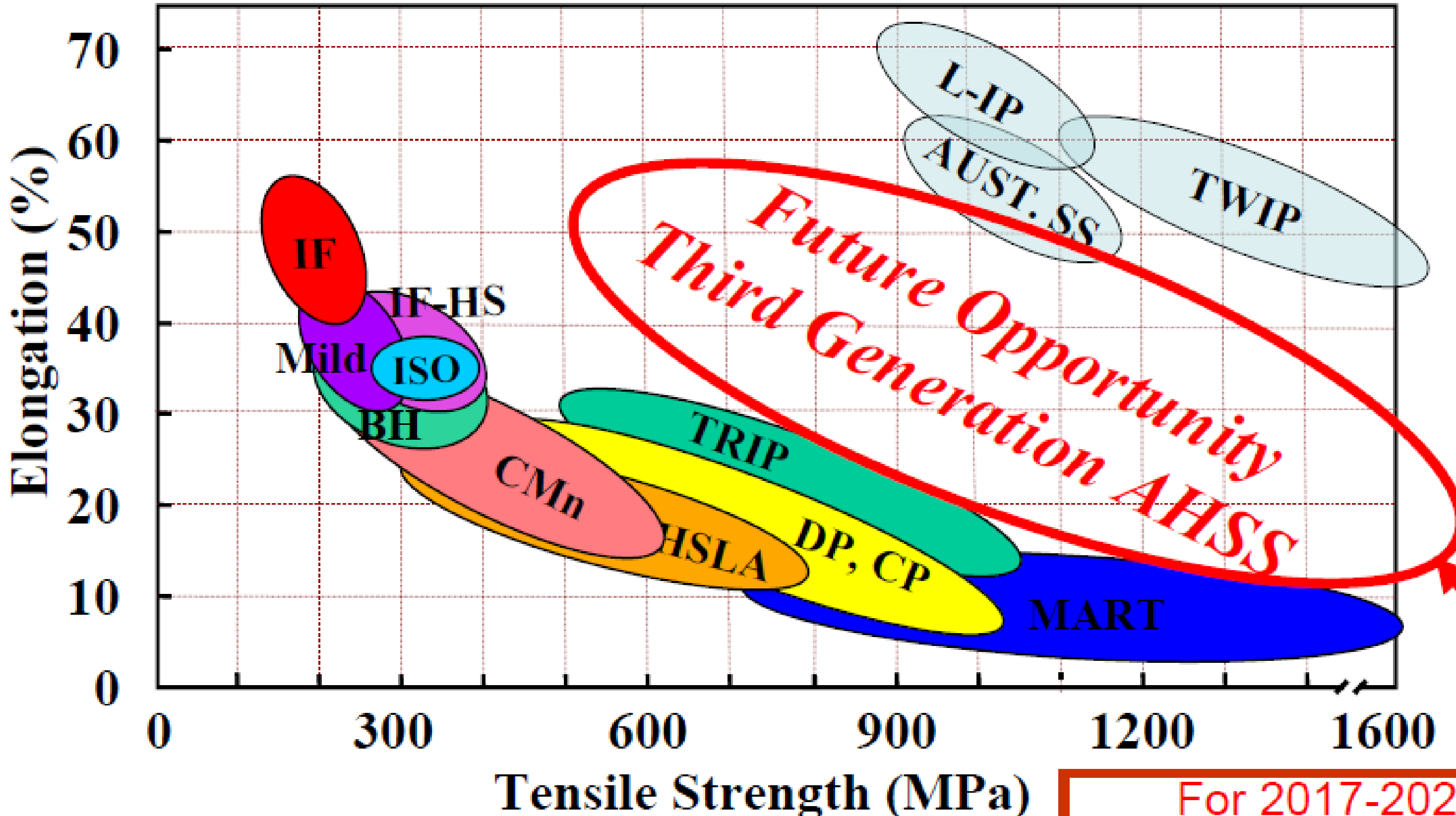
# Low-cost Carbon Composites

Carbon fiber is ~ 50% of the cost of car bon composites and current fabrication techniques are costly

What if carbon micro/nano tubes can be injected and molded and then "polymerized" after injection?

# 3rd Generation Advance High Strength Steels

...we are researching a new generation of steels for the future.




For 2017-2025, new formable AHSS grades will enable more steel mass reduction

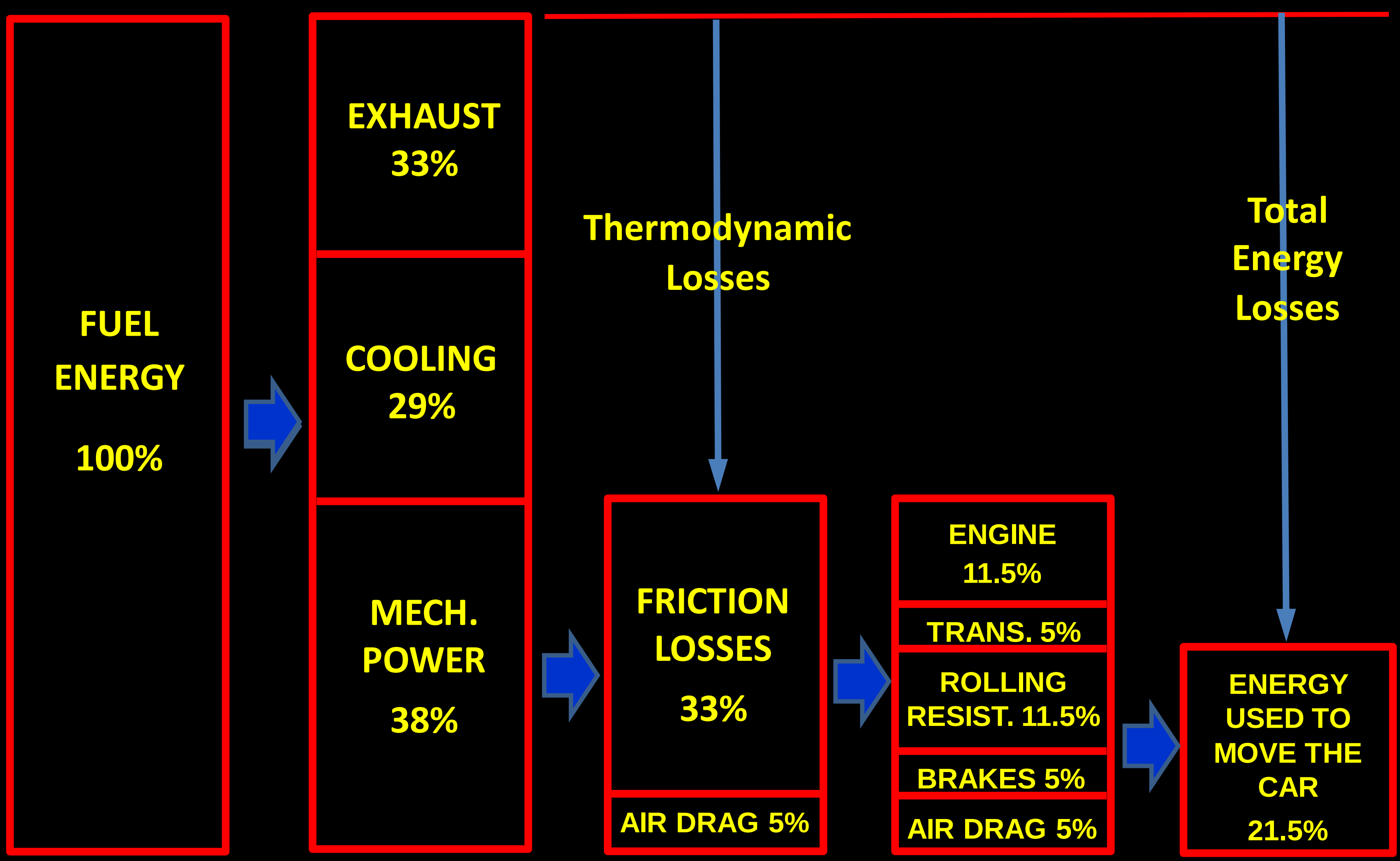
We understand the structural changes at the nano- and meso-scale by forming processes, but don’t yet have a ***fundamental*** understanding of how alloying or treatments (extrusion, pressing, pounding) create those properties.

- Electron microscopy (TEM and analytical)
- X-ray scattering
- Neutron scattering
- Scanning probe microscopy

Can computer simulations help us understand the kinetics of metal alloys and design better **manufacturable** materials?

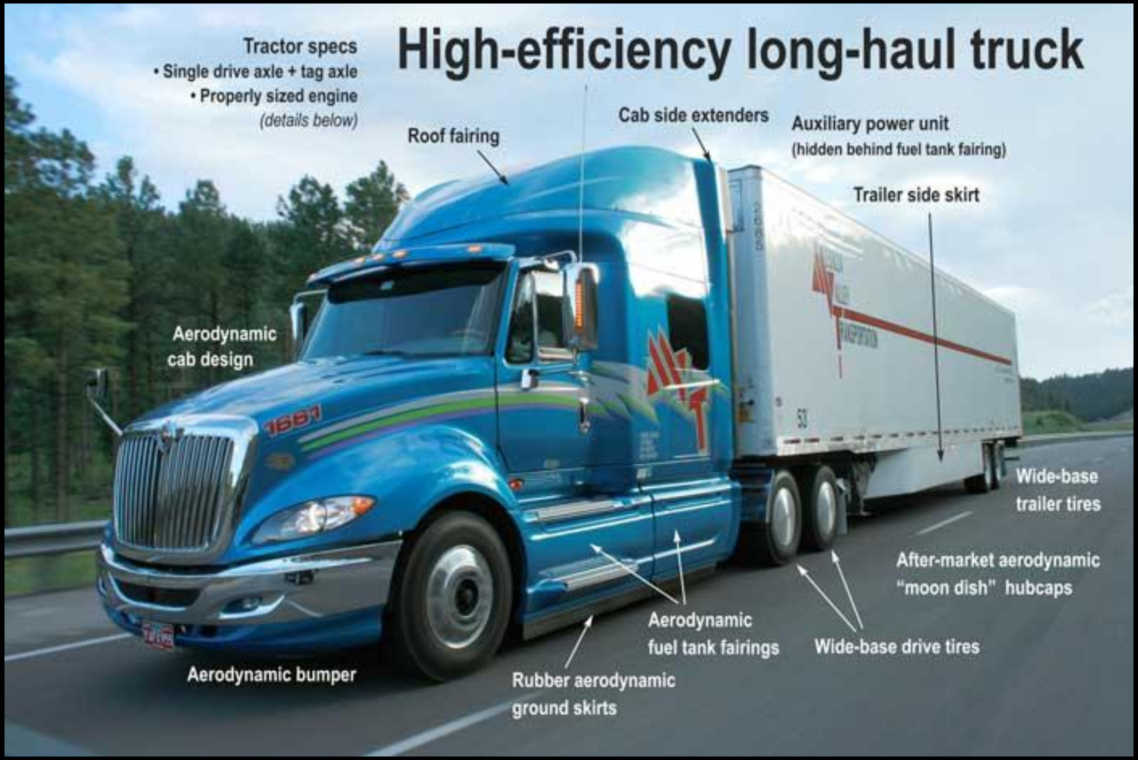
# Global energy consumption due to friction in passenger cars

Friction can be reduced by ~20% in the short term and ~60% over a longer term (15–25 years).




