William F. Banholzer
Executive Vice President and Chief Technology Officer
March 21, 2011

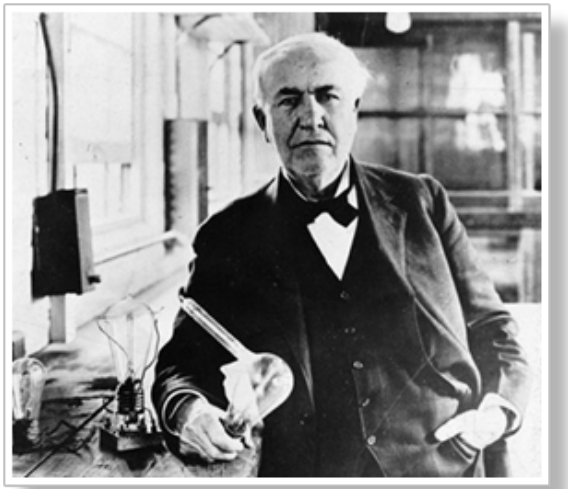
Recognizing Hype versus Practical Limitations in Fuels and Alternative Feedstocks

Call to Engineers and Scientists

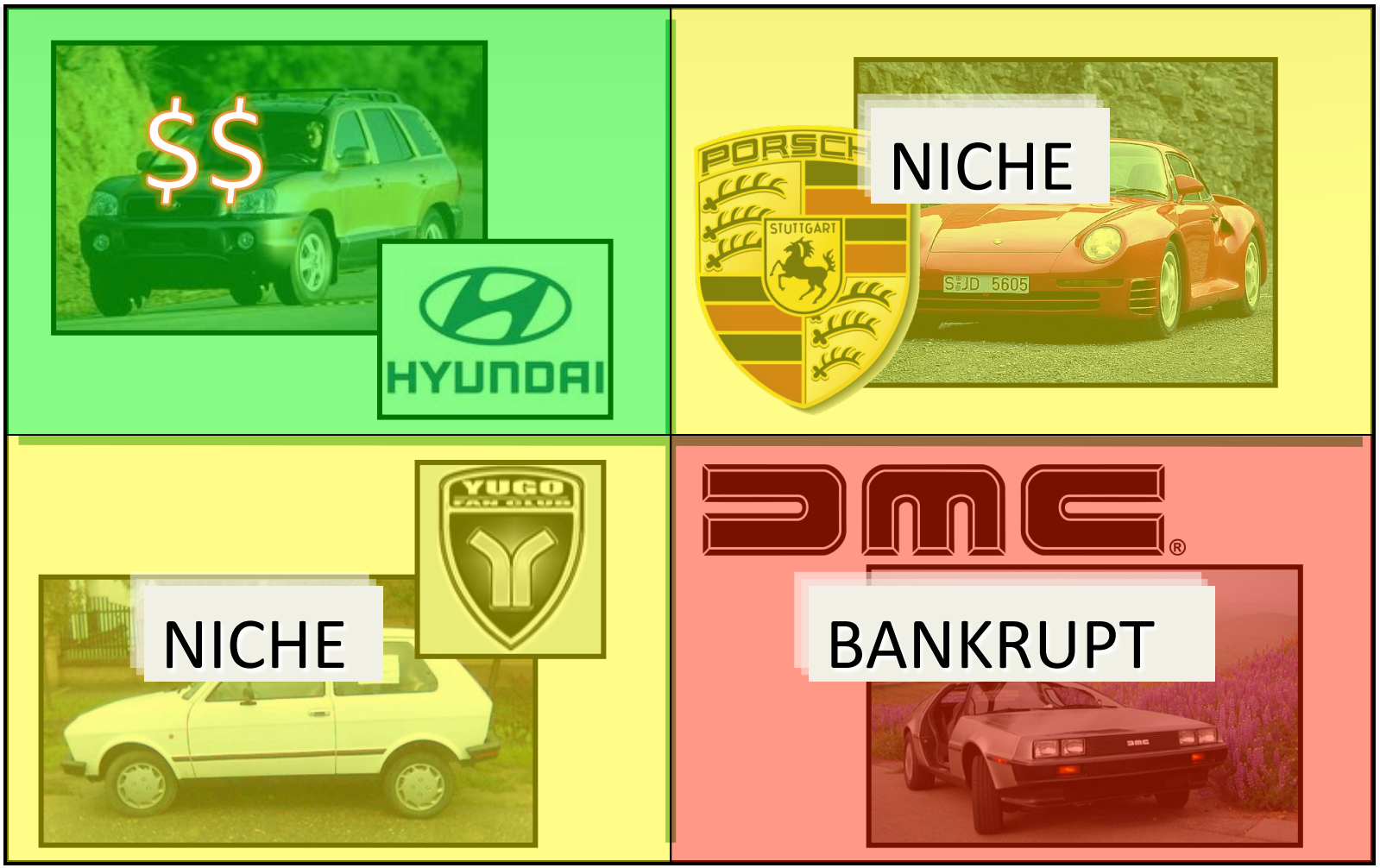
Too much hype for the possible and not enough focus on the practical.

We are letting society down!

Invention to Innovation

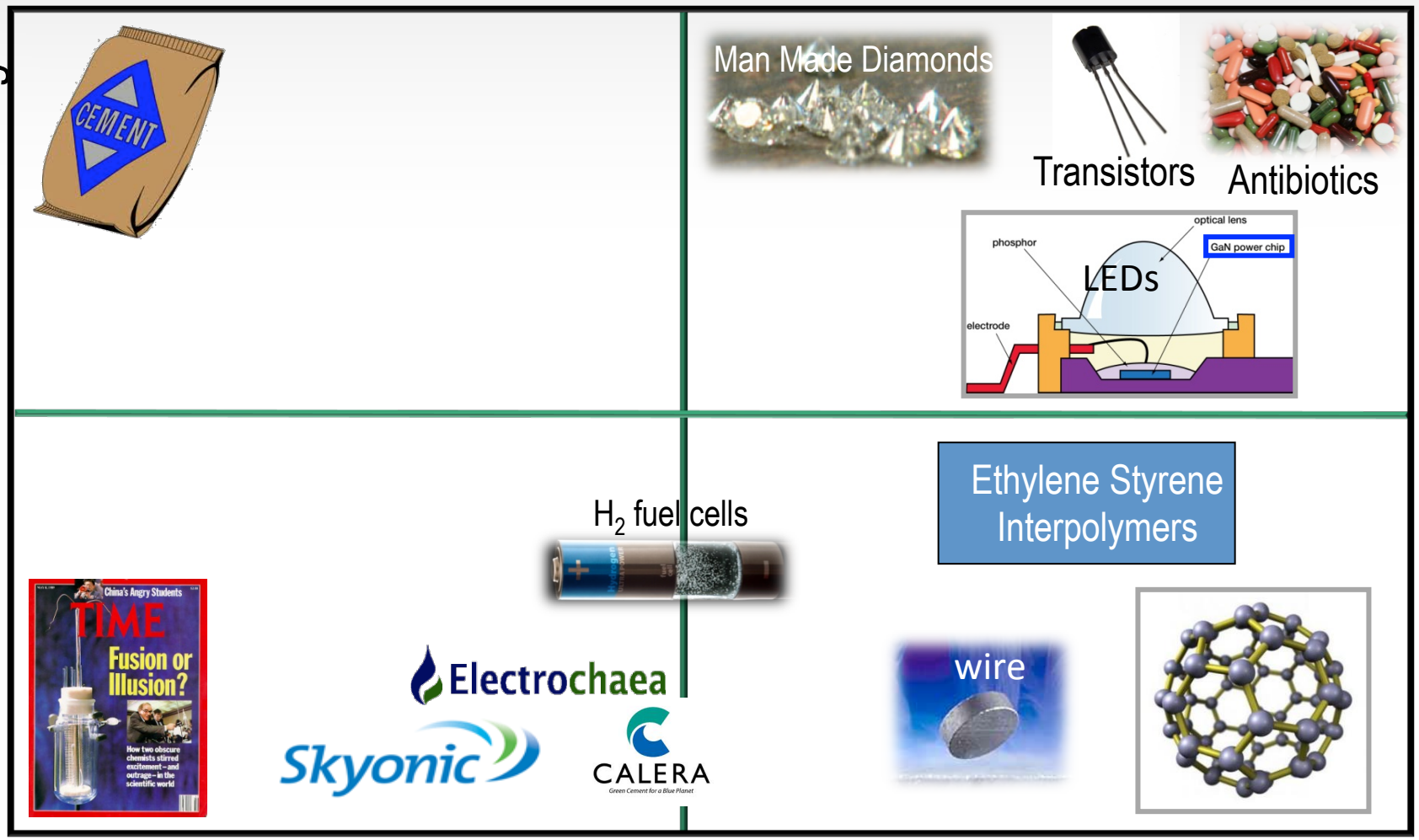


Business Success



Business vs. Academic Success

Business Success vs. SCIENCE



Biology Can Do Great Things

Biofuels Are Like a Jetpack

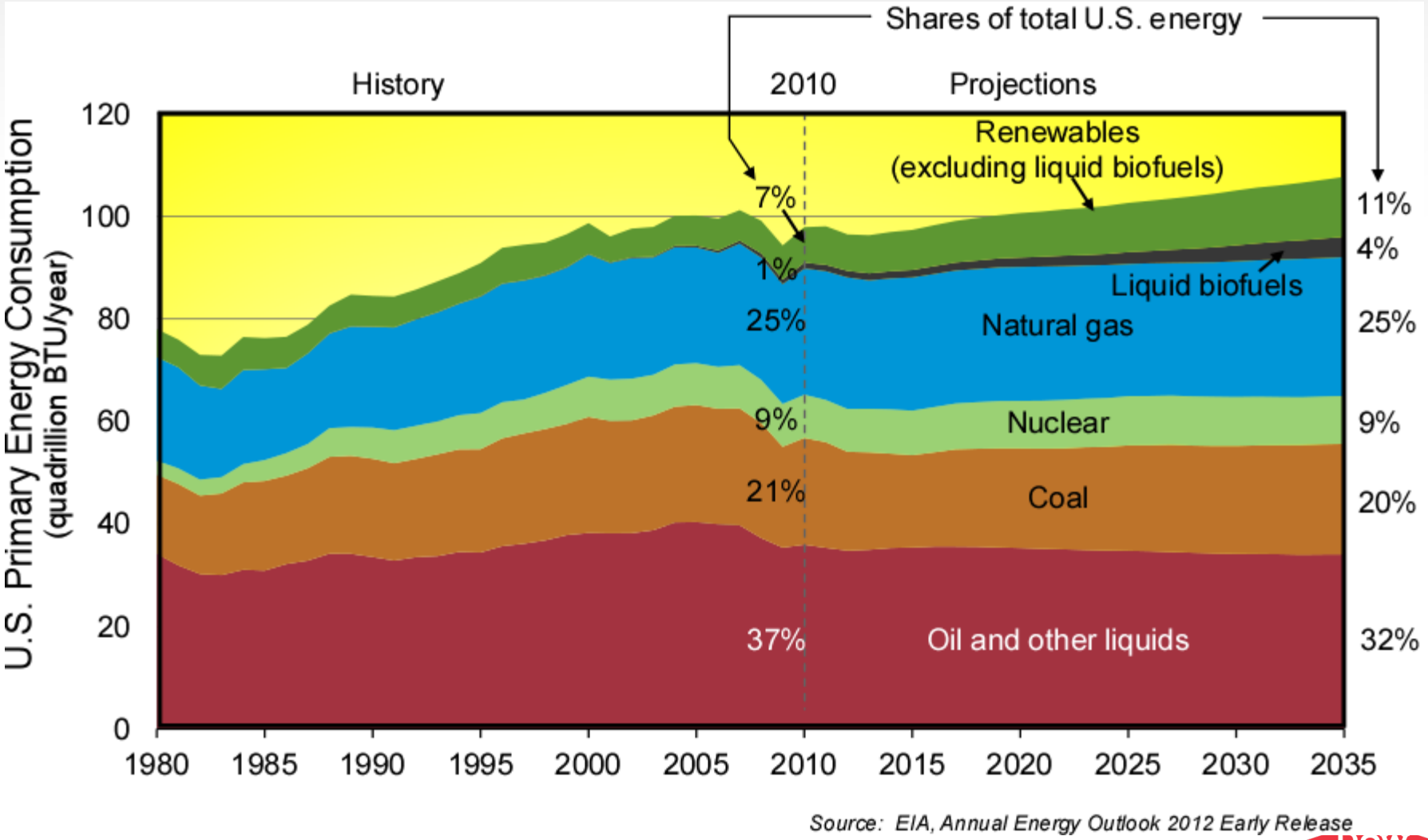
HYPE

ENERGY DENSITY

LIMITATIONS OF BIOLOGY

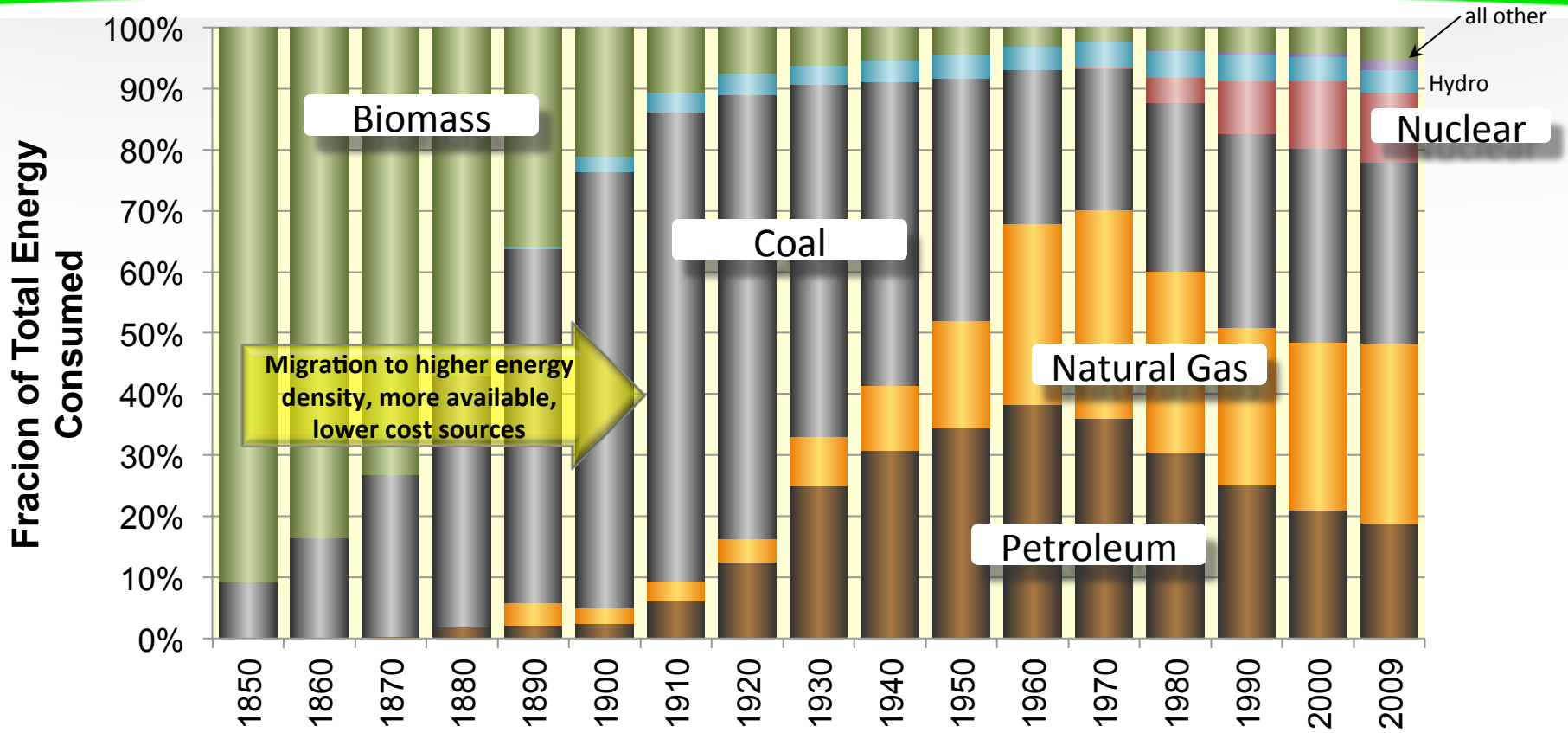
PRACTICAL APPLICATION

Biofuels Growth



Source: EIA, Annual Energy Outlook 2012 Early Release

Energy Sources Always Change



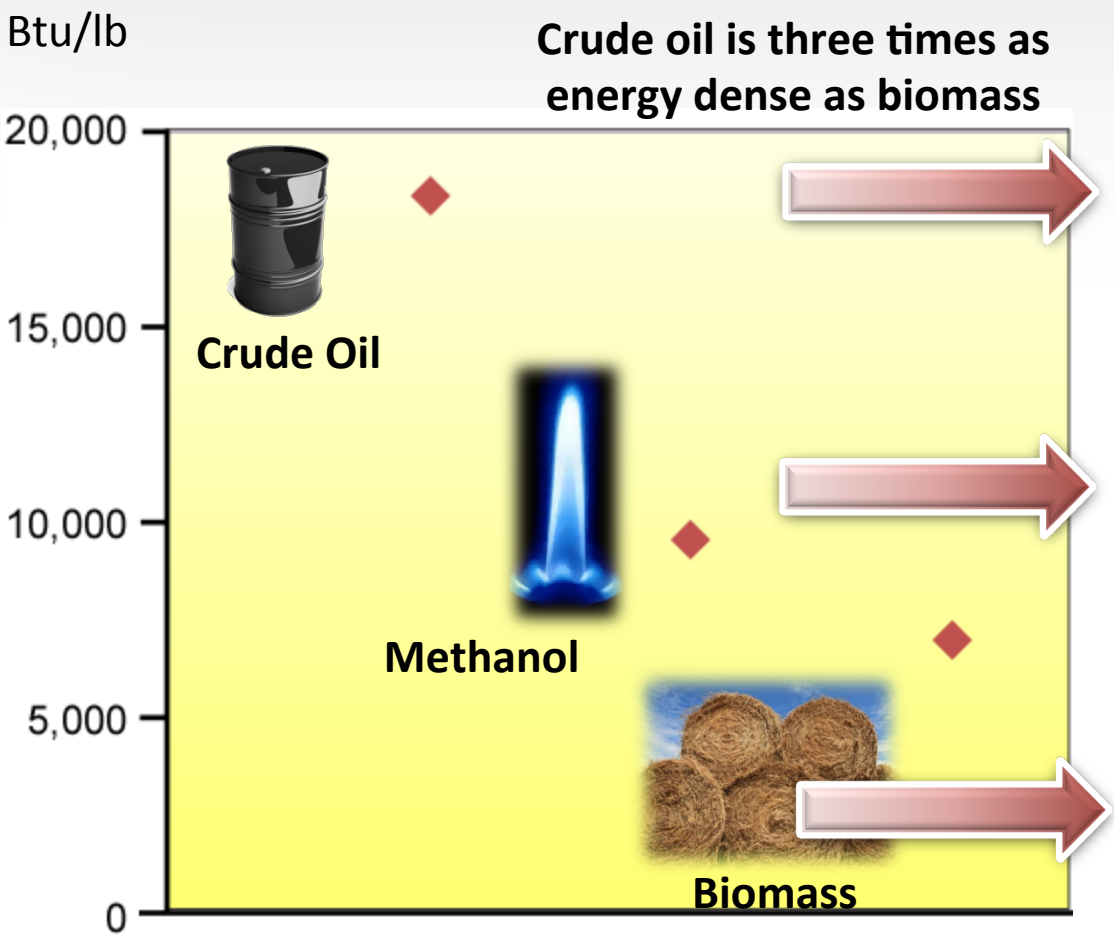
What's Changed?

