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Executive VP and CTO  
The Dow Chemical Company



# The Future of Fuels and Alternative Feedstocks – Recognizing Hype vs. Practical Limitations

# Call to Engineers and Scientists

*Too much hype for the possible and not enough focus on the practical.*

*We are letting society down!*

# Business vs. Academic Success



# Business Success vs. SCIENCE

Impact to Society = Business Success

High



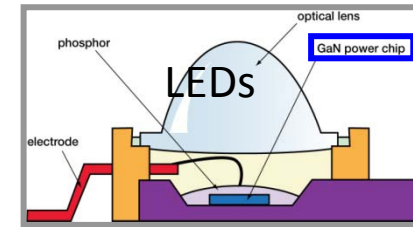
Man Made Diamonds



Transistors



Antibiotics



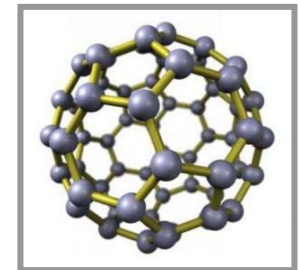
LOW



H<sub>2</sub> fuel cells



Ethylene Styrene Interpolymers

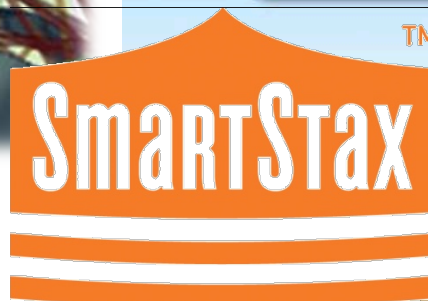


Low

Quality of Science

High

# Biology Can Do Great Things



*HERCULEX XTRA Delivers a Wider Window of Protection than YieldGard VT Triple.*

HERCULEX XTRA  
YieldGard VT Triple

**HERCULEX® XTRA**  
Insect Protection

**HX™**

Black cutworm  
Corn rootworm  
First- and second-generation European corn borer and southwestern corn borer  
Western bean cutworm  
Fall armyworm\*  
First- and second-generation European corn borer and southwestern corn borer  
Corn rootworm

\*YieldGard VT Triple provides intermediate protection against fall armyworm.

# Biofuels Are Like a Jetpack

**HYPE**

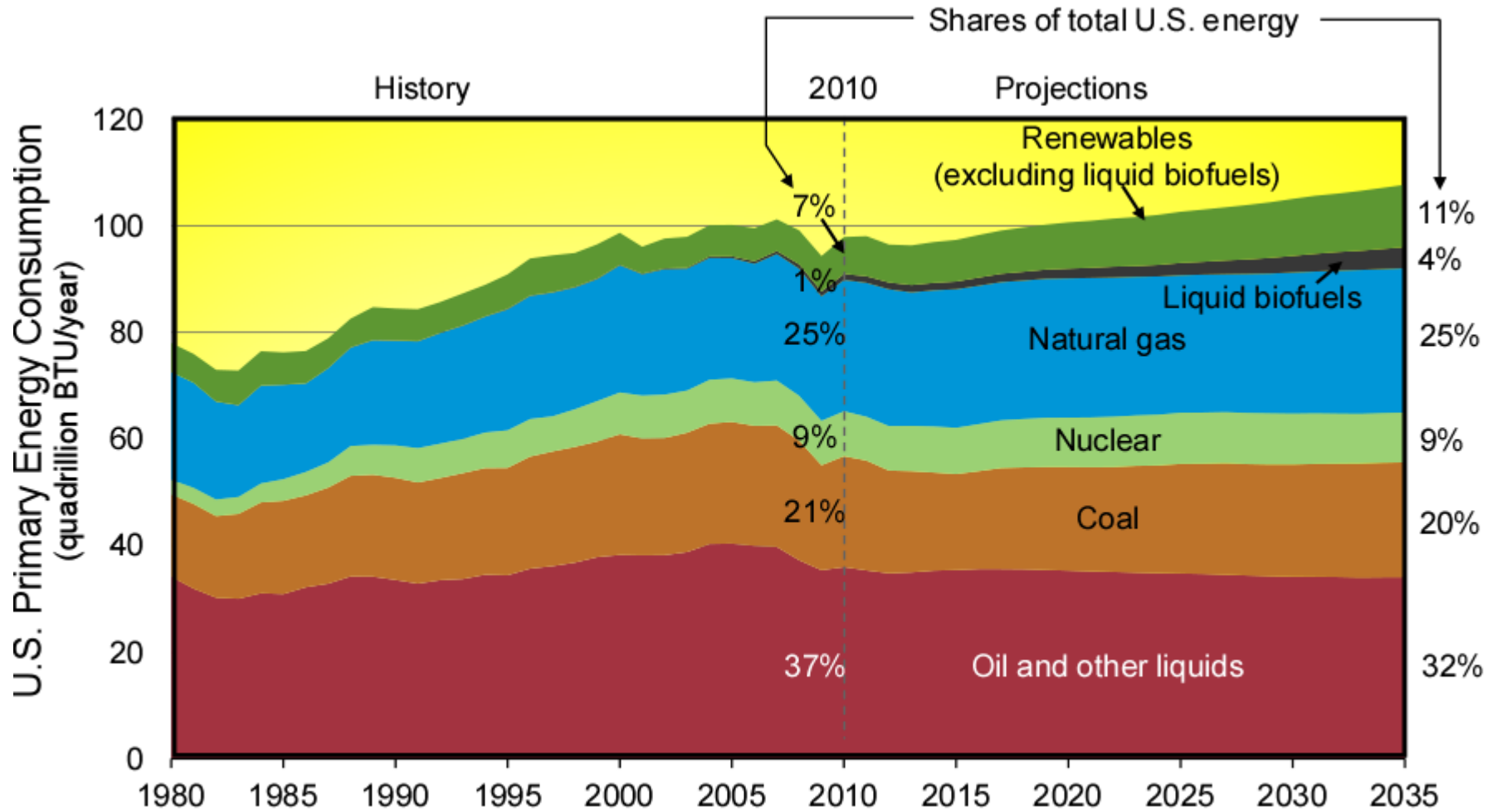
**ENERGY  
DENSITY**

**LIMITATIONS  
OF BIOLOGY**



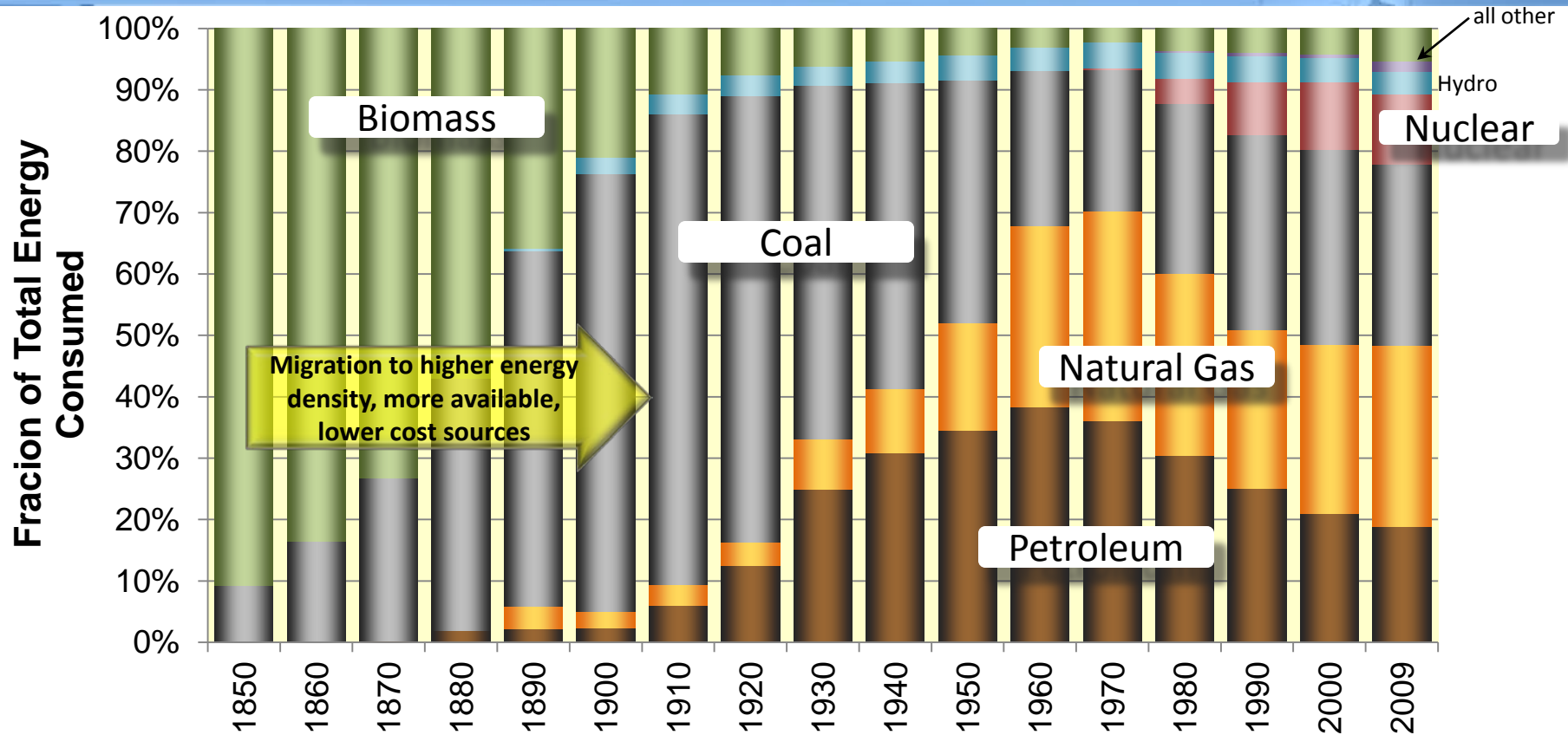
**PRACTICAL  
APPLICATION**

# Biofuels Growth



Source: EIA, Annual Energy Outlook 2012 Early Release

# Energy Sources Always Change



What's Changed?

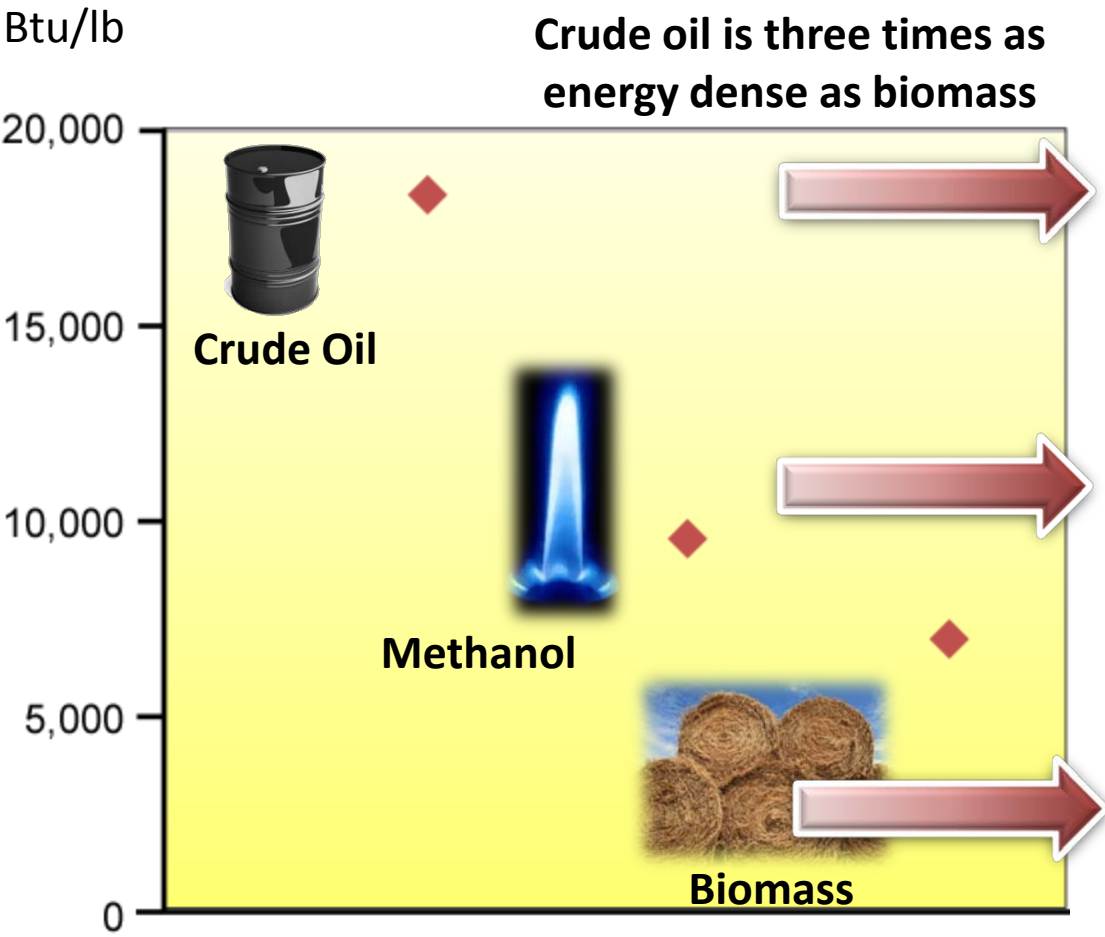
- Oil Price Rise
- CO<sub>2</sub> awareness



Will this reverse the trend?