Holmberg, K., Anderssona, P., Erdemirb, A. *Tribology Int.* 47, 221–234 (2012).

# Applying HPC aerodynamics used in aviation to trucks




# BMI Corp. applies aerospace methods to streamline the undercarriage of long-haul trucks

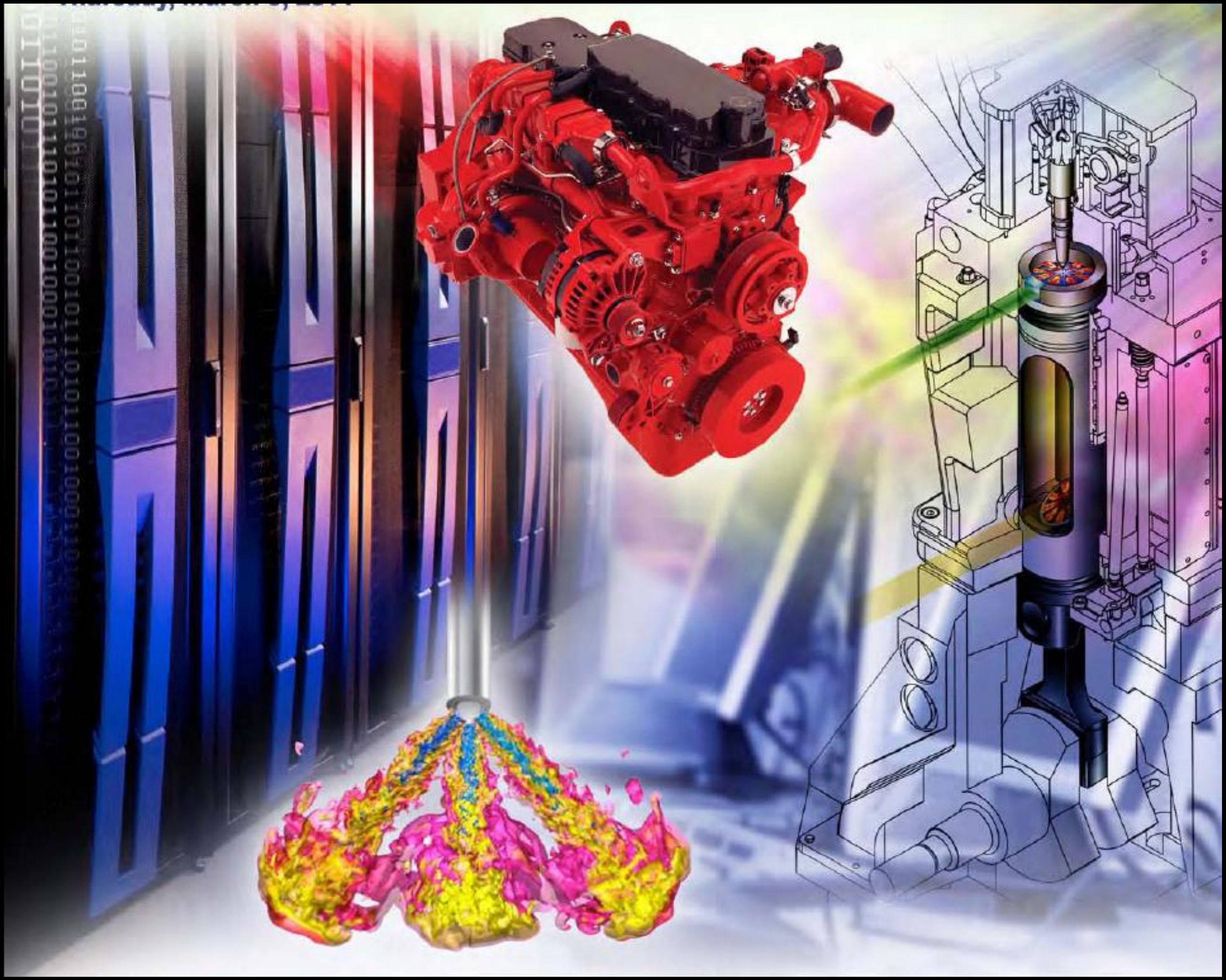
- The original UnderTray system reduces drag by 12%.
  The new UT-1 system can be installed by 1 person in 1 hour. Cost < $1,000 with bulk order.
- Fuel efficiency increase: 5.5–10% increase in fuel efficiency, depending on model installed.
- Average long-haul trucks are driven ~ 100,000 miles a year.  At $4/gal. the trucker saves ~$3,400 - $7400 /year.

The VW Jetta TDI has 140 hp, 236 ft-lbs of torque, 795 mile range, and a highway EPA rating of 43 mpg

Ford 1.0-litre, 3-cylinder turbocharged engine 118 hp, 125 lb-ft torque from 1,300-4,500 rpm and 147 lb-ft on over-boost.
The engine block has a footprint of an 8.5 x 11 sheet of paper.

**An additional 25% improvement in gasoline engines is possible with higher octane fuels.**

# A better understanding the internal combustion engine has led to the computer design of a Cummins diesel engine



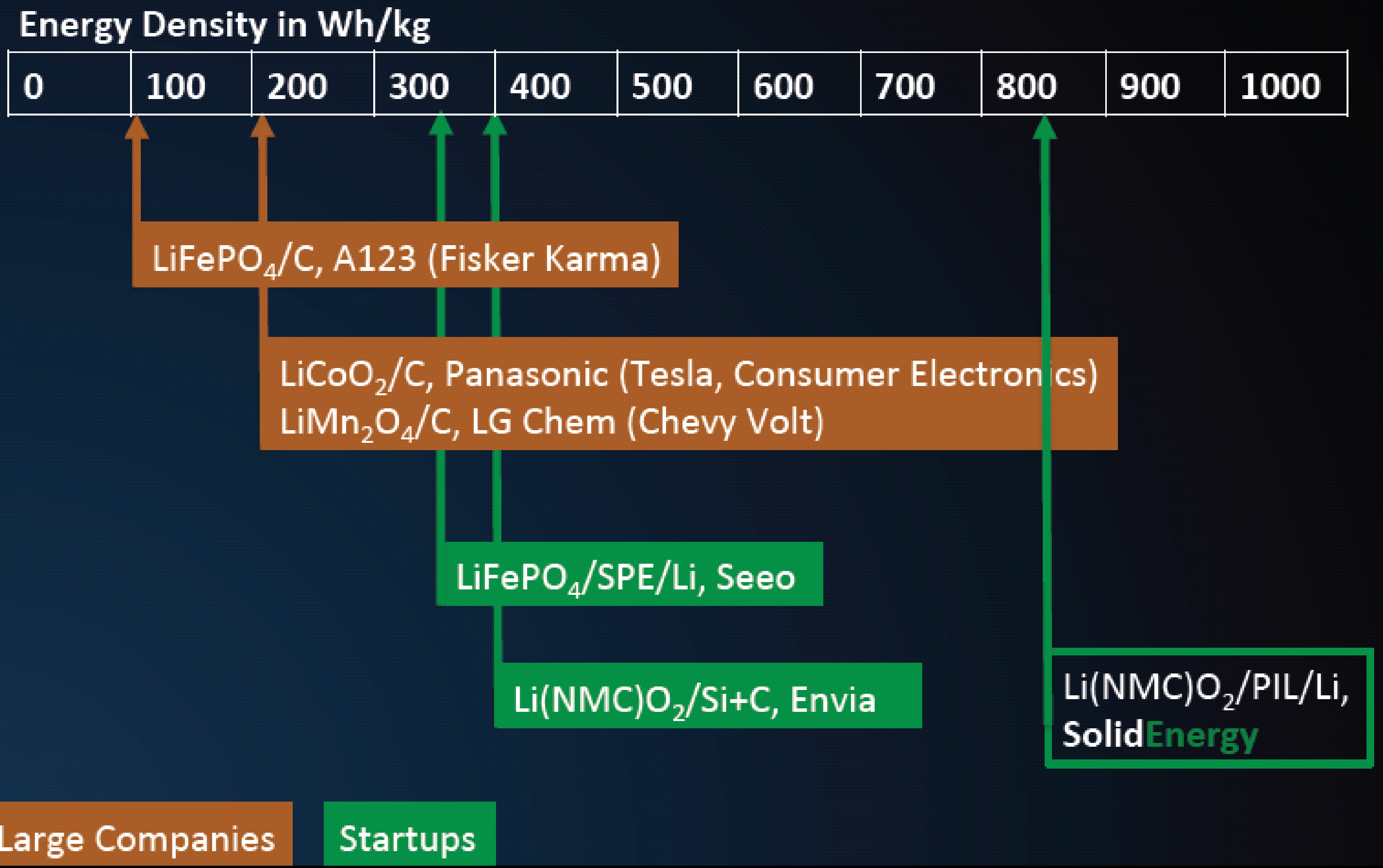
## Electric vehicles

Tesla Model S,
Nissan Leaf,
Ford Focus,
others

## Plug-in hybrid electric vehicles

Chevy Volt,
Fisker,
Prius Plug in,
others

# Energy Densities of Competing Batteries



# ARPA-E's AMPED PROGRAM

Approx. $30 million for disruptive innovation in battery management

Sensing

Modeling | Controls

Systems

Program Director: Dr. Ilan Gur

(Material Science, UC Berkeley)