- Oil Price Rise
- CO_2 awareness

Will this reverse the trend?

Source: IEA. EIA; US Primary Energy

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 literture; Ethanol plant of 100 MM gal/yr from DOE targets assuming 100 MM gal and $10/annual gallon

DOW

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

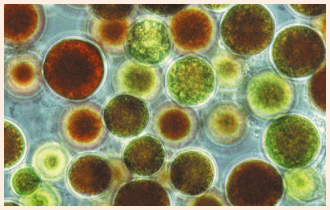
"…the need for trucks, machinery and manpower would come during harvest, already the busiest time of the year on the farm. And that's where a massive federal initiative into cellulosic ethanol may find its biggest bottleneck – on the farm."

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.



Bio Plastics

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

"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

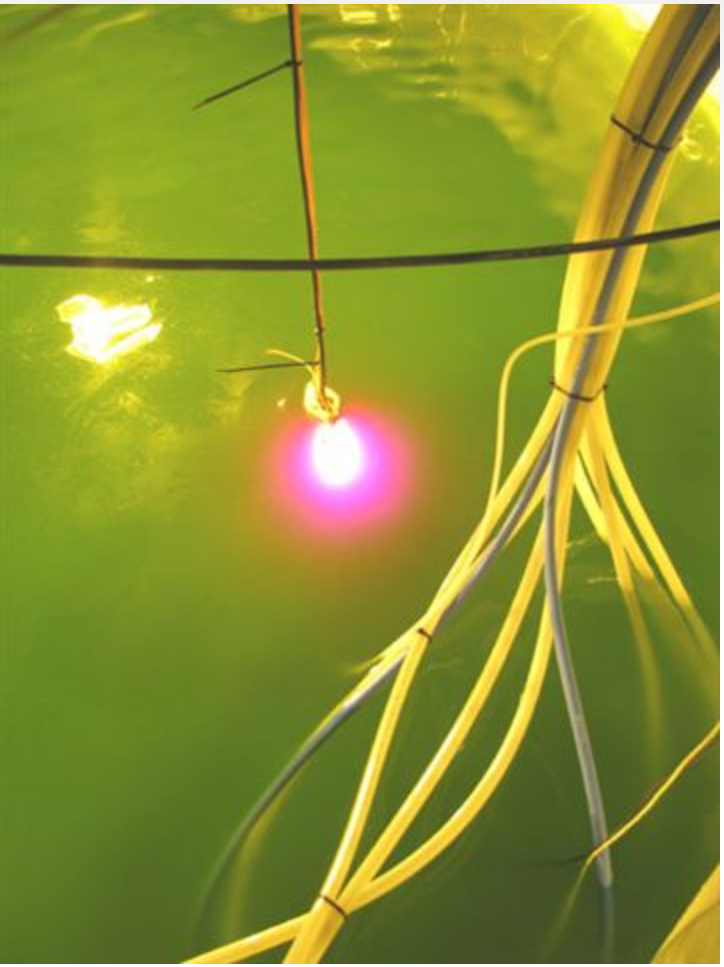
ADM has given notice of termination of the Telles, LLC joint venture for PHA bioplastics

Hype Building for Algae?

> Using sunlight, CO_2 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?

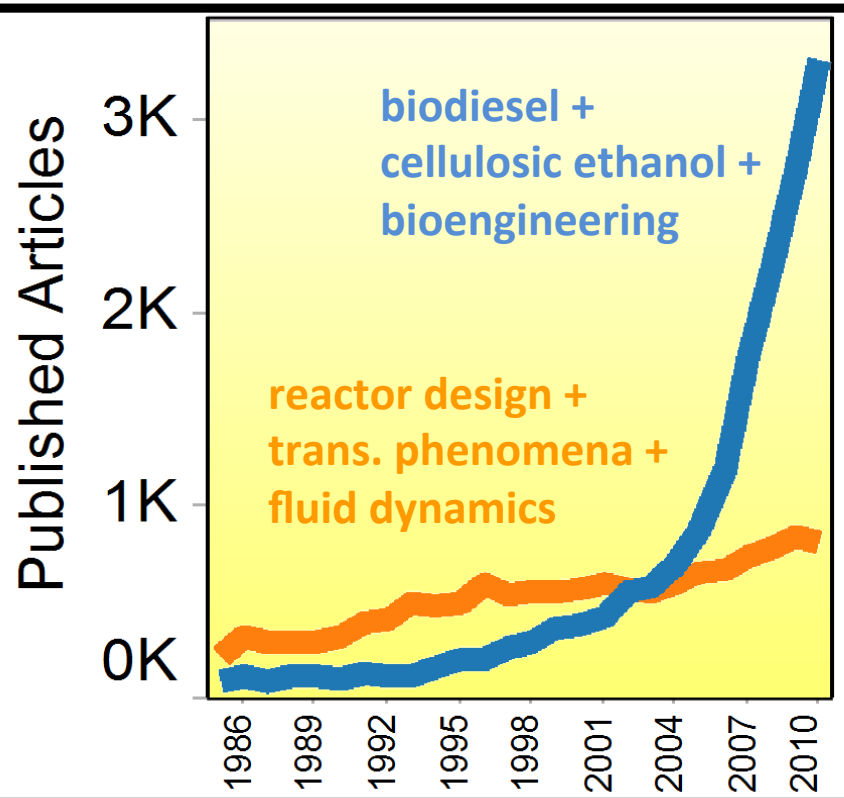


LumiGrow LED technology is instrumental to the operation of Algae Farm's algae biomass production system, which will produce algae for the nutraceutical, cosmetic and *renewable energy market sectors*. By growing in a climate-controlled indoor environment, Algae Farm can achieve predictable and scalable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

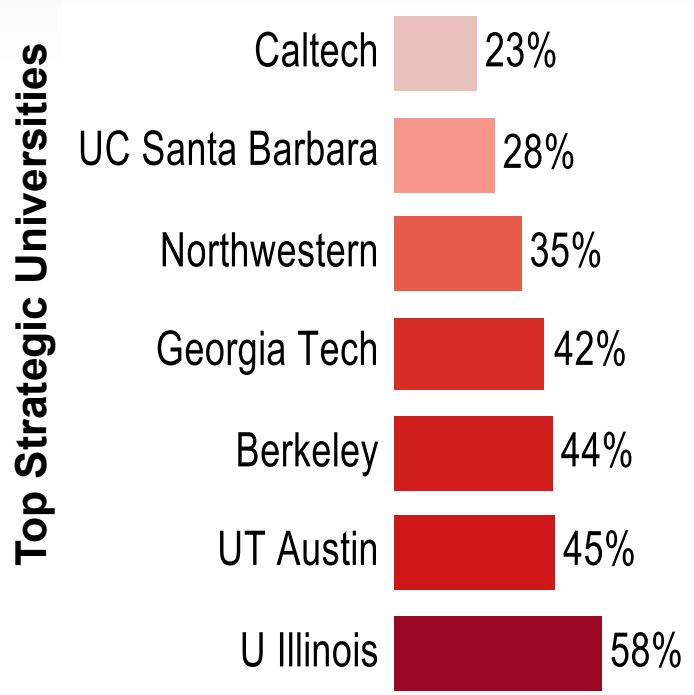
LumiGrow press release "Algae Farm Selects LumiGrow LED Horticultural Lighting November 29, 2011

Funding Follows the Hype

Published Articles Reflect the Focus on "Bio" Related Research:

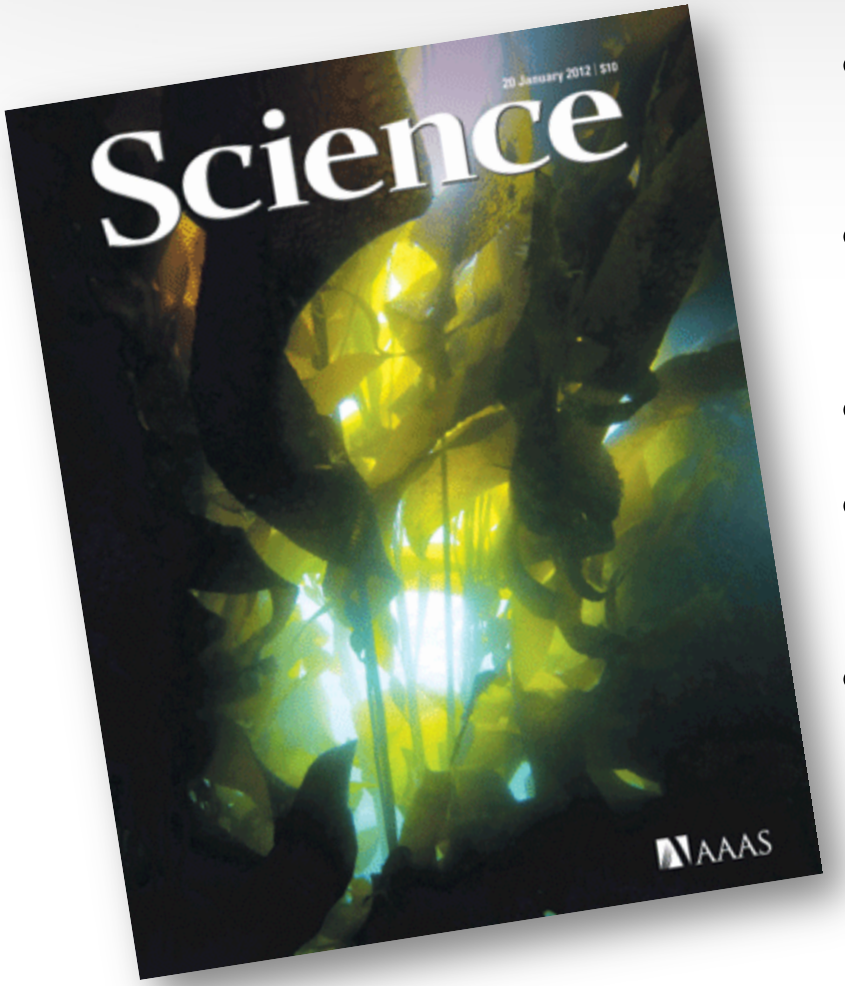


Percentage of Faculty with "Bio" Related Research Interests:



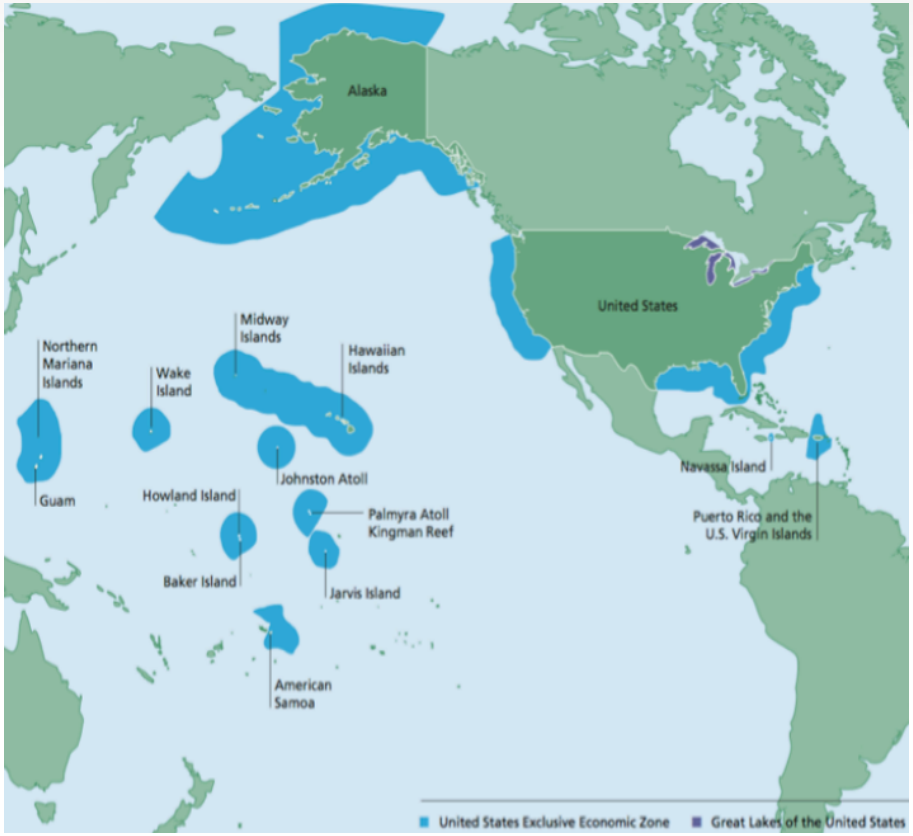
Dynamic range of the discipline is threatened by decreasing support of the traditional core research areas.

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

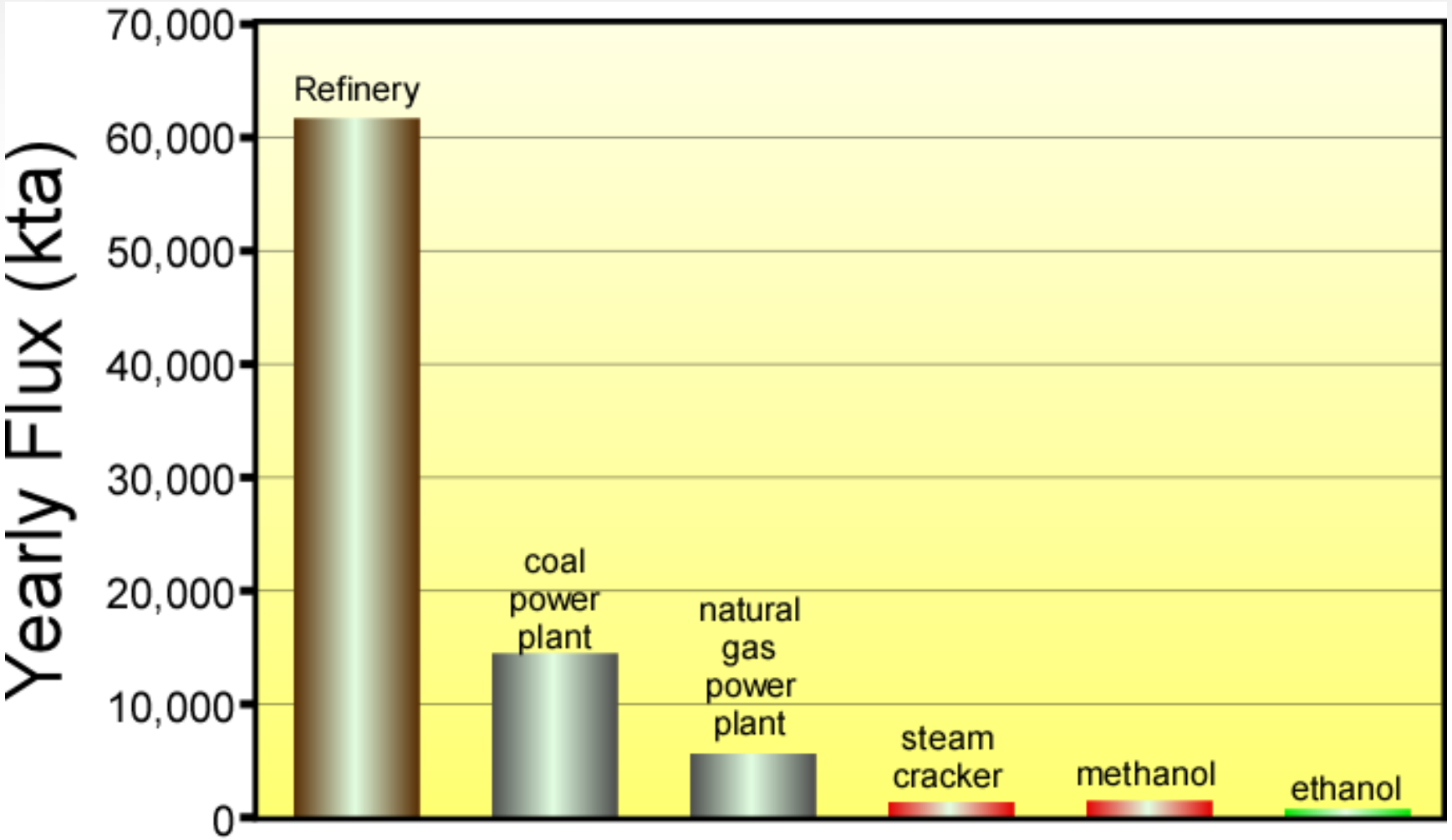
- harvested for over 400 years
- cost for wet biomass are > $400/ton at water levels >70% *more expensive than corn!*
- Redfield ratio still required
- *arable ocean* (analogy to arable land) needed