# Migration to Higher Energy Density Sources



Energy Equivalency	\$ Capital / Usable MM Btu
1 Oil Refinery	\$10
↕	
26 Methanol Plants	\$15
↕	
100 Ethanol Refineries	\$30-120*

\*land & water penalty not included

*Energy from fossil infrastructure built over 80-100 years defines our current standard of living*

Sources: Heating values from GREET, Argonne National Lab, May 2008; Refinery size and economics by Oil & Gas Journal construction update, Apr 2011 for Ras Tanura; Methanol for Atlas, BP annual report and Lurgi literature; Ethanol plant of 100 MM gal/yr from DOE targets assuming 100 MM gal and \$10/annual gallon

# Recognizing Fads

The art of being wise is the art of knowing what to overlook - William James

## Hydrogen Car



"We asked ourselves, 'Is it likely in the next 10 or 15, 20 years that we will convert to a hydrogen car economy?' The answer, we felt, was 'no,'"

Steve Chu, Energy Secretary, May 2009

## Corn Ethanol



"...Using land to grow fuel leads to the destruction of forests, wetlands and grasslands that store enormous amounts of carbon."

Michael Grunwald, TIME April 2007

## Biodiesel

"Biofuels are contributing to higher prices and tighter markets."

Timothy Searchinger, Princeton University April 2011



## Cellulosic Ethanol

"...the need for trucks, machinery and manpower would come during harvest, already the busiest time of the year on the farm. And that's where a massive federal initiative into cellulosic ethanol may find its biggest bottleneck - on the farm."

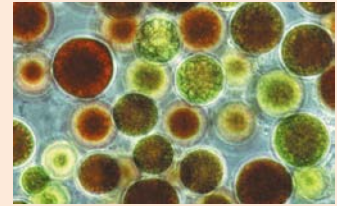
Robert Rapier



## Algae

"...microalgae can be raised on cheap, sun-splashed land that is unsuitable for crops or much of anything else."

Paul Voosen, New York Times, 29 March 2011.



Dow launched the JV with Cargill in 1997 to develop and market PLA from corn, exited the JV in 2004.

## THE WALL STREET JOURNAL

### "Sun Chips Bag to Lose Its Crunch"



Photo: Associated Press

Bio based packaging launched in 2009 but discontinued by late 2010, due to performance perception issues

## Glycerin to Epi

Dow postponed in 2009 due to uncertain supply +

## Natural Oil Polyols

Dow Launched in 2007, exited in 2010.

## ADM-Metabolix



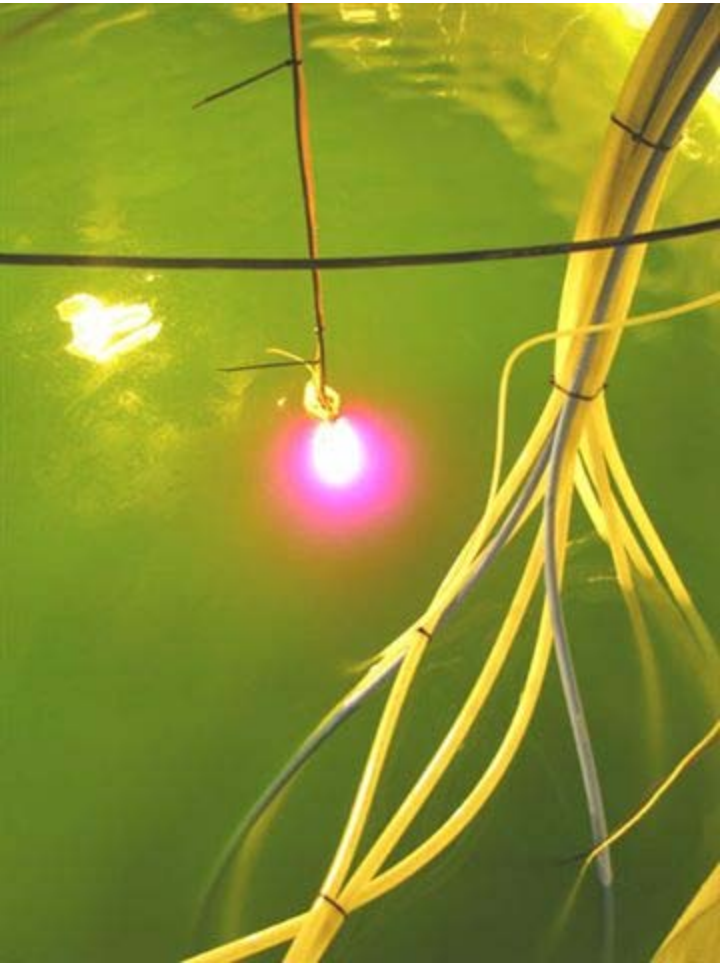
ADM has given notice of termination of the Telles, LLC joint venture for PHA bioplastics

# Hype Building for Algae?

Using sunlight, CO<sub>2</sub> and little else, many varieties of fast-growing pond scum, when starved of nutrients, quickly build up oil in their cells. They need no external sugar from corn or cane to grow, so they don't compete with food crops. Farmed in ponds or translucent reactors, microalgae can be raised on cheap, sun-splashed land that is unsuitable for crops or much of anything else.

Voosen, Paul; "As Algae Bloom Fades, Photosynthesis Hopes Still Shine", New York Times, 29 March 2011.

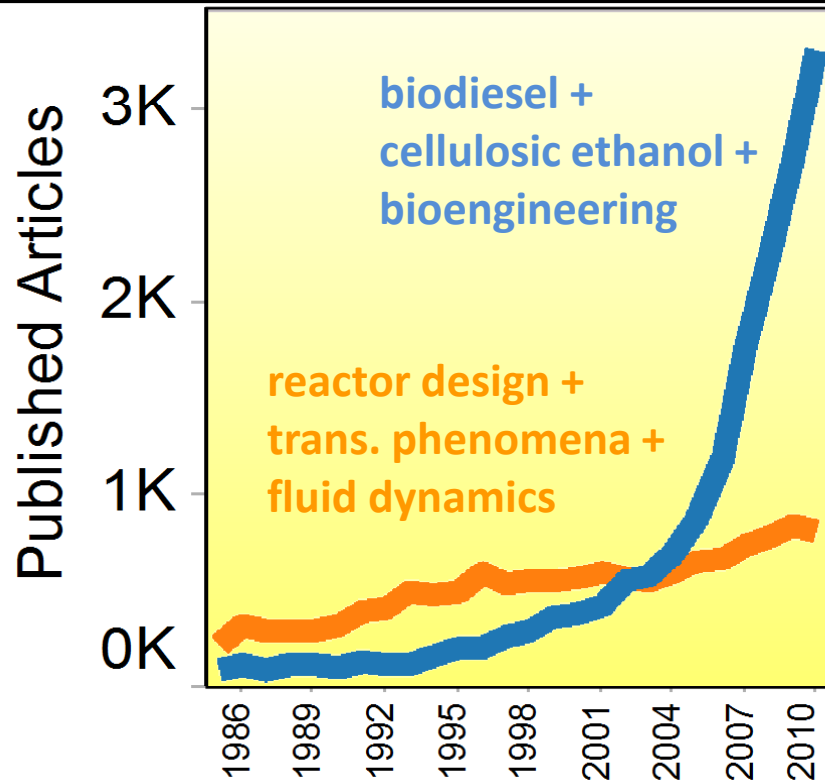
# Practical?



LumiGrow LED technology is instrumental to the operation of Algae Farm's algae biomass production system, which will produce algae for the nutraceutical, cosmetic and renewable energy market sectors. By growing in a climate-controlled indoor environment, Algae Farm can achieve predictable and scalable yields while it maintains the highest purity standards.

# Funding Follows the Hype

Published Articles Reflect the Focus on “Bio” Related Research:

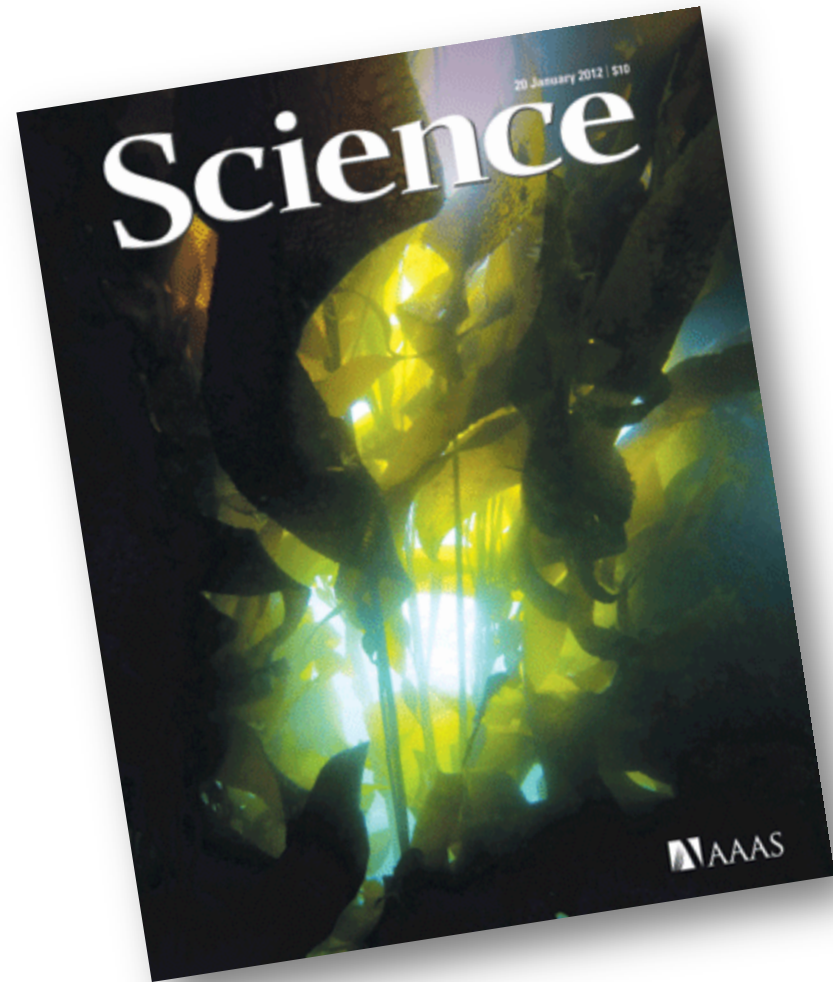


Percentage of Faculty with “Bio” Related Research Interests:



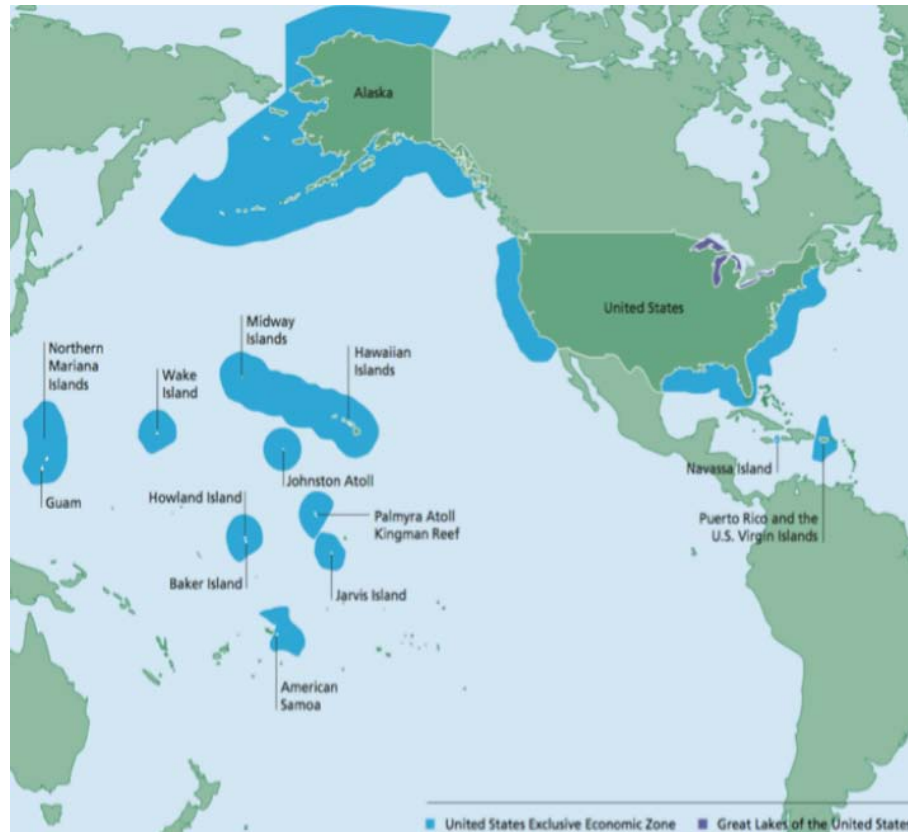
*Dynamic range of the discipline is threatened by decreasing support of the traditional core research areas.*

# Synthetic Biology



- lead story in Science 20 January 2012 issue
- Bio Architecture Lab, Berkeley, CA
- seaweed has no lignin
- alginate not fermented by yeasts
- *E. coli* genetically engineered to ferment alginate and other major sugars present to ethanol

# Hype?



- alginate only about a third of sugars present
- U.S. owns more ocean area than any other country
- “no land, (no) fresh water or (no) fertilizer”

