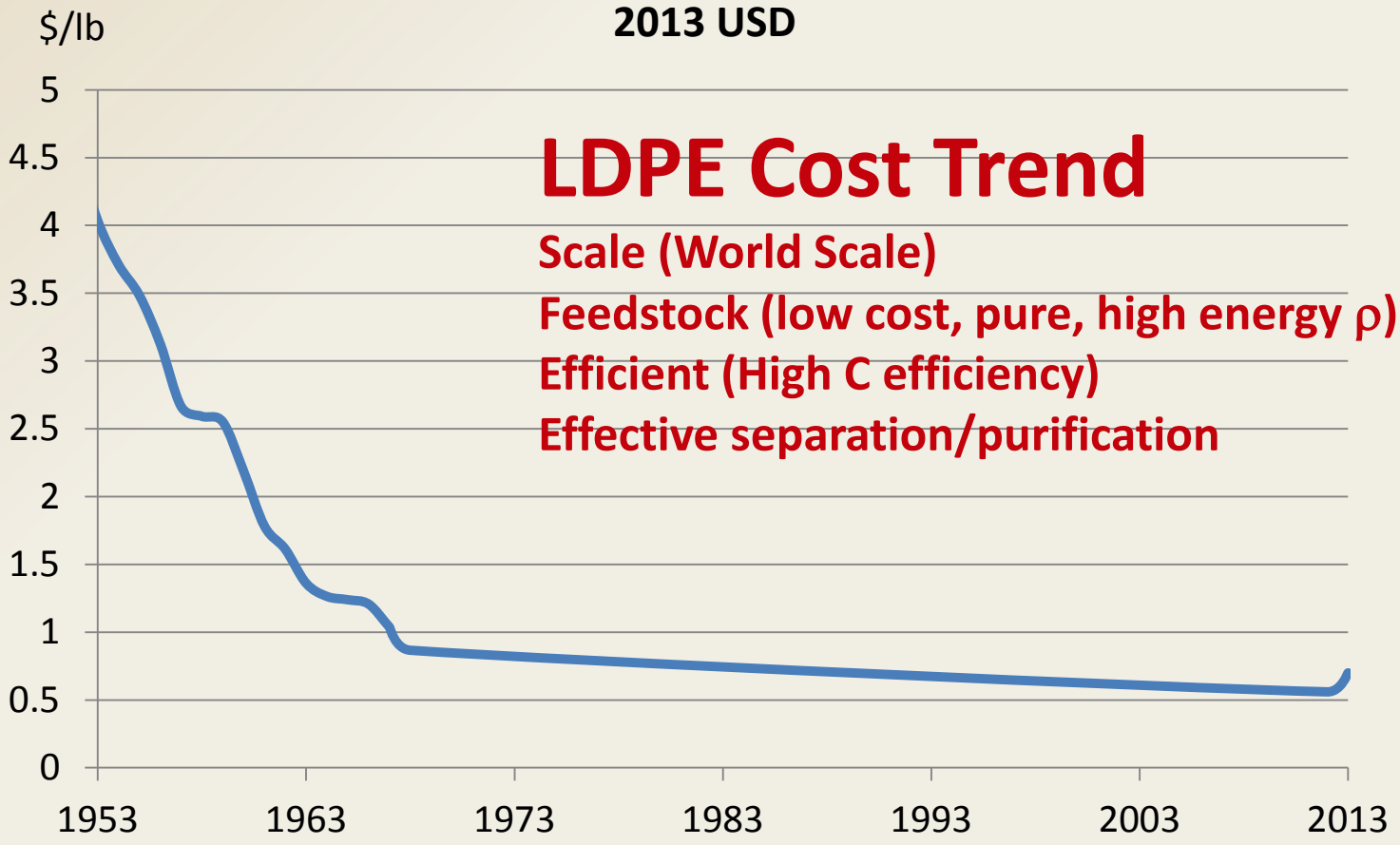
The World Needs Engineering Judgment

William F. Banholzer

AIChE Meeting

March 2014

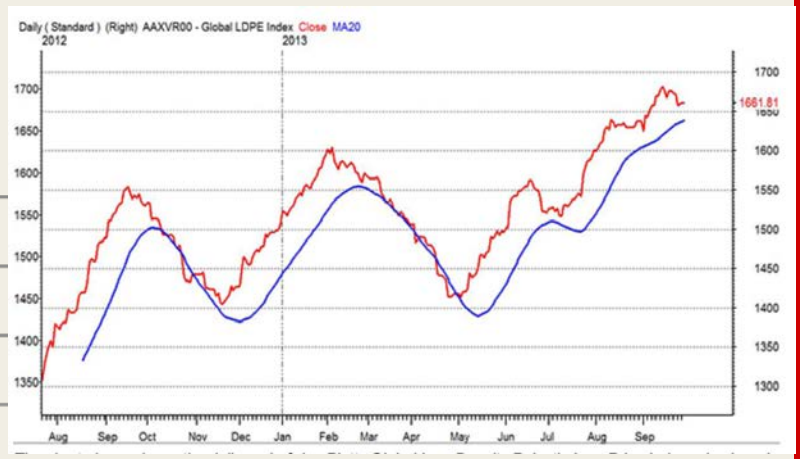
Chemical Engineering Impact



Source PCDB.Santefe.edu

Rules for Business

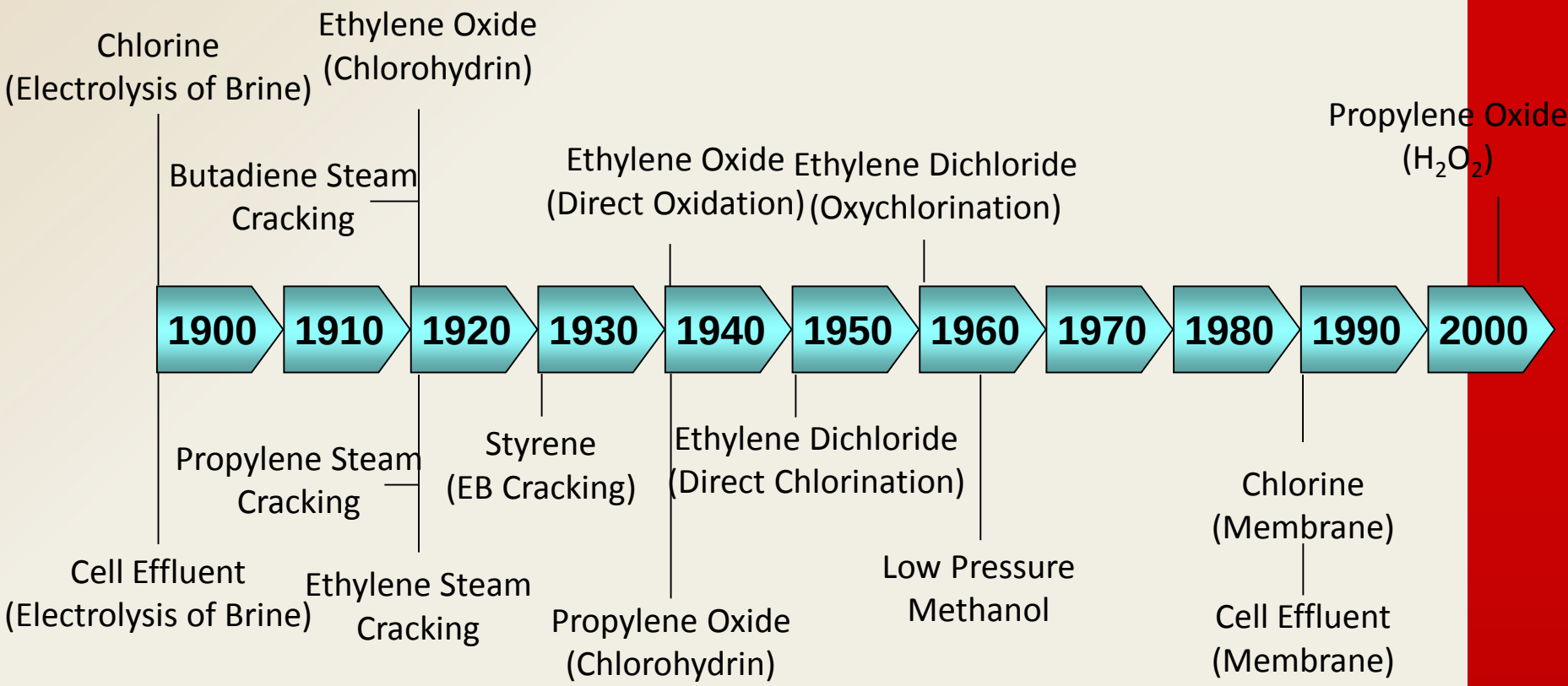
Relative Source of Profit



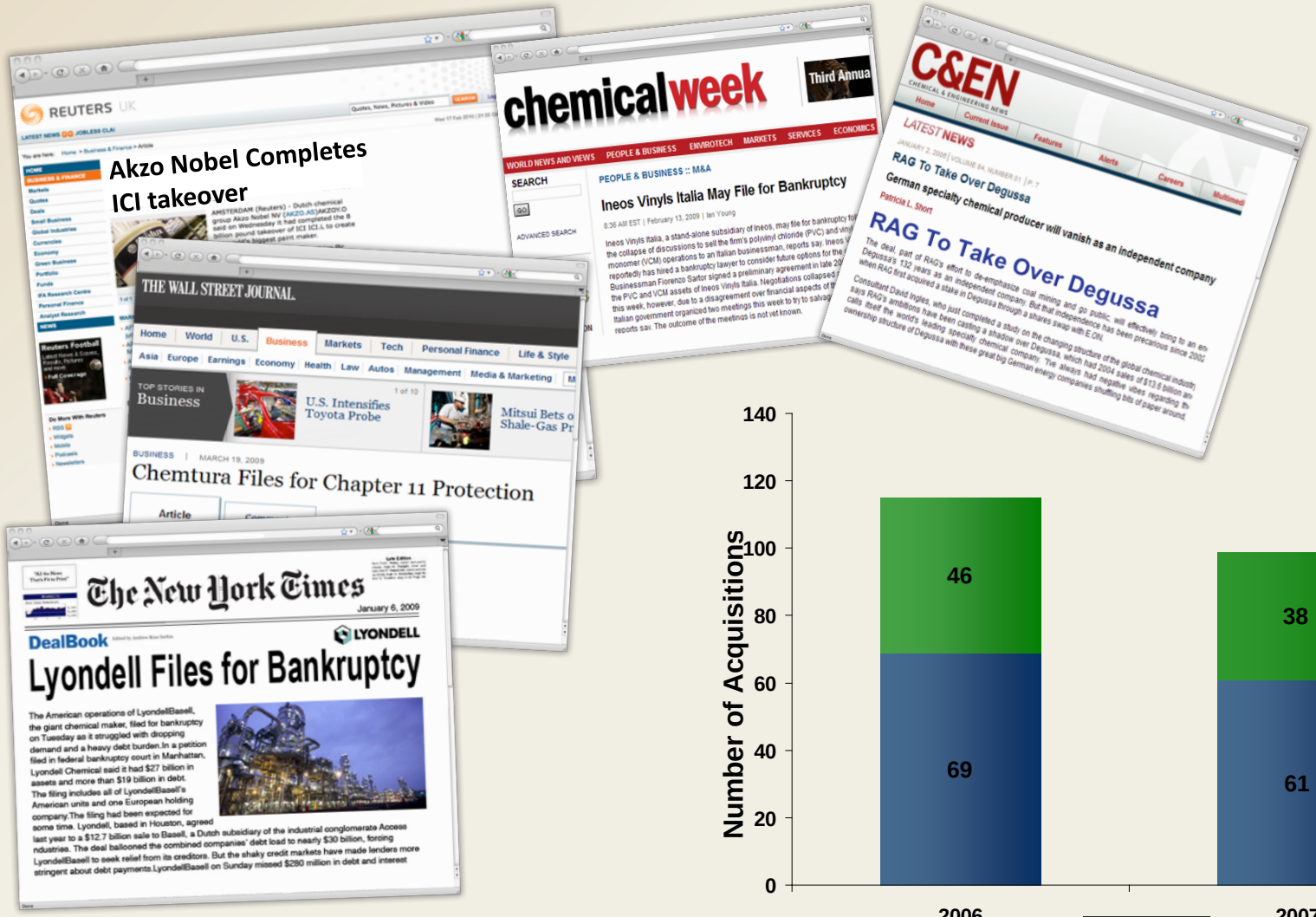
Idealized Data

Basic Raw Material Transformations

Technology is highly optimized



There is NO Entitlement….



Source: Fink, U. Ishikawa, Y., Yang, W. *Overview of the Specialty Chemicals* Industry, SRI Consulting.