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

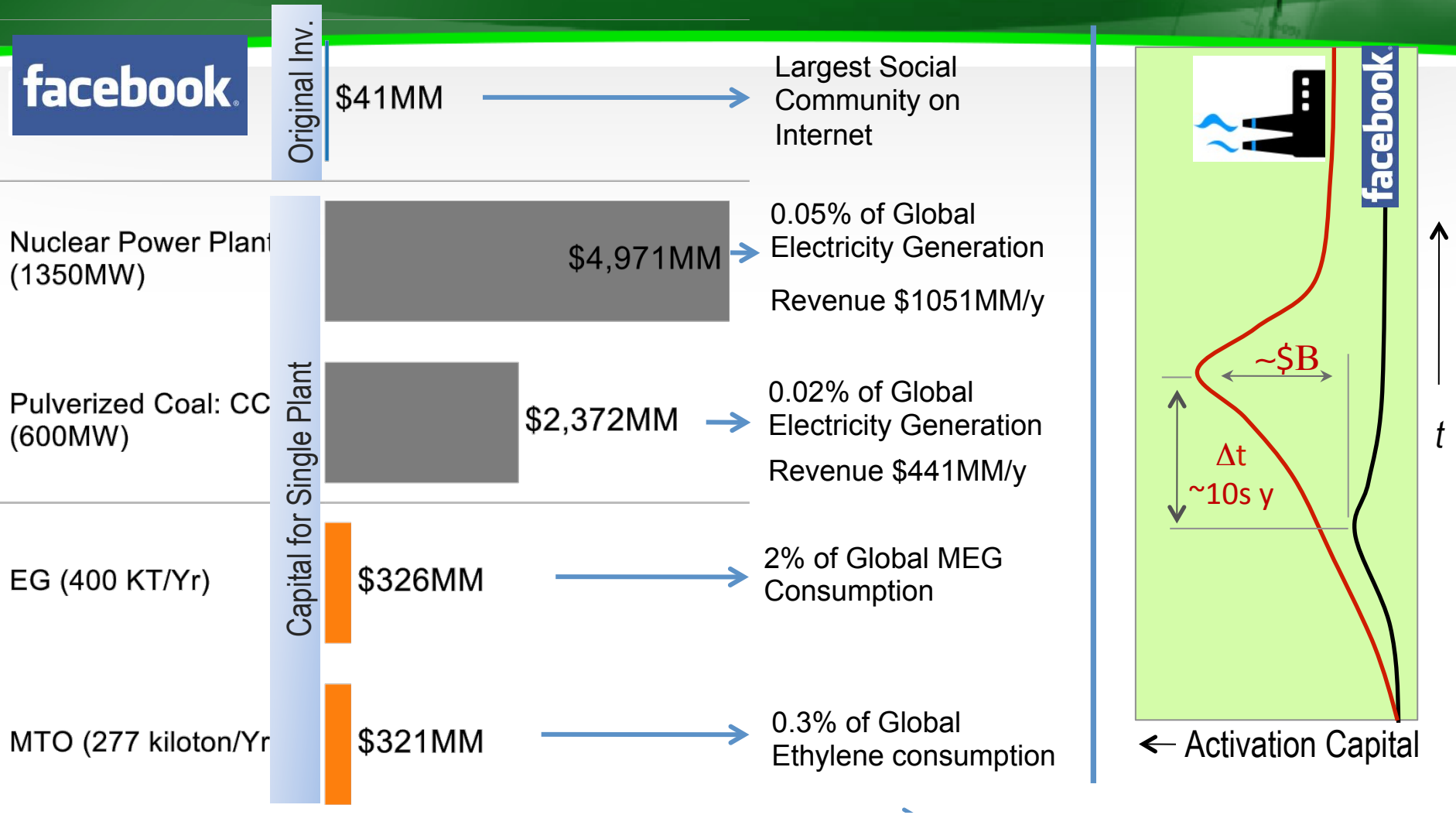
NRC, "Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy", 4 October 2011.

Largest Plants



feedstock limits scale

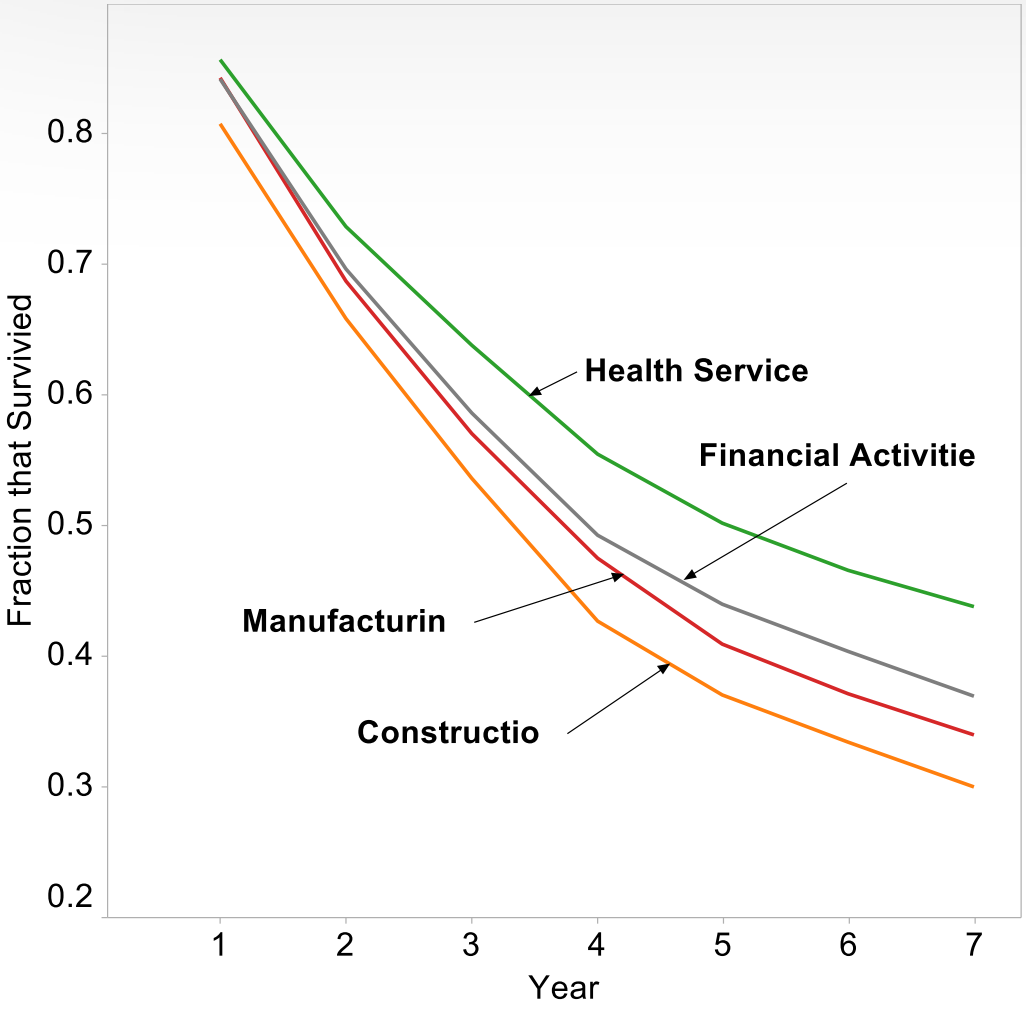
Scale of Fuels Makes it Harder



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 Repor 2I – SRI; **Revenues** for Power Plants calculated using 2010 electricity average retail prices (all sectors) 9.88 cents/kWh (data from DOE)

The Challenge of a New Company

Fraction of companies that survived after launch



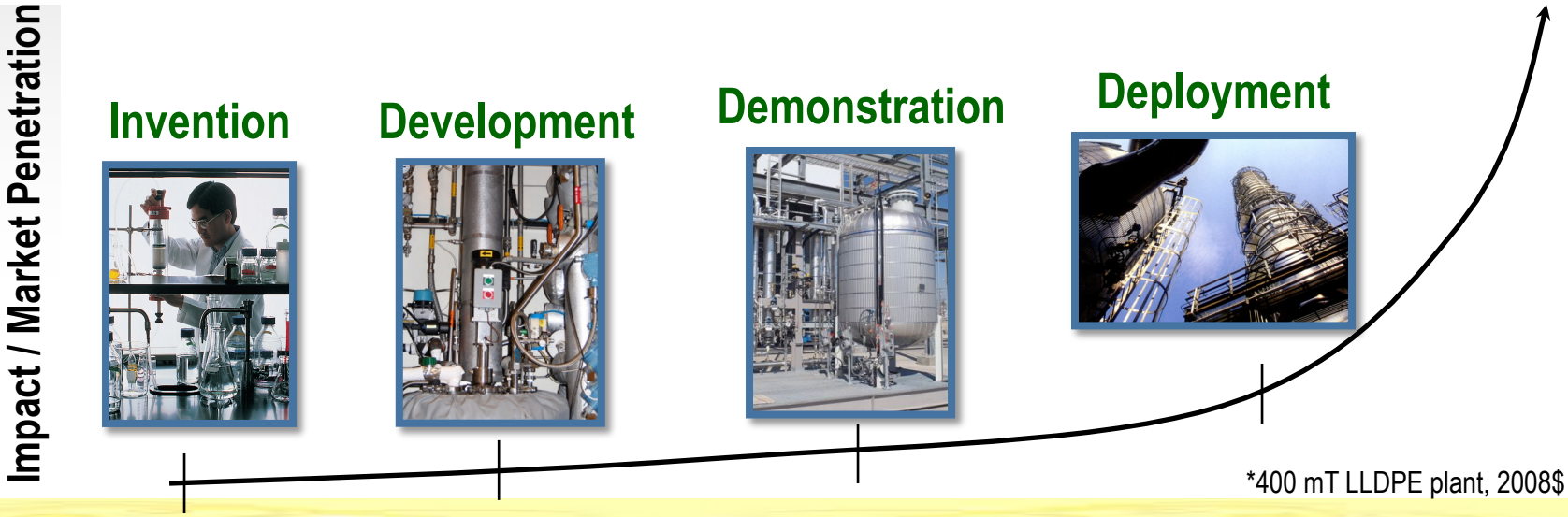
Energy & chemical industries require very high reliability

Energy & chemical industries are extremely capital intensive

Failure has massive financial and social consequences

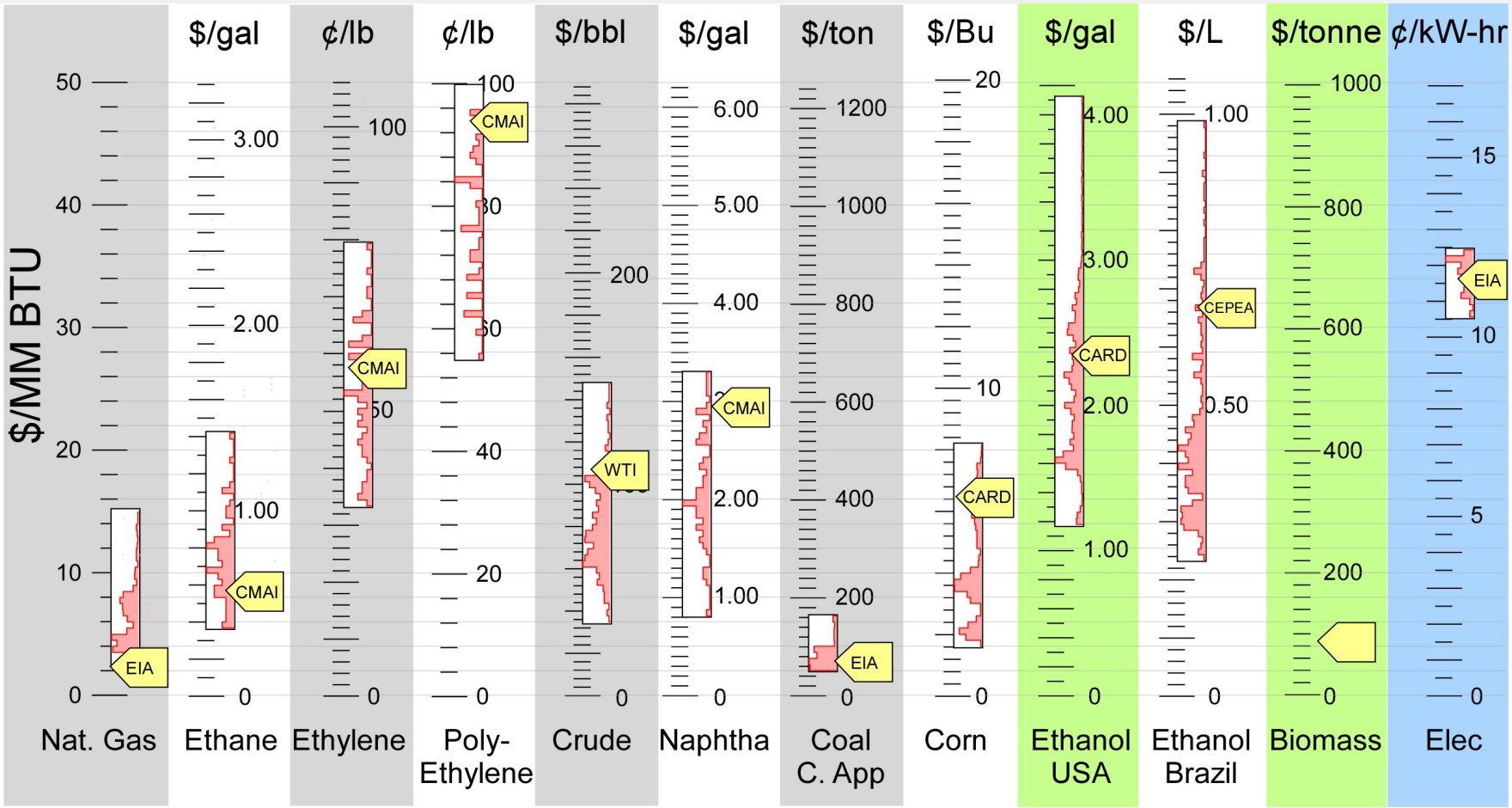
Source: Knaup, Amy E., May 2005, "Survival and longevity in the Business Employment Dynamics data," *Monthly Labor Review*, pp. 50–56; Knaup, Amy E. and MC. Piazza, September 2007, Business Employment Dynamics Data: Survival and Longevity, Monthly Labor Review, pp 3-10.

Timeline for Impact



Sources: SRI PEP LLDPE 36E 2008, SRI PEP 153B 2001 Single site catalysts for PE Production, AEP Power Co, World Bank, EIA 2011 Energy Outlook, Electricity Market Module

Energy Content

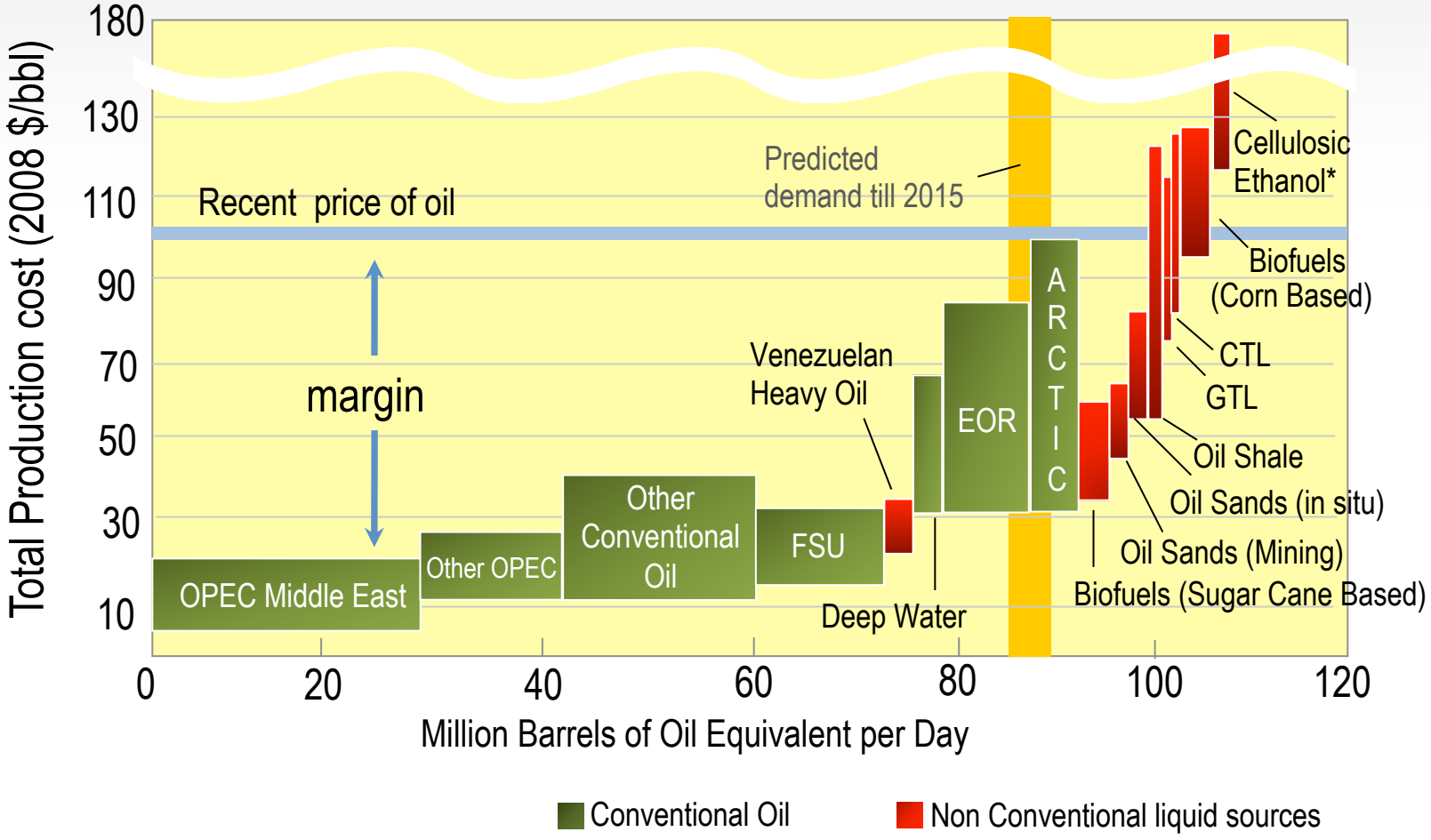


EIA is DOE Energy Information Agency, CMAI is an HIS affiliate, CARD is Iowa State Center for Agricultural and Rural Development, CEPEA is Centro de Estudos Avancado em Economia Aplicada – data for 3-5 years depending on source.