*Erik Stokstad, Science, 20 January 2012, page 273*

# Problem not solved



- harvested for over 400 years
- cost for wet biomass are >\$400/ton at water levels >70% *more expensive than corn!*
- Redfield ratio still required
- *arable ocean* (analogy to arable land) needed

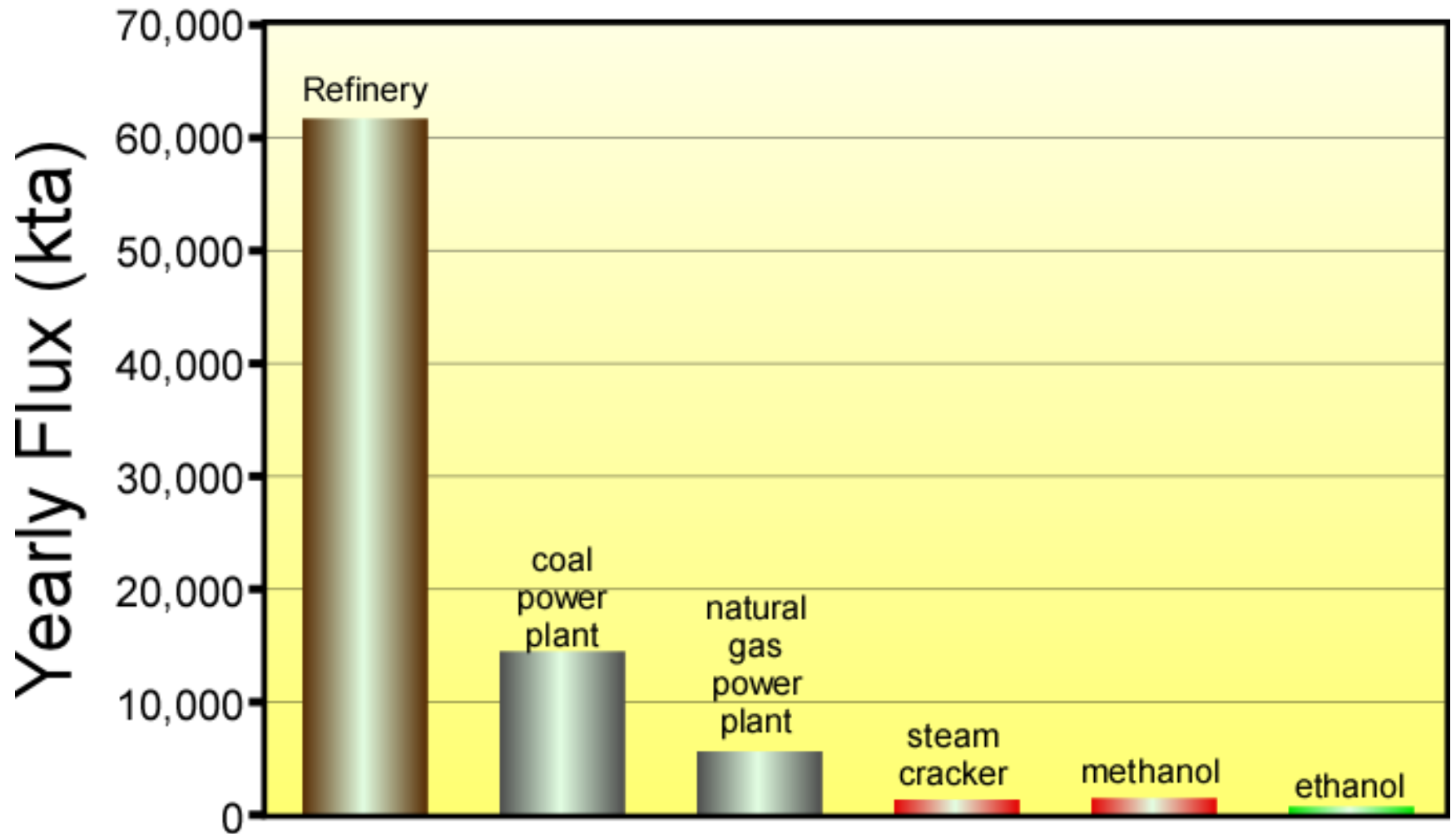


# Biofuels Key Issues



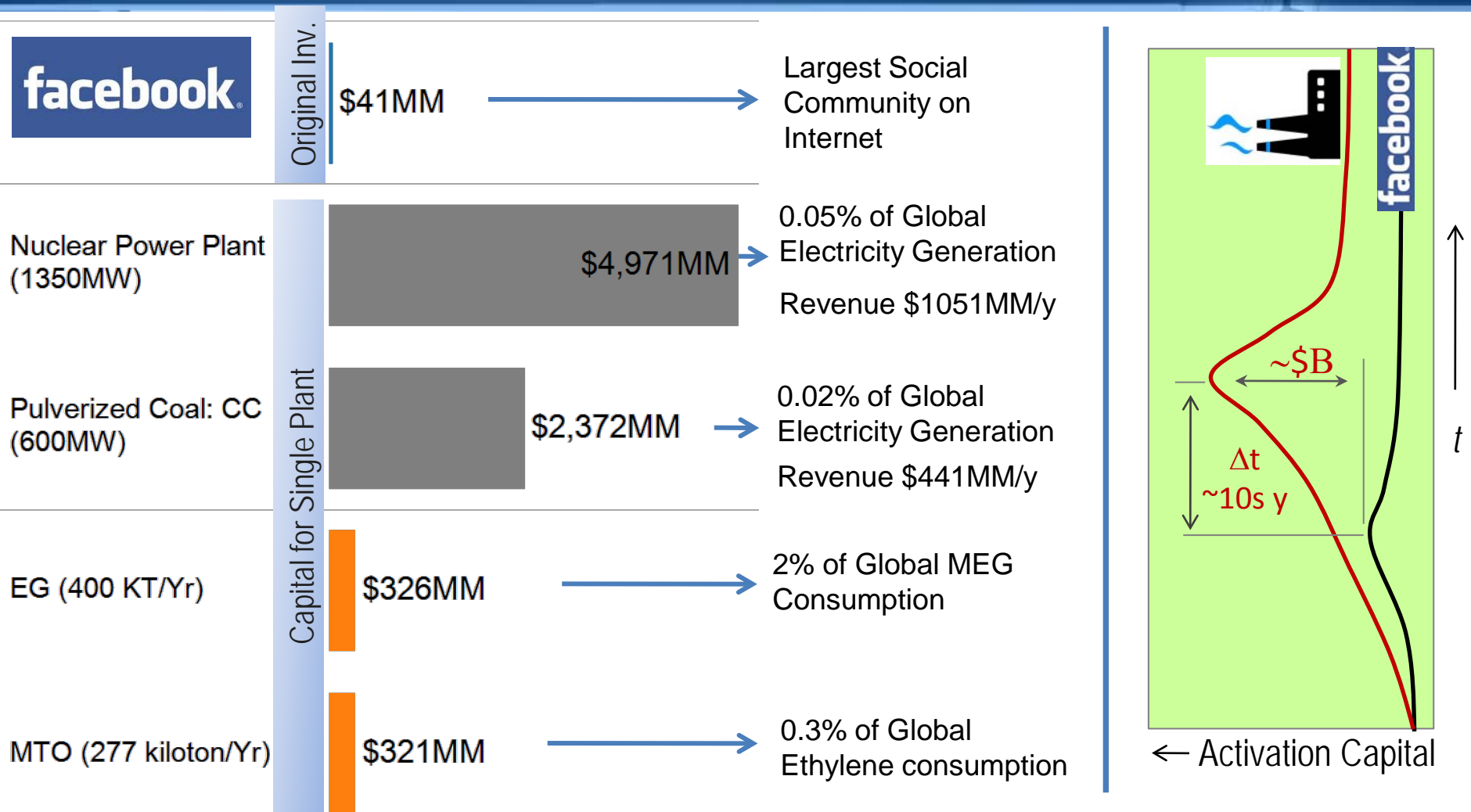
- How much *biomass is available?*  
*not enough to replace fossil fuels*
- How much will the biomass cost?  
*it is not cheap!*
- How much will biofuels cost? *more than fossil*
- How much more are we willing to pay? *no premium*
- How realistic is chemical production from biomass?  
*we already do, but chemical use doesn't address the big issues*

# Largest Plants



*feedstock limits scale*

# Scale of Fuels Makes it Harder



**Sources:** facebook original investment showing combined amounts from Peter Thiel (PayPal cofounder), Accel Partners and Greylock Partners as described in the History of facebook on wikipedia; Power Plants: RL34746 report - Stan Kaplan - Congressional Research Service; MTO: PEP Report 261 – SRI and EG: PEP Report 21 – SRI; **Revenues** for Power Plants calculated using 2010 electricity average retail prices (all sectors) 9.88 cents/kWh (data from DOE)