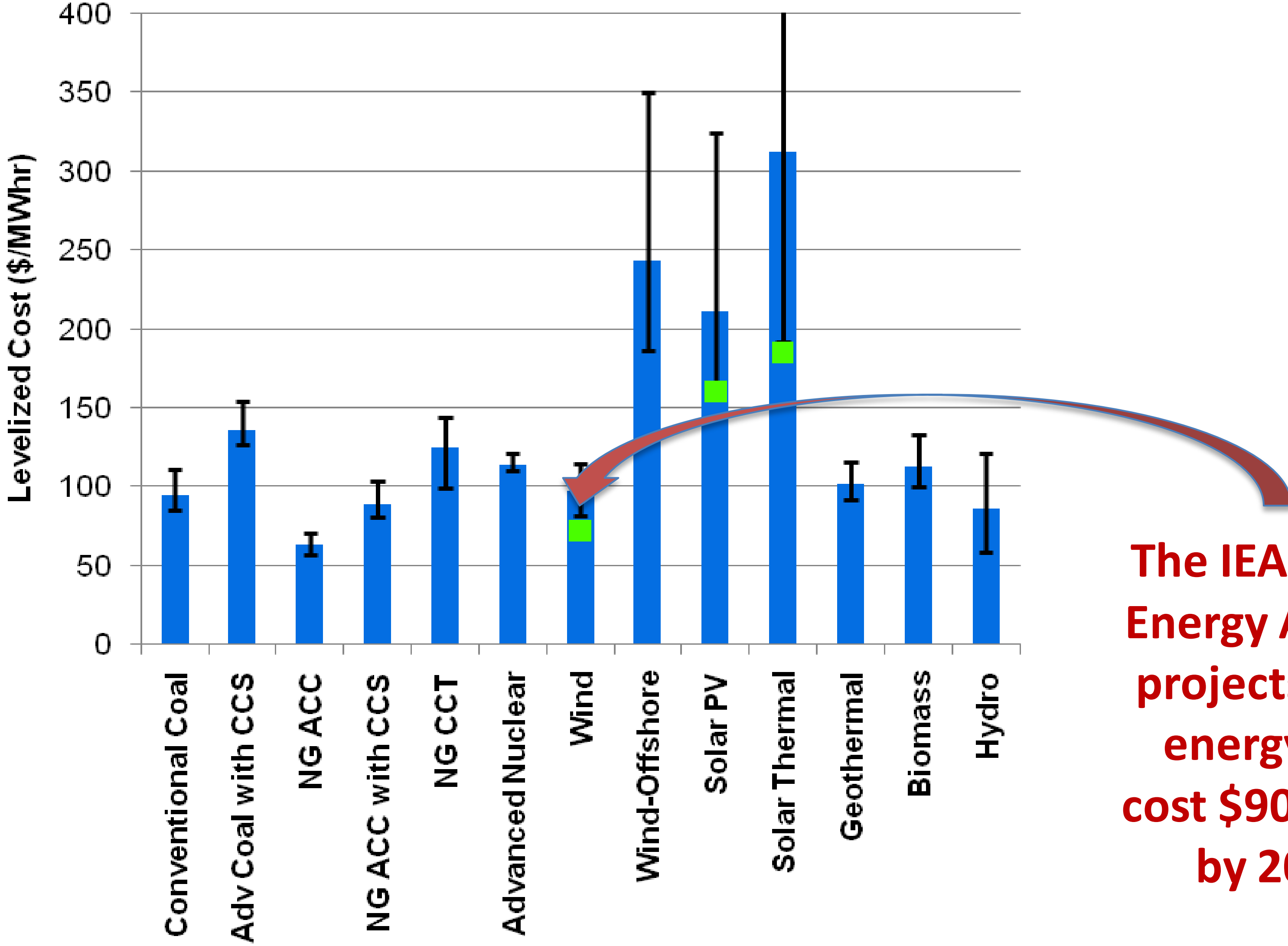
# Opportunities for improved technologies

Energy efficiency

Clean energy sources

U.S. Energy Information Administration (EIA) of the Levelized Cost of Electricity (LCOE) for 2016.

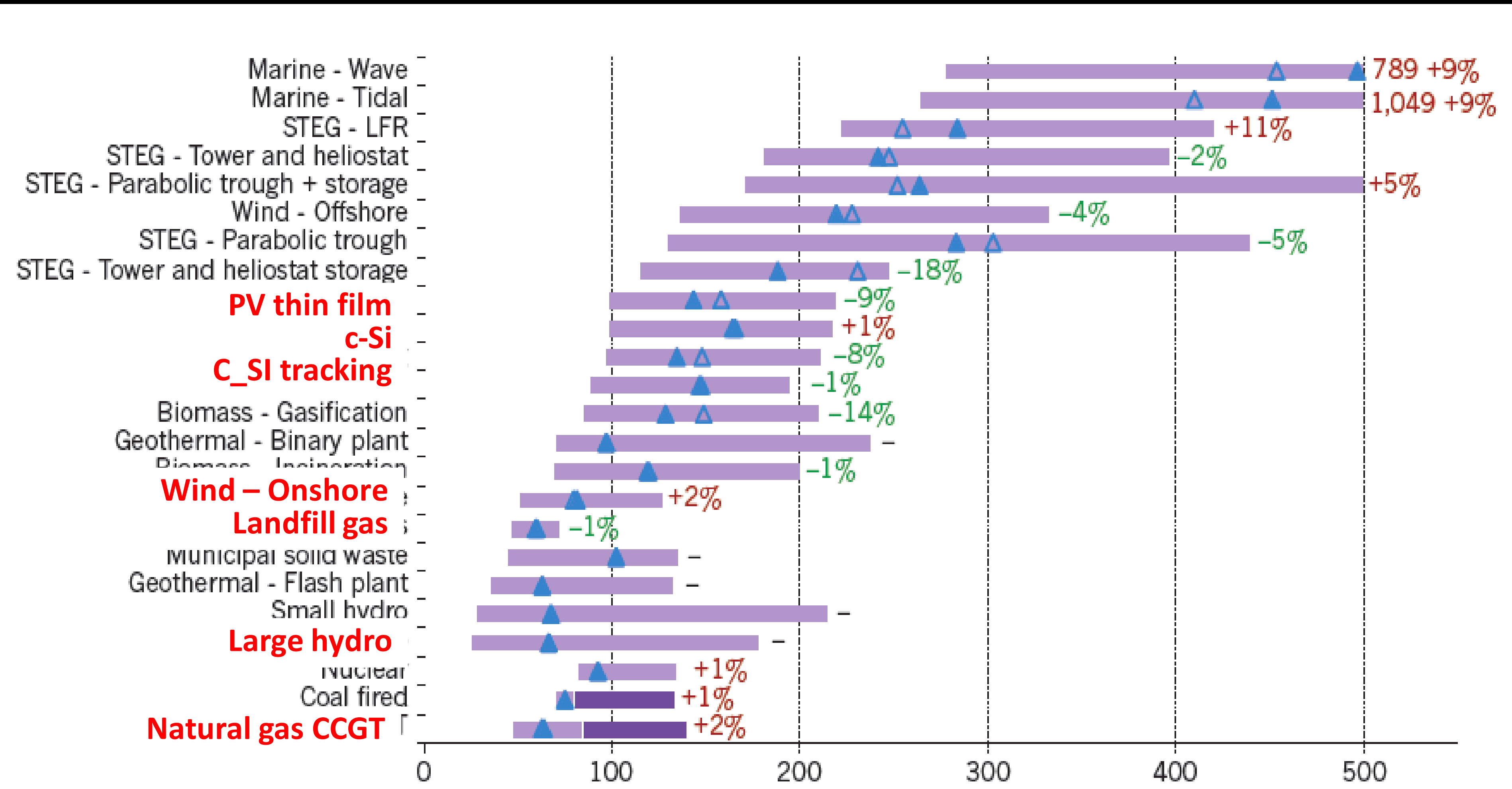
(2012 ***actual*** costs shown in green)