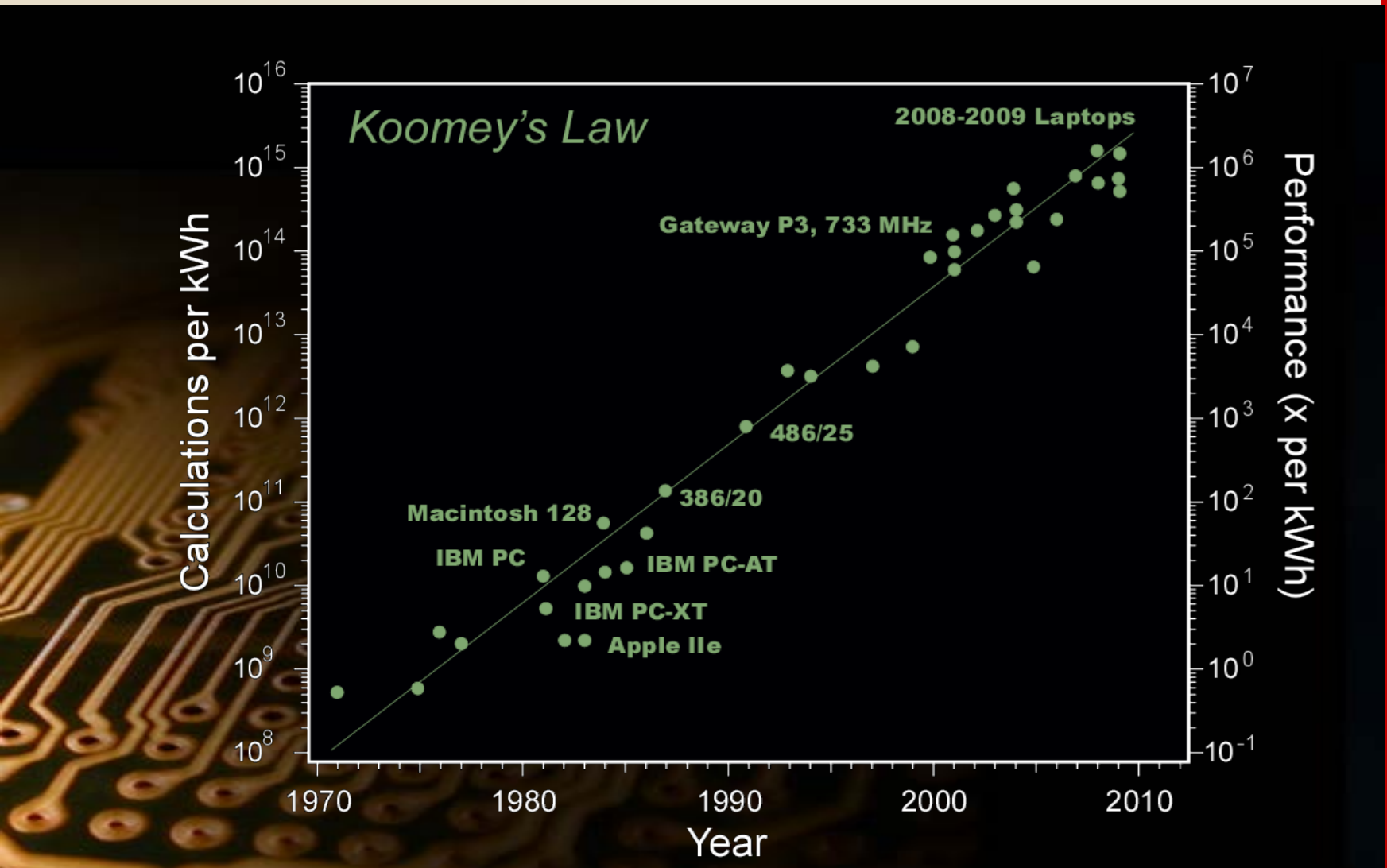
Top US Chemical Companies 1970

Rank '69	Rank '68	Company	Chemical sales (Millions of dollars)	Total revenues[a]	Chemical sales as per cent of total revenues	Company SIC class.[b]	After-tax earnings[c] (Millions of dollars)	Profit margin[d]	Rank '69	Rank '68	Return on investment[e]	Rank '69	Rank '68
						TOTAL COMPANIES							
1	1	Du Pont[f]	$3220	$3,655	88%	281	$343.5	9.4%	4	3	5.6%	7	4
2	3	Union Carbide	1815	2,933	62	281	186.2	6.4	18	24	3.2	36	42
3	2	Monsanto	1735	1,939	89	281	109.4	5.6	26	22	3.3	34	33
4	4	Dow Chemical	1570	1,876	84	281	148.7	7.9	10	12	4.7	15	19
5	7	Celanese	1028	1,250	82	281	76.3	6.1	22	34	3.8	29	45
6	5	W. R. Grace	1015	1,812	56	281	51.0	2.8	45	45	2.8	40	41
7	6	Standard Oil (N.J.)	1004	16,900	6	291	1243	7.4	12	9	5.1	11	9
8	8	Allied Chemical	895	1,316	68	281	68.0	5.2	30	46	2.7	41	48
9	9	Hercules	642	746	86	281	43.9	5.9	24	14	4.1	26	12
10	11	Occidental Petroleum	625	2,059	30	509	174.8	8.5	7	14	7.3	3	3
11	10	FMC	620	1,409	44	281	67.3	4.8	32	29	5.0	13	6
12	12	American Cyanamid	576	1,067	53	281	89.9	8.3	8	5	6.2	6	5
13	13	Shell Oil	544	4,276	13	291	291.2	6.8	15	10	4.2	21	18
14	14	Eastman Kodak	522	2,747	19	383	401.1	14.6	1	1	10.5	1	1
15	16	Uniroyal	513[g]	1,554	33	301	46.6	3.0	44	40	2.7	41	31
16	15	Stauffer Chemical	499	499	100	281	31.6	6.5	17	17	7.2	4	9
17	17	Phillips Petroleum	471	2,227	21	291	134.3	6.0	23	19	3.2	36	35
18	18	Rohm and Haas	448	453	99	281	33.5	7.4	12	8	4.8	14	9
19	19	Mobil Oil	444	7,573	6	291	434.5	5.7	25	22	4.4	17	22
20	21	Borden	394	1,756	23	202	47.9	2.7	46	47	4.2	21	24
21	26	Ethyl Corp.	382	517	74	281	33.0	6.4	18	20	4.3	20	19
22	20	Cities Service	361	1,595	23	291	127.2	8.0	9	5	4.0	27	26
23	23	Ashland Oil	342	1,151	30	291	52.3	4.5	34	32	4.4	17	15
24	28	Diamond Shamrock	327	555	59	281	30.7	5.5	28	17	3.2	36	30
25	24	Continental Oil	325	2,687	13	291	146.4	5.6	26	21	3.7	30	24

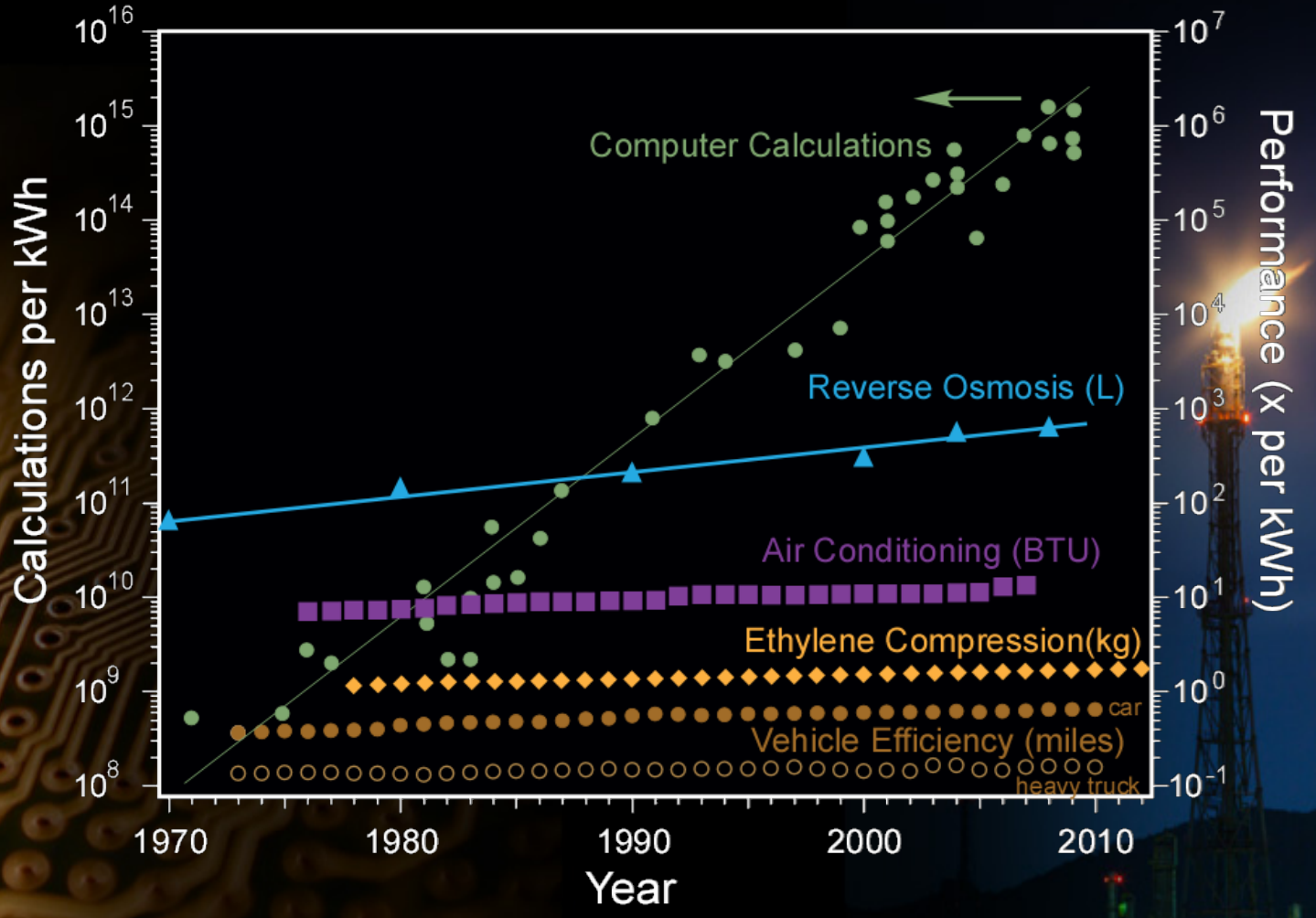
Bio

Bio/Rest.

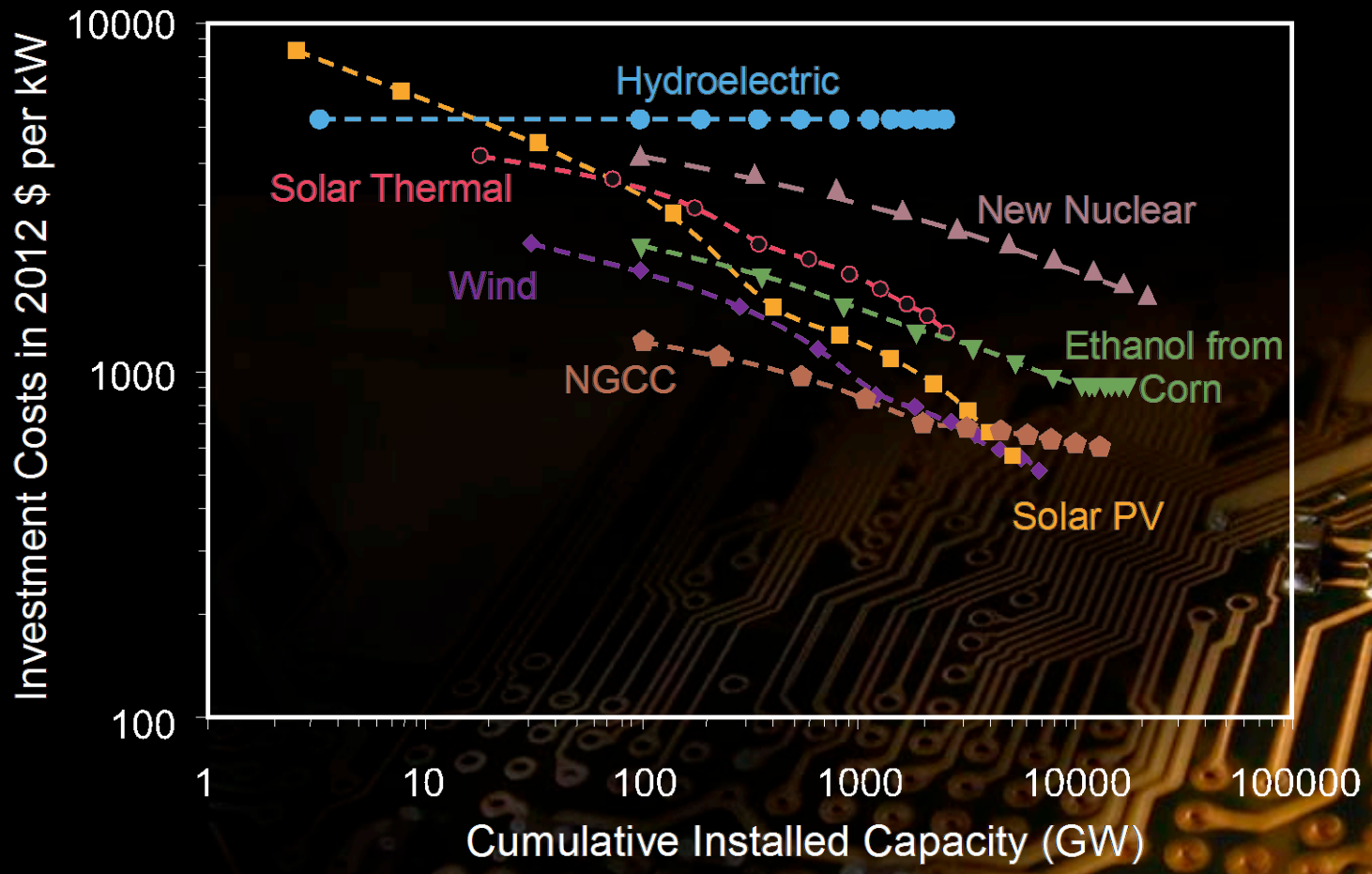
Engineering Triumph



Moore's Law Sets Unrealistic Expectations

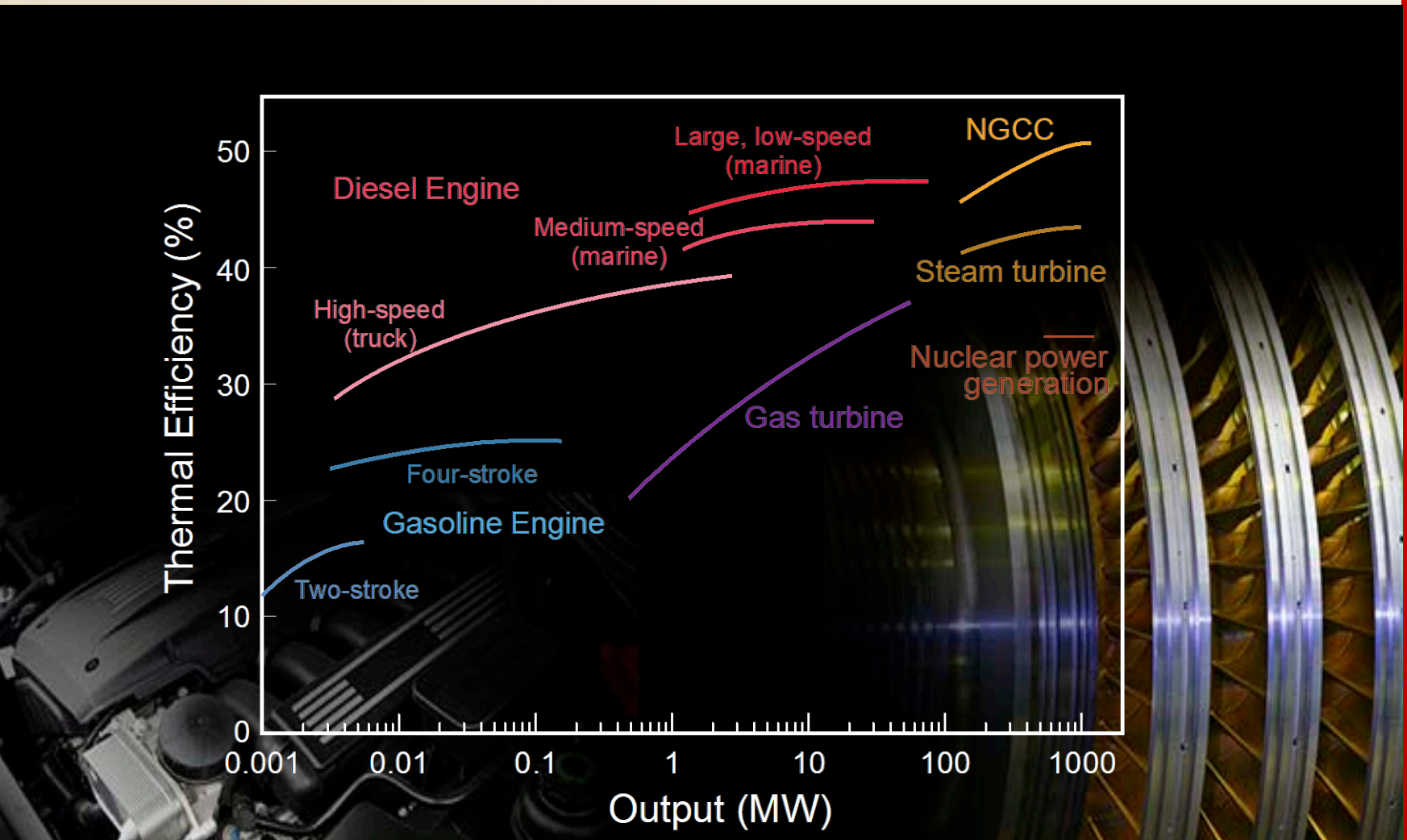


Experience Curves



Adapted from Riahi et al., Energy Economics 26 (2004) 539-564.