# Timeline for Impact

Impact / Market Penetration

Invention



Development



Demonstration



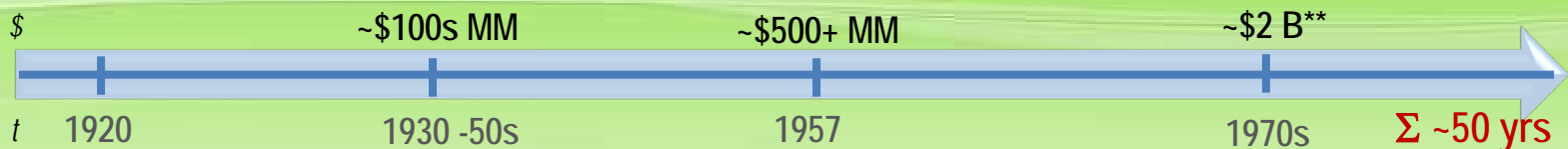
Deployment



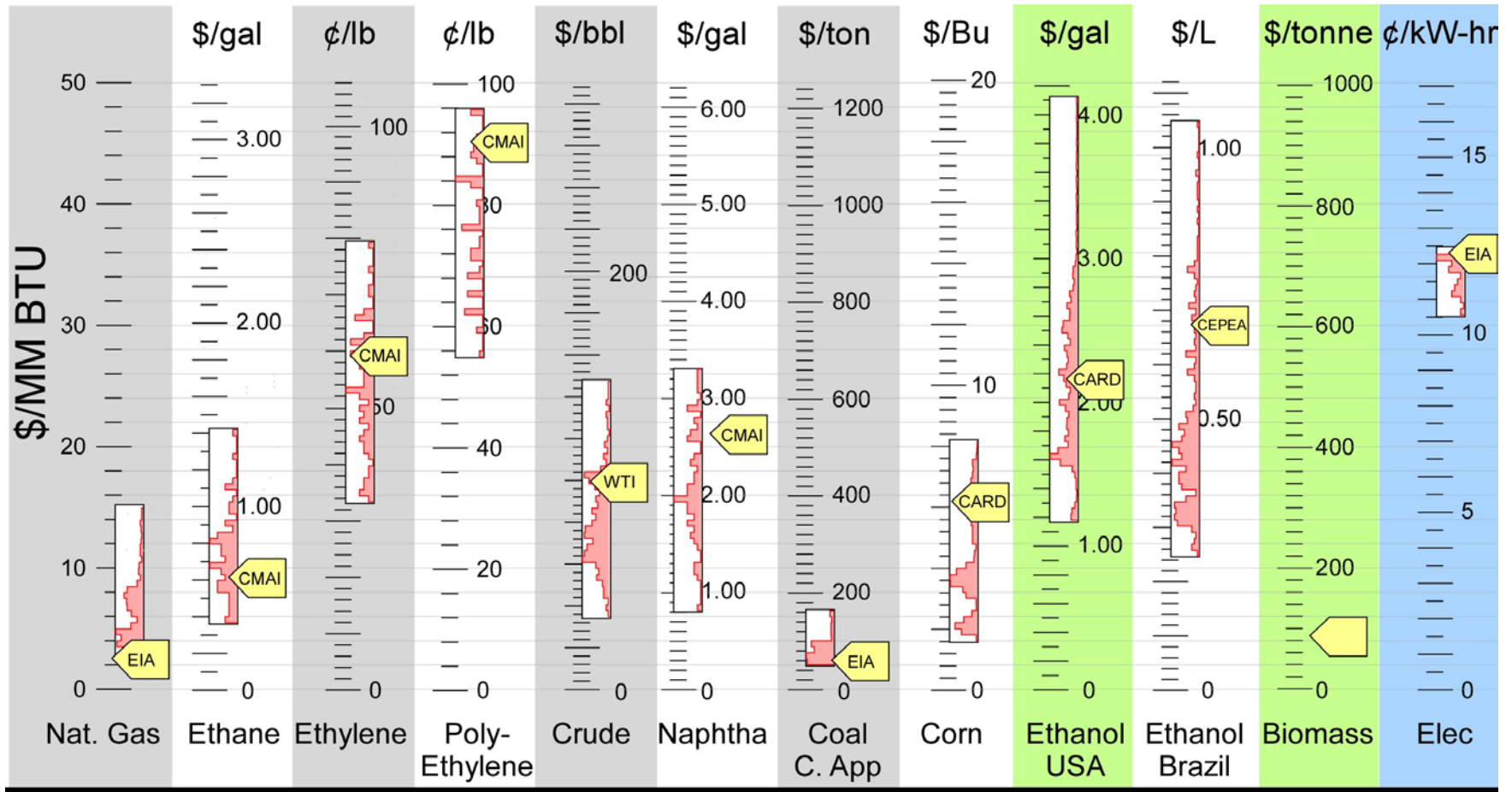
Single Site Catalysis



Super Critical Coal Power



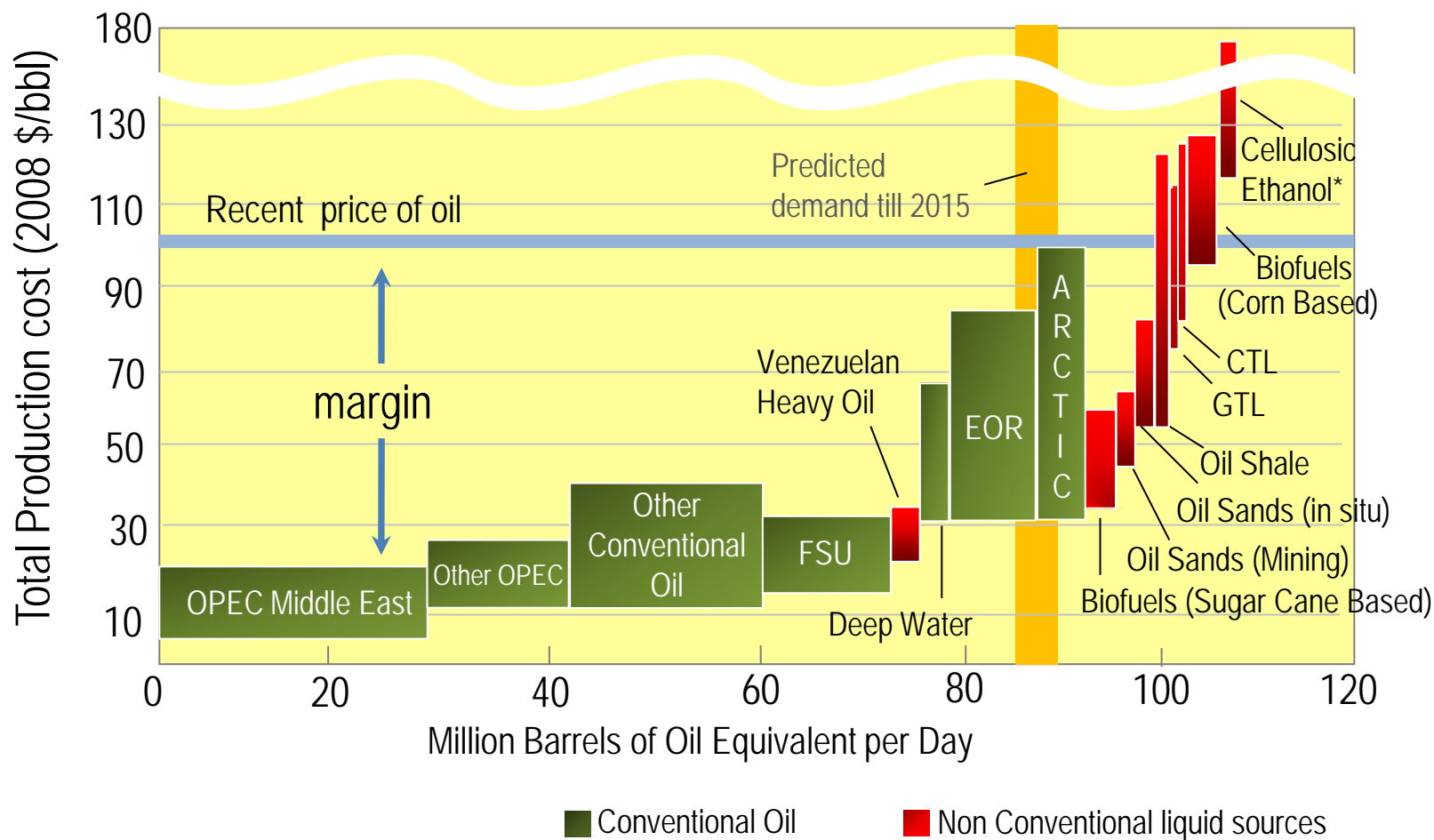
# Energy Content



EIA is DOE Energy Information Agency, CMAI is an HIS affiliate, CARD is Iowa State Center for Agricultural and Rural Development, CEPEA is Centro de Estudos Avancado em Economia Aplicada – data for 3-5 years depending on source.

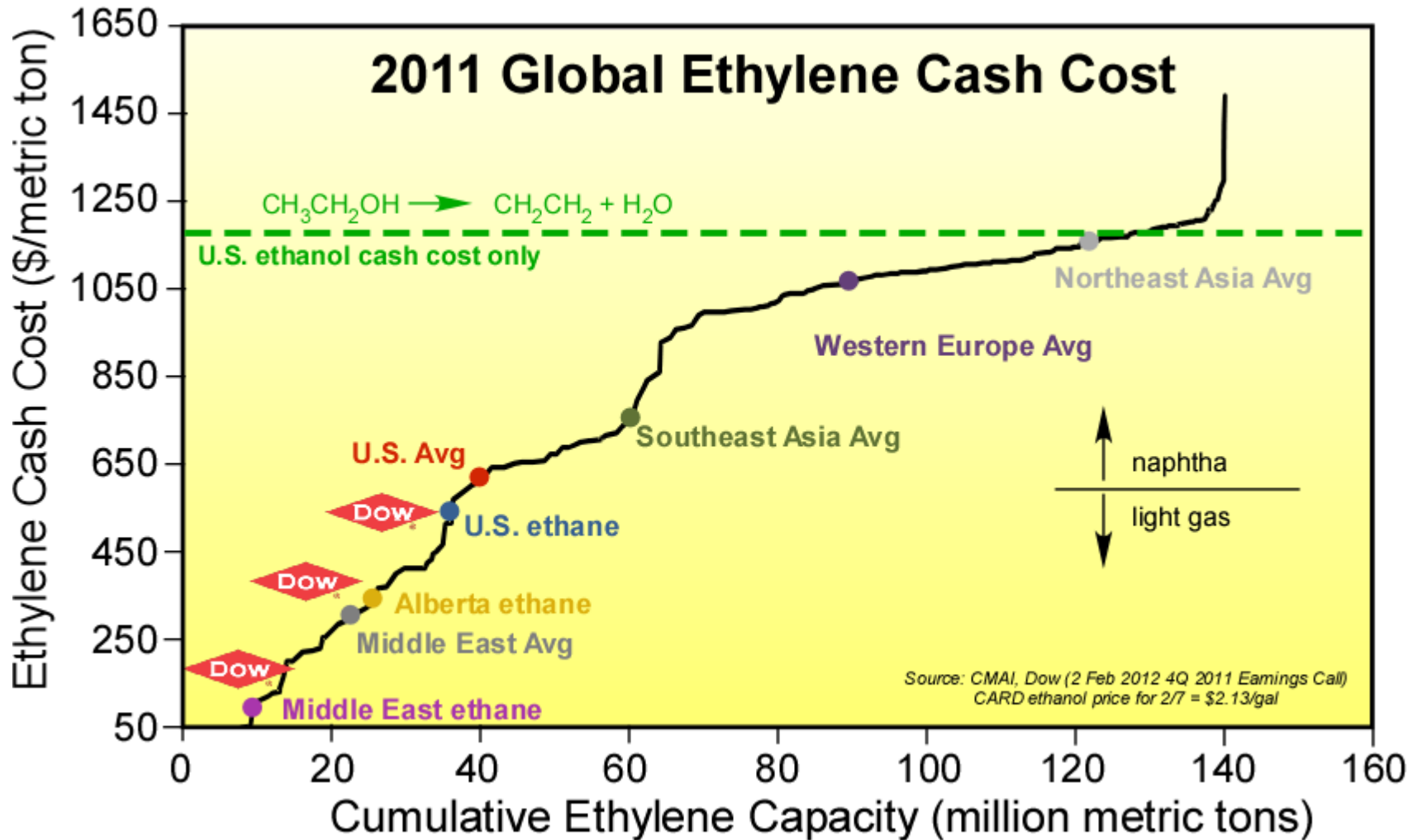
# Energy Industry Dynamics

As oil price rises, new capital will flow to EOR, Arctic, Oil sands, GTL, CTL before biofuels.

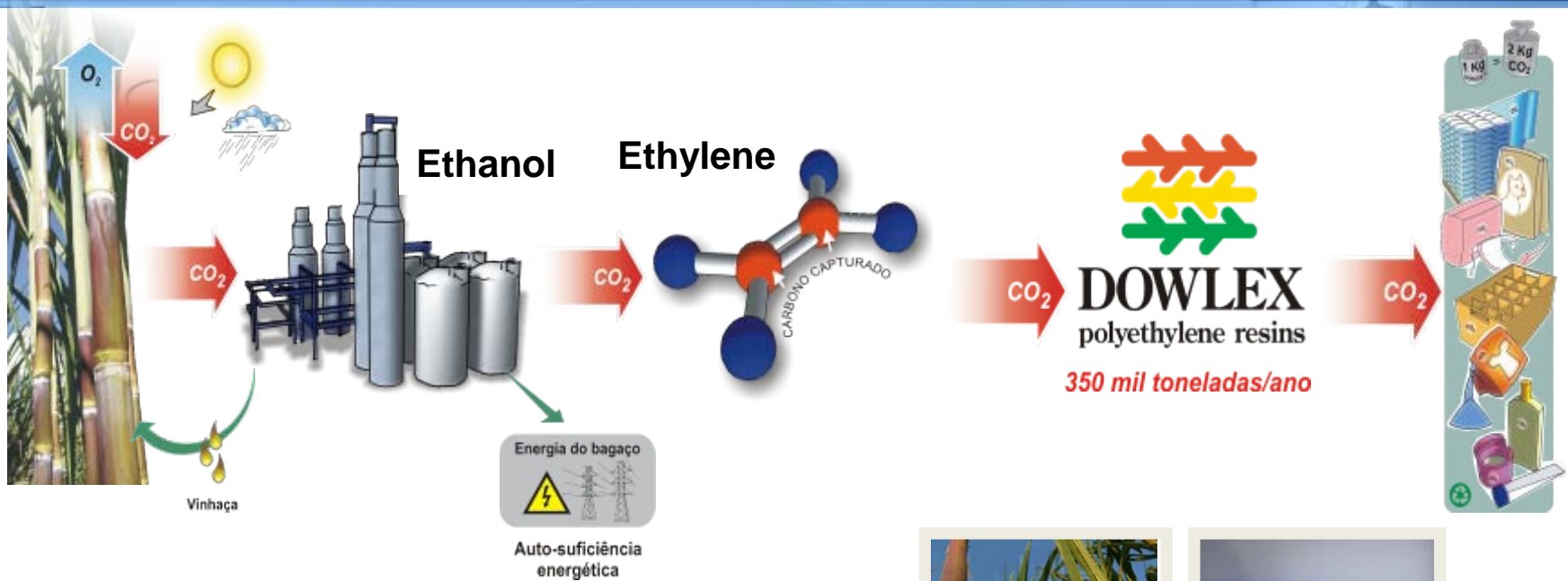


\*Based on DOE volume projections for US in 2022. DOE price target is ~\$113/bbl

# Global Ethylene Cash Cost



# Alternative Feedstock - Cane to LLDPE



Fully-integrated facility in Brazil  
Utilizes state-of-the-art Dow  
polymerization catalysis

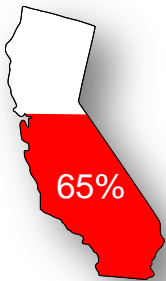




# Ethanol to PE in 2008

*naphtha was looming as the only feedstock choice*

- Existing logistics for ethanol in Brazil
- High polyethylene price in Brazil
- Ethanol price fluctuation requires integration