20 March2012

Energy Industry Dynamics

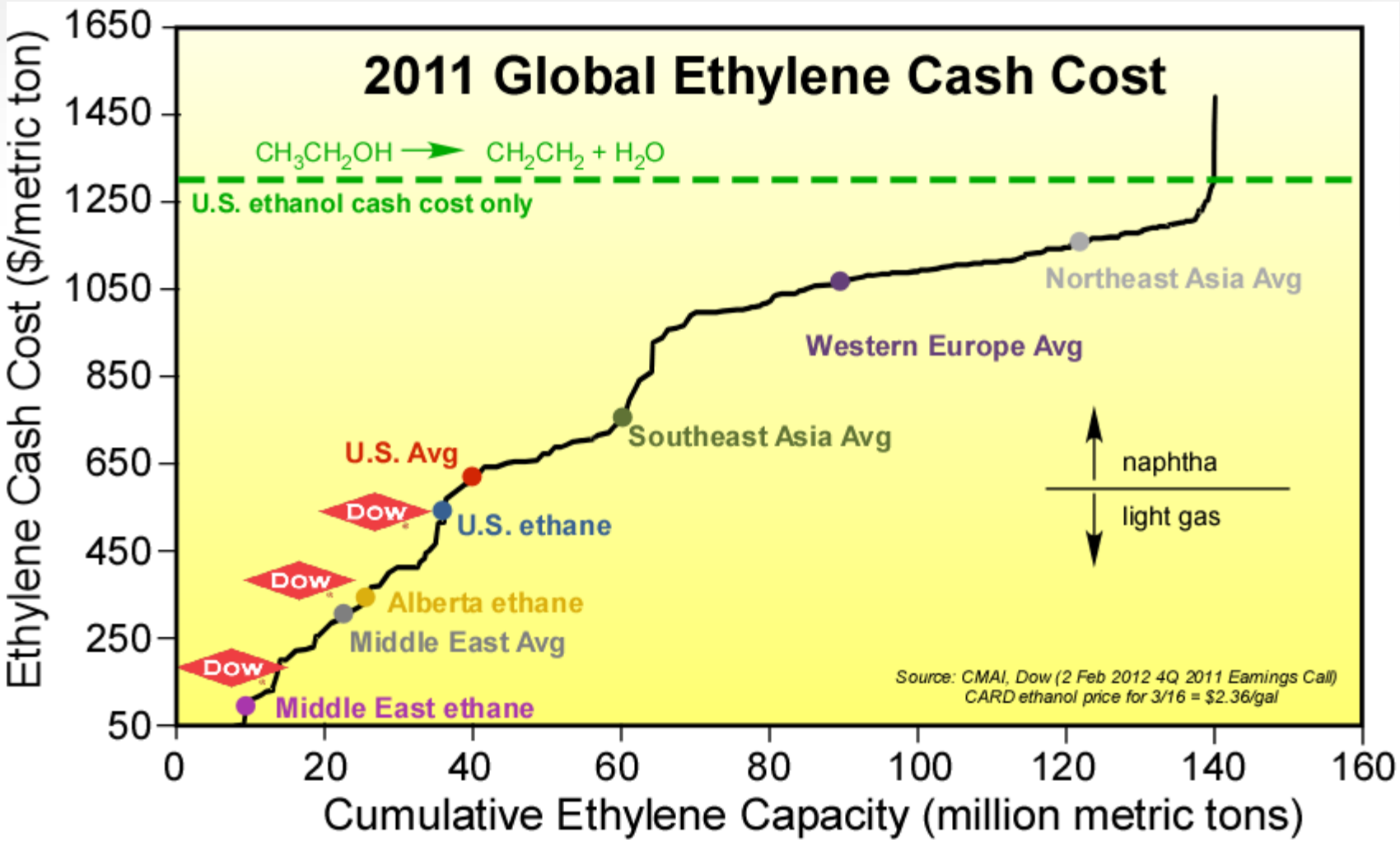
As oil price rises, new capital will flow to EOR, Arctic, Oil sands, GTL, CTL before biofuels.



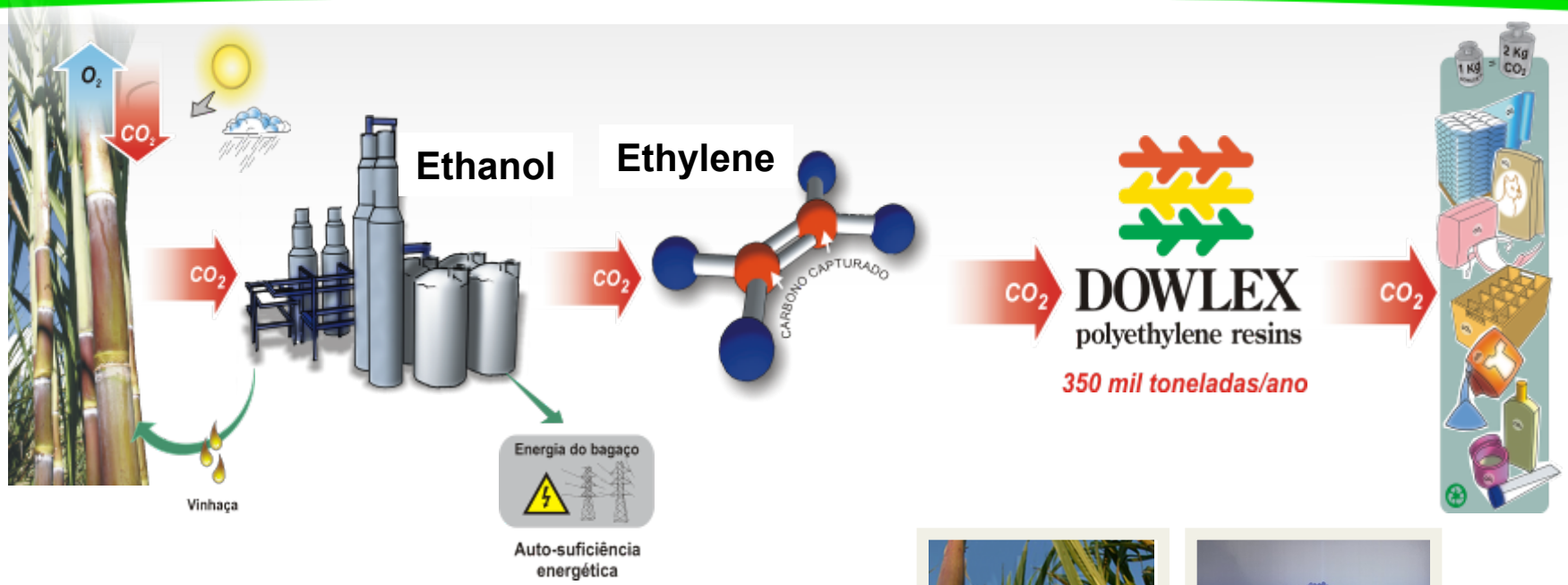
Source: IEA, EIA, Booz Allen Hamilton, DOE Biomass Multiyear Program Plan April 2011, Dow Analysis

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

Global Ethylene Cash Cost



Alternative Feedstock - Cane to LLDPE



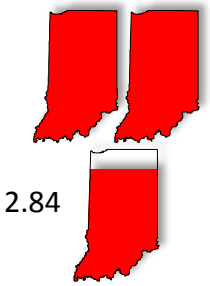
Fully-integrated facility in Brazil
Utilizes state-of-the-art Dow polymerization catalysis

Ethanol to PE in 2008

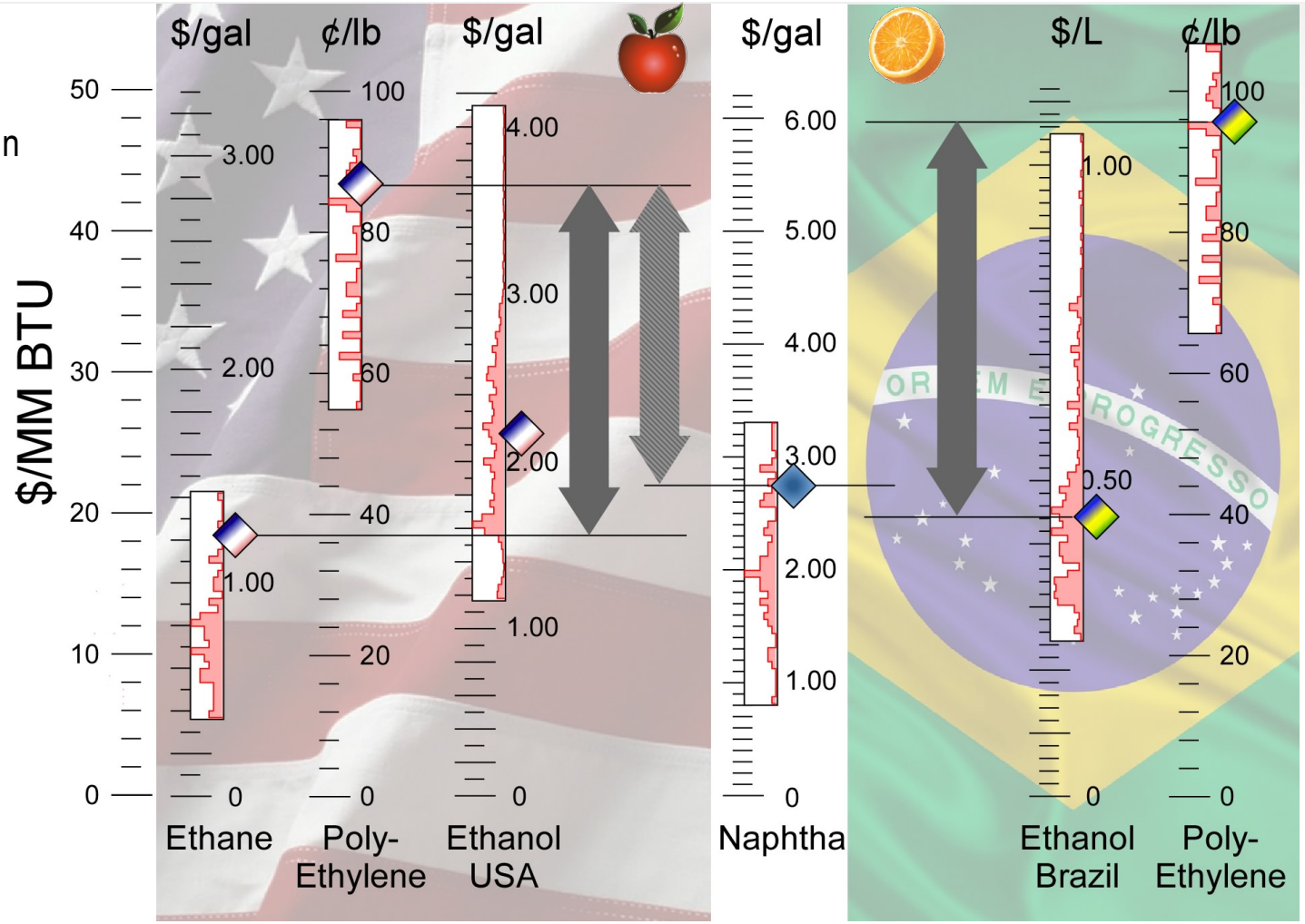
naphtha was looming as the only feedstock choice

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

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 FMar2012; *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
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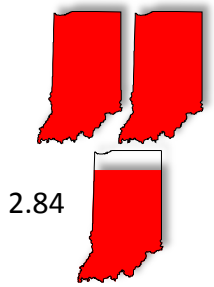

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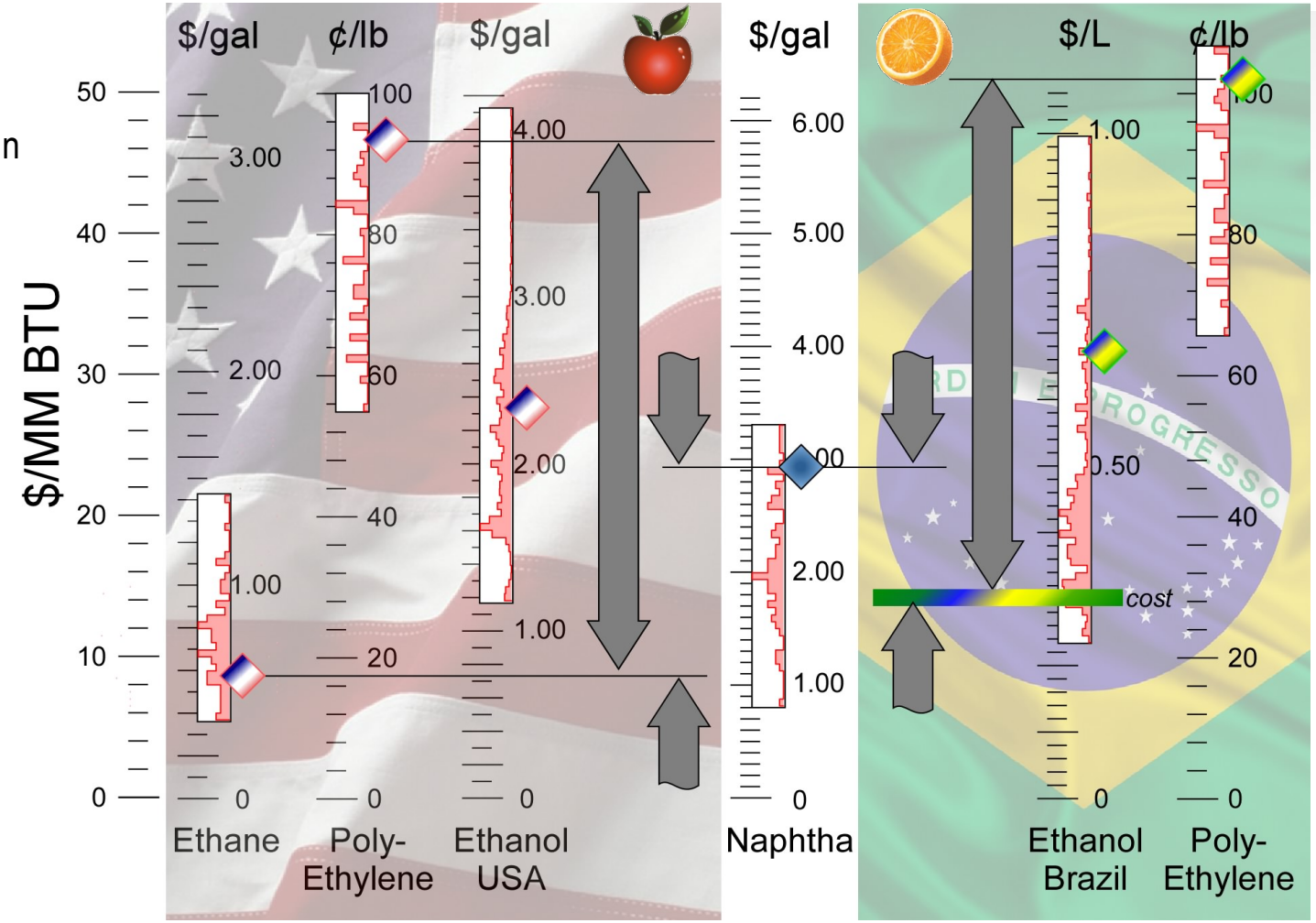