Scale Improves Efficiency

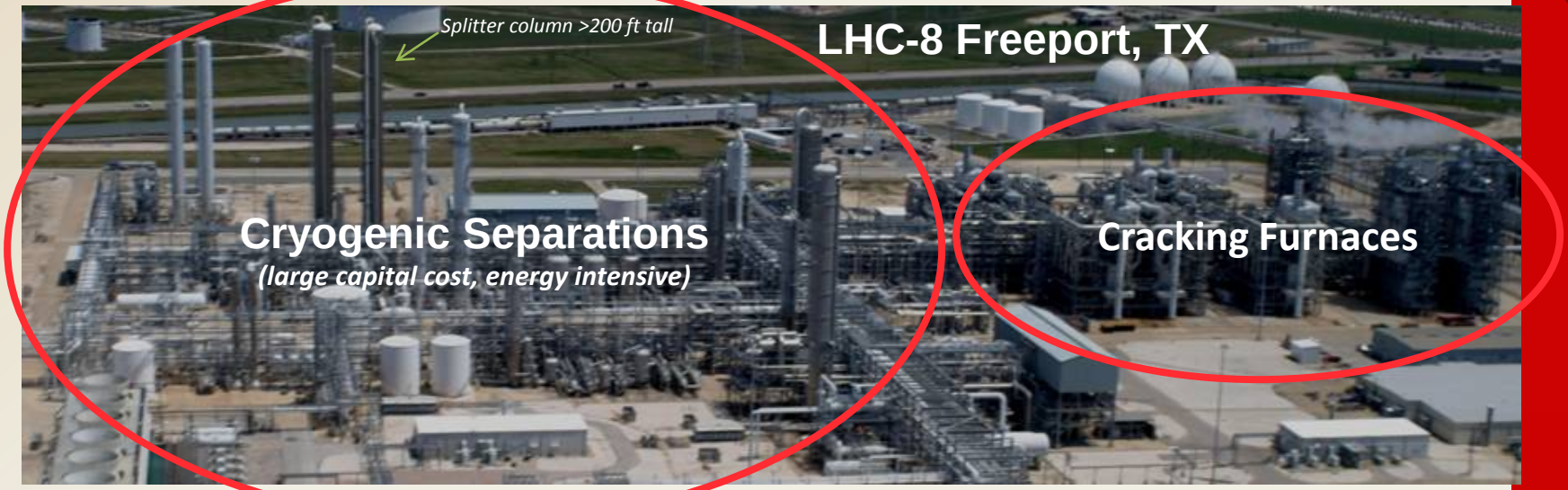


Engineering Fundamentals - Scale

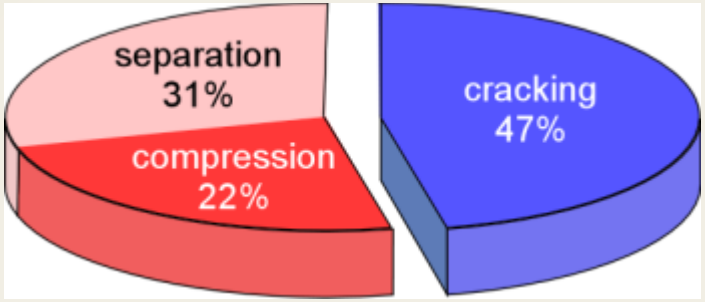
Small Distributed Plants costly
In Chemical/Energy Industry.

Scale reduces the cost of production when materials are consumed or produced.

Separation Cost Significant

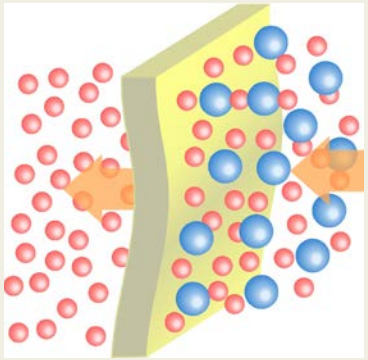


Energy Use



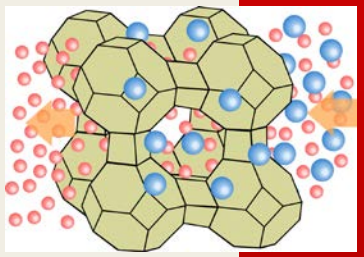
Ethane Cracker Specific
Energy Consumption