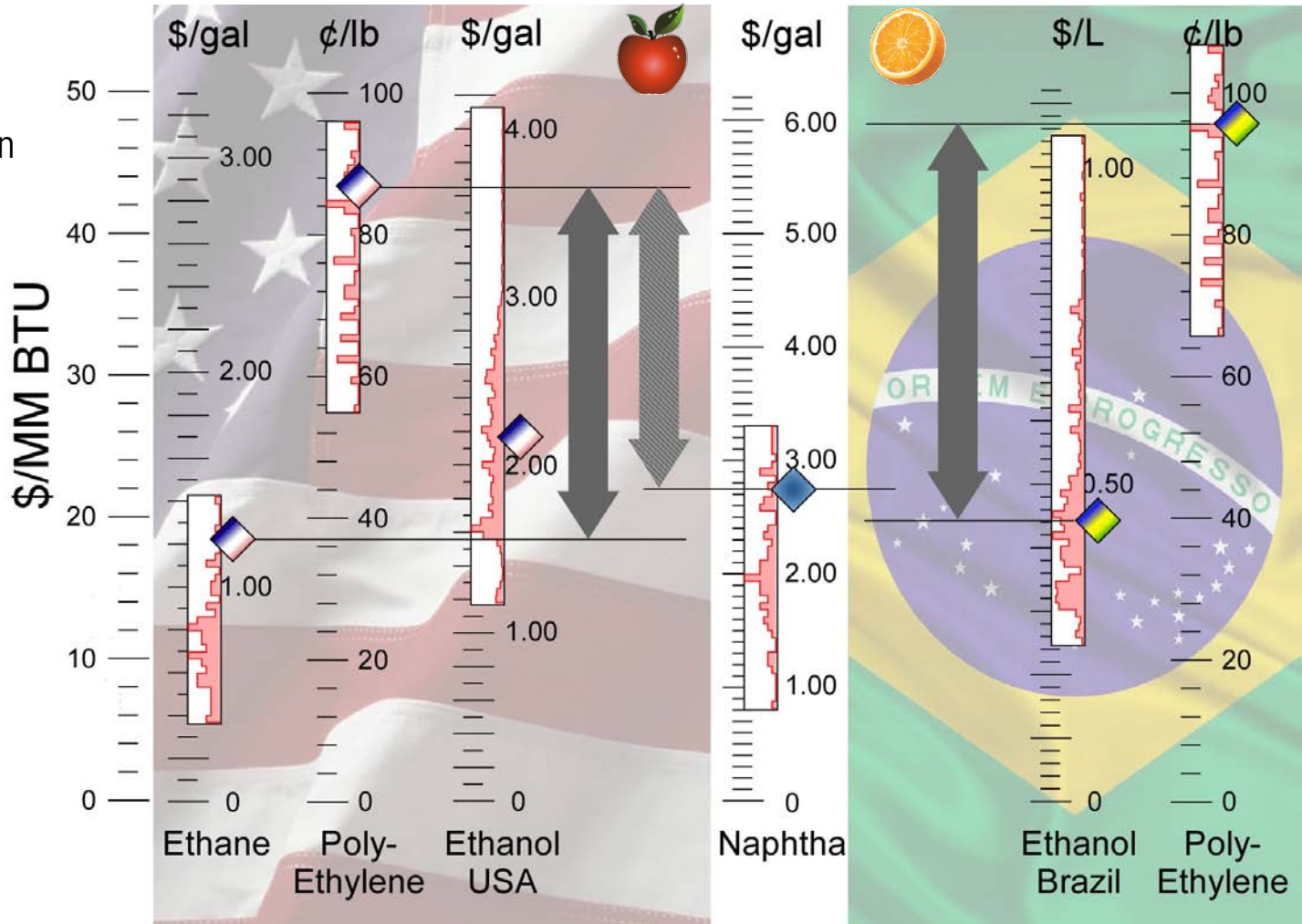


Area required to produce Brazilian cane ethanol sufficient to meet 2011 global PE demand

## Market Prices



USA Brazil World

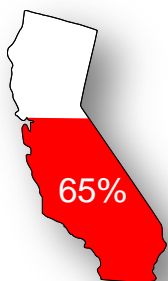


Sources: Ethane, ethylene, polyethylene (US): CMAI; Ethanol US: CARD, Ethanol Br: CEPEA; PE Brazil calculated based on market price differential Br to US. Price histograms shown for 2005 to Feb 2012; Prices shown from Feb 2012. \*Costs: Br EtOH: Data Agro 2009 and Estado de S. Paulo 2007 ratioed to 2012 exchange rate

# Ethanol to PE – A Niche Opportunity

Market prices and selected costs on energy equivalent basis

- Existing logistics for ethanol in Brazil
- High polyethylene price in Brazil
- Ethanol price fluctuation requires integration

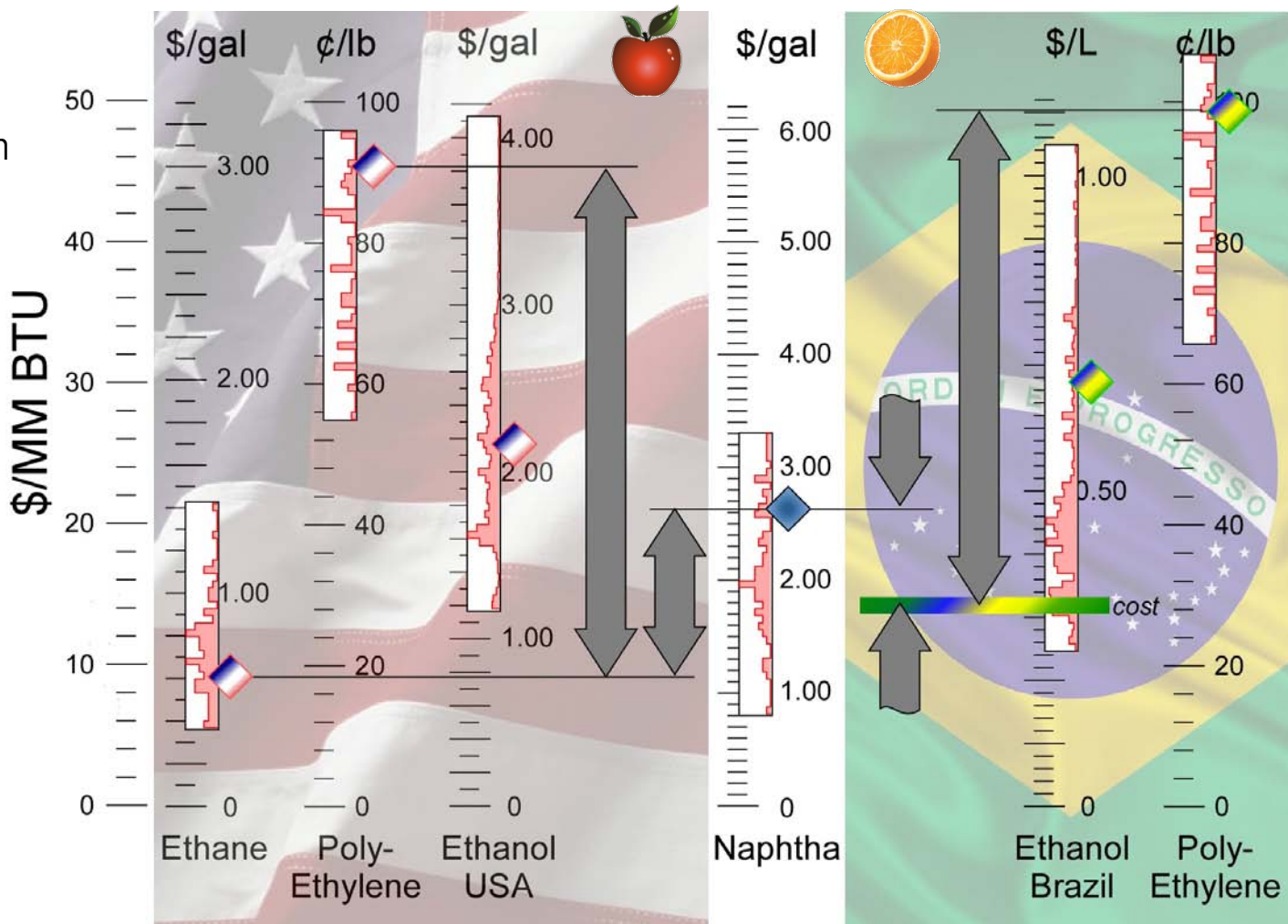


Area required to produce Brazilian cane ethanol sufficient to meet 2011 global PE demand

Market Prices

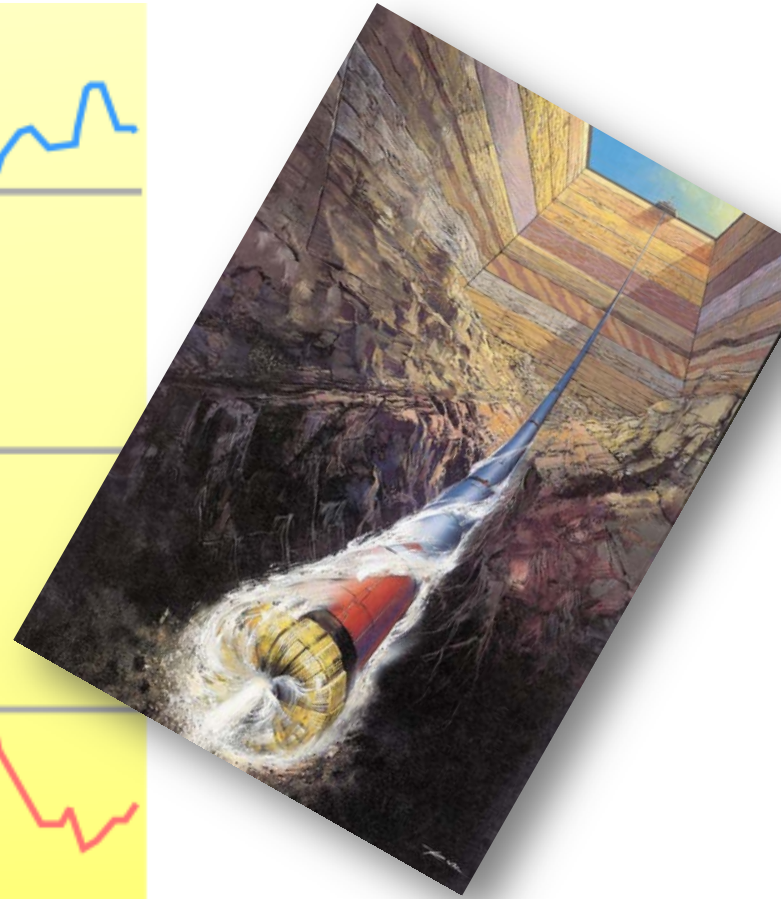
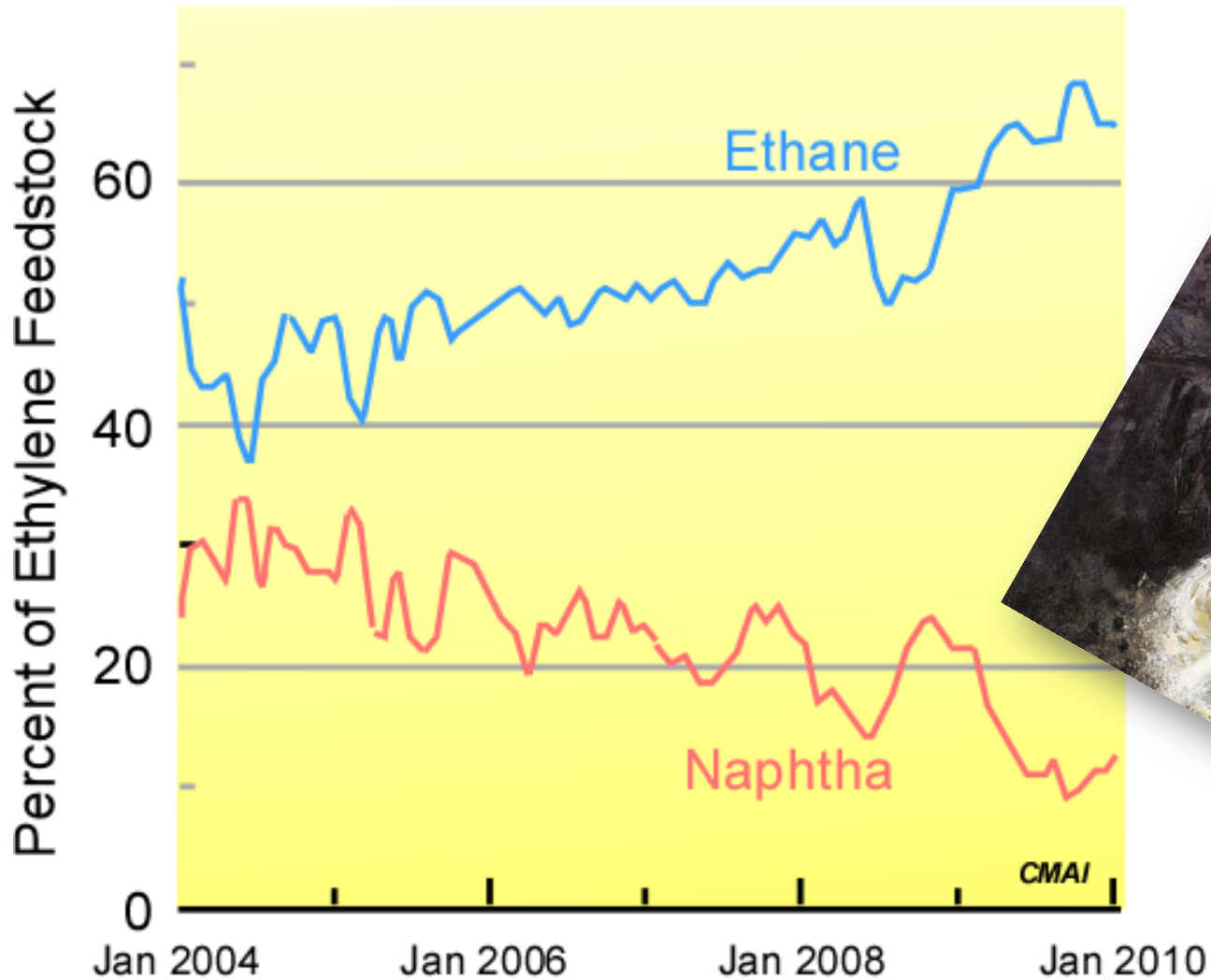