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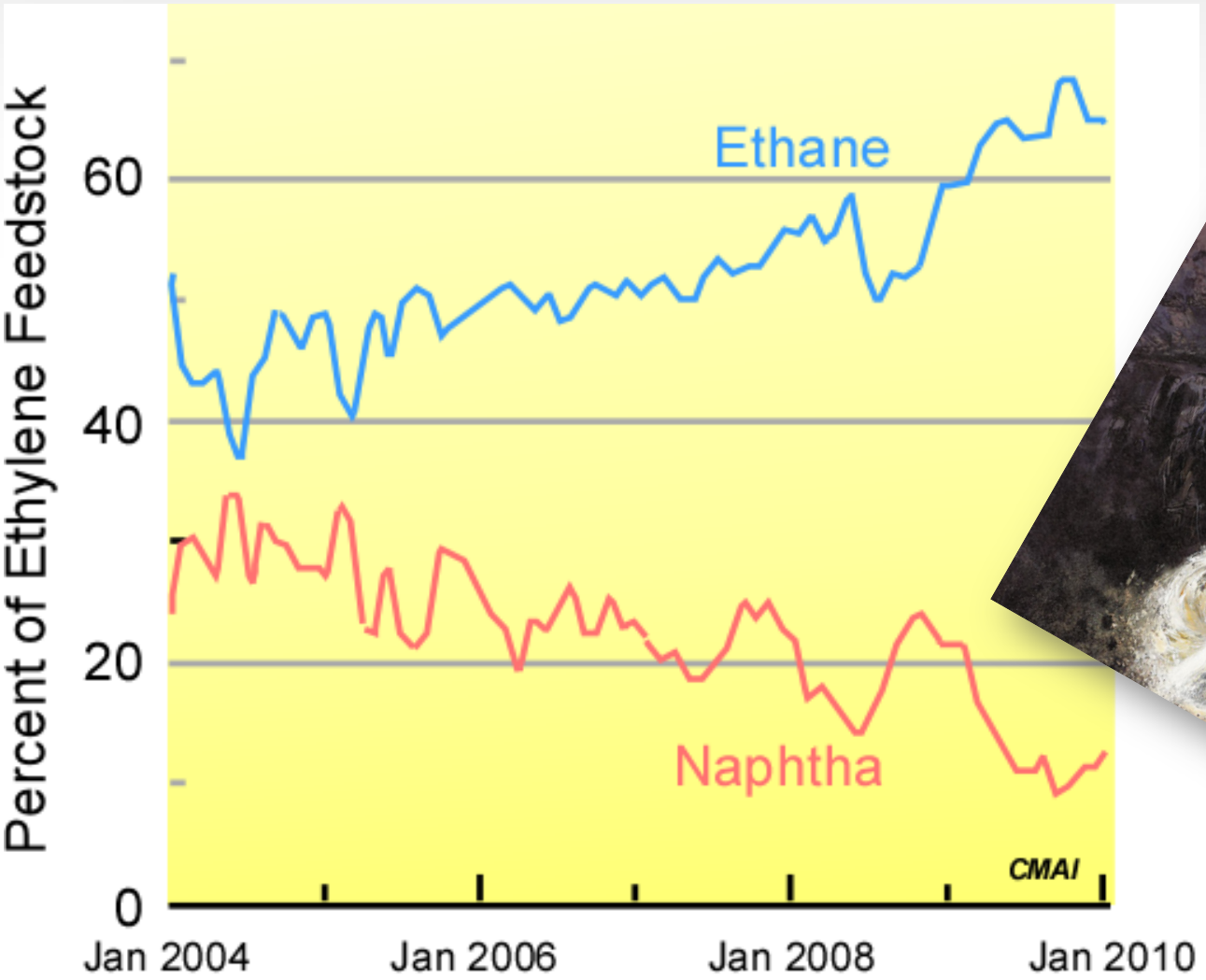
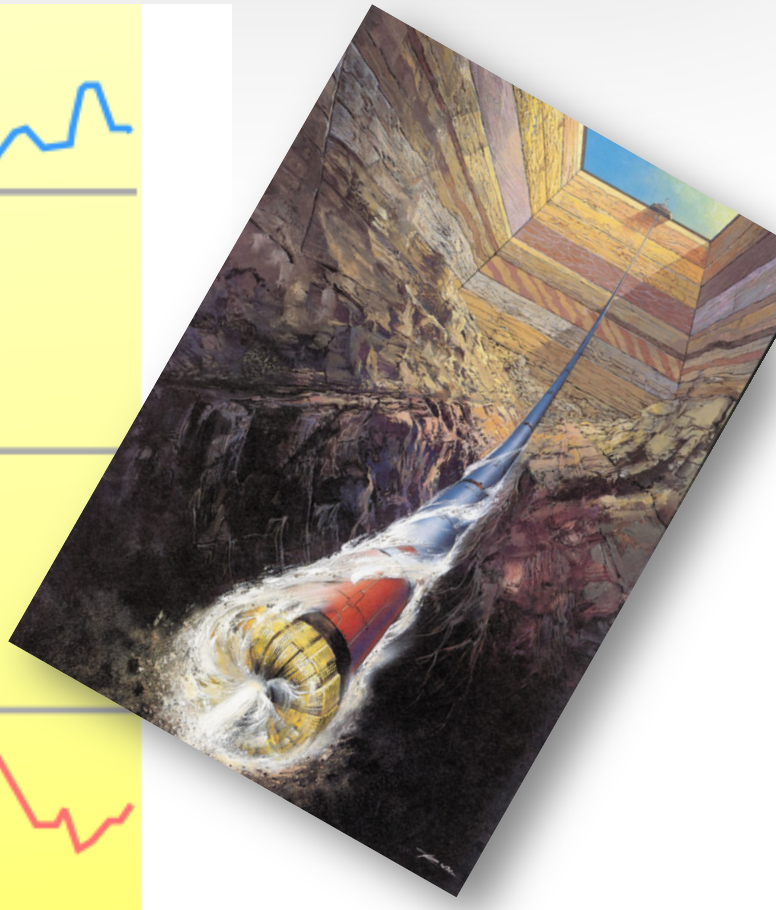
Shale Gas Revitalizes the Industry





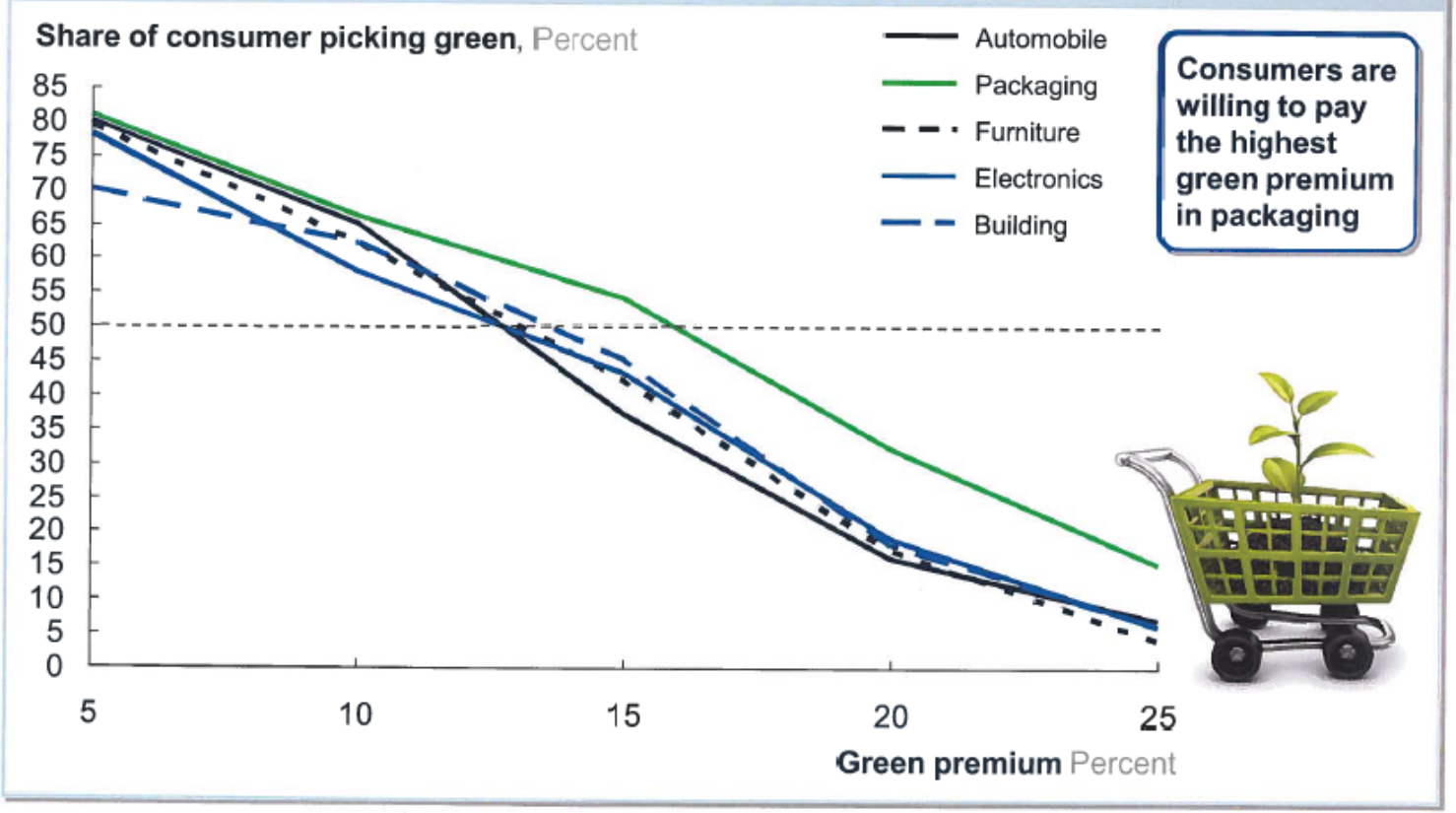
Demand for Bioproducts?

Midland Daily News
1 January 2012

Limit to Green Premium

4 But the proportion of consumers willing to pay premium goes down rapidly and reaches a very low level beyond 20-25% premium

Share of consumers picking green by premium
Percent



SOURCE: McKinsey green survey, August 2011 (n = 1,000 consumers, n = 500 industry executives)

Changing Emphasis

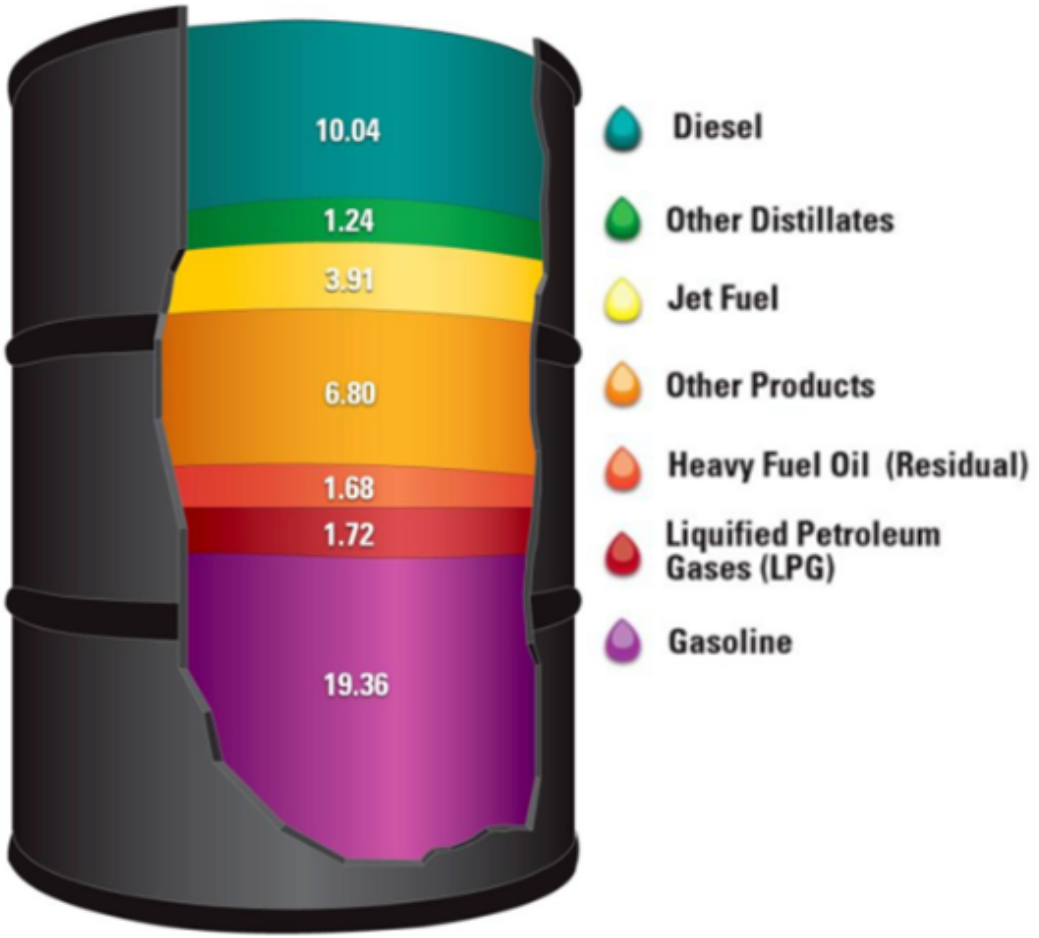
Biomass 2011: Replace the Whole Barrel, Supply the Whole Market

The New Horizons of Bioenergy

July 26–27, 2011

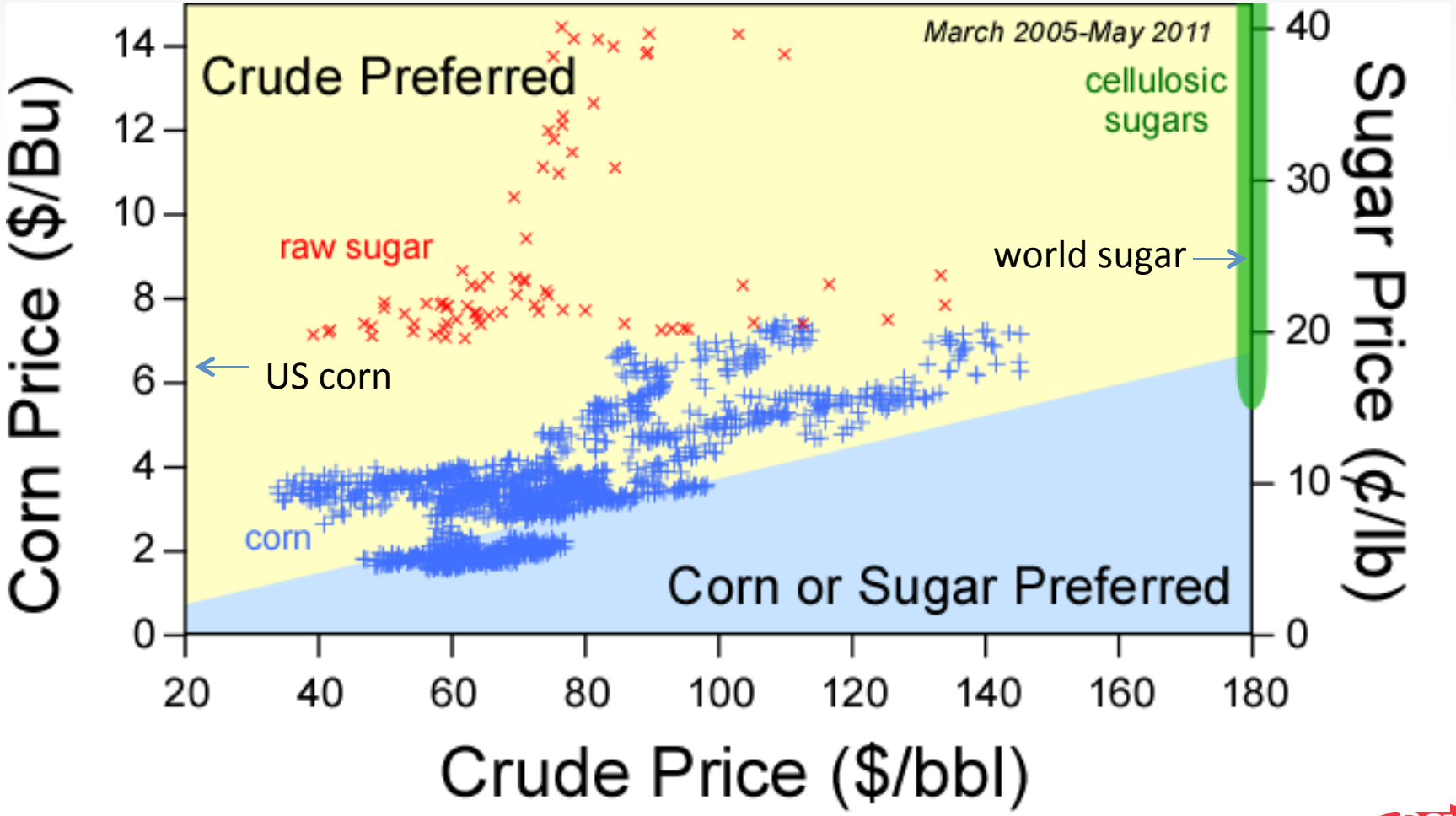
U.S. DEPARTMENT OF ENERGY BIOMASS 2011

"sugar is the new crude"



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. At...

and pressure.

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 ...oups, protection/ deprotection, temporary ...physi... chemical processes) should be ...possible, because such steps require ...d can generate waste.

...eagents (as selective as possible) are ...metric reagents.

...ation: Chemical products should be ...at the end of their function they break down ...egradation products and do not persist in the

...s for Pollution Prevention: Analytical ...eed to be further developed to allow for real- ...monitoring and control prior to the formation ...stances.