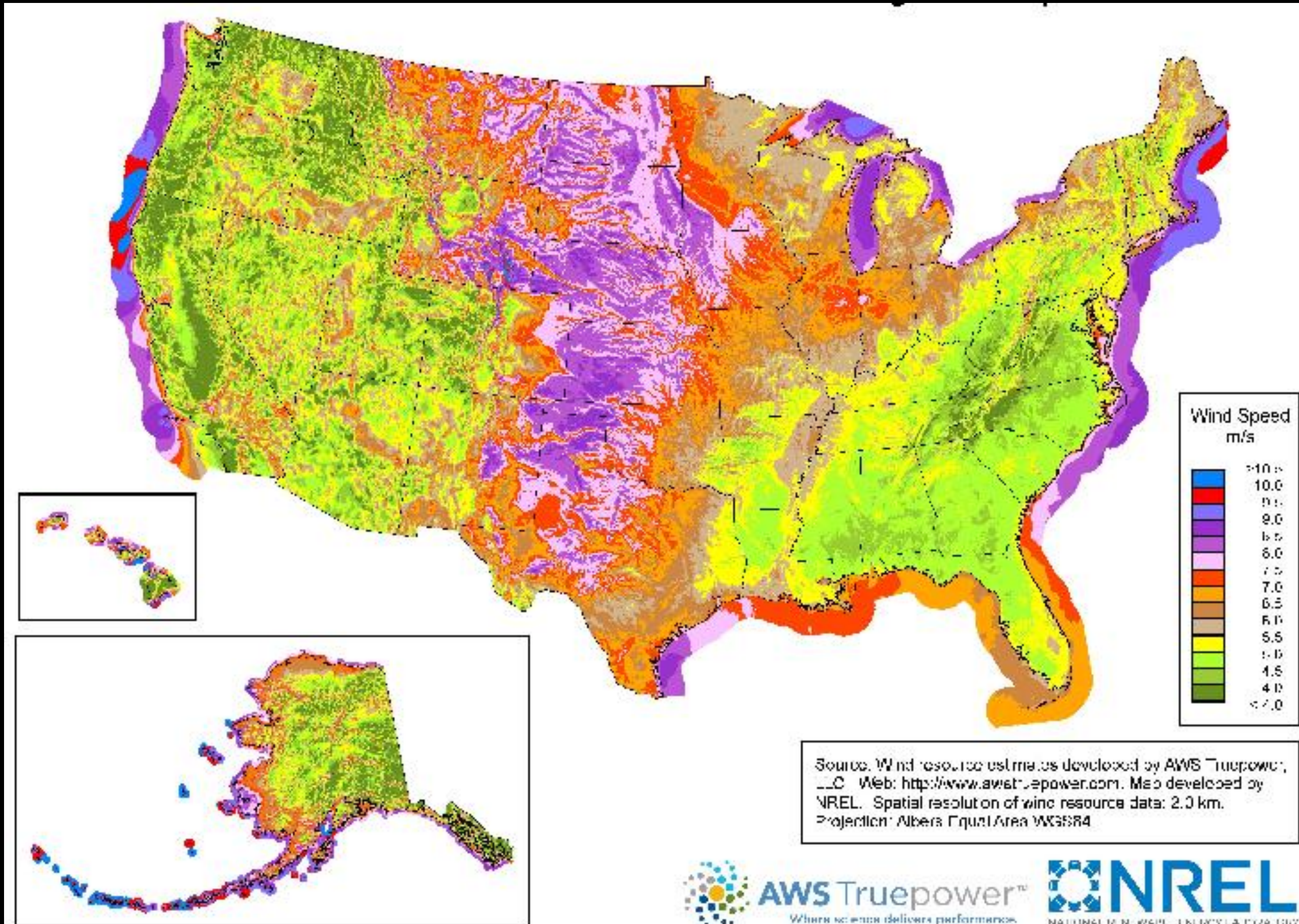

**The IEA (Inter. Energy Agency projects wind energy will cost $90/MWh by 2020**

# Bloomberg New Energy Finance LCOE for Q3 2012

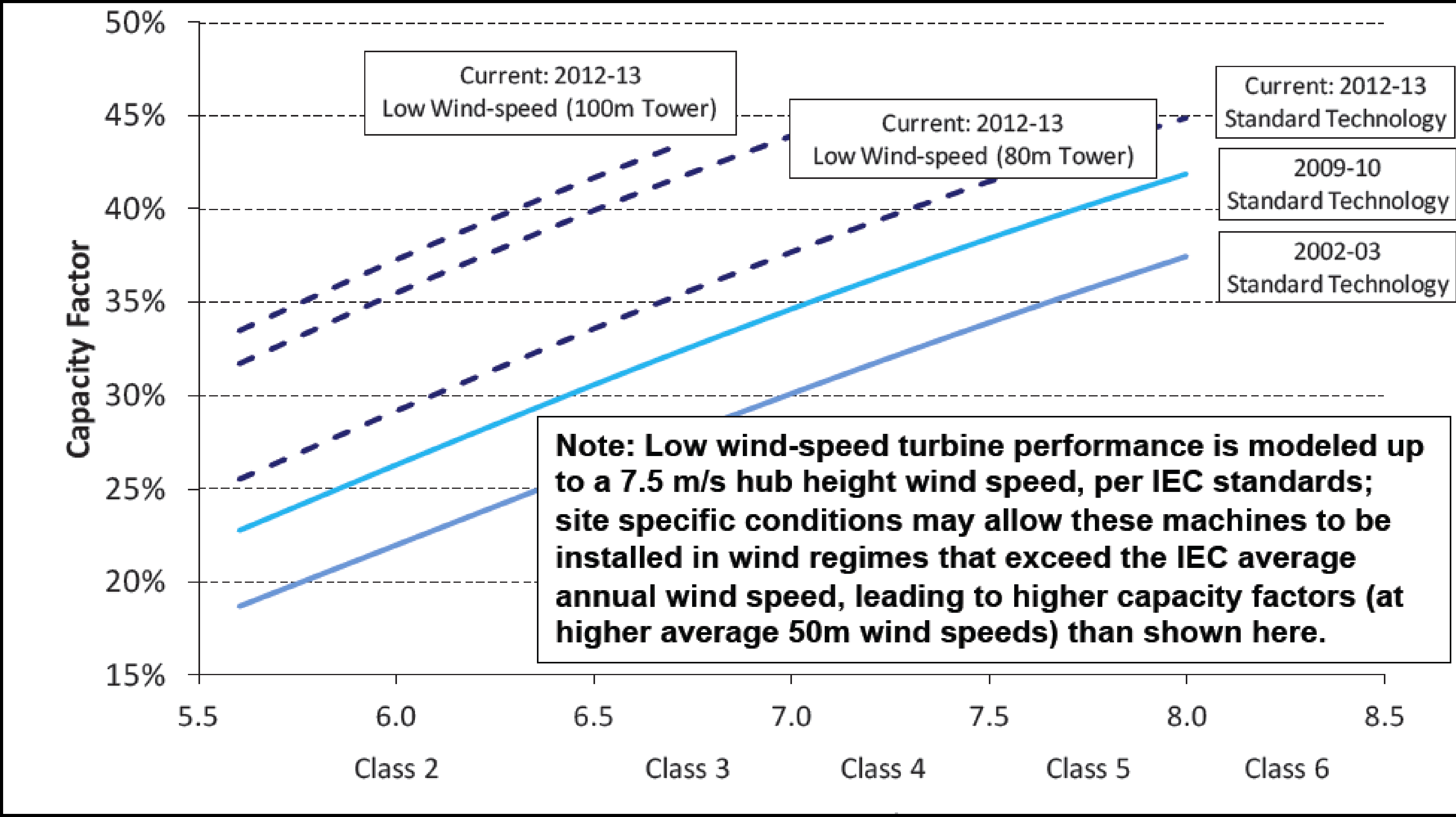
The analysis is based on projects where investment or purchase contracts have been completed. Subsidies such as the PTC (production tax credit) or ITC (Investment tax credit have been taken out.



# U.S. Wind Resources at 80 meter tower height



# The cost of wind continues to decline due to improved performance in gearboxes, blades, increased size and height, and system engineering



# Scaling is size and height improve performance

Airbus 380 wingspan: 80 meters    Wright Brothers first flight: 37 meters



100 meter wind tower

2.3 MW turbine: 93 meter diameter blades, 115 meters high.

Largest diameter installed wind turbine: 126 meters dia.

"One approach to servicing the highest wind turbines is to design cranes that can 'inch worm' themselves up the towers, analogous to the self-lifting cranes used to build tall buildings."



2.3 MW turbine 93 meter diameter blade, 115 meters high. (Off-shore turbines up to 5 MW)

# Power Conversion & Energy Storage

Today

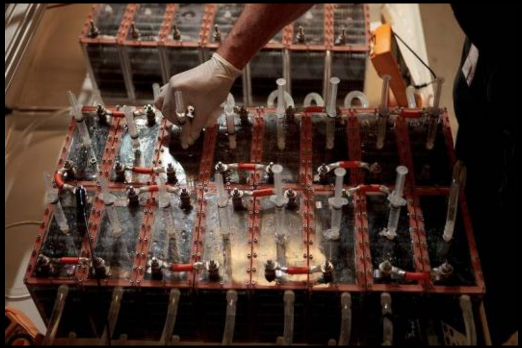
Future

10,000 lbs

100 lbs

And Smart!

$100/kWh



$100/kWh

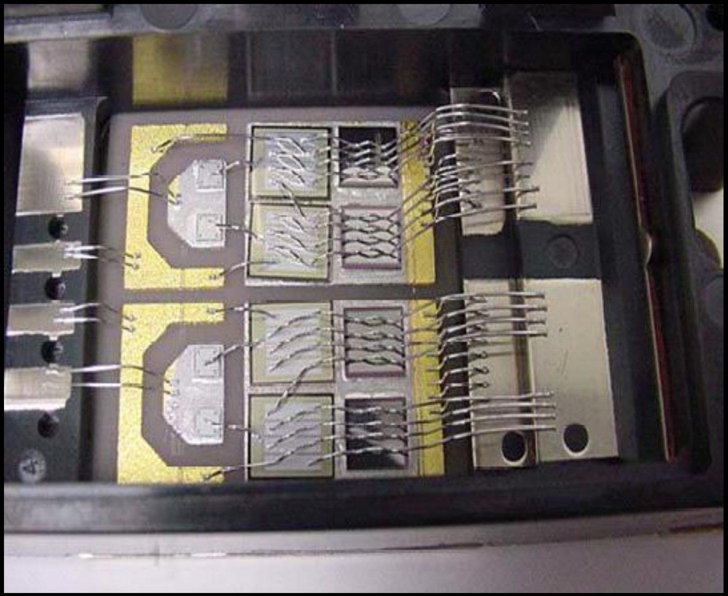
Anywhere In the world

**2010: 30% of all electric power flows through power electronics**

**2030: 80% of all electric power will flow through power electronics**

SiC power modules operate at 1200V and 880 amps. (1MW)