USA Brazil World

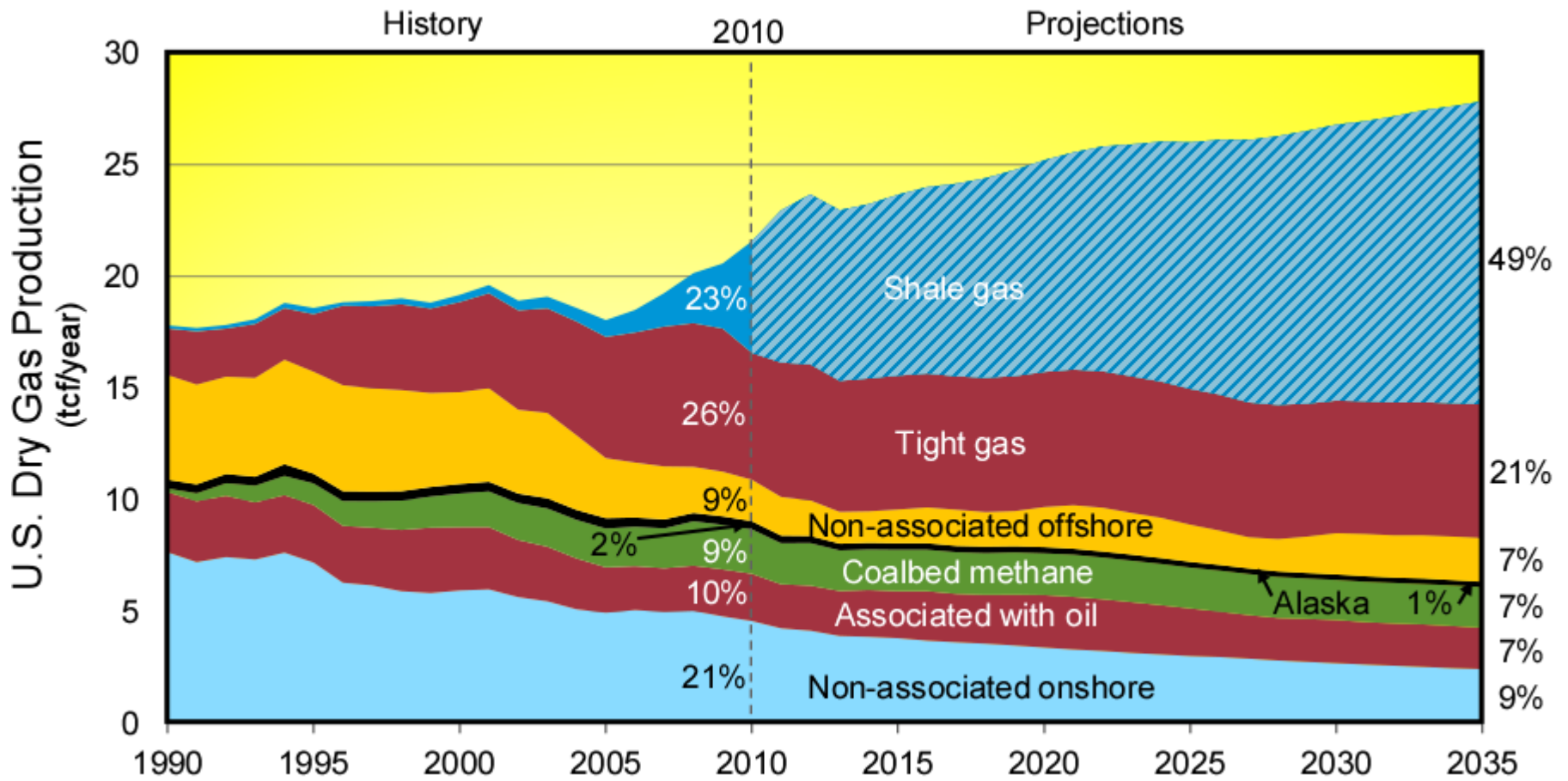


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# Shale Gas Revitalizes the Industry



# Shale Gas Growth

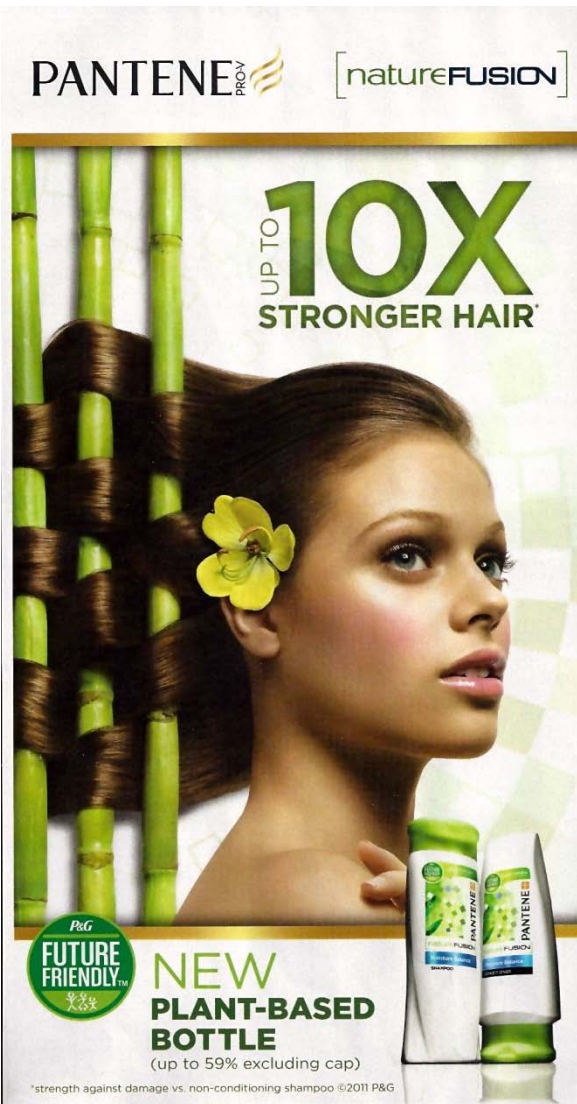


Source: EIA, Annual Energy Outlook 2012 Early Release

# Demand for Bioproducts?

PANTENE PRO-V [natureFUSION]

UP TO **10X**  
STRONGER HAIR\*



**P&G**  
**FUTURE FRIENDLY™**  
NEW  
**PLANT-BASED BOTTLE**  
(up to 59% excluding cap)

\*strength against damage vs. non-conditioning shampoo ©2011 P&G

*Midland Daily News*  
*1 January 2012*



**P&G**  
**FUTURE FRIENDLY™**

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(up to 59% excluding cap)

\*strength against damage vs. non-conditioning shampoo ©2011 P&G

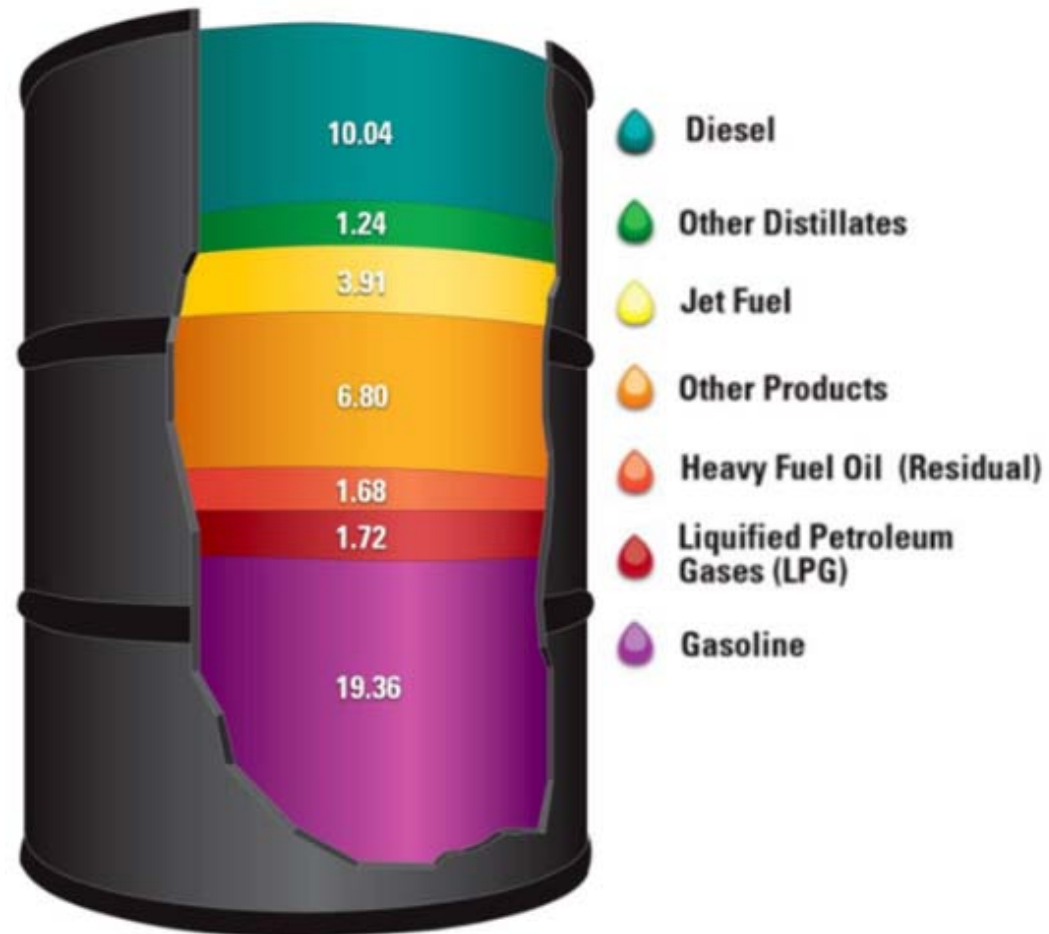
# Changing Emphasis

Biomass 2011: Replace the Whole Barrel,  
Supply the Whole Market  
*The New Horizons of Bioenergy*