Alternatives



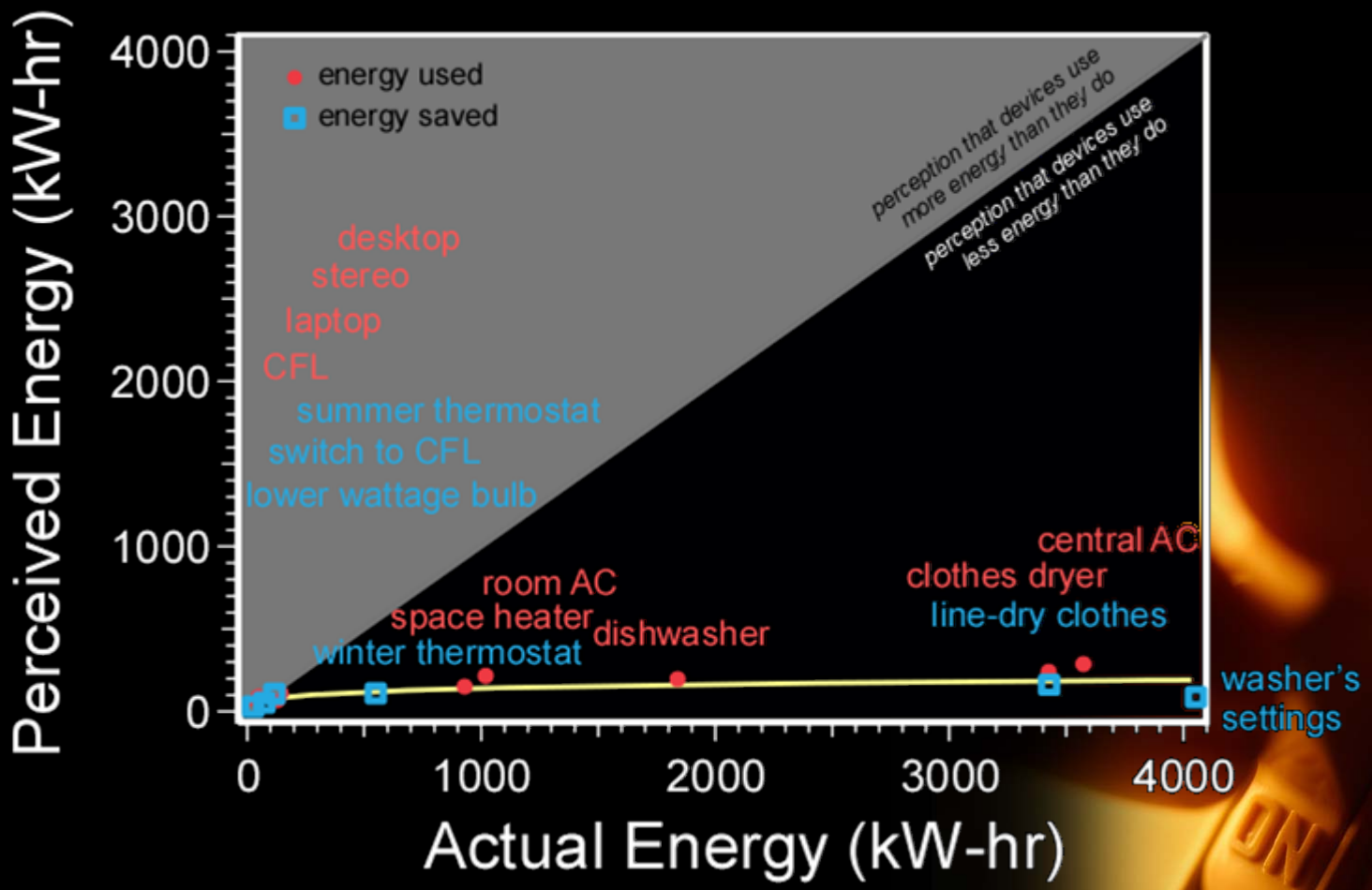
Membrane Separations

Adsorbent Separations



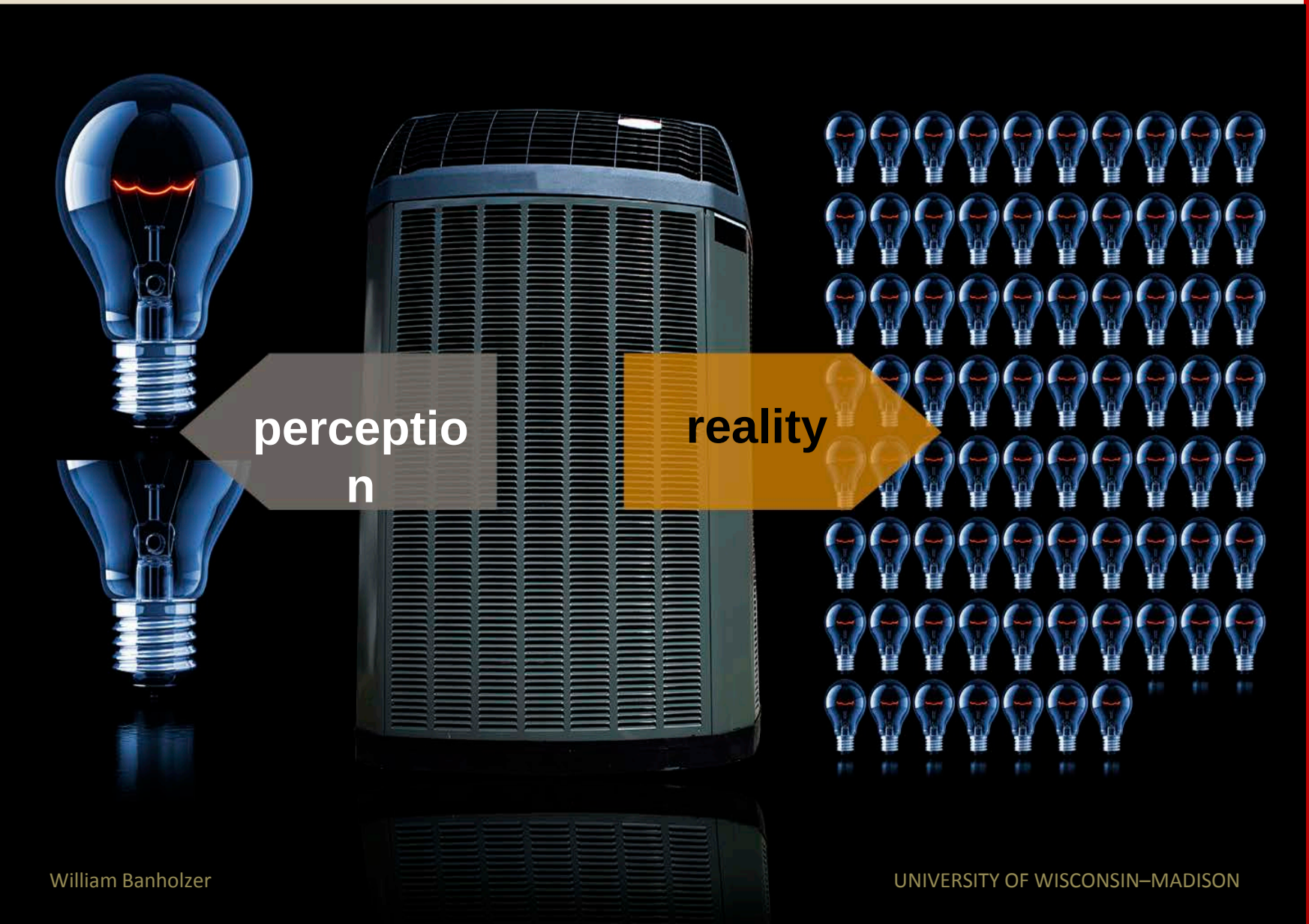
Courtesy Mark Jones @ Dow

We Are Poor Judges of the Energy We Use

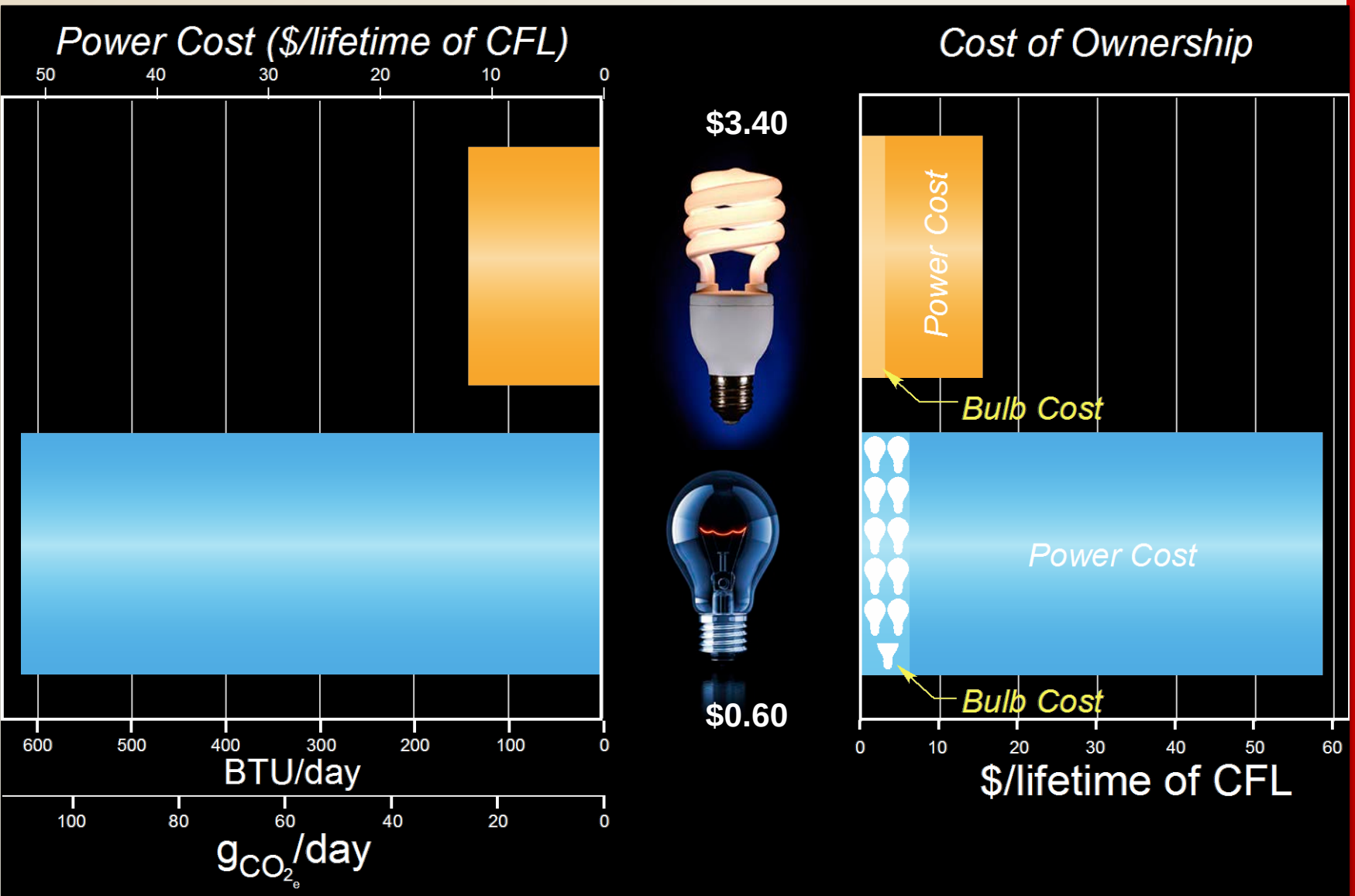


Attari. Sjajzeem Z.; DeKay, Michael L.; Davidson, Cliff I.; de Bruin Wandi Bruine; "Public Perceptions of Energy Consumption and Savings", PNAS doi 10.1073/pnas.1001509107

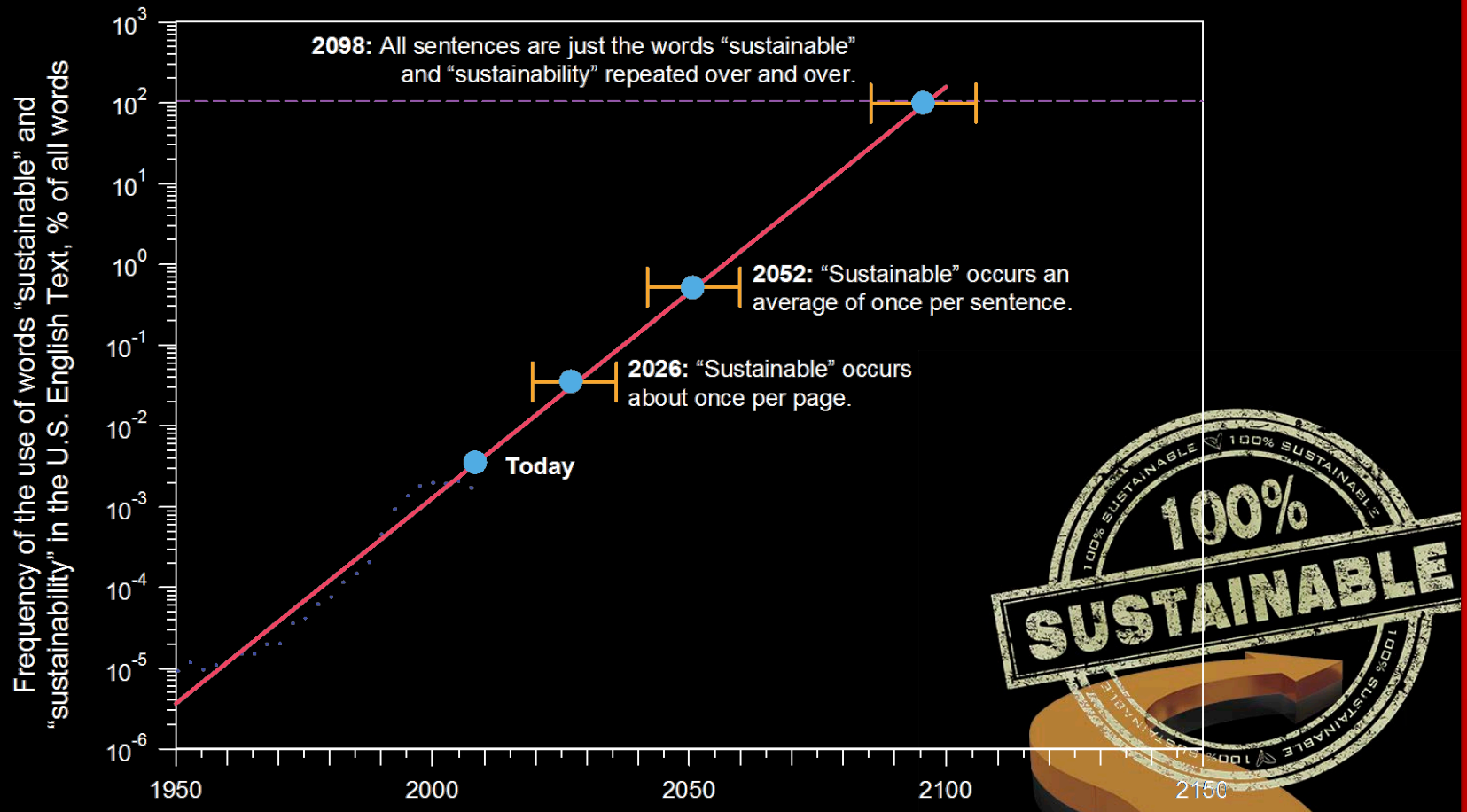
Energy Perception and Reality



People Don't Always Make Smart Choices



Ripe for Hype



Source: Google Ngrams

Hype Around Cleantech

Ivy League Brains Figure Out How to Make Biodegradable Plastic from Greenhouse Gases

September 28, 2012 cleantechnica.com

Two graduates from Princeton University and Northwestern University have developed a process for converting greenhouse gases from sewage treatment plants, landfills, and power plants into a biodegradable plastic called Airflex™

As described by Newlight, the process for making Airflex ™ breaks down into a few simple steps. First, a mix of gases, including methane and carbon dioxide, is funneled into a reactor. Next, carbon and oxygen are separated out, and then they are reassembled into a long-chain thermopolymer.

September 25, 2012 presswire.com

"We are pleased to receive this seventh patent," stated Newlight CEO, Mark Herrema . "While the size of our patent portfolio is a testament to Newlight's pioneering inventions and nearly decade-long leadership in this field, we expect our patent portfolio to continue to grow at a rapid pace, particularly in the areas of new product applications and commercial-scale manufacturing systems."

Permanent Exhalation Conveyance

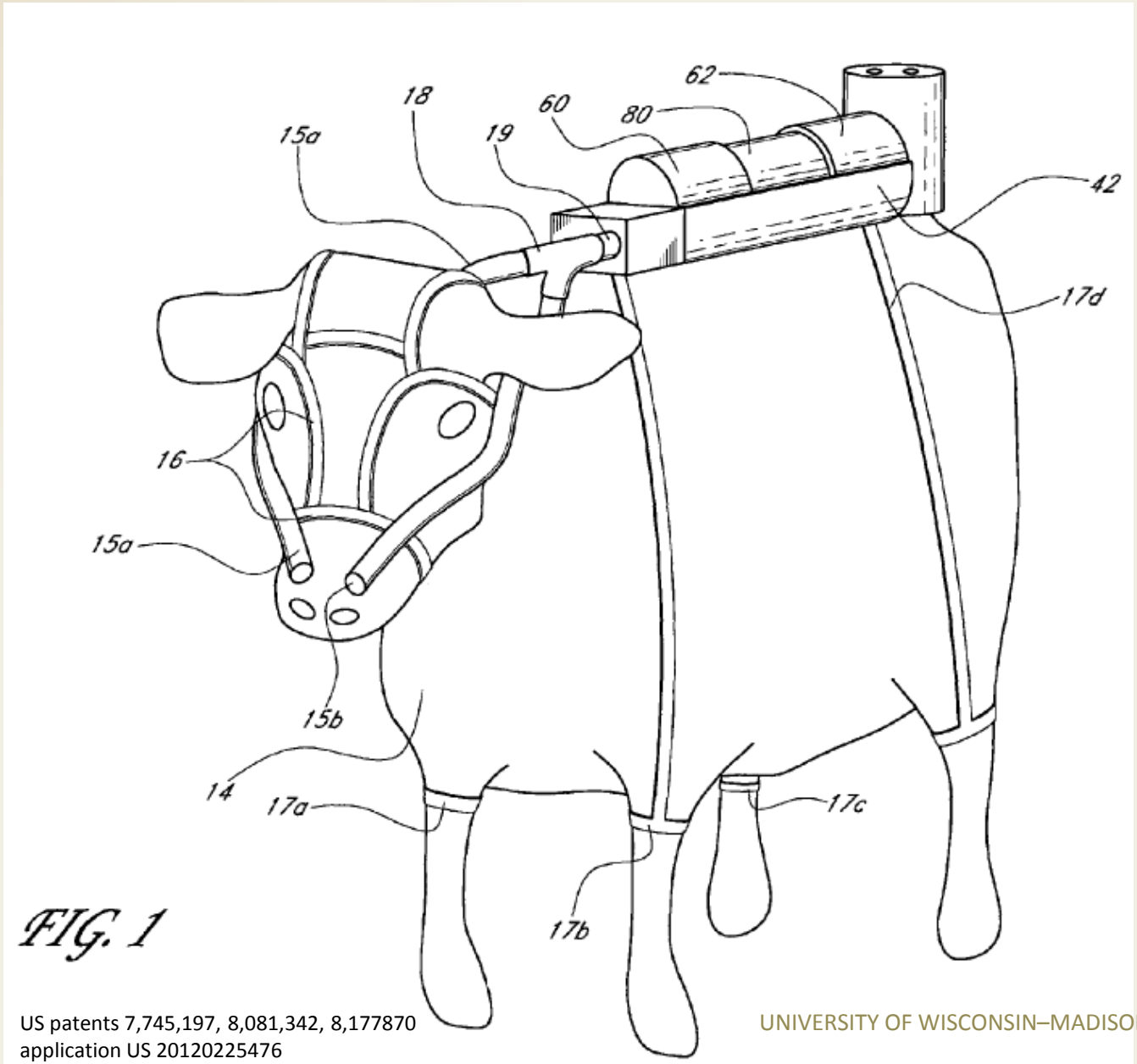
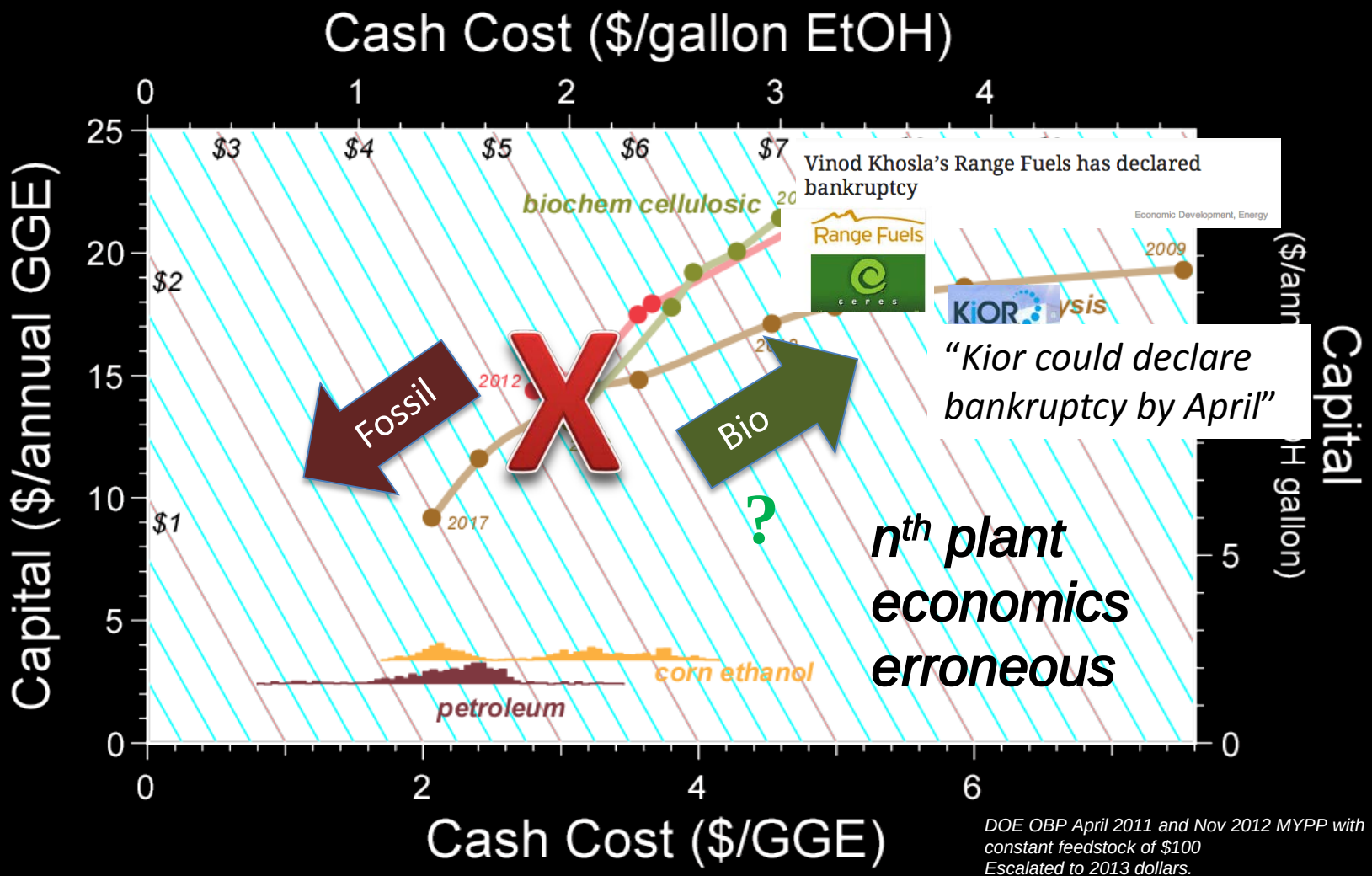