1.2 kV/100A SiC module

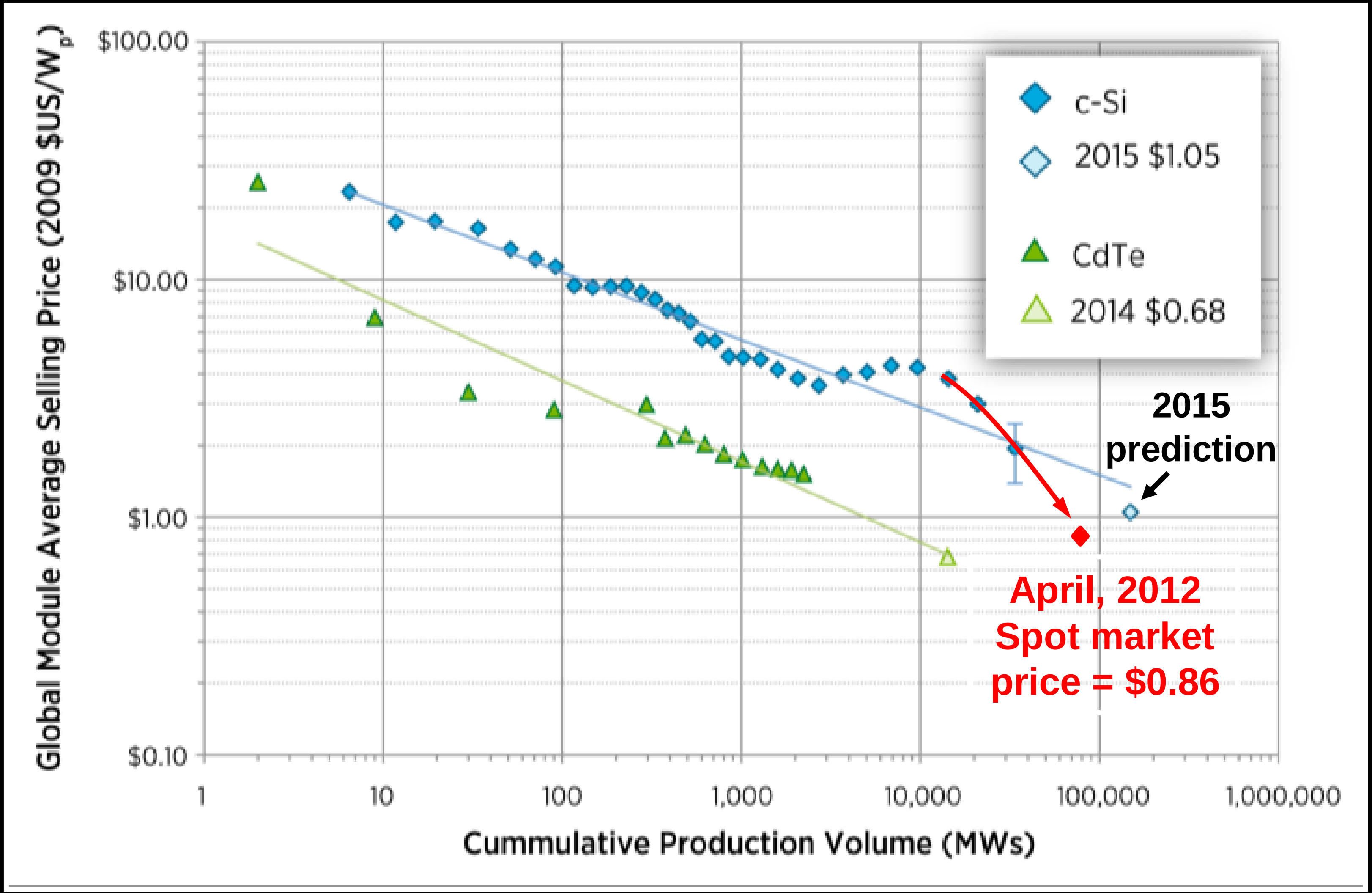


Internal view: 2 80 A SiC MOSFETs and 2 50 A SiC JBS diodes

Latest news is that a > 1 kV, 1 MW ***single*** SiC transistor has been demonstrated.

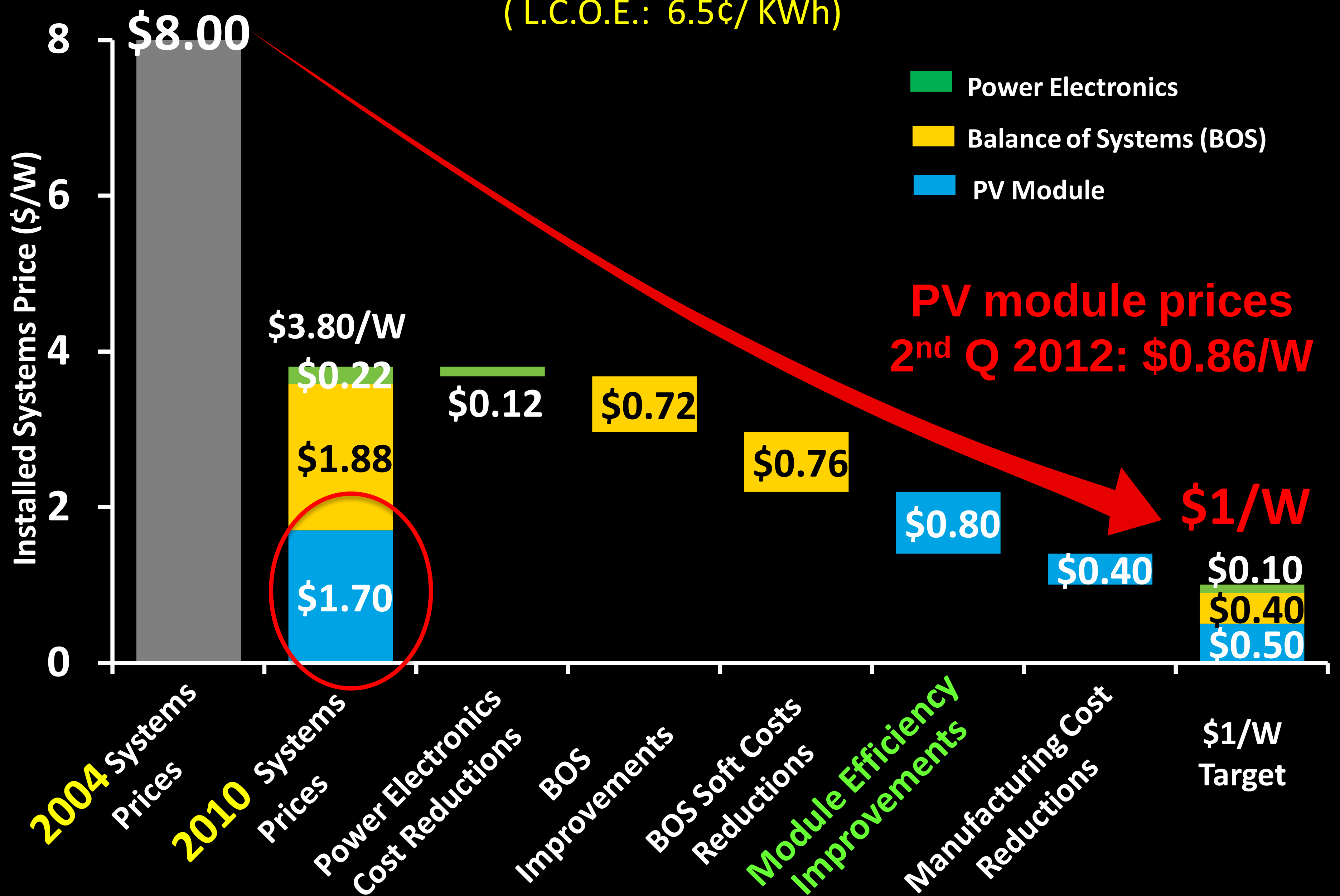
# Cost of PV modules is dropping below the power law experience curves

Source: (CdTe) First Solar Earnings Presentation, SEC Filings;
(c-Si) Navigant, Bloomberg NEF, NREL internal cost models



# SunShot goal: Cost Competitive Solar by 2020

( L.C.O.E.: 6.5¢/ KWh)

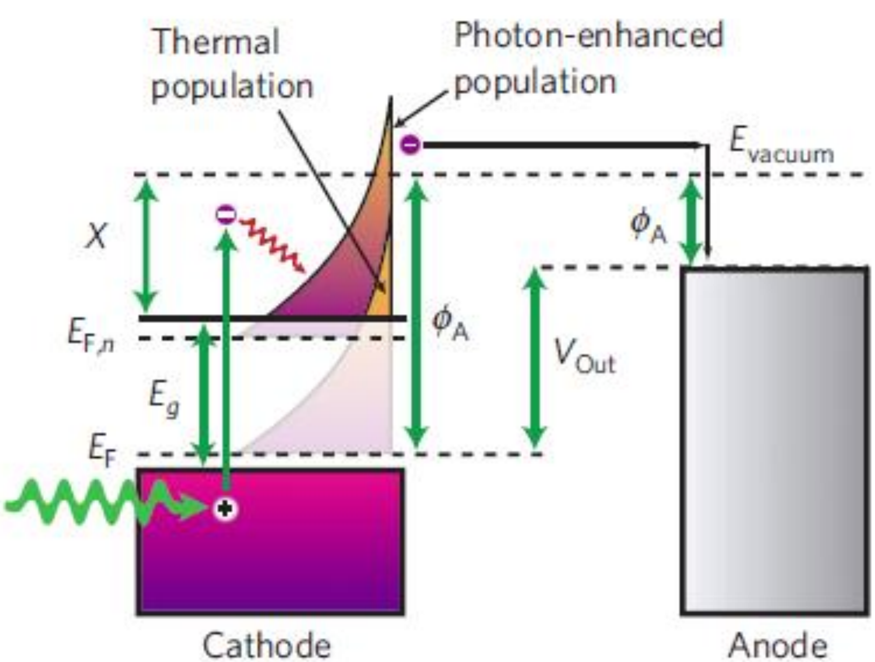


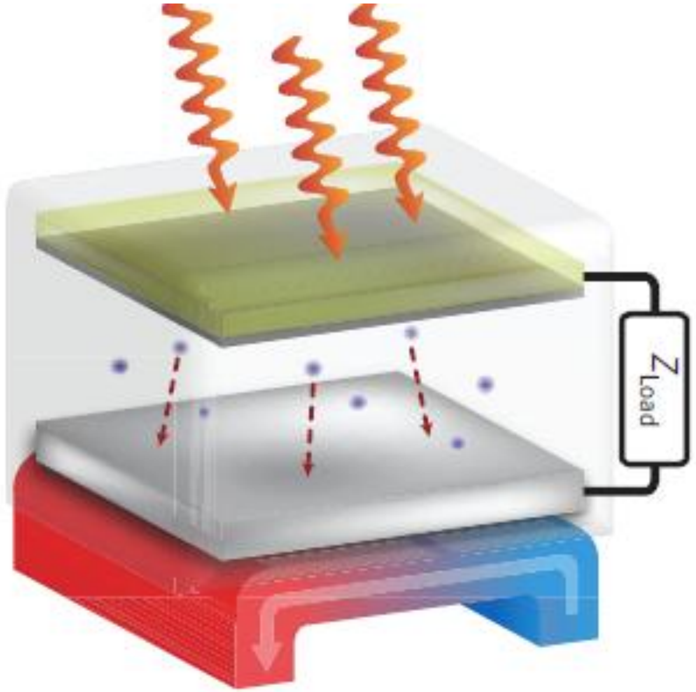
Z-X Shen: "I read the Nature paper by you and Arun with great interest ... I found the statement 'Integrating photovoltaics in a solar thermal absorber may be possible, allowing both approaches to be integrated' very appealing."