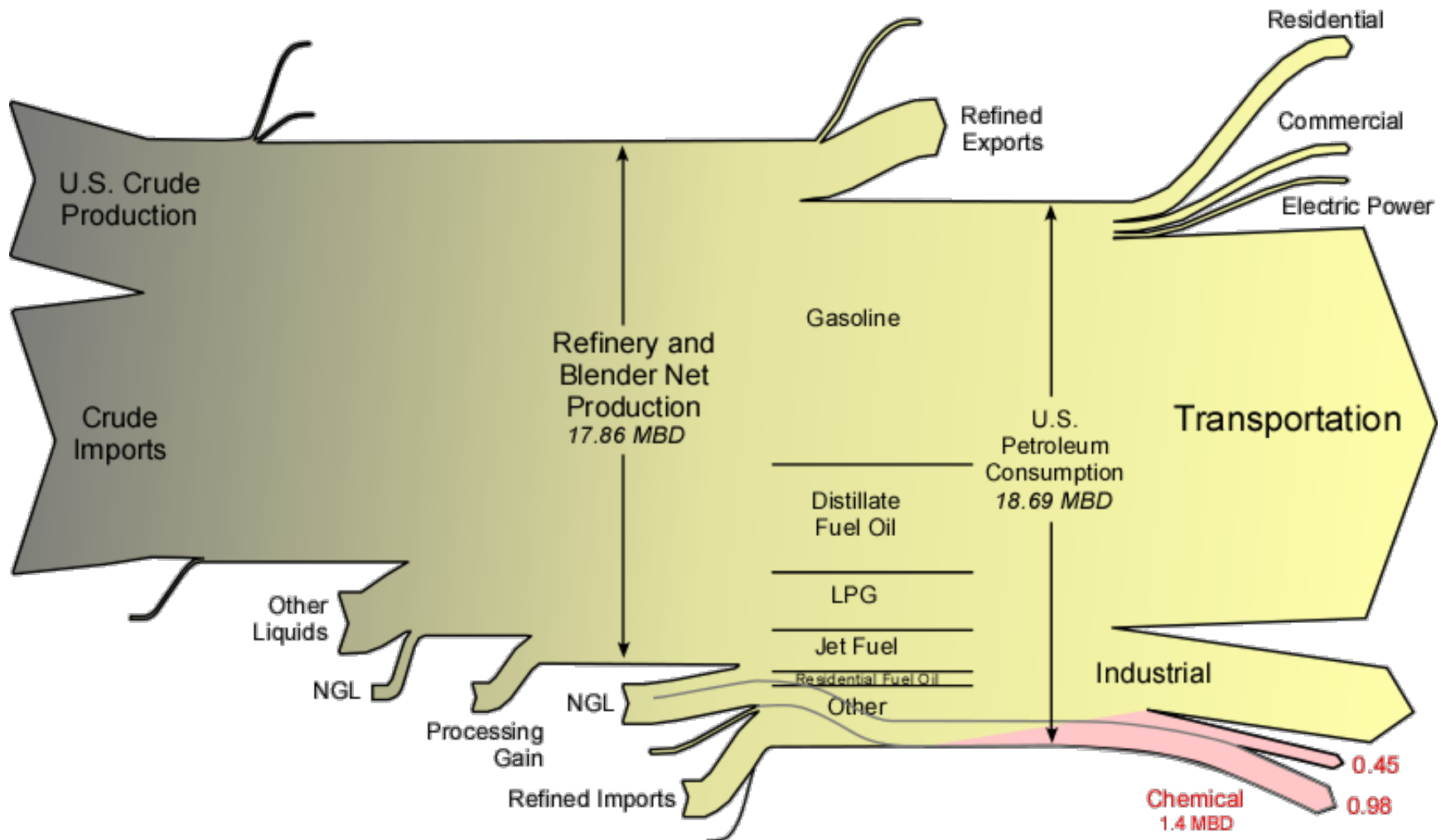
July 26–27, 2011



*“sugar is the new crude”*

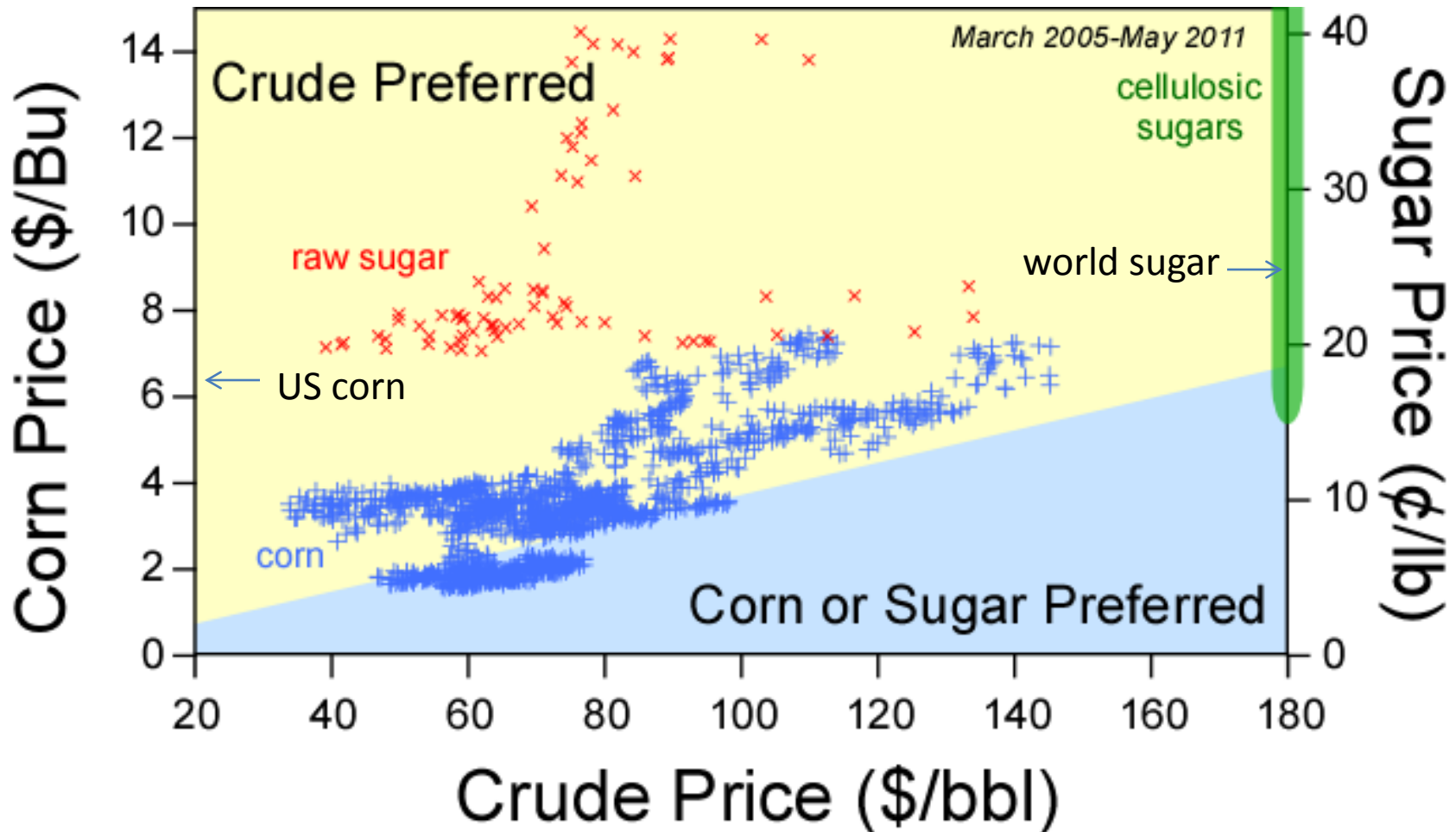


# U.S. Petroleum Flow



# Bio Commodities Too Expensive

*Cash cost* indifference analysis for ethylene from crude oil and bio feedstocks



**\*Excludes Capital**



## Twelve Principles of Green Chemistry

1. Prevention: It is better to prevent waste than to treat or clean up waste after it has been created.
2. Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Use of Renewable Feedstocks:  
A raw material or feedstock  
should be renewable rather  
than depleting whenever  
technically and economically  
feasible.

7. Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary physical/chemical processes) should be avoided whenever possible, because such steps require extra reagents and can generate waste.

9. Safer Reagents (as selective as possible) are preferred to stoichiometric reagents.

10. Design for Degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

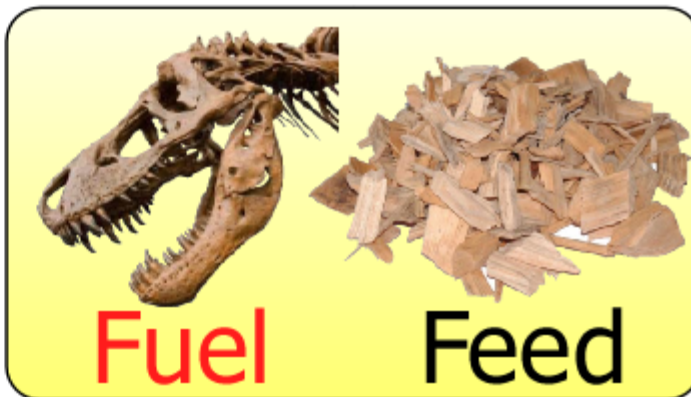
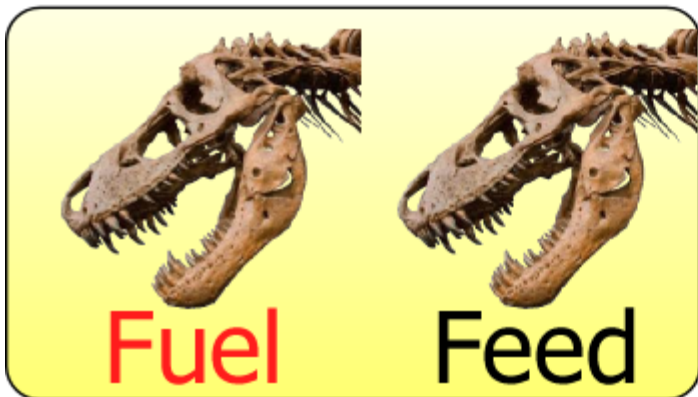
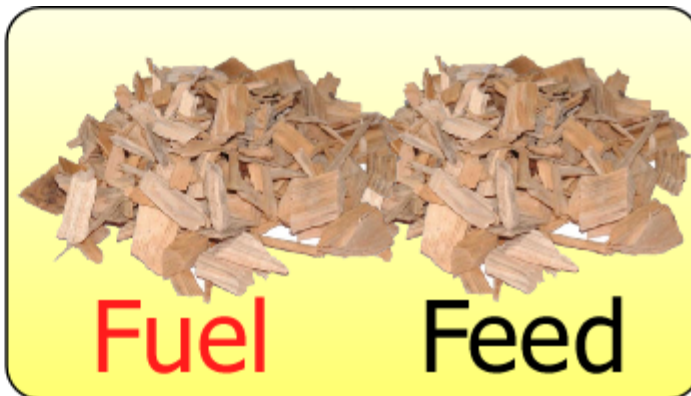
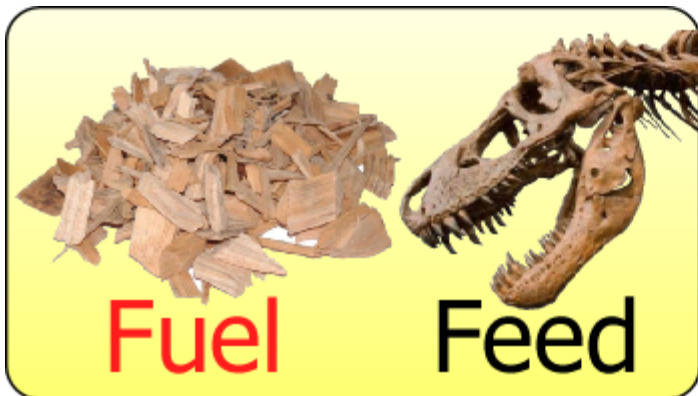
11. Process for Pollution Prevention: Analytical procedures should be further developed to allow for real-time monitoring and control prior to the formation of pollutants under various circumstances.

12. Chemistry for Accident Prevention:

The form of a substance used in a chemical process should be chosen to minimize the potential for

chemical accidents, including releases, explosions, and fires.

# Two Carbon Flavors



# Berkeley Study on PHA

## PHA production requires more fossil fuel energy

### PS vs. PHA – Energy and Fossil Fuel Equivalents (FFE's) comparison

	Energy and FFE (per kilogram polymer)			
	Polystyrene		PHA	
	Energy	FFE	Energy	FFE
Production of raw materials	See below*	1.78 kg*	31,218 kJ	0.80 kg
Utilities				
▪ Steam	7.0 kg	0.4 kg	2.78 kg	0.14 kg
▪ Electricity	0.30 kWh	0.08 kg	5.32 kWh	1.45 kg
<b>Total</b>		<b>2.26 kg</b>		<b>2.39 kg</b>

**High energy requirement of feedstock is largely responsible for high cost of PHA**

### Summary – predictions

- The increased market demand for bioplastics will sustain a small, slow-growth market for PHA
- PHA will not achieve a price parity with petroleum-based plastics
- PHA will be limited to niche applications where compostability creates a value and as a blend to improve performance of other bioplastics
- Perceived environmental benefits of biodegradable plastics will erode over time



# LCA of Polymers

*Biopolymers rank in the middle of LCA rankings*

POLYMER	Material	Green Design Rank	LCA Rank
Polylactic Acid – NatureWorks	Sugar/cornstarch	1	6
Polyhydroxyalkanoate-Stover	Cornstalks	2	4
Polyhydroxyalkanoate-General	Corn kernels	2	8
Polylactic Acid-General	Sugar/cornstarch	4	9
HD Polyethylene	Petroleum	5	2
PET	Petroleum	6	10
LD Polyethylene	Petroleum	7	3
Bio-PET	Petroleum /plants	8	12
Polypropylene	Fossil fuels	9	1
General Purpose Polystyrene	Petroleum	10	5
PVC	Chlorine/petroleum	11	7
Polycarbonate	Petroleum	12	11

# LCA of Polymers

*Biopolymers rank in the middle of LCA rankings*

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PVC	Chlorine/petroleum	11	7
Polyhydroxyalkanoate-General	Corn kernels	2	8
Polylactic Acid-General	Sugar/cornstarch	4	9
PET	Petroleum	6	10
Polycarbonate	Petroleum	12	11
Bio-PET	Petroleum /plants	8	12

# What works in bioproducts?

- nature prepares the molecule:
  - nature puts it in the right oxidation state (*kind of carbon*)
  - nature makes the right molecular structure for the end application (*shape of carbon*)
  - nature makes enough that recovery is economical
- technical risk to serve market is low:
  - identical biomaterial for established markets
  - fossil and bio parity in market

# What are we doing?

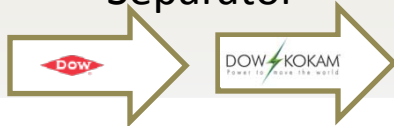
R&D goal is to extract more earnings per dollar of investment