FIG. 1

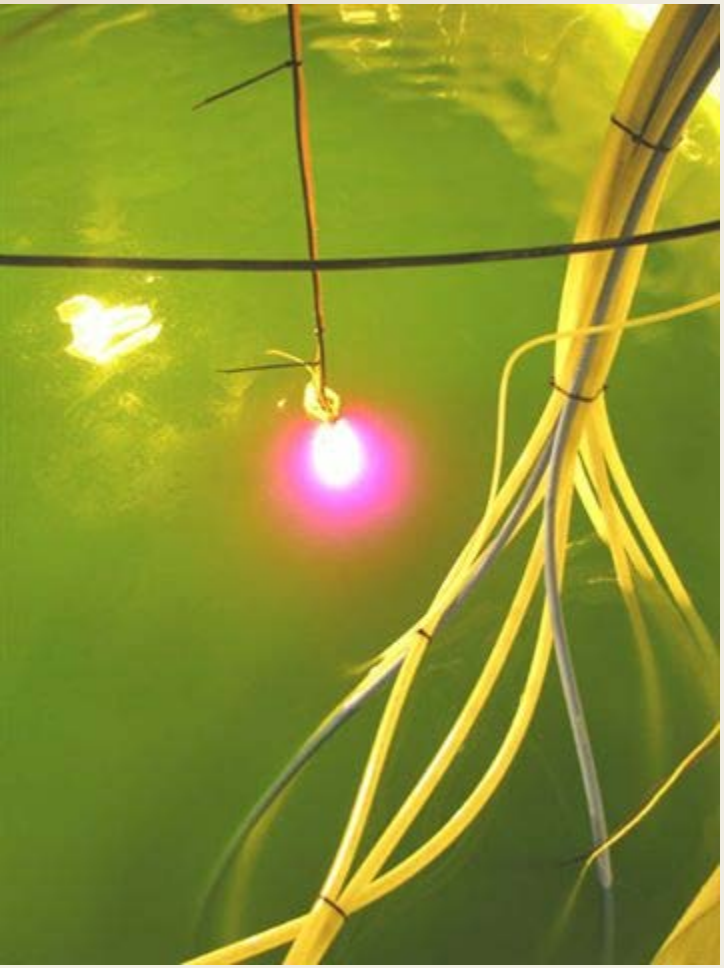
US patents 7,745,197, 8,081,342, 8,177870
application US 20120225476

DOE Estimates



DOE OBP April 2011 and Nov 2012 MYPP with constant feedstock of $100 Escalated to 2013 dollars.

Technical Evaluation- LumiGrow



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

Photon's VERY Expensive Reagents

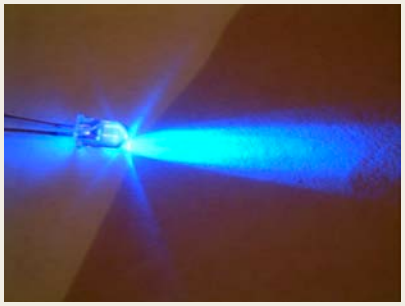
Electricity

Primary Energy N.G

100

30-60

Photons



9-18

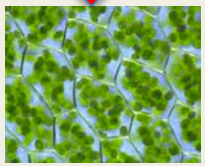
Direct Rx

$0.02/ mole photon

@ $.09/kwh

Ref ethylene = $0.04/mole

Photosynthesis



0.09-0.18

Algae Fuel Production

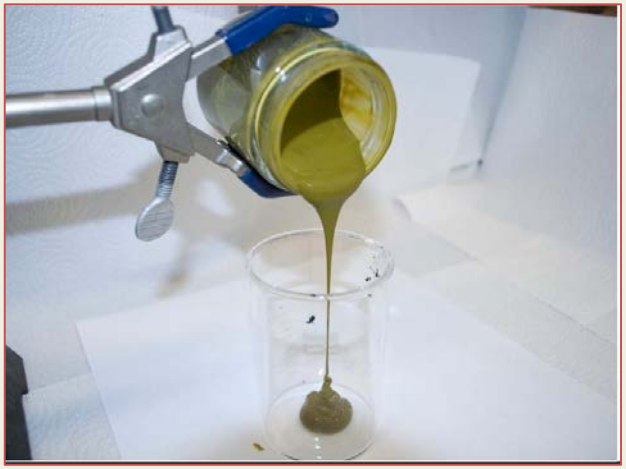
Scientists Turn Algae Into Crude Oil In Less Than An Hour

Researchers believe they have figured out a way to make a promising biofuel that is cheap enough to compete with gasoline

By Tuan C. Nguyen
SMITHSONIANMAG.COM
DECEMBER 31, 2013

Out of all the clean energy options in development, it is algae-based biofuel that most closely resembles the composition of the crude oil that gets pumped out from beneath the sea bed. Much of what we know as petroleum was, after all, formed from these very microorganisms, through a natural heat-facilitated conversion that played out over the course of millions of years.

Now, researchers at the U.S. Department of Energy's Pacific Northwest National Laboratory in Richland, Washington, have discovered a way to not only replicate, but speed up this "cooking" process to the point where a small mixture of algae and water can be turned into a kind of crude oil in less than an hour. Besides being readily able to be refined into burnable gases like jet fuel, gasoline or diesel, the proprietary technology also generates, as a byproduct, chemical elements and minerals that can be used to produce electricity, natural gas and even fertilizer to, perhaps, grow even more algae. It could also help usher in algae as a viable alternative; an analysis has shown that implementing this technique on a wider scale may allow companies to sell biofuel commercially for as low as two dollars a gallon.



http://www.smithsonianmag.com/innovation/scientists-turn-algae-into-crude-oil-in-less-than-an-hour-180948282/?no-ist

Algae Fuel Production- The reality

What is affordable?

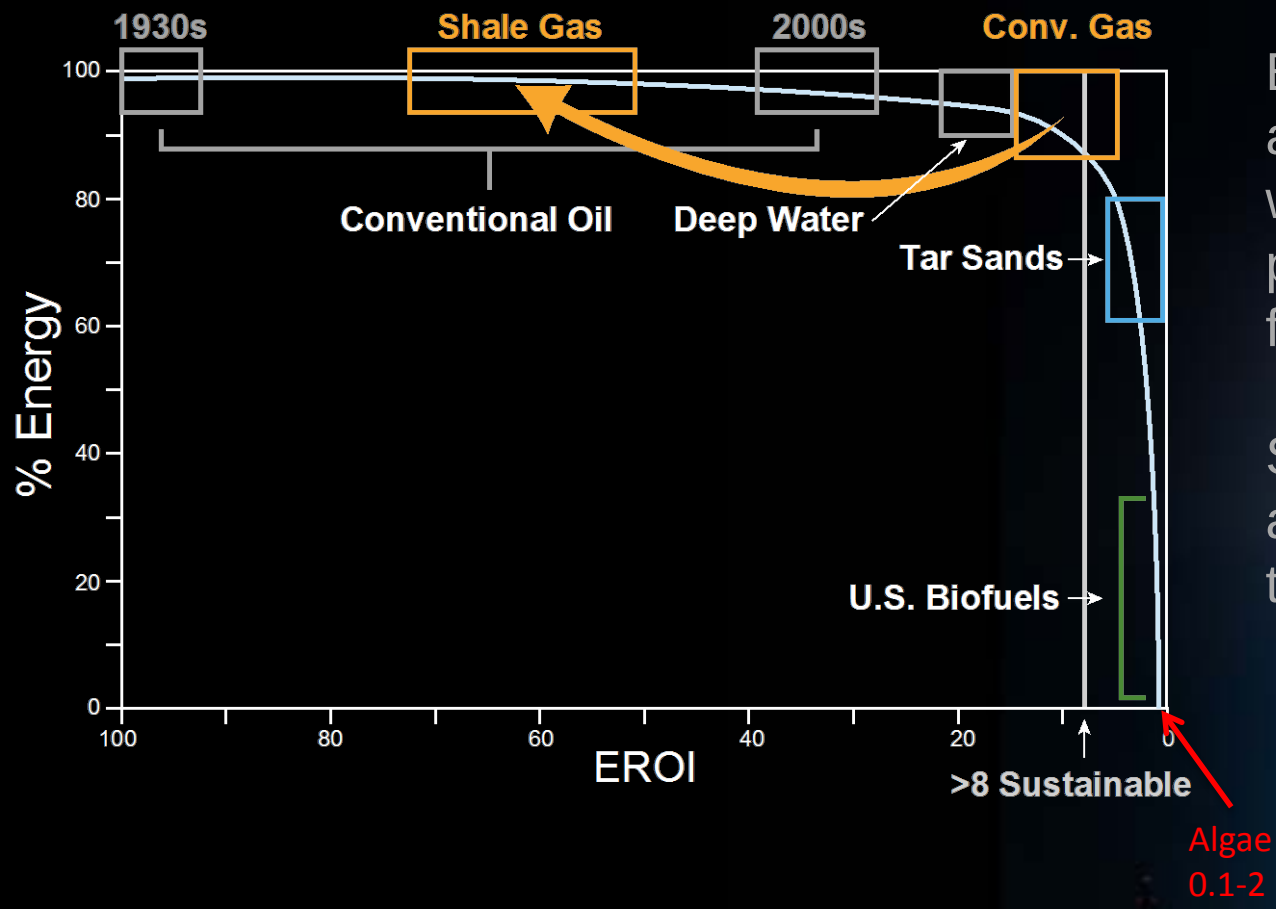
Assumptions:

- 12% Photosynthetic Efficiency (3X best demonstrate)
- 185 W/m^2 Solar Flux Temperate Climate
- $21/mBTU Fuel ($2.8 gal)

→ $14/$m^2$-yr Potential Rev Ignoring Operating Cost

Plastic Greenhouse Capital ~$64/$m^2$
4.5 Yr payback best case – theortical
20Yr with 2.5 % Photosynthesis Eff.
>>20 year with nutrient, liquid/gas handling and separation/purification

Return on Energy Invested

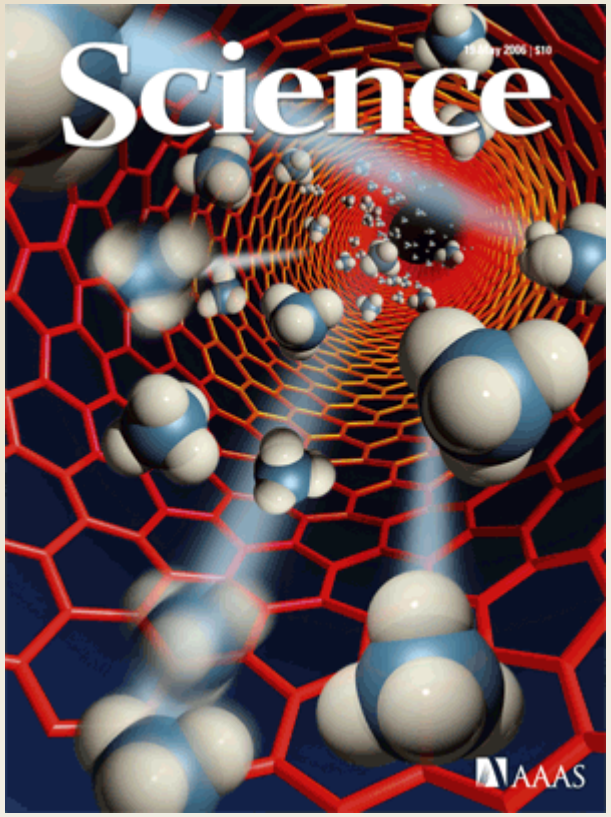


Energy return is a key parameter when the products are fuels.

Shale goes against recent trends.

Suggested reading: Guilford, M.C.; Hall; O'Conner, P.; Cleveland, C.J. A New Long Term Assessment of Energy Return on Investment (EROI) for U.S. Oil and Gas Discovery and Production. Sustainability 2011, 3(10), 1866-1867.

Nanotubes for Desalination



Fast Mass Transport Through Sub–2-Nanometer Carbon Nanotubes

Jason K. Holt,[1*] Hyung Gyu Park,[1,2*] Yinmin Wang,[1] Michael Stadermann,[1] Alexander B. Artyukhin,[1] Costas P. Grigoropoulos,[2] Aleksandr Noy,[1] Olgica Bakajin[1]†

We report gas and water flow measurements through microfabricated membranes in which aligned carbon nanotubes with diameters of less than 2 nanometers serve as pores. The measured gas flow exceeds predictions of the Knudsen diffusion model by more than an order of magnitude. The measured water flow exceeds values calculated from continuum hydrodynamics models by more than three orders of magnitude and is comparable to flow rates extrapolated from molecular dynamics simulations. The gas and water permeabilities of these nanotube-based membranes are several orders of magnitude higher than those of commercial polycarbonate membranes, despite having pore sizes an order of magnitude smaller. These membranes enable fundamental studies of mass transport in confined environments, as well as more energy-efficient nanoscale filtration.

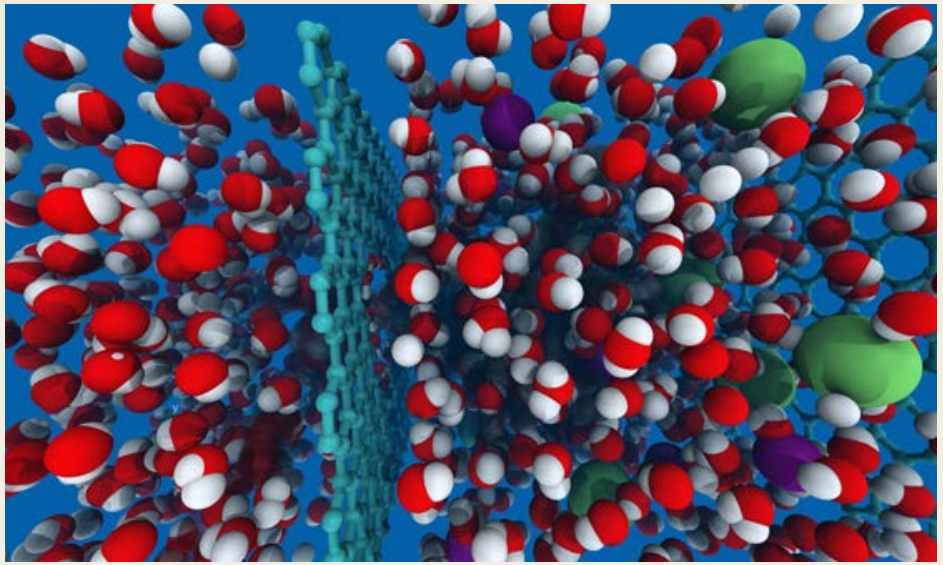
"NanOasis proposes to utilize carbon nanotubes (CNTs) to make industrially-scalable reverse osmosis (RO) membranes ….We target a ten-fold permeability increase compared to today's commercial state-of-the-art, resulting in a 30-50% energy savings…"

Graphene for Desalination Membranes

Pentagon weapons-maker finds method for cheap, clean water

By David Alexander

WASHINGTON | Wed Mar 13, 2013 1:15am EDT



WASHINGTON (Reuters) - A defense contractor better known for building jet fighters and lethal missiles says it has found a way to slash the amount of energy needed to remove salt from seawater.....