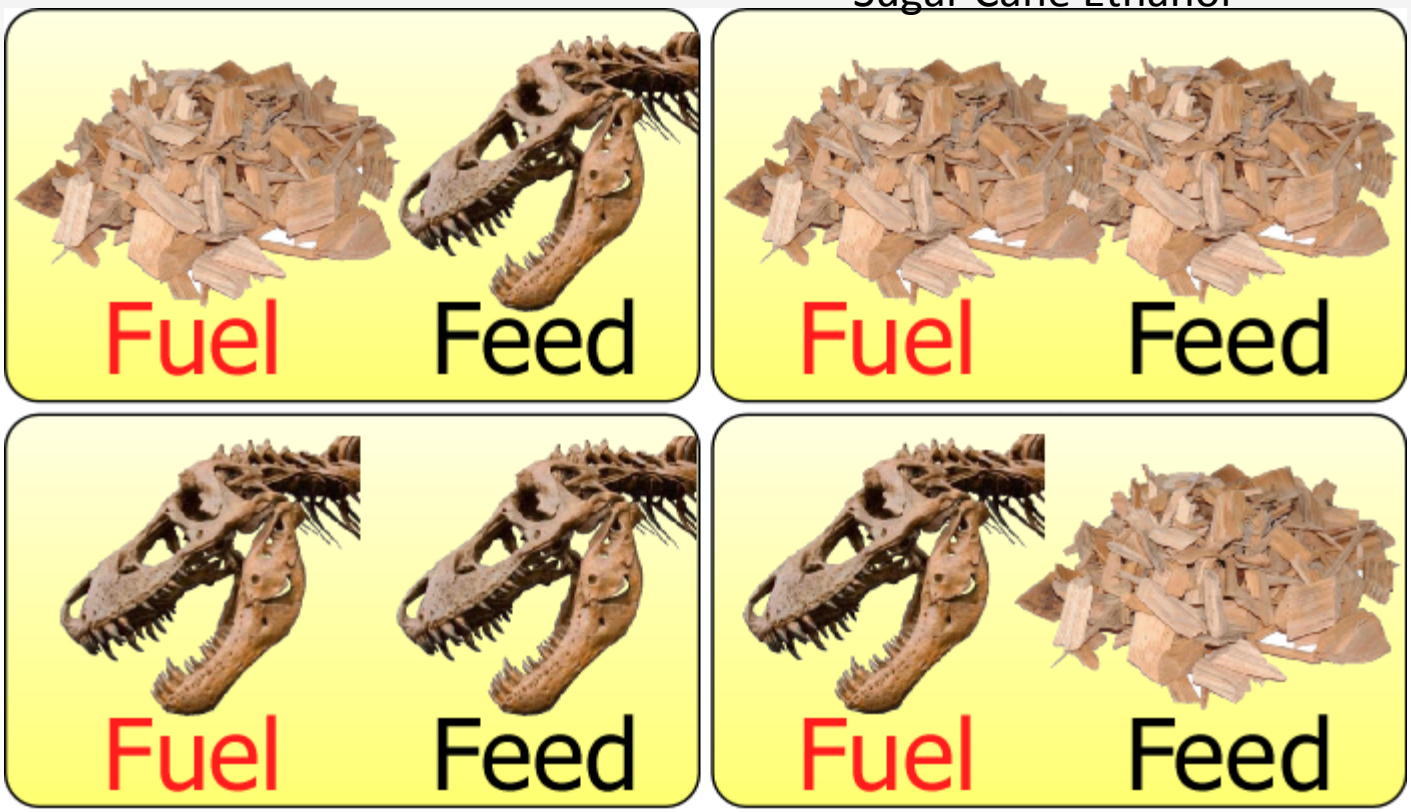
...Chemistry for Accident Prevention: ...he form of a substance used in a chemical ...be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

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

DOW

Two Carbon Flavors

Sugar Cane Ethanol



Petrochemicals

Corn Ethanol

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

Tabone, MD; Cregg, JJ; Beckman, EJ; Landis, AE. Environ. Sci. Technol. 2010, *44*, 8264-9.

LCA of Polymers

Biopolymers rank in the middle of LCA rankings

POLYMER	Material	Green Design Rank	LCA Rank
Polypropylene	Fossil fuels	9	1
HD Polyethylene	Petroleum	5	2
LD Polyethylene	Petroleum	7	3
Polyhydroxyalkanoate-Stover	Cornstalks	2	4
General Purpose Polystyrene	Petroleum	10	5
Polylactic Acid – NatureWorks	Sugar/cornstarch	1	6
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

Tabone, MD; Cregg, JJ; Beckman, EJ; Landis, AE. Environ. Sci. Technol. 2010, *44*, 8264-9.

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

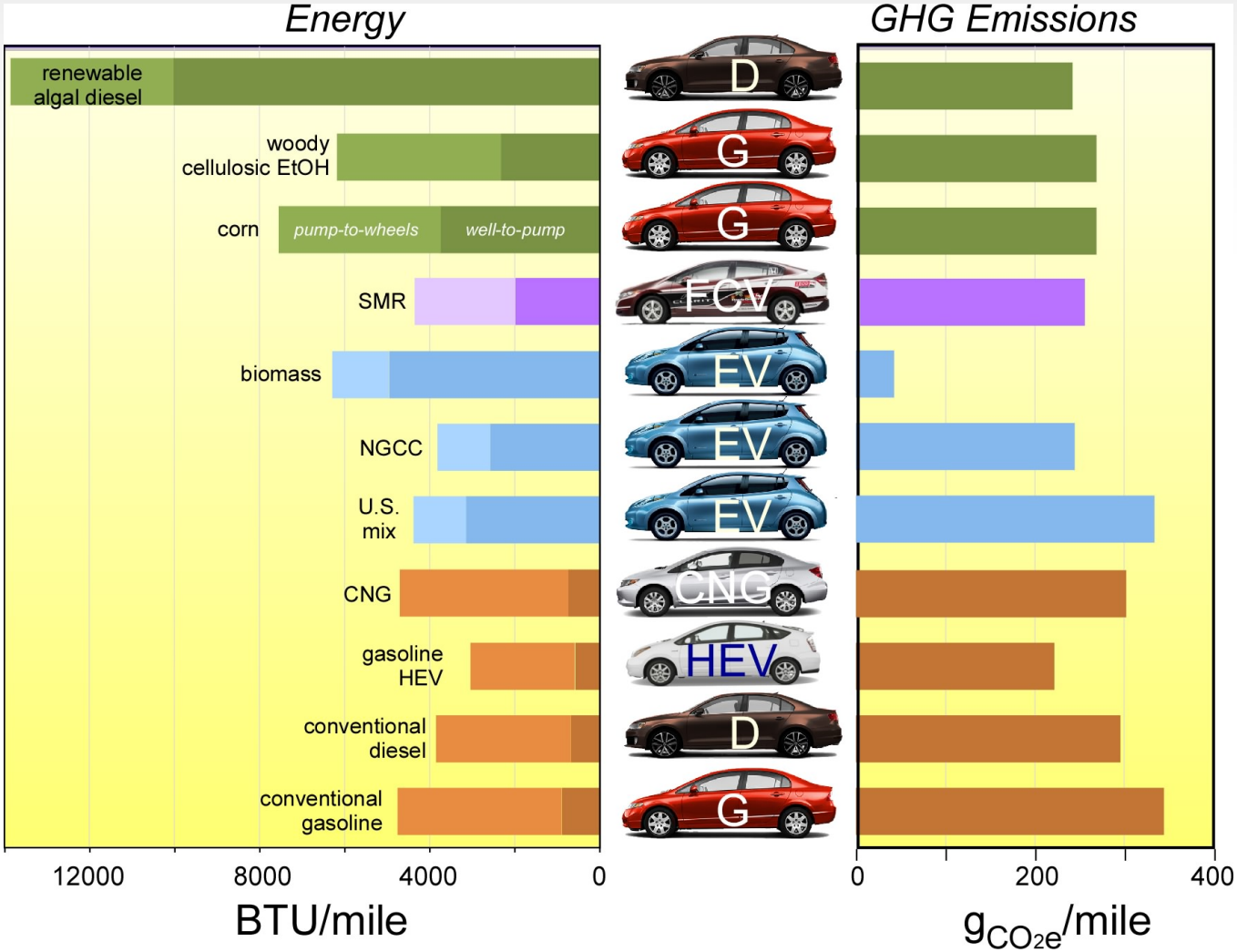
Superior Materials:
Energy efficiency improvements for commercial and industrial products