# Photon-enhanced thermionic emission for solar concentrator systems

Nature Materials 9, 762 (2010)

Jared W. Schwede[1,2,3], Igor Bargatin[4], Daniel C. Riley[1,2,3], Brian E. Hardin[1,5], Samuel J. Rosenthal[1,5], Yun Sun[6], Felix Schmitt[1,2], Piero Pianetta[6], Roger T. Howe[4], Zhi-Xun Shen[1,2,3] and Nicholas A. Melosh[1,2,5]★




**Epitaxial growth of single crystal Si on a reusable single-crystalline silicon template 35 µm thick.**

Proven cell efficiency ~19%

23.5% cell efficiency

22% module efficiency.”

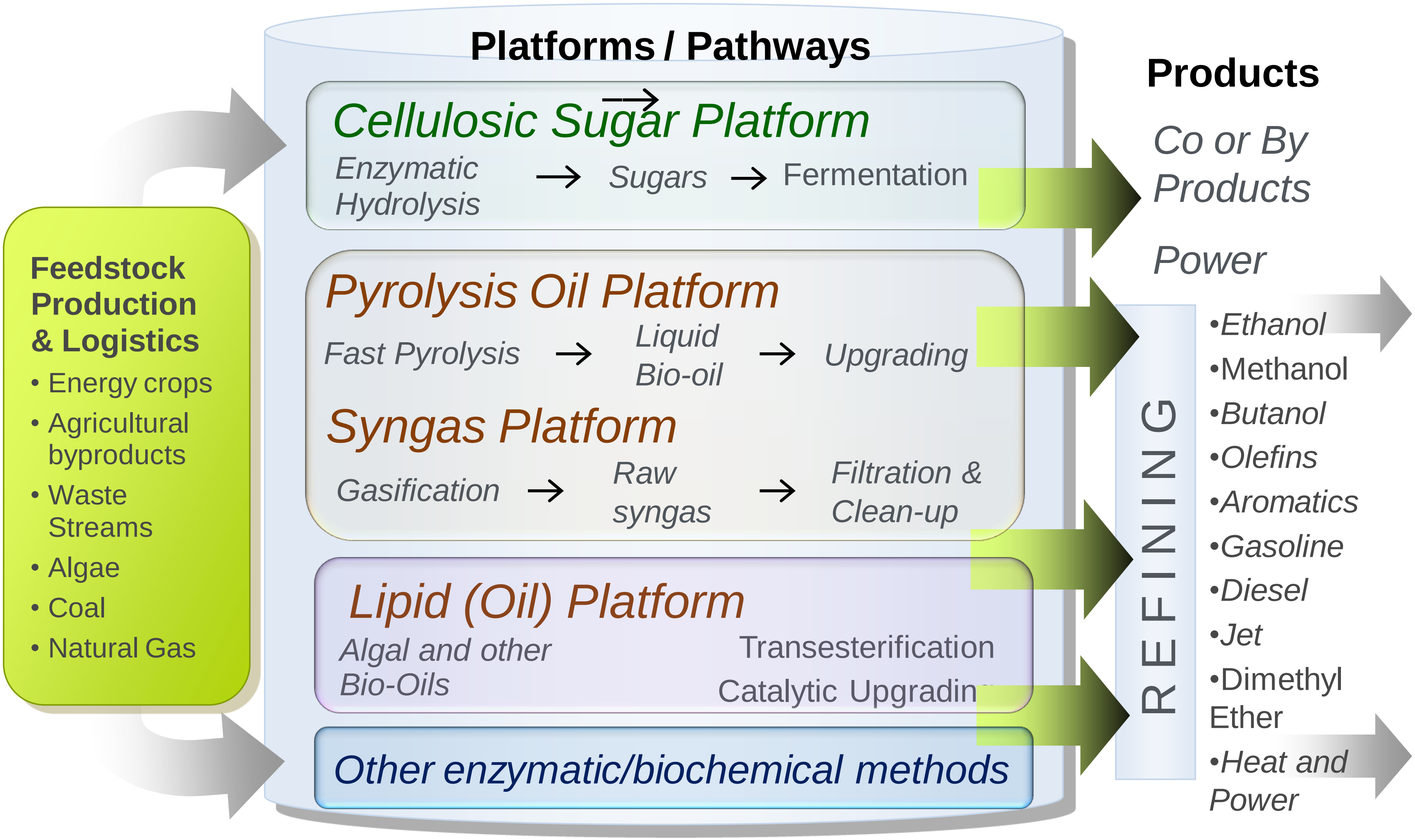
## Why can't the installation of a PV system on your roof be handled like the installation of a gas water heater?


Residential PV in Germany costs ~\$2.50/W

Residential PV in the US costs ~\$6/W

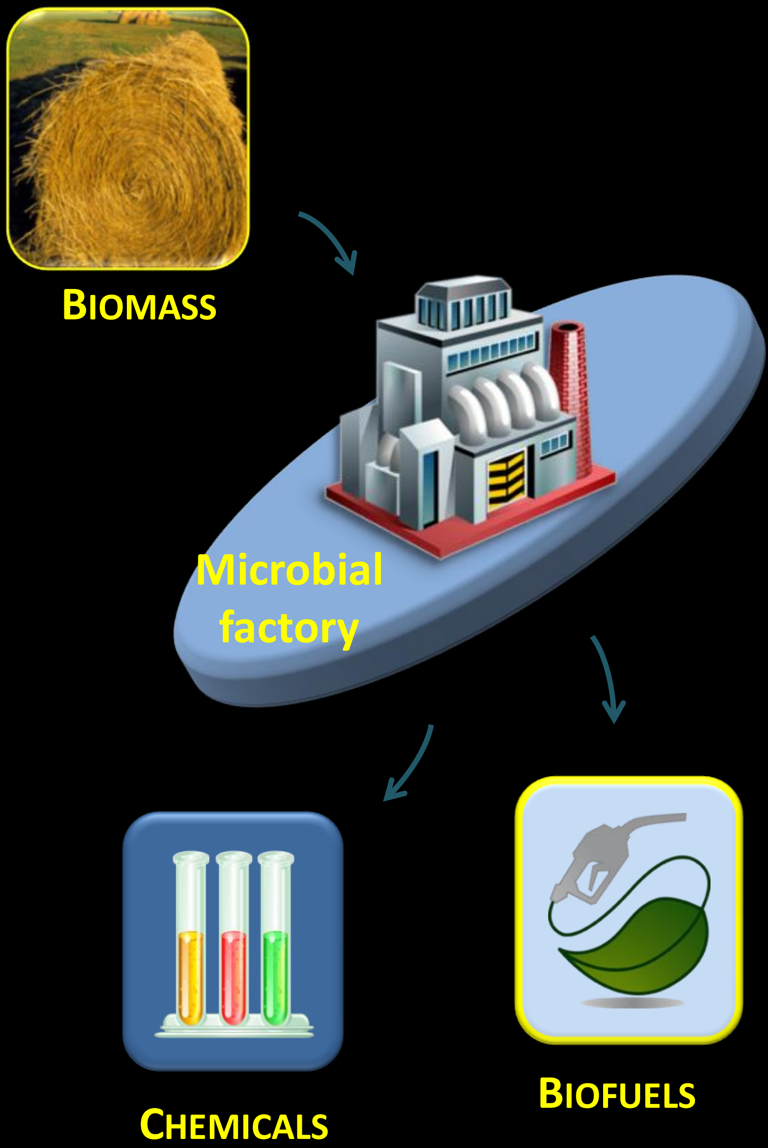
# Approaches to bio-fuel production

- Sugars and starches $\Rightarrow$ ethanol
- Ligno-cellulose $\Rightarrow$ ethanol
- Ligno-cellulose $\Rightarrow$ drop-in fuels
- Sunlight $\Rightarrow$ biofuels



Platforms / Pathways
Cellulosic Sugar Platform
Enzymatic Hydrolysis → Sugars → Fermentation
Pyrolysis Oil Platform
Fast Pyrolysis → Liquid Bio-oil → Upgrading
Syngas Platform
Gasification → Raw syngas → Filtration & Clean-up
Lipid (Oil) Platform
Algal and other Bio-Oils
Transesterification
Catalytic Upgrading
Other enzymatic/biochemical methods
Feedstock Production & Logistics
• Energy crops
• Agricultural byproducts
• Waste Streams
• Algae
• Coal
• Natural Gas
Products
Co or By Products
Power
REFINING
•Ethanol
•Methanol
•Butanol
•Olefins
•Aromatics
•Gasoline
•Diesel
•Jet
•Dimethyl Ether
•Heat and Power

# JBEI–INDUSTRY COLLABORATION: SIMPLE SUGARS AND STARCHES TO DROP-IN FUEL PRECURSORS (AMYRIS)

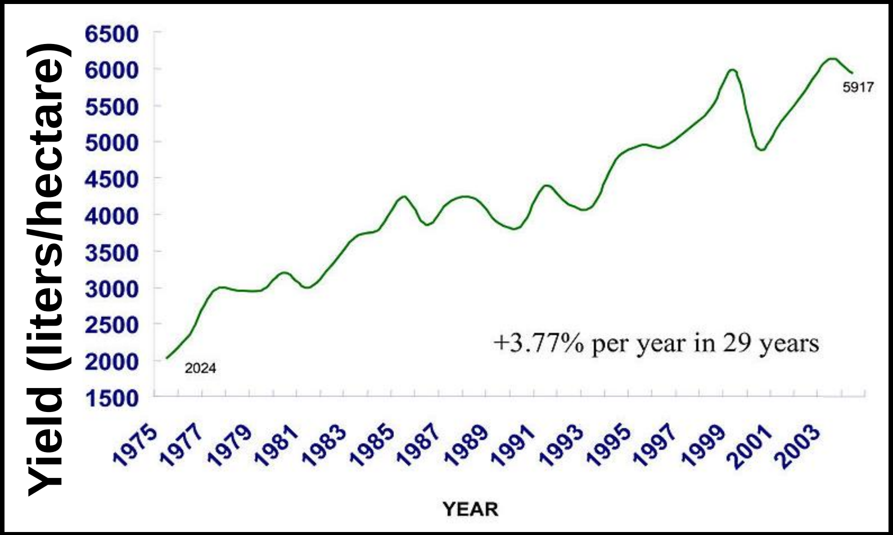



- JBEI and Amyris have genetically altered bacteria to make precursors to diesel and jet fuel
- Pilot production facilities are being built in Brazil and Illinois

# Lowering the cost of biomass harvesting, storage and shipment is a critical issue

Wheat & corn are shipped world-wide at ~$100/ton prices.
Biofuel feed stocks before concentration are less valuable.