Because the sheets of pure carbon known as graphene are so thin - just one atom in thickness - it takes much less energy to push the seawater through the filter with the force required to separate the salt from the water, they said.

The development could spare underdeveloped countries from having to build exotic, expensive pumping stations needed in plants that use a desalination process called reverse osmosis.

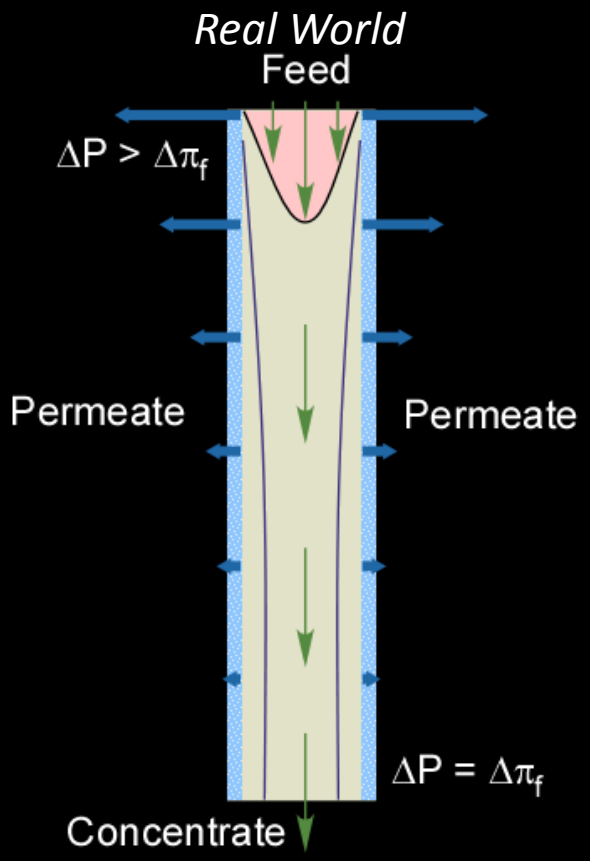
"It's 500 times thinner than the best filter on the market today and a thousand times stronger," said John Stetson, the engineer who has been working on the idea. "The energy that's required and the pressure that's required to filter salt is approximately 100 times less."

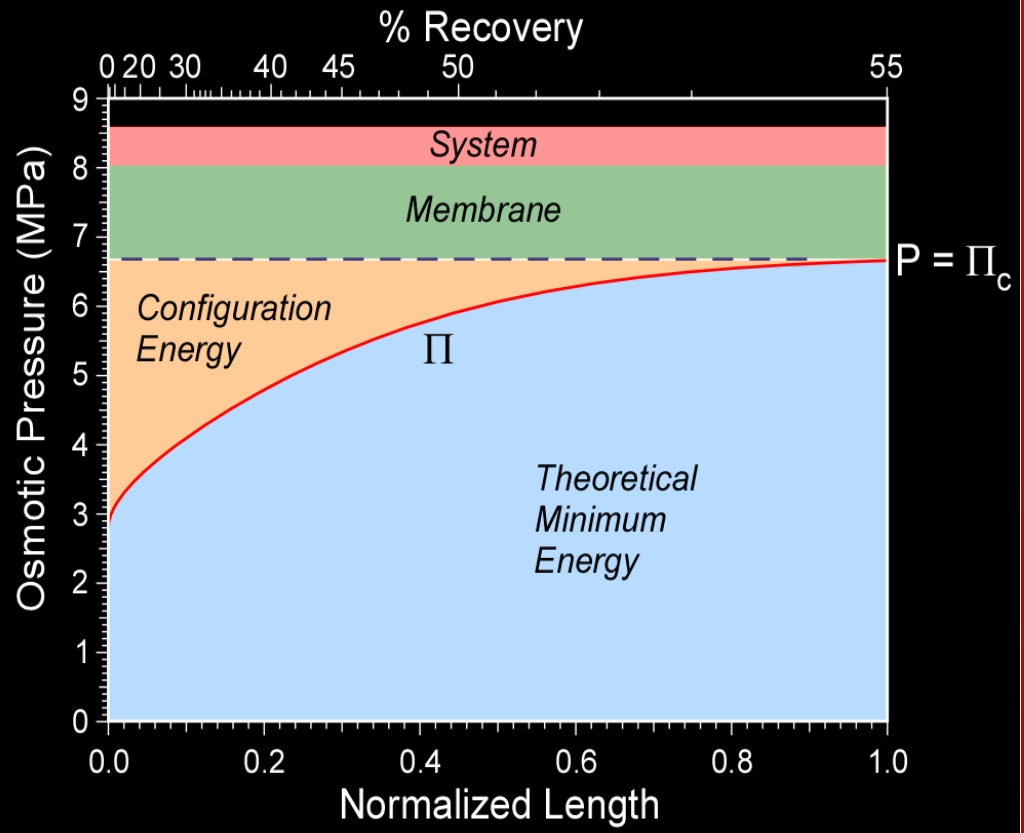
Thermodynamics

$$-d(\Delta G_{mix}) = -RT \ln a_w dn_w = \pi v_w dn_w$$

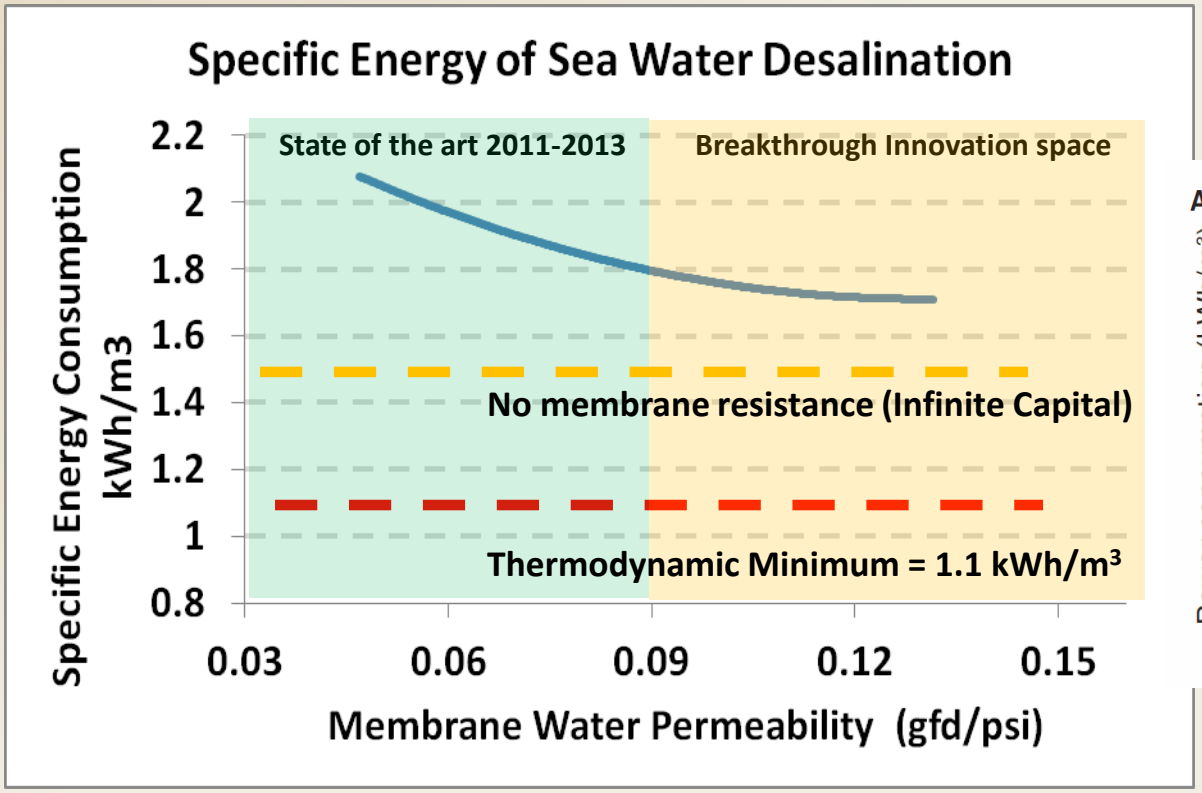
$$E_{thermo,\min} = \frac{V_0 \int_0^R \pi dR}{V_0 R} \quad \text{or} \quad \frac{1}{R}\int_0^R \pi dR$$

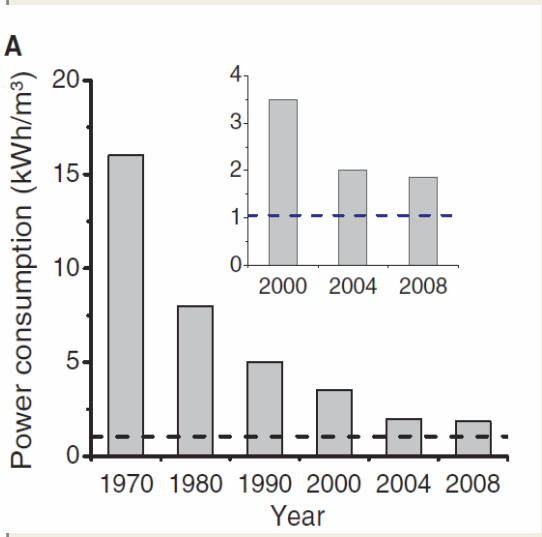
a_w =activity of water
n_w=moles of water
v_w=molar volume of water
π= osmotic pressure





Membrane Improvements





Thermal Desalination ~8-15 kWhr/m^3
Current RO Energy Efficiency ~2 kWhr/m^3
Theoretical Minimum Energy= 1.1 kWh/m^3 (50% Recovery 3.5% salt)
Ideal, Single Stage Energy Efficiency =1.56 kWh/m^3

Elimelech et al., Science 333, Aug 2011
Miller, Sandia report 2003; Elimelech JMS 2003.

The Pepsi “Bio Bottle” Coke “Plant Bottle

On March 15, 2011, PepsiCo announced that it has developed the world’s first PET plastic bottle made entirely from plant-based, fully renewable resources, enabling the company to manufacture a beverage container with a significantly reduced carbon footprint

William Banholzer

Environment

•**Cola Wars Revisited: Coke and Pepsi Duel Over Bottles Made from Plants**
•**By:** **Nick Carbone**

•**Topics: battle, Bottle, coke, ecofriendly, Environment, Pepsi, pet, plastic**
•

Read more: http://newsfeed.time.com/2011/03/26/cola-wars-revisited-coke-and-pepsi-duel-over-bottles-made-from-plants/#ixzz1IZ6S6VeM

“By reducing reliance on petroleum –based materials and using its own agricultural scraps as feedstock for new bottles, this advancement should deliver a double win for the environment and PepsiCo.”

Conrad Mackerron
Senior Program Director, *As You Sow*

Bio PET

PET

plantbottle

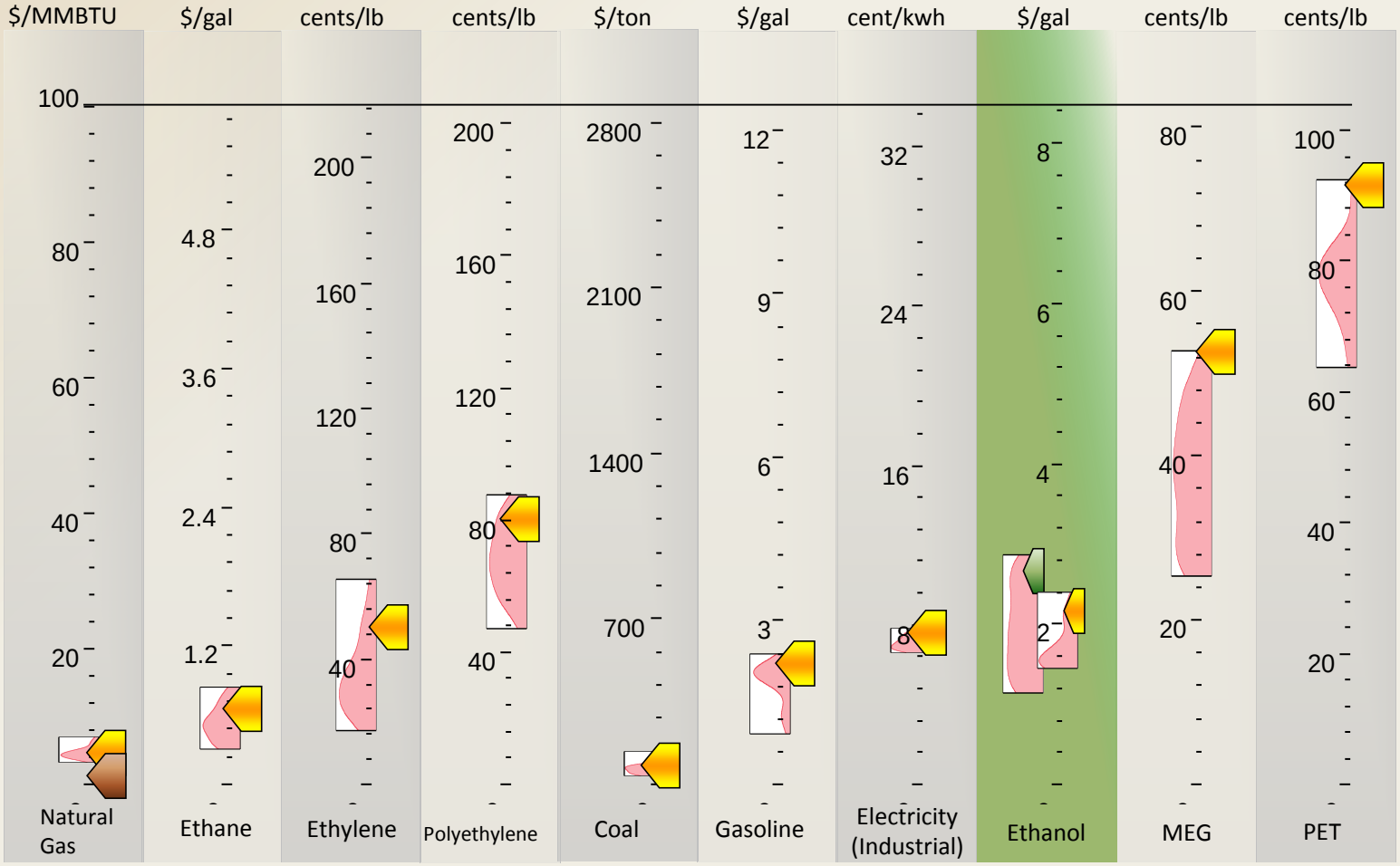
30%

100% renewable PET (not yet available) would required ~80 2 L bottles to offset burning 1 gallon of gasoline or about 400 at today's 30%