*Dow chooses to operate where materials science expertise drives success*

## Energy Storage

### Superior Materials:

Cathode  
Anode  
Electrolytes  
Separator



## Energy Efficiency

### Superior Materials:

Energy efficiency improvements for commercial and industrial products



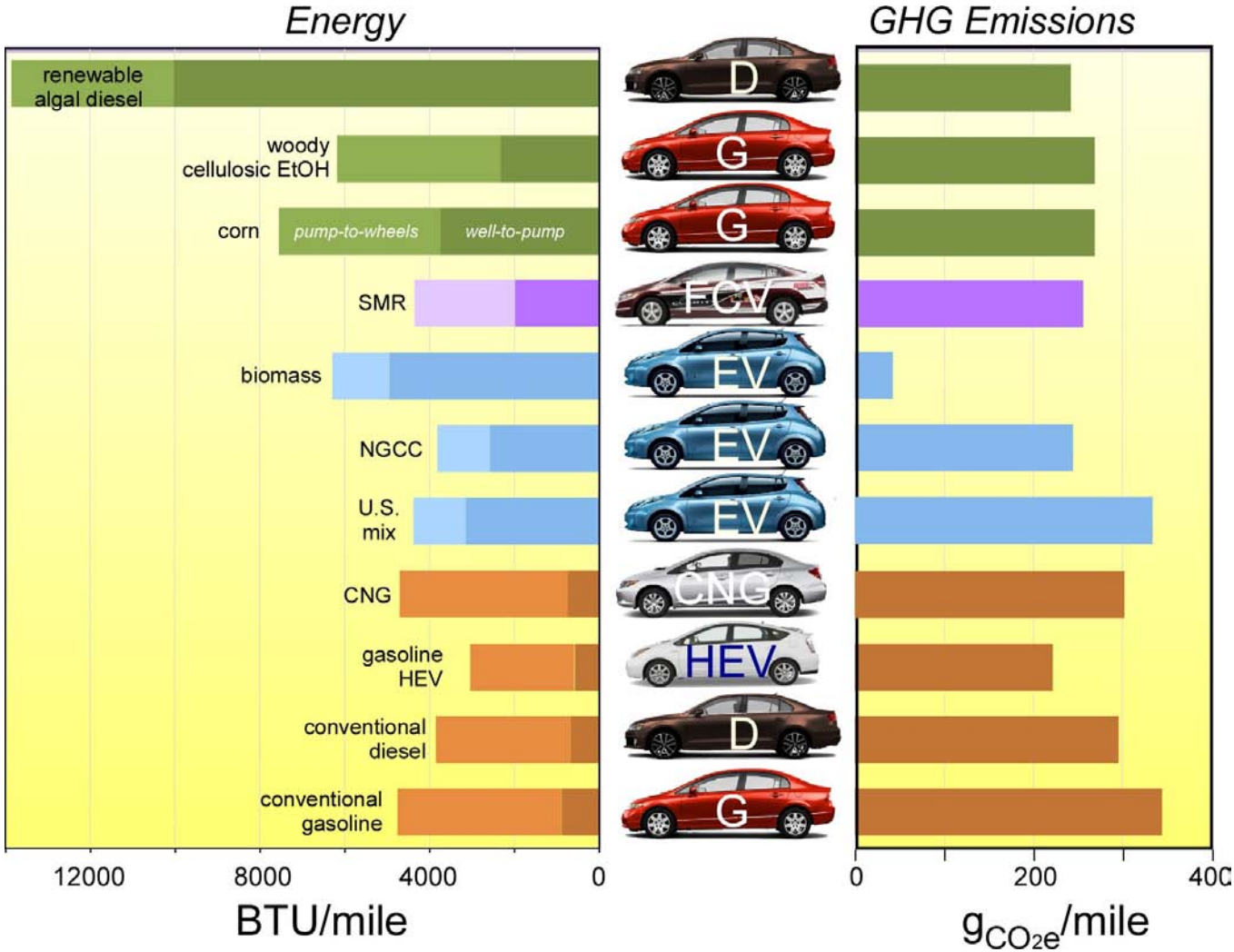
## Energy Generation

### Superior Materials:

Efficiency  
Yield  
Performance  
Durability

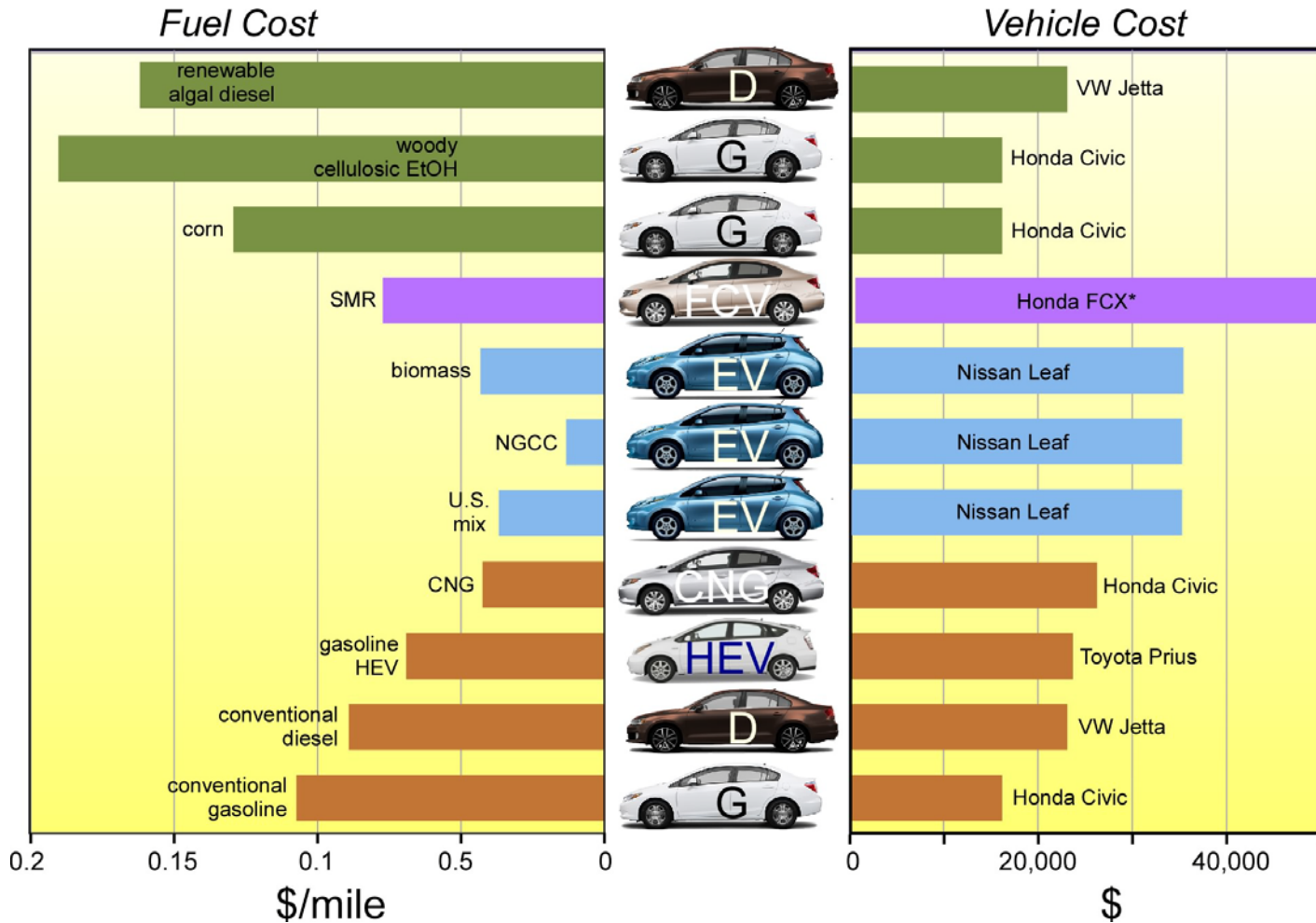


# Electrification Beats Biofuels





# Electrification Beats Biofuels



# Conclusions

- Too much hype for the possible and not enough focus on the practical
  - **Incumbent fossil sources** set the standard for competition
  - It takes **decades** to deploy a new technology
  - Scale wins and biomass availability limits biofuels scale
- **Small companies access to patient capital makes success challenging**
- **Fundamental engineering judgment** is crucial to long term innovation
- Can society afford to pay for a different solution?

*Facts are the air of scientists. Without them you can never fly.*

*- Linus Pauling*



**Thank You**

# Dow Supports Chemical Engineering



- \$250 million total program
- foster better balance
- 10 year program
- 11 major universities
- areas
  - catalysis
  - process development
  - new materials
    - electronics
    - energy
    - transportation
    - consumer applications



Dow expects its own scientists will benefit from university research.

Dow Chemical says it will spend \$250 million over the next 10 years to support breakthrough chemical technologies at 11 major U.S. universities. The program will help significantly increase the number of chemical engineering Ph.D.s at the schools.

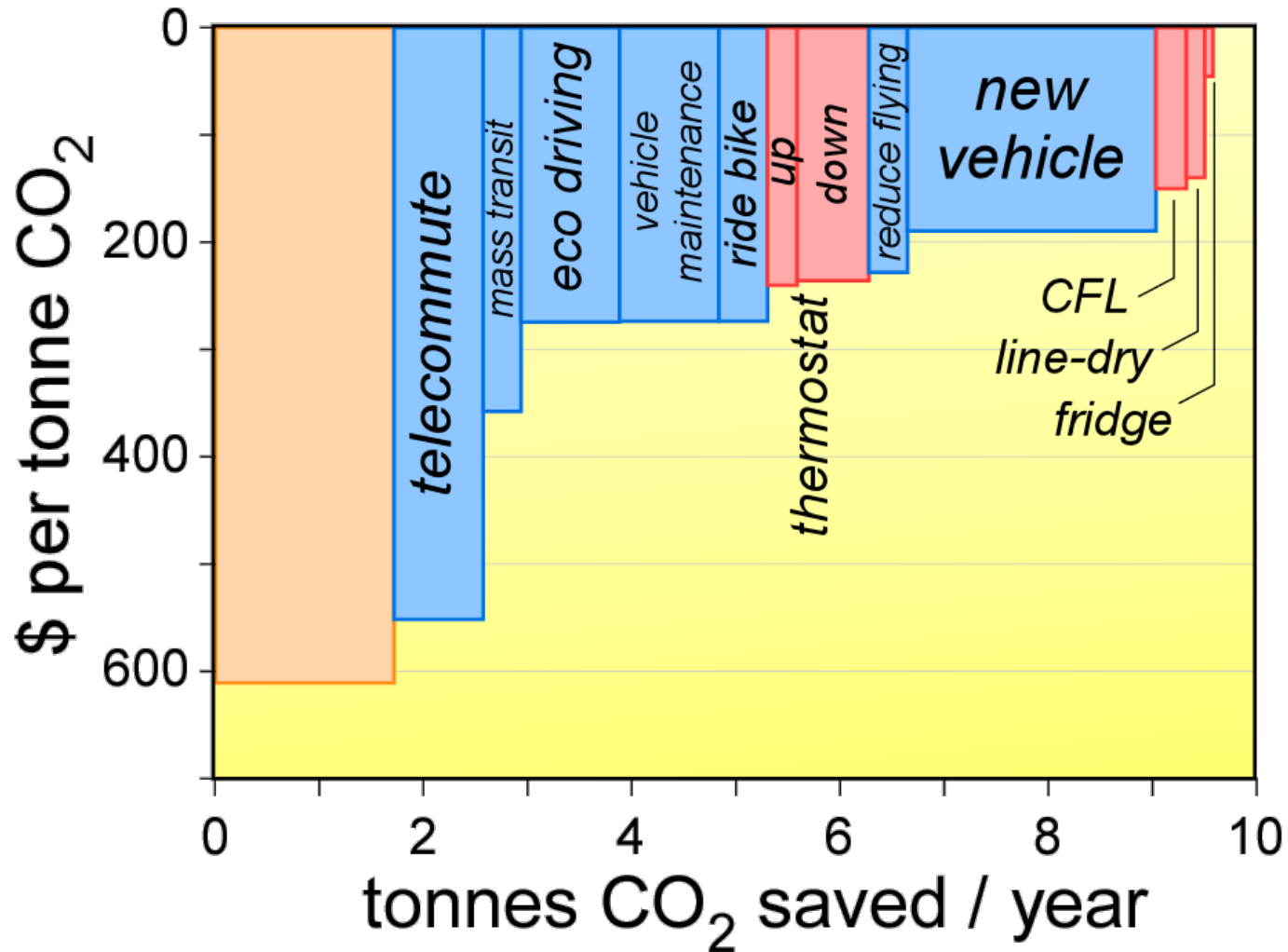
Announcing the program at an Oct. 4 investor day, Andrew N. Liveris said it will help relieve a shortage of graduates attracted to careers in science, technology, engineering and mathematics.

## FUNDED UNIVERSITIES

- California Institute of Technology
- Carnegie Mellon University
- Georgia Institute of Technology
- Northwestern University
- Pennsylvania State University
- University of California, Berkeley
- UC Santa Barbara
- University of Illinois, Urbana-Champaign
- University of Michigan
- University of Minnesota
- University of Wisconsin

# Final Thought

## Average US Household Abatement Curve



# Left for Dead

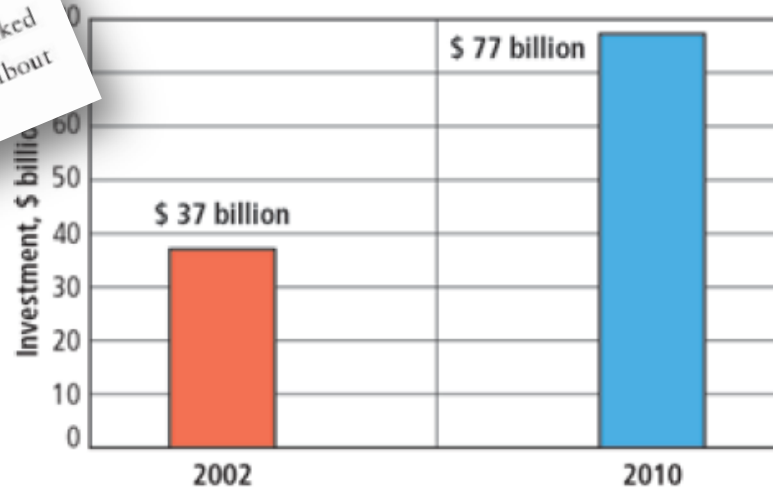


The global petrochemical landscape is evolving inexorably. New companies are appearing and expanding rapidly, taking advantage of low feedstock cost in the Middle East and low labor cost and fast-growing demand in Asia. Long-established Western companies are exiting, shrinking, or moving east, often in partnerships, to try to defend their stakes. Meanwhile, on the horizon, looms a set of new technologies that may transform the industry still further. All this together will lead to a paradigm shift in petrochemicals as the West is abandoned for the East.

*McKinsey*

**A** steady stream of statistics in recent years has pointed to deteriorating competitiveness in the U.S. chemical industry. America's trade surplus in chemicals peaked at \$20.4 billion in 1995 but has flipped since 2002 into a deficit that stood at about \$9 billion last year, according to the American Chemistry Council (ACC), Arlington, Va.

Chemical Processing



**Fig. 1** Middle East petrochemical investment is forecast to reach a staggering \$77 billion in 2010.

*Hydrocarbon Processing*

# Global Commodity Production