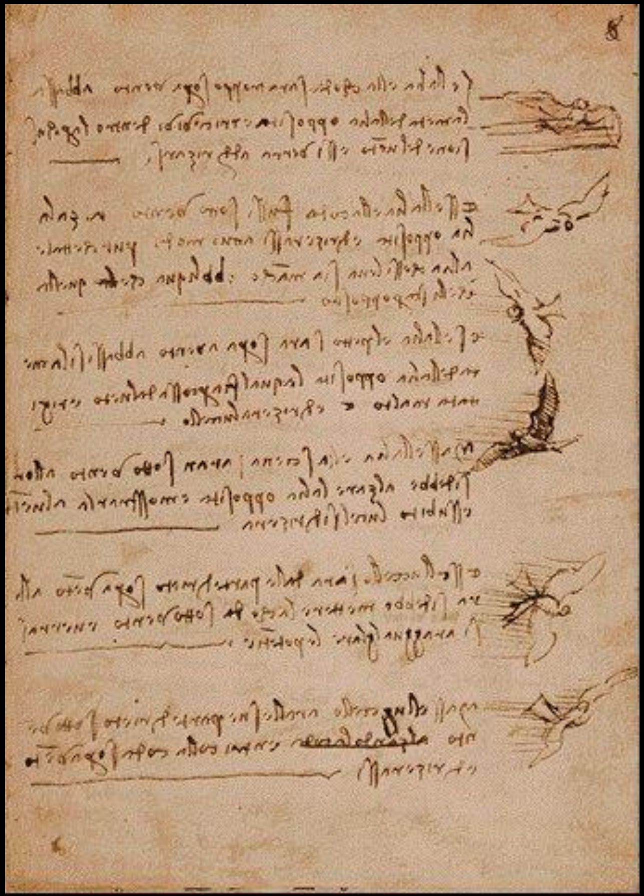
# Sugar Cane-to-ethanol yield per hectare in Brazil has increased 3x in ~30 years