Energy Generation

Superior Materials:
Efficiency
Yield
Performance
Durability

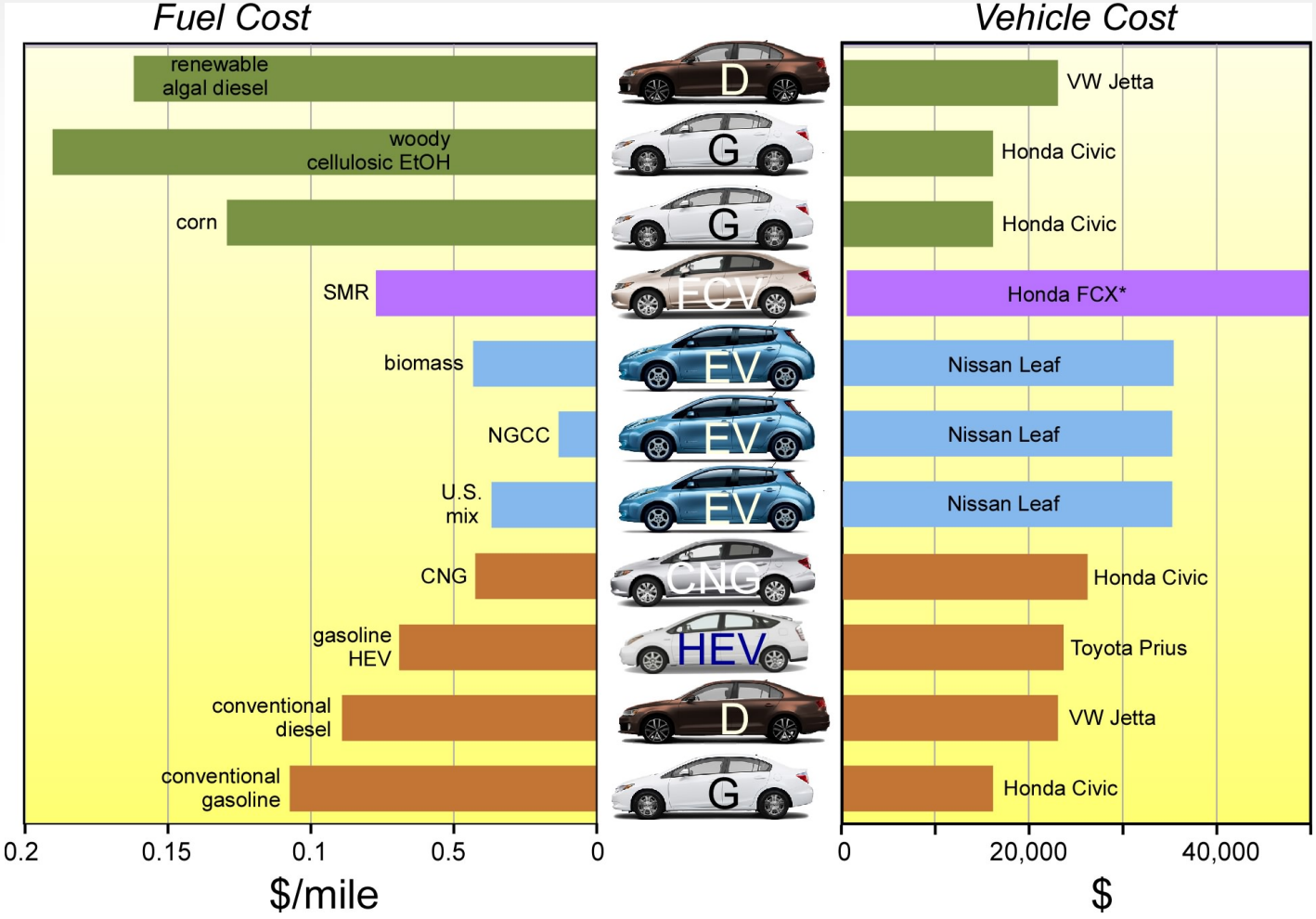

Thank You

Electrification Beats Biofuels



GREET October 2011 update

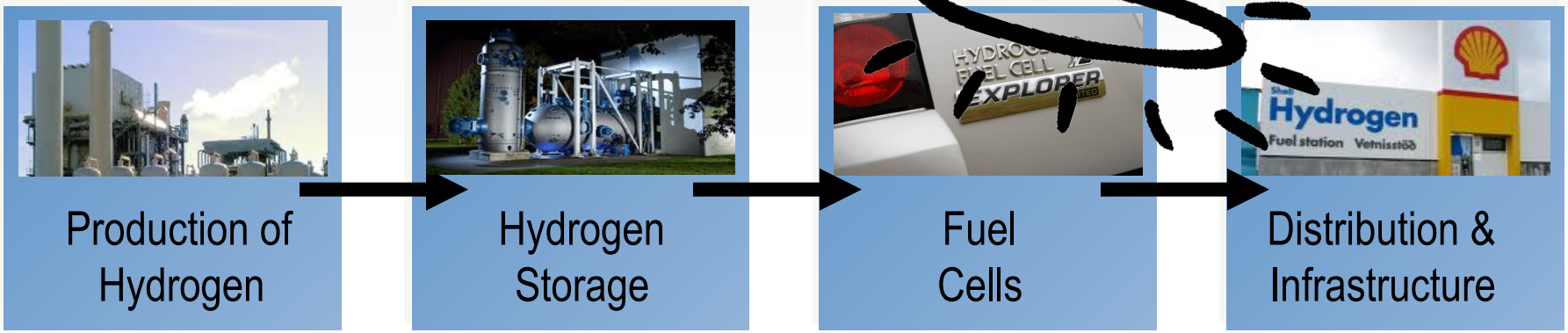
Electrification Beats Biofuels



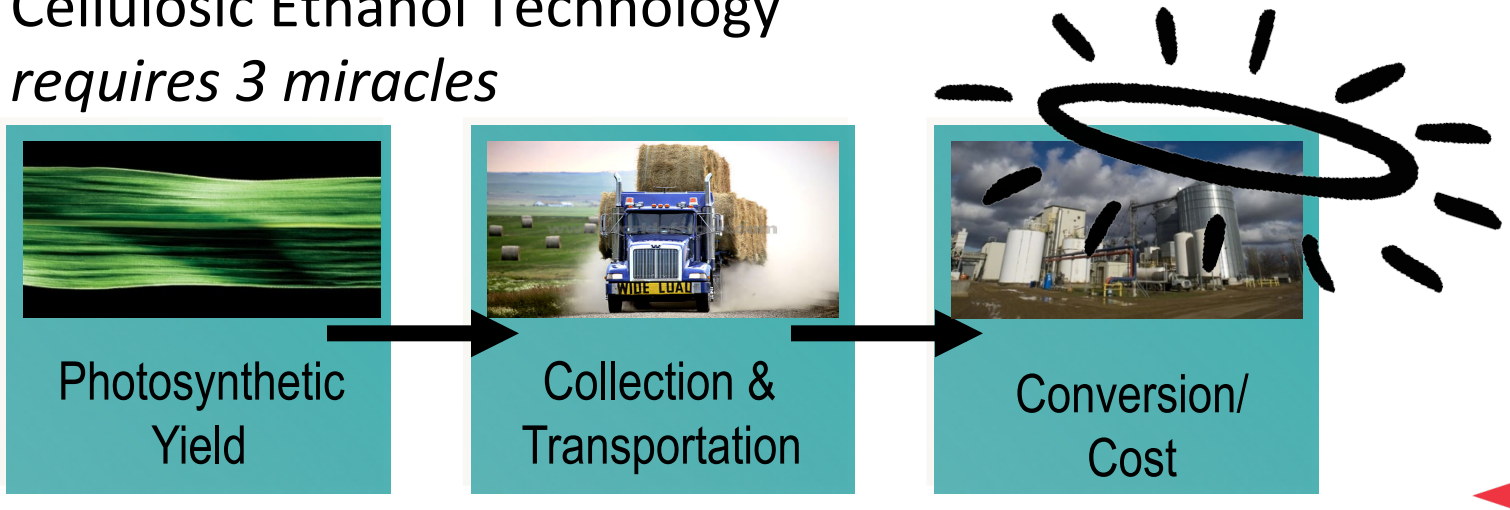
GREET October 2011 update

Compounding Miracles

Hydrogen Fuel Cell Technology
requires 4 miracles



Cellulosic Ethanol Technology
requires 3 miracles



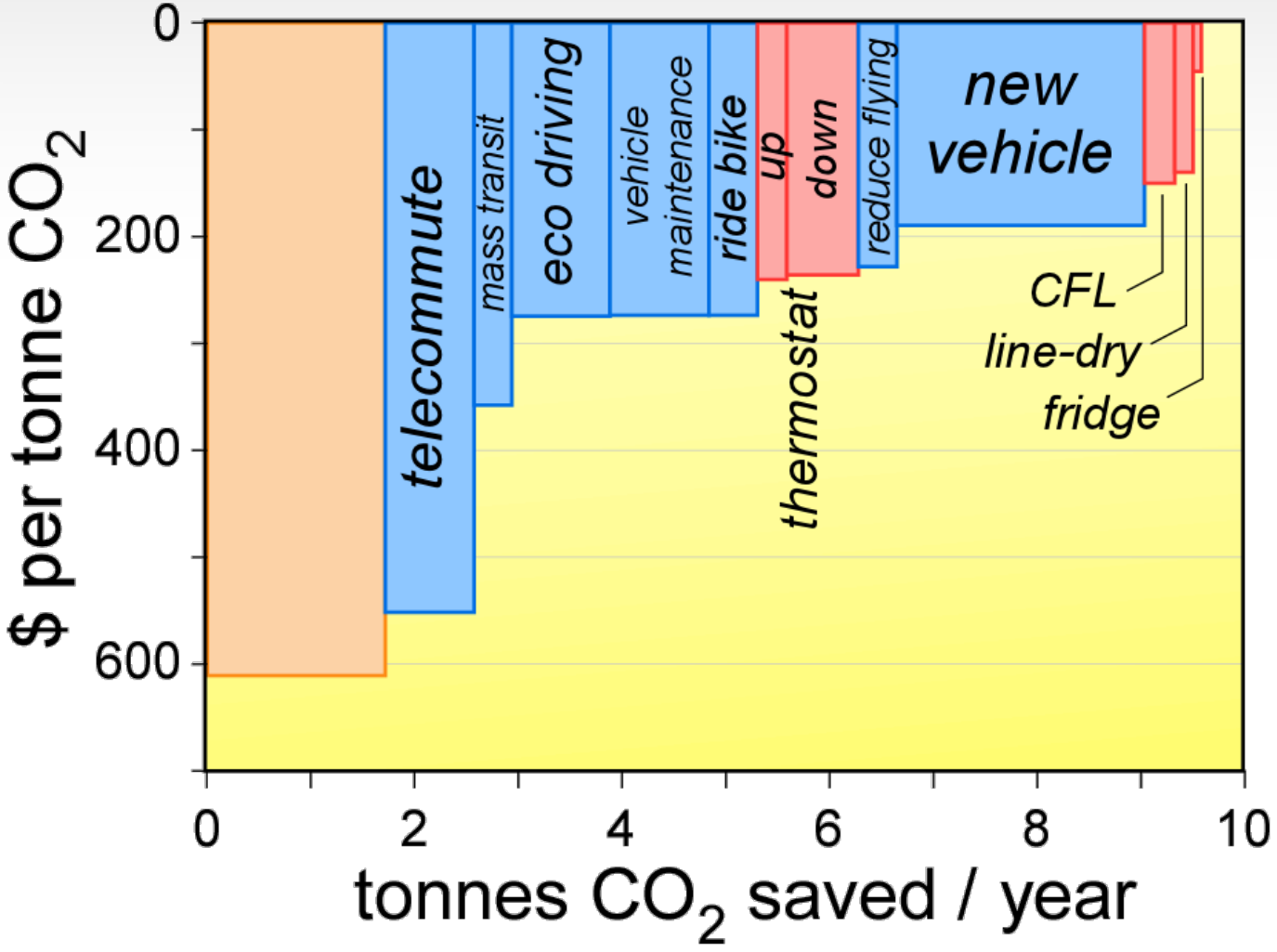
Conclusions

- 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*

Final Thought

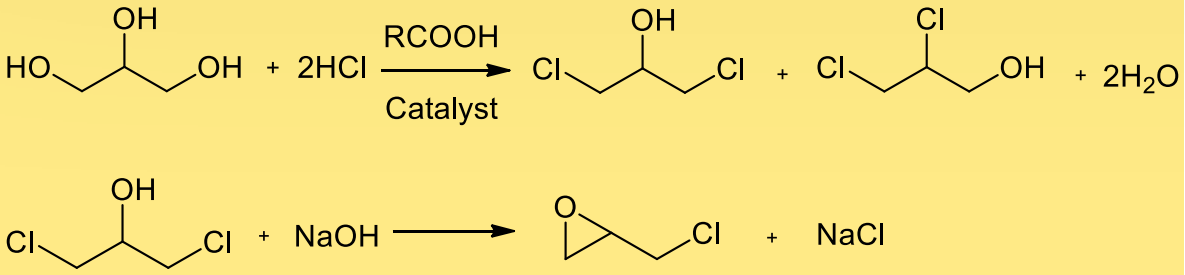
Average US Household Abatement Curve



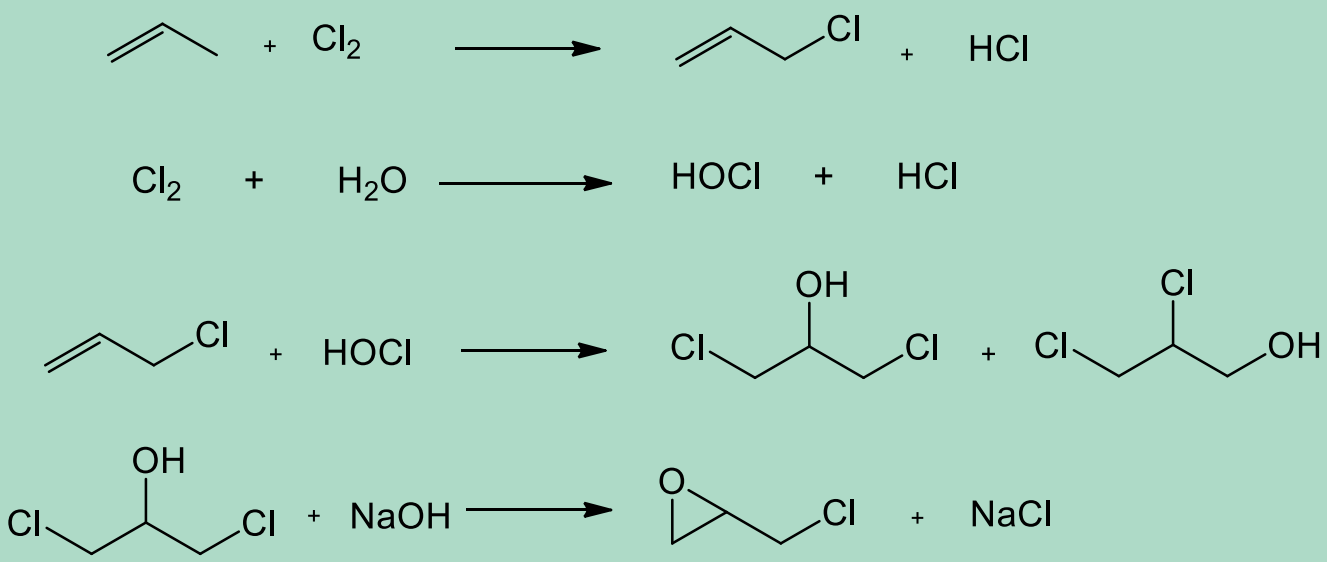
Christopher M. Jones and Daniel M. Kammen; "Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities", *Environ. Sci. Technol.*, 2011, **45** (9), pp 4088-4095; DOI: 10.1021/es102221h

Glycerin to Epichlorohydrin

New Route



Industry Standard Route



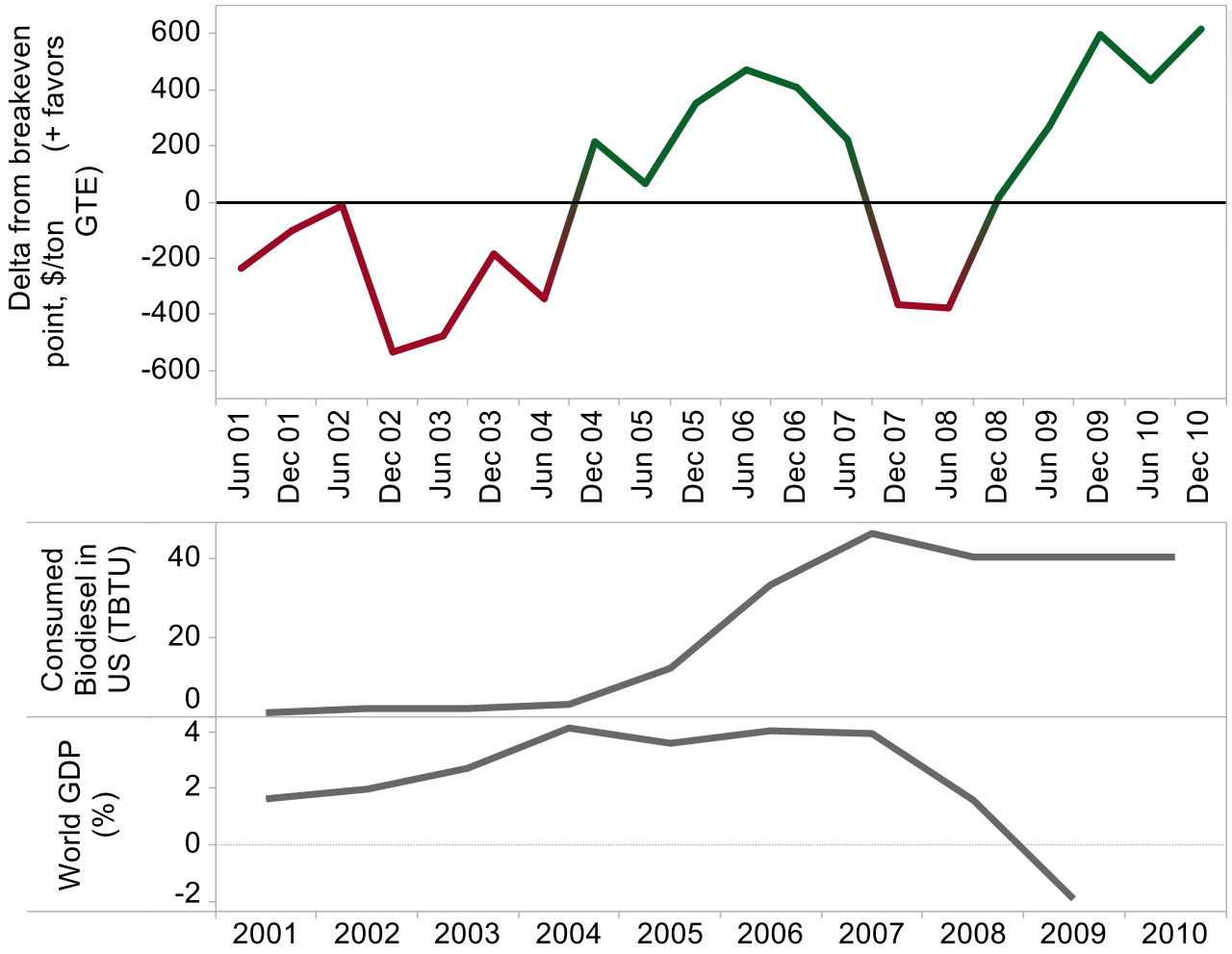
Hypothesis

Glycerin from biodiesel

Economically attractive

- Low Capital (2x lower)
- Simple & competitive process
- Additional market value for renewable feedstock

Glycerin to Epichlorohydrin



Significant Issues: Supply chain uncertainties for crude glycerin

Dependence on biodiesel = uncertain future

Dow's investment decision coincided with global economic downturn

Propylene price variation challenges profitability

Sources:
Glycerin price from December 2010 Oleoline market report with prices corrected to Tallow glycerin.
Propylene prices from CMAI, spot simple average
Biodiesel: EIA Biodiesel Overview 2001-2009, Table 10.4 + AEO 2011 for 2010 data
GDP (%): The World Bank database

The Promise versus The Reality

PROMISE

Switchgrass today = 4.6 ton/acre

Miscanthus – trials only

"Promised" to 10-15 ton/acre in a decade and 15-20 ton/acre over following few decades

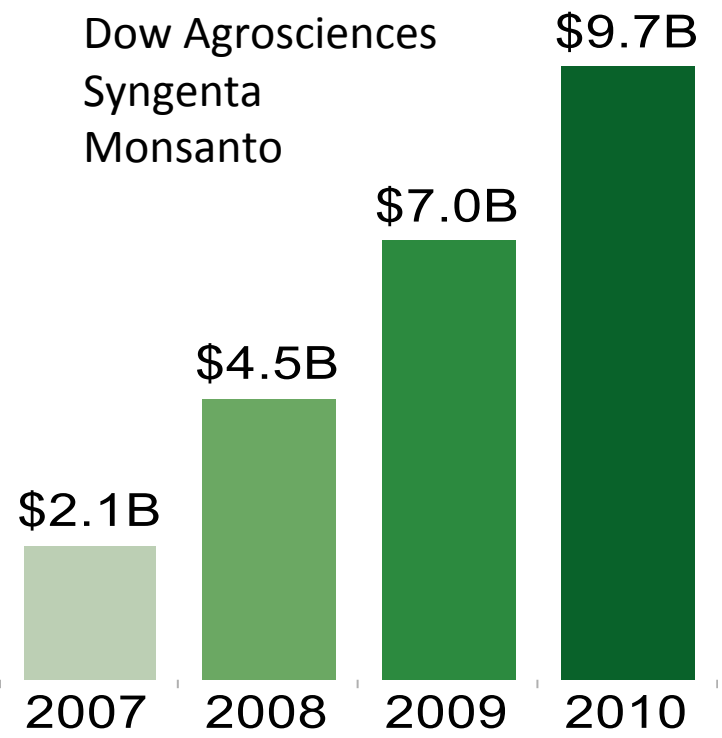
REALITY

Cumulative Total R&D Investment

Dow Agrosciences

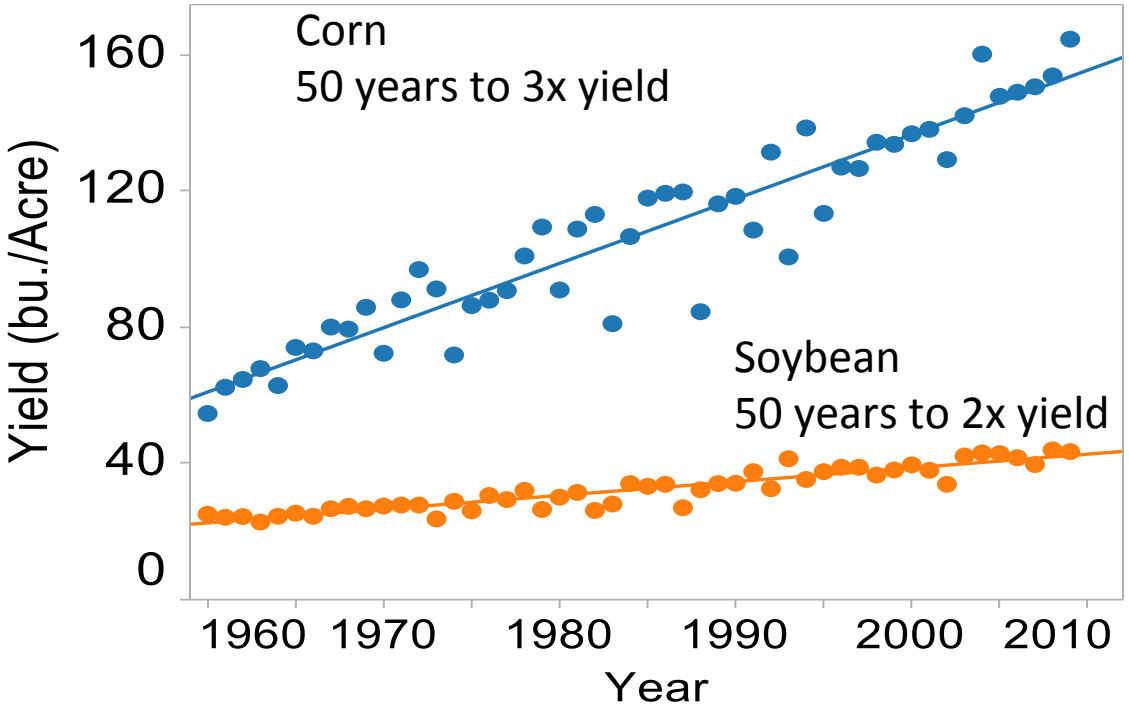
Syngenta

Monsanto



Source: Bloomberg for 2007 to 2009 and Annual financial reports from 2010

Area Productivity



Source: USDA – quickstats.nass.usda.gov – reports:
AFBDFE1E-1AFC-35DE-8A93-7FB72F0DA089
0DB967AF-4F8E-32ED-9D5D-D150ADE7D838

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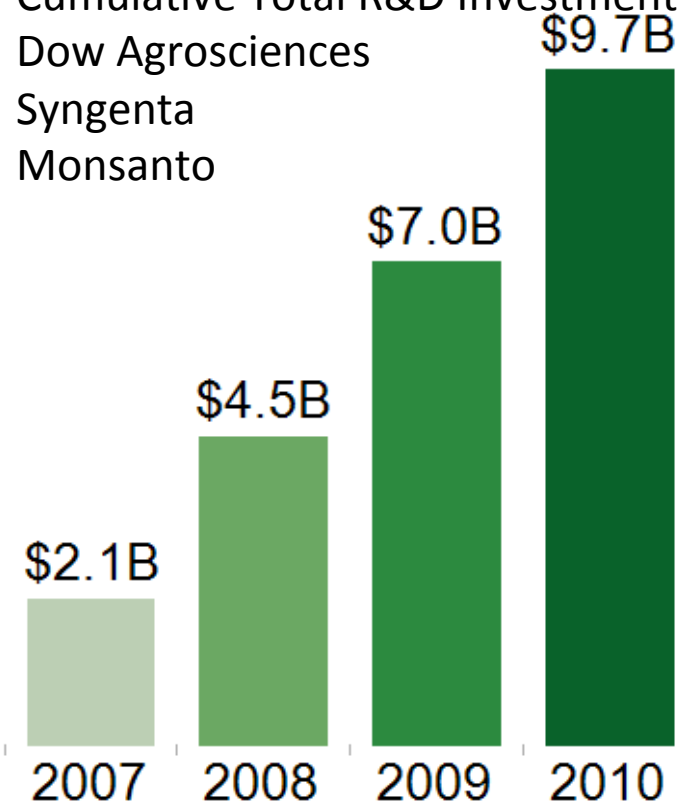

Source: Bloomberg for 2007 to 2009 and Annual financial reports from 2010

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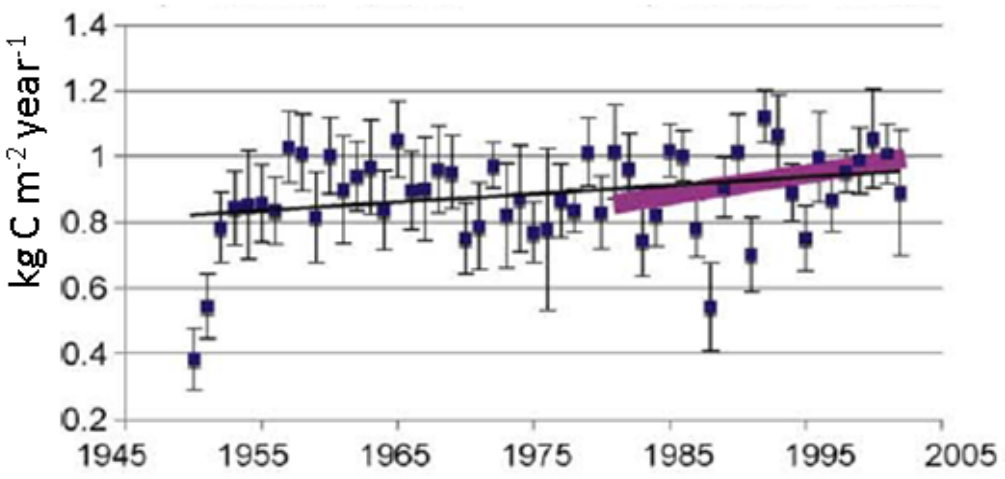
Corn Net Primary Productivity