material	per capita consumption (lb/yr)
PET packaging	17
petroleum	6619
natural gas	8037
coal	6439
gasoline	2495
sand and gravel	13923
cement	512
iron ore	340
salt	403
beef	54.3
chicken	55.7

data from HIS, 2012 ERS USDA, 2011 National Mining Assoc., World Bank

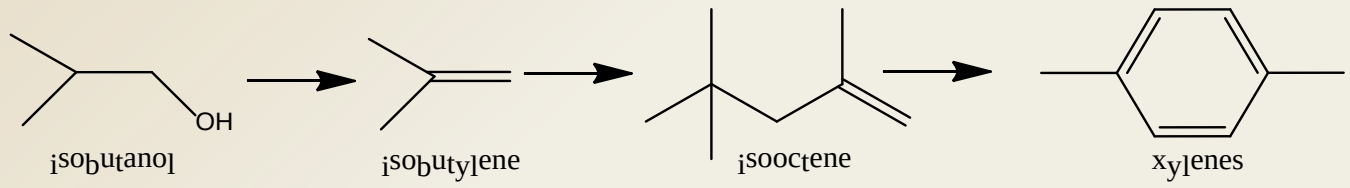
Managing "Green" Fads – Green PET

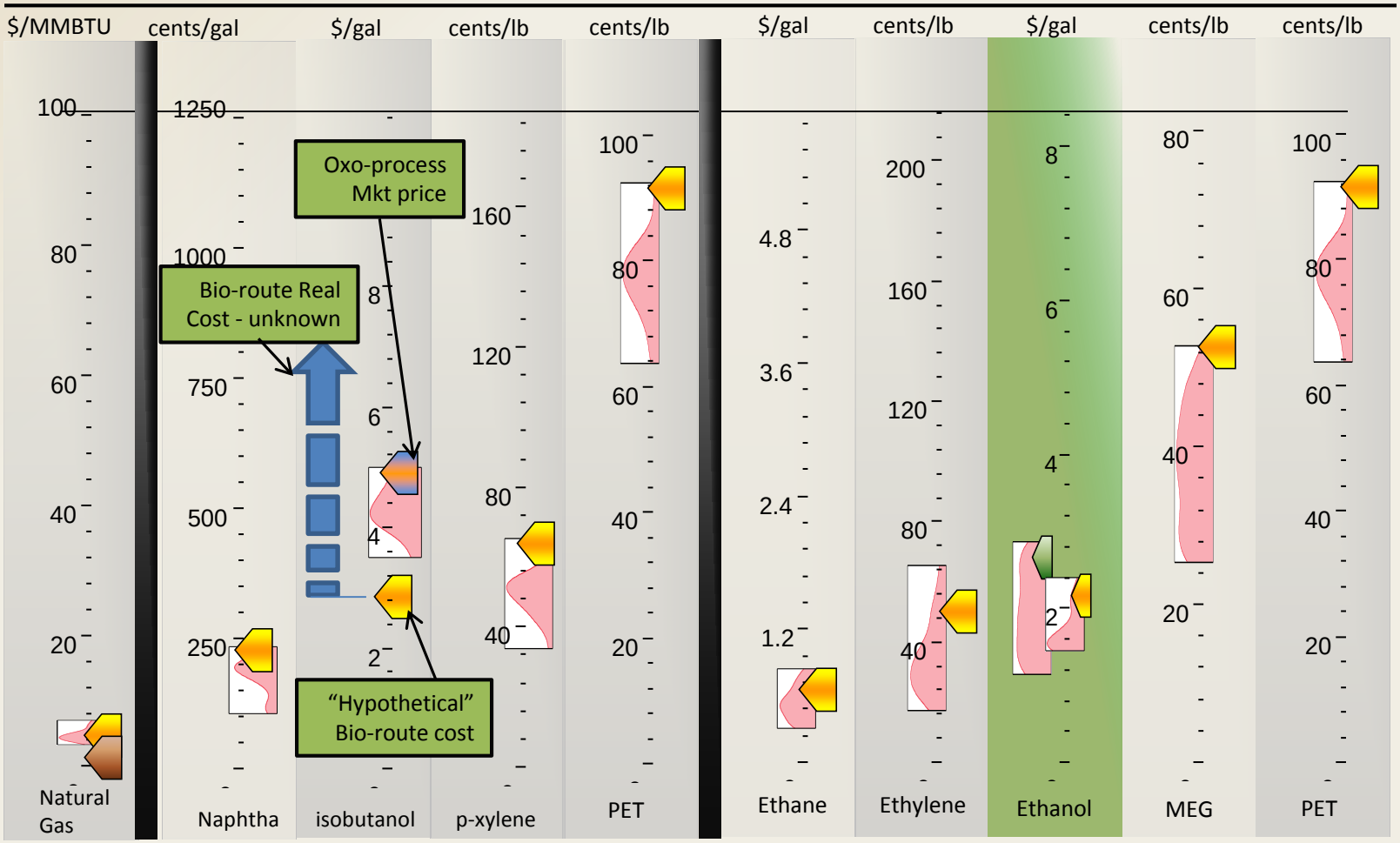


Sources:
Natural Gas, ethane, ethylene, polyethylene, gasoline, MEG, PET: CMAI
Coal: EIA, Electricity: DOE, Ethanol US: ICIS, Ethanol Br: ESALQ
Price Densities shown for Dec 2008 to Dec 2010
Prices shown from Dec 2010

USA Brazil Middle East

Managing "Green" Fads – Green PET



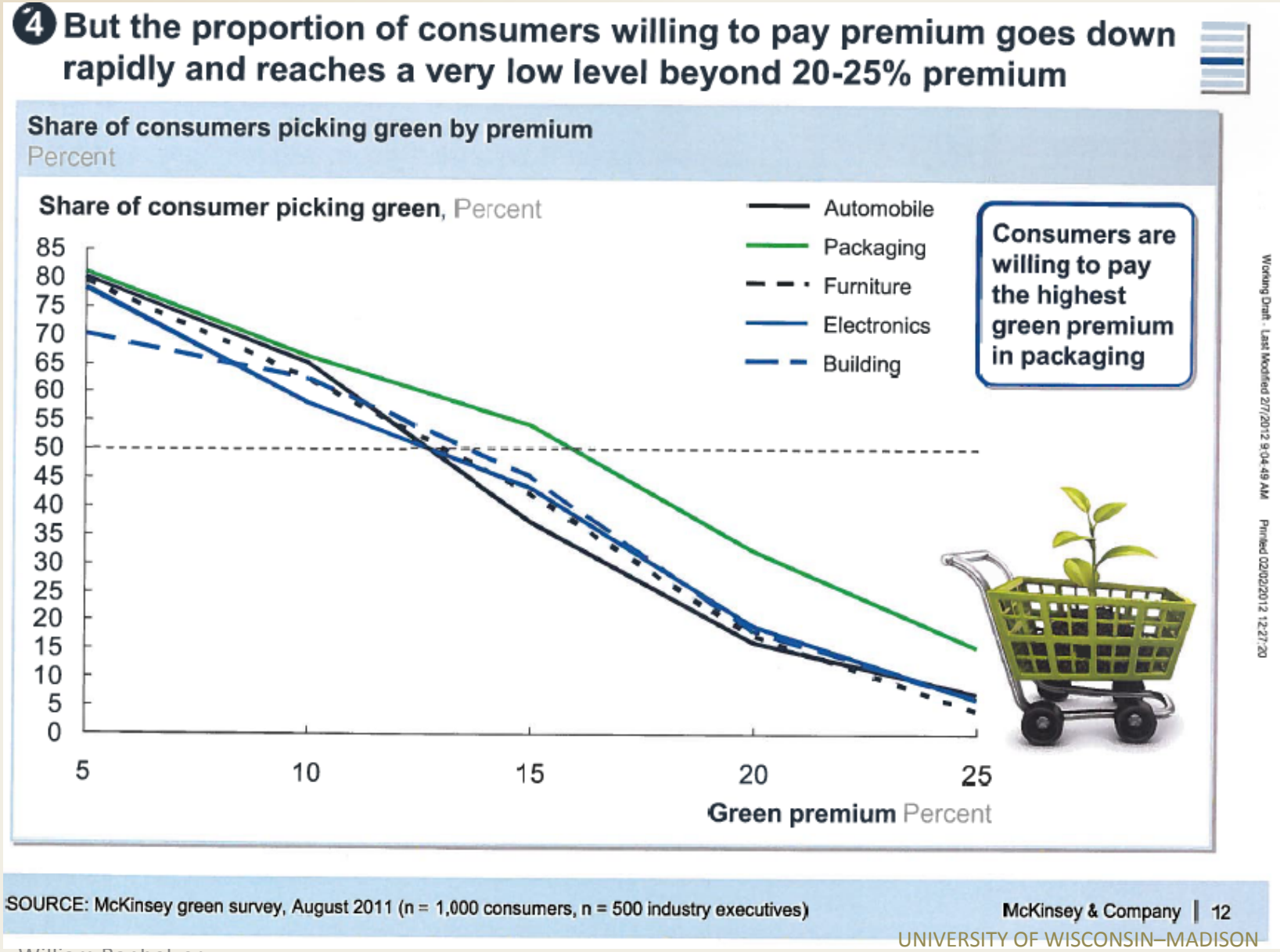


USA Brazil Middle East Global

Natural Gas, Naphtha, xylene, ethane, ethylene, MEG, PET: CMAI
Ethanol US: ICIS, Ethanol Br: ESALQ; isobutanol: report SRI PEP 274

Prices shown as of Dec 2010
2 years price variation

Limit to Green Premium



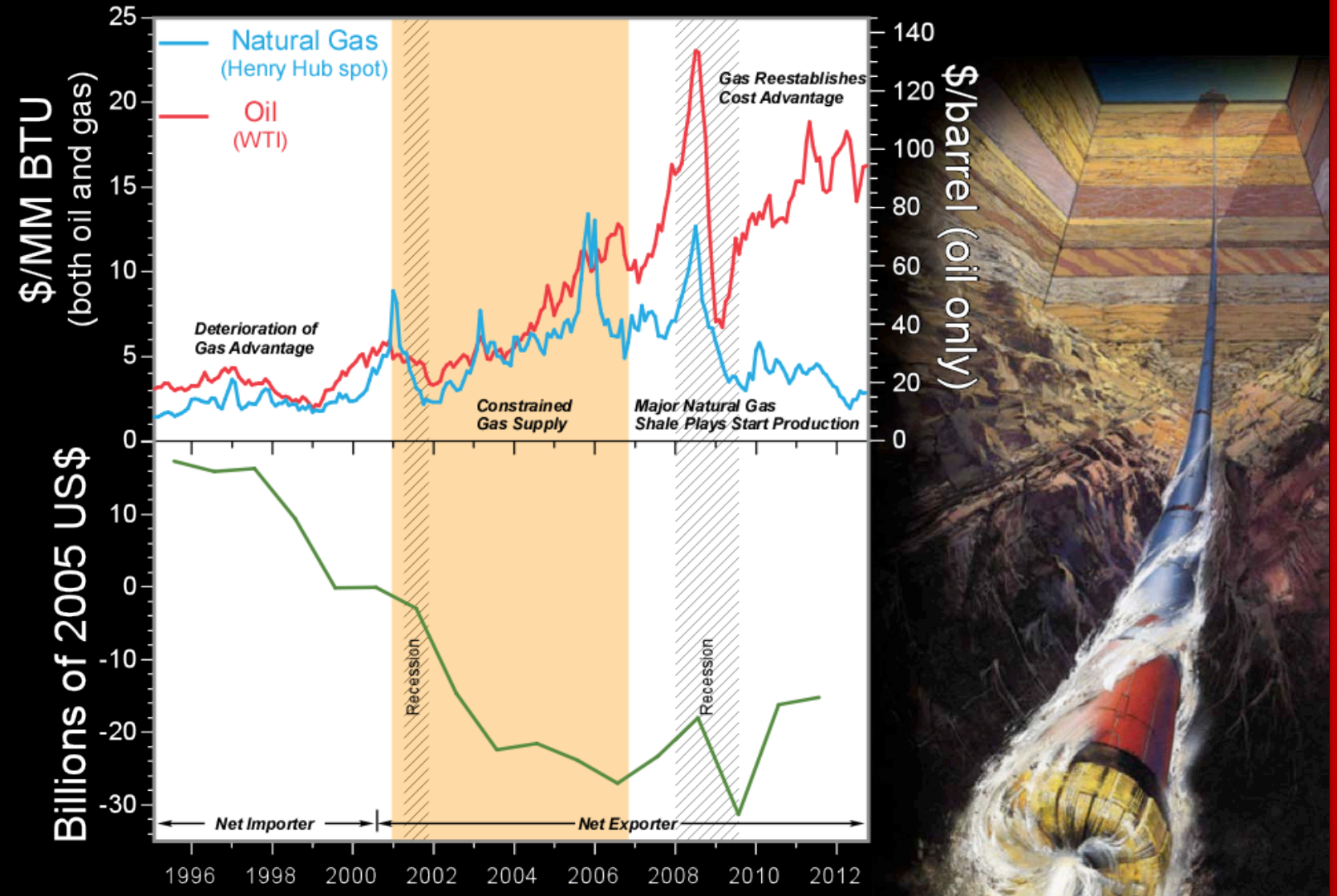
Green Design and LCA Rankings Don't Match Up