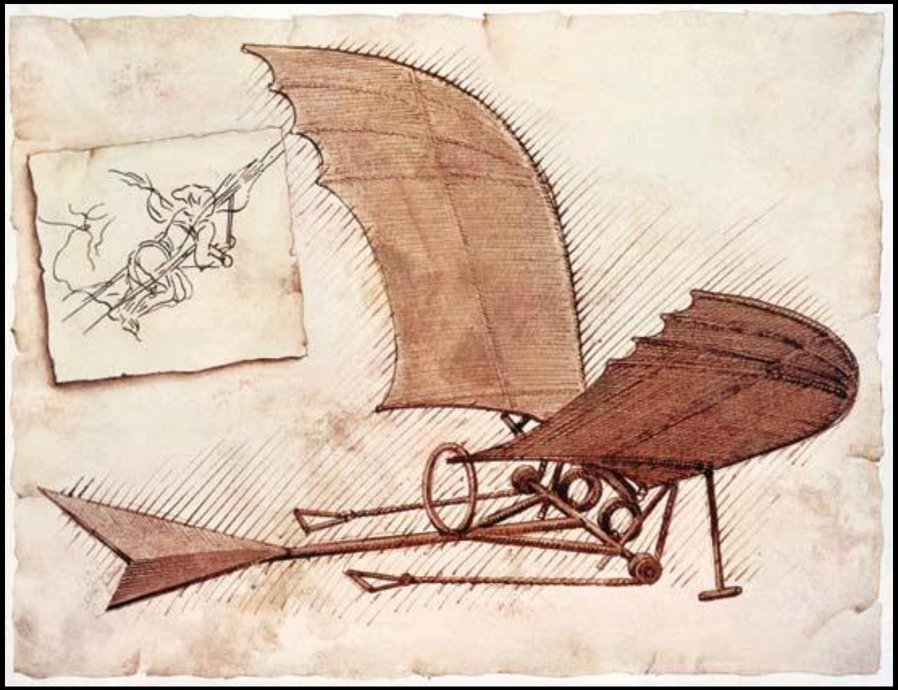


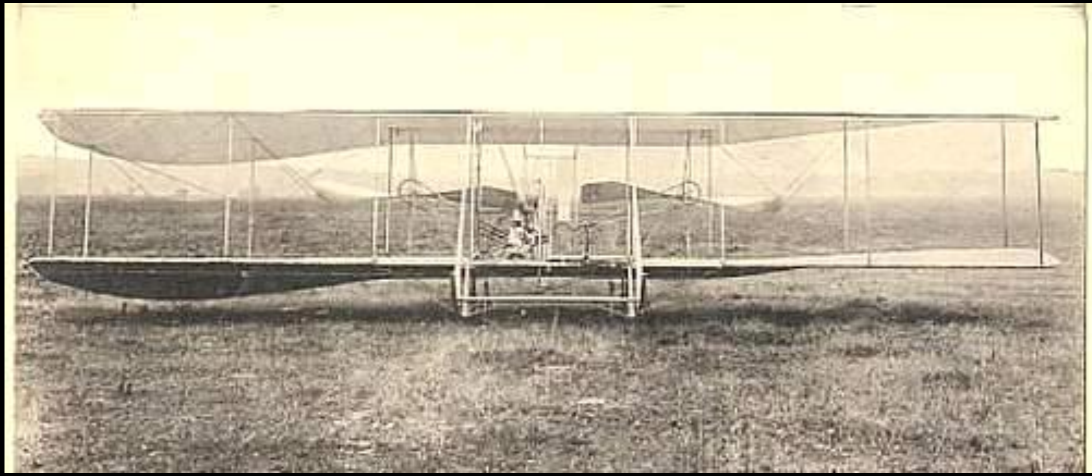

Leaves are left in the field

Stalks are transferred to larger trucks

# Man first learned to fly by imitating nature

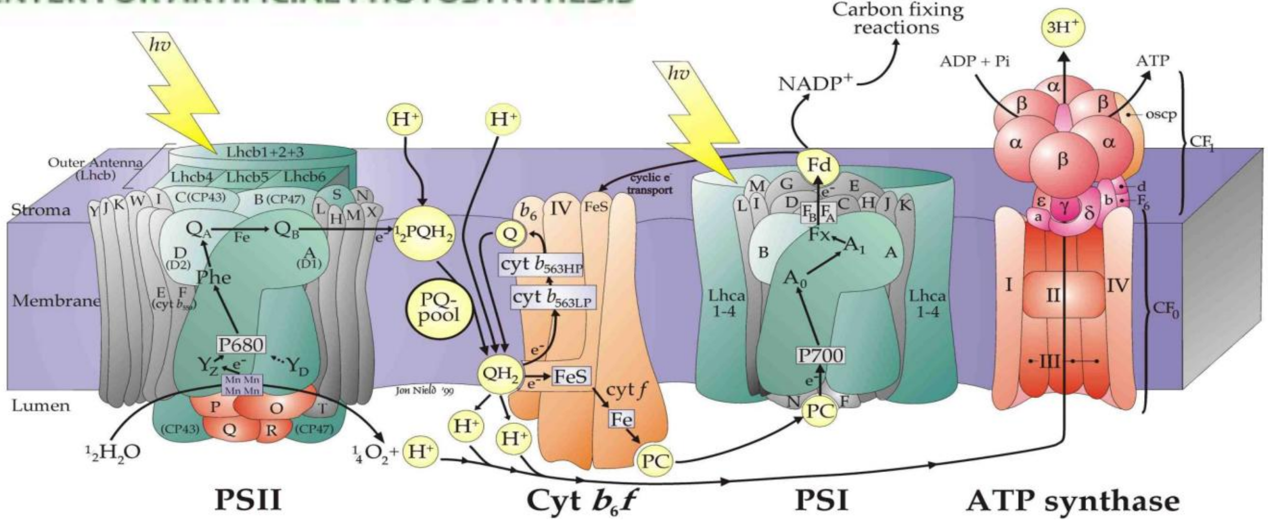


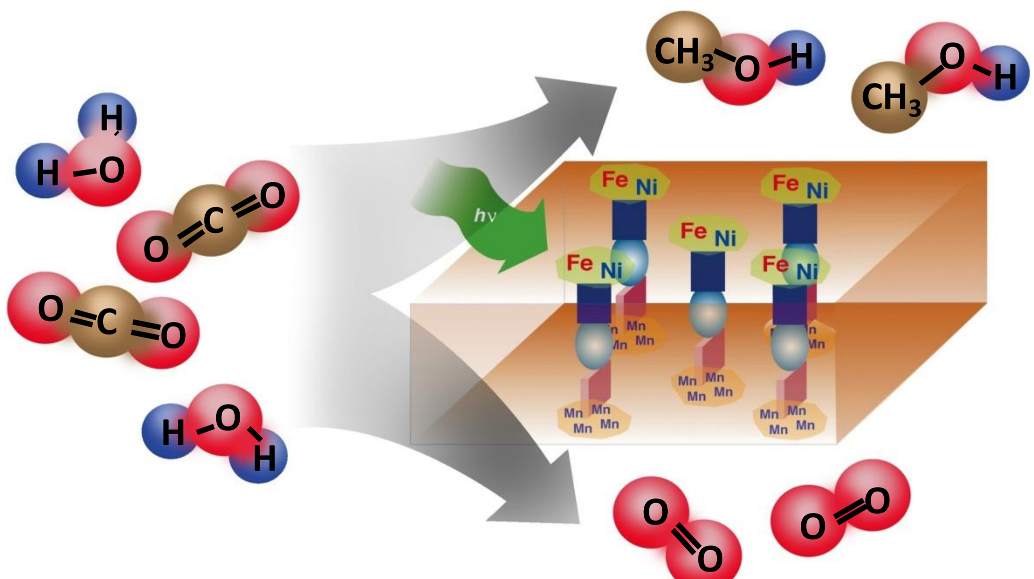




JCAP

JOINT CENTER FOR ARTIFICIAL PHOTOSYNTHESIS



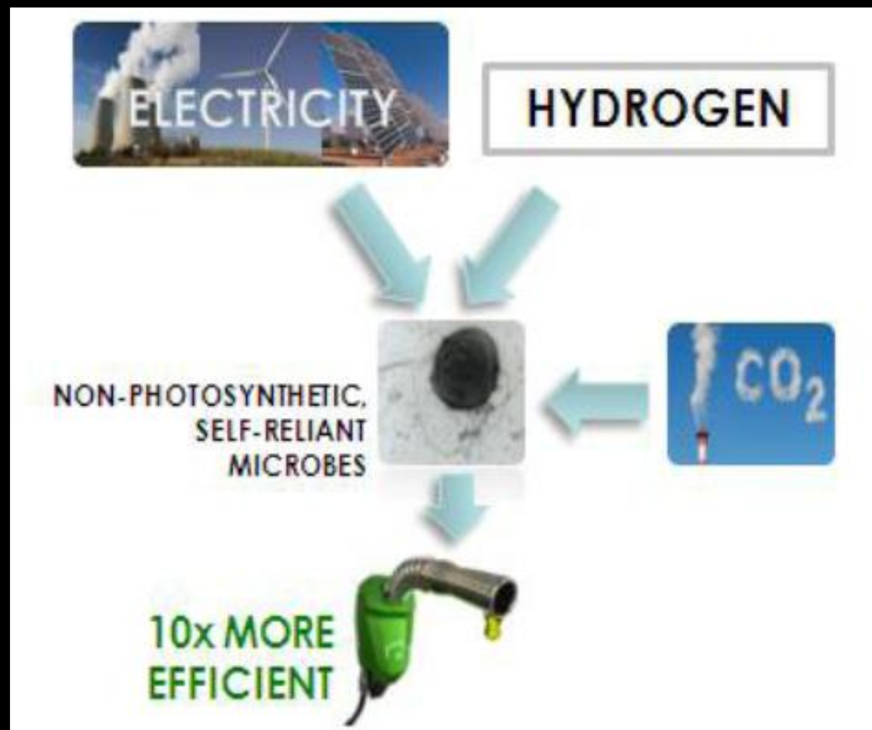




Courtesy of Freefoto.com

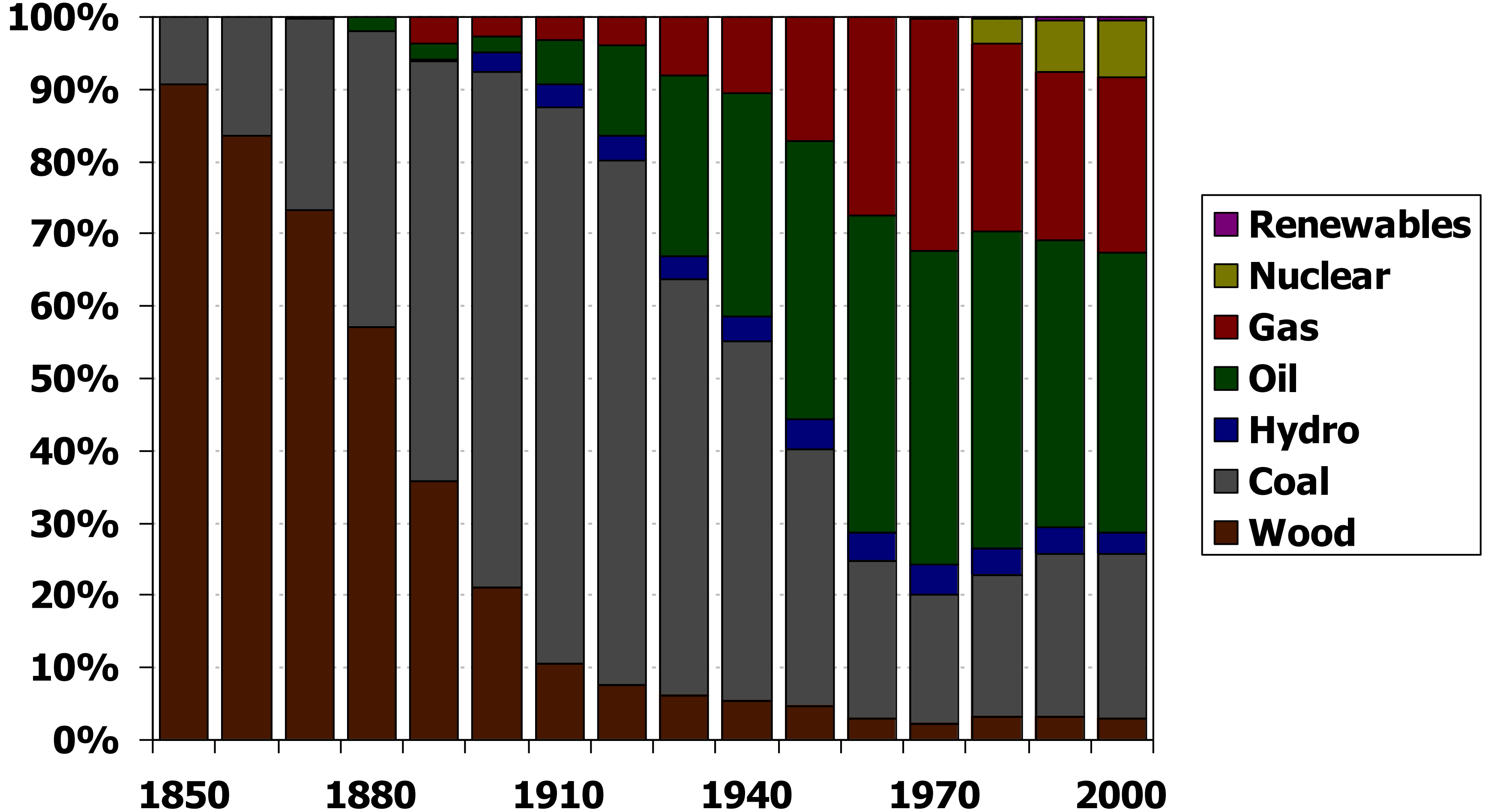
Advanced Research Projects Agency • ENERGY

# ELECTROFUELS

VERSATILE TRANSPORTATION ENERGY SOLUTIONS



# Sources of Energy in the US since 1850



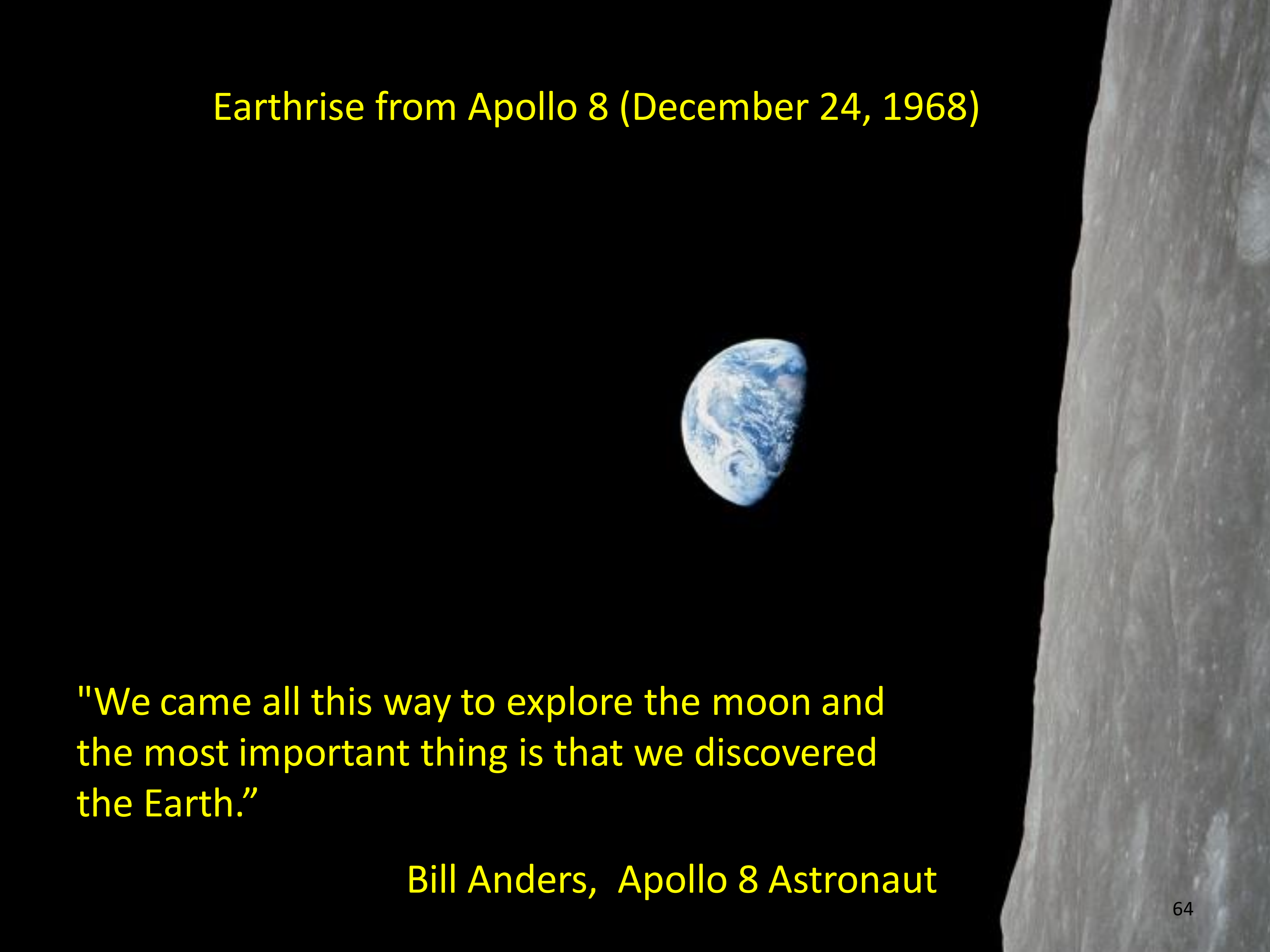

Source: EIA

- Our ability to find and extract fossil fuels continues to improve. Economically recoverable reservoirs are likely to keep pace with the rising demand for decades.

“The Stone Age did not end because we ran out of stones”
Saudi oil minister Sheik Ahmed Zaki Yamani

- We transitioned to better solutions. The cost of renewable energy is rapidly becoming competitive with other sources of energy. We must accelerate the transition to affordable and sustainable energy that will power economic growth, increase energy security and mitigate the risks of climate change.

On the other hand, “If we don’t change direction soon, we’ll end up where we’re heading”.


Earthrise from Apollo 8 (December 24, 1968)
"We came all this way to explore the moon and the most important thing is that we discovered the Earth."
Bill Anders, Apollo 8 Astronaut
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