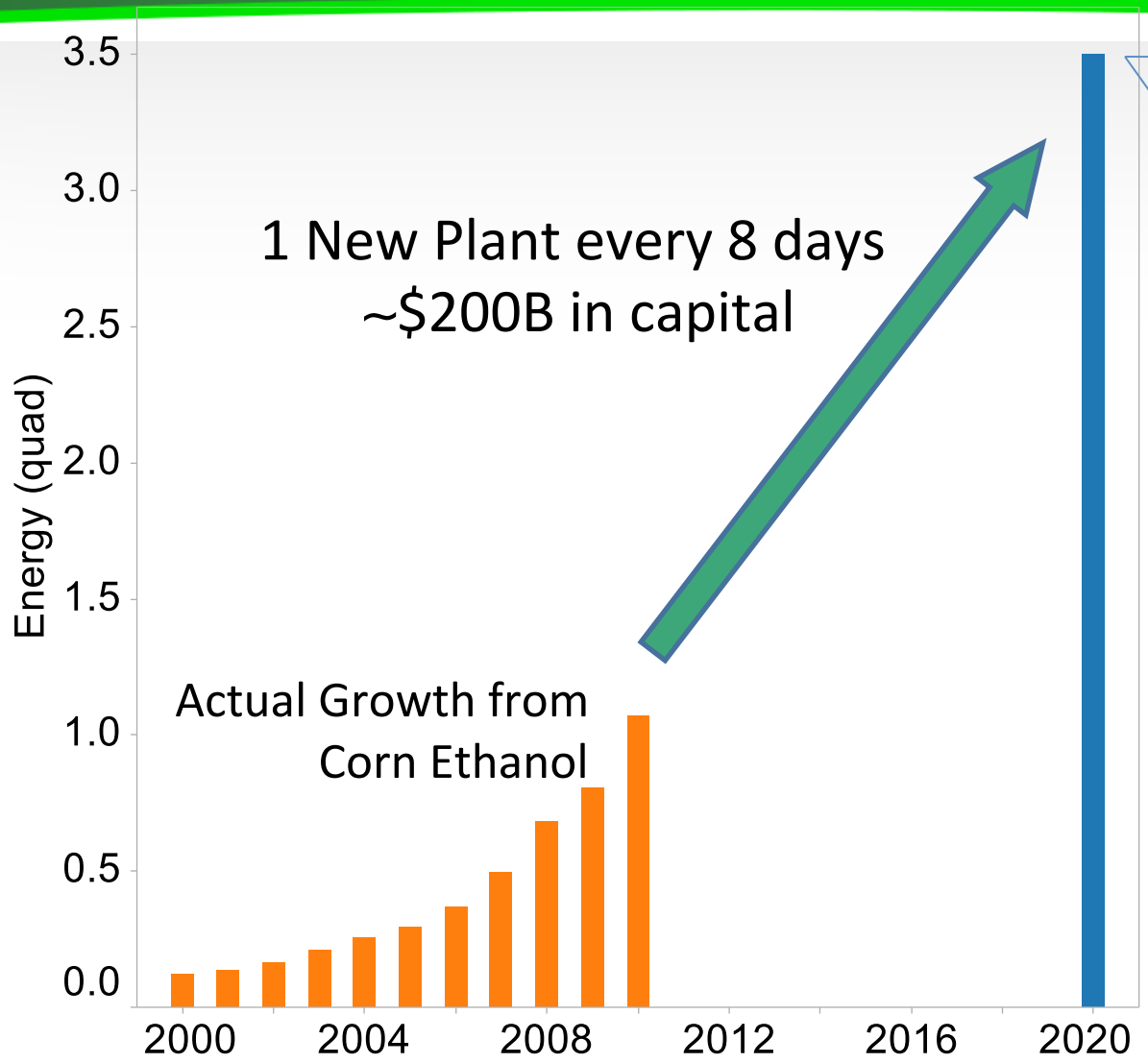
Photosynthesis efficiency is the limit



Tracy E. Twine, Christopher J. Kucharik, Agricultural and Forest Meteorology 149 (2009) 2143–2161

Source: USDA – quickstats.nass.usda.gov – reports:
AFBDFE1E-1AFC-35DE-8A93-7FB72F0DA089
0DB967AF-4F8E-32ED-9D5D-D150ADE7D838

Cost and Time to Implement



9% of US Liquid Fuel Consumption in 2020

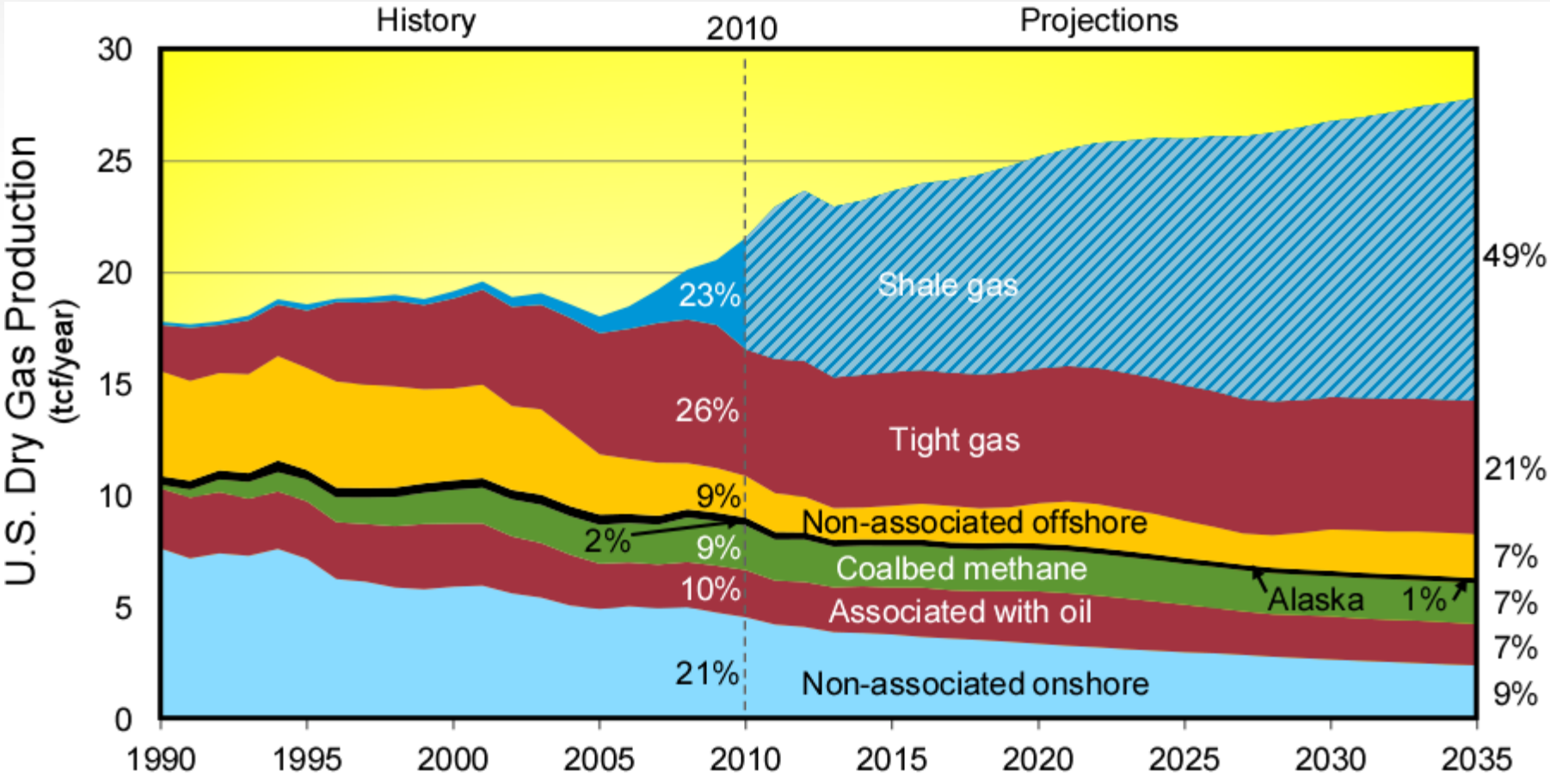
3% of US total Energy Consumption in 2020

National Academy of Sciences Projected Biomass (550MM ton) with Thermochemical Process

Data shown in 2020 includes only the energy generated by the 550 MM ton of biomass (Nat. Academy of Sciences) with performance of 2012 DOE target

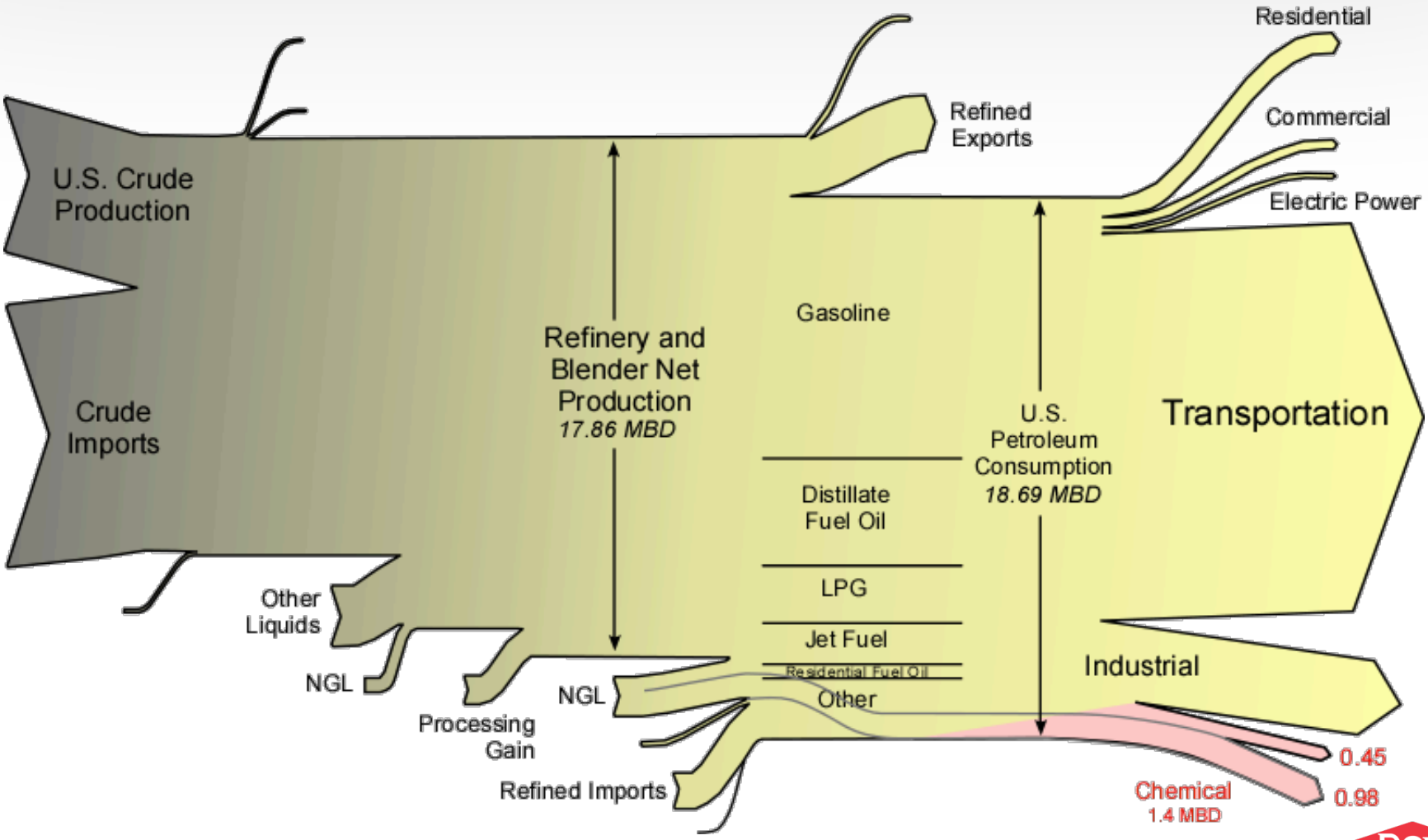

Thank You

Shale Gas Growth



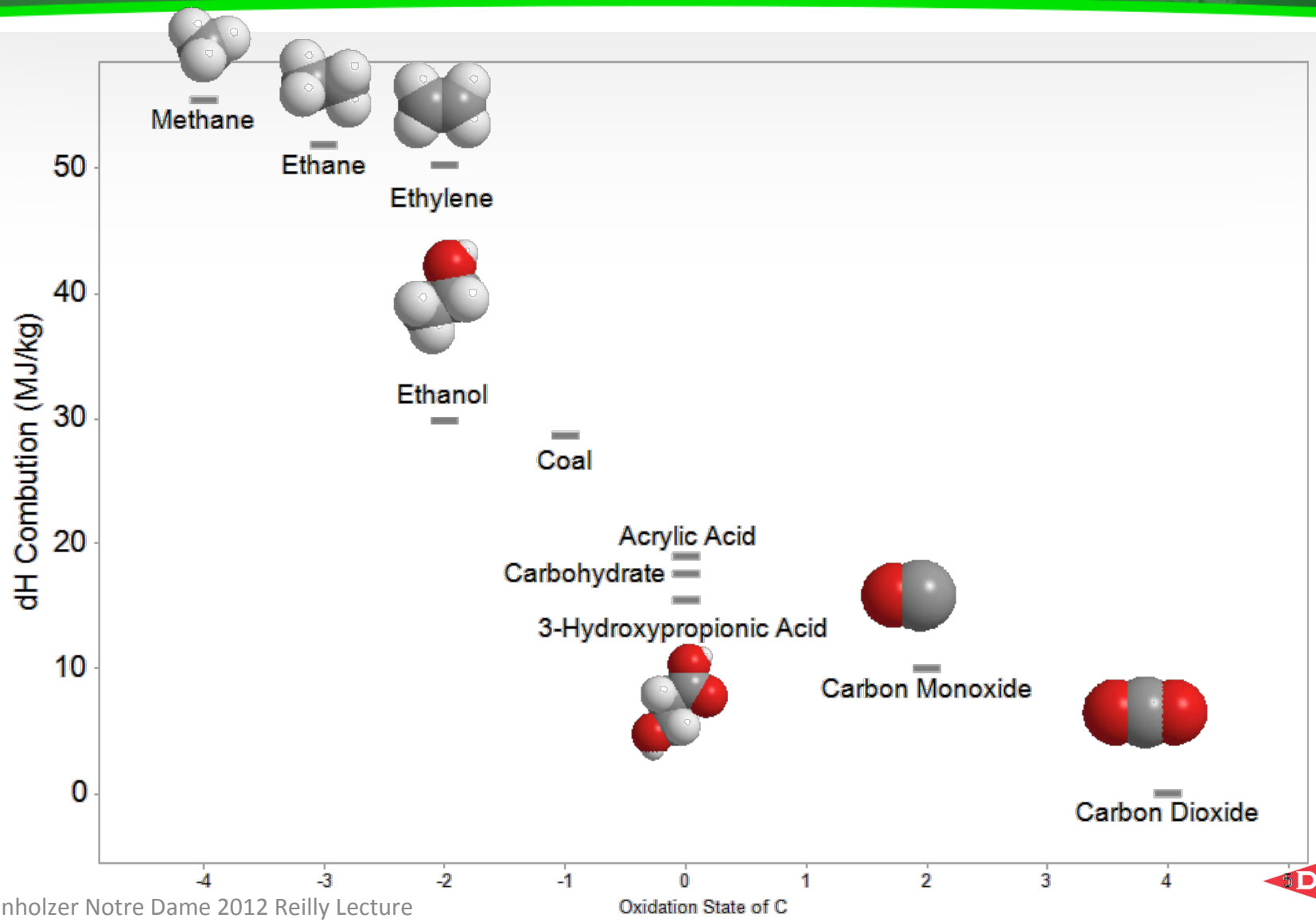
Source: EIA, Annual Energy Outlook 2012 Early Release

U.S. Petroleum Flow



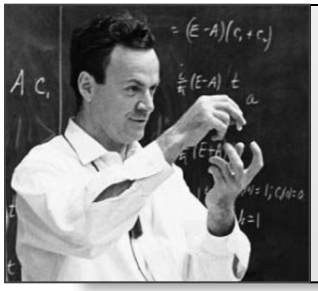
EIA, "Annual Energy Review 2009", August 2010, DOE/EIA-0384(2009) and Sean Davis, "SRI Petroleum Liquid Feedstocks", June 2010

Feedstock Oxidation States



Understanding the Key Issues

- The requirements of CAPITALISM must be addressed.
- ENERGY R&D is a multi level challenge
- NEW FEEDSTOCKS have uncertainty in supply chain complexity, long term availability and market pull
- TIME & SCALE TO IMPLEMENT cannot be ignored
- The relationship between SCIENCE and BUSINESS is hard to predict
- INCUMBENT TECHNOLOGY sets the standard for competition
- COMPANIES FAIL!



For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled.

- Richard Feynman

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
uction 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
Total		**2.26 kg**		**2.39 kg**

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

Abstract

The world aspires for sources of energy and product feedstocks that are 100% sustainable in adequate amounts to support a high standard of living for all. The question is whether these goals are practical.

Which new pathways and technologies will emerge to transform our situation? This question is addressed from the perspective of the chemical industry, which was built on oil, natural gas, and coal. These have served as the major raw material feedstocks and energy sources for driving reactions and separations. The industry is exploring new materials and solutions for energy supply and conversion.

Here we consider the mass and energy balances, capital investment, and resource requirements of several key alternative energy and feedstock technologies. These considerations determine where we can expect realistic progress toward sustainable chemistry in both the short and long term, and where we should place our investments.

How CAPITALISM Works….

Companies have to make money

Money flows towards higher returns

Investors are risk adverse

Wrong investments drive companies to collapse