Biopolymers rank in the middle of LCA rankings

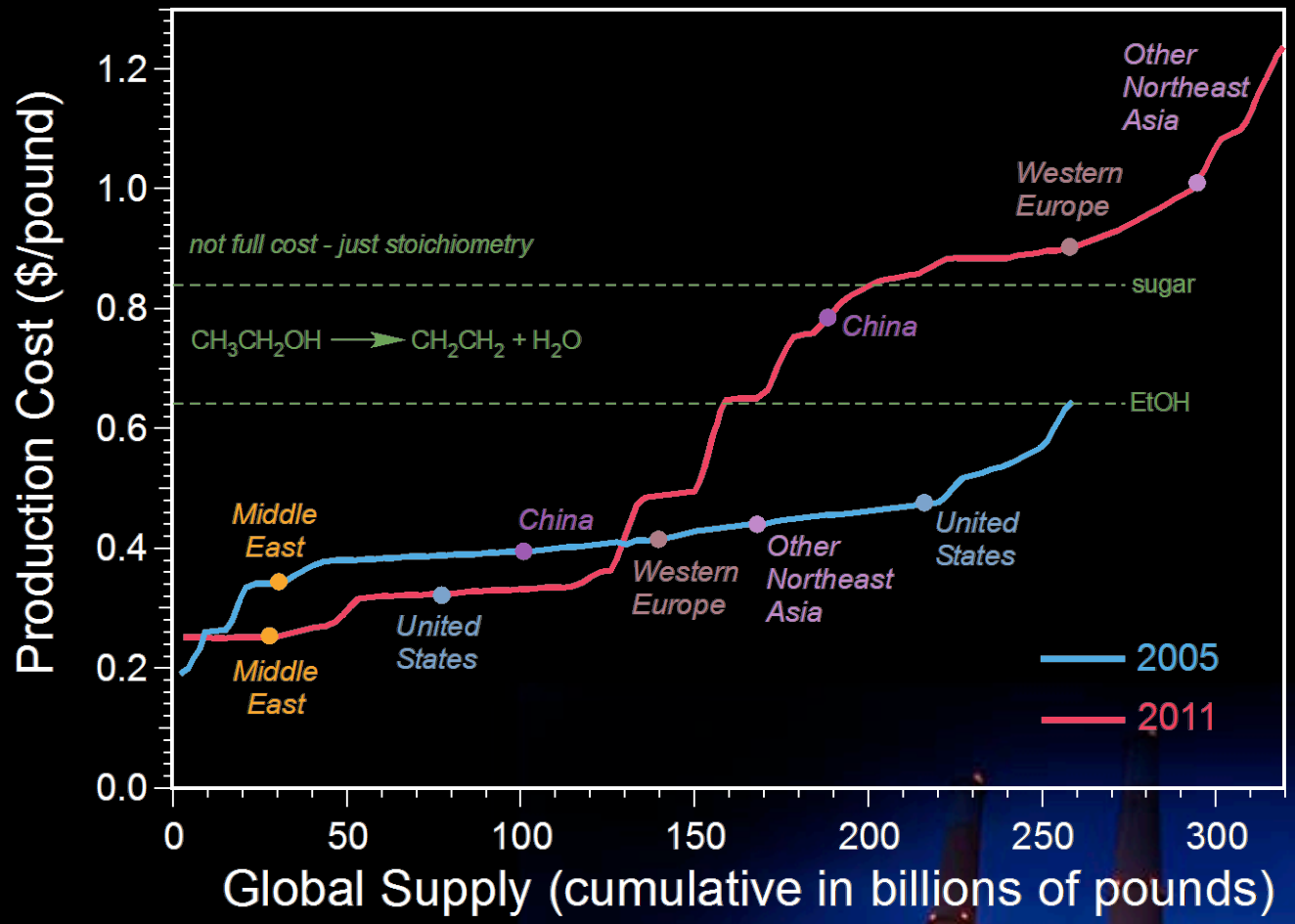
Polymer	Material	Green Design Rank	LCA Rank
Polypropylene	Fossil fuels	9	1
HD Polyethylene	Petroleum	5	2
LD Polyethylene	Petroleum	7	3
Polyhydroxyalkanoate-Stover	Cornstalks	2	4
General Purpose Polystyrene	Petroleum	10	5
Polylactic Acid – NatureWorks	Sugar/cornstarch	1	6
PVC	Chlorine/petroleum	11	7
Polyhydroxyalkanoate-General	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.

Chemical Industry is Rejuvenated



Impact of Low Gas Prices



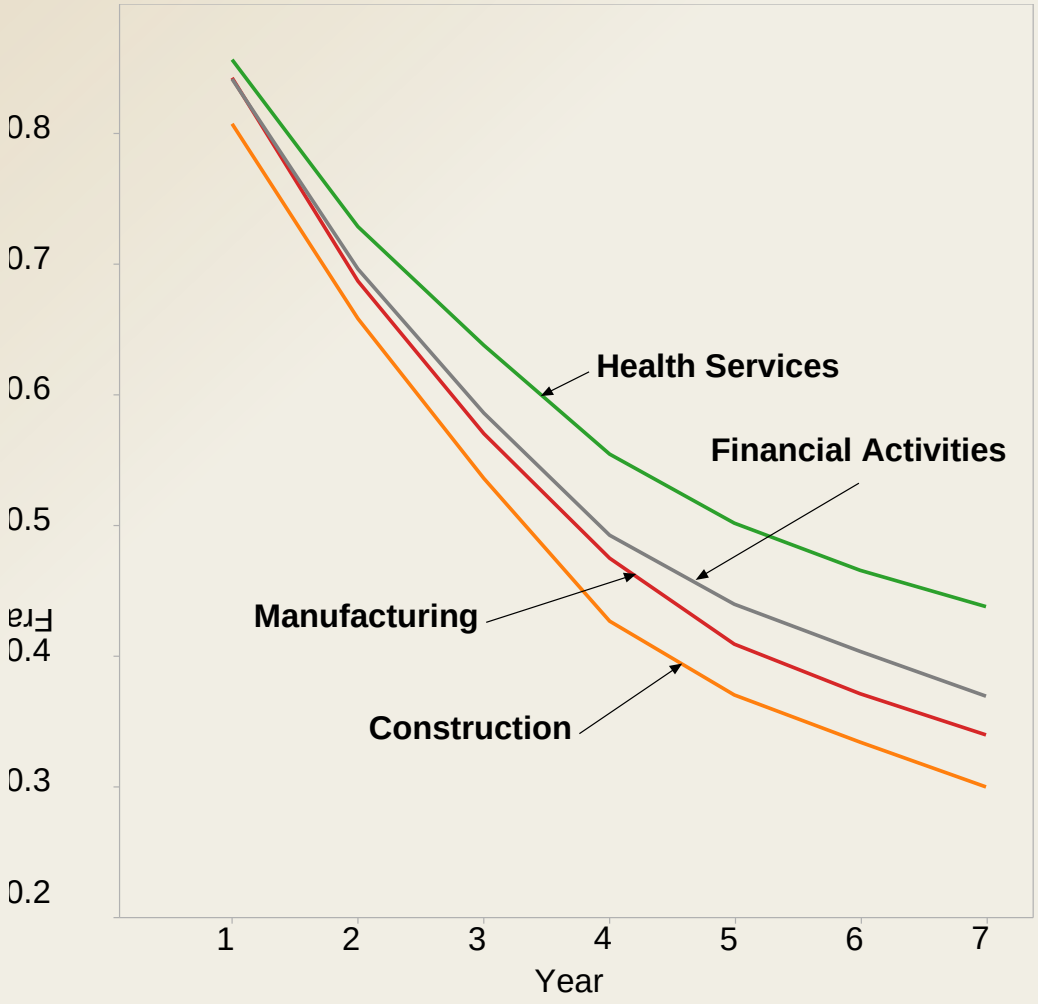
Owen Kean and T.K. Swift, American Chemistry Council, "Industry-Transforming Natural Gas into Products", National Academy Forum on Unconventional Gas, 11 September 2012.
Ethanol and Sugar from 10 Jan 2013 prices sugar is average of monthly close for 2011; EtOH is average of daily close for 2011.

Venture Model in Chemicals?

Where are the Facebook and Google of the Chemical Industry?

The Challenge of a New Company

Fraction of companies that survived after launch



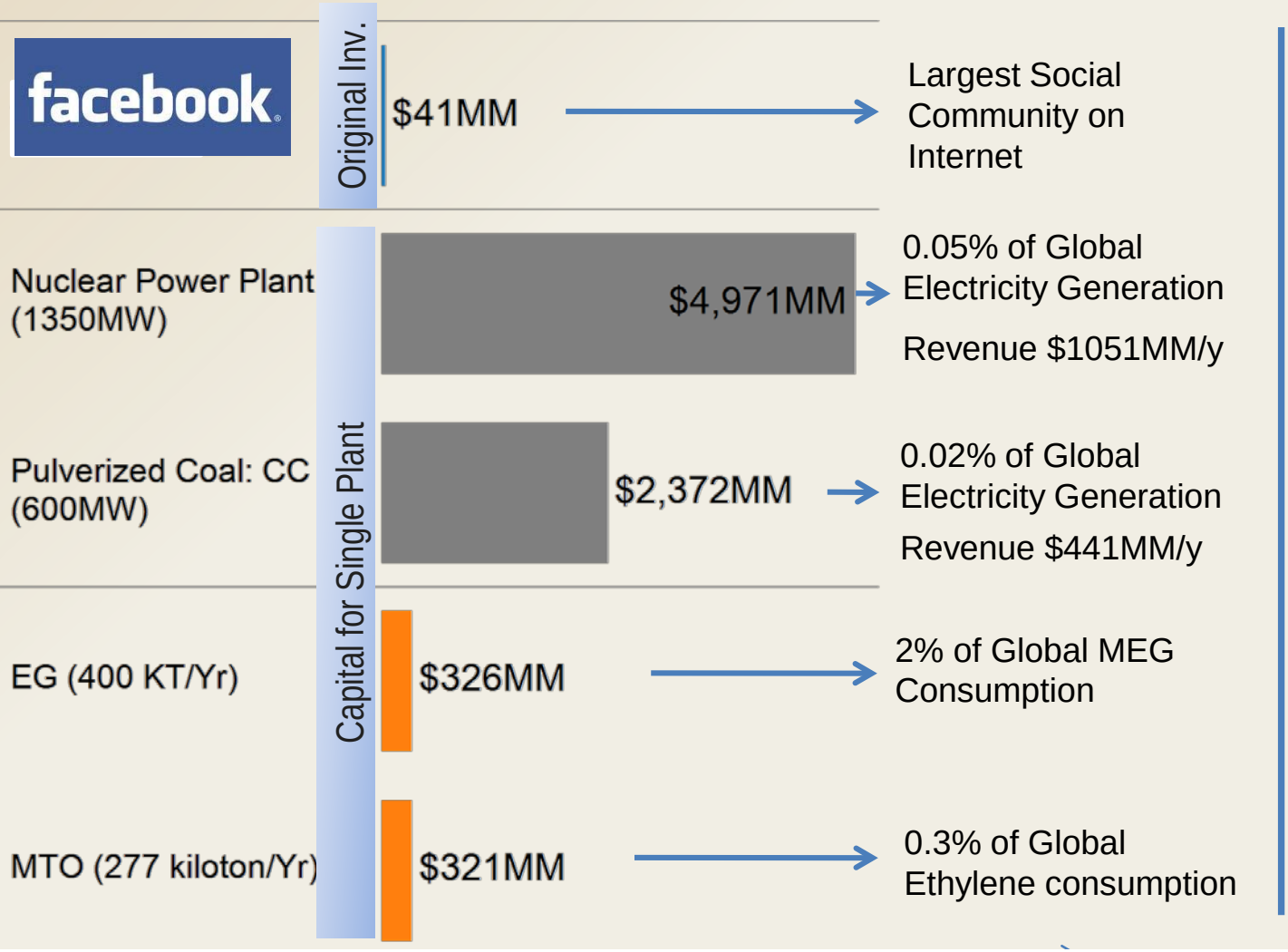
Energy & chemical industries require very high reliability

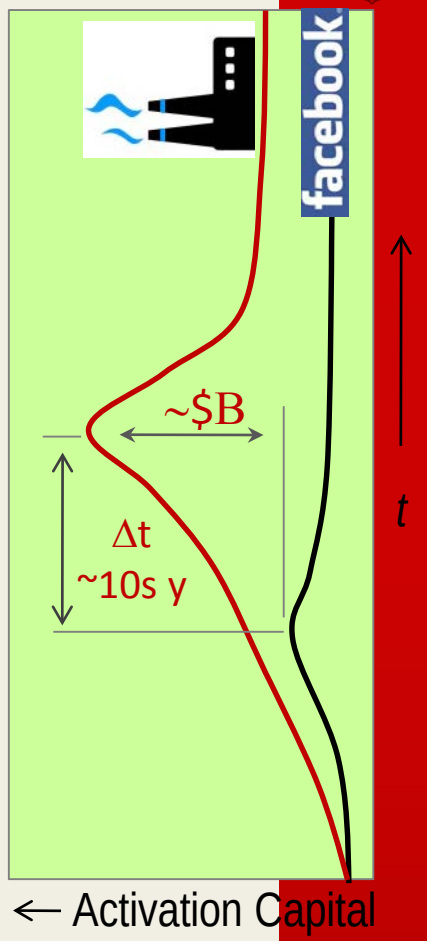
Energy & chemical industries are extremely capital intensive

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.

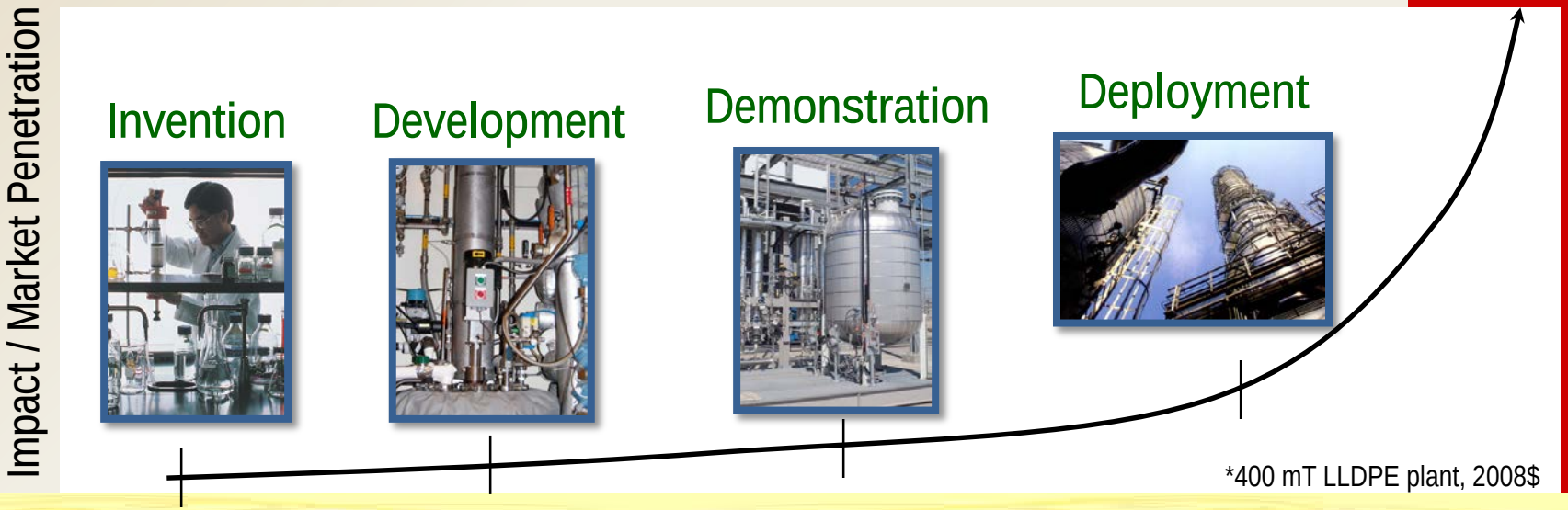
Scale of Fuels Makes it Harder





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)

Timeline for Impact



Single Site Catalysis

	Invention	Development	Demonstration	Deployment
$		~$10s MM	~$50 MM	~$150 MM*
t	1957, 80	1980-90	1989	1991

Σ ~12 yrs

Super Critical Coal Power

**600 MW plant, 2009$

	Invention	Development	Demonstration	Deployment
$		~$100s MM	~$500+ MM	~$2 B**
t	1920	1930 -50s	1957	1970s

Σ ~50 yrs

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

Thank You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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.